EVALUATION OF THREE FISH SPECIES FOR CULTURE USING LOW SALINITY GROUNDWATER IN THE BLACK BELT REGION OF ALABAMA

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EVALUATION OF THREE FISH SPECIES FOR CULTURE USING LOW SALINITY GROUNDWATER IN THE BLACK BELT REGION OF ALABAMA

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THESIS ABSTRACT

EVALUATION OF THREE FISH SPECIES FOR CULTURE USING LOW SALINITY GROUNDWATER IN THE BLACK BELT REGION OF ALABAMA

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The Black Belt region of Alabama is a rural, agricultural-based area with an economy largely dependent upon commercial catfish production. A unique fact about this region is that much of the landmass is underlain with saline aquifers. Many of the catfish farms located in this region currently have access to low salinity well water and several growers currently use it for catfish production. In recent years, the market value of catfish has fluctuated substantially largely due to increased supplies and competition from imports. Lower market prices have had a substantial effect on the already impoverished region. Producing alternative species is one way that farmers may spread financial risk. In a region with resources of this type, the potential for inland culture of marine finfish could prove to be a huge stimulus for the economy.

This work evaluates potential production of three alternative species: southern flounder (*Paralichthys lethostigma)*, Florida pompano (*Trachinotus carolinus*), and hybrid striped bass (*Morone saxatilis* ♀) X (*M. chrysops* ♂*)*, using two sources of inland low salinity pond water. The two sources of water are both low salinity but composed of differing concentrations of ions.

Fish were located at two farm sites utilizing low salinity water in the Black Belt region of Alabama. Hybrid striped bass, Florida pompano, and southern flounder were individually placed into one of the twelve tanks at each site. At the conclusion of the ninety day experiment, growth rates and survival were compared for the two locations.

At conclusion of the study, mean survival at site A was 93.8% for hybrid striped bass, 0% for pompano, and 82.5% for flounder; survival at site B was 97.5% for hybrid striped bass, pompano 80 %, and flounder 91.3 %. Only mean survival of pompano was significantly different with no survival at location A. Mean feed conversion ratio (FCR) for hybrid striped bass at site A was 1.3 and 6.4 for flounder. At site B, mean FCR was 0.9 for hybrid striped bass, 7.8 for flounder, and 1.2 for pompano. Significant differences ($p < 0.05$) were found for FCR of hybrid striped bass at the two locations. Mean specific growth rates for hybrid striped bass were 3.6 (A) and 3.7 (B), for flounder 0.6 (A) and 0.4 (B), and 3.1 for pompano at location B. Water quality at the two locations was similar; the major difference between the two locations was irregular ion concentrations.

With the current knowledge available and based upon this study, hybrid striped bass appear to be the most likely prospect for culture in the Black Belt region of Alabama because of the fish examined they were the most adaptable to growing in low salinity water and high temperatures of the region.

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INTRODUCTION

Addressing the Problem

The region of western Alabama is one of the most impoverished areas in the state of Alabama. Its economy is largely agriculture dependent and channel catfish is the major aquaculture product. A solution to increase economic prosperity could be the culture of alternative fishes using inland low salinity water. Currently, there are farms in Florida, Alabama, Texas, and Arizona that are using similar types of inland low salinity well water. This water has already been proven to work for production of marine shrimp and could prove very useful for growing other marine species, especially those with the ability to tolerate a wide range of salinities, such as euryhaline fish (Roy et al. 2006).

The impact of inland low salinity aquaculture on the fisheries industry could prove to be significant and the industry will likely be expanding rapidly in years to come. A factor likely to contribute to expansion is the fact that so many states have access to low salinity groundwater and oceanic supplies of fish are becoming increasingly over-fished. Establishment of marine aquaculture facilities much farther inland where land prices are more reasonable, as opposed to coastal areas, can provide a solution to meet the growing demand for marine products. In many areas this method could offer a very cost-effective means to produce marine seafood products and provide increased income for farms plagued by low cost imports.

Euryhaline fish are of interest to the aquaculture industry, because in the United States aquaculture is currently over a billion dollar per year industry and growing annually (USDA 2005). The global demand for marine fish is constantly increasing, yet the oceanic supply is becoming depleted and the supply of seafood unstable. Because of high demand, marine aquaculture is currently developing at a rapid pace and may soon surpass freshwater finfish production largely dominated by carps and tilapia. Expansion of marine aquaculture oftentimes means development in areas located within close proximately to the coast. In the U.S., this means extremely high land costs and limited possibilities for fish farming. Euryhaline fish could provide the opportunity to expand marine aquaculture much farther inland, which could allow for production of these fish in an environment in which they would typically not be found. Inland aquaculture of euryhaline marine organisms using low salinity water is currently an emerging industry throughout the world, including west Alabama (Roy et al. 2006). Currently, there are farms producing marine organisms by utilizing inland low salinity well water in several areas within the United States as well as abroad.

In order to bolster the aquaculture industry in western Alabama, the effects that salinity and ion concentrations from inland waters have on the target species must be completely understood. The major difference in culturing fish with water found in the Black Belt region compared to typical low salinity water is the ion composition. Ion ratios in the Black Belt are not the same as would be found in an estuary environment or by use of diluted seawater. The effects of the ion irregularities on growth are not completely understood and the water of the region might not be suitable for culture of marine fish. Without this knowledge the growth of the aquaculture industry will be hindered, also hindering much needed economic growth in the region. This initial research will help to determine if production of these higher value euryhaline fishes is possible, what growth rates can be expected under the local environmental conditions, and how growth will be affected by various inland low salinity water sources. Once the effects of ion composition on the growth of these species have been determined, further research can conclude which specific ions are necessary for optimizing growth.

Hybrid striped bass

Hybrid striped bass belong to the family *Moronidae*, also known as the "temperate bass family" which contains striped bass (*Morone saxatilis*) and white bass (*M. chrysops*), the two fish involved in the most widely accepted inter-specific hybridization. The family Moronidae contains both the genus *Morone* (striped bass) and *Dicentrarchus* (sea bass). Natural distribution of striped bass in the United States ranges from Canada to Florida in the Atlantic and in the Gulf of Mexico from Florida to Texas (Stevens and Whitehurst 1992). When found in its native oceanic waters, the striped bass is anadromous, meaning that it migrates inland to rivers and streams during spawning periods. White bass are very abundant throughout the United States and locally abundant in rivers, lakes, and reservoirs of the southeast. Several hybridizations have been artificially produced among species in this genus; so, the term hybrid striped bass can be rather broad. Table 1 provides some of the common forms (Harrel et al. 1990).

For this work, hybrid striped bass (HSB) will generally refer to the cross breeding of a striped bass female (*M. saxatilis*) and a white bass male (*M. chrysops*). Fish of this cross are also known as "Palmetto Bass", referencing South Carolina, the state where this

Table 1. Common hybridizations of striped bass (Harrel et al. 1990).

Female	Male	Common Name
Striped Bass	White Bass	Palmetto Bass
White Bass	Striped Bass	Sunshine Bass
Striped Bass	White Perch	Virginia Bass
White Perch	Striped Bass	Maryland Bass
Striped Bass	Yellow Bass	Paradise Bass

form of hybridization first took place (Harrel et al. 1990). The benefits for using a hybrid fish such as this are fast growth rates, high survival, and no reproduction. High growth rate is a major consideration when selecting a fish for aquaculture; faster growth rates reduce risk and expenses. In addition, this fish is a good prospect because it already has an established market in the U.S. and can tolerate a wide range of salinities. Due to many of these factors, the HSB industry has expanded rapidly and is now producing over 12 million pounds annually (Carlberg et al. 2006).

Southern flounder

Southern flounder, *Paralichthys lethostigma,* is a prized flatfish belonging to the family Bothidae. The genus name *Paralichthys* is derived from the Greek words (*Paral + ichthys*) meaning parallel fish. The species name *lethostigma* is Latin (*Letho + stigma*) meaning forgotten spots, a distinguishing characteristic of the fish (Archambault and Wenner 2005). This family contains fish in the genus *Paralichthys* or the "left eye" flounders due to their eyes being on that side of the body. Other members of the genus which can also be found within the same range include summer flounder (*P. dentatus*) and the gulf flounder (*P. albigutta*). Southern flounder can be found from the Texas coast to parts of North Carolina. Like other flounder species, it can be found in a variety of coastal environments. This flounder can be located within inshore estuaries or during the spawning periods in offshore locations. They spend a large portion of time in estuaries or even rivers, and, for the first two years of their life, these fish will remain almost exclusively in this environment. After they reach maturity at two years of age, both males and females will migrate offshore to spawn (Daniels 2000).

Flounder catch has declined in the last decade; increased flounder fisherman and improved harvest techniques are to blame for the reduction of wild stocks. The result has been a decline in Atlantic coast landings of flounder from 84 million kilograms in 1984 to just 24 million kilograms in 1994 (Waters 1996). The decrease in quantity has lead to a higher market price and increased interest of aquaculturists. Southern flounder and summer flounder are not reported separately in statistics; so, the total United States catch is not known (Daniels 2000).

In addition to being euryhaline, the southern flounder has another key factor which qualifies it as a good research subject, high market value. Although extensive economical analysis has not been conducted, it appears there are potential profits which favor commercial development (Smith and Denson 2000). Live flounder are regularly sold on the east coast of the United States to upscale Japanese restaurants for high prices (US $15/kg) and can be shipped live to Japan for even higher prices of US $45-60/kg (Ackerman 1997, as cited in Smith and Denson 2000).

Florida pompano

Florida pompano (*Trachinotus carolinus*) belong to the jack family (Carangidae) and can be found in the Atlantic from Cape Cod to as far south as Brazil. In U.S. waters, they can be found around Florida and in the Gulf of Mexico year round (Muller et al. 2002). Spawning occurs offshore and juvenile fish can be found gathering in the sandy surf zones throughout the southern United States in the spring months. Adult and juvenile fish are usually found traveling in schools along beach fronts, inlets, and estuaries. In Florida, they are currently being produced and sold as juveniles (McMaster et al. 2003).

Pompano are one of the most sought after food fish and recent market reports demonstrate good prices for this product. Pompano research dates back to the mid-1960's. During the initial research period, many efforts were made to determine methods for controlled spawning and larval rearing (McMaster 1988). The first, and one of the few, commercial pompano farms was opened in the Dominican Republic in the 1970's by Oceanography Mariculture Industries, Inc. This state-of-the-art facility remained open for only nine months before going out of business (McMaster 1988).

Pompano are one of the nation's highest valued and most desired fish, fishermen are receiving a modest amount of US $7.50 – 12.00/kg, while prices for live fish or fresh iced fish being sold in premium seafood market or to gourmet restaurants are bringing greater than US $26/kg (McMaster et al. 2003). Previous work on this fish has largely concentrated on culture methods involved for commercial growers, but little is known of its tolerance to water quality conditions.

Current aquaculture methods

Aquaculture of hybrid striped bass has been taking place for several decades in the southeast region. Hybrid striped bass can be cultured in a variety of ways, but the predominant method for culture in this region takes place in earthen ponds (Carlberg et al. 2006). Pond production reduces much of the overhead costs associated with aquaculture. The fish are typically spawned indoors and remain in tanks for several days before being transported to outdoor ponds. These fish can also be grown in tanks or other indoor facilities, which is often not realistic for most farmers because of the high costs associated with these methods. Fish can be produced in fresh water and full strength seawater, which makes finding a suitable area for culture much easier. Young fish can be grown with natural productivity from ponds but must be provided commercial feed when natural productivity becomes insufficient (Harrel et al. 1990). Fish are commonly provided feeds containing 40 % crude protein (Sealy et al. 1998). Stocking rates are dependent on the size of fish being grown. Typically, phases of production are divided into several categories depending on size of the animals. For instance, phase I fish are from the fry to fingerling stage and are typically between 2.5 to 6.0 centimeters in length at harvest; phase II fish are usually 7.5 to 25.5 centimeters in size; and phase III fish are commonly yearling fish which will be produced to market size (Harrel et al. 1990). Phase I fingerlings can be stocked into earthen ponds at 20,000 – 30,000/ha and larger phase III fingerlings should be stocked at rates of 7,500 – 10,000/ha (Morris et al. 1999; Hayes and Hodson 1989). Fish can be grown outdoors year round in the southern United States region, with optimal growth occurring between 25º - 27ºC (Morris et al. 1999; Hayes and Hodson 1989). Under optimal growing conditions, fish can reach market size in two years time (Hayes and Hodson 1989).

Florida pompano aquaculture is still a developing industry in the southeast United States. There are very few producers currently growing this species. Most of the production currently takes place in areas within close proximity to the ocean. This current method of production, near the ocean, has limited expansion of this industry due to the fact that land near the ocean is often expensive in the United States. Producers have attempted to grow pompano in several different culture settings. Numerous attempts have been made to grow pompano in cages or ponds, with little success (McMaster et al. 2005). In recent years, indoor production and closed recirculating systems have offered better control over water quality variables which makes it the currently preferred method for culture (Groat 2002).

Florida pompano have commonly been produced in full strength seawater, but research has shown they can survive in extremely low salinities for brief periods of time when properly acclimated (Allen and Avault 1970). Research conducted by McMaster et al. (2005) showed that pompano can be grown in low salinity (< 20 ppt) ponds for extended periods of time. The fish do take well to artificial diets and typically require high protein feeds containing 40% crude protein (Groat 2002). Since wild caught pompano are typically found in warm waters with temperatures between 25 – 32 C (Watanabe 1994; Muller et al. 2002), one can assume that those temperatures are optimal for growth (Kellogg and Gift 1983).

Flounder aquaculture is also a developing industry in the United States. Culture of various species of these fish has taken place in Japan for several decades (Kikuchi and Takeda 2001). The preferred method for growing these fish takes place in tanks. Growing flatfish in ponds provides many problems when it comes to effectively harvesting the fish. Flounder are tolerant of a wide range of salinities and a portion of their life history takes place in estuaries or other locations with reduced levels of salinity. Southern flounder can be grown in fresh water or seawater with temperatures being maintained at roughly 25º C for optimal growth (Daniels et al. 2006). Stocking densities for flounder range from 25 – 35 kg/m^2 during grow-out phase and roughly 15 kg/m^2 during nursery stages (Daniels et al. 2006). These fish also readily take to artificial diets, which should contain approximately 50% crude protein (Daniels et al. 2006). Benetti et al. (2001) suggest that southern flounder can reach sizes of 500 g, 16 months post-hatch. Daniels (2000) states that flounder will reach maturity at two years of age.

Osmoregulation and physiology

Fish are constantly adjusting to their external surroundings which dictate many aspects of their life. Of the many ways in which fish must adapt, maintaining the proper balance of salt solutions within their bodies (osmoregulation) is one of the most important (Bond 1991). The majority of a fish's body is composed of these fluids, which are contained within cell membranes (Davenport and Rankin 1981). The balance of ions is maintained by osmosis and diffusion, the movement of fluids across a semi-permeable membrane often from areas of high concentration to areas of low concentration. Marine teleosts will maintain a balance lower than that of the surrounding water; freshwater teleosts will maintain internal homeostasis at a level much higher than the surrounding waters (Evans 1979). Osmoregulation is the process by which cells and organisms maintain fluid and electrolyte with their surroundings; this function determines in which environment a fish can survive. This function also protects the fish from dehydration or a surplus of fluids, which can be caused by higher or lower external osmolarity. Fish cells are buffered from the effects of surrounding environments by osmoregulation (Wurts 1987).

Some fish can only live within a narrow range of salt concentrations and are referred to as stenohaline. Euryhaline fish are able to regulate plasma ions with changing external salinity, which is necessary for organisms which migrate from fresh water to seawater at various points in their life (McCormick 2001). It is estimated that about 95 % of modern boney fishes are stenohaline and the remaining 5 % are euryhaline. These fishes are able to survive large changes in salinity, typically without adverse effects (Evans 1984). Euryhaline fish fall into several categories: diadromous fish readily move from fresh water to salt water; anadromous live in saline environments and migrate to fresh water during spawning periods; and catadromous fish mostly live in fresh water but migrate to the sea to spawn. It is the small percentage of fish, the euryhaline fish, which are of much interest to the ever growing aquaculture industry.

The effect of salinity on growth rates of stenohaline freshwater fish appears to vary by species (Altinok and Grizzle 2001). Data on the effects of salinity on growth rates of juvenile fishes are inconsistent. Genetic differences could be a possible reason for conflicting reports. Their experiments determined that growth rates for the stenohaline freshwater fishes goldfish and channel catfish were highest in fresh water and decreased with increasing salinity.

Salinity and Trace Minerals

Salinity is the total concentration of all ions in the water and is expressed as the total concentration of major inorganic constituents (Boyd 2000). For the purposes of this paper, this definition will be used when referring to salinity. Inland waters can contain salinity for several reasons. The atmosphere contains salts which are of marine origin and these particles fall to Earth with rain. Typically, the amounts of minerals are small, but can vary with location (Boyd 2000). After rain has fallen, overland runoff offers an opportunity for increased mineralization; increasing amounts of minerals are primarily a result of dissolution of minerals in soil and other geological material (Boyd 2000). As contact with soils and minerals is prolonged, levels of mineralization or salinity will increase accordingly. This accounts for increased levels of mineralization in ground water, such as wells, and can also occur in surface ponds (Boyd 2000). Some aquifers in the region of west Alabama were filled with seawater during previous geological periods. As the oceans receded, seawater has gradually been replaced with fresh water leaving low salinity waters (Boyd and Brown 1990).

Analysis has been conducted on over 100 wells located on the western portion of Alabama. These wells were within an 80 km radius of one another and varied greatly in major constituents (Boyd and Brown 1990). Salinities at farms in surrounding counties ranged from 1.5 to 6 g/l. Conditions for inland low salinity waters vary greatly by location; environmental and geological conditions can also have a large influence on local concentrations of ions. Table 2 provides common constituents of typical seawater. A table providing analysis of the inland low salinity sources, taken at the beginning of the experiment, can be found in the results section.

Physiological effects of salinity and trace minerals

A marine fish will commonly consume from 7 to 35 % of its body weight in water daily and typically maintains a plasma osmolality level between 380-450 (Conte 1969; Johnson 1973; Kirschner 1991 as cited in Bond 1991). A majority (60 – 80 %) of the ingested water is absorbed in the alimentary canal. Along with water, most monovalent ions, such as Na^+, K^-, and Cl^-, remain in the gut; typically less than 20 % are

Table 2. Average amounts of ions present in 34 g/l seawater (Boyd 2000).

Constituent	mg/L
Cl	19,000
Na	10,500
SO_4	2,700
Mg	1,350
Ca	400
K	380
HCO_3	142
Br	65
Sr	8
SiO_2	6.4
B	4.6
F	1.3

absorbed (Bond 1991). The divalent ions, primarily Ca^{+2} and Mg^{+2}, that remain in the digestive tract are excreted through the intestines as waste (Johnson 2000). Kidneys of marine fish play a lesser role in the removal of abundant ions and a greater role in conserving bodily fluids. Freshwater fish excrete larger volumes of urine; so, kidneys are much more important in their life history (Davenport and Rankin 1981). The urine that marine teleosts excrete is much more concentrated than that of their freshwater counterparts. Fluid and molecules pass through the nephron tubes where useful ions are filtered out by active transport, the movement of molecules against the concentration gradient with energy from ATP (Johnson 2000).

A teleost fish's skin provides a physical barrier from the external environment and prevents loss or gain of bodily fluids. The only portion of a fish left exposed to direct contact with water is the gills. Gills are the primary site for osmoregulation and where absorption or secretion of Na^+ and Cl^- takes place (Conte 1969). Fish gills contain "chloride cells", mitochondria rich cells found within the gills, which along with the Na^+ & K^+ ATPase pump, are believed to be responsible for much of the osmoregulation that takes place in the fish. The chloride cells are also responsible for much of the acid – base regulation (Perry 1997).

When fish expend large amounts of energy on cell regulation, less energy is available for somatic growth and growth rates may be reduced (Barton et al. 1990). Mortality can occur from osmotic stress as well. The osmotic influx of water and rapid diuresis can cause severe electrolyte imbalances that tax osmoregulatory capacity and quickly become life threatening (Barton et al. 1990). A water source that contains insufficient ions can produce acute or chronic mortality by limiting availability of ions key to physiological functions. Acute mortality indicates an obvious problem while chronic stress due to ion deficiency is less obvious. The stress of ion deficiency can have several effects on the fish which can include changes in metabolic rate, health, behavior, growth, survival and reproductive success (Brett 1958; Wedemeyer et al. 1976; Esch and Hazen 1980; Billard et al. 1981; Buckley et al. 1985; Little et al. 1985 as cited in Barton et al. 1990). Typically, the highest levels of stress and energy consumption occur upon initial acclimation to a new water source. After fish become successfully acclimated to a new environment, minimal energy is expended for osmoregulation.

This research evaluated the suitability of low salinity water at two operational farm sites in the Black Belt region of western Alabama. For production at these locations, the growth and survival of three euryhaline species: southern flounder (*P. lethostigma*), hybrid striped bass (*M. saxatilis* ♀ X, *M. chrysops* ♂), and Florida pompano (*T. carolinus*) were studied. The goal was to evaluate the suitability of low salinity water located in western Alabama for production of euryhaline teleost fish and determine how growth and survival are affected by site selection, salinity, and ionic composition of water. It also strives to enhance the meager economy by providing a reliable alternative to current agricultural practices, mainly catfish farming. The existing infrastructure provided by the catfish industry may provide the necessary framework to successfully diversify the currently monotonous aquaculture industry.

MATERIALS AND METHODS

Stocking & Set-Up

Fish were acquired from hatcheries or wild caught several weeks prior to the experiment. Original cross (*Morone saxatilis* ♀ X *M. chrysops* ♂) hybrid striped bass were obtained May 2006 from the Marion State Fish Hatchery, located in Perry County, Alabama. The hybrid striped bass had been nursed in freshwater ponds for more than thirty days before being transported to freshwater tanks. Southern flounder (*Paralichthys lethostigma*) were procured from North Carolina State University's (NCSU) research facility during June 2006. Water in the tanks at NCSU was maintained near 25 g/l salinity by using artificial sea salts (Instant Ocean, Aquarium Systems, Mentor, OH). Florida Pompano were wild caught in March 2006 by the use of seines from coastal Alabama. After the fish were captured, they were held at Claude Peteet Mariculture Center at roughly 25 g/l salinity and ambient temperatures and provided commercial feeds.

After being transported, fish were maintained near the study location until the experiments were begun. Upon arrival at the holding facilities, fish were acclimated by gradually reducing the salinity in the hauling tanks by adding low salinity water over several hours before being transferred to holding tanks. They remained in holding tanks for approximately one week.

The experiment was conducted at two operational farm sites located in Greene County Alabama, both of which utilize low salinity water. At each site, a flow-through system consisting of 12 circular polyethylene tanks (760 l each) was constructed (twenty four tanks total). Tanks were covered with shade cloth throughout the study to reduce direct sunlight. Water was supplied to each tank from a nearby earthen pond by the use of a commercial pump. Flow rates were similar at both locations. Plastic flow reducers were used to maintain flow rates of approximately 550 l/hr. Site A used a 0.5-hp pump (Hayward Industries Inc., Elizabeth, NJ) and site B a 1.5-hp pump (Sweetwater, Aquatic Eco-Systems Inc., Apopka, FL). Site B had an additional 12 tanks used for other research, which required a larger pump. Water continuously flowed into each tank and out a screened center standpipe. Aeration was supplied constantly to each of the tanks at both sites using two air lines and diffuser stones, which were fed air by a blower plumbed into the aeration system. Site A used a 0.5-hp blower (Sweetwater, Aquatic Eco-Systems Inc., Apopka, FL) and site B a 0.33-hp blower (Sweetwater, Aquatic Eco-Systems Inc., Apopka, FL).

At each site the three fish species were randomly assigned four tanks each. Fish were randomly selected and stocked at twenty per tank. Fish were counted and group weights were recorded at the time of stocking. Any fish which did not survive the first two or three days after stocking were measured and restocked with fish of similar size. Stocking took place on the 27th of June 2006 (Table 3). Feeding and water quality monitoring commenced the next day and the experiment was continued for 90 days.

Table 3. Mean (± standard deviation) initial individual stocking weights (MSW), tank biomass (TB), and standing crop (SC) for evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water at two sites in the Alabama Black Belt.

		Site A			Site B		
Flounder	MSW[1]	50.1	±	2.2	51.4	±	7.8
	TB[2]	1001.5	±	43.9	1027.5	±	156.7
	SC[3]	1300.0	±	57.2	1336.4	±	202.8
	SC[4]	1200.0	±	52.8	1233.6	±	187.2
HSB	MSW[1]	2.1	±	0.3	1.8	±	0.2
	TB[2]	41.8	±	5.9	35.1	±	3.1
	SC[3]	54.6	±	7.8	46.8	±	5.2
Pompano	MSW[1]	5.0	±	1.1	3.6	±	0.7
	TB[2]	100.9	±	21.1	71.9	±	13.9
	SC[3]	104.0	±	28.6	93.6	±	18.2

[1] MSW = Mean individual stocking weights (g).

[2] TB = Tank Biomass (g).

[3] SC = Initial standing crop g / m^3.

[4] SC = Initial standing crop g / m^2 (flounder only).

Water Quality

Water quality at both locations was monitored on a regular basis. Dissolved oxygen, pH, and temperature were monitored in each tank twice daily, morning and afternoon, using a YSI model 85 or 556 MPS handheld instrument (Yellow Springs Instruments, Inc., Yellow Springs, OH). The pH was also occasionally measured using Pinpoint pH monitor (American Marine Inc., Ridgefield, CT) when the YSI 556 MPS was not used. Alkalinity, hardness, chloride, nitrite, and ammonia were measured periodically throughout the experiment using a model DR 5000 spectrophotometer (Hach Company, Loveland, CO).

Water samples for trace mineral analysis were taken during the first week of the experiment from several tanks at both study sites. These samples were tested at the Auburn University Soils Lab. Laboratory analysis determined the amount of minerals present for the following elements: calcium, magnesium, potassium, chlorides, and sulfate. Trace mineral analysis was done using inductively coupled argon plasma (ICAP) spectrophotometry (Clesceri et al. 1998)

One of the farms (site B) routinely adds the commercial fertilizer K-Mag, which contains potassium, magnesium and sulfate, to their ponds to augment potassium and magnesium. K-Mag is typically added annually depending on the levels present from the last season. At site A, water had not previously been augmented. The individual tanks containing pompano at this site were treated with K-Mag weekly placing one pound of the fertilizer into a perforated container and allowing it to slowly release over several days. The containers used were approximately 950 ml in size, had numerous holes to allow slow release of fertilizer, and were suspended by string near the water surface.

Feeds & Feeding

Feed consisted of a commercially available high protein diet (Rangen Inc., Buhl, ID). Three different sizes of feed were used depending on what the fish were able to consume. The smallest feed (1.6 mm) contained crude protein 44 %, crude fat 15 %, and crude fiber 5 %; the two larger sizes (4.8 and 6.4 mm) contained crude protein 40 %, crude fat 15%, and crude fiber 5 %.

A known amount of feed was offered to the fish twice per day. If the fish were displaying an active feeding response, they were provided more feed of known quantities until apparent satiation was reached. Active feeding response was measured by placing feed into a floating feed ring made of garden hose cut to identical lengths and held together with pieces of dowel. When there was not an active feeding response, no more food was provided. After roughly thirty minutes, feed remaining in the tank was removed and the weight of the leftover food was calculated by counting the remaining feed pellets and using the average weights of dry pellets. To determine the weight of feed pellets, dry pellets were weighed several times and an average weight was determined for individual feed pellets. The size of the food offered was adjusted accordingly as the fish grew. Feeding rates were estimated for expected growth rates during the first 30 days of the study assuming a survival of 100 %. After 30 and 60 days, the fish were sampled and feed rates were adjusted accordingly for the growth rates and biomass present.

Harvest & Analysis

Fish were harvested on the 28th of September 2006, 90 days after stocking. During the course of this experiment, fish were sampled monthly on 24 July 2006 and 24

August 2006 to determine growth and obtain average weights. Sampling consisted of sub-samples of captured fish from each tank being counted and weighed in water, using a Scout Pro balance (Ohaus Corporation, Pine Brook, NJ) to the nearest 0.1 g, then returned to the tank. At the conclusion of this study, fish were each individually measured in millimeters using a measuring board and weighed in water to the nearest 0.1 g using the same scale.

Mean fish weights, survival, and water quality parameters of the two study locations were analyzed for significant differences using SAS version 9.1 (version 9.1 SAS Institute, Cary, NC). Statistical analysis for significant differences was performed using SAS t-tests (PROC TTEST) or SAS analysis of variance (PROC GLM) for multiple comparisons. Significance was determined at $\alpha = 0.05$.

RESULTS

Water Quality

Figure 1 shows the mean weekly dissolved oxygen levels during morning and afternoon at both sites. There were no significant differences ($p > 0.05$) for the mean weekly dissolved oxygen levels between or within sites. Mean weekly dissolved oxygen levels remained between 6.1 and 9.4 mg/l. No mortalities are attributed to low levels of dissolved oxygen and readings indicate dissolved oxygen stayed above levels which would have been stressful (Table 4). Dissolved oxygen levels increased in approximately the ninth week of the study due to the decreasing ambient temperatures.

There were no significant differences ($p > 0.05$) for overall mean weekly temperatures (Fig. 2) between or within sites. Mean water temperatures stayed high for a majority of the research (Table 4). For nine of thirteen total weeks, mean weekly water temperatures at both sites were above 30 C (Fig. 2).

Figure 3 shows mean weekly pH levels during the study and Table 4 shows the number of readings above 9.0 mg/l. The mean daily pH readings remained above 8.5 for much of the study. There were significant differences ($p > 0.05$) for mean weekly pH between sites for weeks two, three, four, and thirteen. Several pH readings at site B were between 9.5 – 10.0, but there were none above those marks. Mean weekly pH at location

Figure 1. Mean weekly dissolved oxygen levels for morning (---) and afternoon (—) readings at site A (■) and site B (▲) during the evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water at two locations in the Alabama Black Belt from 27 June to 28 September.

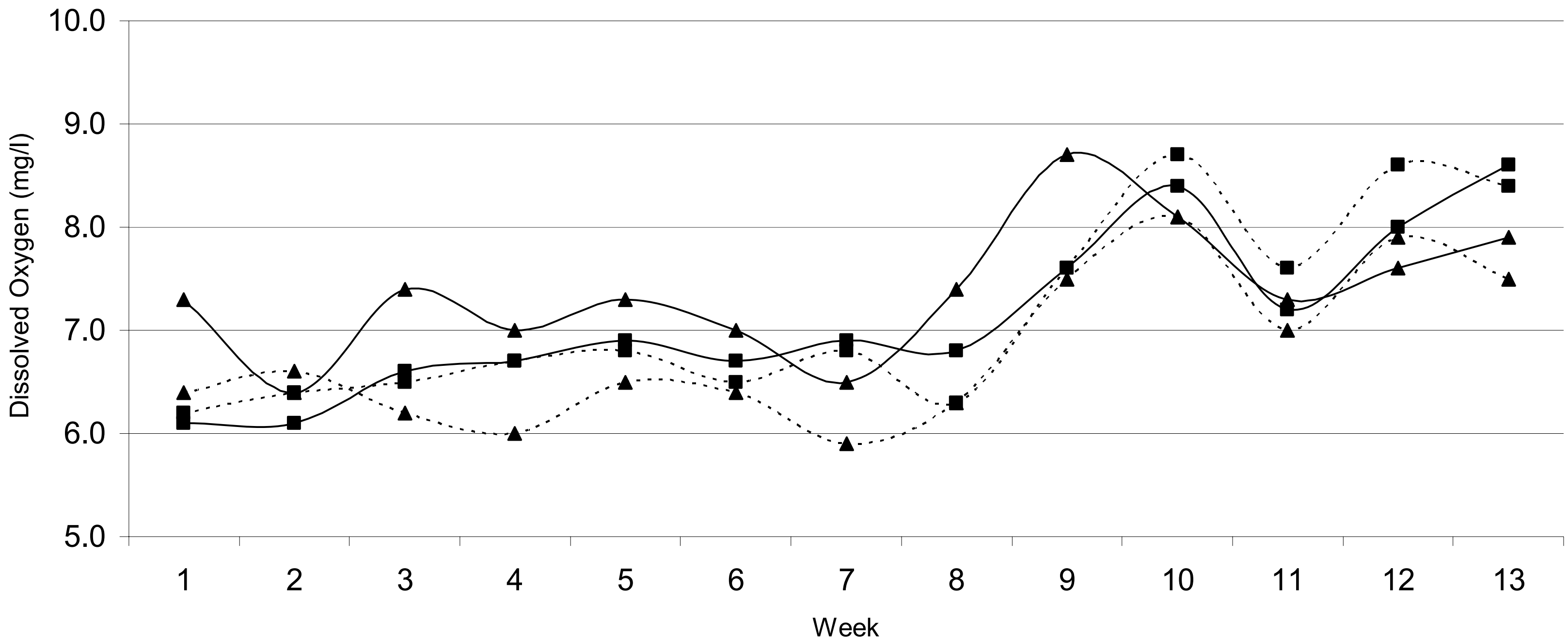

Figure 2. Afternoon mean weekly temperatures for sites A (—) and B (---) displayed with recommended optimal levels for Florida pompano 29 C (– - –), hybrid striped bass 27 C (– – –) and southern flounder 25 C (– - - –) (Morris et al. 1999, Groat 2002, & Daniels et al. 2006, respectively).

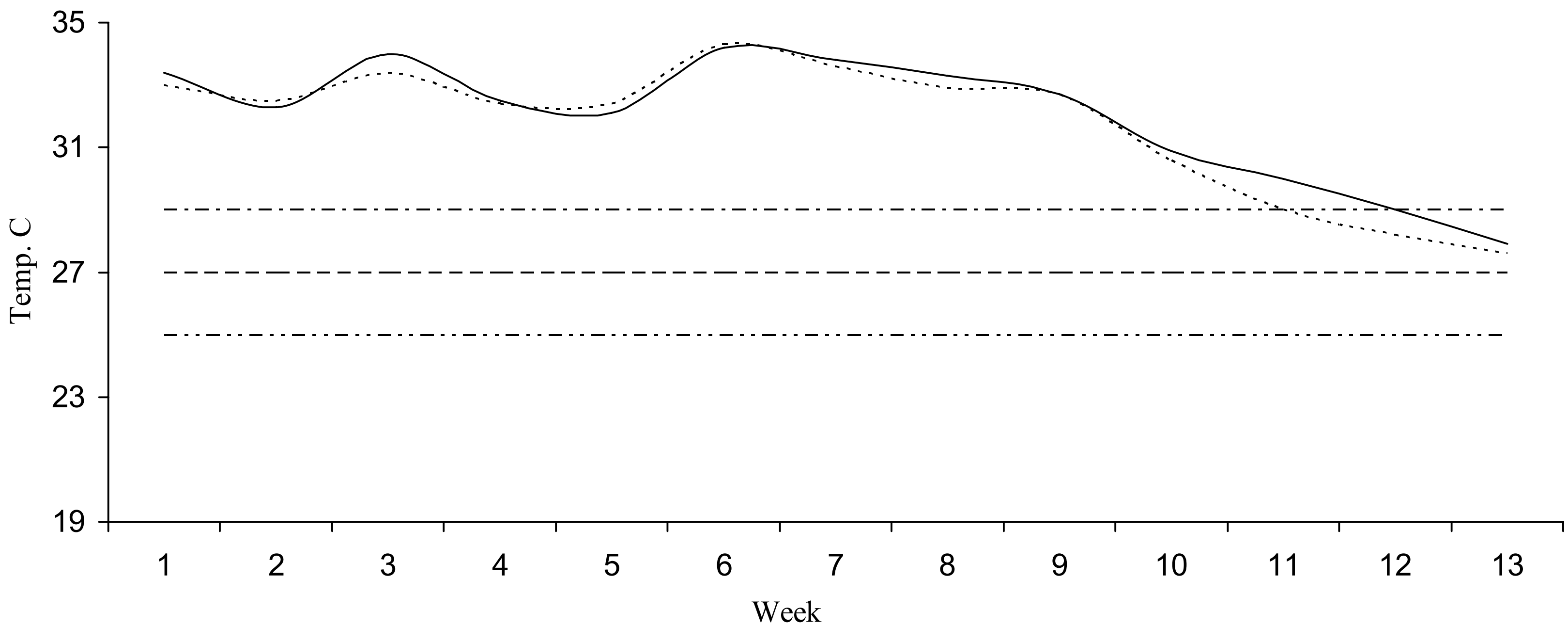

Figure 3. Mean weekly pH levels for morning (---) and afternoon (—) readings at sites A (■) and B (▲) during the evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water at two sites in the Alabama Black Belt.

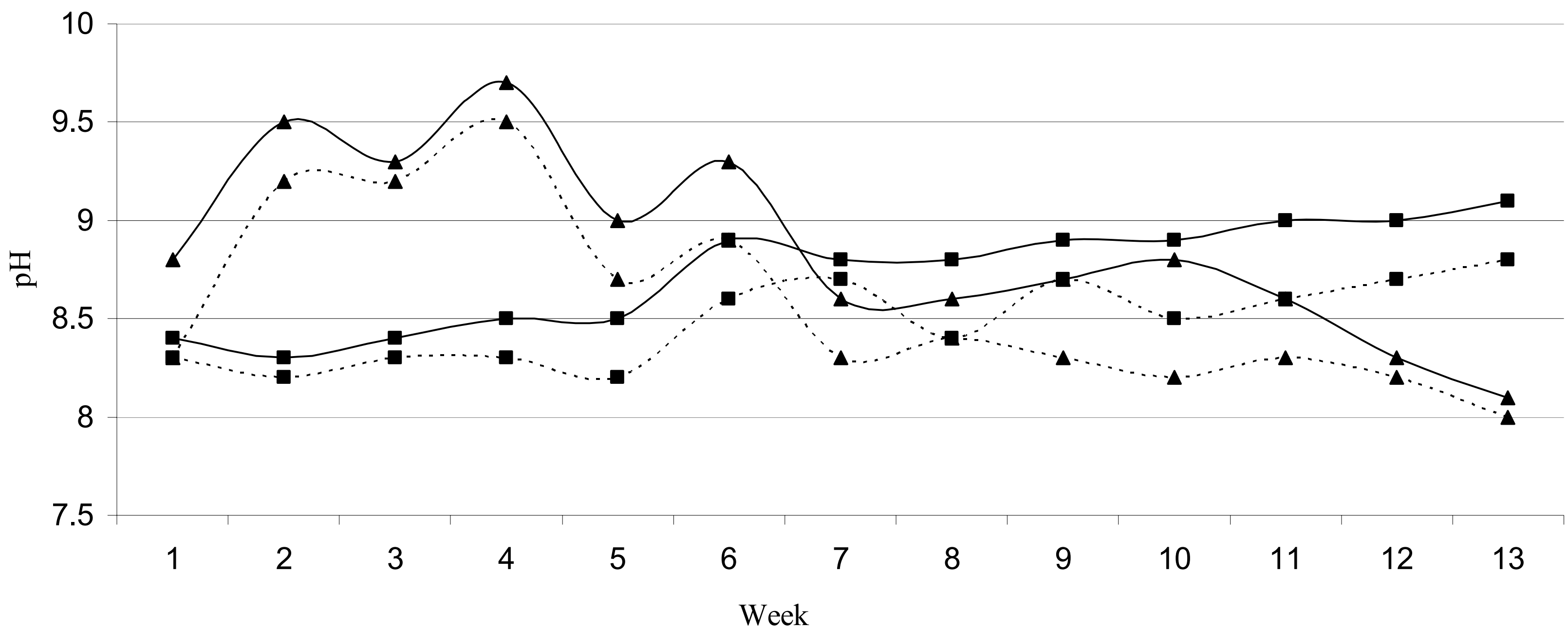

Table 4. Number of days that pH readings were above 9.0 and 9.5, dissolved oxygen readings below 5.0 mg/l, and where temperature readings were above 30 C and 32 C for evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water at two sites in the Alabama Black Belt.

	Site A	Site B
pH > 9.0	6	43
pH > 9.5	0	12
Temperature > 30.0 C	59	59
Temperature > 32.0 C	42	43
D.O. < 5.0	1	1

A gradually increased and at location B gradually decreased; the changes in pH were likely due to phytoplankton density because site B was fertilized.

Overall means for total alkalinity, ammonia, and salinity are given in Table 5. There were no significant differences ($p > 0.05$) between sites for any of these measurements. Site A had an average alkalinity of 93 ± 21.5 and site B had an average of 85 ± 12.5. Total ammonia nitrogen averaged 0.6 mg/l at each location. Mean salinity at site A was 3.4 g/l ± 0.2 and 2.7 g/l ± 0.1 at site B.

Ion composition taken at the beginning of the study can be found in Table 6. There were several differences with ions and ion ratios between the low salinity waters found at the study locations and what would be achieved using dilute or reconstituted seawater. Concentrations in mg/l for sites A and B were as follows: chloride: 1,588 and 1,377; sodium: 1,057 and 903; magnesium: 31 and 22; calcium: 85 and 38; and potassium: 37 and 56, respectively. There were several differences in key ion ratios at each of the locations as well (Table 6).

Production

Mean initial fish stocking, monthly sample, and final harvest weights are found in Table 7. There were no significant differences for stocking weights by species between locations. After the fish were stocked, pompano at both sites, particularly site A, suffered high mortality during the first few days. Fish carcasses were measured and more pompano of similar size were weighed and restocked to replace mortalities. After being restocked, almost all the pompano at location A had died one month after the study began and were not replaced. No apparent mortalities were observed in other fish tanks during

Table 5. Mean daily water quality values (± standard deviation) for pH and dissolved oxygen and mean water quality values (± standard deviation) for ammonia, alkalinity, and salinity during the evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water at two sites in the Alabama Black Belt.

	Site A			Site B		
T.A.N. (mg/l)	0.6	±	0.23	0.6	±	0.35
NH_3 (mg/l)	0.2	±	0.09	0.2	±	0.12
Alkalinity (mg/l)	93.0	±	21.50	85.0	±	12.50
pH	8.6	±	0.26	8.7	±	0.50
D.O. (mg/l)	7.1	±	0.93	7.1	±	0.58
Salinity (g/l)	3.4	±	0.23	2.7	±	0.13

Table 6. Constituents found in dilute sea water (34 g/l) compared to low salinity water from two study site locations shown as parts per million and a ratio of specific elements.

Constituents		Dilute S. W. (3ppt)	Site A	Site B
Cl	mg/l	1,676	1,588	1,377
Na	mg/l	926	1,057	903
Mg	mg/l	119	31	22
Ca	mg/l	35	85	38
K	mg/l	34	37	56
Mg	: K	3.5 : 1	0.8 : 1	0.4 : 1
Ca	: K	1.1 : 1	2.3 : 1	0.7 : 1
Na	: Ca	26.3 : 1	12.4 : 1	23.8 : 1
Na	: K	27.3 : 1	28.6 : 1	16.1 : 1
Mg	: Ca	3.4 : 1	0.4 : 1	0.6 : 1

Table 7. Mean (± standard deviation) individual stocking, sample, and harvest weights (g) at sites A and B during evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water in the Alabama Black Belt. Values for each species in each column with different letters are significantly different at $\alpha = 0.05$.

		Date			
		27-Jun-06	24-Jul-06	24-Aug-06	28-Sep-06
	Site	Stocking	Sample 1	Sample 2	Harvest
Flounder	A	50.1 ± 2.2^{w}	62.4 ± 12.8^{w}	73.7 ± 15.2^{w}	86.4 ± 6.6^{w}
	B	51.4 ± 7.8^{w}	52.8 ± 3.2^{w}	49.4 ± 3.9^{x}	70.9 ± 2.7^{x}
Hybrid Striped Bass	A	2.1 ± 0.3^{w}	7.4 ± 0.8^{w}	17.2 ± 1.7^{w}	39.8 ± 5.0^{w}
	B	1.8 ± 0.2^{w}	9.2 ± 0.7^{x}	24.5 ± 2.5^{x}	50.0 ± 3.3^{x}
Pompano	A	4.0 ± 0.8^{w}	— ± —	— ± —	— ± —
	B	3.6 ± 0.7^{w}	11.9 ± 2.0	33.0 ± 1.1	57.0 ± 2.2

the initial study period. Mean specific growth rates (SGR), % weight gain, and survival can be seen in Table 8. Of fish species examined, flounder proved to have the lowest mean specific growth rates (0.6 ± 0.1 %/d and 0.4 ± 0.2 %/d). Flounder had no significant differences between sites for mean SGR, % weight gain, or survival. Hybrid striped bass at site B had significantly higher mean SGR (3.7 ± 0.1) and % weight gain (2761 %) than those at site A (3.3 ± 0.1 and 1813%, respectively); however, survival did not differ significantly. Pompano at site B had mean SGR of 3.1 ± 0.3; no pompano survived at study site A.

At the conclusion of the study, mean survival for site A was hybrid striped bass 93.8 % ± 6.3, pompano 0 %, and flounder 82.5 % ± 12.6 (Table 8). Mean survival percentages for site B were hybrid striped bass 97.5 % ± 2.9, pompano 80 % ± 10.0, and flounder 91.3 % ± 2.5. Other than pompano at site A, there were no significant differences ($p > 0.05$) for survival between locations.

Mean food conversion ratios (FCR) can be found in Table 8. There were significant differences ($p < 0.05$) in mean FCR of hybrid striped bass and no significant differences for flounder FCR between sites. Mean FCRs for hybrid striped bass and flounder at site A were 1.3 ± 0.1 and 6.4 ± 3.7, respectively. Mean FCRs at site B were 0.9 ± 0.1 for HSB, 7.8 ± 4.1 for flounder, and 1.2 ± 0.1 for pompano.

Table 8. Mean (± standard deviation) specific growth rate (SGR), weight gain (%), survival (%), food conversion ratio, initial weight, and harvest weight for evaluation of the growth of southern flounder, Florida pompano, and hybrid striped bass in tanks using inland low salinity pond water at two sites in the Alabama Black Belt. Values for each species in each row with different letters are significantly different at $\alpha = 0.05$.

		Site A			Site B		
Flounder	SGR (%/d)[1]	0.6	±	0.1^{w}	0.4	±	0.2^{w}
	Weight Gain (%)[2]	72.5	±	10.8^{w}	41.2	±	29.0^{w}
	Survival (%)[3]	82.5	±	12.6^{w}	91.3	±	2.5^{w}
	FCR[4]	6.4	±	3.7^{w}	7.8	±	4.1^{w}
	Initial Weight (g)	50.1	±	2.2^{w}	51.4	±	7.8^{w}
	Harvest Weight (g)	86.4	±	6.6^{w}	70.9	±	2.7^{x}
Hybrid Striped Bass	SGR (%/d)[1]	3.3	±	0.1^{w}	3.7	±	0.1^{x}
	Weight Gain (%)[2]	1812.6	±	157.5^{w}	2760.8	±	226.7^{x}
	Survival (%)[3]	93.8	±	6.3^{w}	97.5	±	2.9^{w}
	FCR[4]	1.3	±	0.1^{w}	0.9	±	0.1^{x}
	Initial Weight (g)	2.1	±	0.3^{w}	1.8	±	0.2^{w}
	Harvest Weight (g)	39.8	±	5.0^{w}	50.0	±	3.2^{x}
Pompano	SGR (%/d)[1]				3.1	±	0.3
	Weight Gain (%)[2]				1536.9	±	372.4
	Survival (%)[3]				80	±	10.0
	FCR[4]				1.2	±	0.1
	Initial Weight (g)				3.6	±	0.7
	Harvest Weight (g)				56.9	±	2.3

[1] Specific growth rate = (ln[mean final weight] - ln[mean initial weight]*100) / days grown

[2] Weight gain percentage = (mean individual harvest wt. - mean individual stocking wt.)/initial stocking wt. * 100

[3] Survival = (Number of fish harvested / Number of fish stocked)*100

[4] Feed conversion rate (FCR) = feed consumed (g) / weight gain (g)

DISCUSSION

Production of Hybrid Striped Bass

Mean specific growth rates for hybrid striped bass proved to be the highest of fish examined. Average specific growth rates (SGR) for hybrid striped bass (3.3 ± 0.1 %/d and 3.7 ± 0.1 %/d) were slightly higher than those provided by Muzinic et al. (2006), who recorded average specific growth rates of 2.0 %/d for 36.2 ± 8.04 g fish grown in outdoor tanks with fresh water being supplied from a nearby earthen pond. During a 36 week experiment conducted by Pine (2005), 5.6 g reciprocal cross hybrid striped bass were grown in freshwater ponds and achieved average SGR of 1.84 %/d. Compared to daily growth rates of 0.6 – 1.0 g /day for similar sized fish presented by Harrel et al. (1990), HSB in this study had slightly lower average weight gains of 0.42 g/d and 0.48 g/d. HSB cultured in a flow-though system during experiments by Muzinic et al. (2006) had a food conversion rate (FCR) of 1.7 which is typical for this species (Hayes and Hodson 1989; Harrel et al. 1990; Rawles et al. 2006). HSB in this study had FCRs of 1.3 and 0.9, which are good, and, given the size of the fish, a possible indication that natural productivity, such as insects or zooplankton, provided a source of energy.

The hybrid striped bass had the best survival, 94% and 98%, with both sites recording high mean survival. Experimentation conducted by Muzinic et al. (2006) achieved a survival of roughly 93% for hybrid striped bass grown in outdoor tanks for 16 weeks and Pine (2005) had 85% for hybrid striped bass grown in freshwater ponds for 36 weeks.

Production of Southern Flounder

Average specific growth rates for southern flounder (0.6 and 0.4 %/d) were lower than what could be achieved under optimal conditions (Gao et al. 2005; Daniels et al. 2006; Daniels 2000). Specific growth rates achieved by Gao et al. (2005) were 1.7-2.1 %/d in experiments examining the effects of varying amounts of protein on 32.9 ± 0.5 g southern flounder grown in cages for 60 days with 31-33 g/l saline water at 26.5-31.5 C. Daniels et al. (2006) suggest that daily growth rates of 1.5 g / day can be obtained with flounder of similar size. During the current research, flounder grew at average rates of 0.40 g /day and 0.22 g / day, lower than the above mentioned rates.

Flounder FCRs of 6.4 ± 3.7 and 7.8 ± 4.1 were much higher than would be expected. FCR values of 1.5-2.0 were obtained when culturing this fish under optimal conditions; optimal conditions being pH 7-8.5 and water temperature 25-30 C (Gao et al. 2005; Daniels et al. 2006; Daniels 2000). Flounder were fed to satiation but feed consumption was routinely low, often much less than 3% body weight/d. They should have been consuming at least 3% body weight/d (Gonzalez et al. 2005; Daniels 2000). The feed consumed by flounder was apparently poorly converted into growth since the same feeding strategy was used on all species of fish, with the others showing good results.

There are several possible reasons for lower growth rates of flounder, but the most likely are high temperatures, low salinity, and ion imbalances. First of all, these fish were kept in covered outdoor tanks which exposed them to seasonal temperatures. When fish are maintained indoors, it typically allows more control of water quality variables such as temperature, alkalinity, and pH. The outdoor production used in this experiment offered little to no control over any of these. High temperatures have been shown to negatively influence feeding characteristics of southern flounder (Benetti et al. 2001), which would also negatively affect growth rates. In the study conducted by Benetti et al. (2001), three month old flounder were grown in large raceways inside a greenhouse with water ranging from 0-32 g/l salinity and fed a diet containing 41% protein. The researchers found that feed consumption and, thus, growth dropped significantly when temperatures were seasonally outside the range of 20 – 28 C. They determined that temperature extremes had a negative effect on the growth rates of cultured southern flounder.

Sample weights (Table 7) indicated that flounder at site B did not grow until the last month of this study. These data could be misleading. In addition to high temperatures, another possible cause of this could have been the sampling method used. Not all of the fish were weighed at each sample date; sub-samples were taken of approximately 50% of the fish in a tank, which could have resulted in unrepresentative samples. If the data correctly represent the growth rates of flounder then pH above 9.0, temperatures over 30 C, or increased ammonia toxicity due to temperature and pH could have affected their growth.

In the current research, flounder were stocked at a rate of 1.2 kg/m^2. The rate recommended by Daniels et al. (2006) for fish of this age and size is roughly 15.6 kg/m^2, which is well above what was used in this study. Lower densities than what would be used in a production environment were necessary for this study because of limited back-up from power outages that would lead to catastrophic events.

Flounder had good survival rates at each of the locations, with values of 91% and 83% at the end of experimentation. Post metamorphosed juvenile southern flounder can be expected to have a survival rate between 80-100% (Jenkins and Smith 1999; Gonzalez et al. 2005; Gao et al. 2005).

Production of Florida Pompano

The average specific growth rate (3.1 ± 0.3 %/d) for 3.6 ± 0.6 g pompano was comparable to rates (2.9-4.2 %/d) achieved by Groat (2002), using larger fish of 17 g in size grown in a closed recirculating system with salinity ranging from 23-28 g/l at 27-29 C. Other private research has shown that pompano of similar size, 10 g, can be grown in low salinity water (19 g/l) to 100g in a 120 day period or 0.83 g/day (McMaster et al. 2005). The pompano in this experiment were approximately 4 g at stocking and grew roughly 55 g in a 90-day period or 0.61 g/day. Pompano at location A had a FCR of 1.2 ± 0.1. Food conversion rates of 1.3 – 3.0 were obtained for 47 g pompano grown in aquaria with full strength seawater during a 5-week experiment conducted by Heilman and Spieler (1999). The experiment conducted by Heilman and Spieler (1999) evaluated the daily feeding rhythm of Florida pompano and found that pompano feed exclusively during the day and most heavily between day break and midday. Pompano in this research were fed during the daylight hours, in the morning and again in the afternoon.

Density did not appear to impact production of pompano. Stocking rates for pompano from previous studies were variable. Groat (2002) using a rate of 900 g /m^3

concluded that overcrowding was not a factor in his results. A dietary protein evaluation conducted by Lazo et al. (1998) stocked pompano at rates of 220 g/m^3 during a seven-week experiment. Mean initial stocking rates for pompano in this experiment were roughly 135 g/m^3; rates at harvest were 1,500 g/m^3. Further research is needed to determine the best stocking rates for pompano of this size (Groat 2002).

All pompano at location A died about 1 month into the study, fish at site B had a survival rate of 80% at the study's conclusion. Groat (2002) achieved survival rates of 96% or higher during his 38 day experiment. Pompano research conducted by Lazo et al. (1998) yielded survival rates of 100% when fish were raised in fiberglass tanks filled with full strength seawater.

Effects of Water Quality

All three of the species studied in this experiment have different optimal temperature ranges. Water temperatures were similar at both locations during the study; however, for a majority of the study period, water temperatures at both sites were much higher than recommended for hybrid striped bass, 25 – 27 C (Morris et al. 1999) and southern flounder, 23 – 25 C (Daniels et al. 2006). High temperatures likely contributed to the lower growth rates of southern flounder. Benetti et al. (2001) observed a decrease in southern flounder feed consumption when temperatures rose above 28 C in the summer months. Temperatures were above 30 C in this study for roughly two-thirds of the 90 days (Table 4 and Fig. 2).

High temperatures found at the locations were closer to the preferred range, 25 - 32 C, of pompano (Watanabe 1994; Muller et al. 2002). During a study conducted by

Groat (2002), pompano were maintained indoors in water temperatures between 27 – 29C with good results. Lazo et al. (1998) kept 4.5 g pompano in a semi-closed recirculating system with 35 g/l salinity and temperatures maintained at 30 C with survival of all pompano and weight gains of 19-26 g in 7-weeks. Pompano have the highest temperature tolerance of the three fishes examined; so, it is probable that temperatures had a lesser impact on growth of pompano.

Recorded dissolved oxygen levels were stable, near or above saturation, during the research, remaining within ranges which were acceptable for good fish health and apparently did not cause any mortality. Hayes and Hodson (1989) mentioned that hybrid striped bass should have dissolved oxygen levels maintained above 4 mg/l. Maintaining dissolved oxygen levels above 5 mg/l is common for experiments involving Florida pompano (Groat 2002; Lazo et al. 1998). Southern flounder typically have dissolved oxygen levels maintained above 5 mg/l (Gonzalez et al. 2005; Moustakas et al. 2004; Smith et al. 1999). Values above these numbers were maintained for the duration of the experiment. There were no chronically low levels of dissolved oxygen during the study and no mortality was attributed to dissolved oxygen problems.

The mean daily pH at site A remained between 8.0 - 9.0 throughout the study period; mean daily pH values at site B remained within 8.0 - 9.6 and no individual readings were above 10.0 during the study. High pH combined with warm temperatures and recorded ammonia levels could have also had a negative impact on the growth of fish. Hayes and Hodson (1989) suggest pH values above 10 would be considered harmful for hybrid striped bass and suggest optimal values being maintained at 7.0 – 8.5 for most species of fish. Morris et al. (1999) also suggested that pH be maintained in the range of 7.0 – 8.5 for production of hybrid striped bass. Most researchers involved in southern flounder culture maintain that pH values between 7.0 – 8.0 are desirable for optimal growth (Smith and Denson 2000; Benetti et al. 2001; and Sampaio and Bianchini 2002). In previous Florida pompano research conducted by Lazo et al. (1998), pH was maintained at 7.8 ± 0.1 with excellent survival rates. During the present study, pH readings were above these optimal levels several times. Site A had 6 daily pH readings above 9.0; site B had 43 daily pH readings above 9.0 and 12 above 9.5.

Alkalinity at both sites was moderate for the duration of the experiment. Site A had an overall mean alkalinity of 93 ± 21.5 mg/l while site B had an average of 85 ± 12.5 mg/l. Alkalinity values fluctuated greatly over the study period from as low as 50 mg/l to as high as 120 mg/l. Alkalinity can fluctuate as carbon is consumed as part of the carbonate cycle. Optimal alkalinity range for most species is typically thought to be between 50-150 mg/l (Wurts and Durborow 1992).

Total ammonia nitrogen averaged 0.6 at both locations and unionized ammonia was also the same at both locations (0.2 mg/l). Values of unionized ammonia were occasionally slightly higher than suggested for some species, but not at levels which would cause growth problems. Daniels et al. (2006) recommend ammonia values of less than 0.5 mg/l for culture of southern flounder; Hayes and Hodson (1989) advised values stay below 1 mg/l for hybrid striped bass; and Groat (2002) maintained a value below 0.3 mg/l for pompano.

Salinity and Ion Composition

Ion composition was a major difference between the two locations. There were no significant differences between sites for any other water quality factors; so, ion composition was the only factor that was not equal at the two locations. Site A contained greater concentrations of calcium and magnesium; site B contained a higher level of potassium. Many of the differences were only slight, but had a great effect on ion ratios; many ratios were not comparable to dilute seawater (Table 5). It is assumed that animals will grow best in low salinity water with ion ratios similar to that of dilute seawater (Boyd 2006). Ion composition and low salinity in general probably affected the results obtained and were probably responsible for pompano mortality at site A.

Magnesium, potassium, sulfate, chloride, sodium, and calcium are all key ions needed for fish growth and are often deficient in the low salinity waters of west Alabama (Boyd 2006). Magnesium and potassium have already proven to be limiting factors affecting the production of shrimp in the region (Roy et al. 2006). Other key ions which are important for normal osmoregulatory function are sodium, calcium, sulfate, and chloride (Roy et al. 2006; Boyd 2006). Ratios for the following combinations of elements differed between sites: magnesium-calcium, magnesium-potassium, calcium-potassium, sodium-calcium, and sodium-potassium. Amending the water to increase ion levels or ratios to amounts comparable to that of dilute seawater may improve chances of resolving problems (Boyd 2006). Potassium is possibly the most important salt found in fish blood and critical for many physiological processes (Wurts and Durborow 1992). It has been suggested that simply increasing potassium concentrations to that which would be expected in dilute seawater and a slight increase in magnesium and sulfate can help to solve problems, such as mortality, associated with low salinity aquaculture (Boyd 2006; Fielder et al. 2001). In the current research this was not the case for either location, potassium levels were near or above levels comparable to dilute seawater and location A still suffered mortality.

In a study of juvenile snapper (*Pagrus auratus*) which were grown in low salinity water suggested that potassium level plays a major role in growth and survival of these fish. The study conducted by Fielder et al. (2001) determined that Australian snapper (*P. auratus*) grown in low salinity water deficient in potassium exhibited lower rates of growth and survival. They suggest that levels of potassium be maintained at least 40% of the equivalent levels found in dilute seawater and that increases in sodium chloride concentrations have very limited effect on growth and survival. Site A had potassium levels slightly higher than 100% of the equivalent found in dilute seawater, site B had amounts of potassium 170% higher than amounts which would be found in equivalent dilute seawater. Potassium concentrations at site B were much higher than site A, supporting the possibility that increased potassium can provide better growth and survival, perhaps at levels higher than that of comparable dilute seawater. However, further research is needed to determine actual ion requirements including potassium.

With increasing salinity, digestibility of energy found in feed will decrease for freshwater stenohaline fish, but increase for euryhaline fish (Altinok and Grizzle 2001); so, at lower salinities less energy is available for growth of euryhaline fish. Instead of expending energy on somatic growth, fish utilize energy in an attempt to maintain proper levels of salts in their blood stream and cells. If salinity or specific ions were too low, this could explain why flounder had lower growth rates and why some pompano did not survive. Growth and survival of larval southern flounder have also been shown to decrease with decreased salinity (Moustakas et al. 2004). They concluded that survival of larval southern flounder was optimized in waters with 34 g/l salinity versus waters with 25 g/l salinity. Experiments with another species of flounder, Brazilian flounder *Paralichthys orbignyanus*, have demonstrated that iono- and osmoregulation are significantly affected in fresh water. When these fish are grown in fresh water, they exhibit lower rates of growth, which may also be true of extremely low salinity water (Sampaio and Bianchini 2002). If salinity or specific ions were in higher concentrations, growth and survival might have been enhanced. Increasing certain ions could enhance survival and growth by reducing high levels of energy consumed during osmoregulation in waters containing deficient levels of salts, allowing more energy to be devoted to somatic growth.

Effect of Water Quality on Survival

Mortality was highest among the pompano. At site A, all but four of the pompano had died by first sampling, about one month into the study. At site B, pompano mortality was also higher than flounder or hybrid striped bass, with a value of 20%. Low mortality at one location and total mortality at another are possible indications that ionic composition played a factor in pompano survival. Salinity and its variations are one of the key factors that influence survival and development of fish (Varsamos et al. 2005). In water with low ion concentrations it is probable that a substantial amount of ions are lost from the fish to the water, reducing fish performance or possibly resulting in mortality (Fielder et al. 2001). Other factors could have also compounded stress from irregular ion concentrations and influenced survival. The temperatures along with high pH and unionized ammonia would compound any stress from ion imbalances.

Conclusion

The region of western Alabama does have the physical potential to produce species other than catfish in the low salinity waters of the region. Of the fish examined, hybrid striped bass appear to have the least number of problems growing in low salinity waters predominant in the area. If key ions necessary for pompano can be identified, this species also has the possibility of being produced in this region; however, further research will need to be conducted. The ions and various ratios that would likely need to be examined include: magnesium, potassium, chloride, sulfate, sodium and calcium. High seasonal water temperatures seem to make outdoor or pond production of flounder unrealistic. In western Alabama, flounder would best be suited for indoor production where temperatures can be maintained between 24-27 C, assuming that further research can explain the necessary ions for optimal production. From the fish examined and based strictly on production characteristics, hybrid striped bass appear to be the best alternative species for production in low salinity waters of the region. Hybrid striped bass could be grown in the region because: 1) they have no problem adapting to low salinities or irregular ion levels, 2) can be over-wintered outdoors, 3) can be grown in earthen ponds, and 4) can reach market size within two years.

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