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Effects of Salinity on Growth and Survival of Channel Catfish, Ictalurus Punctatus (Rafinesque), Eggs Through Yearlings.

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Effects of Salinity on Growth and Survival of Channel Catfish, *Ictalurus punctatus* (Rafinesque), Eggs Through Yearlings

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ABSTRACT

Laboratory tests were conducted to determine the effect of salinity on survival of channel catfish, Ictalurus punctatus (Rafinesque), eggs, sac fry (prolarvae), and fry (postlarvae), and on food consumption, growth, food conversion, and survival of fingerlings and yearlings. Notes were also kept on pathological conditions encountered by fish in the brackish water as compared to fresh water controls.

Eggs and fingerlings, obtained from Meridian, Mississippi, Yazoo City, Mississippi, and Baton Rouge, Louisiana, were tested over a three-year period. Eggs obtained at either one or two days of age were found to increase in tolerance at first, presumedly due to the formation and hardening of the vitelline membrane. At the end of the second day the upper tolerance was about 10 ppt salinity. By the third or fourth day the upper tolerance had increased to about 16 ppt where it remained until hatching. At hatching there was an immediate drop in tolerance to about 8 ppt. This occurred as the vitelline membrane ruptured, permitting the embryo to come in contact with the saline water.

There did not appear to be a change in tolerance during the sac fry stage. However, following yolk absorption the upper tolerance increased slightly to about 9 or 10 ppt during the fry stage.

Fingerlings in a long-term test, beginning at an age of 11 days and continuing for 90 days, had the best growth and survival in fresh water, 5 ppt salinity was a close second, and 10 ppt was a poor third.

By 5 months of age fingerlings had increased their upper salinity tolerance to about 11 ppt and by 6 months it had increased to about 12.5 ppt. At both 5 and 6 months of age, fingerlings acclimated to 5 ppt generally had better values for food consumption, growth, food conversion, and survival than did fingerlings acclimated to fresh water. At 5 months of age there was little differences in results between freshwater, 4, and 8 ppt. Fingerlings 6 months of age, at salinities of 4 and 8 ppt, had slightly better values for food consumption, growth, and food conversion than fingerlings in fresh water.

Tests with 11-to 14-month-old yearlings acclimated to either 5 or 10 ppt for 154 days indicated upper tolerances of 11.5 and 12.5 ppt respectively. Thus the upper tolerance could not be increased beyond 12.5 ppt even with prolonged acclimation to high salinities. Tolerance did not appear to differ among eggs and fish from the three geographic sources.

There were indications that the normal parasito-fauna of channel catfish would be altered in brackish water. Also, fish in higher salinities were noticeably more sluggish than fish in lower salinities or in fresh water.

The results of this study indicate that channel catfish can be cultured in waters up to 12 ppt salinity. However, eggs, fry, and very young fingerlings would be limited to salinities less than 6 or 8 ppt.

INTRODUCTION

In the United States, as well as in other nations, much emphasis is being placed on new systems of agriculture. Current and projected food shortages indicate a drastic need for new sources of foods, particularly animal protein. Mariculture promises to provide one such source.

In Louisiana there are approximately 2 million acres of brackish water habitat (O'Neal, 1949; Chabreck, 1968). Most of this is salt marsh, but about one-fourth to one-third consists of open water. The zone of brackish water lies between the fresh water-marsh on the inland side and the more saline marsh, estuarine, and bay zone on the seaward side. Salinity varies widely both geographically and seasonally, ranging from near fresh water to 12-15 ppt (parts per thousand) or more as the brackish water zone intergrades into the marine zone. Fish or shellfish production is one of the few types of food production that could be practiced in this area without extensive alterations to the environment.

In the United States there have been a number of attempts to rear marine fishes in brackish water (Johnson, 1954; Bearden, 1967; Moe et al., 1968). However, to date, no native estuarine or marine species of fish have been adapted for culture in brackish water.

Attempts to rear fresh water fishes in brackish water are rare. In Europe and Asia fresh water fishes are reared commercially in brackish water. Species of the euryhaline tilapia are cultured in waters up to 50 per cent or more sea strength (Lotan, 1960; Chervinski, 1961 a, b; Hickling, 1962). The common carp, Cyprinus carpio, a primary division fish (Darlington, 1938), is cultured in waters of up to 5 ppt, but growth decreases at 2 to 3 ppt. The upper salinity tolerance is about 7 ppt (Soller, 1965).

In the United States, as aquaculture continues to increase, more attention will be given to the coastal marshes as a potential area for fish culture. This area offers the advantages of plenty of cheap land and a long growing season.

Prior to this study and the studies by Perry and Avault (1968 and 1969), the channel catfish, Ictalurus punctatus (Rafinesque), was generally believed to have a low salinity tolerance. Davis and Hughes (1967) stated that channel catfish could probably not be cultured in salinities exceeding 1.5 ppt. Kelly (1965) captured only one channel catfish in brackish water from a survey of fishes at the Delta Wildlife Refuge (Mississippi Delta). It was found at a salinity of 1.3 ppt. Bayless and Smith (1962) did not find any channel catfish in the brackish waters of the Neuse River, North Carolina. However, Perry (1967) found channel catfish at salinities up to 11.3 ppt in a tidal-bayou complex at Rockefeller Wildlife Refuge. They were not abundant, though, at salinities above 1.7 ppt.

The blue catfish, _I. furcatus_, a close relative of channel catfish, has been found at salinities up to 6.3 ppt (Gunter, 1945), 6.5 ppt (Rounsefell, 1964), 7.0 ppt (Kelly and Carver, 1965), and 11.3 ppt (Perry, 1967). However, most fish were found at salinities less than 1.7 or 2.0 ppt by Kelly and Carver (1965), and by Perry (1967). In a laboratory study, Kendall and Schwartz (1968) found that the white catfish, _I. catus_, had a 60 hour LC_{50} of 14 ppt.

The geographic range of ictalurid catfishes and that of the sunfishes largely coincide. Tebo and McCoy (1964), stated that largemouth bass, _Micropterus salmoides_, were limited by salinities in excess of 3.5 ppt. Keup and Bayless (1964) found sunfishes and other fresh water fishes at salinities up to 10.5 ppt in the Neuse River.

Prior to the present study there was no known information about the effect of salinity on reproduction of channel catfish. In fact, very little is known about the ability of fresh water fishes to reproduce in brackish water. Tebo and McCoy (1964) state that the maximum salinity for hatching and development of largemouth bass and blue-gill fry is about 3.5 to 5.25 ppt. Karpevich (1966) working with grass and silver carps, _Ctenopharyngodon idella_ and _Hypophthalmichthys molitrix_, found that eggs developed normally in water up to about 1.6 to 2.1 ppt salinity. Salinity tolerance increased with age; the fry tolerated up to about 3.1 to 4.2 ppt salinity.

This study was conducted in the laboratcry during the period 1967-70 and was a counterpart to studies conducted in brackish water ponds constructed at the Rockefeller Wildlife Refuge (Perry and Avault, 1968 and 1969). The pond studies consisted of attempts to rear three species of ictalurid catfishes, channel catfish, blue catfish, and white catfish. The three species were stocked at rates and with similar techniques currently utilized in fresh water culture. It was felt that the pond studies would determine the feasibility of brackish water culture of ictalurid catfishes, whereas the laboratory study would answer many questions not answered under the highly variable conditions of the pond studies.

Objectives of this study were to determine the effects of salinity on eggs, sac fry (prolarvae), fry (postlarvae), fingerlings, and yearlings. Eggs were tested for survival ahd hatchability. Sac fry and fry were tested for survival. Fingerlings and yearlings were tested for effects of salinity and prior acclimation on food consumption, growth, food conversion, and survival. It was felt that these parameters would be important from a commercial standpoint and would be good indicators of the adaptability of channel catfish to culture in brackish water.

The effects of salinity on parasites and other pathogens of channel catfish is potentially important. While this subject was not examined in detail, notes were kept and are discussed in this report.

MATERIALS AND METHODS

Eggs and sac fry

The objective of this portion of the study was to determine the salinity tolerance of eggs at various stages of development and at hatching. Also, the tolerance was determined for the period of yolk absorption, or sac fry stage.

In 1968, a spawn estimated to be one day old and containing approximately 3,000 eggs was obtained from a pond near Baton Rouge, Louisiana. Masses of approximately 50 eggs each were suspended in a fine-mesh seine in 19-liter aquaria at salinities of 0 (fresh water controls), 5, 9, 10, 11, 12, 13, and 14 ppt (two replicates each). Two or three air stones, lying on the bottom of each aquarium, permitted compressed air to bubble around the egg-mass. The remainder of the spawn was placed in several 38-liter aquaria containing fresh water or water of 5 ppt. These were utilized as a supply of extra eggs and to hatch fish for future experiments.

Eggs were checked daily. From gross appearance each mass was designated as containing healthy (0) or dead eggs (X). When the eggs in a mass died that mass was replaced with another from the supply of extra eggs. Egg-masses were replaced in order to determine the tolerance at various stages of egg development. This test was terminated after the eggs hatched.

In 1969, a two-day-old spawn containing about 4,000 eggs was obtained from Thompson-Anderson Farm, Yazoo City, Mississippi. Experiments with these eggs were conducted as outlined previously, except salinities of 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, and 17.5 ppt (two replicates each) were used. The salinity levels were adjusted after studying results of the 1968 experiment. This test continued for 2 days after the eggs hatched. Sac fry were checked similarly to eggs. Dead sac fry were removed but not replaced. Surplus fish hatched in fresh water were retained for future experiments.

In 1970, a spawn of approximately 4,000 eggs were obtained from the same Baton Rouge pond as the eggs used in 1968. Testing proceeded as in the 1969 test, except tests continued for 4 days after the eggs hatched. Dead sac fry were removed but were not replaced. The chief purpose of this test was to verify the results of the two previous tests.

<u>Fry</u>

Two-day-old Yazoo City fry[1] hatched in fresh water were tested in 19-liter aquaria for effects of salinity on survival. Salinites of 0, 2, 4, 6, 8, 10, 12, and 14 ppt (two replicates each) were used. Each aquarium contained 10 fish. Mortality was checked daily for 11 days.

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[1] These fish were actually sac fry when testing first began but soon advanced into the fry stage.

A series of studies were conducted with Baton Rouge fry and fingerlings. To test the effects of prior acclimation on salinity tolerance, 5-day-old fry that had been hatched in either 0 or 5 ppt salinity, were tested at salinities of 9, 10, 11, 12, 13, and 14 ppt (unreplicated). Two controls at each acclimation level were used (0 and 5 ppt). As aquaria were not available for this test, 3.8-liter jars were substituted. The test duration was reduced to 6 days, because it was feared metabolites would become abundant in the small containers over a 11-day period. Mortality was checked daily.

Fingerlings

Forty-day-old Baton Rouge fingerlings were tested for effects of salinity and prior acclimation on growth and survival. Fish that had been hatched and reared at either 0 or 5 ppt salinity were tested in 19-liter aquaria at salinities of 9, 10, 11, 12, 13 and 14 ppt (unreplicated). One control at each acclimation level was used (0 and 5 ppt). Each aquarium contained 10 fish. Mortality was checked daily for 22 days. Fish were measured for total length initially and at termination of the experiment.

A 90-day study of the effect of salinity on survival and growth was conducted with still other Baton Rouge fingerlings. The study began at an age of 11 days and continued through an age of 101 days. Fish were tested from two lots that had been hatched and held at 0 and 5 ppt,

and a third lot that was hatched at 5 ppt but gradually acclimated to 10 ppt by 11 days of age. Fish from each of the three lots were placed in 19-liter aquaria at salinities of 0, 5, and 10 ppt respectively. Two replicates at each salinity were maintained. Each aquarium contained 30 to 35 fish. Fish were measured for total length initially, and after 31, 45, 53, 78, 90, 106, and 137 days. Mortalities were recorded daily.

Studies were conducted with fingerlings obtained in 1967 at an age of 4 months from the Meridian, Mississippi National Fish Hatchery. Four lots of fish were maintained for tests: (1) Fish were maintained at 0 ppt (2) After 20 days of acclimation to the laboratory part of these fish were placed at 5 ppt. At an age of 6 months additional lots of fish that had been maintained in fresh water were started at (3) 5 ppt and (4) at 10 ppt.

At an age of 5 months, fingerlings were tested for effects of salinity and prior acclimation on survival, food consumption, growth, and food conversion. Fish acclimated to either 0 or 5 ppt were tested in aquaria that contained a glass partition. This partition divided the container into two equal halves and prevented the exchange of fish between the two halves. However, it was not water tight and there was an exchange of water along the sides and bottom. Thus fish from two different acclimations could be kept separate but tested in a common medium. Five fish from 0 ppt acclimation were placed in one side and five fish from 5 ppt acclimation were placed in the other side.

The fish were tested for 22 days at salinities of 0, 4, 8, 12, 14, 15, and 16 ppt (unreplicated). Mortalities were recorded daily. Determination of food consumption, growth, and food conversion will be discussed separately.

One month after the preceeding experiment, samples of fish from the same two lots were again tested. They were now 6 months of age and the fish at 5 ppt had now been acclimated for 40 days. The chief purpose of this test was to see if additional acclimation time affected the results. The experiment was conducted similarly to the preceeding one, except that a salinity level of 13 ppt was added and levels of 14, 15, and 16 ppt were not used, as they were clearly above the upper tolerance level.

The survival and growth of 5½-month-old Baton Rouge fingerlings were also tested for indirect comparison with the Meridian fish. The former were tested for 22 days at salinities of 12 ppt (four replicates). Each aquarium contained five fish.

Yearlings

In 1968, Meridian fish now 11 months old were tested for long-term effects of salinity and prior acclimation on survival, food consumption, growth, and food conversion. Methods were similar to earlier tests. Fish that had been acclimated to either 5 or 10 ppt for 154 days were utilized to see if additional acclimation effected results. Salinities

of 8, 9, 10, 11, 12, 13, and 14 ppt (unreplicated) were used. Fish acclimated to freshwater were maintained as controls in two aquaria at 0 ppt. This experiment was conducted for 45 days with all the test salinities and in addition critical salinities of 11, 12, and 13 ppt were tested an additional 45 days.

Determination of food consumption, growth, and food conversion

Diet for all fish up to 5 months of age consisted of 40 per cent protein trout food (Purina Trout Chow, Ralston-Purina Company). Food consumption and food conversion were not determined for these fish. In all of the tests involving fish of 5 months or greater age, 32 per cent protein, floating catfish pellets were fed (Purina Catfish Chow). Determinations of food consumption, growth, and food conversion were made. The daily diet consisted of all the feed the fish would take, which was usually one or two pellets per fish. The number of pellets placed in the water was recorded and then approximately one-half hour later the uneaten pellets were removed and the number recorded. The pellets were fairly uniform in size and from sample counts the average weight of each pellet was determined to be 0.087 grams. Food consumed was determined by adding the number of pellets offered, subtracting the number of pellets removed, and multiplying by 0.087.

Weight gain or loss was determined from weights obtained at the beginning of experiments, at intervals during the experiments, and at

the conclusion of the experiments. Food conversion was determined by dividing the food consumed by the weight gained.

Salinity and other chemical-physical factors

Water for experiments was prepared by diluting sea water from Grand Isle, Louisiana with Baton Rouge tap water. Salinity was determined by the mecuric nitrate method (American Public Health Association, Inc., 1965). Salinity usually ranged within ± 0.3 ppt of the stated value and the range rarely exceeded ± 0.5 ppt of the stated value. Dissolved oxygen was usually 5.0 to 6.0 ppm but extremes of 3.8 to 7.5 ppm were recorded. Carbon dioxide was never present in more than trace amounts. The pH ranged from 7.9 to 8.1. Temperature in egg and sac fry studies ranged from 23.5° to 25.0° C. During the studies with fry, fingerlings, and yearlings it usually ranged from 23.5° to 25.0°, but extremes of 19.0° to 27.0° were recorded.

Aeration for the eggs was previously described. Aeration for all tests with fish was supplied by compressed air, dispersed to each aquarium through two air stones. The jars contained one air stone. Filtration was by under-gravel filters plus one box-type filter per aquarium or jar.

Pathology

Fish were frequently examined for external parasites and other pathological conditions. Examinations were made from prepared mounts of gills, body mucus, and fins.

RESULTS

Eggs and sac fry

All of the eggs and sac fry from a particular egg mass responded uniformly to salinity level. They tended to either all live or all die depending on salinity level and age. Similar results were obtained with eggs of catfish obtained at three dates and from two sources (Tables 1-3). At 1 to 2 days of age the upper tolerance (the lowest salinity at which the eggs would be expected to die if the tests were repeated) was about 10 ppt. They rapidly increased in tolerance as they aged until the third or fourth day of age at which time the upper tolerance leveled off at about 16 ppt. However upon hatching there was a drastic reduction in tolerance to about 8 ppt. Close observation revealed this mortality started as soon as the egg membrane ruptured.

Fry

After yolk absorption there appeared to be a small increase in the upper tolerance (the lowest salinity at which the majority of the fry would be expected to die if the tests were repeated) to about 10 ppt (Tables 4 and 5). One or more days were usually required for salinities of 10 through 12 ppt to kill fry. There appeared to be large individual

Table 1. Effects of salinity on survival of Baton Rouge channel catfish eggs.

Salinity level (ppt)	Mortality* 2 days	3 days	4 days	5 days	6 days	7 days	8 days**	9 days
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	X
9	0	0	0	0	0	0	0	X
10	X	0	0	0	0	0	0	X
10	X	0	0	0	0	0	0	X
11	X	0	0	0	0	0	0	X
11	X	0	0	0	0	0	0	X
12	X	0	0	0	0	0	0	X
12	X	0	0	0	0	0	0	X
13	X	0	0	0	0	0	0	X
13	X	0	0	0	0	0	0	X
14	X	0	0	0	0	0	0	X
14	X	0	0	0	0	0	0	X

Eggs were one day old at start of experiment.

0 = 2% or less mortality
X = total mortality

*Dead egg-masses were replaced with fresh egg-masses each day.
**Eggs started hatching on 8th day and hatching was completed during the 9th day.

Table 2. Effects of salinity on survival of Yazoo City channel catfish eggs and sac fry.

Salinity level (ppt)	Mortality*							
	3 days	4 days	5 days	6 days	7 days**	8 days	9 days	10 days
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0
5.0	0	0	0	0	0	0	0	0
5.0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0
10.0	0	0	0	0	X	--	--	--
10.0	0	0	0	0	X	--	--	--
12.5	0	0	0	0	X	--	--	--
12.5	0	0	0	0	X	--	--	--
15.0	0	0	0	0	X	--	--	--
15.0	0	0	0	0	X	--	--	--
17.5	X	X	X	X	X	--	--	--
17.5	X	X	X	X	X	--	--	--

Eggs were two days old at start of experiment.

0 = 2% or less mortality
X = total mortality

*Dead egg-masses were replaced with fresh egg-masses each day; sac fry were not replaced.
**Eggs started hatching on 7th day and hatching was completed during the 8th day.

Table 3. Effects of salinity on survival of Baton Rouge channel catfish eggs and sac fry.

Salinity level (ppt)	2 days	3 days	4 days	5 days	6 days	7 days	8 days**	9 days	10 days	11 days	12 days	13 days
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0
5.0	0	0	0	0	0	0	0	0	0	0	0	0
5.0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	X	--
7.5	0	0	0	0	0	0	0	0	0	0	X	--
10.0	0	0	0	0	0	0	0	X	--	--	--	--
10.0	0	0	0	0	0	0	0	X	--	--	--	--
12.5	X	0	0	0	0	0	0	X	--	--	--	--
12.5	X	0	0	0	0	0	0	X	--	--	--	--
15.0	X	X	0	0	0	0	0	X	--	--	--	--
15.0	X	X	0	0	0	0	0	X	--	--	--	--
17.5	X	X	X	X	X	X	X	X	--	--	--	--
17.5	X	X	X	X	X	X	X	X	--	--	--	--

Eggs were 1 day old at start of experiment.

0 = 2% or less mortality
X = total mortality

*Dead egg-masses were replaced with fresh egg-masses each day; sac fry were not replaced.
**Eggs started hatching on 8th day and hatching was completed during the 9th day.

Table 4. Effects of salinity on survival of Yazoo City channel catfish fry hatched in fresh water. (Tested for 11 days beginning at an age of 2 days.)

Salinity level (ppt)	Percent survival 1 day	2 days	4 days	6 days	11 days
0	100	100	100	100	100
0	100	100	100	100	100
2	100	100	100	100	100
2	100	100	100	100	90
4	100	90	90	90	90
4	100	100	100	100	100
6	100	100	100	100	100
6	100	100	100	100	100
8	100	100	100	80	60
8	100	100	100	100	100
10	100	100	60	40	30
10	90	90	80	60	50
12	90	0	--	--	--
12	90	30	0	--	--
14	0	--	--	--	--
14	0	--	--	--	--

Ten fish were tested in each 19-liter aquarium.

Table 5. Effects of salinity on survival of Baton Rouge channel catfish fry hatched and held in 0 and 5 ppt salinity. (Tested for 6 days beginning at an age of 5 days.)

Salinity level (ppt)	Acclimation level (ppt)	Percent survival 1 day	2 days	4 days	6 days
0(control)	0	100	100	100	100
0(control)	0	100	100	100	100
5(control)	5	100	100	100	100
5(control)	5	100	100	100	100
9	0	100	100	100	100
9	5	100	100	100	100
10	0	90	70	70	70
10	5	80	80	70	70
11	0	100	100	100	10
11	5	80	80	80	80
12	0	70	20	10	0
12	5	70	60	10	0
13	0	0	0	0	0
13	5	70	40	0	0
14	0	0	0	0	0
14	5	0	0	0	0

Ten fish were tested in each 3.8 liter jar.

differences in the tolerance of fry as contrasted to eggs and sac fry. The upper safe level for fry was about 2 or 3 ppt lower than the upper tolerance level.

Fingerlings

Results with 40-day-old fingerlings (Table 6) were somewhat inconclusive due to the early death of fish at 10 ppt, apparently from water fouling. The upper tolerance level,however did appear to be in the neighborhood of 9 to 11 ppt. A paired "t" test indicated the differences in growth and survival between acclimation levels were not significant.

In the long-term test that began with fish 11 days old, fingerlings in fresh water had the best growth followed by fingerlings at 5 ppt (Table 7). The 10 ppt group was a poor third. An analysis of variance of growth after 90 days of testing indicated the differences were significant ($P < .05$). Fingerlings in fresh water had the best survival, followed by fingerlings at 5 ppt salinity (Table 8). Differences in survival at various salinities were significantly different ($P < .05$).

In the experiment with 5-month-old Meridian fish, similar food consumption, growth, food conversion, and survival were obtained at 0, 4, and 8 ppt (Figure 1). Fish acclimated 9 days to 5 ppt salinity achieved better growth and food conversion than fish acclimated to fresh water, but consumed slightly less food. Results indicated that

Table 6. Effects of salinity on growth and survival of Baton Rouge channel catfish fingerlings hatched and reared at 0 and 5 ppt salinity. (Tested for 22 days beginning at an age of 40 days.)

Salinity level(ppt)	Acclimation level(ppt)	Percent survival 1 day	2 days	4 days	6 days	17 days	22 days	Average increase in total length(mm)	Average percent increase in total length
0(control)	0	100	100	100	100	100	100	3.5	14.6
5(control)	5	100	100	100	100	100	100	6.0	26.7
9	0	100	60	50	50	40	40	2.7	11.1
9	5	100	80	70	60	60	60	4.7	20.2
10	0	100	50	30	0*	--	--	--	--
10	5	100	100	80	80*	10	0	--	--
11	0	80	70	60	60	50	0	--	--
11	5	80	80	80	80	70	70	2.5	11.1
12	0	30	20	20	20	0	--	--	--
12	5	30	20	0	--	--	--	--	--
13	0	30	0	--	--	--	--	--	--
13	5	40	10	0	--	--	--	--	--
14	0	0	--	--	--	--	--	--	--
14	5	0	--	--	--	--	--	--	--

Ten fish were tested in each 19-liter aquarium.

*Water fouling was suspected in both these lots.

Table 7. Effects of salinities of 0, 5, and 10 ppt on growth of Baton Rouge channel catfish fingerlings. (Tested for 90 days beginning at an age of 11 days.)

Salinity level (ppt)	Number of fish per aquarium	Average percent increase in total length				
		31 days	45 days	53 days	78 days	90 days
0	34	56.6	82.7	99.3	136.0	146.7
0	35	54.6	84.6	95.3	132.7	144.4
5	30	50.0	62.6	83.3	118.7	129.3
5	35	49.3	76.0	89.3	122.0	132.7
10	34	44.7	50.6	59.3	86.6	116.7
10	30	47.3	48.0	58.7	85.3	102.0

Table 8. Effects of salinities of 0, 5, and 10 ppt on survival of Baton Rouge channel catfish fingerlings. (Tested for 90 days beginning at an age of 11 days.)

Salinity level (ppt)	Number of fish per aquarium	Percent surviving						
		6 days	22 days	31 days	45 days	53 days	78 days	90 days
0	34	94.1	91.2	91.2	88.2	85.3	70.6	67.6
0	35	97.1	68.6	68.6	68.6	68.6	68.6	68.6
5	30	96.6	96.6	90.0	86.6	86.6	83.3	83.3
5	35	88.6	77.1	74.3	71.4	71.4	68.6	68.6
10	34	70.6	32.4	23.5	20.6	17.6	17.6	11.8
10	30	83.3	33.3	26.7	23.3	20.0	16.7	3.3

the fish could not survive indefinitely at 12 ppt or greater salinities. An analysis of variance indicated the differences in parameter values, when all levels of salinity were included, were significantly different ($P < .05$). However, the differences obtained at 0, 4, and 8 ppt only, were not significant.

At 6 months of age they had increased their tolerance and were able to survive and grow slowly at 12 ppt (Figure 2). Food consumption, growth, and food conversion indexes were best for fish at 4 ppt, followed by 8 ppt, and then 0 ppt. Fish given 40 days of acclimation to 5 ppt had slightly better values, at the four parameters, than fish acclimated to fresh water. Neither group was able to maintain themselves at 13 ppt. The results of an analysis of variance were the same as obtained in the previous test.

Baton Rouge fish tested at 5½ months of age at a salinity of 12 ppt did not have any mortality by 22 days. However, all but one fish lost weight even though they fed a little. The average per cent weight decrease of the fish of each aquarium is as follows:

Aquarium	Per cent weight decrease in 22 days	Per cent weight decrease per day
Number 1	4.96	0.23
Number 2	15.52	0.71
Number 3	5.52	0.25
Number 4	8.39	0.38

Figure 1. Effects of salinity and prior acclimation on food consumption, growth, food conversion, and per cent survival of Meridian channel catfish fingerlings. (Tested for 22 days beginning at an age of 5 months. Solid line indicates acclimation to fresh water, broken line indicates acclimation to 5 ppt salinity for 9 days. Five fish were tested in each half of partitioned 38-liter aquaria.)

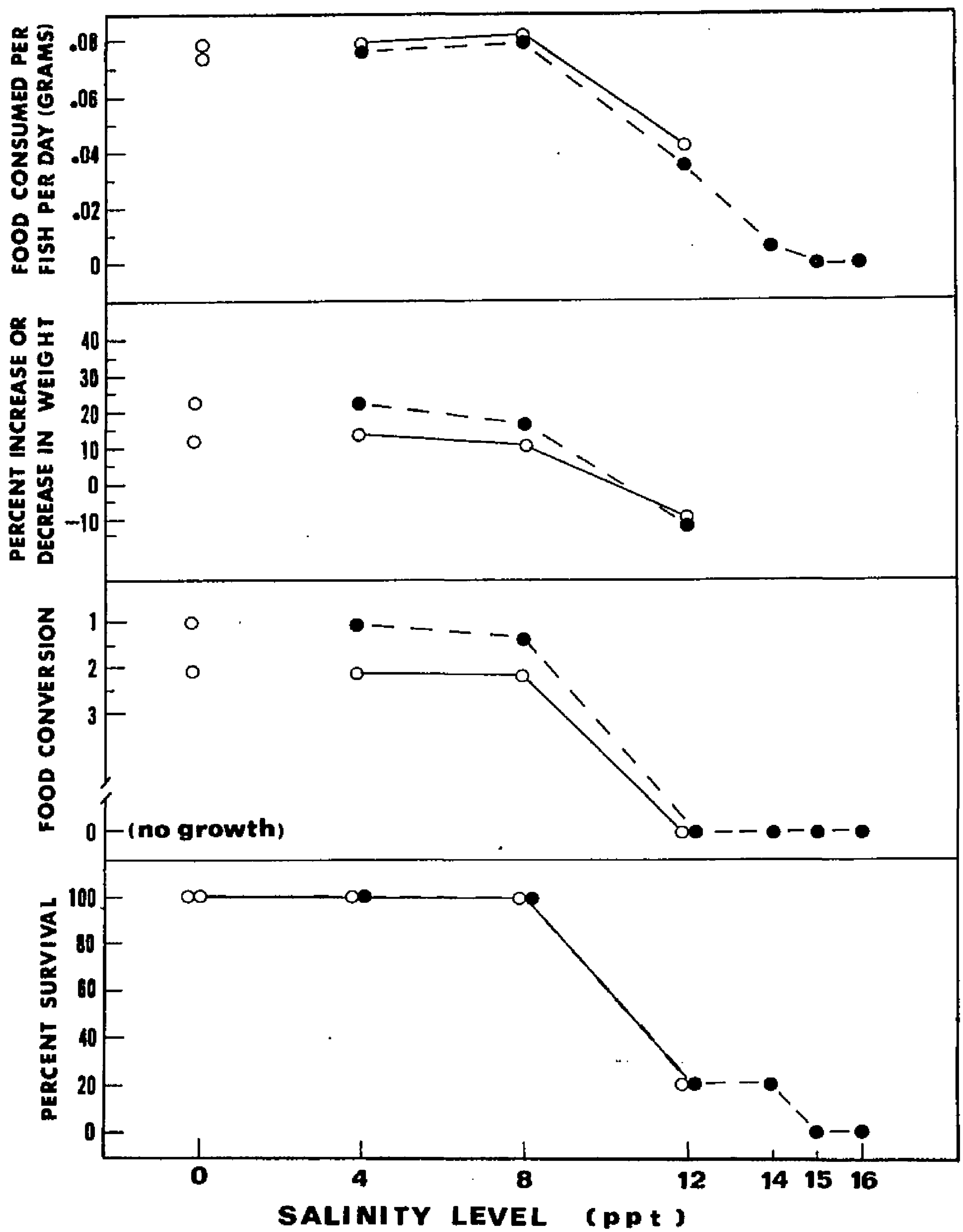
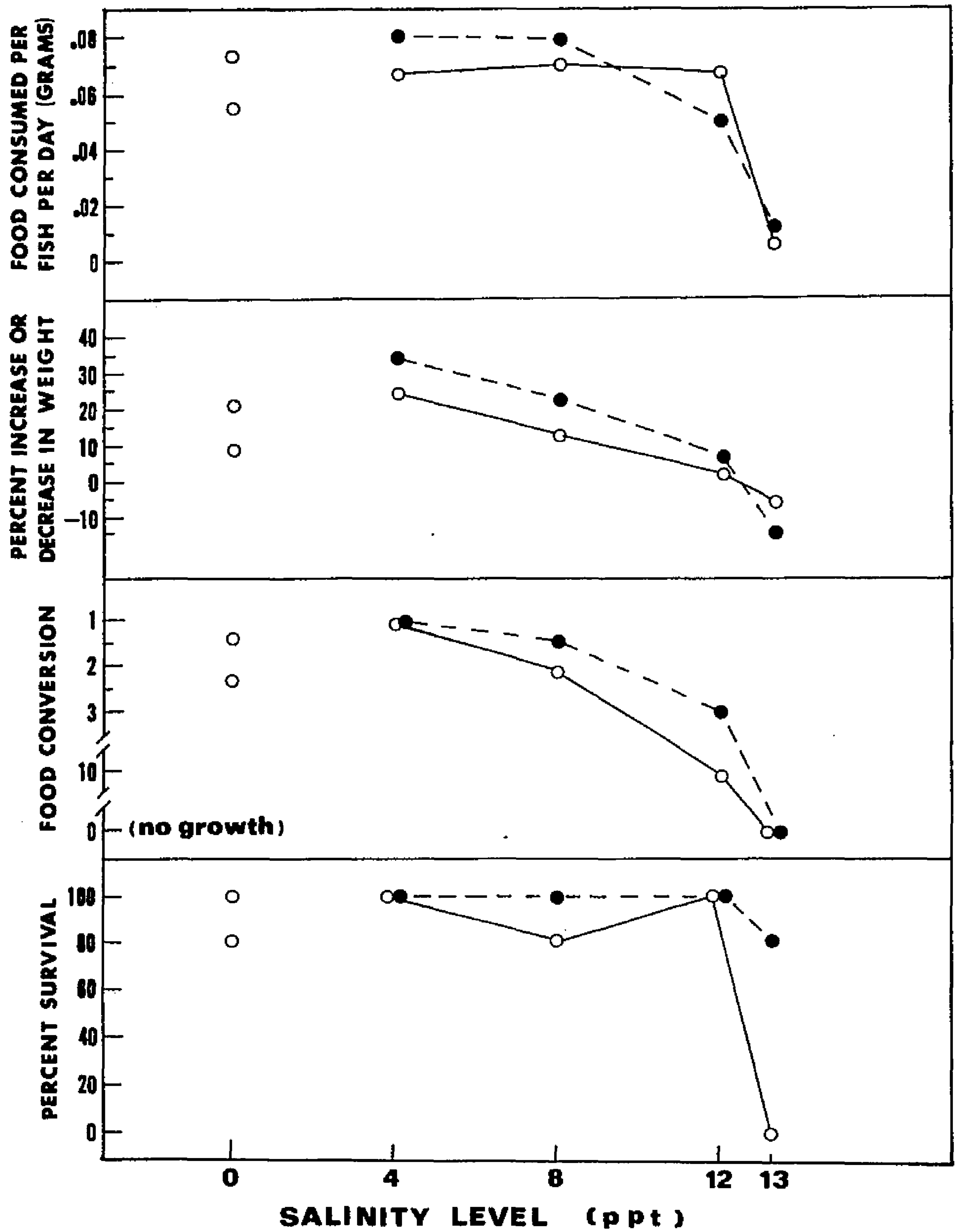

FOOD CONSUMED PER FISH PER DAY (GRAMS)
.08
.06
.04
.02
0
PERCENT INCREASE OR DECREASE IN WEIGHT
40
30
20
10
0
−10
FOOD CONVERSION
1
2
3
0
(no growth)
PERCENT SURVIVAL
100
80
60
40
20
0
0
4
8
12
14
15
16
SALINITY LEVEL (ppt)

Figure 2. Effects of salinity and prior acclimation on food consumption, growth, food conversion, and per cent survival of Meridian channel catfish fingerlings. (Tested for 22 days starting at an age of 6 months. Solid line indicates acclimation to fresh water, broken line indicates acclimation to 5 ppt salinity for 40 days. Five fish were tested in each half of partitioned 38-liter aquaria.)


FOOD CONSUMED PER FISH PER DAY (GRAMS)
.08
.06
.04
.02
0
PERCENT INCREASE OR DECREASE IN WEIGHT
40
30
20
10
0
−10
FOOD CONVERSION
1
2
3
10
0
(no growth)
PERCENT SURVIVAL
100
80
60
40
20
0
0
4
8
12
13
SALINITY LEVEL (ppt)

A comparison of results obtained with $5\frac{1}{2}$-month-old Baton Rouge fish and those obtained with the 5-month-old and 6-month-old Meridian fish tested at 12 ppt (Figures 1 and 2), indicates the tolerance of the Baton Rouge and Meridian fish was about the same at 5 or 6 months of age.

Yearlings

Eleven-to 14-month-old Meridian fish acclimated to 5 ppt had about the same tolerance (Tables 9 and 10) as they did at 6 months (Figure 2). Fish acclimated to 10 ppt had about a 1 ppt greater tolerance than fish acclimated to 5 ppt, but again the fish could not maintain growth at salinities greater than 12 ppt. There was little difference in parameter values between fish in fresh water and fish in 8-12 ppt water. An analysis of variance indicated there were significant differences between results obtained at all salinities ($P < .05$) but differences between 0, 8, 9, 10, and 11 ppt were not significant. Differences between acclimation levels were also not significant.

Pathology

Two parasitic attacks occurred during the studies. During one test with fingerlings, all the fish in the fresh water aquaria (controls) became infected with Ichthyophthirius multifilis. Salinity tolerance tests were temporarily discontinued and the effect of salinity on the parasite was determined. It was found that the parasite was controlled when held for 1 week at salinities of 1 ppt or greater. The results are reported in a separate paper (Allen and Avault, in press).

Table 9. Effects of salinity and prior acclimation on food consumption, growth, food conversion, and survival of Meridian channel catfish yearlings. (Results after 45 days of testing which began at an age of 11 months.)

Salinity level (ppt)	Acclimation level (ppt)*	Percent survival	Food consumed per fish per day (grams)	Weight gain or loss per fish per day (grams)	Average per cent increase or decrease in weight	Average food conversion
0	0	100	.087	.053	25.7	1.64
0	0	100	.088	.058	28.0	1.52
8	5	100	.086	.050	27.0	1.72
8	10	100	.085	.053	29.0	1.60
9	5	100	.088	.045	22.7	1.96
9	10	100	.088	.037	20.1	2.38
10	5	100	.087	.041	21.6	2.12
10	10	100	.087	.034	17.6	2.59
11	5	100	.083	.037	23.1	2.24
11	10	100	.085	.056	28.6	1.52
12	5	80	.061	.008	4.3	7.71
12	10	100	.084	.051	25.3	1.65
13	5	60	.060	.005	2.5	12.00
13	10	80	.075	-.009	-4.5	0
14	5	0	.003	-.080	-12.3	0
14	10	20	.022	-.044	-18.2	0

Five fish were tested in each half of partitioned 38-liter aquaria.

*Test fish were acclimated to either 5 or 10 ppt salinity for 154 days prior to testing.

Table 10. Effects of salinity and prior acclimation on food consumption, growth, food conversion, and survival of Meridian channel catfish yearlings. (A continuation of testing shown in Table 9: cumulative results after 90 days of testing.)

Salinity level (ppt)	Acclimation level (ppt)	Percent survival	Food consumed per fish per day (grams)	Weight gain or loss per fish per day (grams)	Average percent increase or decrease in weight	Average food conversion
11	5	80	.095	.044	46.5	2.16
11	10	100	.095	.048	52.5	1.98
12	5	20	.062	-.002	-2.7	0
12	10	100	.098	.045	44.1	2.18
13	5	20	.055	-.008	-6.2	0
13	10	20	.062	-.007	-5.0	0

Five fish were tested in each half of partitioned 38-liter aquaria.

After the termination of the 90 day study, Baton Rouge fingerlings had a gill infestation of a marine dinoflagellate identified as Oodenium sp. by the Southeastern Cooperative Fish Disease Laboratory, Auburn, Alabama. The organism was believed to have been contacted from pompano, Trachinotus carolinus, brought to the laboratory from the Gulf of Mexico. Some mortalities were experienced before the infection was controlled.

In the tests with fingerlings and yearlings, it was noted that fish at the higher salinities were sluggish and easily netted. This was true even with fish that attained good growth and survival. There were no morphological abnormalities noted on any of the fish.

DISCUSSION

This study indicates that channel catfish can be hatched and reared in brackish water. This is in close agreement with the pond studies of Perry and Avault (1968 and 1969) in which channel catfish were successfully grown in brackish water ponds at salinities which ranged from 2 to 11 ppt.

Effects of age on the upper salinity tolerance

The present study indicated that one-day-old or older channel catfish eggs could be hatched in low-salinity water. Further studies will be required to clarify the effect of salinity on spawning activity, on sperm, and on egg development and survival during the first day. The upper tolerance increased rapidly from a level of about 10 ppt at 1 or 2 days of age to about 16 ppt at 3 or 4 days of age.

This increase in tolerance is probably because eggs of fresh water teleosts are permeable to water and salts for the first few hours after being deposited, but after the vitelline membrane (or chorion) forms they become permeable only to gases (Grey, 1928; Krogh, 1939). This process is known as "water hardening" and in normal fresh water situations is characterized by a rapid up-take of water for the first few hours (Lagler et al., 1962).

In the present study, as the eggs hatched, and the emerging sac fry no longer had the protection of the vitelline membrane, the upper salinity tolerance dropped immediately to about 8 ppt salinity. After yolk absorption the upper tolerance increased slowly to about 9-10 ppt, leveled off, and then increased again at about 5 or 6 months of age to approximately 12.5 ppt. Beyond 6 months there did not appear to be a further increase in tolerance.

Effects of prior acclimation on the upper salinity tolerance

The ability of channel catfish to adapt to higher salinities appeared to be slow and limited. Fish acclimated to 5 ppt salinity for 9 days and for 40 days had slightly greater tolerance than did fingerlings acclimated to fresh water. Fish given 154 days of acclimation to 10 ppt salinity had about a 1 ppt higher tolerance than fish acclimated to 5 ppt for 154 days.

Statistical analyses indicated the differences in results between acclimation levels were not significantly different. However, in all of the tests, fish receiving prior acclimation to salinity had better performances at most of the parameters, and in the opinion of the author there was a slight advantage to receiving prior acclimation to salinity. Older fish appeared to respond more to prior acclimation to salinity than did younger fish.

Kinne (1960), working with the euryhaline fish, *Cyprinodon macularius*, found that acclimation to a new salinity level essentially occurred in

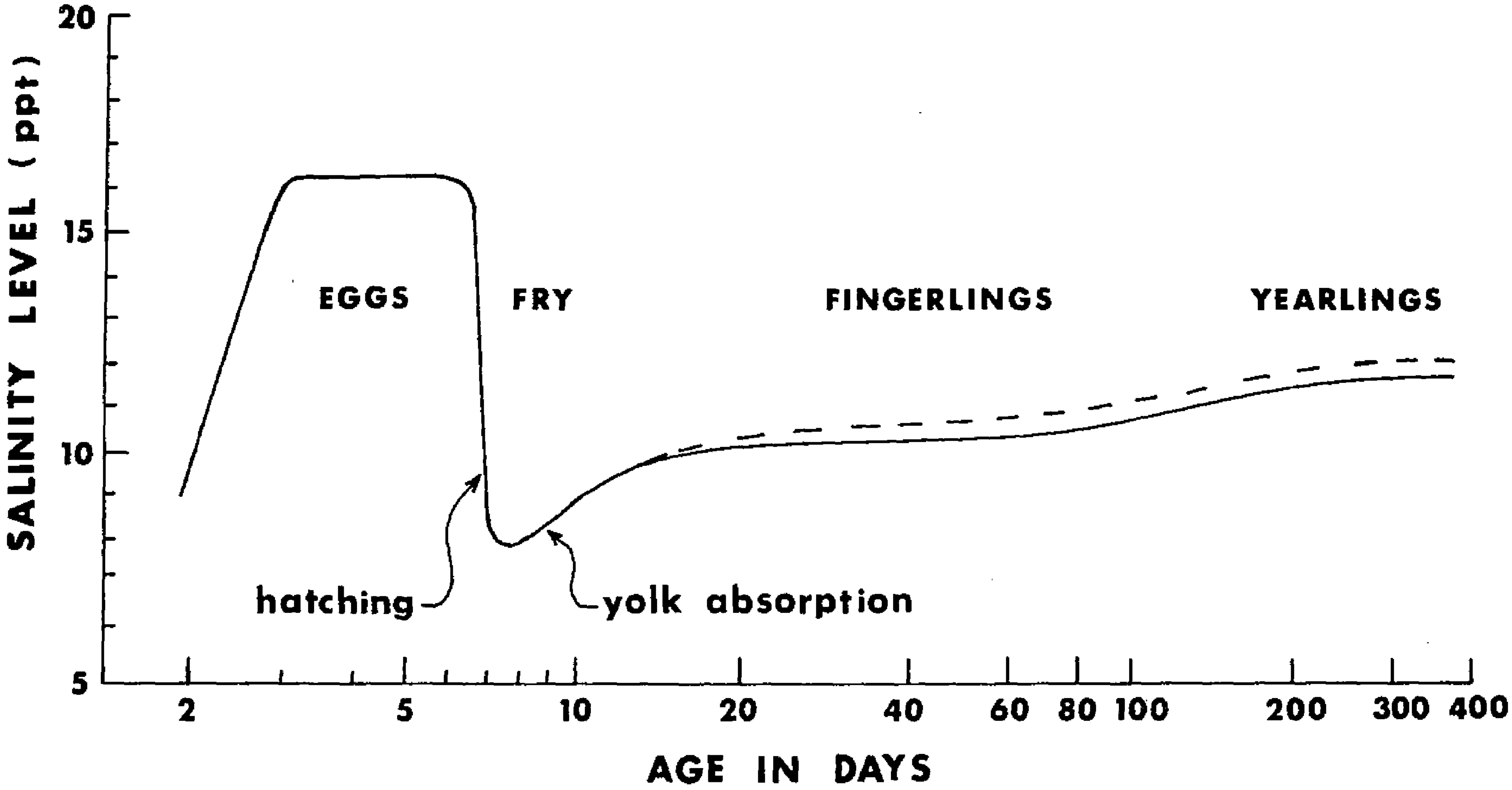
3 to 6 days, but weeks or months were required for full acclimation. He also found that fish reared at high salinities in early life had a greater tolerance later in life than fish reared at lower salinities. Prosser and Brown (1961) stated that the euryhaline Fundulus heteroclitus required only 6 hours to acclimate its body density when going into sea water from fresh water.

It does not appear that channel catfish up to 14 months of age can be indefinitely maintained at salinities greater than 12 ppt, even with increased acclimation time. General effects of age and acclimation on tolerance are schematically shown in Figure 3.

The reader should be cautioned at this point that salinity tolerance has been shown by a number of workers to be affected by other factors, particularly temperature (Kinne, 1960, 1963, 1964, and 1967; Lewis, 1966; Mihursky and Kennedy, 1967; Strawn and Dunn, 1967). Thus in a different environment, results could vary somewhat from those obtained in this study.

All three lots of fish used in this study originated from fresh water populations. Channel catfish native to coastal waters may have a greater tolerance to salinity. Also, catfish with a higher tolerance could possibly be developed genetically. Soler et al. (1965), however, reported only slight improvement in the tolerance of Cyprinus carpio through selection.

Figure 3. A schematic illustration of the effects of age and acclimation on salinity tolerance of channel catfish. (Solid line indicates upper tolerance of fish acclimated to fresh water and broken line indicates upper tolerance of fish acclimated to 5-10 ppt salinity.)



20
15
10
5
SALINITY LEVEL (ppt)
EGGS
FRY
FINGERLINGS
YEARLINGS
hatching
yolk absorption
2
5
10
20
40
60
80
100
200
300
400
AGE IN DAYS

Effects of salinity on food consumption, growth, food conversion, and survival

In the present study there was close agreement among the four parameters of food consumption, growth, food conversion, and survival (see especially Figures 1 and 2). It was also noted that fish did not show much of a decrease in food consumption, growth, etc., until the upper tolerance level was almost reached. This phenomenon was most distinct in older fish (see especially Tables 9 and 10).

Very young fish did better in fresh water than brackish water, but as the fish grew older there appeared to be a reversal of this. In some of the tests with older fingerlings and yearlings, fish at salinities of 4 and 8 ppt had better values for the four parameters than did fish in fresh water. However, overall the differences were not great. Further studies would be required to determine if under some conditions fresh water fishes are more efficient in brackish water. Theoretically, less energy would be required for fish to osmoregulate in brackish water, which is closer to the osmotic pressure of their blood, than either fresh or sea water. Some studies indicate that fresh water fishes survive stresses better if some salts are present in the water (Coward, 1963; Collings and Hulsey, 1967).

Brackish water and sea water is composed of several ions, such as Na^{+}, Ca^{++}, K^{+}, or Mg^{++}, that individually are potentially toxic to fishes.

However, this is not normally a problem to fishes in physiologically balanced solutions such as brackish water or sea water, because the specific toxicity of each ion is neutralized by the antagonistic action of other ions present (Doudoroff and Katz, 1953; Black, 1957). Thus, when fresh water fishes are placed in brackish or sea water their problem consists of making ionic and osmotic adjustments.

The successful rearing of channel catfish in brackish water may encourage efforts to rear them in various salty effluents such as oil field brines. However, most of the salt content of these waters tends to be composed of only one or two ions, and as a result these waters are usually toxic to fish.

Pathology

Sluggishness of fish as noted in the present study could account, in part, for the loss of fish to predation reported by Perry and Avault (1968 and 1969). In aquaria, this sluggishness did not appear to adversely effect the fish. However, in a natural or semi-natural environment in which predation is not controlled by man, this could be an important factor.

The problem encountered with the marine dinoflagellate, *Oodenium* sp., points out that fresh water fishes, such as channel catfish, could encounter difficulties in brackish waters from non-host-specific brackish water or marine parasites. Fresh water fishes would lack natural immunity against marine or brackish water pathogens. It was

noted that Oodenium sp. was always present in small numbers on the pompano brought to the laboratory, but never appeared to cause the pompano difficulties.

Of course, brackish water could also adversely effect fresh water pathogens and work to the advantage of fresh water fishes. In addition to the control of Ichthyopthirius at salinities of 1 ppt or higher as noted in this study, Tesch (1968) controlled this parasite on the eel, Anquilla anguilla, at salinities of 8 to 15 ppt and higher. Thus it appears that the parasito-fauna of fresh water fishes could be altered in brackish water.

Conclusions and recommendations

In conclusion, this study and the studies by Perry (1967), Kendall and Schwartz (1968), and Perry and Avault (1968 and 1969) indicate that ictalurid catfishes have a much closer affinity to sea water than previously believed. This study failed to reveal any major problems in raising channel catfish in brackish waters up to 6 or 8 ppt salinity.

A potential catfish farmer with waters less than 6 ppt salinity could probably begin production with fertilized eggs, fry, or young fingerlings. In salinities of 6-12 ppt, he would have to start with older fingerlings or yearlings. Waters in excess of 12 ppt would not be suitable for channel catfish culture. The salinity range of 0 to 12 ppt would include an area of several million acres along the Gulf of Mexico and Atlantic Ocean. Some disadvantages of brackish water to

channel catfish are indicated by this study, but there also appears to be certain compensating advantages.

Future studies should concentrate on effects of salinity on spawning. Additional information is also needed on interactions of salinity with temperature, dissolved oxygen, and other physical-chemical factors. The effect of brackish water on the parasito-fauna of fresh water fishes should also be further explored.

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APPENDIX

Appendix Table 1. Effects of salinity and prior acclimation on growth of Baton Rouge channel catfish fingerlings. (Supplemental information to Table 6, page 19.)

Salinity level (ppt)	Acclimation level (ppt)	Average total length at start (mm)	Average final total length (mm)	Average gain (mm)
0(control)	0	23.5	27.0	3.5
0(control)	5	22.5	28.5	6.0
9	0	23.5	26.2	2.7
9	5	22.5	27.1	4.6
10	0	22.7	No survivors*	--
10	5	22.9	No survivors*	--
11	0	23.1	No survivors	--
11	5	22.5	25.0	2.5
12	0	22.7	No survivors	--
12	5	23.2	No survivors	--
13	0	23.3	No survivors	--
13	5	23.1	No survivors	--
14	0	22.9	No survivors	--
14	5	22.8	No survivors	--

*Water fouling was suspected in both these lots.

Appendix Table 2. Effects of salinities of 0, 5, and 10 ppt on growth of Baton Rouge channel catfish fingerlings. (Supplemental information to Table 7, page 20.)

Salinity level (ppt)	Number of fish per aquarium	Average total length					
		start	31 days	45 days	53 days	78 days	90 days
0	34	15.0	23.5	27.4	29.9	35.4	37.0
0	35	15.0	23.2	27.7	29.3	34.9	36.6
5	30	15.0	22.5	24.4	27.5	32.8	34.4
5	35	15.0	22.3	26.4	28.4	33.3	34.9
10	34	15.0	21.7	22.6	23.9	28.0	32.5
10	30	15.0	22.1	22.2	23.8	27.8	30.3

Appendix Table 3. Effects of salinities of 0, 5, and 10 ppt on survival of Baton Rouge channel catfish fingerlings. (Supplemental information to Table 8, page 21.)

Salinity level (ppt)	Number of fish per aquarium	Number of fish surviving						
		6 days	22 days	31 days	45 days	53 days	78 days	90 days
0	34	32	31	31	30	29	24	23
0	35	34	24	24	24	24	24	24
5	30	29	29	27	26	26	25	25
5	35	31	27	26	25	25	24	24
10	34	24	11	8	7	6	6	4
10	30	25	10	8	7	6	5	1

Appendix Table 4. Effects of salinity and prior acclimation on food consumption, growth, food conversion, and survival of Meridian channel catfish fingerlings. (Supplemental information to Figure 1, page 23.)

Salinity level (ppt)	Acclimation level (ppt)	Percent survival	Food consumed per fish per day (grams)	Weight gain or loss per fish per day (grams)	Percent increase or decrease in weight	Average food conversion
0	0	100	.073	.034	11.7	2.13
0	0	100	.077	.067	23.2	1.14
4	0	100	.078	.035	12.6	2.23
4	5	100	.077	.065	23.2	1.18
8	0	100	.082	.038	10.8	2.23
8	5	100	.081	.056	15.4	1.43
12	0	20	.042	-.031	-9.8	0
12	5	20	.036	-.028	-10.8	0
14	5	20	.005	-.018	-6.4	0
15	5	0	0	--	--	--
16	5	0	0	--	--	--

Appendix Table 5. Effects of salinity and prior acclimation on growth of Meridian channel catfish fingerlings. (Supplemental information to Figure 1, page 23.)

Salinity level (ppt)	Acclimation level (ppt)	Average weight at the start (grams)	Average weight after 22 days (grams)	Average weight gain or loss (grams)
0	0	4.94	5.52	0.58
0	0	4.92	6.06	1.14
4	0	4.76	5.36	0.60
4	5	4.74	5.84	0.10
8	0	5.92	6.56	0.64
8	5	6.22	7.18	0.96
12	0	5.28	4.76	-0.52
12	5	4.42	3.94	-0.48
14	5	4.70	3.40	-1.30
15	5	4.64	--	--
16	5	5.42	--	--

Appendix Table 6. Effects of salinity and prior acclimation on food comsumption, growth, food conversion, and survival of Meridian channel catfish fingerlings. (Supplemental information to Figure 2, page 25.)

Salinity level (ppt)	Acclimation level (ppt)	Percent survival	Food consumed per fish per day (grams)	Weight gain or loss per fish per day (grams)	Percent increase or decrease in weight	Average food conversion
0	0	80	.055	.023	8.85	2.39
0	0	100	.073	.057	22.42	1.28
4	0	100	.067	.061	24.54	1.10
4	5	100	.081	.077	34.27	1.05
8	0	80	.071	.033	12.41	2.15
8	5	100	.079	.056	22.88	1.41
12	0	100	.067	.066	3.04	11.17
12	5	100	.051	.017	7.09	3.00
13	0	0	.005	-.016	-3.92	0
13	5	80	.012	-.031	-14.28	0

Appendix Table 7. Effects of salinity and prior acclimation on growth of Meridian channel catfish fingerlings. (Supplemental information to Figure 2, page 25.)

Salinity level (ppt)	Acclimation level (ppt)	Average weight at the start (grams)	Average weight after 22 days (grams)	Average weight gain or loss (grams)
0	0	5.42	5.90	0.48
0	0	5.62	6.88	1.26
4	0	5.46	6.80	1.34
4	5	4.96	6.66	1.70
8	0	5.80	6.52	0.72
8	5	5.42	6.66	1.24
12	0	4.60	4.74	0.14
12	5	5.36	5.74	0.38
13	0	4.08	3.92	-0.16
13	5	4.76	4.08	-0.68

Appendix Table 8. Effects of salinity and prior acclimation on growth of Meridian channel catfish yearlings. (Supplemental information to Tables 9 and 10, pages 28 and 29.)

Salinity level (ppt)	Acclimation level (ppt)	Average weight at start (grams)	Average weight after 45 days (grams)	Average weight after 90 days (grams)	Average weight gain or loss after 45 days (grams)	Average weight gain or loss after 90 days (grams)
0	0	5.78	8.16	--	2.38	--
0	0	9.26	11.86	--	2.60	--
8	5	8.36	10.62	--	2.26	--
8	10	8.28	10.68	--	2.40	--
9	5	8.88	10.90	--	2.02	--
9	10	8.22	9.88	--	1.66	--
10	5	8.60	10.46	--	1.86	--
10	10	8.62	10.14	--	1.52	--
11	5	8.58	10.24	12.57	1.66	3.99
11	10	8.72	11.22	13.30	2.50	4.58
12	5	8.40	8.76	8.17	0.36	-0.23
12	10	8.98	11.26	12.94	2.28	3.96
13	5	7.18	7.36	6.73	0.18	-0.45
13	10	7.50	7.15	7.12	-0.35	-0.38
14	5	7.16	--	--	--	--
14	10	7.28	5.70*	--	-1.58	--

*Based on one fish only

VITA

Kenneth Owen Allen was born on January 28, 1935, at Bismarck, Arkansas. He attended the Bismarck Public Schools and graduated from Bismarck High School in May, 1952.

September, 1952 through January, 1956 he attended Henderson State College at Arkadelphia, Arkansas. He received a Bachelor of Arts degree in May, 1956

In October, 1956 he began work for the Division of Hatcheries, Bureau of Sport Fisheries and Wildlife, United States Department of the Interior. He served at five National Fish Hatcheries in five southeastern states over a nine year period. In 1959-60 he attended the Bureau's in-service training school for Warm-Water Fish Husbandry and Management at Marion, Alabama.

In September, 1965 he resigned from the Bureau of Sports Fisheries and Wildlife and entered Graduate School at the University of Arkansas, Fayetteville, Arkansas. In June, 1967 he received a Master of Science degree in Zoology. He entered Graduate School at Louisiana State University,July of 1967,and is now a candidate for the degree of Doctor of Philosophy in Marine Science with a minor in Fisheries.

On December 20, 1956, he married the former Miss Shirley Faye Walker of Malvern, Arkansas. A son, Eddie Everett, was born November 2, 1958, and a second son, Dale Wayne, was born May 30, 1963.

EXAMINATION AND THESIS REPORT

Candidate: Kenneth O. Allen

Major Field: Marine Science

Title of Thesis: Effects of salinity on growth and survival of channel catfish, Ictalurus punctatus (Rafinesque), eggs through yearlings.

Approved:

James Avault
Major Professor and Chairman

Max Goodrich
Dean of the Graduate School

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Date of Examination:

August 5, 1970