REPRINT FROM
Calif. Fish and Game, 63(4) : 210-218. 1977

ACCLIMATION AND REARING OF STRIPED BASS LARVAE IN SEA WATER [1]

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For the first time, striped bass larvae were reared under laboratory conditions in sea water (salinity 33.73°/₀₀) for more than a year. Five-day-old larvae, hatched in fresh water, were rapidly acclimated to 20, 40, and 60% sea water and reared in these salinities for 33 days. The earliest time the larvae could survive transfer to full sea water was at 28 days of age; metamorphosis occurs between 28 and 35 days.

Separate tests were made to determine the effects of different salinities on larval growth and survival. Growth over a period of 4 weeks was measured in 20, 40, and 60% sea water with a control group in fresh water, but no adverse effect on growth was observed on larvae in diluted sea water. In tests of salinity tolerance, 1-day-old eggs and larvae after hatching in fresh water were rapidly acclimated to different salinities and reared without food for 9 and 12 days. Survival was best when the larvae were acclimated just after hatching in 10% sea water. Diluted sea water proved to be better for larval survival than fresh water alone.

INTRODUCTION

A relative lack of predator fishes in the limnetic zone of large warmwater impoundments in California is considered to be a major factor limiting potential game fish production (Anon. 1971). Attempts to correct this deficiency have centered largely on the introduction of limnetically oriented forage and game fish species. Threadfin shad (*Dorosoma petenense*) were introduced from Tennessee in 1953 (Kimsey 1954) and this forage species is now firmly established in many reservoirs throughout California (Burns 1965). Game fish species stocked in selected reservoirs in efforts to more fully utilize shad as forage include crappie (*Pomoxis* sp) (Goodson 1966), white bass (*Morone chrysops*) (von Geldern 1964), and striped bass (*Morone saxatilis*) (Wilson and Christenson 1965). In recent years, a variety of salmonids have also been successfully introduced into warmwater reservoirs containing well-oxygenated hypolimnions (Rawstron 1973, Wigglesworth and Rawstron 1974).

While crappie and white bass may be normally expected to maintain self-

[1] Accepted for publication September 1976. This work was performed as part of Dingell-Johnson project California F-18-R, "Experimental Reservoir Management" supported by Federal Aid to Fish Restoration funds.
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sustaining populations, the development of successful striped bass fisheries is largely dependent on maintenance stocking programs. Such programs involve the introduction of fingerlings or yearlings (Bailey 1975), and California has given high priority to an evaluation of striped bass stocking and the possible development of a firm source of fish within our hatchery system.

An extensive effort has been made across the southern United States to develop the technology for rearing striped bass in freshwater hatcheries (Bailey 1975). Freshwater culture, however, frequently results in heavy mortalities of larval fish. This problem prompted the present study which examines the salinity tolerance characteristics of striped bass larvae as part of a broad program designed to evaluate the feasibility of rearing striped bass in a sea water hatchery.

Increased survival of striped bass eggs and larvae has been reported for periods up to 3 weeks in sea water concentrations ranging from 3% (Albrecht 1964) to 30% (Doroshev 1970, Bayless 1972). Our study is an extension of earlier work and was designed to: (i) determine if striped bass eggs and larvae can be acclimated to higher salinity concentrations, and (ii) determine if larval bass could be reared through metamorphosis in 100% sea water.

METHODS AND RESULTS

Four groups of fertilized striped bass eggs, produced by hormone-induced spawning of ripe fish at the Central Valleys Hatchery of the California Department of Fish and Game, Elk Grove, were shipped by air to La Jolla, California, during May and June 1973. The eggs were hatched in a 122-cm (4-ft) diameter fiberglass trough containing tap water with chlorine reduced to 1.5 ppm. Eggs were kept from settling to the bottom by bubbling air. The incubation period varied from 40 to 48 hours at 18.5 ± 1 C (65 ± 2 F). Between 80 and 95% of the larvae hatched out from the first three groups of eggs received, but only 15 to 20% hatched in the last group due to poor fertilization. For this reason, testing of 1-day-old eggs from the last group was abandoned after hatching. Eggs or larvae for salinity tests were hand counted and transferred into experimental containers. Because of different experimental techniques in each of the three experiments to follow, we have elected to give details of each experiment separately.

Survival of Striped Bass Larvae After Exposure to Different Salinities

Survival after exposure to different salinities was measured using 1-day-old eggs and 1-day-old larvae hatched in fresh water. Larvae 8 to 14 hours after hatching were termed 1-day-old. One-day-old eggs were 16 to 20 hours old as determined from the time fish were artificially spawned at the hatchery. The various stages of development of our eggs and larvae closely resembled those illustrated by Bayless (1972). Twenty-five eggs or larvae were transferred into 4 l (1.06-gal) glass jars, each containing a different volume of tap water, so that after the gradual addition of La Jolla sea water (salinity 33.73‰), the final volume of water was 2½ l (0.66 gal). The acclimation time varied from 2 to 6 hours, depending on the volume of sea water added. In this manner, the desired salinity and stocking density of 10 eggs or larvae per liter was obtained. All the jars were placed inside a water table with running sea water at 19 ± 0.5 C (66 ± 1 F).

In this experiment, we used eggs and larvae from three different groups of eggs received from Elk Grove. Three similar experiments were done in succession. The first was terminated 9 days after acclimation, the second and third after 12 days. One-day-old eggs and 1-day-old larvae in the 9-day experiment were tested separately in 20, 40, 60, 80, and 100% sea water and, in the case of 12-day experiments in 10, 20, 30, 40, 50, 60, and 70% sea water. Eggs in the last 12-day experiment, were not tested due to poor hatch. For each experiment a control group was kept in fresh water, and replicate jars were set up for all salinities tested as well as for the controls.

No food was given to the larvae throughout the experiments. Although 6-day-old larvae commence feeding (our observation agrees with Bayless 1972), nearly all can survive without food for 10 days or longer until complete absorption of their yolk (Mansueti 1958). Dead larvae were removed and counted every day and a terminal count of all survivors was taken at the end.

We saw no abnormal development of the embryos in any salinity tested, although it took 2 to 3 hours longer for the eggs to hatch in 80 and 100% sea water. The larvae appeared shrunken in 80 and 100% sea water and died within 72 and 48 hours, respectively. Less than 50% of the larvae survived in salinities higher than 50% sea water, and survival was 75% or more in salinities ranging between 10 and 50% sea water. If more than one test was made, the combined mean for all tests is shown followed by the individual test means in parenthesis (Table 1). These results show that larvae have a high tolerance for sea water up to 50%, if they are acclimated after hatching rather than while in the egg. There was only 27% survival of acclimated larvae after 9 days in 70% sea water, but in the next lower acclimation salinities (i.e. 60% and 50% sea water), there was a remarkable increase in survival. There was a sharp decline in larval survival at the higher salinities after 12 days. We believe this was due to starvation and the stress of higher salinities.

TABLE 1. Percentage Survival of Striped Bass Larvae from 1-Day-Old Eggs and 1-Day-Old Larvae Reared Without Food at 19 C ± 0.5 C [1]

	Percent survival from 1-day-old eggs			*Percent survival from 1-day-old larvae*		
Percent sea water[1]	*After 6 days*	*After 9 days*	*After 12 days*	*After 6 days*	*After 9 days*	*After 2 days*
Fresh water	38(40,36)[2]	30(30,30)	28	64(48,68,76)	52(35,56,64)	49(44,54)
10	82	82	78	95(90,100)	94(90,98)	93(90,96)
20	78(92,64)	72(84,60)	58	93(98,92,90)	92(98,88,90)	82(82,82)
30	82	68	66	94((98,90)	91(98,84)	78(84,72)
40	77(88,66)	71(84,58)	50	87(88,84,88)	85(88,84,84)	74(80,68)
50	76	54	44	84(84,84)	73(70,76)	53(56,50)
60	34(22,46)	9(8,10)	2	63(84,78,26)	47(54,70,16)	27(50,4)
70	—	—	—	28(58,0)	27(54,0)	—
80	0	0	—	0	0	—
100	0	0	—	—	—	—

[1] Salinity of 100% seawater was 33.73‰.
[2] In instances where more than one test was conducted, the combined mean of all tests is shown, followed by the individual test means in parenthesis.

Sea water with reduced salinity is beneficial for the well being of the eggs as evidenced by the enhanced survival of eggs in 10% sea water compared to those in fresh water.

TABLE 2. Increase in Dry Weight (mg) of Striped Bass Larvae Fed Brine Shrimp, Nauplii *Artemia* sp. at 18 C ± 0.5 C, N = 500 for Each Salinity

		Salinity of 100% sea water = 33.73 °/₀₀							
		Fresh water		*20% sea water*		*40% sea water*		*60% sea water*	
Age (days)	*Sample Size (number of larvae)*	*Range (mg)*	*Mean (mg)*	*Range (mg)*	*Mean (mg)*	*Range (mg)*	*Mean (mg)*	*Range (mg)*	*Mean (mg)*
12	5	0.107–0.185	0.148	0.112–0.277	0.198	0.117–0.227	0.169	0.146–0.223	0.174
19	10	0.093–0.229	0.159	0.123–0.466	0.346	0.114–0.406	0.293	0.155–0.537	0.327
26	10	0.207–0.792	0.480	0.315–0.956	0.738	0.228–0.997	0.645	0.535–1.291	0.892
33	10	0.367–1.384	1.064	0.647–2.598	1.202	0.549–1.363	0.853	0.608–1.931	1.464

TABLE 3. Increase in Total Length (mm) of Striped Bass Larvae Fed Brine Shrimp, Nauplii *Artemia* sp., at 18 C ± 0.5 C, N = 500 for Each Salinity

		Salinity of 100% sea water = 33.73 °/₀₀							
		Fresh water		*20% sea water*		*40% sea water*		*60% sea water*	
Age (days)	*Sample size (number of larvae)*	*Range (mm)*	*Mean (mm)*	*Range (mm)*	*Mean (mm)*	*Range (mm)*	*Mean (mm)*	*Range (mm)*	*Mean (mm)*
5	10	5.3–5.6	5.5	5.3–5.6	5.5	5.3–5.6	5.5	5.3–5.6	5.5
12	5	5.4–6.2	5.9	5.2–6.8	6.0	5.1–6.4	5.8	5.2–6.2	5.7
19	10	5.6–6.8	6.1	5.5–7.6	6.8	5.5–7.3	6.7	5.5–7.6	6.8
26	10	6.2–8.6	7.6	7.5–9.2	8.5	6.3–8.6	7.9	7.5–9.1	8.3
33	10	7.4–9.7	8.9	7.7–11.0	9.0	7.7–9.5	8.4	7.7–9.8	9.3

Effect of Different Salinities on Larval Growth

Five hundred 5-day-old larvae were transferred into each of four 45 l (12-gal) aquaria containing dechlorinated tap water. Sea water was added gradually into three aquaria to produce 20, 40, and 60% sea water; the fourth had fresh water only. Each aquarium was aerated gently, but there was no flow of water. Dead larvae were removed occasionally, and about a quarter of the volume of water in each aquarium was siphoned out once a week from near the bottom and replaced with an equal amount of water of the required salinity. The aquaria had no gravel or substratum on the glass bottom. Temperature was maintained at 18 ± 0.5 C (64 ± 1 F). The larvae were fed brine shrimp, nauplii *Artemia* sp., daily from day 5 until the experiment ended at 33 days.

The total length of ten 5-day-old larvae was measured at the start of the experiment. Thereafter, both total length and dry weight were recorded from a random sample of 10 larvae taken from each aquarium at 7-day intervals, when the larvae were 12, 19, 26, and 33 days old. Total larval length was measured and the larvae were dried in an oven at 60 C (140 F) for a week. The weight of each larva was recorded to within ± 0.2 μg (.00007 oz) on a Cahn balance (Tables 2 and 3).

From age 12 days, i.e., after 1 week of feeding, until age 33 days, growth, as measured by increase in total length, was not different in diluted sea water and in fresh water (Table 3). On the other hand, rate of growth by weight in 60% sea water averaged 0.06 mg/day (.0002 oz), which is more than 25% faster than that in the lower salinities (Table 4). We observed maximal survival in 40% sea water (Table 4). The lowest growth rate in that salinity may have been due to competition for food among the many survivors. On the other hand, the brine shrimp, *Artemia* sp, did not survive well in fresh water and this may have accounted for the slower growth and poor survival.

TABLE 4. Percentage Survival After 33 Days, and Growth Rate for the Last 21 Days of Larvae Reared in Different Salinities Fed Brine Shrimp, Nauplii *Artemia* sp. at 18 C ± 0.5 C.

Percent sea water[1]	Percent survival[2] (N = 500)	Growth rate (N = 10) Dry weight (mg/day)	Growth rate (N = 10) Total length (mm/day)
Fresh water	9	0.044	0.145
20	25	0.048	0.144
40	47	0.034	0.124
60	22	0.060	0.168

[1] Salinity of 100% sea water was 33.73‰.
[2] Does not include 7% larvae killed for length-weight measurements.

Rapid Acclimation of Striped Bass Larvae and Fry to Sea Water

Our goal was to acclimate striped bass larvac to full sea water at the earliest possible age, but, as found earlier, 1-day-old larvae had died within the first 6 days in 80 and 100% sea water. We therefore sought to reduce the mortality of larvae by rearing them initially in 60% sea water and eventually transferring them to higher salinities, until larvae could withstand full sea water. Our criterion for successful acclimation was at least 50% survival of larvae after the increase in salinity.

Larvae reared in a 45 l (12-gal) aquarium containing fresh water were acclimated to 60% sea water within 24 hours at age 5 days. At age 44 days, fry were acclimated again to 95% sea water within 24 hours. At 114 days, these fry were transferred to a 1,900-liter (500-gal) aquarium provided with 100% sea water at 19 ± 2 C (66 ± 3 F).

Larvae up to the age of 37 days were fed a mixed diet of live brine shrimp, nauplii *Artemia* sp and live marine copepods, *Tisbe* sp After that period, fry were fed at least three times a day on trout chow, Oregon Moist Pellets (OMP), chopped anchovies, and squid.

A second batch of larvae reared in a 135 l (35-gal) aquarium containing fresh water was also acclimated to 60% sea water at age 7 days. At age 19 days, five larvae were acclimated to 95% sea water in a 2 l (0.53-gallon) beaker, but none survived beyond 2 days. At age 28 days, another five larvae were acclimated to 95% sea water in 24 hours with 100% survival after 5 days. The remaining untested 34-day-old fry were also acclimated to 95% sea water in 24 hours. We then combined these 31 surviving 96-day-old fry with 16, 115-day-old fry from the previous batch in a 1,900-l (500-gal) aquarium.

The above 47 fry were reared in sea water for 11 months without mortality. Of these, 23 were killed and measured at this time. Only 4 fingerlings were reared for an additional 4 months, when they were measured (Table 5).

TABLE 5. Growth of Striped Bass Fingerlings in Sea Water After Rapid Acclimation as Fry from 60 to 100% Sea Water[1] at 19 ± 2 C.

Age (months)	*Number of fingerlings*	*Range*	*Mean*	*Median*
Total length (cm)				
11	23	10.0–15.0	13.0	13.0
15	4	16.4–23.8	19.3	18.5
Wet weight (g)				
11	23	15.0–47.1	30.7	31.0
15	4	44.0–135.3	77.7	65.7

[1] Salinity of 100% sea water was 33.73‰.

DISCUSSION

Albrecht (1964) pointed out that striped bass eggs can withstand a moderate increase in salinity and that survival of resulting larvae is best in 3% sea water (chlorides 948 ppm). In his experiments, larvae did not survive beyond 3 days in 40% sea water (chlorides 14,100 ppm), whereas in ours, survival was excellent up to 9 days. Turner and Farley (1971) found that survival of striped bass eggs hardened in fresh water at 14.5, 18.5, and 22 C (58, 65, and 72 F) was higher in 3% sea water (TDS 1,000 ppm) than in fresh water (TDS 163 ppm). They also found that at salinities of 6, 15, and 30% sea water (TDS 2,000; 5,000; and 10,000 ppm) at 14.5 C (58 F) survival was about *twice* as high as at 18 and 22 C (65 and 72 F), and that survival of eggs incubated at salinities from 3 to 30% sea water was about the same. Our results showed a similar trend. Survival of 1-day-old eggs hatched in salinities ranging between 10 and 50% sea water was higher than in fresh water control. On the other hand, larval survival progressively declined for eggs hatched in salinities greater than 10% sea water. Therefore, we do not suggest incubating striped bass eggs at salinities exceeding 10% sea water and at a temperature greater than 19 C (66 F). In our experiments, survival of larvae at 19 C (66 F) after 6 days was 50% greater than survival of newly-hatched larvae at 18.5 C (65 F) from 2-hour-old fertilized eggs (Turner and Farley 1971). Evidently, 2-hour-old fertilized eggs are more vulnerable to increased salinities at higher temperatures than 1-day-old eggs. Furthermore, at salinities between 10 and 70% sea water, we obtained 25 to 32% better survival of 1-day-old larvae than with 1-day-old eggs (Table 1).

Different survival rates under identical salinities, as found between our experiments and those of other workers, could be due to differences in the ionic composition of the water. Turner and Farley (1971) showed that survival of striped bass eggs incubated in San Joaquin River water with a TDS of 623 ppm after getting mixed with natural estuarine water was 50% higher than in Tuolumne River water with a lower TDS of 525 ppm, but containing saline irrigation runoff water. Consequently, we regard the ionic composition of diluted sea water to be far more beneficial for the eggs and larvae than comparable fresh water with a high load of total dissolved solids.

We did not find any remarkable growth differences based on length of larvae reared up to 33 days in fresh water and those reared in different salinities (20, 40, and 60% sea water). Length measurements alone are an insufficient index for growth since they do not always reveal the weak and emanciated condition of larvae. Also, we observed that after the first week there was slight shrinkage of larvae in the higher salinities but not in fresh water, and this may have minimized the length differences. This is reflected in growth differences based on dry weight of larvae, because growth rate by weight in 60% sea water was 25% better than in lower salinities or even fresh water, although our best survival was in 40% sea water. Our results do not entirely agree with Bayless (1972) who found maximum growth in 40% sea water and best survival in 30% sea water over a period of 21 days, but he did not test growth in higher salinities. It appears that larvae survive better in low salinities but grow faster in higher salinities. Tolerance to higher salinities increases with age. Even though we recognize that food has a direct effect on growth, it was impossible for us to study this variable because the type of food and the concentration of food organisms available to the larvae in different salinities need to be standardized before exact differences in growth can be accounted for.

Our results show that striped bass fry can be reared in full sea water immediately after metamorphosis without obvious signs of stress behavior, for at least a period of 15 months. Even though our study indicated that the larvae can adjust to full sea water while undergoing metamorphosis, it was safer to transfer them after complete metamorphosis, when they were 33 to 35 days old. The average growth of 13 cm (5.2 inches) in 11 months and the maximum growth of 23.8 cm (9.5 inches) in 15 months in our experiments was approximately the same as Steven (1966) found in a natural population in California, but was 30% above the average first-year growth of 10 cm (4 inches) reported by Clark (1938).

The results of our study indicate that rearing of striped bass larvae in diluted sea water and the fry in sea water should ensure a better survival than found in freshwater hatcheries. The high rate of mortality of larvae reared in fresh water which continues even after metamorphosis has not occurred in our experiments with sea water. To overcome the difficulties encountered in rearing of striped bass larvae, we suggest a program of progressive increase in salinity to enhance survival and growth of striped bass larvae. To hatch eggs, only slightly brackish water, salinity not exceeding that of 10% sea water should be used. For larval rearing through metamorphosis the following regimes are best for growth and survival.

Optimal growth		*Optimal survival*	
Age	*Percent sea water*	*Age*	*Percent sea water*
Day 1 thru 9	20	Day 1 thru 6	10
Day 10 thru 19	40	Day 7 thru 13	20
Day 20 thru 29	60	Day 14 thru 20	40
Day 30 thru 35	80	Day 21 thru 29	60
Day 36	100	Day 30 thru 35	100

SUMMARY

Our study shows that diluted sea water is beneficial for rearing striped bass larvae and for hatching of eggs. Our results on salinity tolerance of striped bass eggs showed higher survival of larvae in salinities between 10 to 50% sea water than in fresh water. However, survival in these salinities was enhanced further by acclimating 1-day-old larvae instead of eggs.

Five-day-old larvae acclimated to salinities of 20, 40, and 60% sea water and reared up to 33 days of age, continued normal development through metamorphosis. Subsequent growth in higher salinities was faster than in fresh water, over a period of 4 weeks. The larvae in salt water looked healthier and better than those in fresh water.

Striped bass larvae were rapidly acclimated to full sea water within 1 month and reared successfully under laboratory conditions for a period of 15 months. Over this extended period of time, the average and maximum growth compared favorably with that found in natural waters. The larvae, if acclimated to full sea water before metamorphosis, did not survive. We found that the best time for the introduction of larvae to full sea water is just after metamorphosis.

ACKNOWLEDGMENTS

We are grateful to Alex Calhoun, former Chief, Inland Fisheries Branch, California Department of Fish and Game, for suggesting this problem. We also thank Frank Cochrane and Mas Yamashita for the supply of striped bass eggs produced at the Central Valleys Hatchery, Elk Grove; Richard L. Johnson for technical assistance; and Charles K. Barry for reviewing the manuscript.

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