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EFFECTS OF TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN ON THE SURVIVAL OF STRIPED BASS EGGS AND LARVAE[1]

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Laboratory experiments were conducted on the effects of salinity, temperature, and dissolved oxygen on the survival of artificially spawned striped bass eggs and larvae. Egg survival in salinities greater than about 1,000 ppm TDS, especially at higher temperatures, are greatly reduced if eggs are not water hardened in fresh water. Moderate reductions in dissolved oxygen (to 4 to 5 mg/liter) adversely affect the percent hatch of eggs and have a detrimental effect on larval survival.

INTRODUCTION

Knowledge of the effects of various environmental factors on the survival of eggs and larvae of striped bass, *Morone saxatilis* (Walbaum), is essential for making decisions which will protect the striped bass population. Water quality in the present spawning and nursery areas will be degraded increasingly by decreases in freshwater flows and increases in waste discharges.

The water quality parameters which will change in the future include salinity, temperature and dissolved oxygen. This paper describes laboratory experiments conducted to define the effects of these parameters on the survival of artificially spawned striped bass eggs and larvae.

METHODS

In the spring of 1968, adult striped bass were captured during their spawning migration with large wire fyke traps as described by Hallock, Fry and LaFaunce (1957). Following capture, female bass were anesthetized in a large tank with 5.0 ppm Quinaldine. Egg samples were taken from each fish with a small glass catheter to determine suitability for induced ovulation as described by Stevens (1964). Suitable fish were injected with 2,500 International Units of human chorionic gonadotropin and then returned to a holding trap in the river for approximately 18 hr. The fish were then anesthetized again and transported a distance of 25 miles to our laboratory, where they were held under sedation in an 80-gallon tank until ovulation took place. The time of ovulation was determined by periodically removing eggs with a catheter tube and comparing them with the developing stages described by Stevens (1964).

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The fish were spawned by hand stripping and the eggs were dry fertilized with sperm from at least two males. Samples of fertilized eggs were then dispensed volumetrically with a syringe into test containers. There were three replicates for each test condition. The number of eggs per test was estimated by counting eggs in at least six samples for each batch of eggs.

The test containers for rearing eggs were constructed of 3-inch sections of 2½-inch polyvinylchloride pipe covered at one end with stainless steel bolting cloth of 38 meshes per lineal inch (mesh opening 0.0198 inch). As many as nine containers were suspended in water in a 5-gallon aquarium.

The aquariums were placed in large wooden tanks in which the temperature was controlled by a Braun constant temperature circulator. Salinities in the aquariums were prepared by adding natural seawater to fresh water from the Delta until the required salinity was reached. Specific conductance was measured with a Wheatstone Bridge. These conductivity values were multiplied by 0.64 to derive a rough estimate of total dissolved solids in parts per million (Richards, 1954).

In tests in which dissolved oxygen was a variable, oxygen concentrations were reduced by passing water through a partial vacuum in an apparatus similar to that described by Mount (1961, 1964). All parts of the system conveying water were plastic or coated with epoxy resin except for several galvanized valves. Water of the desired oxygen level was supplied through ⅛-inch Tygon plastic tubing to each test container in the 5-gallon aquarium. A siphon in the center of the aquarium maintained the water at the desired level. Dissolved oxygen levels were measured in the water entering the container and at the center of the aquarium by the azide modification of the standard Winkler procedure.

In the oxygen experiments the deoxygenating apparatus and aquariums were a closed system. In the salinity experiments each aquarium was a closed system.

One million units of penicillin G and 1 g of streptomycin were added to each 5 gallons of water for bacteria control. The water was filtered daily through a fiberglass filter.

Only three of the 42 female striped bass handled were successfully ovulated. The percent hatch of eggs in the controls was 29.4, 16.3 and 9.7 for the three fish. Control conditions were a water temperature of 65 F, fresh water (130 ppm TDS), and saturated dissolved oxygen. Hatches in all experiments are expressed as a percentage of the hatch of controls.

SALINITY AND TEMPERATURE

Two series of tests were conducted on the effects of salinity and temperature on striped bass egg survival. In one, the eggs were placed directly into the test salinity and temperature; in the other, the eggs were water hardened in fresh water (130 ppm TDS) at 65 F for 2 hr and then placed into the desired test condition. Striped bass eggs water hardened in approximately 1.5 hr (Mansueti, 1958).

In each series of tests, eggs were incubated at 18 salinity-temperature combinations (Tables 1 and 2). The results for concentrations of total dissolved solids (TDS) from 130 to 1,000 are from one spawning and the results from 2,000 to 10,000 are from another.

For the striped bass eggs placed directly into the test conditions (Table 1), the survival is generally good (88% or more of control) in total dissolved solids of 1,000 and less throughout the temperature range tested. The highest survival occurred at 1,000 ppm and 65 F. Survival decreases rapidly above 1,000 ppm, especially at the higher temperatures. None of the eggs survived at 72 F in any salinities above 1,000 ppm.

The survival of eggs water hardened in fresh water (Table 2) was similar to the survival of eggs water hardened at the test salinities up to 1,000 ppm TDS. However, the survival of eggs water hardened in

TABLE 1. Incubation of Striped Bass Eggs at 18 Salinity-Temperature Combinations. The Fertilized Eggs Were Placed Directly into Various Factor Combinations.

Factor level				Total eggs in sample	Egg survival as percent control hatch	
Salinity		Temperature (F)				
Assumed mg/liter TDS	Actual EC	Assumed	Actual	$\overline{X} \pm t_{.05}S_{\overline{x}}$	Range	Mean
130	189	58	57.2–58.9	159.3±9.3	96.9–106.4	102.3
130	196	65	64.8–65.6		97.6–104.0	100.0
130	189	72	71.8–72.6		93.5–114.9	106.4
500	768	58	57.2–58.9		102.0–110.5	106.4
500	837	65	64.8–65.6		106.4–144.5	121.0
500	787	72	71.8–72.6		65.9–106.8	88.7
1000	1617	58	57.2–58.9		89.4–106.4	95.2
1000	1515	65	64.8–65.6		131.2–144.5	136.0
1000	1531	72	71.8–72.6		95.5–114.9	105.4
2000	3046	58	56.4–59.0	259.6±5.2	52.2–141.6	93.8
2000	3007	65	64.0–65.2		52.2–66.2	57.3
2000	3148	72	71.4–72.2		0.0	0.0
5000	7828	58	56.4–59.0		35.4–59.0	44.7
5000	7601	65	64.0–65.2		7.4–40.1	20.4
5000	7640	72	71.4–72.2		0.0	0.0
10000	15671	58	56.4–59.0		11.5–16.3	13.9
10000	15890	65	64.0–65.2		0.0	0.0
10000	15593	72	71.4–72.2		0.0	0.0

TABLE 2. Incubation of Striped Bass Eggs at 18 Salinity-Temperature Combinations. The Fertilized Eggs Were Water-Hardened in Fresh Water (130 mg/liter TDS) for 2 hr and Then Placed Into Various Factor Combinations.

Factor level				Total eggs in sample	Egg survival as percent control hatch	
Salinity		Temperature (F)				
Assumed mg/liter TDS	Actual EC	Assumed	Actual	$\overline{X} \pm t_{.05}S_{\overline{x}}$	Range	Mean
130	189	58	57.2–58.9	159.3±9.3	96.9–106.4	102.3
130	196	65	64.8–65.6		97.6–104.0	100.0
130	189	72	71.8–72.6		93.5–110.5	102.3
500	768	58	57.2–58.9		76.5–89.4	84.3
500	837	65	64.8–65.5		80.9–97.9	89.4
500	787	72	71.8–72.6		68.0–100.0	84.3
1000	1617	58	57.2–58.9		112.5–114.9	113.2
1000	1515	65	64.8–65.6		95.5–129.5	109.1
1000	1531	72	71.8–72.6		87.0–129.5	111.9
2000	3046	58	56.4–59.0	259.6±5.2	84.6–132.0	108.5
2000	3007	65	64.0–65.2		17.4–108.1	66.6
2000	3148	72	71.4–72.2		53.9–61.4	56.1
5000	7828	58	56.4–59.0		99.6–134.0	114.3
5000	7601	65	64.0–65.2		33.1–84.6	60.4
5000	7640	72	71.4–72.2		40.0–70.6	59.7
10000	15671	58	56.4–59.0		108.8–118.0	111.5
10000	15890	65	64.0–65.2		42.3–63.8	54.0
10000	15593	72	71.4–72.2		58.7–75.4	64.1

fresh water was much greater in the higher salinities and temperatures. At the higher salinities and temperatures, survival was consistently on the order of 50 to 60% of control survival, which contrasts with survivals of 0 to 20% under the same conditions for eggs water hardened at test salinities.

Another series of experiments were run to determine whether the mixture of ions making up salinity from inland drainage affects egg survival similarly to the mixture of ions in sea water. This is pertinent because in dry years the flow in the San Joaquin River above Stockton consists of largely saline irrigation return water. Salinity of this type blocks adult striped bass migrations when concentrations exceed about 350 ppm TDS (Radtke and Turner, 1967). In the laboratory experiments, striped bass eggs survived equally well in high and low salinity San Joaquin River water, but fewer eggs survived when incubated in Tuolumne River water (Table 3).

OXYGEN AND TEMPERATURE

Striped bass eggs were exposed to two levels of dissolved oxygen at two temperatures for varying lengths of time. All eggs were placed directly into the various temperature and dissolved oxygen levels to be tested. Samples were removed from the low dissolved oxygen at the

TABLE 3. Incubation of Striped Bass Eggs in Different Sources of River Water.

Source of water	Salinity		Temperature (F)	Total eggs in sample	Egg survival as percent control hatch	
	Approximate mg/liter TDS	Actual EC		$\overline{X} \pm t_{.05}S_{\bar{x}}$	Range	Mean
San Joaquin River at Oulton Point (20 miles below Stockton)	147	230	65	238.2±5.7	85.7–124.1	100.0
San Joaquin River at Patterson (65 miles above Stockton)	623	973	65	238.2±5.7	74.8–115.6	98.6
Tuolumne River at Tuolumne City (58 miles above Stockton)	525	820	65	238.2±5.7	56.1–68.7	64.6

end of the different exposure times and placed into water with high oxygen concentrations until the eggs hatched.

The results for dissolved oxygen values of 5.0 mg/liter are from one spawning and the results from 4.0 mg/liter are from another. The percent hatch in the controls was 16.4 and 9.9 respectively.

Generally, egg survival decreased with an increase in temperature or exposure time or a decrease in dissolved oxygen level (Table 4). The mean survival value of the eggs at 72 F was below 50% of the control hatch for all exposure times at 4.0 mg/liter of dissolved oxygen and for five of six exposure times at 5.0 mg/liter dissolved oxygen. There was a consistent reduction in survival for all exposure times even under the least rigorous conditions (65 F and 5.0 mg/liter dissolved oxygen). The length of time for hatching was slightly longer at the lower concentration of dissolved oxygen.

A number of the larvae hatched with various abnormalities at the 4.0 dissolved oxygen level. To determine their survival, newly hatched larvae were separated by their duration of exposure to low dissolved oxygen levels and held for a period of 6 days (Table 5). The longer that eggs were exposed to low oxygen conditions, the lower the percent survival of larvae after 6 days.

DISCUSSION

We encountered numerous difficulties with our experimental procedures both in successfully ovulating the female bass and in hatching the eggs. As a result we had few fish to work with and low survival of eggs in the controls (9.7 to 29.4%). Hence, all results presented here need to be checked under more suitable environmental conditions. Meanwhile though, the experimental results described here have consistent trends which strongly suggest oxygen and salinity requirements for which there is no other experimental evidence.

TABLE 4. Incubation of Striped Bass Eggs at Several Dissolved Oxygen-Temperature Combinations Exposed for Various Lengths of Time.

Dissolved oxygen (mg/liter)		Temperature (F)			Total eggs in sample	Egg survival as percent control hatch	
Assumed	Actual	Assumed	Actual	Exposure time in hours	$\bar{X} \pm t_{.05}S_{\bar{x}}$	Range	Mean
Saturation	7.6-8.4	65	64.3-67.8	Control	238.2±5.7	94.0-103.6	100.0
Saturation	7.3-8.8	72	71.7-72.6	Control		94.6-101.6	98.3
4.0	3.5-4.8	65	66.8-68.7	6	↓	25.2-62.4	43.5
↓	3.5-4.6	72	71.8-72.6	6		24.9-58.4	41.8
	3.5-4.8	65	66.8-68.7	12		54.4-71.0	64.1
	3.5-4.6	72	71.8-72.6	12		8.3-20.9	16.6
	3.5-4.8	65	66.8-68.7	18		29.2-71.0	47.5
	3.5-4.6	72	71.8-72.6	18		12.6-24.9	20.9
	3.5-4.8	65	66.8-68.7	24		50.1-58.4	54.4
	3.5-4.6	72	71.8-72.6	24		11.9-29.2	20.5
	3.5-4.8	65	66.8-68.7	30		29.2-54.1	41.8
	3.5-4.6	72	71.8-72.6	30		0.0-16.6	10.9
	3.5-4.8	65	66.8-68.7	56 (Hatch)		3.9-71.0	40.1
	3.5-4.6	72	71.8-72.6	40 (Hatch)		0.0-3.9	1.3
Saturation	7.5-8.4	65	64.5-65.8	Control	259.6±5.2	93.1-107.4	100.0
Saturation	7.1-8.7	72	71.6-72.8	Control	↓	97.6-116.6	106.8
5.0	4.6-5.6	65	65.0-66.7	6		46.9-77.5	65.6
↓	4.6-5.6	72	70.6-72.2	6		38.0-56.1	46.2
	4.6-5.6	65	65.0-66.7	12		58.5-91.8	73.4
	4.6-5.6	72	70.6-72.2	12		27.8-58.5	44.5
	4.6-5.6	65	65.0-66.7	18		79.9-101.0	89.1
	4.6-5.6	72	70.6-72.2	18		21.4-39.7	33.6
	4.6-5.6	65	65.0-66.7	24		77.5-95.9	85.7
	4.6-5.6	72	70.6-72.2	24		42.1-63.6	55.7
	4.6-5.6	65	65.0-66.7	30		68.3-98.9	79.9
	4.6-5.6	72	70.6-72.2	30		25.8-52.0	37.7
	4.6-5.6	65	65.0-66.7	54 (Hatch)		52.0-65.9	57.1
	4.6-5.6	72	70.6-72.2	38 (Hatch)		27.8-37.7	31.9

TABLE 5. Survival of Striped Bass Larvae from Hatching to 6 Days of Age. These Larvae Were Hatched from Striped Bass Eggs Exposed to 4 mg/liter Dissolved Oxygen for Varying Lengths of Time.

Exposure time in hours	Sample size	Number surviving	Percent survival
0	70	38	54.3
6	54	28	51.9
12	58	26	44.8
18	49	23	46.9
24	54	21	38.9
30	38	10	26.3
Hatched	30	7	23.3

Numerous authors and our field studies over the past 6 years have found that striped bass spawn principally in fresh water (1,000 mg/liter TDS or less). Albrecht (1964) and this study indicate that eggs can survive in higher salinities than where the adult bass spawn. However, the results of the current experiments indicate that egg survival in salinities greater than about 1,000 ppm TDS are greatly reduced if the eggs are not water hardened in fresh water.

Few studies have been done on the dissolved oxygen requirements of striped bass eggs. Our observations suggest that even moderate reductions in dissolved oxygen adversely affect the percent hatch of eggs and have a detrimental effect on larval survival.

REFERENCES

Albrecht, Arnold B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. Calif. Fish Game 50(2) : 100–113.

Hallock, Richard J., D. H. Fry, Jr., and Don A. LaFaunce. 1957. The use of wire fyke traps to estimate the runs of adult salmon and steelhead in the Sacramento River. Calif. Fish Game 43 : 271–298.

Mansueti, Romeo. 1958. Eggs, larvae and young of the striped bass, *Roccus saxatilis*. Md. Dep. Res. Educ. Contrib. No. 112, 35 p.

Mount, D. I. 1961. Development of a system for controlling dissolved oxygen content of water. Trans. Am. Fish. Soc. 90(3) : 232–327.

———. 1964. Additional information on a system for controlling the dissolved oxygen content of water. Trans. Am. Fish. Soc. 93(1) : 100–103.

Radtke, Larry D. and Jerry L. Turner. 1967. High concentrations of total dissolved solids block spawning migration of striped bass, *Roccus saxatilis*, in the San Joaquin River, California. Trans. Amer. Fish. Soc. 96(4) : 405–407.

Richards, L. A. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dep. Agr. Handbook 60, 160 p.

Stevens, Robert E. 1964. A final report on the use of hormones to ovulate striped bass, *Roccus saxatilis* (Walbaum). Proc. S. E. Assoc. Game and Fish Comm. 18 : 525–538.

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