

Effect of Hardness and Salinity on Survival of Striped Bass Larvae

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Abstract.—Larval striped bass *Morone saxatilis* were exposed to three hardness (40, 100, and 160 mg/L as CaCO₃ equivalents) and two NaCl salinity (2.0 and 3.0‰) treatments for 10 d in a modified flow-through system. Salinity had a greater effect on larval survival than did hardness over the ranges tested. Elevated NaCl salinity appeared to be detrimental; larvae exposed to 3.0‰ NaCl had significantly higher mortality than did those exposed to 2.0‰ NaCl. At 2.0‰ salinity, hardness does not appear to play an important role in larval survival (probability of survival > 0.70). At 3.0‰ salinity, mortality was greatest at hardness levels of 40 and 100 mg/L (probability of survival = 0.06 and 0.01, respectively), whereas at 160 mg/L, mortality was reduced (probability of survival = 0.39). The reason for this response is not clear, although there may be an optimal ratio of different ions contributing to total salinity. By comparison, other studies in which diluted seawater was used indicated that salinities of 0.5–10.0‰ enhance the survival of striped bass larvae.

Successful rearing of larval striped bass *Morone saxatilis* is partly based on water quality. Low to moderate salinity levels (1–10‰) increase larval survival (Bonn et al. 1976; Setzler et al. 1980; Morgan et al. 1981). It is also generally accepted that water hardness is an important factor in fish culture, and that water with low hardness and correspondingly low alkalinity has a poor capacity to buffer against acidification (Piper et al. 1982). In addition, moderate hardness or low-level salinity tends to decrease the susceptibility of fish to toxicants (Hazel et al. 1971; Lewis and Heidenger 1981; Palawski et al. 1985; Sprague 1985). Bonn et al. (1976) stated that hardness is an important factor in the survival of striped bass larvae and that a total hardness of 150 mg/L is desirable but not critical.

At present there is no consensus concerning the optimum hardness range for culture of striped bass larvae. The goal of our study was to determine if varying hardness at 2.0 and 3.0‰ salinity affected larval survival. Three hardness levels were tested: 40, 100, and 160 mg/L (measured as CaCO₃ equivalents).

Methods

Striped bass larvae were obtained 12 h post-hatch from EA Engineering Science and Technol-

ogy, Inc., Verplanck, New York. Parental stocks were derived from the Hudson River, New York. At the hatchery, eggs and milt were manually stripped from brood fish, and eggs were fertilized according to the dry method (Piper et al. 1982). After transport to the Aquatic Toxicology Facility of the University of Maryland School of Medicine, larvae were maintained in a 200-L aquarium with biological filtration and daily 20% water changes. Holding water consisted of moderately hard, reconstituted bioassay water (Marking and Dawson 1973), with a hardness of 100 mg/L and a pH of 7.6–7.8, to which laboratory-grade NaCl (Fisher Scientific, Springfield, New Jersey) was added at a rate of 1.0 g/L. The holding tank was maintained at 18.0°C (± 1.0°) in a temperature-controlled water bath (LSW-700 Living Stream System, Frigid Units, Inc., Toledo, Ohio).

At 2 d of age, 40 randomly chosen larvae were transferred to each of 12 exposure vessels. These were used in a 3 × 2 experimental design with three hardness and two salinity treatments, and there were two replicates of each hardness–salinity combination. Exposure vessels were 1.0-L polyethylene containers with three 2.0-cm holes cut in the side walls. The holes were covered with 400-μm-mesh Nitex screen (Tetko, Inc., Elmsford, New York). Exposure vessels were submerged in 4.0-L glass flow-through test chambers (Kane et al. 1988a) in which the initial water quality was the same as for holding conditions. Test chambers were maintained at 18.0°C (± 1.0°) by a temperature-controlled recirculating water bath.

At 3 d of age, larvae began receiving live *Arte-*

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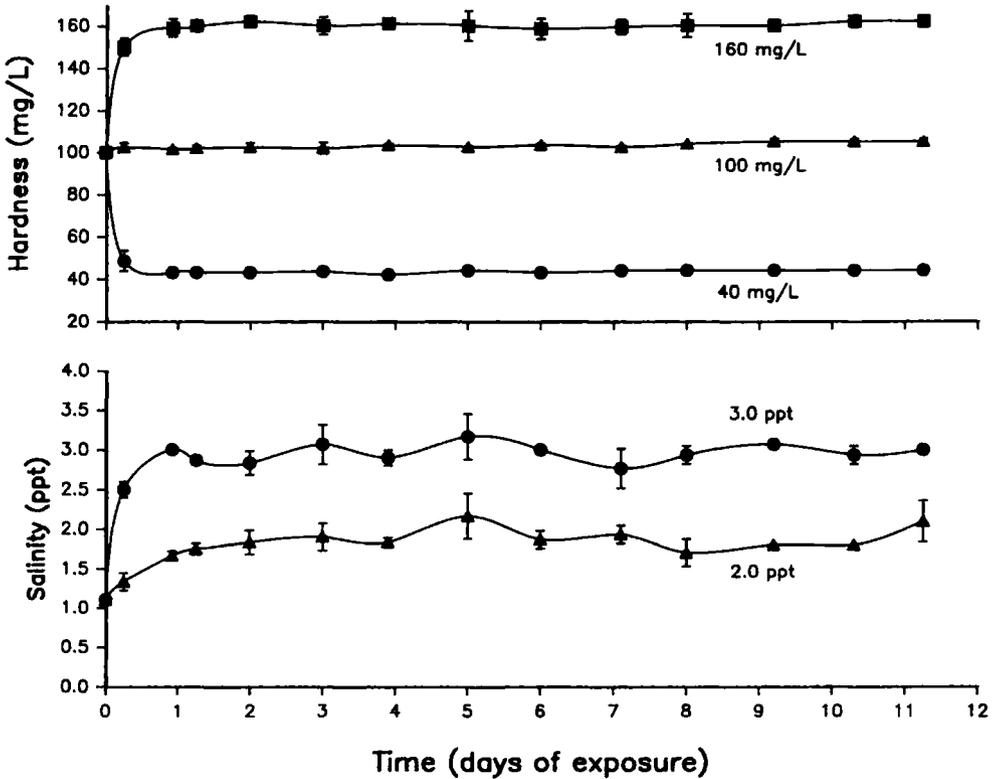


FIGURE 1.—Hardness (CaCO_3 equivalents) and salinity measurements from chambers used to test survival of striped bass larvae. Data are daily means for two replicates of each treatment. Vertical bars represent SEs; ppt = parts per thousand.

mia sp. nauplii twice daily. Additional feeding was not required because the nauplii remained alive in the exposure vessels for over 12 h.

When the larvae were 4 d old, they were gradually exposed to experimental hardness and salinity conditions. This was accomplished with a modified flow-through dosing system (Kane et al. 1988a). Three 450-L polyethylene carboys were used as reservoirs for recirculating test waters for the three hardness treatments. Test water from each carboy was then metered through a series of splitting and mixing chambers, from which water was gravity-fed to exposure chambers. Salinity was controlled by metering a proportionate amount of a 2.0-M-NaCl stock solution into appropriate mixing chambers in the dosing system.

Throughout the 10 d of exposure, water flowed through the test chambers for 8 h/d and was static for 16 h/d. This constraint ensured sufficient quantities of test waters. The initial flow rate metered to test chambers was 12.5 mL/min during the first 6 h of the experiment. Flow was then reduced and maintained at 5.0 mL/min throughout the re-

maining flow-through intervals. Dead larvae were removed and recorded twice daily, and test chambers were cleaned by siphoning at the same time.

Hardness was measured by EDTA titration (APHA et al. 1980). Salinity was determined from specific-gravity measurements as well as with a YSI salinity meter (model 33, Yellow Springs Instruments, Yellow Springs, Ohio). Dissolved oxygen and pH were measured with gas-sensing (model 9708-00, Orion Research, Boston, Massachusetts) and potentiometric (model 5773591-010BV12, pHoenix Electrodes, Houston, Texas) electrodes, respectively, on an Orion ion analyzer (model EA920). Mortality data were analyzed according to a proportional-hazards model with the SAS (1985) Lifereg and Lifetest procedures.

Results and Discussion

Hardness and salinity measurements from test chambers are shown in Figure 1. During the initial 6 h of flow, water in the lowest and highest hardness treatments gradually attained hardnesses of 40 and 160 mg/L, respectively. The intermediate

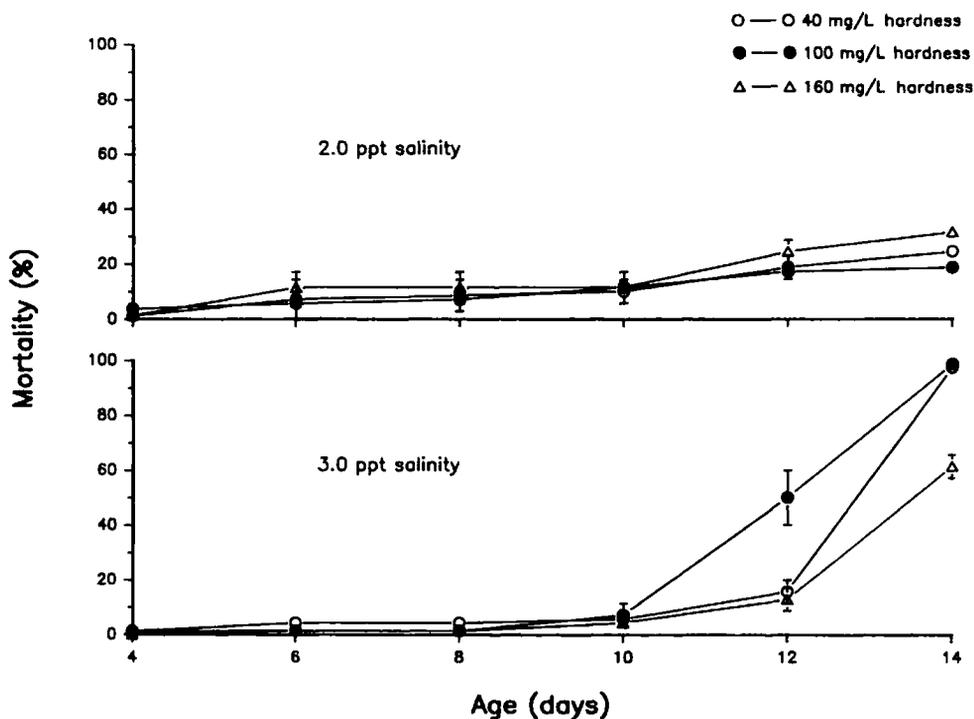


FIGURE 2.—Cumulative mortalities of striped bass larvae exposed to different levels of hardness (CaCO_3 equivalents) and salinity. Vertical bars represent SEs; ppt = parts per thousand.

hardness level, 100 mg/L, remained constant. During the initial 24 h of flow, salinity stabilized at 2.0 or 3.0‰ at each of the three hardnesses. Dissolved oxygen for all exposures remained above 80% saturation throughout the exposure period. The pH levels for the 40, 100, and 160 mg/L hardness treatments were 7.6, 7.9–8.0, and 8.1–8.2, respectively. These pH levels fell within the optimal range for striped bass fry production (Bonn et al. 1976; Lewis and Heidenger 1981).

Cumulative mortality for the 10 d of exposure ranged from 17 to 31% at 2.0‰ salinity and from 57 to 100% at 3.0‰ salinity (Figure 2). Mortality was significantly greater ($P < 0.0001$) at 3.0‰ salinity than at 2.0‰ salinity, and the effect of salinity was shown to be dependent on hardness ($P < 0.0012$). Mortality differences due to hardness were also more pronounced in fish exposed to 3.0‰ salinity than in those exposed to 2.0‰. This interaction was indicated by the survival probabilities calculated with the SAS (1985) Lifetest procedure when the Weibel model was used (Table 1). At 2.0‰ salinity, hardness does not appear to play an important role in larval survival, but at 3.0‰ salinity, mortality was greater at hardnesses of 40 and 100 mg/L than at 160 mg/L. The reason

for this response is not clear, although the elevated hardness may have played a role in reducing the negative effects of the 3.0‰ NaCl treatment. For the development of striped bass larvae, we speculate that there may be an optimal ratio of ions contributing to total salinity. Salinity contributed solely from NaCl may alter a potentially important ionic balance.

The data show that there was a very gradual increase in mortality in all exposure groups until the larvae were 10 d old. At day 10 there was a pronounced increase in mortality, particularly in the group exposed to 3.0‰ NaCl. This indicates

TABLE 1.—Probability of survival (P) for striped bass larvae exposed to hardnesses of 40, 100, and 160 mg/L (CaCO_3 equivalents) at 2.0 and 3.0‰ NaCl. Probabilities were determined with the SAS (1985) Lifetest procedure.

Salinity	Hardness	P
2.0	40	0.76
	100	0.82
	160	0.70
3.0	40	0.06
	100	0.01
	160	0.39

that there may be a critical developmental stage beginning at about 10 d of age, the approximate time of yolk-sac absorption, during which the effects of salinity on mortality may be most pronounced.

Studies by Bailey (1975) and Germann and Reeves (1975) have suggested that hardness has no effect on the survival of striped bass larvae and that brood-stock differences would more likely account for variability in survival among experimental groups exposed to different hardnesses. However, elevated hardness has been reported to enhance larval survival in fresh water. Hazel et al. (1971) could not use low-hardness (25–30 mg/L) river water for bioassays due to low survival of control fish. This problem was eliminated by either adding salts or using different river water with higher hardness (150–200 mg/L). Murray-Brown (1987) observed enhanced larval survival in elevated (60–240 mg/L) hardness treatments, and mortality was greatest with no hardness.

During bioassays with striped bass larvae, Bayless (1972) found that, when NaCl was substituted for seawater salts, survival decreased at 3.5‰ salinity, and all fish died at higher salinities. This corroborates our data, which show that 3.0‰ NaCl is detrimental to the survival of striped bass larvae. However, in salinity experiments with diluted seawater, Lal et al. (1977) found that larval survival at 3.4–17.0‰ salinity was higher than in fresh water. Larval survival was highest at salinities between 3.4 and 6.8‰. (Survival at salinities below 3.4‰ was not measured.) Albrecht (1964) reported enhanced larval survival at 1.7‰ salinity (diluted bay water), and salinities of 8.3–8.6‰ were not detrimental. Murray-Brown (1987) noted that larval survival was enhanced at all salinity treatments from 0.5 to 10.0‰ (diluted seawater), as compared with that of control fish in fresh water. In pond trials, Shell (1974) reported a significantly higher mean survival rate for larvae in rearing ponds with 1.0‰ NaCl. Barwick (1974) also reported higher survival in ponds treated with 1.0‰ NaCl than in ponds with no additional salinity, although plankton blooms were reduced in ponds with added salinity.

Using soft reconstituted water in flow-through bioassays, Kane et al. (1988b) found that maintenance of 1.1‰ NaCl enhanced larval survival over that of larvae exposed to a reduction in salinity from 1.1 to 0.6‰ over a 24-h period. Further, larvae exposed to reduced salinity were more susceptible to shifts in pH than were larvae maintained at 1.1‰ salinity.

This study indicates that salinity is more important than hardness to the survival of larval striped bass. Hardness is most likely a contributor of necessary ions for basic physiological functions during larval development. In addition, elevated hardness may have a protective effect in conditions of above-optimal salinity. This is illustrated by the reduced larval mortality in the group exposed to 3.0‰ NaCl and a hardness of 160 mg/L (Figure 2). Hardness also contributes to pH stability and stimulates phytoplankton and zooplankton blooms in ponds (Boyd 1979; Piper et al. 1982). Low-level salinities from diluted seawater (0.5–10.0‰) or from NaCl (1.0–1.1‰) have a positive effect on larval survival. However, NaCl salinities above 2.0‰ may prove deleterious.

Acknowledgments

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