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Bait and Temperature Effects on Striped Bass Hooking Mortality in Freshwater

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Abstract.—We compiled results of published and unpublished studies of hooking mortality for striped bass *Morone saxatilis* that were conducted in freshwater. We used logistic regression to model the effects of bait type and water temperature on mortality of 1,275 striped bass. Both factors were significant predictors ($P < 0.0001$) of hooking mortality. Striped bass hooking mortality was greater in fish captured with natural baits than with artificial baits and was positively related to water temperature. These results allow prediction of striped bass hooking mortality based on bait type and water temperature. For a smaller data set that also included total lengths of fish captured, we used logistic regression to model hooking mortality as a function of bait type, water temperature, and total length for 549 fish. There were significant bait and temperature effects ($P < 0.0001$), but there was no evidence ($P = 0.2994$) that striped bass hooking mortality was size dependent.

Striped bass *Morone saxatilis* have been widely introduced in reservoirs throughout the United States to create recreational and trophy fisheries and to control populations of pelagic prey fishes (Axon and Whitehurst 1985). Many of these fisheries are managed with minimum length and bag limits that are intended to protect and enhance fish stocks. Protective regulations also have been used to allow depleted East Coast striped bass stocks to rebuild (Diodati and Richards 1996; Nelson 1998). These regulations can be effective in achieving their intended purposes only if survival is high among the captured and released fish (Muoneke and Childress 1994).

To assess the potential effectiveness of regulations requiring release of captured striped bass, studies of hooking mortality have been conducted in freshwater impoundments and rivers (Harrell 1988; Childress 1989; RMC, Inc. 1990; Hysmith et al. 1994; Tomasso et al. 1996; Bettoli and Osborne 1998; Lukacovic and Florence 1998; Nelson 1998). However, the results of these studies are often contradictory, thus making them difficult to apply to other striped bass fisheries. The objectives of this study are to synthesize results from previous investigations of striped bass hooking mortality and resolve differences in the results of those studies. We test three hypotheses.

- H_1: Striped bass hooking mortality does not differ between fish captured on natural versus artificial baits.
- H_2: Striped bass hooking mortality is unrelated to the water temperature in which fish are captured and held.
- H_3: Striped bass hooking mortality is unrelated to total length of captured fish.

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TABLE 1.—Summary of striped bass hooking mortality studies included in logistic regression analyses.

Study site[a]	N	Mortality (%)	Bait type	Water temperature (°C)	Total length (%)	Control mortality (%)	Observation period (d)	Reference
Tims Ford Reservoir, TN	89	41.6	Artificial, natural	11.0–31.0	508–838			Bettoli and Osborne (1998)
Lake Buchanon, TX	7	0.0	Artificial	22.5			3	Childress (1989)
Lake Texoma, OK–TX	106	43.4	Natural	8.3–25.8			3	Childress (1989)
Lake Texoma, OK–TX	307	38.1	Artificial, natural	6.0–30.0	229–737		3	Hysmith et al. (1994)
Susquehanna Flats, MD	277	7.9	Artificial	14.6–19.7	279–813		3	Lukacovic and Florence (1998)
Roanoke River, NC	153	13.1	Artificial, natural	16.0–23.5	293–610	6.7	3	Nelson (1998)
Susquehanna River, MD	172	73.8	Artificial	25.6–26.1	201–900[b]	11.6	3	RMC (1990)
Ponds, SC	164	9.1	Artificial	17.5–28.0	100–150		31–43	Tomasso et al. (1996)

[a] MD = Maryland, NC = North Carolina, OK = Oklahoma, SC = South Carolina, TN = Tennessee, and TX = Texas.
[b] Total length was reported in 100-mm intervals (e.g., 201–300, 301–400, 401–500, 501–600, 601–700, 701–800, and 801–900).

Methods

We compiled results of seven published and unpublished studies of striped bass hooking mortality. Studies were included in our analyses if they were conducted in freshwater and reported mortality rate, sample size, water temperature, and bait type (Table 1). In most studies, captured striped bass were held 3 d to evaluate mortality. The holding period was 31–43 d in Tomasso et al. (1996). In Bettoli and Osborne (1998), released fish were tagged and monitored with ultrasonic transmitters for a minimum of 3 d. We made no adjustment for differences among studies in holding period length (e.g., Wilde 1998), nor does any seem necessary. There is no apparent relationship between hooking mortality and holding period length (Table 1); striped bass that die as a result of hooking generally do so within the first 24 h after release (Bettoli and Osborne 1998; Nelson 1998).

Water temperature was reported in a variety of ways. In some cases, water temperature at the time of capture was reported (Bettoli and Osborne 1998; Nelson 1998); others reported the mean (RMC 1990) or range (Childress 1989; Tomasso et al. 1996; Lukacovic and Florence 1998) in daily temperatures from capture through the holding period. When ranges were reported, we used the midpoint of the range.

Various types of baits and terminal tackle have been used in striped bass hooking mortality studies. We dichotomized baits, regardless of numbers and types of hooks, as natural (live fishes and cut baits) and artificial (jigs, crank baits, spinners, and spoons). Generally, results for natural and artificial baits were presented separately. Childress (1989) conducted three hooking mortality trials using a combination of natural and artificial baits. In one trial, all fish were captured with artificial baits and in the remaining trials (N = 47 and 59) all but eight fish (four per trial) were captured with natural baits. Because results for natural and artificial baits were not reported separately in these latter trials, we consider them as being for natural baits. For purposes of analysis, bait types were coded 0 for natural baits and 1 for artificial baits.

To evaluate the potential effects of fish length on striped bass hooking mortality, we assembled observations (bait type, water temperature, and total length in millimeters) for individual fish from the original data sheets of Hysmith et al. (1994), Bettoli and Osborne (1998), and Nelson (1998).

We used logistic regression to model the effects of bait type, water temperature, and fish length on striped bass hooking mortality. For each analysis, we first fit a model that included main effects and all interaction terms, and then refit the model sequentially dropping individual nonsignificant ($P >$ 0.05) terms, unless there was a significant higher-order (interaction) term. The general model fit was

$$P_m = e^{\eta}/(1 + e^{\eta}), \qquad (1)$$

where P_m is the probability of mortality, e is the base of natural logarithms, and η is a linear combination of the independent variables (i.e., $\eta = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i}$, where β_0 is a regression intercept; β_1, β_2, β_3 are regression coefficients; and X_{1i}, X_{2i}, X_{3i} represent the independent variables, such as bait type, water temperature, and fish length, for the ith fish). All statistical analyses were performed using S-Plus (MathSoft 1999).

Results

Striped bass hooking mortality was 29% across all studies (Table 1); however, mortality was substantially greater in fish captured with natural baits (42%, N = 340) than with artificial baits (25%, N = 935). Water temperatures at which fish were captured and held for observation ranged from 6°C

TABLE 2.—Analysis of deviance table for the logistic regression of striped bass hooking mortality on bait type and water temperature (all studies combined). Also shown are regression coefficients and their standard errors. Bait type assumes a value of 0 for natural baits; thus, the bait-type coefficient reduces to 0 for natural bait. Bait type assumes a value of 1 for artificial baits; therefore, the bait-type coefficient can be added to the intercept ($-4.59 + -0.41 = -5.00$). This allows models for both bait types to reduce to an intercept and water temperature coefficient.

Factor	χ^2	df	P	Coefficient	SE
Intercept				−4.59	0.350
Bait type	31.72	1	0.0001	−0.41	0.073
Water temperature	188.41	1	0.0001	0.17	0.014
Residual	1,322.91	1,272	0.1564		

to 31°C (Table 1). Total length measurements were available for 549 fish and ranged from 100 to 838 mm.

Bait type and water temperature were significant predictors ($P < 0.0001$) of hooking mortality in striped bass (Table 2). Between these two factors, water temperature explained a much greater proportion of variation in hooking mortality (12.2%) than did bait type (2.0%). Regression coefficients showed that hooking mortality was lower among fish captured with artificial baits than among those captured with natural baits and that mortality was directly related to water temperature. Combining intercept and bait type coefficients in Table 2 allowed estimation of mortality for each bait type as a function of water temperature (Figure 1):

$$P_{\text{natural}} = e^{-4.59\ +\ 0.17\cdot\text{temp}}/(1 + e^{-4.59\ +\ 0.17\cdot\text{temp}}) \quad (2)$$

and

$$P_{\text{artificial}} = e^{-5.00\ +\ 0.17\cdot\text{temp}}/(1 + e^{-5.00\ +\ 0.17\cdot\text{temp}}), \quad (3)$$

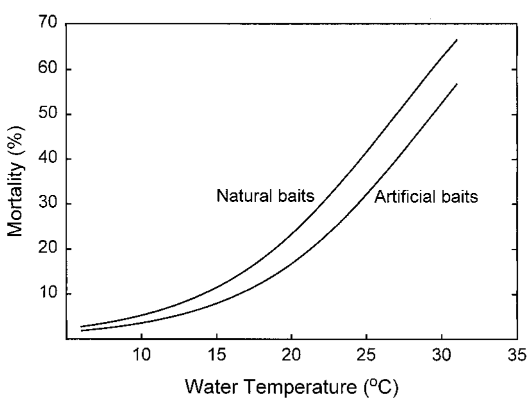

FIGURE 1.—Striped bass hooking mortality predictions based on bait type (natural versus artificial) and water temperature. Predictive equations are presented in the text.

where P_{natural} and $P_{\text{artificial}}$ represent the probabilities of mortality for fish captured with natural and artificial baits and temp is water temperature (°C). Mortality was low (2–14%) and differed little among bait types between 6°C and 16°C (<5%). Both mortality and the magnitude of the difference between bait types increased rapidly at temperatures beyond 16°C, reaching 67% for natural baits and 57% for artificial baits at 31°C.

Logistic regression of striped bass hooking mortality on bait type, water temperature, and total length showed significant bait ($\chi^2 = 14.86$, df = 1, $P < 0.0001$) and temperature ($\chi^2 = 71.54$, df = 1, $P < 0.0001$) effects, but there was no evidence ($\chi^2 = 1.08$, df = 1, $P = 0.2994$) that total length affected striped bass hooking mortality (Table 3). There was a significant ($\chi^2 = 8.99$, df = 1, $P = 0.0077$) bait × total length interaction; striped bass hooking mortality was negatively related to total length among fish captured with natural baits but was positively related to total length among those captured with artificial baits. Because the magnitude of the bait × total length interaction was sensitive to water temperature, as was hooking mortality, the bait × water temperature × total length interaction term also was significant ($\chi^2 = 13.71$, df = 1, $P = 0.0002$).

Discussion

Previous studies have presented conflicting results regarding use of natural versus artificial baits.

TABLE 3.—Analysis of deviance table for the logistic regression of striped bass hooking mortality on bait type, water temperature, and total length.

Factor	χ^2	df	P
Bait type	17.18	1	0.0001
Water temperature	69.22	1	0.0001
Total length	1.08	1	0.2994
Bait × temperature	0.01	1	0.9334
Bait × total length	8.99	1	0.0077
Temperature × total length	2.65	1	0.1037
Bait × temperature × total length	13.71	1	0.0002
Residual	572.92	541	0.1655

Harrell (1988) and Hysmith et al. (1994) reported that striped bass hooking mortality was greater in fish captured with natural baits than artificial baits; however, Bettoli and Osborne (1998) and Nelson (1998) failed to find any such difference. Combining results from previous studies, we found that mortality among striped bass captured with natural baits was greater than among fish captured with artificial baits. The magnitude of the difference between bait types is highly dependent on water temperature and this may, in part, explain differences among previous studies. For example, between 6°C and 16°C, the difference in mortality due to bait type ranges from 1% to 5%; that difference increases to 10% between 26°C and 31°C. Hooking mortality in other species has commonly been greater in fish captured with natural versus artificial baits (Taylor and White 1992; Muoneke and Childress 1994). Fish captured on natural baits often swallow hooks and baits more deeply, thus increasing the likelihood of being hooked in sensitive locations (e.g., pharynx, esophagus, and gills; Diodati and Richards 1996; Nelson 1998) and the risk of injury when hooks are removed (Pelzman 1978; Siewert and Cave 1990). Fish hooked in those sensitive areas are more likely to die than those hooked in other areas (Diodati and Richards 1996; Nelson 1998).

Our results show that there is a positive, nonlinear relation between hooking mortality and water temperature. Such a relation might be expected, based on studies of other species (Hoffman et al. 1996; Wilde 1998). However, only two previous studies have directly assessed the relation between striped bass hooking mortality and water temperature. One study (Nelson 1998) found evidence of a significant relation, the other (Bettoli and Osborne 1998) did not. Other studies provide indirect support for an effect of temperature on striped bass hooking mortality. Harrell (1988) and Hysmith et al. (1994) reported that hooking mortality varied among seasons, being lowest in winter and spring and greatest in summer and fall. Bettoli and Osborne (1998) reported that hooking mortality was related to air temperature. However, these studies failed to provide any model for use in estimating striped bass hooking mortality with respect to temperature.

Our predictive model for striped bass hooking mortality, based on bait type and water temperature, may overestimate mortality. Three studies estimated an average mortality of 7–12% among control fish captured by electrofishing (Harrell 1988; Nelson 1998) and fish traps (RMC 1990). Mortality of control fish appears to increase slightly with water temperature, but there is insufficient information available at this time to model this potential relationship. Therefore, at this time, we do not recommend adjusting hooking mortality to account for mortality among control fish. However, fishery managers using our model should be aware of this limitation.

Finally, our results provide no evidence that hooking mortality of striped bass is related to fish length, so we failed to reject the hypothesis that mortality is unrelated to total length. Hysmith et al. (1994) reported a positive relationship between mortality and total length; however, Bettoli and Osborne (1998) and Nelson (1998) failed to demonstrate any significant relationship between total length and hooking mortality. In our study, two interaction terms that included both bait type and total length were significant; striped bass hooking mortality was negatively related to total length among fish captured with natural baits but was positively related to total length among fish captured with artificial baits. Bettoli and Osborne (1998) noted that their experimental design was unbalanced, with varying sample sizes among treatments, and in some seasons only one bait type was used. This problem is common in striped bass hooking mortality studies and reflects seasonal patterns in fish and angler behavior (Bettoli and Osborne 1998). Inspection of our results leads us to conclude that the length effects we observed are spurious and are the result of unbalanced experimental designs. We therefore conclude that striped bass hooking mortality is unrelated to total length.

Our models for predicting striped bass hooking mortality are specific to fishes captured in freshwater because hooking mortality appears to be lower in brackish versus freshwater. Mortality of striped bass captured and held at three salinities, 0.0, 0.5–4.2, and 7.7–8.3‰, was 74, 39, and 3%, respectively (RMC 1990). Observations of striped bass hooking mortality in brackish waters include 26% mortality at salinities of 9.7–10.2‰ (Lukacovic and Uphoff 1997) and 9% mortality at 31‰ (Diodati and Richards 1996). These results suggest an inverse relation between striped bass hooking mortality and salinity; however, given the magnitude of bait type and water temperature effects observed in our study, additional studies are needed to better establish this relation.

Management Implications

Mortality of striped bass caught and released increases rapidly as water temperatures exceed

25°C. Based on our predictive model, 50% of striped bass captured on natural baits die when water temperatures reach 27°C, and this increases to 67% mortality at 31°C. In comparison, mortality of striped bass captured on artificial baits is 10% less (40–57%) over this temperature range, and exceeds 50% when water temperatures exceed 29°C. Therefore, it may be difficult to enhance striped bass fisheries in which angler effort and catch rates are high during periods of elevated water temperatures. If possible, managers should implement regulations that direct fishing effort toward seasons with cooler water temperatures because striped bass angled and released in warm water may experience significant mortality. The direct relationship between hooking mortality and water temperature suggests that stress is an important contributor to mortality among striped bass captured in warm waters (Tomasso et al. 1996). Any step taken to minimize stress, such as using heavy tackle to land fish quickly, handling fish briefly, and keeping fish in the water during hook removal will probably reduce catch-and-release mortality.

Because of high mortality of striped bass captured on natural baits in spring and summer, Hysmith et al. (1994) proposed a seasonal restriction on the use of natural baits. However, as they noted, this proposal would be unpopular with striped bass anglers, many of whom oppose bait restrictions (Wilde and Ditton 1991). Given the relatively small difference (≤10%, depending on temperature) in striped bass hooking mortality attributable to bait type, we believe bait restrictions may have limited benefit for reducing catch-and-release mortality. Instead, anglers should be informed of the differences in mortality associated with use of different baits and encouraged to adopt the use of artificial baits (e.g., Nelson 1998).

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