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Hooking Mortality and Physiological Responses of Striped Bass Angled in Freshwater and Held in Live-Release Tubes

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Abstract.—Mortality and physiological responses of adult striped bass *Morone saxatilis* angled from Lake Murray, South Carolina, and held in live-release tubes were evaluated during the spring and summer of 2003. To estimate mortality, we attached external ultrasonic transmitters to 59 striped bass (mean total length [TL] = 585 mm). Striped bass were caught with angling gear, tagged, and immediately released or held in live-release tubes for 2, 4, or 6 h prior to release. No mortality of striped bass was observed during spring. Overall mortality during summer was 83%. Mortality of summer-caught striped bass was not related to tube residence time, fish TL, depth of capture, or surface water temperature. To characterize physiological stress, we measured the plasma cortisol, glucose, lactate, and osmolality levels of 62 additional striped bass (mean TL = 563 mm) that were angled and immediately released or angled and held in live-release tubes. Plasma cortisol, glucose, lactate, and osmolality were positively related to tube residence time. When the hematological characteristics were considered only in relation to tube residence time, responses indicative of physiological stress continued for about 150 min, after which blood chemistry began to return to normal. Live-release tubes appear to be useful for keeping striped bass alive when they are angled from cool water, but they are not effective for striped bass angled from warm water. The high summer mortality of striped bass suggests a need for restrictive fishing regulations during the summer for the Lake Murray striped bass fishery.

Catch-and-release angling of striped bass *Morone saxatilis* can often be a significant source of mortality and has been extensively evaluated (Harel 1988; Hysmith et al. 1994; Diodati and Richards 1996; Bettoli and Osborne 1998; Nelson 1998). Mortality rates of striped bass angled in freshwater range from 0% to 74% and are positively related to the use of natural baits and to water temperature (see review by Wilde et al. 2000).

Mortality can occur from fish injury during capture and handling, gas bubble disease brought about by rapid decompression, or associated secondary infections. Physiological disturbances associated with capture and handling include increases in circulating cortisol concentrations, hyperglycemia, osmotic disturbances, and elevated plasma lactate concentrations (Wood 1991).

Striped bass tournaments are popular in the southeastern United States. The National Striped Bass Association (NSBA) holds more than 70 tournaments annually throughout the Southeast. Regional and local angling clubs hold additional striped bass tournaments throughout the year. Most striped bass tournaments weigh in dead fish because standard live wells are not large enough to accommodate striped bass. Recently, the NSBA endorsed the use of live-release tubes in an effort to reduce angling mortality and allow the culling of live fish. Each live-release tube consists of a large tube in which the fish is placed headfirst and a bilge pump that recirculates water through the tube. The objective of this study was to characterize striped bass mortality and physiological stress associated with angling and subsequent holding in live-release tubes. If striped bass survive being held in live-release tubes, then the tubes
can be used to reduce angling mortality and will allow anglers to cull live fish during tournaments.

**Methods**

*Study area.*—Lake Murray is a 19,600-ha impoundment on the Saluda River in central South Carolina. The Lake Murray Dam was constructed in 1930 by Lexington Water Power Company (now named the South Carolina Electric and Gas Company) and is operated as a storage reservoir in a hydroelectric peaking operation. Lake Murray has a surface elevation of 110 m above mean sea level, a maximum depth of 61 m, and an average depth of 14 m. The reservoir is mesotrophic to eutrophic and has an average hydraulic retention time of 769 d. Thermal stratification in Lake Murray typically occurs between the months of March and November, and the hypolimnion is anoxic during the summer months.

Lake Murray supports a popular recreational striped bass fishery, and at least one organized striped bass tournament occurs there each month. Between July 2001 and June 2002, 14 angler-hours/ha of fishing pressure were estimated as being directed towards striped bass (Hayes and Penny 2002). Striped bass were first stocked in 1960 by the South Carolina Department of Natural Resources (SCDNR), and the fishery is currently maintained by the stocking of more than 1 million fingerlings annually. Current fishing regulations allow anglers 5 fish/d with a minimum length limit of 533 mm except during July and August, when two of the five-fish creel may be less than 533 mm.

*Study design.*—There were two components to our study. We used telemetry to determine whether fish survived angling and holding in live-release tubes. The blood chemistry of a separate group of fish was examined to profile the physiological responses of the fish to angling and holding in live-release tubes.

Striped bass were collected with angling gear during the late winter–early spring (February–April) and summer (June–August) of 2003. A local tournament angler or professional guide accompanied us on most trips. Only natural baits were used to collect fish. Live blueback herring *Alosa aestivalis* were fished on standard offset bait hooks from the surface to 12 m in depth, and cut blueback herring were occasionally fished on the bottom. For each captured striped bass, we recorded total length (TL), angling time, total handling time, depth of capture, surface water temperature, bait type, and tube residency time. We also measured the dissolved oxygen and water temperature in the live-release tube when a fish was placed in the tube and again when the fish was released. Approximately one-fourth of the fish were processed and immediately released; the remaining fish were stored in tubes for approximately 2, 4, or 6 h and then were processed and released.

Live-release tubes (Live Release Systems, Inc., Greer, South Carolina) were constructed of plastic and had outside dimensions of $1.0 \times 0.322 \times 0.322$ m (Figure 1). Inside the plastic housing, a large-diameter (203 mm) black plastic tube with a funnel at the bottom was mounted vertically. A bilge pump (3,785 L/h) was fixed to the bottom of each tube and forced water from the plastic housing up through the tube. Water exited the top of the tube through six small-diameter (26 mm) holes and cascaded down into the plastic housing, agitating the water surface and providing aeration.

Our research boat was equipped with 10 tubes that were encased in 30 mm of foam insulation. Each tube was filled with approximately 57 L of lake water, and rock salt was added to achieve a concentration of 10 g/L in each tube. During the summer, 2-L bottles of frozen water were placed in the tubes to reduce water temperature. Fish were placed headfirst into the tube to allow the water to pass through the mouth and gills.

*Survival studies.*—Angled striped bass were fit-
tube contained no additive and was processed to obtain plasma for lactate determination. The third tube contained sodium heparin and was processed to obtain plasma for osmolality and plasma sodium determination. The second tube contained potassium oxalate and was processed to obtain plasma for glucose. The first tube contained Lakes, New Jersey). Three tubes of blood were collected from each fish. The first tube contained a 21-gauge hypodermic needle fitted to a 6-mL Vacutainer tube (Becton Dickinson, Franklin Lakes, New Jersey). Three tubes of blood were collected from each fish. The first tube contained sodium heparin and was processed to obtain plasma for osmolality and plasma sodium determination. The second tube contained sodium fluoride and potassium oxalate and was processed to obtain plasma for lactate determination. The third tube contained no additive and was processed to obtain serum for cortisol determination. The first and second tubes were centrifuged immediately after collection, and the plasma was transferred to a cryotube and stored on dry ice until transfer to a laboratory freezer (±8°C). The third tube was allowed to clot in the shade at ambient temperature for 30 min before centrifugation and frozen storage.

Serum cortisol concentration was determined by means of an enzyme-linked immunosassay according to the analytical kit manufacturer’s instructions (Diagnostic Systems Laboratories, Inc., Webster, Texas) with the following modifications: Serum samples were 20 μL, and the lowest standard included in the standard curve was 0.1 μg/dL. The average correlation coefficient of the standard curves in the four runs was 0.935, and a common serum sample analyzed in each of the runs had a coefficient of variation of 28%. Plasma glucose concentration was determined on 10-μL samples by means of the glucose oxidase method according to the instructions of the analytical kit manufacturer (Pointe Scientific, Inc., Lincoln Park, Michigan). Recovery of standard additions of glucose to striped bass plasma averaged 94% by this method. Plasma lactate concentration was determined on 10-μL samples by means of the lactate oxidase–chromogen method performed according to the instructions provided by the analytical kit manufacturer (Sigma Diagnostics, Saint Louis, Missouri). Recovery of standard additions of lactate to striped bass plasma averaged 99% by this method. Osmolality of plasma was determined on 10-μL samples by means of a vapor pressure osmometer (Wescor, Inc., Logan, Utah; Model 5500). Due to clotting, a few samples could not be analyzed and are reflected in the N value reported for each characteristic.

**Statistical analysis.**—Fisher’s exact test was used to evaluate seasonal differences in survival. Logistic regression was used to model the effects of tube residence time, fish TL, depth of capture, and surface temperature on striped bass hooking mortality during the summer season. An analysis of covariance (ANCOVA) was used to compare adjusted mean spring and summer levels of glucose, osmolality, lactate, and cortisol while controlling for the effects of angling time (linear and quadratic relationships), residence time in the live-release tubes (linear and quadratic effects), TL, and depth of capture. A probability of 0.05 was used to evaluate significance. Within seasons, linear regression models were developed for each dependent variable by means of a stepwise forward
selection approach that incorporated the same co-
variates used in the ANCOVA. Variables were re-
tained if they were significant at the 0.15 level. All statistical analyses were conducted with the Statistical Analysis System (SAS Institute 1988).

Results

During the spring and summer of 2003, 59 striped bass were caught and fitted with transmitters and blood was collected from an additional 62 fish. The mean TL of tagged striped bass was 585 mm (range = 455–721 mm TL). The mean TL of striped bass used for recovery studies was 563 mm (range = 390–719 mm TL). The mean angling time was 74 s (range = 26–185 s), and the overall handling time (the time required to angle a fish and collect blood or attach a transmitter) averaged 129 s (range = 59–357 s). Water surface temperature ranged from 8°C to 16°C in spring and from 24°C to 29°C in summer; however, the summer surface water temperature during tagging ranged from 28°C to 29°C. Striped bass residence time in live-release tubes ranged from 0 to 430 min. Dissolved oxygen levels in live-release tubes averaged 6.7 mg/L (range = 5.4–8.1 mg/L). We recovered 39 of the 59 transmitters attached to striped bass during the study.

Survival Studies

During the spring, no mortality of striped bass was observed and all fish placed in live-release tubes were released alive (Table 1). Of the 14 fish fitted with temperature-sensing transmitters, two were never located and 12 were located at least once. The 12 fish survived for at least 3 d, and 10 of the 12 fish were relocated and alive after 7 d.

During the summer, overall mortality was 83%. The lowest mortality rate (73%) was observed for fish that were held in tubes for 2 h, while the highest mortality rate (100%) was observed for fish that were held in tubes for 6 h (Table 1). During the summer, 11 fish died while being held in the tubes. Of the 45 fish that were tagged and tracked, 34 fish were known to or assumed to have expired, 4 fish were never located, and 7 fish were alive at the conclusion of the study. Carcasses from 22 fish were retrieved, and 12 other fish were assumed to have expired based on lack of movement or because their transmitter temperatures were consistent with reservoir bottom temperatures.

Fish angled and released in the spring exhibited significantly greater survival than fish angled during the summer (Fisher’s exact test: $P = 0.001$). Tube residence time, fish TL, depth of capture, and surface water temperature did not significantly affect mortality of summer-caught fish (logistic regression: $P > 0.28$).

Blood Chemistry

Serum cortisol concentrations varied significantly ($P < 0.0001$, $r^2 = 0.566$, $N = 56$) among fish, ranging from a low of less than 0.1 µg/dL in a fish bled immediately after landing to 51.3 µg/dL in a fish bled after being held in a live-release tube for 243 min. Residence time in the live-release tube was the only treatment variable that elicited a significant ($P = 0.0001$) change in cortisol concentration (an increase in cortisol concentration with increasing residence time) (Table 2). A summary of the stepwise regression statistics for the four physiological characteristics measured is presented in Table 2.

Plasma glucose concentration varied significantly ($P = 0.0001$, $r^2 = 0.498$, $N = 46$) among fish, ranging from 54 mg/dL in a fish bled immediately after landing to 349 mg/dL in a fish bled after a tube residence time of 123 min. Season ($P = 0.0256$) and tube residence time ($P = 0.0001$) significantly affected plasma glucose concentration. The average glucose concentration was higher in spring than in summer, and an increase in plasma glucose level was observed with increasing residence time.

Plasma lactate concentration varied significantly among fish ($P = 0.0001$, $r^2 = 0.537$, $N = 56$). We observed plasma lactate values ranging from 12 mg/dL in a fish sampled immediately after landing to 232 mg/dL in a fish sampled after a tube residence time of 148 min. Season ($P = 0.0176$) and tube residence time ($P < 0.0001$) significantly affected plasma lactate concentration. The average plasma lactate concentration was higher in the summer than in spring, and levels increased with increasing residence time.

Plasma osmolality varied significantly among...
Season Variable  N  R²  Intercept  Angling time  Residence time  TL (mm)
Spring Glucose  24  0.555  111.8  NS  NS  1.2188  –0.0024  NS
Osmolality  24  NS  NS  NS  NS  NS  NS
Lactate  22  NS  NS  NS  NS  NS  NS
Cortisol  22  0.437  7.23  NS  NS  0.1768  –0.0003  NS
Summer Glucose  21  0.667  123.9  NS  –0.0038  1.0975  –0.00295  NS
Osmolality  21  0.693  346.6  NS  NS  0.4135  –0.0011  NS
Lactate  22  0.868  34.43  NS  NS  1.6833  –0.0046  NS
Cortisol  22  0.743  0.2168  NS  NS  0.2310  –0.0004  NS

Table 2.—Regression statistics for physiological responses by striped bass that were angled from Lake Murray, South Carolina, and then held in live-release tubes (N = number of fish sampled; NS = not significant). Residence time refers to the time held in live-release tubes. See text for details of analysis.

fish (P = 0.0001, r² = 0.323, N = 57) and ranged from 330 mmol/kg (for a fish bled immediately after landing) to 410 mmol/kg (for a fish sampled after 40 min in a live-release tube). Season (P = 0.0159) and tube residence time (P < 0.0001) significantly affected plasma osmolality. The average plasma osmolality in spring was higher than the summer average, and an initial increase of plasma osmolality was observed as residence time increased.

When the physiological responses are considered together and only in relation to residence time in live-release tubes, clear response patterns are evident (Figure 2). In spring and summer, significant nonlinear relationships were observed for cortisol, glucose, and lactate. Osmolality was significantly related to tube residence time during summer. In all four cases, responses characteristic of physiological stress continued for about 150 min and then began to return to normal.

Discussion

Season was the only variable that significantly affected survival. Summer mortality of striped bass was significantly greater than spring mortality; this result was probably caused by the warmer water temperatures present during the summer season. Summer surface water temperatures (28–29°C) during tagging were higher than the reported thermal tolerances of striped bass (Merriman 1941). In a review of striped bass hooking mortality studies, Wilde et al. (2000) found that water temperature was positively related to mortality. Although we expected to see greater mortality during the summer than during spring, the observed summer mortality rate (83%) was higher than that reported for other southeastern reservoirs. In Tim’s Ford Reservoir, Tennessee, the summer (July–August) mortality rate was 67% (Bettoli and Osborne 1998). In Lake Texoma, Texas–Oklahoma, spring and summer mortality rates were 70% and 47%, respectively (Hysmith et al. 1994). Higher mortality rates in Lake Murray striped bass may have been related to the exclusive use of live bait during angling. Use of natural baits instead of artificial baits has been reported to increase hooking mortality (Harrell 1988; Hysmith et al. 1994), particularly when striped bass are angled from warm water (Wilde et al. 2000).

Although water temperature was probably the underlying variable that explained the higher mortality in summer than in spring, summer surface water temperature did not explain survival of summer-caught striped bass. Minimal variation (28–29°C) in surface water temperature at the time of tagging greatly reduced the predictive power of this variable during the summer treatment.

Serum cortisol concentrations observed in this study were comparable to other serum cortisol values reported for striped bass (Young and Cech 1993; Cech et al. 1996; Tomasso et al. 1996). Significant increases in serum cortisol levels concomitant with increasing residence time in live-release tubes indicate a stress response. Elevated serum cortisol concentrations are a primary stress response in vertebrates, and cortisol in fishes has been shown to increase in response to a number of stressors (Barton and Iwama 1991). The fish in our study did not demonstrate a significant increase in serum cortisol concentration in response to angling time, probably because most fish (88%) were angled for less than 120 s. Previous work (Tomasso et al. 1996) showed that about 180 s of angling are required before increases in serum cortisol levels in striped bass are observed.

Plasma glucose concentrations observed in this study were similar to other reported plasma glucose values for striped bass (Hopkins and Cech 1992; Cech et al. 1996; Tomasso et al. 1996). We observed higher plasma glucose levels for fish cap-
FIGURE 2.—Relation of hematological characteristics (y) to residence time (x) for striped bass angled from Lake Murray, South Carolina. Spring-caught fish are represented by solid circles; summer-caught fish are represented by open circles. Regression equations and \( r^2 \) values are as follows: cortisol (spring): \( y = -0.0003x^2 + 0.172x + 7.296 \) (\( r^2 = 0.46 \)); cortisol (summer): \( y = \frac{-0.0005x^2 + 0.259x - 0.169}{r^2 = 0.65} \); glucose (spring): \( y = -0.0024x^2 + 1.118x + 116.05 \) (\( r^2 = 0.35 \)); glucose (summer): \( y = -0.0024x^2 + 0.989x + 102.78 \) (\( r^2 = 0.50 \)); lactate (spring): \( y = -0.0012x^2 + 0.498x + 57.33 \) (\( r^2 = 0.24 \)); lactate (summer): \( y = -0.0039x^2 + 1.511x + 37.292 \) (\( r^2 = 0.74 \)); and osmolality (summer): \( y = -0.0009x^2 + 0.359x + 347.80 \) (\( r^2 = 0.56 \)).
stress response. However, the decrease in plasma lactate concentration indicates a return to aerobiosis, which is generally associated with recovery from handling-associated stress. The apparent physiological recovery of the summer-caught fish was inconsistent with the observed 83% mortality after release and indicates that other factors should be considered. Fatigue, over-inflated swim bladders, and perhaps gas bubble disease are factors that should be carefully considered in examining the inability of the fish to return to capture depth (and acclimation temperature).

Management Implications

Based on the observations in this study, live-release tubes show promise as a means of keeping striped bass alive until weigh-in during cool water (surface water temperature ≤16°C) tournaments and allowing anglers to cull live fish. However, the tubes do not appear to be effective when fish are angled from warm water. Perhaps combining live-release tubes with a means to return the fish to depth would prove effective during warmwater tournaments. Further research is needed to determine a suitable range of temperatures where the live-release tubes can be used with confidence. Future research should also consider the survival of large striped bass. Our study was limited to fish less than 722 mm, and 90% of study fish were less than 660 mm.

The results of our study also demonstrate the need for more restrictive regulations for the Lake Murray striped bass fishery during the summer months. Current creel and length restrictions are probably ineffective during the summer, given the high postrelease mortality. Fishery managers should consider reducing the summer mortality of striped bass by implementing a moratorium on striped bass fishing during July and August of each year. An alternate approach would be to prohibit anglers from releasing fish during the summer months (Bettoli and Osborne 1998), allowing anglers to keep every fish regardless of length until the five-fish creel limit is reached.

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