

Reduced Swimming Performance of Striped Bass after Confinement Stress

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Abstract.—Length of confinement in a dip net affected subsequent performance of 2–3-year-old striped bass *Morone saxatilis* in a swimming challenge. Fish that were not confined or were confined for only 5 min could consistently swim for 10 min at 100 cm/s, whereas fish confined for longer than 15 min often could not. Average swimming time was significantly less for striped bass confined for 15 min or longer than for unconfined controls. Plasma cortisol, glucose, and lactate concentrations were always higher in fish after a swimming challenge than in resting fish sampled from the holding tank, although length of net confinement before swimming had little effect on postchallenge plasma variables. Time of postchallenge blood sampling, however, had a significant effect on all three plasma variables: glucose and cortisol concentrations were higher in striped bass immediately after they were removed from the swimming chamber, whereas lactate concentration was higher after 45 min of recovery. Resting and stress levels of the plasma variables resembled those measured in other fishes, except for the extremely large and rapid rise in plasma cortisol concentration from less than 50 ng/mL in resting fish to over 500 ng/mL in fish that had swum for 10 min.

Culture and management practices often require the handling and confinement of fish, a procedure which, if too stressful, may be lethal (see review by Parker 1984). If the fish do not die, however, the extent to which their future performance may be compromised is unknown. Three physiological changes routinely found in stressed fish are the elevations of plasma cortisol, glucose, and lactate concentrations (e.g., Nikinmaa et al. 1984; Woodward and Strange 1987). The question then arises whether such changes indicate some sublethal but deleterious effect, or simply reflect successful accommodation to the stressor that carries no measurable future cost.

To address the problem of evaluating sublethal stress in fish, Wedemeyer and McLeay (1981) described the concept of the challenge test. This requires a sequence of two different stressors, the second one being amplified by the effect on the fish of the first. Although rainbow trout *Oncorhynchus mykiss* had a greater cortisol response to confinement if they had previously been exposed to acidic conditions (Barton et al. 1985), they showed no empirical evidence of reduced performance. According to Wedemeyer and McLeay (1981), appropriate challenges include a first stressor that mimics the procedure being evaluated and a second stressor (challenge) that has an

empirically discernible endpoint of recognized adaptive significance. Our objective was to evaluate the effect of net confinement on striped bass *Morone saxatilis* in a test with a meaningful challenge (high-speed swimming) while making physiological measurements helpful in defining the stress level.

Methods

Two- and 3-year-old striped bass (500–1,600 g live weight) from the California Department of Fish and Game's Central Valleys Hatchery were raised at the Department of Wildlife and Fisheries Biology, University of California, Davis. This study was performed during the summers of 1988 and 1989. Although the weight of the fish varied considerably, analysis of variance (ANOVA) showed no significant difference in average weight of striped bass used in 1988 or 1989 ($P = 0.82$). Fish were held in aerated, 510-L fiberglass tanks supplied with flowing, nonchlorinated, air-equilibrated well water at 25°C. Fish were subjected to an initial stress by confining them in a rectangular (40 × 25 cm) 30-cm-deep dip net submerged just below the surface of the water; the water was vigorously aerated beneath the net. The depth of the net was adjusted to yield a comparable degree of

confinement to varying sizes of fish. Striped bass were confined for 5, 15, 25, or 35 min.

After net confinement, fish were subjected to a swimming challenge by being placed in a 34-cm-diameter, clear acrylic swimming chamber equipped with a variable-speed motor-impeller assembly. The swimming apparatus was calibrated by relating water velocity measured in the swimming chamber by a electromagnetic flow meter to motor shaft speed measured by a variable-frequency stroboscopic light. After a few seconds of low water velocity that allowed the fish to become oriented, velocity was increased to 100 cm/s. Each fish remained in the chamber for 10 min or until it failed to swim against the current. Control fish (0-min initial stress) were not confined in the net, but were placed directly into the swimming chamber. Cross-sectional area of each fish was less than 10% of the area of the swimming chamber; thus, no swimming velocity correction was needed (Beamish 1978). In the summer of 1988, 20 fish (4 from each confinement period or treatment group) were challenged. In the summer of 1989, 40 fish (8 from each treatment group) were challenged.

Timing of blood sampling differed between years. In 1988, blood samples were taken 45 min after the swimming challenge, while the fish recovered in water containing 10‰ NaCl. Also in 1988, four fish were bled immediately after being removed from the holding tank to provide resting values. In 1989, blood samples were taken immediately after fish were removed from the swimming tank. Samples were obtained by cardiac puncture with a heparinized syringe. After hematocrit values were obtained (1989 only), remaining blood was centrifuged and the plasma was withdrawn and frozen until further analysis. Lactate and glucose concentrations in the thawed plasma were measured with a calibrated analyzer. Plasma cortisol concentration was determined at the University of Tennessee by "Coat-A-Count" radioimmunoassay from Diagnostic Products Corporation. The assay used ^{125}I -labeled cortisol to determine percent binding over a range of standards of 0.25–12.50 ng/tube. Depending on cortisol concentration, either 5 or 25 μL of plasma were assayed per tube. An internal standard of pooled striped bass plasma was run with each of five assays and yielded a mean of 253 ng/mL and an SE of 16. Cross-reactivity with other naturally occurring steroids was less than 1.5%. Statistical differences were determined by ANOVA and analysis of covariance (ANCOVA).

Results

Net-confinement time affected subsequent performance in the swimming challenge (Figure 1). Fish were treated exactly the same way both years in this portion of the study and there was no significant difference between years (ANOVA, $P = 0.239$). Striped bass that were not confined (controls) or confined for only 5 min could consistently meet the challenge (swim at 100 cm/s for 10 min) whereas fish confined for 25 or 35 min often could not. Average swimming time fell to about 7 min after 15 min confinement in the net and to less than 6 min for the longer confinement periods (Figure 1).

Data from both years analyzed together indicate a significant (ANOVA, $P = 0.058$) effect of length of confinement on swimming time; fish confined for 15 min or longer swam for a shorter time than unconfined controls. After the longer confinements, individual performances varied widely: some fish met the 10-min challenge and others failed after only a few seconds in the chamber. Regression analysis revealed no relationship between weight (wt) of fish and swimming time (y): $y = -0.003 \text{ wt} + 10.2$; $r^2 = 0.059$; slope was not significantly different from 0, $P = 0.063$.

All three plasma constituents (cortisol, glucose, and lactate) were significantly ($P < 0.05$) higher in striped bass after the swimming challenge than in resting fish sampled from the holding tank (Figure 1). Plasma cortisol concentration increased from 45 ng/mL in unstressed animals to between 500 and 800 ng/mL immediately after the swimming challenge. Striped bass sampled during the recovery period (45 min postchallenge) had significantly (ANCOVA, $P < 0.001$) lower plasma cortisol than fish bled on removal from the chamber. Longer confinement before the challenge test tended to result in slightly higher plasma cortisol concentrations in fish sampled immediately after swimming, though this effect was not significant (ANCOVA, $P = 0.238$).

Plasma glucose increased from 75 mg/dL in animals in the holding tank to between 150 to 300 mg/dL in fish after swimming. There was a significant (ANCOVA, $P = 0.029$) effect of time of blood sampling on glucose concentration: glucose was higher in fish bled immediately after removal from the chamber than after 45 min recovery in three out of five treatments. Length of confinement had a significant effect only on fish bled immediately after removal from the chamber; longer confinement (25 min and 35 min) resulted in sig-

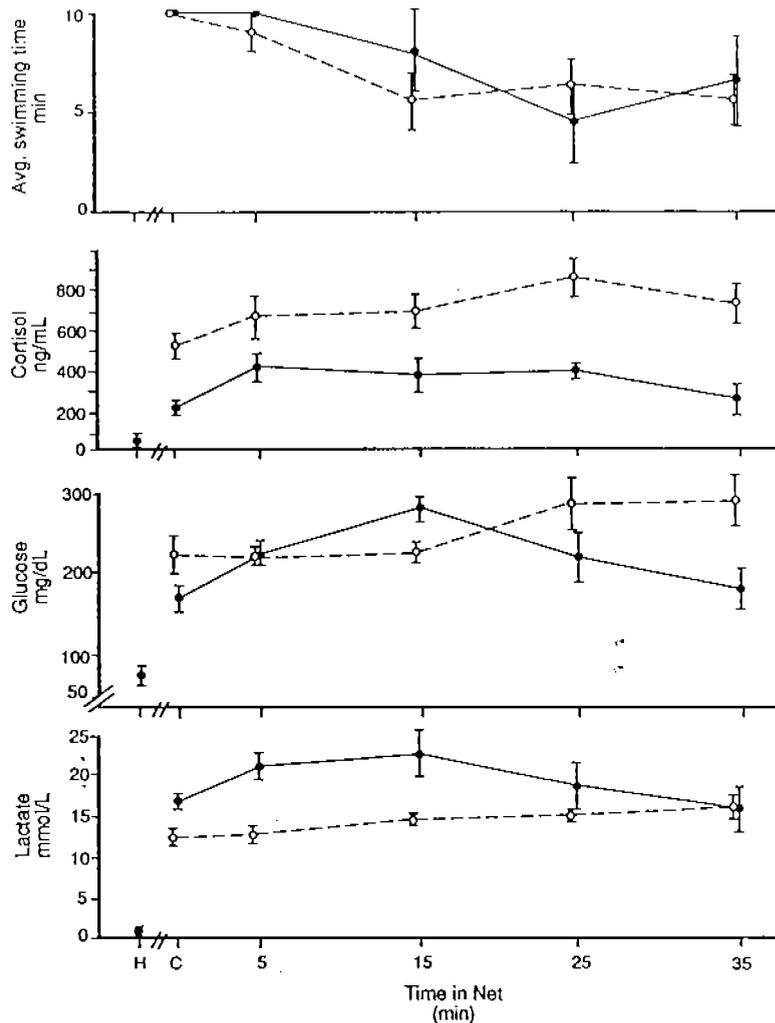


FIGURE 1.—Average swimming time and plasma cortisol, glucose, and lactate concentrations in striped bass confined for different times in a dip net and then challenged by forced swimming at a 100-cm/s water velocity. H indicates fish sampled directly from the holding tank and C indicates controls that were not confined before swimming. Solid circles represent 1988 fish sampled for blood 45 min after they were removed from the swimming chamber (mean \pm SE, $N = 4$). Open circles represent 1989 fish sampled for blood immediately after they were removed from the swimming chamber (mean \pm SE, $N = 8$).

nificantly higher glucose levels (ANCOVA, $P = 0.031$).

Plasma lactate concentration increased from 0.6 mmol/L in resting striped bass to between 10 and 25 mmol/L in fish after the challenge. Lactate concentration was consistently higher in fish bled 45 min after removal from the chamber than in those bled immediately (significantly different by ANCOVA, $P < 0.001$) except for fish subjected to the longest net confinement (35 min). Length of confinement appeared to have little effect on lactate

concentration measured immediately after swimming.

Hematocrit (mean % with SE) measured immediately after swimming tended to increase with longer confinement (min):

Confinement (min)	Hematocrit (%)
0	30.8 (3.4)
5	31.5 (3.1)
15	33.6 (0.9)
25	33.0 (2.0)
35	34.3 (4.4)

Discussion

We found a dose-dependent relationship between initial confinement and subsequent swimming performance for striped bass (Figure 1). Fish that were not subjected to confinement, or confined only 5 min, almost always swam the full 10 min at 100 cm/s. For our fish, this water velocity approximated the 3.3 and 2.9 body lengths/s that Freadman (1979) determined as the maximum sustainable swimming speed for striped bass forced to swim for 30 and 45 min, respectively. Thus, it is not surprising that our unstressed fish had little problem swimming at that rate for 10 min, although the appearance of lactate in the plasma indicated that white muscle was being used (Roberts and Graham 1979).

Striped bass confined for 25 min or longer were unable to meet the swimming challenge consistently. We suspect that prolonged net confinement increased maintenance metabolic demands and decreased active metabolic capacity (see reviews by Fry 1971 and Brett and Groves 1979). We conclude that slight handling stress equivalent to 5 min or less of confinement does not impair the ability of striped bass to swim at high speed, whereas stress equivalent to confinement of 25 min or longer does compromise high-speed swimming.

Plasma cortisol concentration in striped bass from the holding tank (45 ng/mL) was comparable to the range of 10–60 ng/mL measured in adult striped bass collected by electrofishing from fresh water (Tisa et al. 1983). Plasma cortisol measured in our striped bass immediately after removal from the swimming chamber showed a slight, though not statistically significant, increase with longer confinement. Striped bass confined for 25 min and bled immediately after removal from the swimming chamber had a mean plasma cortisol concentration of 860 ng/mL. Fingerling striped bass subjected to transport in freshwater had concentrations of about 1,000 ng/mL after 3 h (Mazik et al. 1991).

Plasma glucose concentration of striped bass in our holding tank (75 mg/dL) was slightly lower than concentrations reported for freshwater striped bass collected from the wild (80–120 mg/dL; Tisa et al. 1983). After confinement and swimming, our striped bass had plasma glucose concentrations in the range of 200–300 mg/dL, which is similar to the concentrations Mazik et al. (1991) reported from fingerling striped bass after pond harvest and a few hours into transport. Length of

confinement before swimming had a significant effect on plasma glucose only in samples we took immediately after swimming ended and then only with the longest confinement times (25 and 35 min). This may be due to the time (e.g., >30 min in channel catfish; Strange 1980) necessary for hyperglycemia to appear after the onset of stress.

Mean plasma lactate concentration before our 10-min swimming challenge (0.6 mmol/L) was similar to resting mean blood lactate concentration measured in cannulated striped bass (Nikinmaa et al. 1984). Swimming time appears to influence lactate concentrations in this species because Nikinmaa et al. (1984) measured 8.2 mmol/L lactate in striped bass blood after 5 min of vigorous exercise, and we measured 12.2–23.3 mmol/L lactate in the plasma after net confinement and 10 min of vigorous swimming. On the other hand, we did not find length of confinement to have a significant effect on lactate concentration. Presumably, lactate was produced primarily as a consequence of swimming rather than of net-confined struggling. The slight decrease in lactate seen in fish bled during recovery at longer confinement times may be related to their lower mean swimming time.

Timing of the blood sampling influenced the blood characteristics; cortisol was higher immediately after fish were removed from the swimming chamber than after 45 min of recovery, whereas lactate was higher after 45 min. These findings probably resulted from the rapid secretion of cortisol from interrenal tissue into the blood of the closely associated posterior cardinal veins, whereas lactate must diffuse into the blood from the poorly vascularized white muscle (Bone 1978; Groman 1982). Cortisol was lower after 45 min of recovery than immediately after fish were removed from the swimming chamber even though the recovery took place in 10‰ NaCl. This concentration of salt has been shown to increase plasma cortisol in striped bass (Davis et al. 1982).

Finally, as a practical conclusion of our study, we suggest that fisheries managers take care not to introduce striped bass into situations that require fast swimming after handling stress of over 5 min.

Acknowledgments

We acknowledge the University of Tennessee and the University of California Agricultural Experiment Stations (grant 3455-H) and the California Department of Fish and Game (contract C-1733 to J.J.C.) for research support. We thank

R. Petric for technical assistance with the cortisol assay, which was performed in the laboratory of H. Kattesh, Department of Animal Science, University of Tennessee. We also thank K. Hashagen and M. Cochran of the California Department of Fish and Game for striped bass, and W. Berg and A. Heath for critical readings of the manuscript.

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Received January 14, 1991

Accepted August 29, 1991