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[Management Brief]

Swimming Performance of Brook Trout after Simulated Catch-and-Release Angling: Looking for Air Exposure Thresholds

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Abstract.—Air exposure has been hypothesized as one of the primary stressors present during catch-and-release angling. However, there are few studies that systematically vary air exposure duration and evaluate the consequences on individual fish. Here, we evaluated the short-term, sublethal effects of exercise (to simulate angling) and air exposure on the swimming performance of hatchery brook trout *Salvelinus fontinalis* at 10°C. The duration of the angling event (i.e., chasing the fish by hand) was held constant at 30 s, while air exposure duration was systematically varied between 0, 30, 60, and 120 s. The results showed that air exposures of 60 s or less did not affect swimming performance. However, air exposure of 120 s resulted in a dramatic (~75%) reduction in swimming performance. In fact, nearly half of the fish held out of the water for 120 s were unwilling or unable to swim at all. No mortality was observed after any of the treatments (fish were monitored for 3 months). This work suggests that fish possess air exposure thresholds that, once exceeded, result in performance impairments. Fish released after extended air exposure may become easy prey for predators or could be displaced downstream by flows in fluvial environments. We conclude that air exposure should be restricted to less than 60 s and ideally should be avoided entirely.

The fate and condition of fish that are angled and released is an important consideration in recreational fisheries due to the widespread practice of catch-and-release angling (Policansky 2002; Cooke and Cowx 2004). Although mortality, both acute and delayed, is an obvious indicator of the failure or success of this practice (Muoneke and Childress 1994), it is also important to determine the sublethal effects on fish that survive. Sublethal effects include physical injury, physiological disturbance, behavioral alterations, and fitness impairments (Cooke et al. 2002a). The primary goal of research on this topic is to develop angling guidelines that attempt to minimize mortality and the sublethal consequences of catch-and-release angling (Wydoski 1977; Muoneke and Childress 1994; Cooke and Suski 2005). One guideline that is consistently identified as being important is the need to minimize air exposure duration (Cooke and Suski 2005). Air exposure occurs after capture when anglers are handling the fish in an attempt to remove the hook(s) or to admire or photograph the fish. Interestingly, the amount of research on air exposure is rather scarce relative to other topics, such as gear type (e.g., circle hooks, barbless hooks), duration of angling events, and angling at high water temperatures. Anglers and fisheries managers are looking to researchers to provide more information on the duration of air exposure that generates substantial sublethal effects and/or leads to mortality.

To date, research on this topic has revealed that significant physiological disturbances (i.e., extracellular acidosis, buildup of metabolites, cardiovascular alterations, reductions in gas exchange) and physical damage (i.e., collapse and adhesion of gill filaments) can occur even from short durations of air exposure (Ferguson and Tufts 1992; Cooke et al. 2001, 2002b; Suski et al. 2004). A consistent finding in these studies is that the effects of air exposure are additive and that lengthier air exposure tends to result in longer recovery periods. There is a need, however, for more research that attempts to identify thresholds for air exposure by means of ecologically relevant sublethal endpoints for various species. In this study, we assessed the effects of different air exposure durations on the swimming performance of hatchery brook trout *Salvelinus fontinalis*. Swimming performance is a sensitive indicator of overall organismal health and physiological condition. It is also ecologically relevant (Hammer 1995; Plaut 2001) for a fluvial species such as brook trout, because swimming is essential for evasion of predators,

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acquisition of prey, migration, and maintenance of position in flows. Because air exposure results in an increased oxygen debt and physiological disturbance, we hypothesized that as the duration of air exposure was increased, swimming performance would decrease.

Methods

Twelve hatchery brook trout from the Canton Fish Farm at the Cooperative Extension Learning Center in Canton, New York, were transported to a laboratory at the State University of New York at Potsdam in February of 2005. The fish (fork length mean ± SD: 27.2 ± 1.8 cm) were held in an 800-L tank (274 cm long × 61 cm wide × 56 cm deep) equipped with a chiller and foam and charcoal filters (Frigid Units, Inc., Toledo, Ohio; LS-900 living stream system). Temperature was held constant at 10°C, and approximately 20% of the water was replaced daily. The foam filter was cleaned daily, and the charcoal filter was cleaned every 2 weeks. The water was salted (Aquarium Pharmaceuticals, Inc., Chalfont, Pennsylvania; Doc Wellfish's aquarium salt for freshwater fish) for maintenance purposes every week at a concentration of 0.2%. Fish were fed approximately 25 g of floating fish pellets (Zeigler Bros, Inc., Gardner, Pennsylvania; 5.0-mm Silver floating pellets) to satiation every other day. Ammonia concentration was measured twice per week.

Each fish was subjected to weekly experiments and was fasted for approximately 24 h prior to treatment. All fish were exposed to all treatments (i.e., repeated measure). The type of treatment a fish was exposed to was selected randomly without replacement. Individual fish were allowed to recover for 1 week before being subjected to further experimentation. Repeated sampling of individual fish across all treatments has been shown to be statistically rigorous in swimming performance studies because performance is highly repeatable for a given individual (Kolok 1992). Thus, it is possible to conduct direct comparisons of an individual's performance after exposure to different stressors to assess whether the stressors cause an alteration in swimming performance. In fact, this method is now the preferred approach for swimming performance studies that involve comparison of different treatments (Kolok 1999). This type of swimming protocol is not effective for training fish (Davison 1997), so it can be used for repeated challenges. To simulate angling, we chased fish by hand in a 40-L container for 30 s; this approach is frequently used for catch-and-release research (Kieffer 2000; Cooke et al. 2001; Suski et al. 2004). Thirty seconds is a fairly short angling duration but would be a typical fight duration for brook trout of the size used in this study. While being chased, fish exhibited several rapid bursts of activity and typically became much less active toward the end of the angling simulation. Fish were then held out of the water in a knotless nylon net (Barthel et al. 2003) for 0, 30, 60, or 120 s. Air temperature was 22°C. After the simulated angling and the air exposure treatment, fish were immediately placed in a 60-L Blazka-type respirometer (Blazka et al. 1960). Velocity was held at 0 cm/s during the fish's first 5 min in the swim tube so that the end cap could be bolted into place. After that, fish were immediately exposed to a critical swimming challenge, which provided information on the maximum aerobic capacity (McDonald et al. 1998) of brook trout after exposure to different stressors.

To quantify swimming performance, we increased the velocity in the swim tube by 10 cm/s every 600 s until the fish was exhausted (i.e., after repeated efforts, the fish could no longer swim off the back screen of the swim tube; Beamish 1978). The critical swimming speed (cm/s; Brett 1964) for each trial was calculated as $U_{\mathrm{crit}} = V_p + [(t_f/t_i) \times V_i]$, where V_p = the highest velocity reached (cm/s), t_f = the elapsed time (s) for which the fish swam at the fatigue velocity, t_i = the time (s) between velocity increments, and V_i = the velocity increment (cm/s). To test for difference across the four treatments, we compared individual U_{crit} values by use of a repeated-measures analysis of variance (ANOVA) in version 9 of SYSTAT (Systat 1992). Because there is no post hoc test for repeated-measures ANOVA, a second repeated-measures ANOVA was conducted on just the 0-, 30-, and 60-s treatments. For all tests, the significance level α was equal to 0.05. To assess mortality, we monitored fish for 3 months after the final experimentation.

Results and Discussion

Consistent with our hypothesis, increasing air exposure resulted in poorer swimming performance by brook trout ($P < 0.001$, Figure 1). However, the trend was not linear. Fish held out of the water for 30 or 60 s had similar swimming performance to control fish that were not exposed to air (repeated-measures ANOVA conducted on 0-, 30-, and 60-s treatments only: $P = 0.203$). It was only at 120 s of air exposure that swimming performance decreased. This decrease was dramatic:

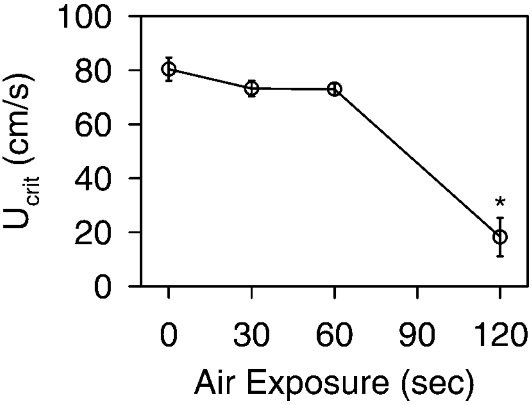

FIGURE 1.—Swimming performance, measured as critical swimming speed (U_{crit}; mean ± SE), of brook trout chased by hand for 30 s and subjected to 0-, 30-, 60-, and 120-s air exposures. The asterisk indicates a significant difference. The duration of air exposure had a significant effect on swimming performance ($P < 0.001$). However, only the 120-s treatment showed a significant decrease ($P < 0.001$). The 30- and 60-s treatments were not significantly different than controls when the 120-s treatment was removed from the analysis.

fish exposed to air for 120 s had an average U_{crit} value of less than 20 cm/s, while all other groups had average values greater than 70 cm/s. In fact, nearly half of the fish in the 120-s treatment were unwilling or unable to swim at all after air exposure. This is not the first documented instance of impaired swimming performance subsequent to air exposure. Mitton and McDonald (1988) exposed rainbow trout *Oncorhynchus mykiss* to exercise, electrofishing shock, and different air exposure durations (range = 0–4 min). Those authors reported that increasing durations of postelectroshock air exposure caused swimming impairments that were progressively prolonged and that ranged from 1 to 6 h. Swimming performance is an ecologically relevant endpoint for the assessment of sublethal effects because it depends upon the coordinated integration of multiple organ systems and biological processes and is essential for predator avoidance, foraging activity, selection of appropriate habitats, maintenance of position in a fluvial environment, and general movement and activity (Hammer 1995; Plaut 2001).

Other research on air exposure has revealed that sublethal physiological disturbances can be substantial. For example, Ferguson and Tufts (1992) have shown that rainbow trout exposed to air for 60 s after exhaustive exercise had much larger extracellular acidosis and blood lactate concentrations than fish that were only exercised. The physiological cause of these findings is the collapse and adhesion of gill filaments during air exposure and consequent reduction of oxygen uptake (Ferguson and Tufts 1992). More recent research on rock bass *Ambloplites rupestris* (Cooke et al. 2001) and smallmouth bass *Micropterus dolomieu* (Cooke et al. 2002b) has identified that longer air exposure periods (120 s) translate into prolonged cardiovascular disturbance relative to little (30 s) or no air exposure. Suski et al. (2004) determined that air exposure caused significant accumulation of metabolites and significant reductions in tissue energy stores in the white muscle of largemouth bass *M. salmoides*.

Although our research focused on sublethal alterations, when air exposure duration or the combined stress of other factors (e.g., water temperature and exercise) exceeds some threshold, mortality is inevitable. In our study, no mortality was observed over a period of 3 months. The absence of mortality suggests that at 10°C, brook trout can tolerate and compensate for oxygen debt and other physiological disturbances within a range of air exposure durations up to 120 s. However, in our study, brook trout were held in a laboratory setting and were not exposed to predators or displaced into regions with potentially suboptimal environmental conditions. Furthermore, the water temperature used in our study (10°C) was also well below any thermal conditions that would have magnified the stress or mortality potential (e.g., Hyndman et al. 2003). Although the angling duration used in our study was short (30 s), it constituted a typical fight duration for brook trout of the size under study. Other research has noted mortality as a result of air exposure. For example, survival of rainbow trout decreased from 88% for exercised fish to 62% and 28% for fish that were exercised and exposed to air for 30 and 60 s, respectively (Ferguson and Tufts 1992). It is important to note that those fish were cannulated, which may have inflated mortality values. In a field-based study, Cooke and Philipp (2004) noted that bonefishes *Albula* spp. exposed to longer handling and air exposure durations were more likely to have problems maintaining equilibrium and were susceptible to shark (family Carcharhinidae) predation.

From a management perspective, our findings indicate that catch-and-release angling is an effective management tool for brook trout, but only under specific conditions (e.g., when air exposure is 60 s or less and water temperature is 10°C). To date, no studies have systematically varied air exposure duration and water temperature to evaluate the interaction of these factors. We have several suggestions for minimizing air exposure times. First, anglers can chose gear and bait that promote shallow hooking and easy hook removal. For example, research has revealed that the use of barbed hooks can delay hook removal and extend air exposure relative to use of barbless hooks (Cooke et al. 2001; DuBois and Dubielzig 2004; Meka 2004). Similarly, use of conventional J-style hooks tends to result in deeper hooking relative to circle hooks, and deeper hooking can affect air exposure duration (Cooke and Suski 2004; Meka 2004). Finally, use of organic bait can lead to deeper hooking, which also requires longer air exposure to remove the hook relative to flies or artificial lures (e.g., Muoneke and Childress 1994; Cooke et al. 2001).

Anglers must be prepared with pliers and hemostats to ensure rapid removal of hooks from fish that will be released. Photographs should be taken quickly so as to avoid prolonged air exposure. Most of these activities (hook removal, holding prior to photographing) can be accomplished with the fish held in water, thus completely eliminating air exposure, which should be the goal for all anglers who want to successfully release their catch. However, there will always be instances where air exposure is prolonged; some threshold may therefore be exceeded, resulting in permanent tissue damage or mortality. For catch and release to be an effective management tool (i.e., minimize mortality) and to maintain fish welfare (i.e., minimize sublethal effects), we need a better understanding of air exposure thresholds and how they are influenced by other factors (e.g., water temperature, degree of exhaustion; Wood et al. 1983). We suggest that swimming performance may serve as a useful and ecologically meaningful endpoint for determining these thresholds. Indeed, for brook trout, it was quite evident that when air exposure reached 120 s, the fish exhibited significant performance impairments.

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References

Barthel, B. L., S. J. Cooke, C. D. Suski, and D. P. Philipp. 2003. Effects of landing net mesh type on injury and mortality in a freshwater recreational fishery. Fisheries Research 63:275–282.

Beamish, F. W. H. 1978. Swimming capacity. Pages 101–187 *in* W. S. Hoar and D. J. Randall, editors. Fish physiology, volume 7. Academic Press, New York.

Blazka, P., M. Volf, and M. Cepela. 1960. A new type of respirometer for the determination of the metabolism of fish in an active state. Physiologia Bohemoslovaca 9:553–558.

Brett, J. R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. Journal of the Fisheries Research Board of Canada 21: 1183–1226.

Cooke, S. J., and I. G. Cowx. 2004. The role of recreational fisheries in global fish crises. BioScience 54:857–859.

Cooke, S. J., and D. P. Philipp. 2004. Behavior and mortality of caught-and-released bonefish (*Albula* spp.) in Bahamian waters with implications for a sustainable recreational fishery. Biological Conservation 118:599–607.

Cooke, S. J., D. P. Philipp, K. M. Dunmall, and J. F. Schreer. 2001. The influence of terminal tackle on physical injury, handling time, and cardiac disturbance of rock bass. North American Journal of Fisheries Management 21:333–342.

Cooke, S. J., J. F. Schreer, K. M. Dunmall, and D. P. Philipp. 2002a. Strategies for quantifying sublethal effects of marine catch-and-release angling: insights from novel freshwater applications. Pages 121–134 *in* J. A. Lucy and A. L. Studholme, editors. Catch and release in marine recreational fisheries. American Fisheries Society, Symposium 30, Bethesda, Maryland.

Cooke, S. J., J. F. Schreer, D. H. Wahl, and D. P. Philipp. 2002b. Physiological impacts of catch-and-release angling practices on largemouth bass and smallmouth bass. Pages 489–512 *in* D. P. Philipp and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Cooke, S. J., and C. D. Suski. 2004. Are circle hooks effective tools for conserving freshwater and marine recreational catch-and-release fisheries? Aquatic Conservation: Marine and Freshwater Ecosystems 14:299–326.

Cooke, S. J., and C. D. Suski. 2005. Do we need species-specific guidelines for catch-and-release recreational angling to conserve diverse fishery resources? Biodiversity and Conservation 14:1195–1209.

Davison, W. 1997. The effects of exercise training on teleost fish: a review of recent literature. Comparative Biochemistry and Physiology 117A:67–75.

DuBois, R. B., and R. R. Dubielzig. 2004. Effect of hook type on mortality, trauma, and capture efficiency of wild stream trout caught by angling with spinners. North American Journal of Fisheries Management 24:609–616.

Ferguson, R. A., and B. L. Tufts. 1992. Physiological effects of brief air exposure in exhaustively exercised rainbow trout (*Oncorhynchus mykiss*): implications for ''catch and release'' fisheries. Canadian Journal of Fisheries and Aquatic Sciences 49:1157–1162.

Hammer, C. 1995. Fatigue and exercise tests with fish. Comparative Biochemistry and Physiology 112A: 1–20.

Hyndman, C. A., J. D. Kieffer, and T. J. Benfey. 2003. Physiology and survival of triploid brook trout following exhaustive exercise in warm water. Aquaculture 221(1–4):629–643.

Kieffer, J. D. 2000. Limits to exhaustive exercise in fish. Comparative Biochemistry and Physiology 126A: 161–179.

Kolok, A. S. 1992. The swimming performances of individual largemouth bass (*Micropterus salmoides*) are repeatable. Journal of Experimental Biology 170:265–270.

Kolok, A. S. 1999. Interindividual variation in the prolonged locomotor performance of ectothermic vertebrates: a comparison of fish and herpetofaunal methodologies and a brief review of the recent fish literature. Canadian Journal of Fisheries and Aquatic Sciences 56:700–710.

McDonald, D. G., W. J. McFarlane, and C. L. Milligan. 1998. Anaerobic capacity and swim performance of juvenile salmonids. Canadian Journal of Fisheries and Aquatic Sciences 55:1198–1207.

Meka, J. M. 2004. The influence of hook type, angler experience, and fish size on injury rates and the duration of capture in an Alaskan catch-and-release rainbow trout fishery. North American Journal of Fisheries Management 24:1309–1321.

Mitton, C. J. A., and D. G. McDonald. 1994. Effects of electroshock, air exposure, and forced exercise on swim performance in rainbow trout (*Oncorhynchus mykiss*). Canadian Journal of Fisheries and Aquatic Sciences 51:1799–1803.

Muoneke, M. I., and W. M. Childress. 1994. Hooking mortality: a review for recreational fisheries. Review of Fisheries Science 2:123–156.

Plaut, I. 2001. Critical swimming speed: its ecological relevance. Comparative Biochemistry and Physiology 131A:41–50.

Policansky, D. 2002. Catch-and-release recreational fishing: a historical perspective. Pages 74–94 *in* T. J. Pitcher and C. E. Hollingworth, editors. Recreational fisheries: ecological, economic, and social evaluation. Blackwell Scientific Publications, Oxford, UK.

Suski, C. D., S. S. Killen, S. J. Cooke, J. D. Kieffer, D. P. Philipp, and B. L. Tufts. 2004. Physiological significance of the weigh-in during live-release angling tournaments for largemouth bass. Transactions of the American Fisheries Society 133:1291–1303.

Systat. 1992. SYSTAT for Windows statistics, version 5 edition. Systat, Inc., Evanston, Illinois.

Wood, C. M., J. D. Turner, and M. S. Graham. 1983. Why do fish die after severe exercise? Journal of Fish Biology 22:189–201.

Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43–87 *in* R. A. Barnhart and T. D. Roelofs, editors. Catch-and-release fishing as a management tool. Humboldt State University, Arcata, California.