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Simulated Thermal Tempering Versus Sudden Temperature Change and Short-Term Survival of Fingerling Rainbow Trout

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Abstract.—We examined the effects of thermal shock on poststocking survival of fingerling rainbow trout *Oncorhynchus mykiss* (mean total length, 99 mm; mean weight, 10 g), some of which were thermally tempered at stocking and others not. In one experiment we assessed survival when fish experienced increases in water temperature from 8°C to 24°C at two tempering rates (4°C/h and 8°C/h) and by an immediate transfer. In a second experiment we assessed survival when water temperatures were cooled to 0.3°C for 2 h and fish were subsequently transferred into 8°C and 24°C water without tempering. Both experiments were conducted with controls at 8°C that were subjected to the same handling procedures without any changes in water temperature. Fingerling rainbow trout were found to be very tolerant of all treatments, with few or no mortalities during the treatments or during the 2 weeks following treatment. Our experiments suggest that rapid changes to high but sublethal temperatures will not directly cause high mortalities of fingerling rainbow trout stocked into waters for sport fisheries, but short-term behavior anomalies or other stressors may affect poststocking survival in the wild.

Because fish are ectothermic poikilotherms, water temperature influences their metabolic rates, locomotor abilities, and orientation responses and can act as a lethal agent (Fry 1947). Water temperature is so important to fish that it has been called the "abiotic master factor" (Brett 1971). Salmonids have shown the ability to withstand very low temperatures (Becker et al. 1977; Currie et al. 1998) but are among the least tolerant of elevated temperatures (Grande and Anderson 1991) among well-studied fishes.

Thermal tolerance studies of salmonids are complicated by several factors. The temperature at which fish are acclimated before the temperature challenge can have a significant effect on study results (Currie et al. 1998; Beitinger and Bennett 2000). Size and age of fish affect their thermal tolerance (Lee and Rinne 1980; Elliott and Elliott 1995; Benfey et al. 1997). The quality of acclimation and test waters can also influence results (Craige 1963). Thermal tolerance comparisons among studies are complicated by differing experimental methods, particularly differences between static lethal methods and dynamic thermal methods (Currie et al. 1998). In static methods, fish are transferred from the acclimation temperature into a container containing water at the test temperature. The test temperature producing 50% mortality in exposed fish is the incipient lethal temperature for the particular acclimation temperature. Dynamic methods involve a gradual temperature change from the acclimation temperature to a predetermined endpoint. The test temperature at which 50% of the exposed fish survive to the endpoint is the critical lethal temperature for the particular acclimation temperature. The particular endpoint chosen by researchers (e.g., loss of equilibrium, onset of muscular spasms, response to prodding, and death) complicates comparisons of static and dynamic studies. Static and dynamic methods attempt to describe the thermal tolerances of fish, but they do not measure the same response (Currie et al. 1998). Few studies have measured temperature tolerances by both static and dynamic methods (Beitinger and Bennett 2000).

Until recently, it was common practice to temper salmonids in transport tanks with the receiving water before stocking. This was done by pumping or bucketing the transport water out while bringing in equal quantities of the receiving water to fish transport tanks. By doing this, fish in transport tanks were gradually acclimated to the temperature of the receiving water as well as its physical and chemical properties. Fish culturists believed that tempering salmonids before stocking reduced the stress associated with changes in water temperature and quality and would enhance poststocking survival. The practice of tempering salmonids before stocking has been discontinued by many agencies because of the potential for spreading pathogens such as *Myxobolus cerebralis*, the causative

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agent of whirling disease. More frequently, salmonids are being released from transport tanks directly into receiving waters. Whether or not this practice has had negative effects on poststocking survival of salmonids has yet to be determined. However, as an initial examination of this question, we conducted two experiments. Fingerling rainbow trout *Oncorhynchus mykiss* were transferred into high but sublethal water temperature (24°C) in the presence of adequate oxygen (>90% saturation) and identical water chemistry. The experiments compared dynamic (different rates of tempering) and static (immediate transfer) techniques with control techniques (transfer without temperature changes).

Methods

Two experiments were conducted using the Eagle Lake strain of rainbow trout obtained from the Wyoming Game and Fish Department, Como Bluffs Fish Hatchery, Rock River, Wyoming. The fish were transported to the University of Wyoming's Red Buttes Environmental Laboratory, where they were held in one 0.3-m^3 fiberglass circular tank for 4 weeks before experimentation. The tank was supplied with a continuous flow of 8°C well water, and the fish were fed a formulated diet to satiation once daily.

Both experiments were conducted in 38-L aquaria fitted with standpipes and continuous single-use water flows. Water was continuously aerated throughout the experiments using air stones connected to a cylinder of compressed oxygen. For all replicates, dissolved oxygen levels and temperatures were continually recorded with a calibrated dissolved oxygen meter. Dissolved oxygen levels were maintained above 90% of saturation for the relevant water temperature throughout the experiments. Water was supplied to the aquaria through pipes that connected the aquaria to one of three 0.3-m^3 fiberglass circular tanks, where hot and cold sources of well water were mixed to the desired temperature before delivery to the aquaria. Fish were exposed to a single temperature trial, after which they were returned to the acclimation temperature and monitored for 2 weeks. Mortality was recorded for each replicate throughout thermal trials and for 2 weeks following the experiment. Fish were fed daily to satiation with the formulated feed during the 2-week monitoring period. To reduce preexperiment stress, all fish were weighed and measured at death or at the termination of the experiment. Fish were determined to be dead when all opercular movements had ceased.

In the first experiment we simulated three potential acclimation options for fish held at 8°C that were to be stocked into 24°C receiving waters and subsequently returned to 8°C water. For this experiment, 120 fingerling rainbow trout acclimated to 8°C were netted from the circular holding tank. Ten fish were haphazardly (assumed to be random) assigned to each of the 12 aquaria. The 12 aquaria were divided into one control and three treatments for each of three replicates. Control fish were stocked directly into aquaria at the acclimation temperature (8°C) and held at this temperature throughout the experiment. Fish in the first treatment group began at 8°C, were subjected to a temperature increase of 4°C/h up to 24°C, held at 24°C for 4 h, and then returned to 8°C at a rate of 4°C/h. Similarly, fish in the second treatment began at 8°C, were subjected to a water temperature increase of 8°C/h up to 24°C, held at 24°C for 6 h, and then returned to 8°C at 4°C/h. Fish in the third treatment group were taken from the acclimation tank, placed directly into aquaria at 24°C, held at 24°C for 8 h, and then returned to 8°C at 4°C/h. Mortality in the control and treatments was recorded for 2 weeks following exposures.

The second experiment was designed to examine how the practice of transporting fingerling rainbow trout in chilled water may alter their ability to survive sudden temperature increases when stocked into warm receiving waters. For the second experiment, 90 fish were removed from the acclimation tank and haphazardly placed into nine 38-L aquaria with 8°C water. The aquaria were equally divided into controls and two treatments, each with three replicates. Fish in the control were similarly handled but remained at 8°C throughout experiment. After fish had been stocked into treatment aquaria, cubed ice was added until nearly one-third of each aquarium was filled with ice. The ice was kept in the aquaria for 2 h, and water temperature was maintained at 0.3°C, during which time no inflow was provided. After 2 h, the fish were removed from their respective aquaria and placed into adjacent aquaria. Fish in the first treatment group were transferred to aquaria at 8°C and held there for 2 weeks. Fish from the second treatment group were placed in aquaria at 24°C. The second treatment group was maintained at 24°C for 8 h, after which fish were returned to 8°C at 16°C/h. Mortality in all groups was recorded for 2 weeks following exposures.

Results

Fingerling rainbow trout used in both experiments had a mean length of 99 mm (range, 80–

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117 mm) and a mean weight of 10 g (4–20 g). In the first experiment, no mortality was observed in the control (no temperature change) group, and mortalities in the three treatments (fish tempered from 8–24°C at three different rates) were limited. The 4°C/h tempering treatment resulted in one death (3.3% mean mortality). The more rapidly tempered treatment (8°C/h), resulted in three deaths during the experiment (10.0% mean mortality). The treatment group that was transferred directly from 8°C into 24°C water, resulted in one death (3.3% mean mortality). All deaths occurred as the water was being warmed or during the holding period at 24°C, but no mortalities occurred in the control or treatment groups as the water was cooled or during the 2 weeks following exposure.

In the second experiment, fish were acclimated to 8°C and cooled to 0.3°C in ice water before transfer into 8°C or 24°C water. In this experiment, one fish from the control group died during the temperature manipulation period (3.3% mean mortality), whereas no deaths occurred in either of the treatments. No mortalities occurred for the 2 weeks following exposure in the control and treatment groups.

Discussion

Fingerling rainbow trout were able to survive remarkably well when subjected to large and rapid temperature changes. In our experiments we were very careful not to exceed the reported upper lethal temperature for rainbow trout (i.e., 26°C), and we kept dissolved oxygen levels above that required for rainbow trout, thereby eliminating these factors as possible causes of mortality. Based on our results, fingerling rainbow trout stocked at more moderate temperatures would probably experience few, if any, mortalities from temperature changes alone.

Sudden temperature change may affect poststocking behavior and ability to avoid predators. Rainbow trout that were transferred into 24°C, regardless of delivery temperature or tempering rate, behaved differently than control fish in our experiments. Fish transferred into 24°C water remained at the surface of the receiving water. For the first 1–2 min following placement, these fish expended large amounts of energy swimming haphazardly. Following this period of intense activity the fish became lethargic but maintained their position near the surface. After about 1 h at 24°C, the fish could be handled with very little evasive response. Because of this behavior, fingerling rainbow trout stocked into 24°C receiving waters with no thermal refuge would be easy prey for predators. Further, fish that were cooled to 0.3°C in the second experiment were very lethargic and remained at the bottom of the aquaria when transferred to 24°C water. These fish appeared disoriented for several minutes, and some individuals temporarily lost equilibrium. The behavior of these fish would also make them easy targets for predators. Additionally, sudden temperature change may be a stressor that, when combined with transport and stocking stress, affects poststocking survival.

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