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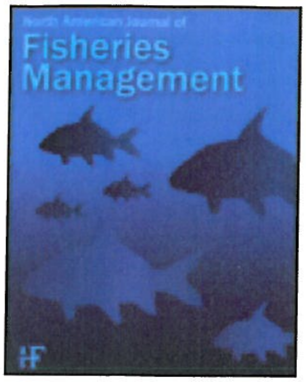

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MANAGEMENT BRIEF

Physiological Responses of Adult Rainbow Trout Experimentally Released through a Unique Fish Conveyance Device

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Abstract

We assessed the physiological stress responses (i.e., plasma levels of cortisol, glucose, and lactate) of adult Rainbow Trout *Oncorhynchus mykiss* at selected time intervals after they had passed a distance of 15 m through a unique fish conveyance device (treatment fish) or not (controls). This device differs from traditional fish pumps in two important ways: (1) it transports objects in air, rather than pumping them from and with water; and (2) it uses a unique tube for transport that has a series of soft, deformable baffles spaced evenly apart and situated perpendicular within a rigid, but flexible outer shell. Mean concentrations of the plasma constituents never differed ($P > 0.05$) between control and treatment fish at 0, 1, 4, 8, or 24 h after passage, and only minor differences were apparent between the different time intervals within a group. We observed no obvious injuries on any of our fish. Our results indicate that passage through this device did not severely stress or injure fish and it may allow for the rapid and safe movement of fish at hatcheries, sorting or handling facilities, or passage obstacles.

Moving fish is a common husbandry and management practice. At hatcheries or other aquaculture facilities, fish are often moved from ponds, tanks, or raceways to transport vehicles or other areas. At dams, fish are often moved from tailrace to forebay or other areas (e.g., trap and haul operations), or from fish sorting or handling facilities to transport vehicles. In addition to simply moving fish, managers are often concerned about providing effective passage for fish in areas where they may be impeded, such as at low-head dams or poorly designed culverts. Exploring new and innovative ways to facilitate the passage of fish is important for maintaining the habitat connectivity of migratory fishes.

Traditionally, fish have been moved using lift or other types of nets or various types of pumps, or by hand, and all of these methods or devices subject them to various levels of stress, injury, or mortality (Barton et al. 1986; Grizzle et al. 1992; Davis et al. 1994; Wagner and Driscoll 1994). Perhaps the most "fish-friendly" device in current use today is the screw centrifugal impeller (Hidrostal) pump, which has had mostly minor impacts on fish and has been effective in passing salmonids (Weber et al. 2002; McNabb et al. 2003; Helfrich et al. 2004; Thompson et al. 2011), American Eels *Anguilla rostrata* (Patrick and Sim 1985), and other fishes (Rodgers and Patrick 1985). Ideally, a fish conveyance or passage device should be easy and efficient to operate, cause minimal stress, injury, and mortality to fish, and be adaptable to a variety of situations. Because no single device currently meets or (preferably) surpasses these criteria, the continued search for fish conveyance or passage devices that may offer advantages over existing technologies seems prudent.

Recently, Whooshh Innovations (Whooshh), a private research and development company, developed a unique device that rapidly, safely, and effectively transports fruit for the agricultural sector (see www.whooshh.com for more information). During implementation of this technology, questions arose about whether such a device might be useful for moving fish. The technology—which is vacuum-based but uses a unique tube for transporting objects in air over distance (dubbed the TruePort tube and described below)—may rapidly and safely move fish over long distances with a significant reduction in handling and use of water and energy. Unlike traditional fish pumps, which use large motors and lots of energy to create a strong vacuum for moving large quantities of water and fish simultaneously, the Whooshh transport device moves objects through air and thus requires a weaker vacuum and less energy use. A device that quickly, gently, and safely moves fish from one place to another may be particularly useful at hatcheries, dams with no passage facilities, irrigation diversions, and other obstacles to fish passage and movement. However, before such

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technology could be integrated into modern fisheries management, basic information was needed on the physiological responses of and extent of injury in fishes that pass through the device. In this study, we compared the physiological responses of adult, hatchery-reared Rainbow Trout *Oncorhynchus mykiss* that did and did not pass through a prototype Whooshh transport device. Specifically, we measured changes in plasma levels of cortisol (a fast-responding, primary stress hormone), glucose (a secondary, somewhat delayed indicator of stress), and lactate (an indicator of anaerobic metabolism) in fish at selected time intervals after they had passed through the device or not.

METHODS

Study device.—The Whooshh transport device we evaluated comprises a large, rectangular aluminum tank with top-mounted vacuum motors and a 15-m length of TruePort tubing entering on top (Figure 1). The tank (2.4 × 1.2 × 1.8 m), which received and held fish after passage through the tube, was filled to a depth of 1.5-m with ambient well water (about 7°C) from a removable garden hose. The tank was flushed continuously with freshwater except when it was sealed, the vacuum motors were operating, and fish were being passed (described below). Access to the tank was through an opening on top that was covered by a clear plastic lid. We covered the outside of the tank with sheet insulation to help control water temperature. Three vacuum motors (120 V, 50/60 Hz) were used to create negative pressure inside the tank when the lid was closed. The TruePort tube (Figure 2)—through which the fish traveled on their way from a measuring station to the tank—consisted of short sections of rigid, but flexible, ribbed plastic tubing that snapped together to make the 15-m length. Each section had a series of soft, deformable baffles with a hole in the center, spaced at 5.1-cm intervals and situated perpendicular within a 15.2-cm-diameter flexible tube. Each baffle was designed to expand to seal around an object larger than the diameter of the center hole. Thus, when negative pressure (i.e., pneumatic pressure differentials) was applied, an object moved rapidly through the tube—sequentially from baffle to baffle. Because the baffles were made with soft yet durable materials, the object was transported in a suspended state within the tube (i.e., with little or no contact with the more rigid, outer components), thereby allowing for gentle movement over various distances. The pressure inside the TruePort tube approximated that between 71 and 114 cm of water (6.9–11.0 kPa) continuously over its entire length. We placed the tube in wooden supports that held it about 1 m off the ground. The tubing ran parallel to the ground for about 12 m, rose at about a 45° angle to a metal support at the top of the tank, and entered the tank through the top at a 30° angle.

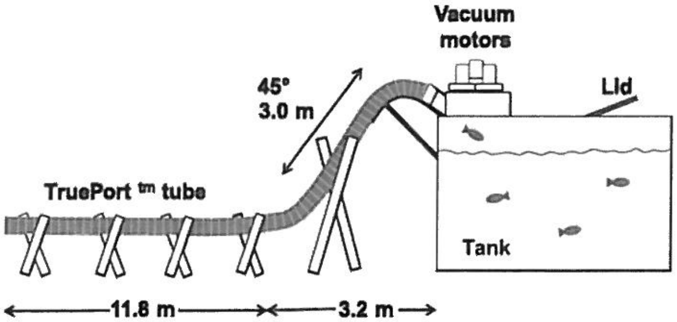

FIGURE 1. Schematic diagram of the Whooshh Innovations transport device. The drawing is not to scale, and all measurements are approximate.

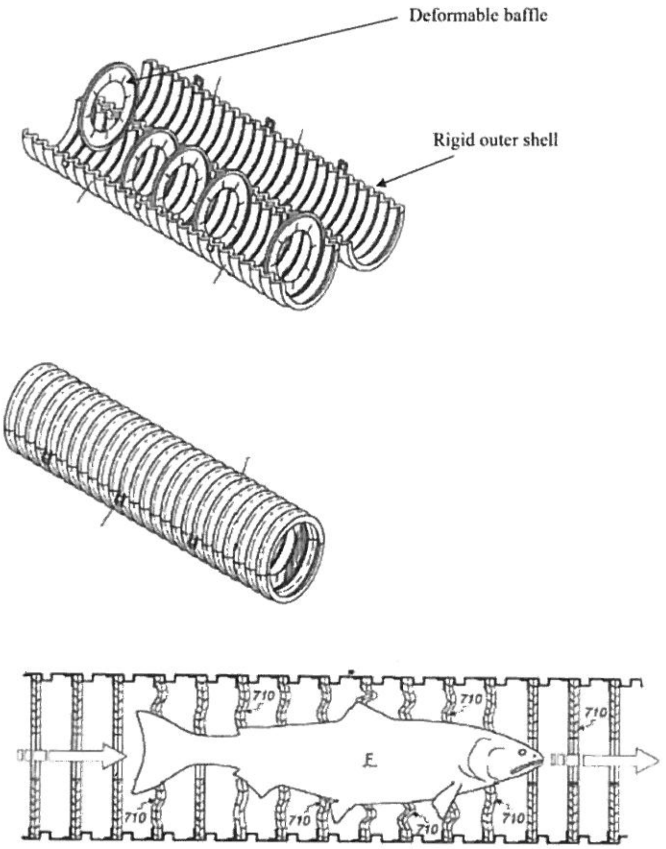

FIGURE 2. Details of the TruePort tube used in the Whooshh Innovations transport device. The upper panel shows details of the deformable baffles and rigid outer shell, the middle panel shows the tube in its closed position, and the lower panel illustrates the passage of a fish through the tube. Note how the baffles deform to match the shape of the fish as it passes. (Source: Whooshh Innovations).

Passage of fish through the Whooshh transport device.—On 9 August 2011, adult Rainbow Trout (range = 40.5–50.0 cm FL and 753–1,680 g) from Troutlodge (Sumner, Washington) were transported to our laboratory using a truck equipped with an insulated tank and aerated water. We held fish outside in 1.5-m-diameter tanks receiving well water at about 7°C. During holding, fish were fed either trout pellets or live hatchery-reared juvenile Chinook Salmon *O. tshawytscha* at about 2% of their body mass 3 times/week.

About 1–2 weeks before testing, fish were removed serially from their holding tank and placed in a 45-L cooler with water containing a sleep dose of anesthetic (50 mg/L MS-222 [tricaine methanesulfonate] buffered with an equal amount of sodium bicarbonate). When the fish were quiescent, we implanted a PIT tag (Biomark Model HPT12; 12.5 mm, 134.2 kHz International Organization for Standardization, 0.1 g in air) into their peritoneal cavity via a syringe and needle implanter, and gave them either a left (for treatment fish that passed through the tube) or right (control fish that did not pass through the tube) pelvic fin clip. After marking, we placed 14 fish (7 treatment and 7 control) into each of five tanks, which were randomly assigned a poststressor sampling interval of 0, 1, 4, 8, or 24 h. Food was withheld from fish 24 h prior to testing.

On the morning of a test, we set up the Whooshh transport device by submersing sections of the tube in water to wet the inside (there was no water source that kept the inside of the tube continually wet during operation), connecting them together and placing them on their supports, inserting the tube into the tank, and checking operation of the vacuum motors. After this, a tank was chosen (with a preselected poststressor sampling interval), the water level in the tank was lowered to a depth of 38 cm, and a sleep dose of anesthetic (50 mg/L MS-222) was added to sedate the fish. When the fish were quiescent, individuals from the treatment group (identified by their fin clip) were gently netted from the tank, placed into two large coolers (three or four fish per cooler) containing water and the same dose of anesthetic, and carried to the open end of the transport tube. At this time, we turned on the vacuum motors. Using gloved hands, fish were removed serially from the cooler, rapidly scanned for a PIT tag, weighed (nearest g) and measured (FL to the nearest 0.5 cm), and placed head first into the tube, where they were instantly sucked toward the holding tank. We used a stopwatch to record the travel time of each fish. We continued this process until all seven treatment fish were in the tank, after which we shut off the vacuum motors. Once fish were in the coolers, the entire process required about 3 min. As each cooler was emptied of treatment fish, control fish were gently netted from the tank into the empty cooler and carried to the open end of the tube where they were quickly processed like treatment fish, placed individually into 19-L buckets with freshwater, carried to the Whooshh holding tank, and gently lowered into the tank through the opening on the top. This process also required only a few minutes. The sampling interval time countdown was started when all fish were in the holding tank.

When the time came to sample fish, we removed the water inflow, opened the drain, and lowered the water level in the tank to 30 cm (which required about 25 min). When the desired water level was reached, MS-222 was added to the tank to achieve a dose of 50 mg/L. When the fish were quiescent, they were gently removed from the tank and euthanized in a cooler containing 200 mg/L MS-222 (three or four fish per cooler). When respiration ceased, fish were removed from the cooler, scanned for a PIT tag, and a blood sample was removed from the caudal vasculature about 2 cm posterior to the vent using a 6.0-mL Vacutainer containing sodium heparin and a 21-gauge needle. The blood was placed on ice until all sampling was completed. We centrifuged the blood samples at 4,000 rpm for 5 min at 4–6°C, transferred the plasma to prelabeled tubes, and stored them at −80°C for later analysis.

Plasma assays and data analysis.—Plasma cortisol levels were measured from unextracted samples with a commercially available ELISA kit (Neogen, Lexington, Kentucky) that had been previously validated for use in Rainbow Trout (Ackerman and Iwama 2001). Glucose and lactate levels were measured with the Sigma (St. Louis, Missouri) glucose hexokinase kit and Trinity Biotech (Jamestown, New York) lactate kit. Mean lengths and weights of treatment and control fish were compared using Student's *t*-test. We also used *t*-tests to compare the mean values of plasma constituents between control and treatment fish at each time point and ANOVA, followed by Tukey's procedure, to compare values between sample periods within each treatment. All analyses were done with GraphPad Prism software (GraphPad Software, La Jolla, California).

RESULTS

The mean (±SD) length and mass of control fish (44.7 ± 1.8 cm and 1,116 ± 133 g) did not differ significantly from values of treatment fish (44.8 ± 2.2 cm and 1,106 ± 177 g; $t = 0.176$ for length and 0.267 for mass, $P > 0.05$; $N = 35$ fish per group). On average, it required 6.8 s (range = 5–14 s) for fish to traverse the 15-m of TruePort tubing. Mean concentrations of plasma cortisol, glucose, and lactate never differed between control and treatment fish at any time period (*t*-tests, $P > 0.05$; Figure 3). Mean cortisol titers in both groups at time 0 were significantly higher than values at 4 and 24 h, and the value at 1 h was also higher than that at 24 h (control: $F = 4.97$; df = 4, 30; $P = 0.003$; treatment: $F = 6.05$; df = 4, 30; $P = 0.001$; Figure 3). Although mean glucose concentrations showed some increases over time within each group (Figure 3), the levels at each sample period never differed significantly (control: $F = 0.72$; df = 4, 30; $P = 0.582$; treatment: $F = 2.39$; df = 4, 30; $P = 0.073$). Mean plasma lactate concentrations increased from 0 to 1 h in each group and declined thereafter, and the only significant difference was between the means at 1 and 24 h in control fish ($F = 4.03$; df = 4, 30; $P = 0.009$; Figure 3). We observed no obvious injuries—such as extensive descaling, abrasions, or loss of mucous—on any of our fish.

DISCUSSION

The Whooshh transport device quickly and effectively moved large, adult Rainbow Trout a distance of about 15 m in air without causing overt injuries or severely stressing them. The physiological responses seen in our fish were less severe than those of others that were moved or stressed via other methods, such as netting or fish pumps. For example, Weber et al. (2002) recorded peak plasma cortisol concentrations greater than 150 ng/mL in juvenile Chinook Salmon after passage through Archimedes lifts or Hidrostal pumps. Also, Vijayan and Moon (1992) reported plasma cortisol, glucose, and lactate concentrations of around 140 ng/mL, 117 mg/dL, and 54 mg/dL in Rainbow

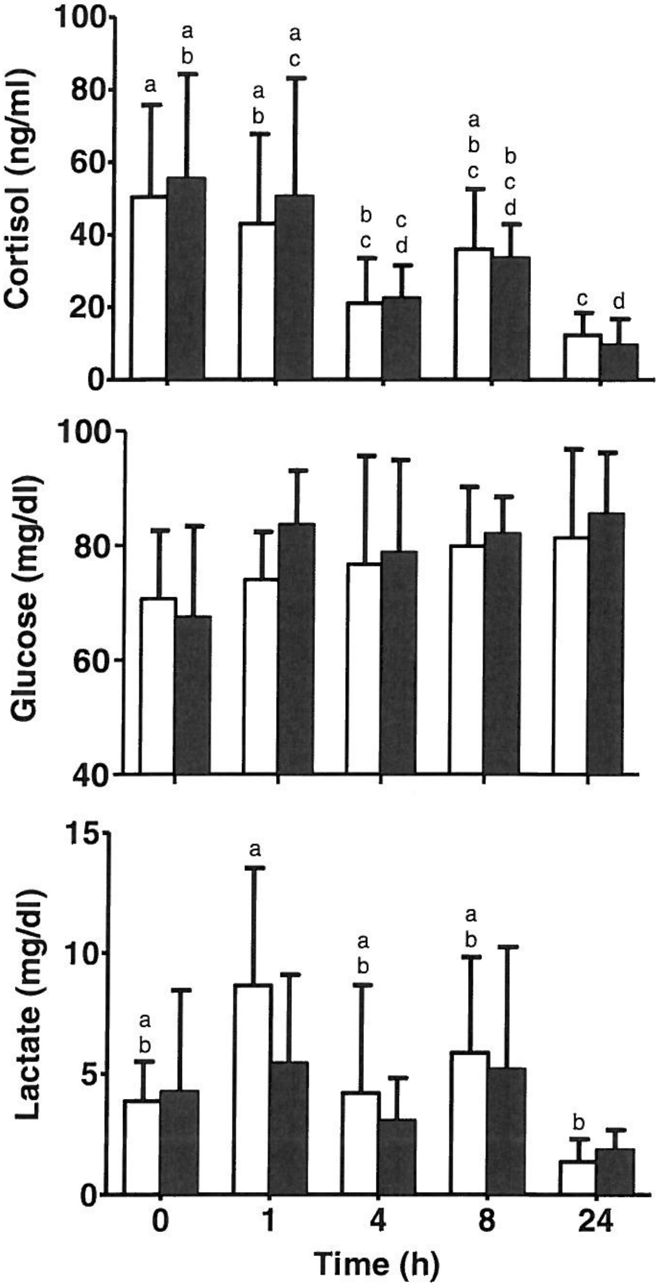

FIGURE 3. Mean (and SD) concentrations of plasma cortisol, glucose, and lactate in Rainbow Trout at different times after they were passed through the Whooshh transport device (black bars) or not (control fish = clear bars). The sample size for each bar was seven fish. Concentrations of plasma constituents in treatment and control fish at each time period never differed. Means at different time intervals within a treatment group with no letters in common were significantly different.

Trout 0.5 h after a 3-min handling and netting stress. However, we should reiterate that the stress responses of our fish may have been suppressed due to our use of MS-222 on fish prior to exposing them to the stressor. For example, although Wagner et al. (2002) showed that adult Rainbow Trout anesthetized by MS-222 had cortisol levels near 100 ng/mL 1 h after a handling stressor, these fish also showed a quicker return (within 7 h) to prestress levels compared with unanesthetized fish. Also, Sink et al. (2007) reported that exposing Rainbow Trout to MS-222 combined with netting and confinement stress resulted in cortisol concentrations (ca. 33 ng/mL) not significantly different from undisturbed control fish. In short, we felt it was necessary to anesthetize fish prior to handling them and placing them into the TruePort tube to facilitate the procedures and prevent injury to fish (e.g., dropping them on the ground). We also feel that our methods (i.e., anesthetizing fish prior to placing them into the tube) would be commonly used at many fish handling, marking, and sorting facilities at dams and hatcheries, and thus represent a real, working application and a good initial testing of the device.

Although we tested only one size of TruePort tube, various sizes of tubes can be made to accommodate a variety of fish sizes—even large, adult Pacific salmon (Todd Deligan, Whooshh Innovations, personal communication). As such, this device could be used in a variety of situations, including moving and sorting broodstock at hatcheries, moving fish from handling or monitoring facilities at dams or from ponds at hatcheries into transport vehicles, or moving fish over low-to-medium-head dams that do not have passage facilities. Recent discussions have centered on devising ways to attract and guide fish into the entrance of the tube, thus facilitating its use as a passage device at dams or other obstacles with poor or nonexistent passage options. The Whooshh transport device may be suitable for many situations where biologists or hatchery personnel have to move fish singly from one place to another, but, as we discuss below, more research is necessary to fully evaluate its potential. The use of this device in real-world situations, coupled with the creativity of its users, will ultimately determine its effectiveness and utility to hatchery operations, passage, and other fish conveyance situations.

Despite the potential promise of the Whooshh fish transport device, our work represents only a small first step towards a complete evaluation of its efficacy. There are still many outstanding questions to be addressed about this device before it will gain widespread acceptance and use in the fish passage and aquaculture community, including (1) the effectiveness of moving fish over longer distances (e.g., tens or hundreds of meters) and at various angles, (2) the physiological responses of and potential injuries to fish that may be moved over longer distances, (3) evaluation of longer term potential effects (e.g., 7 d) after passage through the device, (4) determining the range of sizes of fish that could be effectively passed, (5) developing solutions for various technical issues (such as cleaning the tube or what to do if a fish becomes stuck), and (6) developing ways to attract and guide fish so they volitionally enter the tube and are passed. Answers to these questions—and probably the development of more questions—will come from directed research and from those using the device in actual working situations. Currently, based on our results, the Whooshh transport device seems to have passed its first, initial testing. Its full potential awaits discovery.

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