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Influence of Water Velocity and Vertically-Suspended Structures on Rainbow Trout Rearing Performance

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Abstract

This study evaluated the effects of two water velocities and three types of vertically-suspended environmental enrichment during the rearing of juvenile rainbow trout (*Oncorhynchus mykiss*; mean ± SE, initial weight 4 ± 1 g and total length 71 ± 2 mm) in 1.8-m diameter circular tanks. The 2 × 3 experimental design used two velocities (12.2 $cm \cdot s^{-1}$ and 30.5 $cm \cdot s^{-1}$) and three structural treatments (aluminum rod array, plastic spheres, or no structure). After 116 days, the fish reared without any structure (control) at 30.5 $cm \cdot s^{-1}$ had significantly lower total tank weight, gain, percent gain, feed conversion ratio, and specific growth rate compared to the other treatments. Similarly, the fish reared with a velocity of 30.5 $cm \cdot s^{-1}$ without structure were significantly shorter and lighter than those in the other treatments. There was no significant difference in condition factor and relative fin lengths among the treatments. These results indicate that vertically-suspended environmental enrichment may be impacting fish rearing performance by altering tank water velocities.

Keywords

Environmental Enrichment, Exercise, Salmonid, *Oncorhynchus mykiss*

1. Introduction

Environmental enrichment in fish culture has been categorized into physical, sensory, dietary, social, or occupational enrichment [1] [2]. Physical enrichment involves alteration of the rearing environment to increase complexity, such as by adding structure. Sensory enrichment comprises of rearing techniques that stimulate the fish senses, while dietary enrichment relates to changes in food types or delivery. Social enrichment comprises anything affecting interaction with other fish or humans. Exercise is the primary type of occupational enrichment. Obviously, there can be overlap among these categories. For example, adding structures to rearing tanks (physical enrichment), may very well lead to sensory stimulation (sensory enrichment), interaction among the fish (social enrichment), and impact in-tank velocities (occupational enrichment) [3] [4].

Physical enrichment has been intensively studied. Investigators have placed a variety of structures in rearing tanks, including tree roots [2], woody debris [2] [5] [6] [7] [8], rocks and concrete blocks [8]-[14], and imitation aquatic plants [1] [2] [15]-[20]. However, most of these structural enhancements are incompatible with production-level hatchery rearing because they interfere with tank hydraulic self-cleaning, subsequently increasing labor demands and creating conditions favorable for disease outbreaks [14] [21] [22]. However, positive results have been reported using vertically suspended environmental enrichment that does not affect hydraulic self-cleaning [23]-[28].

Occupational enrichment frequently involves increasing water velocity to force fish to exercise. Exercise can lead to increased swimming abilities, rearing performance, and changes in behavior [29]-[34]. Previous studies have examined the effects of combining exercise with structural enrichment [29]-[34]. Kientz and Barnes [23] investigated vertically-suspended structure and exercise, but they only used one type of suspended structure (aluminum rods) and two velocities that were very similar over a relatively short period of time.

The objective of this study was to examine selected structural enrichments (vertically-suspended rods and vertically-suspended strings of spheres) at two different velocities during the long-term rearing of juvenile rainbow trout (*Oncorhynchus mykiss*) in circular tanks.

2. Methods

The experiment was conducted at McNenny State Fish Hatchery, Spearfish, South Dakota, USA, using degassed and aerated well water at a constant temperature of 11˚C (total hardness as $CaCO_3$, 360 mg·L^{-1}; alkalinity as $CaCO_3$, 210 mg·L^{-1}; pH, 7.6; total dissolved solids, 390 mg·L^{-1}). Approximately 1800 (7.2 kg·tank^{-1}) juvenile Shasta strain rainbow trout (mean ± SE; initial weight 4 ± 1 g and total length 70.8 ± 1.8 mm; $n = 30$) were placed into 24 ($n = 4$), 2000-L circular tanks (1.8 m diameter × 0.6 m deep) on June 1, 2017. The study lasted 116 days.

A 2 × 3 factorial experimental design was used to evaluate the effects of two water velocities and three structures on rearing performance of rainbow trout. The two velocities use were 12.2 cm·s^{-1} and 30.5 cm·s^{-1}. The lower velocity was the minimum velocity needed to maintain tank hydraulic self-cleaning. Velocities were recorded using a flow probe (FP111 Global Water Flow Probe, Global Water, College Station, Texas, USA). Readings were taken directly behind the incoming water spray bar about 0.3 m deep (half way in water column). Velocities were set at the beginning of the experiment and were kept constant throughout the study. The three different structural treatments used were no structure, aluminum rod array, and spherical array. The aluminum rod array consisted of fifteen aluminum rods (0.95 cm diameter × 57.15 cm long) suspended through a corrugated plastic tank cover as described by Huysman *et al.* [35]. The spherical array consisted of five strings of seven hard-plastic spheres (6.35 cm diameter, PVC-free pit balls; Kiddy Up brand; Imperial Toy LLC, North Hill, California, USA) suspended through the corrugated plastic tanks cover as described by Kientz *et al.* [24]. A 32-g weight as added to the top and bottom of the strings to ensure the spheres remained submerged in the tanks. The spheres were solid-colored (red, green, blue, yellow, pink, or purple) and colors were randomly selected from a common pool to eliminate potential bias.

Fish were fed every 15 min during daylight hours with 1.5 mm, extruded floating feed (Classic Trout, Skretting USA, Tooele, Utah, USA) using automatic feeders. Feeding rates were determined by the hatchery constant method [36], with an expected feed conversion ratio of 1.1 and a projected growth rate of 0.08 $cm \cdot d^{-1}$, which was a rate at or slightly above satiation. All tanks in this experiment received 86.7 kg of feed over the course of the experiment.

At the end of the experiment, total tank weights were acquired by weighing all fish in the tank to the nearest 0.1 kg. In addition, five fish per tank were individually weighed to the nearest 0.1 g, measured (total length) to the nearest 1.0 mm, and fin lengths (dorsal, one pectoral, and one pelvic) were measured to the nearest 0.01 mm to obtain relative fin lengths [37]. The following equations were used:

$$\text{Gain} = \text{final weight} - \text{initial weight}$$

$$\text{Percent gain (\%)} = 100 \times \text{gain}/(\text{initial weight})$$

$$\text{Feed conversion ratio (FCR)} = (\text{food fed})/\text{gain}$$

$$\text{Specific Growth Rate (SGR)} \\ = 100 \times (\ln(\text{end weight}) - \ln(\text{start weight}))/(\text{number of days})$$

$$\text{Condition Factor (K)} = 10^5 \times (\text{fish weight})/(\text{fish length})^3$$

$$\text{Fin indices (relative fin length)} = 100 \times (\text{fin length})/(\text{fish length})$$

Data were analyzed using the SPSS (24.0) statistical program (IBM Corporation, Chicago, Illinois, USA), with significance predetermined at $p < 0.05$. A two-way analysis of variance (ANOVA) was initially performed. If the two-way ANOVA indicated a significant interaction, then a one-way analysis of variance was conducted. Tukey HSD was used for all post hoc means separation testing.

3. Results

Significant interactions were observed between the velocity and structure treatments with total tank weight, gain, percent gain, feed conversion ratio, and specific growth rate. Subsequent analysis indicated that fish reared without any structure (control) at the higher velocity (exercise) had significantly lower total tank weight, gain, percent gain, feed conversion ratio, and specific growth rate compared to all the other treatments. Total tank gain was only 74.1 ± 6.5 kg in the exercised control tanks, compared to over 100 kg in all the other treatment groups. Similarly, percent gain (Figure 1), feed conversion ratio (Figure 2), and specific growth rate (Figure 3) were also significantly different. Mortality was less than 0.5% during the experiment and was not significantly different among treatments.

There was also a significant interaction between the velocity and structure treatments with individual fish length and weight. Similar to the total tank data, the fish in the higher velocity exercised control tanks were significantly shorter and lighter than those in all of the other treatments (Table 1). There was no significant difference in condition factor and relative fin lengths among treatments. No negative impacts on circular tank hydraulic self-cleaning were observed in any of the tanks or treatments.

Table 1. Mean (±SE) individual total lengths, weights, fin indices[a] (dorsal, pectoral, and pelvic), and condition factors[b] (K) of rainbow trout reared in circular tanks containing different vertically-suspended structures with two water velocities. Means with different letters in same row differ significantly ($p < 0.05$, $n = 4$).

Velocity	High			Low		
Structure	None	Rods	Spheres	None	Rods	Spheres
Length (mm)	156 ± 5 y	182 ± 2 z	174 ± 1 z	178 ± 2 z	180 ± 0 z	179 ± 1 z
Weight (g)	42.0 ± 3.4 y	70.6 ± 3.3 z	59.8 ± 1.2 z	63.9 ± 3.7 z	66.3 ± 3.7 z	65.0 ± 5.1 z
Dorsal index (%)	7.1 ± 0.7	7.1 ± 0.8	6.9 ± 0.5	6.2 ± 0.6	6.6 ± 0.7	7.1 ± 1.0
Pectoral index (%)	9.0 ± 0.6	8.3 ± 0.6	8.3 ± 0.5	8.4 ± 0.6	7.7 ± 0.4	8.7 ± 0.6
Pelvic index (%)	7.2 ± 0.6	6.5 ± 0.5	6.7 ± 0.2	6.7 ± 0.5	6.5 ± 0.3	6.9 ± 0.4
K	1.10 ± 0.03	1.17 ± 0.02	1.13 ± 0.02	1.12 ± 0.06	1.12 ± 0.08	1.16 ± 0.06

a) Fin indices = 100 × (fin length/fish length); b) K = 10^5 × (fish weight/(fish length)^3).

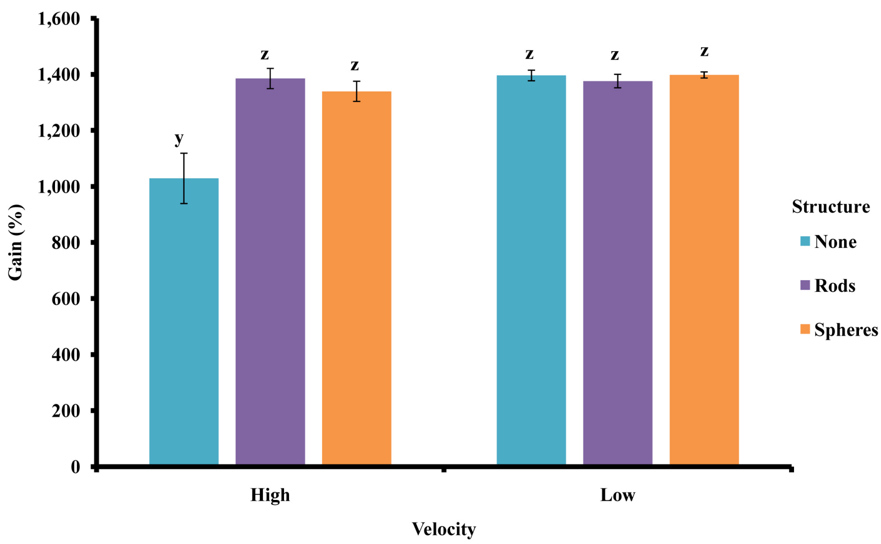

Figure 1. Mean (±SE) percent gain of juvenile rainbow trout reared at two different velocities and with three different types of structures for 116 days. Means with different letters are significantly different ($p < 0.05$, $n = 4$).

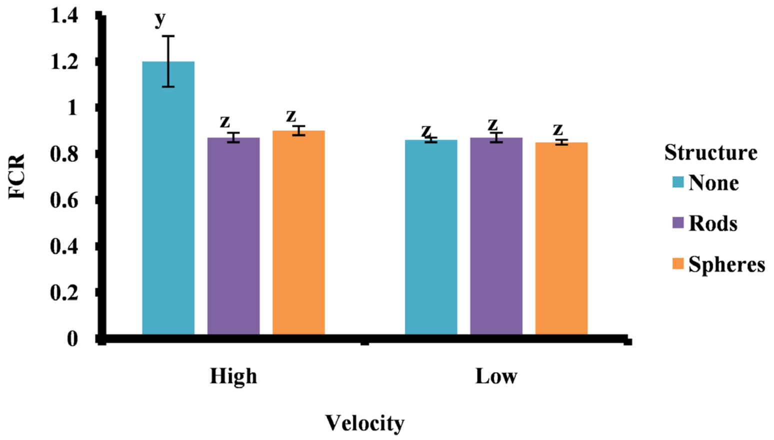

Figure 2. Mean (±SE) feed conversion ratio (FCR) of juvenile rainbow trout reared at two different velocities and with three different types of structures for 116 days. Means with different letters are significantly different ($p < 0.05$, $n = 4$).

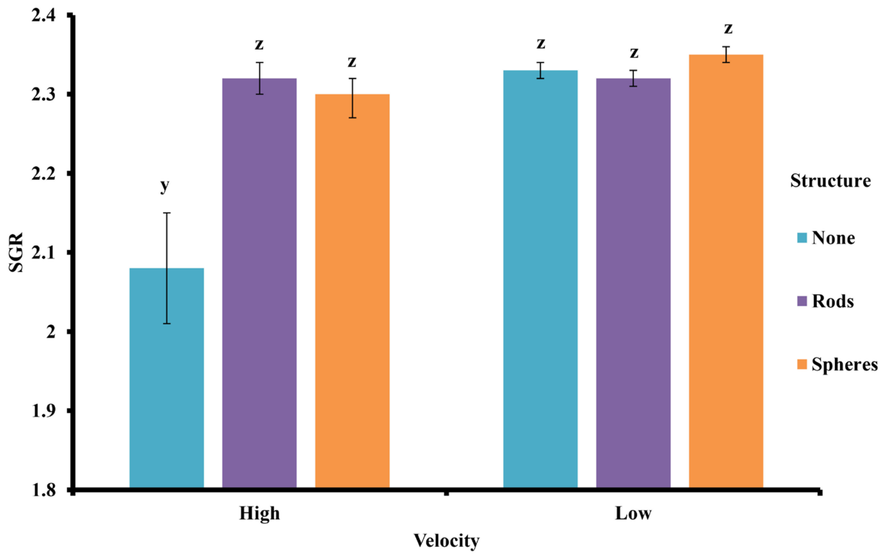

Figure 3. Mean (±SE) specific growth rate (SGR) of juvenile rainbow trout reared at two different velocities and with three different types of structures for 116 days. Means with different letters are significantly different ($p < 0.05$, $n = 4$).

4. Discussion

The results of this study suggest that vertically-suspended structure may positively impact trout rearing performance by reducing water velocities. Moine *et al.* [3] and Muggli *et al.* [4] both showed that vertically-suspended structures significantly alter velocity profiles in circular tanks, particularly by reducing velocities immediately behind the structures. Kientz and Barnes [28] suggested vertically-suspended structure may be providing bioenergetics benefits by creating lower velocity microhabitats. In this study, control fish reared with high velocity were subjected to continual exercise without the refuge provided by suspended structure. In addition, they did not receive the additional feed required to offset the increased energy expenditures from continual exercise [38]

[39].

It is possible that the higher velocity treatment used in this experiment was too high initially and too difficult for the fish to sustain over 116 days. Exercise at velocities of 1.0 to 2.0 Body Lengths seconds^{-1} (BL s^{-1}) has been reported as optimal fish rearing performance [30] [32] [40] [41] [42] [43] [44]. In contrast, the high velocities used in this study were 4.0 BL s^{-1} initially, and 1.8 BL s^{-1} at the end of the experiment. The initial high velocity may have been too great for fish that did not have the lower velocity refuge created by structure [38] [44] [45] [46]. However, because percent mortality was not significantly different among the treatments, the higher velocities were not high enough to be lethal [45].

The feed conversion ratio in all treatments was typical for juvenile rainbow trout reared with exercise [39] [47] [48] or structure [24] [25] [26] [28] [35] [49]. However, feed conversion ratios in this study were lower than those reported in the only other study examining vertically-suspended structure and exercise [23].

Improvements in relative fin length have been reported in fish that are exercised, likely due to decreased agonistic behavior such as fin nipping [30] [31] [32] [39] [42] [50] [51]. Increasing structural complexity with environmental enrichment has also been shown to decrease agonistic behavior [1] [2] [6] [52] [53] [54] [55]. The lack of differences in relative fin length in this study may indicate that even the low velocities were enough to overcome any potential negative effects of fin length from the lack of structure in the control tanks.

It is possible that the long duration of this experiment may have impacted the results. Huysman *et al.* [35] indicated that growth will slow if carrying capacities are reached in tanks receiving experimental treatments prior to the end of a trial. This allows the slower-growing tanks in other treatments the opportunity to catch-up, thereby masking any potential advantages from selected treatments.

The results of this experiment indicate that water velocity can be increased for prolonged periods with no negative effects on trout rearing performance if vertically-suspended structure is present. Subsequent experimentation using vertically-suspended structure at velocities between 1.0 - 2.0 BL s^{-1}, particularly if these values were maintained throughout the study by periodic adjustment, would be beneficial. In addition, intermittent exercise, induced by periodic changes in water velocity, in conjunction with vertically-suspended environmental enrichment, may be a productive area for further experimentation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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