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Use of Exercise and Structure during Rainbow Trout Rearing

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Abstract

A combination of two forms of environmental enrichment (in-tank structure and exercise) was evaluated during the hatchery rearing of juvenile rainbow trout *Oncorhynchus mykiss*. The study used four treatments: 1) neither exercise nor structure, 2) exercise without structure, 3) structure without exercise, and 4) both exercise and structure. Velocities in the unexercised tanks were a constant 12.2 $cm \cdot s^{-1}$. Velocities in the exercised tanks alternated weekly with one week at 12.2 $cm \cdot s^{-1}$ followed by a week at 30.5 $cm \cdot s^{-1}$. Structural enrichment consisted of an array of vertically-suspended aluminum angles. The use of either environmental enrichment technique significantly improved final tank weight, gain, percent gain, and specific growth rate. Feed conversion ratio was significantly and positively influenced only by structure, but fish on the exercise routine were overfed. There were no significant interactions between exercise and structure, indicating that each form of environmental enrichment operates independently. The results of this study indicate fish rearing performance can be improved with the addition of either vertically-suspended aluminum angles or an exercise routine, but the combination of the two techniques may not be needed to improve rainbow trout growth.

Keywords

Routine, Velocity, *Oncorhynchus mykiss*, Salmonids, Environmental Enrichment

1. Introduction

Hatchery rearing conditions can have a significant effect on fish behavior and physiology [1]. Enriching typically barren hatchery tanks, raceways, and other rearing units has been shown to be beneficial during hatchery rearing [2]. Environmental enrichment may also improve survival of hatchery-reared fish released into the natural environment [3]. Several types of environmental enrichment during fish production have been identified, including physical, dietary, sensory, social, and occupational categories [4] [5]. Physical enrichment is the addition of structure to the rearing unit. Dietary enrichment involves changes to the delivery or type of food. Sensory enrichment is sensory stimulation and social enrichment involves interactions among fish. Occupational enrichment is primarily exercise. These categories overlap, however. Physical enrichment, such as adding structure to a tank, likely leads to sensory enrichment as the fish senses are stimulated, social enrichment as fish behavior changes, and occupational enrichment as the structure impacts in-tank water velocities and swimming exercise [6] [7].

Considerable attention has focused on physical and occupational enrichment. Structures added to hatchery tanks include woody material [8] [9] [10] [11] [12] [13] [14]; concrete and rocks [3] [11] [15] [16], and plastic plants [17] [18] [19] [20] [21]. However, these physical environmental techniques are largely incompatible with production-level hatchery rearing because they impede tank hydraulic self-cleaning. This leads to the accumulation of uneaten feed and feces, which increases hatchery labor demands and the risk of potential disease outbreaks [22] [23] [24]. Recently however, vertically-suspended structures which have positively impact fish growth while still allowing for hydraulic self-cleaning have been developed and evaluated [25]-[34].

Exercise as a form of occupational environmental enrichment occurs when the fish are forced to swim by adjusting water velocities. Exercise is generally regarded as beneficial by improving swimming stamina, increasing hatchery growth, and positively impacting fish behavior [35]-[41]. Continual exercise for long durations may lead to exercise fatigue however [42] [43] [44] [45]. Routines that balance exercise with rest periods are likely more beneficial [46]-[51].

Despite the plethora of studies examining physical and occupational enrichment, only two studies have examined them in combination. Kientz and Barnes [25] used vertically-suspended structure and two water velocities. However, the two velocities were relatively similar and only one type of structure was used. In addition, the Kientz and Barnes [25] study was of relatively short duration. More recently, Voorhees *et al.* [44] used two dissimilar velocities and three types of structure and reported significant interactions between the velocity (exercise) and the structure type. Both Kientz and Barnes [25] and Voorhees *et al.* [44] used constant exercise. There have been no studies evaluating a combination of an exercise routine and physical enrichment during hatchery rearing. Thus, the objective of this study was to evaluate the effect of an exercise routine and physical enrichment on hatchery rearing performance.

2. Methods

This experiment was conducted at McNenny State Fish Hatchery, rural Spearfish, South Dakota, USA using degassed and aerated well-water (constant temperature 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 2400 (8.4 kg) Shasta strain rainbow trout *Oncorhynchus mykiss* (mean ± SE, initial weight = 3.6 ± 0.2 g, initial length 69 ± 1 mm, n = 30) were placed into each of 16 circular tanks (1.8 m diameter × 0.6 m deep; 0.4 m water depth) on May 31, 2008. The experiment started the following day and lasted 109 days.

Four treatments were used in this study: 1) neither exercise nor structure, 2) exercise routine without structure, 3) vertically-suspended structure without exercise, and 4) both exercise and structure. The vertically-suspended structure was an array of four aluminum angles (2.5 cm wide on each angle side × 57.15 cm long) as described by Krebs *et al.* [27] which were suspended through a corrugated black plastic cover [52] (**Figure 1**). The angles were placed so the peak of the angle faced into the water current. Velocities in the unexercised tanks were a constant 12.2 cm·s^{-1}. Velocities in the exercise routine tanks alternated weekly with one week at 12.2 cm·s^{-1} followed by a week at 30.5 cm·s^{-1}. Velocities were adjusted by rotating the incoming water spray bar and were measured using a flow probe (FP111 Global Water Flow Probe, Global Water, College Station, Texas, USA). All readings were taken directly behind the spray bar about 0.2 m deep (half-way in water column).

All fish were fed 1.5 mm; extruded floating trout diet (Protec, Skretting USA, Tooele, Utah, USA) every 15 minutes during daylight hours by means of automatic feeders. Feeding rates were determined by the hatchery constant method [53], with and expected feed conversion ratio of 1.1. Unexercised tanks were fed at a projected growth rate at or slightly above satiation (0.08 cm·d^{-1}), while exercised tanks were fed at a higher projected growth rate (0.09 cm·d^{-1}) to compensate for the increased energy demands from exercise [40].

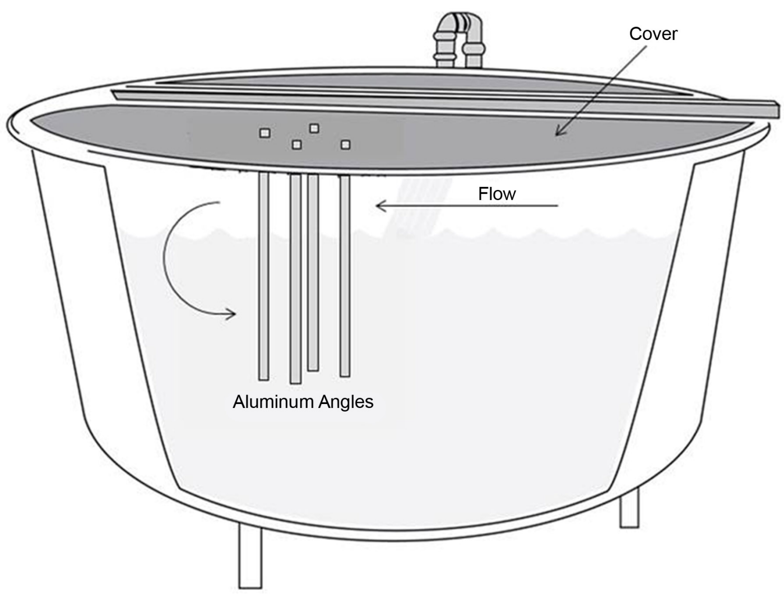

Figure 1. Circular tank with suspended array of four aluminum angles, with the peak of the angle facing in the direction of the water flow.

At the completion of the experiment total tank weight was recorded to the nearest 0.1 kg. Ten individual fish from each tank were also weighed to the nearest 0.1 g, and measured (total length) to the nearest 1.0 mm. Gain (1), percent gain (2), specific growth rate (SGR; 3), feed conversion ratio (FCR; 4), and condition factor (K; 5) were calculated using the following formulas:

$$\text{Gain} = \text{end weight} - \text{start weight} \tag{1}$$

$$\text{Percent gain}(\%) = 100 * \frac{\text{gain}}{\text{start weight}} \tag{2}$$

$$\text{SGR} = 100 * \frac{\ln(\text{end weight}) - \ln(\text{start weight})}{\text{number of days}} \tag{3}$$

$$\text{Feed conversion ratio}(\text{FCR}) = \frac{\text{food fed}}{\text{gain}} \tag{4}$$

$$\text{K} = 10^5 * \frac{\text{fish weight}}{\text{fish length}^3} \tag{5}$$

Data were analyzed using SPSS (24.0) statistical program (IBM, Armonk, New York, USA) with significance predetermined at $p < 0.05$. Tanks were the experimental unit, not the individual fish. Two-way analysis of variance (ANOVA) was performed and if a significant difference was observed, post hoc means separations tests were conducted using Tukey HSD.

3. Results

No significant interactions were observed between exercise and structure in any variables. Final tank weight, gain, percent gain, and feed conversion ratio were all significantly improved in the tanks containing vertically-suspended structure (**Table 1**). Final tank weight, gain, and percent gain were also significantly improved in the tanks receiving the exercise routine. However, exercised tanks received significantly more feed and had a significantly greater feed conversion ratio. Mortality was less than 1% and was not significantly different among the treatments.

Individual fish in tanks containing structure were significantly heavier, longer, and greater specific growth rate (**Table 2**). Exercised fish had a significantly greater total lengths and specific growth rates, but individual fish weights were not significantly different. Condition factor was not significantly different among any of the treatments.

4. Discussion

The lack of interaction between structure and exercise observed in this study indicates that these two forms of environmental enrichment act independently of each other. There appears to be no combined effect. These results are consistent with those reported by Kientz and Barnes [25], who used vertically-suspended rods for 51 days with juvenile rainbow trout at two continuous velocities (2.0 body lengths (BL)$\cdot s^{-1}$ and 2.75 BL$\cdot s^{-1}$) and also reported no interactions between

Table 1. Mean (± SE) final tank weight, gain, food fed, feed conversion ratio (FCR[a]), and percent mortality of rainbow trout reared with or without vertically-suspended strcture and with or without an exercise routine ($n = 4$).[b]

		Structure		
	Exercise	None	Angles	Overall
Final weight (kg)	None	104.4 ± 6.0	113.4 ± 4.4	108.9 ± 3.8 y
	Routine	108.9 ± 6.0	135.6 ± 2.8	122.2 ± 5.9 z
	Overall	106.7 ± 4.0 y	124.5 ± 4.8 z	
Gain (kg)	None	96.0 ± 6.0	105.0 ± 4.4	100.5 ± 3.8 y
	Routine	100.5 ± 6.0	127.2 ± 2.8	113.8 ± 5.9 z
	Overall	98.3 ± 4.0 y	116.1 ± 4.8 z	
Gain (%)	None	1143 ± 71	1250 ± 52	1196 ± 46 y
	Routine	1196 ± 71	1514 ± 33	1355 ± 70 z
	Overall	1169 ± 48 y	1382 ± 58 z	
Feed fed (kg)	None	99.5 ± 0.8	99.5 ± 0.8	99.5 ± 0.5 z
	Routine	154.8 ± 0.0	154.8 ± 0.0	154.8 ± 0.0 y
	Overall	127.1 ± 10.4	127.1 ± 10.4	
FCR	None	1.05 ± 0.06	0.95 ± 0.03	1.00 ± 0.04 z
	Routine	1.56 ± 0.10	1.22 ± 0.03	1.39 ± 0.08 y
	Overall	1.30 ± 0.11 y	1.09 ± 0.05 z	
Mortality (%)	None	0.4 ± 0.3	0.1 ± 0.0	0.2 ± 0.1
	Routine	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.0
	Overall	0.3 ± 0.1	0.2 ± 0.1	

[a]FCR = food fed/gain; [b]Overall means with different letters in same column or row differ significantly ($p < 0.05$).

Table 2. Individual mean (± SE) total length, weight, speicic growth rate (SGR[a]), and condition factor (K[b]) of rainbow trout reared with or without vertically-suspended strcture and with or without an exercise routine ($n = 4$).[c]

		Structure		
	Exercise	None	Angles	Overall
Total length (mm)	None	156 ± 2	164 ± 1	160 ± 2 y
	Routine	156 ± 3	173 ± 2	165 ± 4 z
	Overall	156 ± 2 y	169 ± 2 z	
Weight (g)	None	45.2 ± 2.9	55.9 ± 0.8	50.5 ± 2.5
	Routine	47.9 ± 3.9	63.0 ± 3.2	55.5 ± 3.7
	Overall	46.6 ± 2.3 y	59.4 ± 2.1 z	
SGR	None	2.33 ± 0.05	2.41 ± 0.03	2.37 ± 0.03 y
	Routine	2.37 ± 0.05	2.57 ± 0.02	2.47 ± 0.05 z
	Overall	2.35 ± 0.03 y	2.49 ± 0.04 z	
K	None	1.19 ± 0.03	1.26 ± 0.01	1.23 ± 0.02
	Routine	1.25 ± 0.04	1.21 ± 0.02	1.23 ± 0.02
	Overall	1.22 ± 0.03	1.24 ± 0.01	

[a]SGR = 100 × (ln(end weight) − ln(start weight))/(number of days)); [b]K = 10^5 × ((fish weight)/(fish length)^3); [c]Overall means with different letters in same column or row differ significantly ($p < 0.05$).

structure and exercise. However, Voorhees *et al.* [45] did report a significant interaction. Vertically-suspended rods and vertically-suspended plastic spheres were used for 119 days at two continuous velocities (approximately 1.7 $BL \cdot s^{-1}$ and 4.0 $BL \cdot s^{-1}$) and found significantly poorer rearing performance in exercised trout reared without structure. It is likely however, that the continuous exercise regime used by Voorhees *et al.* [45] led to the significant interaction between velocity and exercise by causing exercise fatigue [42] [43] [44] [45], unlike the intermittent exercise protocol used in this study.

The positive effects of the exercise routine used in this study on trout growth and feeding efficiency are not surprising. Farrell *et al.* [47] observed that rainbow trout subjected to a routine of ten hours of exercise and two hours of rest were larger than unexercised fish. Liu *et al.* [51] exercised Ya-fish *Schizothorax-prenati* for eight hours per day for two days per week and reported improved growth in the fish receiving moderate exercise. However, at higher velocity levels that produced vigorous exercise, positive effects on fish rearing performance were not observed. This is similar to the results of other studies using high velocities for exercise or not allowing for any rest periods [25] [44] [45], which all likely produced exercise fatigue [42] [43] [44] [45]. In general, exercise has been shown to be beneficial for fish by reducing stress [54] [55] [56], decreasing agonistic behavior [36] [57], increasing swimming performance [48] [49] [58] [59], increasing disease resistance [50] [51] and increasing post-stocking survival [60].

The positive results in rearing performance observed in this study with the use of vertically-suspended structure as a form of environmental enrichment are also not surprising. The benefits of using a variety of vertically-suspended structures during hatchery rearing have been well-documented [25] [26] [27] [29] [30] [32] [34]. It must be noted however, that the results from using structure in this study differ from those of White *et al.* [28], Huysman *et al.* [31], and Jones *et al.* [33]. These differences could be due to differences in the size and species of fish used in each experiment, as well as the duration of each study.

At 109 days this study was considerably longer than other exercise experiments, which typically last four to six weeks [36] [47] [50] [51] [54] [57] [59]-[66]. However, the long duration of this study may have influenced the results because final tank loadings may have become excessive. Huysman *et al.* [31] used identical tanks and suggested that their final tank weights of nearly 110 kg may have led to density-dependent reduced growth rates in the faster-growing tanks containing structure. By allowing slower-growing fish in other treatments the opportunity to catch-up in size, the long study duration may have precluded any determination of significant differences among the treatments. Final tank weights in the current study were nearly 140 kg, which was 30 kg greater than Huysman *et al.* [31] densities may have been too high.

Despite the relatively high loading densities, the feed conversion ratios observed in this experiment are similar to those previously reported for rainbow trout [25] [28] [30] [31] [32] [33] [45]. At 2.3 to 2.6, the specific growth rates, which is basically the percentage growth per day of fish, in this study were also similar to those reported by Huysman *et al.* [32] and Voorhees *et al.* [45]. Condition factors were also similar to those reported previously for rainbow trout [25] [30] [31] [33].

5. Conclusion

In conclusion, the results of this study indicate fish rearing performance can be improved with the addition of either vertically-suspended aluminum angles or an exercise routine, but the combination of the two techniques may not be needed to improve rainbow trout growth. Conversely, the combination of the two types of environmental enrichment is also not problematic and may provide benefits later in the production cycle or after stocking. Future research needs indicated by this study include investigations into different exercise regimes, the interactions between rearing densities and environmental enrichment, the effects of single or multiple environmental enrichment techniques on post-stocking survival, and the impacts of environmental enrichment on rearing unit carrying capacities.

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Conflicts of Interest

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

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