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Vertically-Suspended Environmental Enrichment Improves Growth of Landlocked Fall Chinook Salmon during Initial Hatchery Rearing

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Abstract

Environmental enrichment has been shown to improve juvenile salmonid growth during hatchery rearing. This study examined the effects of vertically-suspended environmental enrichment starting seven days after feed training and continuing for the next 32 days of landlocked fall Chinook salmon (*Oncorhynchus tshawytscha*) rearing. At the end of this experiment, final tank weights, gain, percent gain, and feed conversion ratio were all significantly improved in the tanks of salmon with environmental enrichment compared to barren tanks, with a nearly 25% improvement in feed conversion ratio. Individual salmon in tanks with environmental enrichment were significantly longer and weighed significantly more than salmon from tanks without enrichment. Specific growth rate was also significantly improved with the use of enrichment. The use of vertically-suspended environmental enrichment to improve growth and rearing efficiency is recommended during the initial rearing of landlocked fall Chinook salmon.

Keywords

Oncorhynchus tshawytscha, Environmental Enrichment, Structure, Initial Feeding

1. Introduction

Environmental enrichment is the modification of a typically barren hatchery rearing unit to add complexity or imitate natural environments. Physical structure has been added to fish rearing tanks as a form of environmental enrichment

[1]-[7]. However, materials located at the bottom of the tank to mimic natural habitats have negative consequences for the hydraulic self-cleaning of circular tanks, leading to decreased water quality, increased labor requirements, and increased disease potential [8]-[13].

In order to add enrichment, but still maintain circular tank hydraulic self-cleaning, vertically-suspended environmental enrichment was developed. Kientz and Barnes [14] and Kientz *et al.* [15] reported an increase in rainbow trout (*Oncorhynchus mykiss*) growth using suspended aluminum rods and suspended strings of plastic spheres. Subsequent studies used a variety of vertically-suspended structures with a variety of salmonid species, including Chinook salmon (*Oncorhynchus tshawytscha*) [16]; brown trout (*Salmo trutta*) [17], Atlantic salmon (*Salmo salar*) [18], and rainbow trout [19] [20] [21] [22], showed similar results.

Although there have been numerous studies examining vertically-suspended environmental enrichment during the hatchery rearing of salmonids in circular tanks, these studies have primarily used juvenile or larger fish. No studies have examined the use of such enrichment beginning with initial feeding. Thus, the objective of this study was to evaluate the use of vertically-suspended environmental enrichment during the initial feeding and rearing of Chinook salmon.

2. Methods

This 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 10,000 (4.54 kg·tank^{-1}) juvenile fall Chinook salmon (initial mean ± SE; weight 0.38 ± 0.01 g, total length 37.88 ± 0.38 mm; n = 30) were placed into 10, 2,000-L circular tanks (1.8-m in diameter, 0.8-m deep, 0.6-m operating depth) on January 3, 2019. These fish had been feed trained for seven days prior to the start of the experiment. The study lasted 32 days, ending on February 5, 2019.

Two treatments (n = 5) were used. Corrugated plastic covered the top of all tanks, with only a small area open for feed delivery, as described by Walker *et al.* [23]. Control tanks had no structure present, while the other tanks had a vertically-suspended array of four aluminum angles. The aluminum angles (each side 2.5-cm wide × 57.15-cm long) were suspended through the corrugated plastic covers as described by Krebs *et al.* [19]. The angles were arranged so that the angled portion faced into the direction of water flow and did not inhibit the hydraulic self-cleaning of circular tanks [19].

The salmon were fed BioVita Starter (Bio-Oregon, Longview, Washington, USA) every 15-min during daylight hours using automatic feeders. Feeding rates were determined by the hatchery constant method [24], with an expected feed conversion ratio of 1.1 and a projected growth rate of 0.08 cm·d^{-1}, which was a rate slightly above satiation.

At the end of the experiment, tanks of fish were weighed to the nearest 0.1 kg to obtain final tank weight. In addition, at the end of the study ten fish per tank were individually weighed to the nearest 0.01 g and measured (total length) to the nearest 0.1 mm. Gain, percent gain, feed conversion ratio (FCR), specific growth rate (SGR), and condition factor (K) were calculated using the following formulas:

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

$$\text{Gain}(\%) = 100 * \frac{\text{gain}}{\text{start weight}}$$

$$\text{Feed Conversion Ratio}(\text{FCR}) = \frac{\text{food fed}}{\text{gain}}$$

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

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

Data were analyzed using the SPSS (24.0) statistical program (IBM, Armonk, New York, USA), with significance predetermined at $P < 0.05$. T-tests were used to compare the variables from the vertically-suspended treatment group and the control group.

3. Results

Final tank weight, gain, percent gain, and feed conversion ratio were all significantly improved in the vertically-suspended environmentally enriched tanks compared to control tanks, with a nearly 25% improvement in feed conversion ratio (**Table 1**). Individual salmon in tanks with environmental enrichment were significantly longer and weighed significantly more than salmon from tanks without enrichment (**Table 2**). Specific growth rate was also significantly improved with the use of enrichment. Salmon were on average 1.5 mm longer and 0.1 g heavier in enriched tanks compared to un-enriched control tanks.

Table 1. Mean (± SE) total tank weight, gain, percent gain, and feed conversion ratio (FCR) for landlocked fall Chinook salmon reared with (enriched) or without (control) vertically-suspended environmental enrichment. Means in a row with different letters are significantly different ($n = 5$, $P < 0.05$).

	Control	Enriched	*P*
Tank weight (kg)	15.2 ± 0.7 z	17.5 ± 0.3 y	0.02
Gain (kg)	10.6 ± 0.7 z	13.0 ± 0.3 y	0.02
Gain (%)	234 ± 16 z	286 ± 6 y	0.02
FCR*	1.78 ± 0.14 z	1.43 ± 0.03 y	0.04

* Feed Conversion Ratio (FCR) = food fed/gain.

Table 2. Mean (± SE) final individual fish length (total), weight, specific growth rate (SGR), and condition factor (K) for landlocked fall Chinook salmon with (enriched) or without (control) vertically-suspended environmental enrichment. Means in a row with different letters are significantly different ($n = 5$, $P < 0.05$).

	Control	Enriched	*P*
Length (mm)	56.0 ± 0.5 z	57.4 ± 0.2 y	0.04
Weight (g)	1.45 ± 0.04 z	1.56 ± 0.01 y	0.04
SGR[1]	4.3 ± 0.1 z	4.6 ± 0.0 y	0.04
K[2]	0.83 ± 0.02	0.82 ± 0.01	0.70

1. Specific growth rate (SGR) = 100 × [(ln(end weight) − ln(start weight))-number of days], 2. Condition factor (K) = 10^5 × [weight/(length^3)].

4. Discussion

The results of this study clearly indicate that vertically-suspended environmental enrichment is beneficial during the initial rearing of Chinook salmon. These results are consistent with those observed using larger juvenile Chinook salmon by Rosburg *et al.* [16]. They are also consistent with the numerous other studies showing the positive impacts of vertically-suspended structures during hatchery rearing on the growth of other salmonid species during hatchery rearing in circular tanks [14] [15] [17]-[22] [25].

It is unknown how vertically-suspended enrichment is improving growth in hatchery-reared fish. Kientz *et al.* [15] hypothesized the benefits from vertically-suspended environmental enrichment were due to the creation of lower water velocity microhabitats that allowed the fish to decrease energy expenditures when not feeding [26]. The alterations in circular tank flow dynamics from vertically-suspended structure reported by Moine *et al.* [27] and Muggli *et al.* [28] support this hypothesis. The improved feed conversion ratios observed in this study provide further evidence of bioenergetic improvements with vertically-suspended enrichment. Because the salmon in the barren tanks were subjected to continual velocities, in comparison to the salmon in the enriched tanks containing locations with lower velocities, the fish in the unenriched tanks may have experienced exercise fatigue due to higher feed conversion ratios [25]. Other investigations not using suspended structures have also reported changes in overall water velocities can influence trout growth [29] [30] [31] [32].

As in previous studies utilizing vertically-suspended environmental enrichment, no negative effect on the self-cleaning nature of circular tanks was observed [19] [21] [22]. As long as adequate incoming water flows are maintained, no extra maintenance or cleaning is needed with the small array of angles as used in this study.

5. Conclusion

In conclusion, this study expands the window of expected benefits from vertically-suspended environmental enrichment to include the period of initial feeding, at least with landlocked fall Chinook salmon. These results are likely not specific to the unique form of vertically-suspended enrichment used, given the variety of other suspended structures shown to provide similar benefits in larger sized salmonids. However, the impacts of introducing vertically-suspended environmental enrichment during initial rearing on long-term hatchery rearing performance or post-stocking survival for those fish to be released into the natural waters are unknown. Further research should examine the use of vertically-suspended structures throughout the entire hatchery residence time of Chinook salmon.

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Conflicts of Interest

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

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