

Rearing Performance of Atlantic Salmon Grown in Circular Tanks with Vertically-Suspended Environmental Enrichment

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Abstract

Environmental enrichment is the incorporation of materials into hatchery tanks to simulate a more natural rearing environment. This study investigated the use of a vertically-suspended plastic conduit array as enrichment in 3.63 m circular tanks during Atlantic salmon (*Salmo salar*) rearing. After 168 days, feed conversion ratio was significantly improved for salmon reared in tanks with enrichment compared to the barren control tanks. Final tank weights and weight gain were not significantly different, although the difference in mean gain of 182.0 kg in the enriched tanks compared to 162.9 kg in the control tanks approached significance. There were no significant differences in individual fish length, weight, or condition factor between the treatments, likely because of large variances in body size due to sexual dimorphism and small sample sizes. The suspended array did not interfere with the hydraulic self-cleaning of the circular tanks. The results of this study support the use of vertically-suspended structures to improve the hatchery rearing performance of Atlantic salmon in circular tanks.

Keywords

Salmonids, Growth, *Salmo salar*, Vertically-Suspended Array

1. Introduction

Environmental enrichment is the addition of material within a barren hatchery rearing unit to imitate natural environments normally encountered by fish. It has been used in an attempt to alter fish behavior and physiology to improve hatchery rearing performance or post-stocking survival [1]-[9]. Forms of environmental enrichment have included natural and artificial plants, sand and gra-

vel substrate, wood, rocks, and concrete blocks [2] [4] [9]-[14]. While these supplements attempt to replicate a natural environment, they also disrupt the hydraulic self-cleaning of circular tanks. As a result, there may be a potential increase of disease outbreaks and increased labor requirements from hatchery staff [14] [15] [16] [17].

The use of vertically-suspended arrays as environmental enrichment is a recent development. In general, the suspension of vertical structures has improved feed conversion ratios and salmonid growth without disrupting circular tank self-cleaning [14] [18] [19] [20] [21] [22]. In contrast, White *et al.* [23] did not observe improved hatchery rearing performance with the use of vertically-suspended arrays in juvenile Atlantic salmon (*Salmo salar*) during a 125 day study. However, the 125-day study duration may not have been long enough to detect any effects from environmental enrichment with Atlantic salmon. Brockmark *et al.* [12] did not observe any environmental enrichment effects on Atlantic salmon growth until after 311 days of hatchery rearing. Thus, the objective of this study was to evaluate the hatchery rearing performance of Atlantic salmon after long-term rearing with vertically-suspended environmental enrichment.

2. Methods

Juvenile Atlantic salmon, Saint John's River strain, were reared initially in 1.8 m diameter unenriched circular tanks at McNenny State Fish Hatchery in rural Spearfish, South Dakota, USA, using well water at a constant temperature of 11 °C (water hardness as CaCO₃ = 360 mg/L, alkalinity as CaCO₃ = 210 mg/L, pH = 7.6, total dissolved solids = 390 mg/L). On May 23, 2018, approximately 2000 fish (mean ± SE; total length = 125.4 ± 3 mm, mean weight = 19.8 ± 1.5 g, N = 20) were moved into six larger tanks (diameter = 3.63 m, height = 1.09 m, water depth = 0.71 m). Each tank initially received 4.60 kg (approximately 330 fish). The experiment duration was 168 days.

Two different treatments were assigned to the six circular tanks (N = 3). Three control tanks were devoid of any internal structure, while three tanks contained vertically-suspended structure as environmental enrichment, as described by White *et al.* [23]. All tanks were near fully covered by corrugated plastic overhead covers [24]. The vertically suspended enrichments consisted of 20 hollow plastic polyvinyl chloride (PVC) electrical conduit pipes (diameter = 4.34 cm, length = 0.94 m), suspended from attachment points on the overhead covers. The pipes were evenly spaced approximately 16.5 cm from each other, arranged in an array with an area of 43 cm × 117 cm. The array was situated approximately 58 cm from the edge of the tank at a quarter turn of the tank away from the spray bar from which water entered the tank (Figure 1(a) and Figure 1(b)).

All fish were fed 3.0 mm BioVita feed (Bio-Oregon, Longview, Washington, USA) daily over a 12 hour period during daylight hours using automatic belt feeders (Pentair Aquatic Ecosystems, Apopka, Florida, USA). Feeding rates were determined for each experiment by the hatchery constant method [25] with

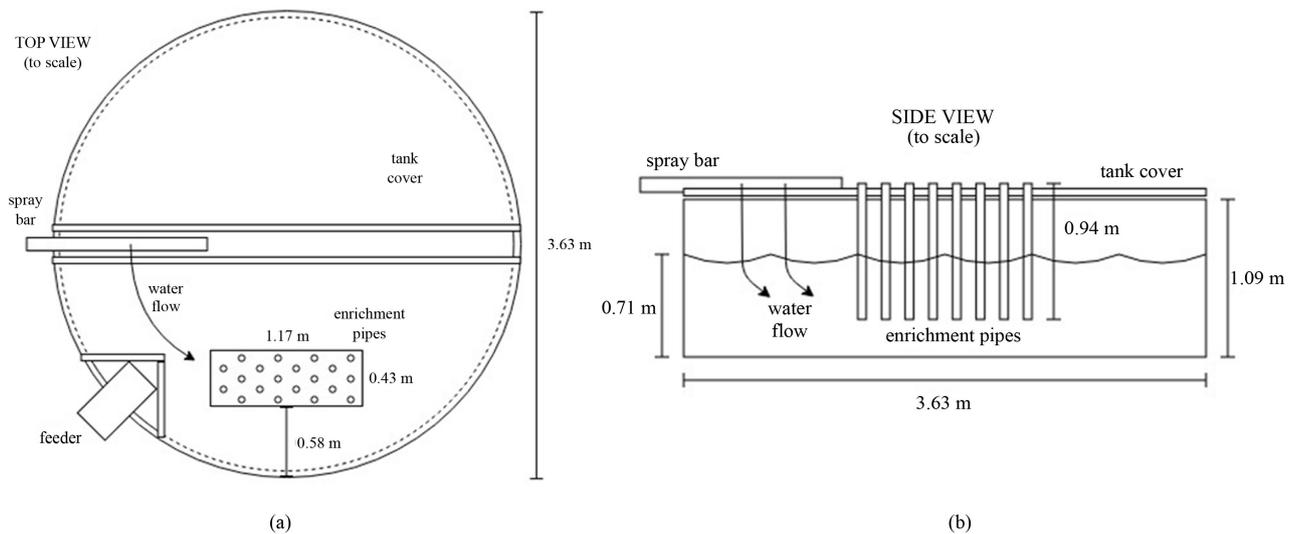


Figure 1. (a) Top view of a 3.63 m diameter circular tank indicating location of suspended plastic array used as environmental enrichment; (b) Side view of a 3.63 m diameter circular tank containing the array of suspended plastic conduit.

a projected growth rate of 0.08 cm/day and a planned feed conversion of 1.1.

Total tank weights were recorded to the nearest 0.2 kg at the conclusion of the experiment. Also at the end of study, ten randomly sampled fish from each tank were weighed to the nearest 0.1 g, and total length was measured to the nearest 1.0 mm.

The following equations were used:

Total weight gain = final tank weight – initial tank weight

Feed conversion ratio (FCR) = total feed fed to tank/total tank weight gained

Condition factor (K) = $10^5 \times [\text{weight}/(\text{body length})^3]$

Data were analyzed using the SPSS (24.0) statistical analysis program (Systat Software, Inc., Chicago, Illinois, USA) using one-way Analysis of Variance (ANOVA). Because the tanks were the experimental units, not individual fish, nested ANOVA was conducted on the individual fish data. Because of the small sample sizes (N = 3), significance was pre-determined at $P < 0.10$ [26].

3. Results

Feed conversion ratio was significantly improved in the tanks of Atlantic salmon containing environmental enrichment compared to control tanks (**Table 1**; $F_{1,4} = 4.867$, $P = 0.092$). Final tank weights and weight gain were not significantly different, although the difference in mean gain of 182.0 kg in the enriched tanks compared to 162.9 kg in the control tanks approached significance ($F_{1,4} = 4.500$, $P = 0.101$). There were no significant differences observed between the treatments for individual fish body length ($F_{1,4} = 0.155$, $P = 0.714$), weight ($F_{1,4} = 0.511$, $P = 0.514$), or condition factor ($F_{1,4} = 1.596$, $P = 0.275$; **Table 2**). Mortality for all tanks was not significantly different and was less than 2%.

Table 1. Mean \pm SE total tank weights, gain, food fed, and feed conversion ration (FCR^a) for Atlantic salmon reared with or without vertically-suspended environmental enrichment structures. Means with different letters within the same row differ significantly ($P < 0.10$, $N = 3$).

Variable	Control	Enriched	F _{1,4}	P
Rearing days	168	168		
Initial weight (kg)	71.5 \pm 0.4	70.9 \pm 0.4	1.373	0.306
Final weight (kg)	232.8 \pm 4.6	251.7 \pm 8.1	4.070	0.114
Gain (kg)	162.9 \pm 4.9	182.0 \pm 7.5	4.500	0.101
Food fed (kg)	184.7 \pm 0.00	184.7 \pm 0.00		
FCR	1.14 \pm 0.03 z	1.02 \pm 0.04 y	4.867	0.092

^aFCR = total food fed/tank gain.

Table 2. Mean \pm SE individual fish total length, weight, and condition factor (K^a) for Atlantic salmon reared with or without vertically-suspended environmental enrichment structures ($N = 3$).

Variable	Control	Enriched	F _{1,4}	P
Length (mm)	396 \pm 11	402 \pm 8	0.155	0.714
Weight (g)	744.5 \pm 75.8	802.2 \pm 27.5	0.511	0.514
K	1.19 \pm 0.02	1.24 \pm 0.04	1.596	0.275

^aK = $10^5 \times$ individual weight/body length³.

4. Discussion

The addition of vertically-suspended plastic conduit had positive effects on Atlantic salmon rearing performance when used for 168 days in this experiment. These results differ from White *et al.* [23], who reported no significant improvement in Atlantic salmon feed conversion or growth after 125 days of rearing with another form of vertically-suspended environmental enrichment in much smaller circular tanks. Study duration may be a crucial determinant for observing significant results. Brockmark *et al.* [12] observed no effect of environmental enrichment on Atlantic salmon growth after 123 days, but reported growth improvements with enrichment after 311 rearing days. Similarly, White *et al.* [23] reported that vertically suspended structures did not produce any improvements in brown trout (*Salmo trutta*) or Chinook salmon (*Oncorhynchus tshawytscha*) growth at 59 and 78 days, respectively. However, improvements in rearing performance were reported for brown trout growth after 126 days [22] and Chinook salmon at 90 days [21].

This experiment produced similar results to numerous other studies investigating vertically-suspended environmental enrichment during salmonid rearing [18] [19] [20] [21] [22]. Only White *et al.* [23] was unable to discern any positive effects of such enrichment on the rearing performance of salmonids. Although Näslund and Johnsson [27] suggest that environmental enrichment techniques

may need to be modified to fit the needs of individual fish species, the consistent results obtained using vertically-suspended structure appear to indicate a more universal response, at least among salmonids.

The alteration of water velocity behind the suspended conduit array may be responsible for the positive affect on Atlantic salmon feed conversion ratio observed in this study. Moine *et al.* [28] and Muggli *et al.* [29] reported that vertically-suspended structure arrays produce significant changes in circular tank water velocity profiles, with decreased water velocities behind the arrays. These lower velocity microhabitats likely positively influence fish energy expenditure [18] [30]. In addition, the existence of a variety of in-tank water velocities may allow fish to experience periodic exercise [29] [31]. Exercise from higher velocities is beneficial to fish [32] [33] [34] as long as it is not for extended periods of time [35] [36].

Routine fish husbandry demands were not negatively affected by the use of the conduit arrays in this study. The vertically-suspended environmental enrichment maintained the self-cleaning nature of the circular tanks, as has also been reported by Kientz and Barnes [18], Kientz *et al.* [19], and White *et al.* [22]. Although other types of vertically-suspended arrays have been shown to decrease velocities below the level needed for hydraulic self-cleaning [29], the structure used in this study is acceptable for use in production fish hatcheries where circular tanks must be self-cleaning.

Suspended structure did not significantly affect individual fish length, weight, or condition factor. This may be due to small sample sizes [37]. The lack of attention to sexual dimorphism may also have played a role; the ten fish sampled from each tank in this study were chosen at random, without regard to sex. The differences in body size between male and female Atlantic salmon [38] [39] likely produced the relatively high variance in individual fish metrics, which would be particularly pronounced if the sample was dominated by one gender.

5. Conclusion

In conclusion, the vertically-suspended environmental enrichment structures used in this study produced improvements in Atlantic salmon rearing performance. It is unknown if such improvements would become more pronounced over a longer rearing period. Given that these structures did not interfere with circular tank hydraulic self-cleaning, their use is recommended during the hatchery rearing of Atlantic salmon. Future studies should focus on even longer study durations, the possible physiological changes induced by the use of vertically-suspended structure, and their potential effects on post-release survival for salmon reared at conservation or recreational fish hatcheries.

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Conflicts of Interest

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

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