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Use of a Large Vertically-Suspended Rod Array in Circular Tanks during Juvenile Rainbow Trout Rearing

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Abstract

Environmental enrichment is the inclusion of materials into hatchery rearing tanks to create more natural or complex environments. This study evaluated juvenile rainbow trout *Oncorhynchus mykiss* rearing with the use of a vertically-suspended array consisting of 15 rods in comparison to an established enrichment array of nine vertically-suspended rods, and unenriched controls. At the end of 116 days, there were no significant differences in gain, feed conversion ratio, total length, or individual fish weight among any of the treatments. In addition, relative fin lengths were also not significantly different among the treatments. These results were likely impacted by the high final rearing densities of approximately 70 kg/m^3 in all of the treatments, as well as possible feeding levels below satiation, as indicated by the feed conversion ratios of less than 0.88.

Keywords: environmental enrichment; structure; *Oncorhynchus mykiss*; salmonids

Introduction

Typically, fish hatchery rearing tanks are devoid of any type of internal structure to facilitate routine cleaning and also reduce areas where pathogens could potentially reside [1,2]. Environmental enrichment is defined as the addition of complexity to these otherwise barren rearing environments [3]. Enrichment has been used during salmonid rearing to try and increase post stocking survival [4,5,6], promote learning and behavioral adaptations [7,8,9], improve fin condition [10,11], and also to increase growth during hatchery rearing [12,13,14,15,16].

Enrichment techniques have ranged from placing real or plastic vegetative material in tanks [4,6,7,9,11,17], to cobble-based bottom structures [8,9,10,17]. While these methods may have been beneficial to the fish, they were typically not appropriate for use in production hatcheries because they impede the hydraulic self-cleaning inherent to circular tanks [18,19]. However, Kientz and Barnes [12] described vertically-suspended environmental enrichment that did not affect tank self-cleaning, but also improved rainbow trout *Oncorhynchus mykiss* growth during hatchery rearing. Other arrays of vertically-suspended structures have also produced positive results during salmonid rearing [13,14,15,16,20]. However, one study did not observe any hatchery-rearing benefits from using suspended environmental enrichment [21].

In the studies where vertically-suspended arrays have produced growth benefits, some of the largest improvements have been associated with increased water volume displacement by the environmental enrichment (i.e. better growth with bigger structures). The rod array successfully used previously consisted of only nine aluminum rods [12,13,16]. The objective of this study was to evaluate an expanded array of 15 rods during rainbow trout rearing in circular tanks.

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; alkalinity as $CaCO_3$, 210 mg/L; pH, 7.6; total dissolved solids, 390 mg/L). Approximately 1,800 (7.2 kg/ tank) juvenile Shasta strain rainbow trout (mean ± SE, weight and total length; 4 ± 1 g, and 70.8 ± 1.8 mm; n = 30) were placed into 12 fully covered, 2,000 L circular tanks (1.8 m diameter, 0.8 m depth, 0.6 m operating depth). Incoming water velocities were 12.2 cm/s. This 116 day study began on June 1, 2017 and ended on September 26, 2017.

Two different vertically-suspended enrichment treatments were used, in addition to a control with no suspended structure (n = 4). One treatment used an array of nine aluminum rods (0.95 cm diameter x 57.15 cm long) suspended vertically through a corrugated plastic tank cover as described by Kientz and Barnes [12] (figure 1). The other treatment expanded the nine-rod array to 15 rods to encompass a 50 x 24 cm area. This doubled the rod coverage area from 600 cm^2 for the 9 rod array to 1,200 cm^2 for the 15 rod array.

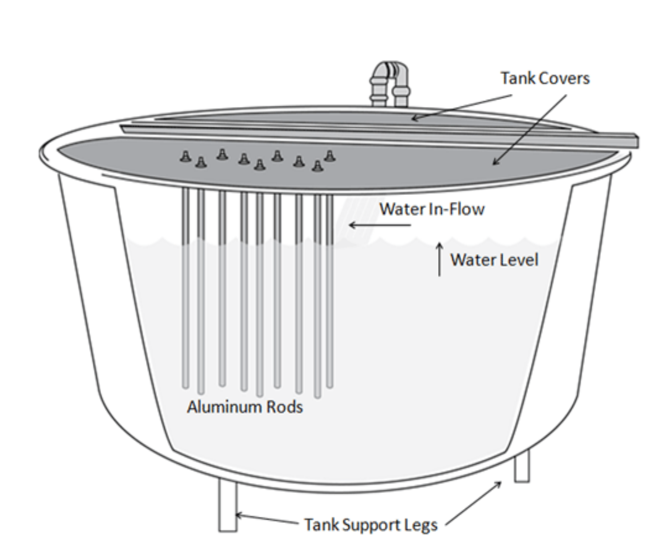

Figure 1: Schematic of a 2,000 L circular rearing tank (1.8 m diameter, 0.8 m deep, 0.6 m operating depth) containing a 9-rod array as environmental enrichment.

Fish were fed a diet of 1.5 mm floating Classic Trout feed (Skretting USA, Tooele, Utah, USA) every 15 min during daylight hours using automatic feeders. Feeding rates were determined by the hatchery constant method [22], with an expected feed conversion ratio of 1.1 and a projected growth rate of 0.08 cm/d.

At the end of the experiment, total tank weights were recorded to the nearest 0.1 kg. A subsample of five fish per tank were individually weighed to the nearest 0.1 g, and measured (total length) to the nearest 1.0 mm, with fin (dorsal, pectoral, and pelvic) lengths measured to the nearest 0.01 mm. To calculate gain, percent gain, Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), condition factor (K), and relative fin lengths [23], the following equations were used:

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

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

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

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

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

$$\text{Relative fin length} = 100 * \frac{\text{fin length}}{\text{fish length}}$$

Data were analyzed using the SPSS (9.0) statistical analysis program (SPSS, Chicago, Illinois, USA). Individual tanks were the experimental units, not individual fish. Thus, for individual fish lengths and weights, the mean of the individual fish sampled in each tank was used for analysis. One way Analysis of Variance (ANOVA) was conducted, and if the treatments were significantly different, pair wise mean comparisons were performed using the Tukey HSD test. Because of the small sample sizes used in this experiment (n=4), significance was predetermined at $P < 0.10$ [24].

Results

There were no significant differences in tank ending weights, gain, percent gain, or feed conversion ratio among any of the treatments (table 1). Similarly, there were no significant differences in individual fish weight, length, specific growth rate, or relative fin lengths among the treatments (table 2).

Table 1: Mean (± SE) final tank weights, gain, percent gain, Feed Conversion Ratio (FCR[a]), and percent mortality for rainbow trout reared in circular tanks with no environmental enrichment, a vertically-suspended array of nine rods, or a vertically-suspended array of 15 rods.
[a]FCR = Food fed / gain

	Environmental Enrichment		
	None	**9-Rod Array**	**15-Rod Array**
End tank weight (kg)	107.7 ± 1.4	108.3 ± 1.8	106.3 ± 1.7
Gain (kg)	100.5 ± 1.4	101.1 ± 1.8	99.1 ± 1.7
Gain (%)	1396 ± 19	1404 ± 25	1376 ± 24
Food fed (kg)	86.7 ± 0.0	86.7 ± 0.0	86.7 ± 0.0
FCR	0.86 ± 0.01	0.86 ± 0.01	0.88 ± 0.02
Mortality (%)	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0

Table 2: Mean (± SE) length, weight, Specific Growth Rate (SGR[a]), condition factor (K[b]), and relative fin lengths[c] of rainbow trout reared in circular tanks with no environmental enrichment, a vertically-suspended array of nine rods, or a vertically-suspended array of 15 rods.
[a] SGR = 100 * [ln(end weight) – ln(start weight)/number of days]
[b] K = 10^5 * [fish weight/fish length^3]
[c] Relative fin length = 100 * [fin length/fish length]

	Environmental Enrichment		
	None	**9-Rod Array**	**15-Rod Array**
Length (mm)	179 ± 2	175 ± 2	181 ± 1
Weight (g)	63.9 ± 3.7	60.6 ± 1.6	66.2 ± 5.0
K	1.12 ± 0.06	1.12 ± 0.02	1.12 ± 0.07
SGR	2.33 ± 0.01	2.34 ± 0.01	2.32 ± 0.01
Dorsal length (%)	6.2 ± 0.3	6.6 ± 0.4	6.6 ± 0.7
Pectoral length (%)	8.4 ± 0.6	8.6 ± 0.1	7.6 ± 0.4
Pelvic length (%)	6.7 ± 0.5	6.8 ± 0.3	6.5 ± 0.3

Discussion

Increasing the size of the array from the nine rods previously used [12,13] to 15 rods did not positively affect rainbow trout growth. The duration of this experiment and starting size of the fish may explain the difference in results compared to prior studies that reported positive effects of enrichment on rainbow trout growth using the same rearing tanks, genetic strain, and feeding rates [12,13]. However, other methods used in these two previous studies did differ substantially from this study. They used fish three times larger, had study durations of 51 and 70 days, respectively, and achieved a highest final density of 72.1 kg/m^3 in only one treatment, with all of the other treatments below 60.9 kg/m^3. In contrast, this study began with relatively small fish, lasted 116 days, and all three of the treatments had final densities of approximately 70 kg/m^3. It is possible that the trout in the experimental tanks initially grew more rapidly at the start of the experiment, with growth slowing as they quickly achieved relatively high densities. Numerous studies have found reduced growth rates at higher densities, with two [25,26] reporting reduced growth rates of juvenile rainbow trout at high rearing densities. A review paper stated that 30 out of 40 published experiments reported a negative effect of increased density on rainbow trout growth [27]. In addition, an upper limit of 50 kg/m^3 for rainbow trout has been suggested [28], which was much less than the final densities used in the current experiment. This suggests that the fish in the control tanks may have grown more slowly throughout the course of the trial and only achieved the high final densities because of the long duration of the experiment. Supporting this argument are the results from the 141 day experiment using 1.8 g trout conducted previously, which also showed only small differences in treatment effects with final densities ranging from 65.8 kg/m^3 to 70.8 kg/m^3 [14].

The feed conversion ratios of 0.86 to 0.88 reported in this study were lower than the values previously reported for rainbow trout in similar experiments [2,13,15]. Substantially higher feed conversion ratios of 1.25 and 1.31 for enriched tanks using the same feeding rates and regimes as this present study have been noted previously [2,13]. The smaller starting size of the juvenile fish in this study may partially explain the lower feed conversion ratios [29], but fish size alone likely does not explain the lack of significant differences between treatments. In addition, while the satiation feeding rates used in this study were based on prior studies and numerous observations, it is possible that the fish may have been able to consume additional feed.

The lack of difference in feed conversion ratio and gain among the treatments in this study may not support the hypothesis that environmental enrichment creates an area of reduced velocity that leads to improvements in foraging efficiency compared to un-enriched tanks [12,30,31]. Also, one study did not observe any significant improvement in growth or feed conversion ratio with the use of vertically-suspended structures utilizing brown trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), or Chinook salmon (*Oncorhynchus tshawytscha*) [21]. However, numerous other studies evaluating vertically suspended environmental enrichment structures have reported positive effects on feed conversion ratio and gain [12,13,14,15].

While the use of environmental enrichment in sterile tank environments for fish rearing is not a novel concept, vertically-suspending structure is a very recent development. Many experiments have used a bottom structure or matrix to mimic natural environments [2,4,5,6,7,8,9,10,32,33,34,35,36]. However, these types of structures can impede the hydraulic self-cleaning inherent to circular tanks [2,18,37]. Just as reported by Crank et al. [15] who used different vertically-suspended enrichment structures, neither of the rod arrays used in this trial affected tank self-cleaning with appropriate tank velocities.

The relative fin lengths in this study were similar to those obtained by Kientz et al. [13] and lower than those obtained by Crank et al. [15] using the same strain of rainbow trout and tanks. However, Crank et al. [15] used relatively low initial stocking densities which may have led to less fin abrasion and aggressive behavior. Environmental enrichment has been hypothesized to reduce aggression while providing areas of shelter for subordinate fish to hide, which in turn improves fin conditions [3]. These behaviors have been observed in Atlantic salmon [7] and steelhead trout (*Oncorhynchus mykiss*) [38,39]. Enriching raceways with cobble-based bottoms has also been shown to improve fin indices of rainbow trout [18]. Fin erosion comparisons across different strains of rainbow trout is difficult to compare as there could possibly be genetic differences for fin sizes across strains [40]. Hatchery fish in general have reduced fin lengths in comparison to their wild counterparts due to "fin-nipping" and aggressive behaviors [41,42], tank or raceway wall abrasion, and density related fin erosional processes [43,44,45]. The vertically-suspended rod arrays used in this study may not have provided enough hiding or refuge areas to impact the social behaviors related to aggression and fin condition [3].

Conclusion

The results of this study do not support the use of vertically-suspended structure as environmental enrichment to improve rainbow trout growth during hatchery rearing. However, these results should be interpreted with caution. They were likely influenced by potentially below-satiation feeding rates, as well as very high final rearing densities. In addition, many prior studies have consistently reported benefits from the use of vertically-suspended environmental enrichment in circular rearing tanks.

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Declarations

Conflict of Interest: NA

Ethical Approval: NA

References

1. Baynes SM, Howell BR. Observations on the growth, survival and disease resistance of juvenile common sole, *Solea solea* L. Aquac Fish Manag. 1993;24(1):95-100.
2. Krebs J, Crank KM, Krebs E, Barnes ME. Use of bottom structure and tank cover during rainbow trout rearing in circular tanks. Journal of Fisheries & Livestock Production. 2017;5(3):247.
3. Näslund J, Johnsson JI. Environmental enrichment for fish in captive environments: effects of physical structures and substrates. Fish Fish. 2014;17(1):1-30.
4. Berejikian BA, Tezak EP, Flagg TA, LaRae AL, Kummerow E, Mahnken CVW. Social dominance, growth, and habitat use of age-0 steelhead *Oncorhynchus mykiss* grown in enriched and conventional hatchery rearing environments. Canadian Journal of Fisheries and Aquatic Sciences. 2000;57(3):628-636.
5. Hyvärinen P, Rodewald P. Enriched rearing improves survival of hatchery-reared Atlantic salmon smolts during migration in the River Tornionjoki. Canadian Journal of Fisheries and Aquatic Sciences. 2013;70(9):1386-1395.
6. Roberts LJ, Taylor J, Gough PJ, Forman DW, Garcia de Leaniz C. Silver spoons in the rough: can environmental enrichment improve survival of hatchery Atlantic salmon *Salmo salar* in the wild. J Fish Biol. 2014;85(6):1972-1991.
7. Näslund J, Rosengren M, Del Villar D, Gansel L, Norrgård JR, Persson L, et al. Hatchery tank enrichment affects cortisol levels and shelter-seeking in Atlantic salmon (*Salmo salar)*. Canadian Journal of Fisheries and Aquatic Sciences. 2013;70(4):585-590.
8. Salvanes AGV, Moberg O, Ebbesson LOE, Nilsen TO, Jensen KH, Braithwaite VA. Environmental enrichment promotes neural plasticity and cognitive ability in fish. Proc Royal Soc B. 2013;280(1767).
9. Bergendahl IA, Miller S, Depasquale C, Giralico L, Braithwaite VA. Becoming a better swimmer: structural complexity enhances agility in a captive-reared fish. J Fish Biol. 2016;90(3):1112-1117.
10. Bosakowski T, Wagner EJ. Experimental use of cobble substrates in concrete raceways for improving fin condition of cutthroat (*Oncorhynchus clarkii*) and rainbow trout (*Oncorhynchus mykiss*). Aquaculture. 1995;130(2-3):159-165.
11. Berejikian BA. Rearing in enriched hatchery tanks improves dorsal fin quality of juvenile steelhead. N Am J Aquac. 2005;67(4):289-293.
12. Kientz JL, Barnes ME. Structural complexity improves the rearing performance of rainbow trout in circular tanks. N Am J Aquac. 2016;78(3):203-207.
13. Kientz JL, Crank KM, Barnes ME. Enrichment of circular tanks with vertically suspended strings of colored balls improves rainbow trout rearing performance. N Am J Aquac. 2018;80(2):162-167.
14. Krebs E, Huysman N, Voorhees JM, Barnes ME. Suspended arrays improve rainbow trout growth during hatchery rearing in circular tanks. International Journal of Aquaculture and Fishery Sciences. 2018;4(3):27-30.
15. Crank KM, Kientz JL, Barnes ME. An evaluation of vertically suspended environmental enrichment structures during rainbow trout rearing. N Am J Aquac. 2019;81(1):94-100.
16. White SC, Krebs E, Huysman N, Voorhees JM, Barnes ME. Use of suspended plastic conduit arrays during brown trout and rainbow trout rearing in circular tanks. N Am J Aquac. 2019;81(1):101-106.
17. Cogliati KM, Herron CL, Noakes DLG, Schreck CB. Reduced stress response in juvenile Chinook salmon reared with structure. Aquaculture. 2019;504:96-101.
18. Timmons MB, Summerfelt ST, Vinci BJ. Review of circular tank technology and management. Aquacultural Engineering. 1998;18(1):51-69.
19. Lekang OI. Aquaculture Engineering. 2nd ed. Chichester: Wiley-Blackwell. 2013.
20. Rosburg AJ, Fletcher BL, Barnes ME, Treft CE, Bursell BR. Vertically suspended environmental enrichment structures improve the growth of juvenile landlocked fall Chinook salmon. International Journal of Innovative Studies in Aquatic Biology and Fisheries. 2019;5(1):17-24.
21. White SC, Barnes ME, Krebs E, Huysman N, Voorhees JM. Addition of vertical enrichment structures does not improve growth of three salmonid species during hatchery rearing. Journal of Marine Biology and Aquaculture. 2018;4(1):48-52.
22. Buterbaugh GL, Willoughby H. A feeding guide for brook, brown, and rainbow trout. The Progressive Fish-Culturist. 1967;29(4):210-215.
23. Kindschi GA. Method for quantifying degree of fin erosion. The Progressive Fish-Culturist. 1987;49(4):314-315.
24. Cohen J. A power primer. Psychological Bulletin. 1992;112(1):155-159.
25. Holm JC, Refstie T, Bø S. The effect of fish density and feeding regimes on individual growth rate and mortality in rainbow trout (*Oncorhynchus mykiss*). Aquaculture. 1990;89(3-4):225-232.
26. Procarione LS, Barry TP, Malison JA. Effects of high rearing densities and loading rates on the growth and stress responses of juvenile rainbow trout. N Am J Aquac. 1999;61(2):91-96.
27. Ellis T, North B, Scott AP, Bromage NR, Porter M, Gadd D. The relationships between stocking density and welfare in farmed rainbow trout. J Fish Biol. 2002;61(3):493-531.
28. Mäkinen T, Ruohonen K. The effect of rearing density on the growth of Finnish rainbow trout (*Oncorhynchus mykiss* Walbaum 1792). J Appl Ichth. 1990;6(4):193-203.
29. Robinson EH, Li MH. Feed conversion ratio for pond-raised catfish. Mississippi Agricultural and Forestry Experiment Station. 2015;1364.
30. Moine J, Barnes ME, Kientz J, Simpson G. Flow patterns in circular rearing tanks containing vertical structure. Journal of Fisheries & Livestock Production. 2016;4:4.
31. Muggli AM, Barnes JM, Barnes ME. Vertically suspended environmental enrichment alters the velocity profiles of circular fish rearing tanks. World Journal of Engineering and Technology. 2019;7(1):208-226.
32. Maynard DJ, Flagg TA, Mahnken CVW. A Review of Seminatural Culture Strategies for Enhancing the Postrelease Survival of Anadromous Salmonids. In: Schramm Jr. HL, Piper RG, editors. Uses and effects of cultured fishes in aquatic ecosystems. Symposium 15; Bethesda: American Fisheries Society. 1995:307-314.

33. Berejikian BA, Smith RJF, Tezak EP, Schroder SL, Knudsen CM. Chemical alarm signals and complex hatchery rearing habitats affect antipredator behavior and survival of Chinook salmon *Oncorhynchus tshawytscha* juveniles. Canadian Journal of Fisheries and Aquatic Sciences. 1999;56(5):830-838.
34. Brown C, Davidson T, Laland K. Environmental enrichment and prior experience of live prey improve foraging behavior in hatchery-reared Atlantic salmon. J Fish Biol. 2003;63(s1):187-196.
35. Fast DE, Neeley D, Lind DT, Johnston MV, Strom CR, Bosch WJ, et al. Survival comparison of spring Chinook salmon reared in a production hatchery under optimum conventional and seminatural conditions. Trans Am Fish Soc. 2008;137(5):1507-1518.
36. Roberts LJ, Taylor J, Garcia de Leaniz C. Environmental enrichment reduces maladaptive risk-taking behavior in salmon reared for conservation. Biological Conservation. 2011;144(7):1972-1979.
37. Tvinnereim K, Skybakmoen S. Water Exchange and Self-cleaning in Fish-rearing Tanks. In: De Pauw N, Jaspers E, Ackefors H, Wilkens N, editors. Aquaculture: A biotechnology in progress. Bredena: European Aquaculture Society. 1989:1041-1047.
38. Berejikian BA, Tezak EP, LaRae AL, Riley SC. Competitive ability and social behavior of juvenile steelhead reared in enriched and conventional hatchery tanks and a stream environment. J Fish Biol. 2001;59(6):1600-1613.
39. Lee JSF, Berejikian BA. Effects of the rearing environment on average behaviour and behavioural variation in steelhead. J Fish Biol. 2008;72(7):1736-1749.
40. Bosakowski T, Wagner EJ. Assessment of fin erosion by comparison of relative fin length in hatchery and wild trout in Utah. Canadian Journal of Fisheries and Aquatic Sciences. 1994;51(3):636-641.
41. Abbott JC, Dill LM. Patterns of aggressive attack in juvenile steelhead trout (*Salmo gairdneri*). Canadian Journal of Fisheries and Aquatic Sciences. 1985;42(11):1702-1706.
42. Latremouille DN. Fin erosion in aquaculture and natural environments. Reviews in Fisheries Science. 2003;11(4):315-335.
43. Wagner EJ, Intelmann SS, Routledge MD. The effects of fry rearing density on hatchery performance, fin condition, and agonistic behavior of rainbow trout *Oncorhynchus mykiss* fry. J W Aquac Soc. 1996;27(3):264-274.
44. Brockmark S, Neregård L, Bohlin T, Björnsson BT, Johnsson JI. Effects of rearing density and structural complexity on the pre and postrelease performance of Atlantic salmon. Trans Am Fish Soc. 2007;136(5):1453-1462.
45. Calabrese S, Nilsen TO, Kolarevic J, Ebbesson LOE, Pedrosa C, Fivelstad S, et al. Stocking density limits for post-smolt Atlantic salmon (*Salmo salar* L.) with emphasis on production performance and welfare. Aquaculture. 2017;468(1):363-370.