Open Journal of Marine Science, 2021, 11, 80-91
https://www.scirp.org/journal/ojms
ISSN Online: 2161-7392
ISSN Print: 2161-7384

Exercise and Structure Improve Juvenile Chinook Salmon Rearing Performance

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How to cite this paper: Voorhees, J.M., Huysman, N., Krebs, E. and Barnes, M.E. (2021) Exercise and Structure Improve Juvenile Chinook Salmon Rearing Performance. *Open Journal of Marine Science*, **11**, 80-91.
https://doi.org/10.4236/ojms.2021.112006

Received: March 9, 2021
Accepted: April 22, 2021
Published: April 25, 2021

Abstract

This experiment evaluated the use of an exercise routine and vertically-suspended structure during juvenile landlocked fall Chinook salmon (*Oncorhynchus tshawytscha*; mean ± SE, initial weight 1.47 ± 0.03 g, total length 56.4 ± 0.4 mm) rearing. Four treatments were used: 1) no exercise routine nor vertically-suspended structure, 2) exercise and structure, 3) exercise and no structure, and 4) no exercise and structure. Water velocities in tanks without exercise were 12 cm/s, where-as the exercise routine consisted of seven days at 12 cm/s followed by seven days at 18 cm/s. The structure was an array consisting of four vertically-suspended aluminum angles. Total tank gain and percent gain were significantly greater after 50 days in the tanks of salmon subjected to the exercise routine and structure compared to the three other treatments. Gain and percent gain were also significantly greater in the tanks receiving structure without exercise compared to tanks with exercise and no structure or tanks with neither exercise nor structure. Feed conversion ratio was significantly improved in the salmon tanks with structure and without exercise compared to all other treatments. There were no significant differences for individual fish weight, total length, specific growth rate, or condition factor among any of the treatments at the end of the experiment. These results indicate that the use of both an exercise routine and vertically-suspended structure may be beneficial during the rearing of juvenile landlocked fall Chinook salmon.

Keywords

Environmental Enrichment, Salmonid, *Oncorhynchus tshawytscha*, Vertically-Suspended

1. Introduction

Exercise and structure are both forms of environmental enrichment during hatchery rearing. The benefits of using either on fish growth have been well documented. In particular, exercise has been shown to increase growth [1] [2] [3] [4], swimming performance [1] [5], disease resistance [4] [6], and post-stocking survival [7]. In addition, exercise decreases stress levels [8], stress recovery time [9] [10] [11], and agonistic behavior [12] [13]. Structural enrichment has produced similar benefits [14] [15].

While fish in circular tanks can be easily exercised by simply adjusting in-tank radial velocities, the addition of structure has been varied and complex. Parts of trees [16] [17] [18] [19] [20], cobble [19] [21] [22] [23], artificial plant material [24] [25] [26] [27] [28], concrete blocks [29], and polyvinyl chloride [17] [27] [28] [30] [31] [32] have all been added to hatchery rearing tanks. Although many of these structures have produced positive results, they are not practical on a production scale because the addition of these structures impedes the hydraulic self-cleaning nature of circular tanks, dramatically increasing tank cleaning labor and the possibility of disease outbreaks [29] [33] [34].

To retain the inherent self-cleaning of circular tanks and also provide in-tank enrichment, Kientz and Barnes [35] developed vertically-suspended structure. Kientz and Barnes [35] observed hatchery rearing improvements associated with the vertical-suspension of an aluminum rod array. Subsequent experiments with suspended strings of spheres, aluminum angles, and plastic conduit produced similar benefits during the rearing of salmonids [15] [35]-[41]. However, positive results from vertically-suspended structure were not observed by White *et al.* [42], Huysman *et al.* [43], and Jones *et al.* [44]. Because these structures are vertically-suspended they do not interfere with the self-cleaning nature of circular tanks like the other structures discussed do.

Little research has been done evaluating the potential impacts of using both exercise and structure. These experiments have all used juvenile rainbow trout (*Oncorhynchus mykiss*) and the results have been inconsistent. Voorhees *et al.* [45] noted a significant interaction between exercise and vertically-suspended structure on trout rearing performance. In contrast, Voorhees *et al.* [46] reported no such interaction, stating that each form of environmental enrichment is likely acting independently. This study was undertaken to provide more clarity into the possible combined effects of both an exercise regime and vertically-suspended structure. In addition, juvenile fall Chinook salmon (*Oncorhynchus tshawytscha*) were used to expand the knowledge base beyond rainbow trout.

2. Methods

This study occurred at McNenny State Fish Hatchery, rural Spearfish, South Dakota, USA, using degassed and aerated well-water (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). Juvenile Chinook salmon (mean ± SE, length: 56.4 ± 0.4 mm, weight: 1.47 ± 0.03 g, n = 110) were reared in twelve circular tanks (1.8 m diameter × 0.6

m deep; 0.4 m water depth). Approximately 10,000 fish (14.7 kg) were placed into each tank on February 6, 2019. This study lasted for 50 days.

Four treatments (n = 3) were used: 1) no routine exercise nor vertically-suspended structure (control), 2) both an exercise routine and structure, 3) exercise routine and no structure, and 4) no exercise routine and structure. Water velocities in tanks without exercise were 12 cm/s, where-as the exercise routine consisted of alternating seven days at 12 cm/s followed by seven days at 18 cm/s. Velocities were measured directly behind the spray bar at a depth of 0.2 m (halfway in water column) using a flowmeter (JDC Electronics Flowatch Flowmeter, JDC, Yverdon-les-Bains, Switzerland). Tank velocities were adjusted by adjusting the angle of the spray bars, and water flows were kept constant throughout the study. All tanks, regardless of treatment, were almost fully covered with corrugated plastic as described by Walker *et al.* [47]. The vertically-suspended structure used was an array of four aluminum angles suspended through the corrugated-plastic covers as described by Krebs *et al.* [36].

Feed was projected using the hatchery constant method [48] with an expected feed conversion ratio of 1.1. The feeding rates used were at or slightly above satiation and varied between the exercise and non-exercise treatments [49]. Tanks of fish not subjected to the exercise routine were fed for a projected growth rate of 0.065 cm/day, while exercised fish were fed for a projected growth rate of 0.75 cm/day.

At the end of the experiment ten fish from every tank were individually weighed to the nearest 1.0 g and measured (total length) to the nearest 1.0 mm, and the total biomass of each tank was weighed to the nearest 0.05 kg. The following equations were used:

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

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

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

$$\text{Specific Growth Rate}(\text{SGR}) = 100 * \left[(\ln(\text{end weight}) - \ln(\text{start weight}))/(\text{number of days})\right]$$

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

One-way Analysis of Variance (ANOVA) was used to analyze the data with SPSS (24.0) statistical program (IBM, Armonk, New York, USA). Because the tanks were the experimental units, and not the individual fish, nested ANOVA was conducted on individual fish data. If the ANOVA indicated significant differences, Fisher's Protected Least Significant Difference procedure was used for pair-wise comparisons. Significance was pre-determined at $P < 0.05$.

3. Results

Final tank weight, gain, and percent gain were all significantly greater in the tanks of fish receiving both an exercise routine and structure compared to all other treatments (Table 1). Gain and percent gain were also significantly greater in the tanks receiving structure without exercise compared to tanks with exercise and no structure or tanks with neither exercise nor structure. Feed conversion ratio was significantly better in the unexercised tanks with structure (mean ± SE; 1.02 ± 0.01), compared to unexercised and unstructured tanks (1.15 ± 0.03) which was similar to routine exercise with structure (1.18 ± 0.03). The tanks on routine exercise without structure were significantly poorer than all other treatments (1.45 ± 0.01). Percent mortality was relatively minor and not significantly different among the treatments.

There were no significant differences in individual fish length, weight, specific growth rate, or condition factor among any of the treatments (Table 2). Specific growth rates were similar among the treatments, ranging from 2.90 ± 0.08 (mean ± SE) in the fish receiving the exercise routine without structure to 3.04 ± 0.04 in the fish receiving both exercise and structure.

4. Discussion

The results of this study indicate that using two forms of environmental enrichment in combination can have positive effects during fish rearing. These results with Chinook salmon support those obtained by Voorhees *et al.* [45] with rainbow trout subjected to continual exercise. However, Voorhees *et al.* [46] reported no benefits of combining both exercise and structure during juvenile

Table 1. Mean ± SE final tank weight, gain, percent gain, food fed, feed conversion ratio (FCR[a]), and percent mortality of Chinook salmon reared with or without vertically-suspended structure and with or without routine exercise. Means with different letters in the same row differ significantly ($p < 0.05$; $n = 3$).

	Control			Exercise			Structure			Combination			*P*-value
Tank weight (kg)	55.7	±	1.1 x	55.0	±	0.3 x	60.7	±	0.4 y	64.1	±	1.1 z	0.000
Gain (kg)	41.0	±	1.1 x	40.3	±	0.3 x	46.0	±	0.4 y	49.4	±	1.1 z	0.000
Gain (%)	278.7	±	7.8 x	274.2	±	2.0 x	312.9	±	2.6 y	336.0	±	7.7 z	0.000
FCR	1.15	±	0.03 y	1.45	±	0.01 x	1.02	±	0.01 z	1.18	±	0.03 y	0.000
Mortality (%)	0.6	±	0.1	0.8	±	0.1	1.6	±	0.5	0.9	±	0.1	0.124

[a]FCR = food fed/gain.

Table 2. Individual mean ± SE total length, weight, specific growth rate (SGR[a]), and condition factor (K[b]) of Chinook salmon reared with or without vertically-suspended structure and with or without routine exercise ($n = 3$).

	Control			Exercise			Structure			Combination			*P*-value
Length (mm)	87.5	±	0.2	87.1	±	0.8	87.4	±	1.7	87.9	±	0.9	0.957
Weight (g)	7	±	0	6	±	0	6	±	0	7	±	0	0.695
SGR	3.01	±	0.08	2.9	±	0.08	2.98	±	0.11	3.04	±	0.04	0.681
K	0.98	±	0.03	0.94	±	0.01	0.97	±	0.02	0.98	±	0.01	0.574

[a]SGR = 100 * (ln (end weight) − ln (start weight))/(number of days). [b]K = 10^5 * (fish weight)/(fish length)^3.

rainbow trout rearing. The Voorhees *et al.* [46] study lasted 109 days, and final tank weights were likely excessive. As suggested by Huysman *et al.* [43], density-dependent growth rates may have hindered the ability to detect significant differences in the Voorhees *et al.* [46] experiment. Of course, there may be species-specific differences in response to environmental enrichment [14].

The intermittent exercise routine used in this study was designed to prevent exercise fatigue [50] [51]. Although a combination of both exercise and structure led to rearing improvements in this study, the lack of effect of exercise alone on Chinook salmon growth is not unexpected. Davison [52] indicated that Chinook salmon do not benefit from exercise and Parker and Barnes [53] reported similar growth between exercised and non-exercised Chinook salmon. Kiessling *et al.* [54] and Gallaugher *et al.* [12] observed decreased growth in exercised Chinook salmon. In other fish species, exercise has been shown to generally increase growth [1] [4] [6] [11] [50] [55]-[61], though this is not always the case [8] [13] [54].

The duration of this study was typical for other experiments evaluating intermittent exercise routines [2] [4] [6] [11] [12], as well as those using continuous exercise [1] [9] [13] [35] [49] [57] [62] [63]. The velocities used in this experiment correspond to approximately 2 to 3 body lengths/sec at the start and 1.5 to 2 body lengths/sec at the end, both of which are slightly faster than the 0.5 to 1.7 body lengths/sec suggested by McKenzie *et al.* [64]. However, these velocities were taken prior to structure and fish being added to tanks. Vertically-suspended structure radically changes and typically decreases circular tank water velocities [65] [66] [67], and the presence of fish alter velocity profiles as well [67] [68]. It is possible that the positive effect on gain observed in the tanks receiving both exercise and structure, in comparison to the lack of effect of just exercise, could be due to the water velocity changes caused by the aluminum angle array [35].

Similar to the results observed in this study, salmonid growth has been improved using a variety of vertically-suspended structures in numerous experiments [15] [35]-[41]. Rosburg *et al.* [41] also reported increased growth in similarly-sized landlocked fall Chinook salmon reared with vertically-suspended structure. However, no effects on salmonid growth from suspended structure were observed by White *et al.* [13], Huysman *et al.* [53], and Jones *et al.* [44].

The relatively poor feed conversion ratios observed in the exercised tanks was likely the result of over-feeding. Feeding rates were elevated in the exercise treatments because Parker and Barnes [49] indicated exercise only improved growth if food rations were increased in comparison to unexercised fish. Overall, the feed conversion ratios seen in this study are similar to those reported in other salmonid experiments evaluating exercise [46] [49] [69], vertically-suspended structure [15] [35] [36] [37] [38] [41] [42] [43] [44] [70] [71] [72], or exercise and structure in combination [45] [73]. However, Parker and Barnes [53] and Huysman *et al.* [39] reported poorer feed conversion ratios in their exercise and structure studies using landlocked fall Chinook salmon.

The lack of significant differences in individual fish lengths and weights is not surprising given the small sample sizes [74]. In addition, as is typically observed during the rearing of feral landlocked Chinook salmon at McNenny Hatchery, considerable variation in fish size was also evident and likely affected the ability to detect any significant differences in individual fish metrics [75].

The specific growth rate in this study is higher than that observed with exercised Chinook salmon by Kiessling *et al.* [54]. However, it is lower than the 4.5% reported by Huysman *et al.* [39] for the same strain of landlocked fall Chinook salmon. The salmon used in the Huysman *et al.* [39] study were smaller than those used in this study, and specific growth rate is affected by the size of the fish [76]. Huysman *et al.* [39] also reported a condition factor 20% lower than that reported in this study and by other authors examining Chinook salmon during rearing with exercise [8] [53] [54] or structure [40] [42] [70].

5. Conclusion

In conclusion, this study indicates that the use of both an exercise routine and vertically-suspended structure may be beneficial during the rearing of juvenile landlocked fall Chinook salmon. The exact mechanism where-by both exercise and structure are beneficial, while exercise alone is not, has yet to be determined. Additional research should be conducted on other possible benefits resulting from the combination of exercise and structure during the hatchery rearing of Chinook salmon, particularly with the positive effects of environmental enrichment on Chinook salmon stress reduction and post-stocking survival reported by Cogliati *et al.* [31] and Fast *et al.* [77]. There is also still a need to determine the ideal swimming speeds and exercise routines for the different sizes of nearly all fish species.

Acknowledgements

We thank Misty Jones and Lynn Slama for their assistance in this study.

Conflicts of Interest

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

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