JUVENILE FALL CHINOOK SALMON REARING PERFORMANCE IS NOT AFFECTED BY EXERCISE AND STRUCTURE

Shaylee R. Martling[1], Jill M. Voorhees[2], Nathan Huysman[2] and Michael E. Barnes[2]
[1]South Dakota Department of Game, Fish and Parks
Cleghorn Springs State Fish Hatchery
4725 Jackson Blvd.
Rapid City, South Dakota 57702, USA
[2]South Dakota Department of Game, Fish and Parks
McNenny State Fish Hatchery
19619 Trout Loop
Spearfish, South Dakota 57783, USA
*Corresponding author email: jill.voorhees@state.sd.us

ABSTRACT

This experiment evaluated the effects of exercise and in-tank structure on landlocked juvenile Chinook salmon (*Oncorhynchus tshawytscha*) rearing performance beginning six days after the start of feeding and continuing for 79 days. Three treatments were used: 1. no exercise routine nor vertically-suspended structure, 2. no exercise routine with structure, or 3. both an exercise routine and structure. The exercise routine consisted of alternating a baseline rotational velocity of 5 cm s^{-1} for 84 hours with an increased rotational water velocity of either 8 or 13 cm s^{-1} for 84 hours. Tanks of fish with no exercise routine and no structure had significantly improved final weight, weight gain, percent weight gain, and feed conversion ratio compared to the other two groups after the first 49 days of rearing. Individual fish weight, condition factor, and specific growth rate were also significantly greater in the no-exercise, no-structure tanks. However, there were no significant differences among treatments in any of the response variables during the 50 to 79-day rearing period or by the end of the experiment (day 79). These results indicate that the use of structure, either with or without an exercise routine, does not improve the growth of landlocked fall Chinook salmon during early rearing.

Keywords

Chinook salmon; environmental enrichment, structure, exercise

INTRODUCTION

The purpose of environmental enrichment during hatchery rearing is to create a more complex rearing environment than that found in traditionally barren hatchery rearing tanks (Huysman et al. 2020). Environmental enrichment has many different forms, including in-tank structure and exercise (Gerber et al. 2015; Näslund and Johnsson 2016). Numerous salmonid species have shown positive responses to exercise (Leon 1986; Anttila et al. 2011; Voorhees et al. 2018a, 2018b, 2020a). A number of salmonid species have also responded favorably to structure (Berejikian et al. 2000; Cogliati et al. 2019; White et al. 2019). However, experiments combining exercise and structure have produced inconsistent results (Kientz and Barnes 2016; Morris et al. 2020; Voorhees et al. 2020b, 2020c, 2021).

While many types of structure have been used, most are unsuitable for use at production hatcheries because they interfere with the hydraulic, self-cleaning nature of circular tanks, leading to increased labor demands and elevated risks of disease (Baynes and Howell 1993; Tuckey and Smith 2001; Krebs et al. 2017). Vertically-suspended structure that maintains circular tank self-cleaning while still providing environmental enrichment benefits during hatchery rearing was created by Kientz and Barnes (2016), and has been repeatedly shown to improve the growth of salmonids (Crank et al. 2018; Kientz et al. 2018; Krebs et al. 2018; Voorhees et al. 2018a, 2018b, 2020b; Huysman et al. 2019a, 2019b, 2020; Jones et al. 2019; Rosburg et al. 2019; White et al. 2019).

Research focused on combining structure and exercise during salmonid rearing have all used juvenile fish well beyond initial feeding (Kientz and Barnes 2016; Mottis et al. 2020b; Voorhees et al. 2020b, 2020c, 2021). No studies have examined the use of both structure and exercise on salmonids beginning shortly after initial feeding. Thus, the objective of this study was to evaluate the use of both vertically-suspended, in-tank structure and an exercise routine on the growth of landlocked fall Chinook salmon (*Oncorhynchus tshawytscha*) immediately after initial feeding.

METHODS

All experiments were conducted at McNenny State Fish Hatchery near 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}). Landlocked fall Chinook salmon (mean ± SE) weight = 0.39 ± 0.01 g, total length = 38.49 ± 0.48 mm; n = 25) that first transitioned to feed on January 7, 2020, were used. On January 13, approximately 5,700 salmon (2.25 kg; 0.39 g fish^{-1}) were placed into each of 12 circular tanks (1.8 m diameter × 0.6 m deep; 0.4 m water depth). Three treatments were used: 1. no exercise routine nor vertically-suspended structure, 2. no exercise routine with structure, or 3. both an exercise routine and structure. Four tanks received the same treatment (N = 4). The exercise routine consisted of alternating a baseline self-cleaning rotational velocity for 84 hours with an increased rotational water velocity for 84 hours. The baseline constant (non-exercise) velocity for all tanks was 5 cm s^{-1}. For the exercise regime, the velocity was set to 5 cm s^{-1} for the first week to allow fish to acclimate and was then increased by changing the angle of the spray bar. For the first 49 days (day 1-49) the higher velocity was 8 cm s^{-1}. After day 49 (day 50-79) the velocity was increased to 13 cm s^{-1} during the 84-hour exercise period. Water flows were kept constant in all tanks throughout the study. Velocities were measured with a flowmeter (JDC Electronics Flowatch Flowmeter, JDC, Yverdon-les-Bains, Switzerland) in all tanks directly across from the spray bar at approximately 0.2 m of depth (halfway in water column).

The vertically-suspended structure consisted of an array of four aluminum angles, as described by Krebs et al. (2018), which were suspended from corrugated plastic tank covers (Walker et al. 2016). Figure 1 is a schematic of the suspended structure within a circular tank.

Fish feeding rate was projected using the hatchery constant method (Buterbaugh and Willoughby 1967) with an expected feed conversion ratio of 1.1. The growth rate was projected at 0.06 cm day^{-1} for days 1-49 and was increased to 0.07 cm day^{-1} from days 50-79. Growth rate was increased due to the increase in fish size, as per normal hatchery practices. On day 49 and final day 79, ten fish from each tank were individually weighed to the nearest g and total length measured to nearest mm. In addition, all fish in a tank were weighed to obtain total fish weight (kg of fish/tank). The following formulas were used:

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

$$\text{Gain (\%)} = 100 \times \frac{\text{gain}}{\text{total fish start weight}}$$

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

$$\text{Mortality (\%)} = 100 \times \frac{\text{number of dead fish}}{\text{total number of fish}}$$

$$\text{Specific Growth Rate (SGR)} = 100 \times (e^{\frac{\ln \text{end weight} - \ln \text{start weight}}{\text{number of days}}} - 1)$$

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

The SPSS (24.0) statistical program (IBM, Armonk, New York, USA) was used for data analysis. One-way analysis of variance (ANOVA) was performed, with Fisher's Protected Least Significant Difference used for means comparison if the ANOVA indicated significant differences. Significance was predetermined at $P < 0.10$.

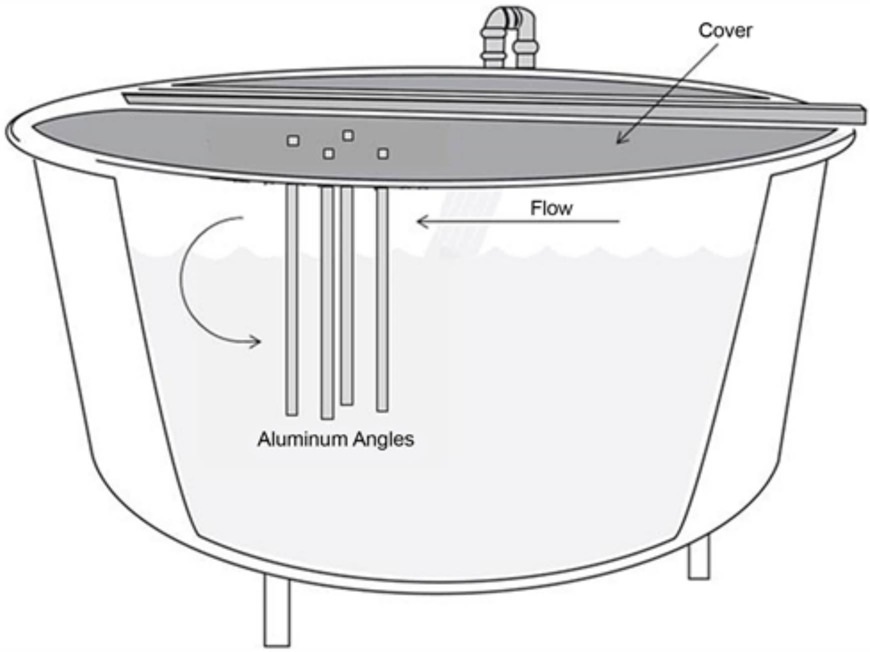

Figure 1. Circular tank with suspended array of four aluminum angles, with the peak of the angle facing in the direction of the water flow.

RESULTS

In the initial phase (days 1-49) of the experiment, mean total weight of fish in each tank, mean weight gain, mean percent gain, and mean feed conversion ratio were significantly improved in the tanks without exercise or structure compared to the other two treatments (Table 1). Feed conversion ratios for the first rearing period were less than 1.0 in all treatments. There were no significant differences among the treatments in weight, gain, percent gain, and feed conversion ratio for phase two (days 50-79) or the overall duration of the study (day 1-79). Fish mortality was approximately 2% and was not significantly different among treatments.

At rearing day 49, individual fish weight, condition factor, and specific growth rate from fish reared without structure and without exercise were significantly greater than fish in the other two treatments (Table 2). Individual fish total length was not significantly different among the treatments. No significant differences in individual fish length, weight, specific growth rate, or condition factor were observed during the second period (days 50-79) or for the duration of the entire study (day 1-79).

DISCUSSION

The results of this study, where both structure and structure in combination with exercise produced poorer salmon growth differs from other studies using older fish. Voorhees et al. (2021) observed that the use of both an exercise regime and vertically-suspended structure was beneficial during the rearing of Chinook salmon. However, the salmon used in their study were over three times larger than the salmon used in this study and had been on feed much longer. Two experiments evaluated both structure and exercise during the rearing of relatively large juvenile rainbow trout (*Oncorhynchus mykiss*). Voorhees et al. (2020b) noted that structure produced positive results at the higher water velocities used for exercise. Voorhees et al. (2020c) reported that trout rearing performance was improved with the addition of either vertically-suspended structure or an exercise regime, but the two environmental enrichment techniques were not beneficial when used in combination.

Table 1. Mean (± SE) ending total weight, gain, percent gain, feed conversion ratio (FCR[a]), and mortality for juvenile Chinook salmon reared in tanks with three different environmental enrichment treatments (N = 4). Period 1 = rearing days 1-49, period 2 = days 50-79, and overall = days 1-79. Means with different letters in same row differs significantly (P < 0.10).

Period		Environmental Enrichment: None			Structure Only			Structure and Exercise			p-value
1	Total weight (kg fish/tank)	18	±	0.3 z	16.6	±	0.5 y	17.3	±	0.3 y	0.07
	Gain (kg)	15.7	±	0.3 z	14.3	±	0.5 y	15	±	0.2 y	0.07
	Gain (%)	698	±	13 z	637	±	22 y	667	±	11 y	0.07
	FCR	0.85	±	0.02z	0.93	±	0.03 y	0.89	±	0.01 y	0.08
	Mortality (%)	1.9	±	0.2	1.9	±	0.5	1.4	±	0.1	0.45
2	Total weight (kg fish/tank)	33.4	±	0.5	33.6	±	1.3	32.9	±	0.9	0.87
	Gain (kg)	15.5	±	0.3	17	±	1.6	15.6	±	1	0.58
	Gain (%)	86	±	2	103	±	12	91	±	7	0.34
	FCR	1.33	±	0.03	1.24	±	0.13	1.33	±	0.09	0.75
	Mortality (%)	0.2	±	0.1	0.2	±	0.1	0.2	±	0	0.79
Overall	Gain (kg)	31.2	±	0.5	31.3	±	1.3	30.6	±	0.9	0.86
	Gain (%)	1,384	±	23	1,391	±	56	1,360	±	41	0.86
	FCR	1.09	±	0.02	1.09	±	0.05	1.11	±	0.03	0.87
	Mortality (%)	2.1	±	0.2	2	±	0.4	1.6	±	0.1	0.47

[a] FCR = (food fed) / gain

Table 2. Mean (± SE) ending individual fish total length, weight, specific growth rate (SGR[a]), and condition factor (K[b]) of Chinook salmon reared in tanks with three different environmental enrichment treatments (N = 4). Period 1 = rearing days 1-49, period 2 = days 50-79, and overall = days 1-79. Means with different letters in same row differs significantly (P < 0.10).

		Environmental Enrichment			
Period		**None**	**Structure Only**	**Structure and Exercise**	**p-value**
1	Length (mm)	70 ± 1	69 ± 0	69 ± 0	0.53
	Weight (g)	3.46 ± 0.11 z	3.07 ± 0.06 y	3.20 ± 0.12 y	0.06
	SGR	4.64 ± 0.07 z	4.39 ± 0.04 y	4.47 ± 0.08 y	0.06
	K	1.02 ± 0.01 z	0.94 ± 0.02 y	0.97 ± 0.02 y	0.05
	Mortality (%)	1.9 ± 0.2	1.9 ± 0.5	1.4 ± 0.1	0.45
2	Length (mm)	89 ± 1	87 ± 1	88 ± 1	0.77
	Weight (g)	7 ± 0	7 ± 0	7 ± 0	0.82
	SGR	2.57 ± 0.16	2.87 ± 0.16	2.77 ± 0.16	0.43
	K	1 ± 0.04	1.01 ± 0.02	1 ± 0.02	0.97
	Mortality (%)	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0	0.79
Overall	SGR	3.88 ± 0.05	3.84 ± 0.04	3.85 ± 0.07	0.82

[a] SGR = 100 (eg - 1), where g = [ln(end wt) - ln(start wt)]/number of days
[b] K = 105 * (fish weight) / (fish length)[3]

The results of this study are supported by those of Morris et al. (2020a). In their study with rainbow trout which began at initial feeding, they observed no benefits from vertically-suspended structure during the first 48 days of feeding. However, from days 49 to 132, trout growth was significantly improved with the use of structure. Similarly, Morris et al. (2020b) reported that the use of an intermittent exercise regime did not improve the rearing performance of small juvenile rainbow trout. They concluded that exercise beginning with initial feeding was not needed.

It is possible that the water velocities used in this experiment may have impacted the results. Velocities between 1.5 and 2.0 body lengths/second have been recommended for optimal exercise in juvenile salmonids (Christiansen et al. 1989; Parker and Barnes 2014, 2015). The baseline velocity of 5 cm s^{-1} was approximately 1.3 body lengths/second at the start of the experiment and decreased to 0.8 body lengths/second at the end. In contrast, the greater velocities used for the exercise regime exceeded the recommended maximum of 2.0 body lengths/second at the start of the experiment, 1.88 body lengths/second at the start of the second rearing period and dropped to nearly 1.5 body lengths/second by the end of the experiment. The relatively high velocities used for exercise at the start of the trial may have been particularly deleterious. Feed conversion ratios were negatively impacted when juvenile Chinook salmon were exercised at 3.0 body lengths/second compared to those exercised at 1.5 body lengths/second (Parker and Barnes 2014). Other studies examining the effects of exercise on Chinook salmon have produced inconsistent results, with only some showing benefits (Dougan 1993; Kiessling et al. 1994; Voorhees et al. 2021).

Most research examining exercise and/or structure use slightly larger fish. Though a few have examined smaller fish with structure (Huysman et al. 2020; Morris et al. 2020a) or intermittent exercise (Morris et al. 2020b). Small rainbow trout were used in the Morris et al. (2020a, 2020b) experiments. The only other experiment that examined Chinook salmon, though slightly larger, with structure and routine exercise used one week of exercise and one week off and found significantly improved total fish weight and gain for fish with routine exercise and structure over only exercise, only structure, or neither exercise nor structure (Voorhees et al. 2021). The Chinook salmon were larger at the start of Voorhees et al. (2021) experiment compared to this experiment, however they were smaller, than the fish on day 49, but the fish in both experiments were approximately the same size at the cessation of the studies. The exercise routines used in these experiments were also different: our study changed velocities bi-weekly, while Voorhees et al. (2021) changed velocities every week. Voorhees et al. (2021) used velocities that were slightly higher, however the velocities in their experiment were measured without structure and fish present. Muggli et al. (2019) found vertically-suspended aluminum angles (without fish) slowed the water down approximately 50% throughout the tanks compared to the control, and Caasi et al. (2020) found similar results with structure. However, Caasi et al. (2020) showed that when lower density of fish and structure were present, velocities were similar to those without fish, but at a higher density with structure, velocities were almost non-existent. These experiments show velocities are most accurate if taken when fish and structure are present, thus the velocities used here may be more similar or even faster than Voorhees et al. (2021) used.

Since there was insignificant growth from day 50-79, maybe the bi-weekly adjustment of water was not enough, or the velocity was not different enough between exercise and unexercised tanks. It could also be that Chinook salmon do not do well with exercise (White and Li 1985; Dougan et al. 1993; Kiessling et al. 1994; Thorarensen and Farrell 2006; Gallaugher et al. 2001; Parker and Barnes 2014). However, the fish in tanks that were exercised performed similarly to the fish in tanks that were unexercised and only had structure present.

The feed conversion ratios observed in this study are similar to other studies evaluating exercise (Parker and Barnes 2015; Morris et al. 2020b; Voorhees et al. 2020a), vertically-suspended structure (Kientz and Barnes 2016; Kientz et al. 2018; Krebs et al. 2018) or exercise and structure in combination (Voorhees et al. 2020b, 2020c, 2021). Although exercised fish may feed less efficiently and require increased feed rations (Kiessling et al. 1994; Parker and Barnes 2014, 2015), this was not observed in the current study.

In conclusion, this study indicates that environmental enrichment beginning near initial feeding does not provide any benefits to growth for landlocked fall Chinook salmon. Thus, if improvements in feeding efficiency, specific growth rate, or other growth metrics is of primary concern, neither structure nor exercise is warranted. However, environmental enrichment may have other benefits beyond growth that were not measured in this study (Näslund and Johnsson 2016), such as improving disease resistance (Castro et al. 2011; Liu et al. 2018), swimming performance (Leon et al. 1986; Anttila et al. 2011) and (or) post-stocking survival (Evenson and Ewing 1993). In addition, environmental enrichment has been shown to decrease stress and stress recovery times (Woodward and Smith 1985; Barrett and McKeown 1988; Chistiansen and Jobling 1990; Hoffnagle et al. 2006), and agonistic behavior (Gallaugher et al. 2001; Jørgensen and Jobling 1993).

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