The effects of swimming exercise and dissolved oxygen on growth performance, fin condition and survival of rainbow trout *Oncorhynchus mykiss*

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Abstract
Swimming exercise and dissolved oxygen (DO) are important parameters to consider when operating intensive salmonid aquaculture facilities. While previous research has focused on each of these two variables in rainbow trout *Oncorhynchus mykiss*, studies examining both variables in combination, and their potential interaction, are absent from the scientific literature. Both swimming exercise (usually measured in body lengths per second, or BL/s) and DO can be readily controlled in modern aquaculture systems; therefore, we sought to evaluate the effects of these variables, separately and combined, on several outcomes in rainbow trout including growth performance, fin health and survival. Rainbow trout fry (18 g) were stocked into 12 circular 0.5 m\(^3\) tanks, provided with either high (1.5–2 BL/s) or low (approximately 0.5 BL/s) swimming exercise and high (100% saturation) or low (70% saturation) DO, and grown to approximately 1 kg. By the conclusion of the study, higher DO was independently associated with significantly \(p < .05\) increased growth performance. Significant differences were not noted in other outcomes, namely feed conversion, condition factor and mortality, although caudal and right pectoral fin damage was associated with low oxygen and low swimming exercise treatments respectively. Cardiosomatic index was significantly higher among exercised fish. These results suggest that swimming exercise and DO at saturation during the culture of rainbow trout can be beneficial to producers through improved growth performance and cardiac health.

Keywords
circular tanks, dissolved oxygen, rainbow trout, swimming exercise
1 | INTRODUCTION

Optimizing environmental quality can provide significant benefits for cultured fish performance and welfare, as well as enhancing the overall profitability of commercial aquaculture operations. Increasing operational productivity without compromising fish health and welfare is a constant challenge faced by aquaculturists, and ongoing research is necessary to continue identifying and refining important environmental variables that can be manipulated to improve farmed fish production. Two such variables are swimming speed, which can be regulated by creating water currents to stimulate swimming exercise (Josse, Remacle, & Dupont, 1989), and dissolved oxygen (DO) (Fischer, 1963). Swimming exercise and DO interact to the extent that increased metabolic rate during exercise increases the need for, and consumption of, dissolved oxygen (Lauff & Wood, 1996). The independent effects of swimming exercise and dissolved oxygen on a range of outcomes have been previously studied; however, these parameters have not been assessed in combination in rainbow trout *Oncorhynchus mykiss*. Hence, we sought to assess the relative impacts of exercise and DO on a range of performance, health and welfare outcomes with rainbow trout grown from fry to a harvest size of 1 kg.

Several salmonid species have demonstrated improved growth performance with prolonged moderate exercise; these include rainbow trout (Greer-Walker & Emerson, 1978; Houlihan & Laurent, 1987; Josse et al., 1989), Atlantic salmon *Salmo salar* (Castro et al., 2011; Totland et al., 1987; WalDROP, Summerfelt, Mazik, & Good, 2018), brook trout *Salvelinus fontinalis* (East & Magnan, 1987; Leon, 1986), brown trout *Salmo trutta* (Davison & Goldspink, 1977) and Arctic char *Salvelinus alpinus* (Grünebaum, Clouties, & François, 2008). Sustained, moderate exercise has also been shown to improve feed conversion (Jobling, Baardvik, Christiansen, & Jørgensen, 1993; Leon, 1986), improve fin quality (Jørgensen & Jobling, 1993), decrease aggression (Postlethwaite & McDonald, 1995), increase endurance (Besner & Smith, 1983), and increase disease resistance and survival during pathogen challenge studies (Castro et al., 2013).

Appropriately designed circular tanks can be self-cleaning if rotational water velocities are maintained between 15 and 30 cm/s (Burrows & Chenoweth, 1970; Makinen, Lindgren, & Eskelinen, 1988), such that solids are quickly flushed to the centre drain and do not remain in the tank to dissolve and deteriorate water quality. Rotational water velocities can also provide swimming exercise and can be managed independent of tank exchange rate. Fish in circular tanks tend to be more evenly distributed (Larmoyeux, Piper, & Chenoweth, 1973), although rotational velocities must be kept at appropriate levels so as to not be exhaustive; Wood, Turner, and Graham (1983) reported that exhaustive exercise stress can be severe enough to cause death due to intracellular acidosis. Parker and Barnes (2015) demonstrated that well-fed rainbow trout can be safely cultured in velocities high enough to maintain self-cleaning characteristics of circular tanks. As such, rearing vessel water velocities should be checked on a regular basis to ensure that animals are not being exhausted, or conversely, that swimming speeds are not inappropriately low.

Growth performance in relation to exercise may be optimized when salmonids swim at, or close to, their optimal speed ($U_{opt}$) (Davison, 1997). Rainbow trout $U_{opt}$ has been reported ranging from 0.9 body lengths per second (BL/s) to 1.4 BL/s (Bushnell, Steffensen, & Johansen, 1984; Shingles et al., 2001; Webb, 1971). Other studies have noted maximum growth at swimming speeds ranging from 0.85 to 1.8 BL/s (East & Magnan, 1987; Greer-Walker & Emerson, 1978). Conversely, Farrell, Johansen, and Suarez (1991) noted that some rainbow trout exercised continuously at 1.6 BL/s demonstrated signs of fatigue; however, these studies were conducted in swim tubes, wherein a range of water velocities is not present. Fish in circular tanks, by comparison, can self-select a range of water velocities across a given tank’s radius, with the highest velocities occurring immediately beside the tank wall (Davidson & Summerfelt, 2004).

Dissolved oxygen must be sufficient to support fish performance, welfare and survival, and in intensive production, pure oxygen is often employed to sustain high feed loadings and stocking densities. Pure oxygen can increase an aquaculture system’s carrying capacity without an increase in water flow rate; however, use of pure oxygen can also substantially increase production costs (Timmons et al., 2002). Salmonids in general are strong, active swimmers and perform best in well-oxygenated environments (Spence et al., 1996). Dissolved oxygen saturation levels between 80% and 100% have been recommended for many salmonid species to support maximum growth and feed conversion efficiency, whereas lower DO saturation levels have been associated with stress, reduced growth performance, decreased wound healing, increased disease susceptibility and mortality (Cameron, 1971; Fischer, 1963; Herrmann, Warren, & Doudoroff, 1962; Itazawa, 1970).

Land-based, closed containment salmonid production is a growing industry sector (Summerfelt & Christianson, 2014), and research is necessary to more fully understand and optimize conditions in these relatively novel environments. As such, we sought to evaluate the relative impacts of exercise and DO on the performance, health and welfare of rainbow trout raised from juveniles to approximately market size, in a similar approach to our previously published research on Atlantic salmon (WalDROP et al., 2018). In the present study, we assessed the individual and combined effects of high versus low swimming exercise (1.5–2.0 versus approximately 0.5 BL/s, or ~0.5 BL/s respectively) and high versus low DO levels (100% versus 70% saturation respectively), on multiple outcomes, including growth performance, fin condition and survival, as juvenile rainbow trout were raised from approximately 18 g up to a maximum of 1,020 g mean weight. Our maximum swimming exercise was selected based on previous studies (Castro et al., 2011; Davison, 1997; Jobling et al., 1993; Jørgensen & Jobling, 1993); lower ranges of both swimming exercise and DO were meant to be comparable to typical conditions in raceway-based culture.
2 | MATERIALS AND METHODS

All-female diploid rainbow trout eggs were obtained from a commercial supplier and hatched in a vertical heath tray stack incubator. At approximately 17 days post-hatch, fry (<1 g) were transferred to a flow-through system containing twelve 0.5 m³ circular tanks. Study treatments (see below) began at 18.04 ± 0.47 g mean fry weight and 10.9 ± 0.1 cm mean fry length, and concluded at 341 days post-hatch (approximately 950 ± 11.9 g mean weight, and 38.1 ± 0.4 cm mean length, among all treatment groups).

2.1 | Experimental conditions

A 2 × 2 factorial study design (n = 3) was utilized with all 12 flow-through circular tanks, with juvenile rainbow trout being exposed to either high or low DO (100% versus 70% saturation respectively) and high or low swimming exercise (1.5–2.0 BL/s versus ~0.5 BL/s respectively), and with tanks being assigned a particular treatment regime based on random number selection. Methodologies to induce the experimental conditions are described in detail by Waldrop et al. (2018). Briefly, each tank was retrofitted with a magnetic pump connected to an inlet and discharge manifold, inducing rotational water velocities for swimming exercise by removing water from the tank and pumping it back through the discharge manifold. Water was injected beneath the surface to reduce surface agitation and the potential for tank dissolved gas conditions being disrupted. Maximum pump output was constant, and therefore, the discharge manifold angle was altered to increase or decrease velocities to achieve targeted BL/s swimming exercise as fish length increased over time. Each tank was also fitted with a water manifold, providing incoming spring water and additional rotational flow; likewise, the water manifold angle could also be adjusted to supplement water velocity control if necessary. Combined flows provided exercised groups with at least 1.5 BL/s swimming exercise for the duration of the experiment, while non-exercised fish were exposed to water velocities of ~0.5 BL/s via perpendicular angle placements of the manifolds. Rotational velocities were measured regularly by timing floating velocity spheres at various points along tank perimeters, as well as with an underwater flow meter.

For the high and low DO treatments, tank effluents were maintained at approximately 100% and 70% saturation, respectively, with twice-weekly measurements carried out using a Hach portable dissolved oxygen Flexi HQ 30D meter (Hach). Oxygen solubility tables (Colt, 1984) were consulted to set target DOs of 10.5 mg/L and 7.3 mg/L for the 100% and 70% saturation tanks respectively. Dissolved oxygen levels were adjusted with each feeding rate change, as well as in response to tank biomass increase over time, through either increasing or decreasing oxygen gas flow and/or increasing or decreasing total influent water flow rates. Normally, degassed water entering tanks in this particular system first passes through a modified packed column oxygen vessel adding pure oxygen; however, in this experiment, a water line bypassing the packed column oxygen vessel was installed to supply degassed spring water (referred to as ‘bypass’ water) to the six 70% DO treatment tanks, while 100% DO tanks received water as per usual through the modified oxygen pressure vessel.

Tank densities were allowed to reach a maximum of 80 kg/m³, at which point densities were reduced to approximately 40 kg/m³ through culling. A standard commercial feed (42:16 protein:fat) was administered to all tanks by a computer-controlled programme, with daily feed levels being determined via established rainbow trout feed charts fine-tuned through daily observations of feeding activity as well as tank-side triple sumps that settled out feed and faeces leaving each tank.

2.2 | Data collection and analysis

2.2.1 | Water quality monitoring

In addition to DO measurements described above, carbon dioxide (CO₂), total gas pressure (TGP), pH, alkalinity, total suspended solids (TSS), nitrite nitrogen (NO₂⁻N) and total ammonia nitrogen (TAN) measurements were taken on a weekly basis. Total ammonia nitrogen and NO₂⁻N were determined using Hach methods 8038 and 8507, respectively, and employing a Hach spectrophotometer (Model DR/4000). Total gas pressure was determined via DO measurements in combination with an In-Situ Model 300E tensionometer (In-Situ, Inc.). Standard methods (APHA, 2005) were employed for quantifying TSS (method 2540), CO₂ (method 4500-CO₂) and alkalinity (method 2320).

2.2.2 | Fish performance and welfare

Fish growth performance, feed conversion, survival and fin condition were measured or calculated at regular intervals throughout the study. Monthly length and weight sampling was carried out after sedating the fish with 75 mg/L tricaine methanesulfonate (Tricaine-S; Western Chemical Inc.). Sample sizes were determined using the formula:

\[ n = \left( \frac{Z \times \text{stdev}_{\text{grams}}}{\text{accepted error}_{\text{grams}}} \right)^2 \]

where \( Z = 1.95 \) (relative to a 95% confidence interval), assuming an accepted error of 5 g. Condition factor (K) was calculated using the formula:

\[ K = 100 \times \frac{W(\text{g})}{L(\text{cm})^3} \]

Feed conversion ratio (FCR) was calculated by dividing the total amount of feed administered (kg) by the total weight gain (kg) observed in each tank. Mortality data were collected daily, while fin erosion, an established indicator of fish welfare (Ellis et al., 2008), was assessed qualitatively during the final length and weight sampling based on a three-point visual scale (none/mild, moderate or severe) for dorsal, caudal and pectoral fins.
Cardiosomatic indices were calculated from data collected during the final performance sampling event, wherein five fish per tank were humanely euthanized using 200 mg/L tricaine methanesulphonate followed by carefully removing and weighing the hearts, in order to assess heart weight as a proportion of total body weight.

Statistical analyses were performed using Stata 9 software (Stata Corp LP) using multivariable ANOVA models with DO, swimming speed and an interaction term serving as independent variables. Non-normally distributed outcome variables were assessed non-parametrically for association with each treatment variable via the Kruskal–Wallis rank test. A level of $p \leq .05$ was used to determine significant relationships between independent and dependent variables.

### 2.2.3 Product quality

At the end of the experiment, fish from each treatment were either butterfly filleted or processed as boneless/skinless fillets. Each of these fillet portion types were assessed for overall fillet yield (percentage fillet as a proportion of total body weight) and analysed for cook yield % and texture (Kramer g/gwt). To determine cook yield %, fillet sections were thermally processed in a microprocessor-controlled smoked oven (Model CVU-490; Enviro-Pak) set at 82°C; fillets were considered cooked once the internal fillet temperature reached 65.5°C, with total cooking time being approximately 45 min. Once the product was cooked and had reached room temperature, weight was determined for cooked sections. The cook yield was calculated by expressing cooked weight as a per cent of raw weight (Aussanasuwannakul et al., 2010). Texture was determined from the cooked fillet sections as measured using a 5-blade, Allo-Kramer shear attachment mounted to a TA-HDi® Texture Analyzer (Texture Technologies Corp.) which was equipped with a 50 kg load cell. Tests were performed at a crosshead speed of 127 mm/min, and shear force was applied perpendicular to muscle fibre orientation. Force-deformation graphs were recorded, and maximum shear force (g/g sample) was determined using the Texture Expert Exceed software (version 2.60; Stable Micro Systems Ltd.) (Aussanasuwannakul et al., 2010).

### 3 RESULTS

#### 3.1 Water quality

Weekly measurements for each water quality parameter were averaged over the entire study period and summarized in Table 1. All measured water quality parameters were not statistically different ($p > .05$) among treatment groups and were within typical concentration ranges for normal fish culture. Mean total ammonia nitrogen (TAN) was slightly higher in the high DO groups, presumably due to higher feed consumption.

#### 3.2 Fish performance and welfare

Dissolved oxygen had a significant, positive influence on final weight (Table 2; Figure 1). Swimming exercise also had a positive effect on cardiosomatic index (Table 2). There were no significant differences among treatment groups for the other performance outcomes, namely condition factor, mortality and feed conversion; however, at study’s end, the higher caudal fin damage was associated with the low oxygen groups, while right pectoral fin damage was associated with the low swimming exercise groups (Tables 3).

#### 3.3 Product quality

No significant differences in butterfly fillet yield (%), boneless/skinless fillet yield (%), cook yield (%) and texture (Kramer g/gwt) were observed among all treatment groups at study’s end (Table 4).

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**TABLE 1** Mean ($\pm$ SE) water quality parameters and conditions during the study period

| Condition   | 1.5–2 BL/s | ~0.5 BL/s | 1.5–2 BL/s | ~0.5 BL/s |
|-------------|------------|-----------|------------|-----------|
| Velocity (BL/s) | 1.66 ± 0.02 | 0.55 ± 0.01 | 1.65 ± 0.02 | 0.522 ± 0.10 |
| DO (mg/L)    | 10.2 ± 0.1  | 10.4 ± 0.1 | 7.14 ± 0.04 | 7.29 ± 0.03  |
| TAN (mg/L)   | 0.231 ± 0.018 | 0.210 ± 0.018 | 0.174 ± 0.010 | 0.166 ± 0.009 |
| NO$_2$-N (mg/L) | 0.00405 ± 0.00047 | 0.00322 ± 0.00029 | 0.00340 ± 0.00038 | 0.00332 ± 0.000108 |
| Alkalinity (mg/L) | 277 ± 2 | 274 ± 2 | 273 ± 2 | 272 ± 3 |
| CO$_2$ (mg/L) | 18.3 ± 0.4   | 18.8 ± 0.4 | 18.8 ± 0.3 | 18.4 ± 0.3  |
| TSS (mg/L)   | 1.58 ± 0.15  | 1.69 ± 0.13 | 1.78 ± 0.24 | 1.71 ± 0.21  |
| TGP (%)      | 95.4 ± 0.3  | 95.8 ± 0.3 | 95.7 ± 0.3 | 95.6 ± 0.3  |
| Temperature (°C) | 13.6 ± 0.04  | 13.5 ± 0.04 | 13.6 ± 0.04 | 13.6 ± 0.04  |
Our results indicate that rainbow trout raised to a harvest size of 1 kg show increased growth performance when provided dissolved oxygen at 100% saturation, independent of whether the fish were exercised or not. Our previous study with Atlantic salmon (Waldrop et al., 2018) demonstrated that both exercise and 100% DO were significantly associated, independently, with increased growth performance. One explanation for the discrepancy between the results from Waldrop et al. (2018) and the present study, aside from the species examined, is the final fish size at study termination: the salmon in the previous study were grown to approximately 350 g, while the rainbow trout were grown to over a mean weight of 1 kg. As the trout grew in size it became more difficult to maintain the higher BL/s swimming speed, and this may have influenced why swimming exercise had less of an impact on rainbow trout growth compared to Atlantic salmon. Having larger fish swimming in small circular tanks might have also influenced overall drag and energy expenditure; however, further research is needed to investigate fish size relative to circular tank diameter in order to further understand the swimming speed and growth performance association.

Swimming exercise, however, did have a significant effect on cardiosomatic index, an indicator of cardiac performance (Helland, Lein, Hjelde, & Bæverfjord, 2009). Farrell et al. (1991) reported that exercised rainbow trout had an 18% increase in cardiac output and a 25% increase in maximum power output, while Poppe, Johansen, Gunnes, and Tørud (2003) determined differences in cardiac morphology between domesticated and wild salmonids, with domesticated individuals having more rounded ventricles in comparison with the triangular shaped ventricles and pointed apex of wild salmonids. Poppe et al. (2003) also reported a strong positive correlation between the triangular shape and optimal cardiac performance, and that the abnormal

**TABLE 2** Final rainbow trout performance, health and welfare results (means ± SEs)

| Outcome                   | DO 100% saturation | DO 70% saturation |
|---------------------------|---------------------|-------------------|
|                           | 1.5–2 BL/s          | ~0.5 BL/s         |
| Final weight (g)          | 1.048 ± 0.41        | 0.990 ± 0.56      |
| Condition factor (K)      | 1.75 ± 0.08         | 1.82 ± 0.02       |
| Feed conversion ratio (FCR)| 1.25 ± 0.02         | 1.24 ± 0.06       |
| Mortality (%)             | 2.12 ± 0.82         | 1.78 ± <0.01      |
| Cardiosomatic index (%)   | 0.12 ± <0.01        | 0.11 ± <0.01      |

**Fin damage score**

|                  | DO 100% saturation | DO 70% saturation |
|------------------|--------------------|-------------------|
|                  | 1.5–2 BL/s          | ~0.5 BL/s         |
| Dorsal           | 0.413 ± 0.081       | 0.693 ± 0.082     |
| Caudal           | 0.253 ± 0.054       | 0.267 ± 0.061     |
| Right pectoral   | 0.066 ± 0.044       | 0.227 ± 0.065     |
| Left pectoral    | 0.013 ± 0.013       | 0.081 ± 0.037     |

**Note:** Superscripts indicate parameters significantly (p < .05) impacted by swimming exercise (a) and/or dissolved oxygen (b); fin score based on 0 = none/mild, 1 = moderate, 2 = severe.

**TABLE 3** Summary of statistically significant (p < .05) differences among performance, health and welfare outcomes for rainbow trout raised under study conditions

| Outcome                  | 100% dissolved oxygen | 1.5–2.0 BL/s |
|--------------------------|------------------------|-------------|
| Final weight ↑           |                       |             |
| Cardiosomatic index ↑    |                       |             |
| Caudal fin damage ↓      |                       |             |
| Right pectoral fin damage|                       |             |

**Note:** Arrows indicate direction of effect of treatment condition on outcome parameter.
rounded cardiac morphology was associated with higher mortality during stressful handling and sampling events. Therefore, providing fish with exercise could help aquaculture facilities reduce mortalities during times of stress. Castro et al. (2011) demonstrated that non-exercised Atlantic salmon had reduced disease resistance compared to those exercised either continuously or through interval training and that heart health was improved with aerobic exercise through reducing inflammation and increased removal of free radicals.

Condition factor (K) is another fish performance and welfare parameter potentially linked to cardiac health. Claireaux et al. (2005) reported a correlation between rounded ventricles and higher condition factors. Elevated condition factor can be indicative of a lower parameter potentially linked to cardiac health. Claireaux et al. (2005) reported a correlation between rounded ventricles and higher condition factors. Elevated condition factor can be indicative of a lower parameter potentially linked to cardiac health.

In our study, no statistical difference in mortality was observed among treatment groups; however, the study had a final minimum harvest size of 1 kg, whereas some salmonids species have higher market size target weights. In such cases, it is possible that longer culture periods in the low swimming exercise and DO environments could result in lower survival rates, although further research is necessary to investigate this possibility. Problems such as increased fat deposition, hepatic lipidosis and decreased cardiac performance over longer durations could result in higher mortalities and decreased fish performance.

The causes and consequences of fin erosion have been reviewed by Latremouille (2003). Frayed fins can provide a portal for opportunistic pathogens and subsequent systemic infection (Turnbull, Adams, Richards, & Robertson, 1998), while market-size fish with poor fin quality can lead to challenges in selling whole fish (Klima et al., 2013). Cvetkovikj, Radeski, Dimovska, Kostov, and Vangjel (2013) reported that fin erosion was prevalent to some degree on all fins among cultured rainbow trout, and that the dorsal and pectoral fins were the most susceptible for erosion. Findings in the present study were similar; however, the higher dissolved oxygen treatments resulted in significantly less caudal fin erosion, while the higher swimming exercise treatments resulted in less pectoral fin erosion. This latter finding was expected, to an extent, as other studies have documented increased antagonistic behaviours and fin biting in low swimming environments (Christiansen & Jobling, 1990; Postlethwaite & McDonald, 1995). Overall, the higher swimming speed and dissolved oxygen regimes reduced antagonistic behaviours among fish resulting in better fin condition, which is in agreement with Solstorm et al. (2015) who suggested that swimming exercise be kept at moderate speeds of 0.8–1.0 BL/s to minimize the effects of antagonistic behaviours but also keep the fish from being stressed and exhausted from faster water velocities.

No statistical significances among product quality parameters were noted between treatment groups; proximate analyses, butterfly fillet yield, boneless fillet yield, cook yield and texture were all not associated with one or more specific treatments. One major criterion of flesh quality is texture, which is determined by muscle cellularity and connective tissue characteristics (Johnston, 1999; Kiessling, Espe, Ruohonen, & Mørkøre, 2004). Previous exercise studies with Atlantic salmon (Totland et al., 1987) and brown trout (Bugeon, Lefevre, & Fauconneau, 2003) have shown improvements to the textural characteristics of flesh quality when fish are exercised. Totland et al. (1987) reported a 38% growth increase in exercised Atlantic salmon, mainly as increased white muscle growth. Given that Sänger and Stoiber (2001) determined that white skeletal muscle accounts for up to 98% of the edible fillet, with a minimum value of 70%, this suggests a likely mechanism for how texture can be affected by swimming exercise.

Our findings confirm better growth performance in oxygen saturated environments, with trout in the high DO treatment having a 17% growth advantage compared to those raised in low DO. Although not significantly different in this study, feed conversion rates were generally lower in the high DO regimes, and given that exercised fish had a higher intake of feed with a lower feed conversion, exercised fish were likely more metabolically efficient than unexercised cohorts. Grisdale-Helland, Takle, and Helland (2013) concluded that continuously exercised post-smolt Atlantic salmon were able to respond to higher activity costs by utilizing energy and protein more efficiently for growth. Houlihan and Laurent (1987) demonstrated that rainbow trout forced to swim at 1.0 BL/s grew almost twice as fast and converted protein more efficiently for growth. Houlihan and Laurent (1987) demonstrated that rainbow trout forced to swim at 1.0 BL/s grew almost twice as fast and converted protein more efficiently for growth.

### Table 4

| Outcome                          | DO 100% saturation | DO 70% saturation | ANOVA model p-value |
|----------------------------------|--------------------|-------------------|---------------------|
|                                  | 1.5–2 BL/s         | –0.5 BL/s        |                     |
| Butterfly fillet yield (%)       | 66.30 ± 2.923      | 66.20 ± 2.442     |                     |
| Boneless/skinless fillet yield (%) | 46.20 ± 3.157     | 46.59 ± 2.756     |                     |
| Cook yield (%)                   | 88.04 ± 2.878      | 89.09 ± 1.804     |                     |
| Texture (Kramer g/gwt)           | 309.3 ± 115.5      | 272.2 ± 76.74     |                     |
|                                  |                    |                   |                     |
|                                  | 1.5–2 BL/s         | –0.5 BL/s        |                     |
| Butterfly fillet yield (%)       | 66.76 ± 2.125      | 67.24 ± 3.622     | .7337               |
| Boneless/skinless fillet yield (%) | 46.68 ± 2.791     | 48.81 ± 2.203     | .0502               |
| Cook yield (%)                   | 88.07 ± 1.349      | 88.77 ± 2.852     | .5175               |
| Texture (Kramer g/gwt)           | 284.1 ± 81.20      | 330.1 ± 91.04     | .3243               |

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was more efficient when converting the feed to flesh. A similar trend (higher oxygen, slightly better feed conversion rates and increased growth) was observed in our previous exercise and DO trend (higher oxygen, slightly better feed conversion rates and was more efficient when converting the feed to flesh. A similar ORCID

Data are available upon request to the corresponding author.

The authors do not have any conflicts of interest to declare.

CONFLICT OF INTEREST

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descriptive purposes only and does not imply endorsement by the Use Committee. Any use of trade, firm or product names is for proved by The Freshwater Institute's Institutional Animal Care and with the Animal Welfare Act (9CFR) requirements and were ap-

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was more efficient when converting the feed to flesh. A similar trend (higher oxygen, slightly better feed conversion rates and increased growth) was observed in our previous exercise and DO study with Atlantic salmon (Waldrop et al., 2018). Additional previous research has also supported these findings: Lovell (1989) reported that fish convert food less efficiently as DO decreases; Pedersen (1987) suggested that oxygen levels should be at least 7 mg/L for optimized feed conversion and growth in juvenile rainbow trout; and Saravanan et al. (2013) reported that rainbow trout kept in hypoxic conditions (6.0 mg/L) demonstrated substantially lower feed intake than those fed under normoxic conditions (Saravanan et al., 2013). This lower feed intake during hypoxic conditions is likely associated with the consequent reduction in metabolic scope of aerobic activities and metabolism (Glencross, 2009).

In conclusion, the results of our study suggest that swimming exercise and DO at saturation during the culture of rainbow trout can be beneficial to producers through improved growth performance and cardiac health. Facilities utilizing salmonids and other species with a high metabolic scope and positive rheotaxis may benefit by maintaining dissolved oxygen at saturation and providing moderate swimming exercise in the right balances.
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