Influence of stocking density on growth, body composition and energy budget of Atlantic salmon *Salmo salar* L. in recirculating aquaculture systems

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Abstract  Atlantic salmon *Salmo salar* were reared at four stocking densities—high density *D*₁ (final density ~39 kg/m³) and *D*₂ (~29 kg/m³) and *D*₃ (~19 kg/m³) and low density *D*₄ (~12 kg/m³)—for 40 days to investigate the effect of stocking density on their growth performance, body composition and energy budgets. Stocking density did not significantly affect specific growth rate in terms of weight (SGRₚ) but did affect specific growth rate in terms of energy (SGRₑ). Stocking density significantly influenced the ration level (RLₚ and RLₑ), feed conversion ratio (FCRₚ and FCRₑ) and apparent digestibility rate (ADR). Ration level and FCRₑ tended to increase with increasing density. Fish at the highest density *D*₁ and lowest density *D*₄ showed lower FCRₑ and higher ADR than at medium densities. Stocking density significantly affected protein and energy contents of the body but did not affect its moisture, lipid, or ash contents. The expenditure of energy for metabolism in the low-density and high-density groups was lower than that in the medium-density groups. Stocking density affected energy utilization from the feces but had no effect on excretion rate. The greater energy allocation to growth at high density and low density may be attributed to reduced metabolic rate and increased apparent digestibility rate. These findings provide information that will assist selection of suitable stocking densities in the Atlantic-salmon-farming industry.

Keyword: stocking density; Atlantic salmon; growth; body composition; energy budget; recirculating aquaculture system

1 INTRODUCTION

Aquaculture is one of the fastest growing global animal producing sectors and contributes approximately 50% of all fish consumed (FAO, 2010). Stocking density, a potential source of chronic stress that may affect the physiology and behavior of farmed fish, is widely recognized as a critical husbandry factor in intensive aquaculture (Wedemeyer, 1997; Ellis et al., 2002; North et al., 2006; Turnbull et al., 2005; Merino et al., 2007; Sirakov, 2007; Sirakov and Ivanchev, 2008; Tolussi et al., 2010). However, owing to the diversity of physiological stress responses in fish, these effects appear to be species-specific (Barton, 2002). The inappropriate stocking densities may impair the growth, feed conversion ratio (FCR), feed intake, apparent digestibility rate (ADR), and health of fish (Lambert and Dutil, 2001; Kristiansen et al., 2004; Schram et al., 2006; Merino et al., 2007; Sirakov, 2007; Sirakov and Ivanchev, 2008; Tolussi et al., 2010). Therefore, stocking density must be taken into account in planning and monitoring of performance in fish industry, and in setting production limits by authorities (Ellis et al., 2002; Turnbull et al., 2005; North et al., 2006; Oppedal et al., 2011). For these reasons, stocking density has attracted particular attention in fish farming. Several studies have demonstrated that
causative mechanisms by which stocking density affects growth and feed utilization are still unclear, making it difficult to establish threshold guidelines for rearing density (Larsen et al., 2012).

The growth of fish is determined by the amount of energy available for growth (Zhang and Tang, 2002; Lupatsch et al., 2010). Determination of fish energy budgets in relation to growth performance might help us to understand the mechanisms whereby inappropriate stocking densities impair growth and feed utilization. To date, studies of the effect of stocking density on growth and energy expenditure have provided inconsistent results. Lefrancois et al. (2001) found that density did not affect the routine metabolic rate (RMR) of rainbow trout Oncorhynchus mykiss, but Larsen et al. (2012) showed that high stocking density groups had higher RMR, which resulted in a lower specific growth rate (SGR). Moreover, in European sea bass (Dicentrarchus labrax), low-density groups required more energy for maintenance and growth than did high-density groups (Lupatsch et al., 2010).

The Atlantic salmon Salmo salar is one of the most important aquaculture species among salmonids. Recirculating aquaculture systems (RAS) used in the culture of Atlantic salmon provide an important model for the global aquaculture industry in terms of conservation of resources, low environmental impact, and product safety (Timmons and Ebeling, 2007; Martins et al., 2010). Although high-stocking density is the main feature of RAS, little is known about its influence on fish growth. Most studies of the effect of stocking density on Atlantic salmon have focused on the apparent growth performance and health of fish in sea-cages (Soderberg et al., 1993; EFSA, 2008; CIWF, 2009; Hosfeld et al., 2009). Clearly, there is a need for more information on the causative mechanisms by which stocking density affects growth of Atlantic salmon in RAS.

The present study attempts to understand the relationships among stocking density, growth and energy partitioning of Atlantic salmon based on mortality, growth performance, feed intake, digestibility rate and energy budgets of salmon reared at four different stocking densities. These data on the growth characteristics and energy strategy of Atlantic salmon will enhance the management of RAS-cultured salmon in terms of finding the optimal stocking density.

2 MATERIAL AND METHOD

2.1 Holding facilities

The experiment was conducted in 12 RASs each consisting of a rearing tank, a whirl-separator for solids removal, biofilter, sump, foam separator, and UV-sterilizer (Fig.1). The rearing tanks were 100 cm in diameter and 50 cm deep, and contained 348±6 L of water. The volume of the whirl-separator was approximately 60 L, which was large enough to collect most of the feces. Total water flow to the rearing tanks through standpipes covered with 1.0 cm screen was 800 L/h, replacing 100 % of the volume of the seawater in the system daily. Recommended values for water quality parameters in Norwegian land-based salmonid farming facilities are: O₂ >80% at the outlet; CO₂ <15 mg/L; and total ammonia nitrogen <2 mg/L (Anon, 2004). In the present work, the water quality of all rearing tanks was monitored periodically and maintained at 15.5±0.5°C, pH