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The use of acoustic acceleration transmitter tags for monitoring of Atlantic salmon swimming activity in recirculating aquaculture systems (RAS)

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ABSTRACT

Successful operation of recirculating aquaculture systems is dependent on frequent monitoring of the optimal function of water treatment processes in order to maintain environmental conditions for optimal growth and welfare of the fish. Real time monitoring of fish status is however usually not an integrated part of automatized systems within RAS. The aim of this study was to evaluate the use of implanted acoustic acceleration transmitters to monitor Atlantic salmon swimming activity. Twelve salmon post-smolts were individually tagged and distributed in three tanks containing salmon at start density of 50 kg m^{-3}. The tagging did not cause any mortality and all individuals increased their body weight during this study. Following initial recovery, acceleration data were continuously logged for one month, including treatment periods with exposure to hyperoxic (170% O_2 saturation) and hypoxic (60% O_2 saturation) conditions, and different tank hydraulic retention times (HRT; 23 and 58 min). Changes in-tank dissolved oxygen levels to hyperoxic and hypoxic conditions reduced the total activity of Atlantic salmon in this study. On the contrary, increased and reduced tank HRT increased the total activity levels. Feeding periods induced a sharp increase in the Atlantic salmon swimming activity, while irregular feeding caused larger oscillations in activity and also lead to increased swimming activity of the tagged fish. Atlantic salmon responded with a maximum recorded total activity to stress caused by technical problems within the system and consequent changes in the RAS environment. The results of this study indicate that Atlantic salmon respond quickly with changed swimming activity to changes in the water quality and acute stress caused by normal management routines within RAS. The use of acoustic acceleration transmitters for real time monitoring of swimming activity within aquaculture production systems may allow for rapid detection of changes in species-specific behavioural welfare indicators and assist in the refinement of best management practices. In addition, acceleration tag could potentially serve as a valuable research tool for behavioural studies, studies on stress and welfare and could allow for better understanding of interaction between fish and RAS environment.

1. Introduction

The use of recirculating aquaculture systems (RAS) for production of Atlantic salmon is increasing worldwide. Closed containment systems offer a number of advantages that appeal both to the aquaculture industry and to the society in general; environmentally controlled production, less dependence of the season, increase in overall production, reduction in use of the new water and reduction of potential escapees from fish farms (Rosten et al., 2013; Terjesen et al., 2013). On the other hand, this new technology is facing a number of challenges, for example more complex management, increased running costs and the need for more skilled personnel (Hofseth, 2008). In addition, the current knowledge on

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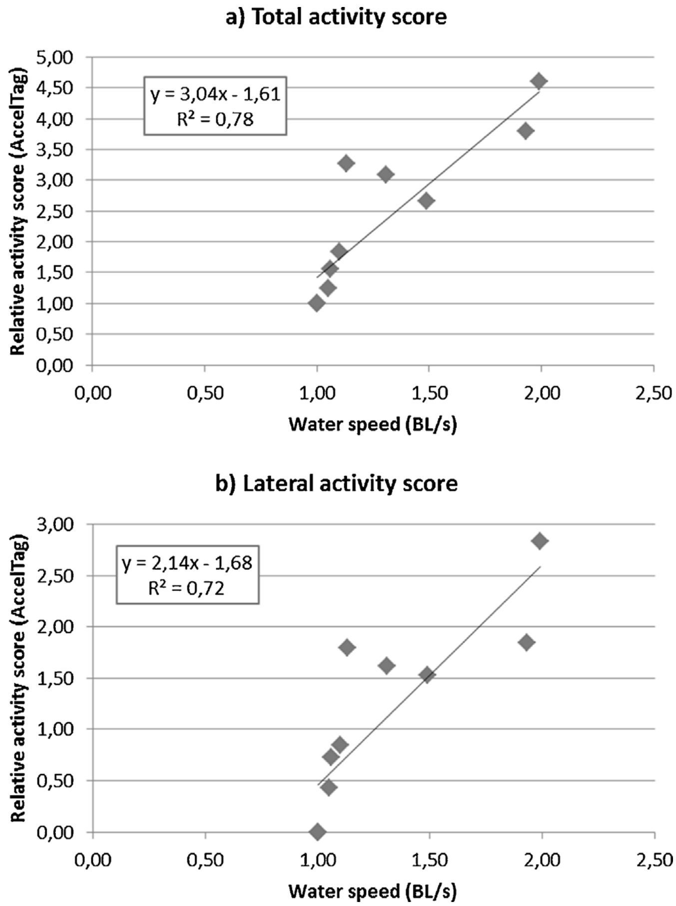

Fig. 1. Average total- (a) and lateral- (b) relative activity scores registered from the AccelTag in a single Atlantic salmon during exposure to different water velocities (given as body length s^{-1}) in the swim tunnel pilot experiment: The data represent the complete data set for N = 1 fish during the swim test (n = 12 measurement cycles and about 20 acceleration scores per measurement cycle).

the effects of the RAS environment on Atlantic salmon welfare and performance must be improved (Terjesen et al., 2013).

Monitoring and control systems are an integrative part of RAS, installed to provide accurate, real-time information on system status and performance, and to prevent catastrophic loss due to equipment or management failures (Timmons and Ebeling, 2007).

However, the possibility for real-time monitoring of fish status without humane presence and knowledge on how the RAS environment actually influences the biology of the free-swimming fish is limited, as the higher turbidity of RAS water limits the use of camera systems.

Changes in swimming activity can reflect how a fish is sensing and responding to its surrounding environment (Martins et al., 2012). There are a number of water quality parameters, like oxygen, pH and carbon dioxide, nitrate-nitrogen that can affect swimming of farmed fish (Davidson et al., 2011; Conte, 2004; Crocker and Cech, 1997; Day and Butler, 1996; Espmark and Baeverfjord, 2009; Schurmann and Steffensen, 1994; Tang and Boisclair, 1995). In addition, a number of feeding management factors can have impact on swimming behaviour of fish within aquaculture systems (Martins et al., 2012). Increased water speed within rearing tanks can also affect swimming activity and ensure better water quality and better distribution of feed reducing the aggressive behaviour and loss of energy due to the spontaneous activity (Castro et al., 2011; Davison, 1997).

Bio-telemetry techniques have been successfully applied for monitoring of individual behaviour of both wild and farmed fish (Cubitt et al., 2008; Manel-La et al., 2009; Rillahan et al., 2009). *In situ* measurements of the swimming activity in salmonids have been done by electromyogram telemetry (Booth et al., 1997; Cooke et al., 2000). Recently an acoustic acceleration transmitter was developed (AccelTag; Thelma Biotel, Trondheim, Norway).

Using these tags, algorithms of three dimensional acceleration and gravity forces could be measured with high sensitivity, processed, and transmitted on-line to acoustic receivers. The development of the receiver equipment technology has also allowed the continuous real time data access through internet or local network solutions. An earlier version of the AccelTag was used to detect changes in the swimming activity of Atlantic salmon in sea cages during feeding and non-feeding events (Føre et al., 2011).

The use of AccelTag in RAS could allow for immediate data-capture of the fish responses to changes in the environment. The integration of received data into the RAS monitoring systems may thus provide real time monitoring of fish behaviour and could allow for improvement and alignment of today's best practices with required welfare standards. In addition, a standalone tag receiver system could be used as a tool for behavioural studies in RAS environment.

However, the presence of different pumps and other electronical equipment within RAS could potentially interfere with signal recording. In addition, the use of AccelTag has not been tested on Atlantic salmon of relevant size for land based production.

The aim of this study was to evaluate the use of implanted acoustic acceleration transmitter tags to monitor Atlantic salmon swimming activity within RAS, including possible responses to changes in oxygen saturation levels, tank hydraulic retention time (HRT) and feeding events. A pilot study was done to verify the relation between acceleration measurements and actual changes in the Atlantic salmon swimming activity. In addition, AccelTag was evaluated as a potential tool for real time monitoring of fish in RAS.

2. Materials and methods

2.1. Telemetry equipment

Acoustic acceleration transmitter tags (AccelTag; ThelmaBiotel, Trondheim, Norway) were used to measure individual fish activity levels. The tags were cylindrical (9 mm diameter, 39 mm long, 6.25 g in air) with estimated battery life between one and three months, but otherwise generally as described by Føre et al. (2011). Each tag contained a 3-axis accelerometer which registered gravity forces and acceleration in the x-, y and z directions with very high sensitivity. Since acoustic telemetry generally has a limited transmission capacity, the raw data were processed, analysed and compressed within the tag before being transmitted acoustically at 69 kHz (ultrasound). In the present experiment, the tags used were customized to process and transmit relative measures of two different activity parameters: a measure of total activity (i.e. a tag algorithm based on acceleration changes in all three directions) and lateral activity (i.e. a tag algorithm based on acceleration changes in one direction influenced by changes in tail-beat frequency). Recorded activity parameters were transmitted from each tag every 30–50 s and collected by acoustical receiver systems (VR2 and VR-100, Vemco Ltd., Halifax, Canada). The received tag data were later decoded to yield individual tag identification and a categorical relative activity score for each of the two activity parameters. This relative activity score consisted of 16-categories from 0 (low activity) to 15 (high activity). The tag algorithms and the sensitivity-range of the relative activity scale were identical for all tags, and were set during tag production based on experience from preceding tests with free-swimming Atlantic salmon.