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Crowding of Atlantic salmon in net-pen before slaughter

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ABSTRACT

Crowding of Atlantic salmon in a net-pen before slaughter was studied from start to finish. Environmental parameters (dissolved oxygen, temperature, pH, current velocity and water depth), fish behaviour, ventilation rates, blood chemistry (cortisol, pH and lactate), initial pH in white muscle and related time to onset of rigor mortis were assessed to evaluate the condition of the fish during crowding. Even though the fish in the net-pen were severely stressed before the crowding operation started, crowding led to considerably higher cortisol levels and ventilation rates. However, prolonged crowding did not significantly increase the cortisol levels further. The initial pH of the muscle also showed that the fish were severely stressed before crowding, but in this case the fish were not further stressed to exhaustion by crowding. Using fish behaviour as single stress indicator for evaluation welfare-related issues must be done with caution since under the prevailing circumstances, diametrically opposed conclusions were drawn from monitoring fish behaviour versus evaluation of acute stress (blood chemistry and muscle biochemistry). The results were discussed in terms of animal welfare, stress, fish processing, and whether choice of technology actually could improve conditions for crowded fish in cases where they are slaughtered just after crowding.

Statement of relevance: The present research is relevant for salmon processors who are using waiting cages before slaughter. The goal was to provide background information for improving fish handling operations and choosing technology. The data are also useful in connection with various steps in the production chain where crowding is an integral part of the unit operations.

1. Introduction

In the salmonid farming industry in Norway, Atlantic salmon (*Salmo salar*) or rainbow trout (*Oncorhynchus mykiss*) are transported live by well-boats from fish farms to centralized processing plants where the fish are slaughtered and processed. Several studies have shown that a normal well-boat transport per se with open valves does not cause major stress effects, flesh quality is not affected, and fish welfare can be considered good (Erikson et al., 1997; Erikson, 2001; Iversen et al., 2005; Farrell, 2006; Nomura et al., 2009; Tang et al., 2009). After transport, the fish are either pumped directly to the slaughter line or into net-pens located at the quay-side (waiting cage) next to the processing plant where the fish are kept for typically 1–6 days (without feeding) before they are pumped to the slaughter line. Pressure-vacuum pumps are used for this purpose, a unit operation proved to be stressful for salmonids (Erikson, 2008; Gatica et al., 2010; Merkin et al., 2010; Roth et al., 2012; Lerfall et al., 2015). In cases where the fish are kept in waiting cages, crowding before pumping to processing plant has also been shown to be an additional stressor (Erikson, 2008; Merkin et al., 2010; Roth et al., 2012; Lerfall et al., 2015). However, relevant research has previously mostly focused on value chain assessment of stress (including crowding) and, to our knowledge, no published research has studied the entire crowding process in great detail. For a better understanding of the crowding process per se and its effect on the fish, our goal was to follow the entire process, from the first to the last fish out from the crowded part of the net-pen. In addition, the prevailing environmental and physical conditions in the net-pen were also recorded. Our hypothesis was that we would observe an increasing stress level as a function of crowding time. The results were intended to be used as baseline values for suggesting improved crowding routines, or, as ideas for designing new technology to reduce handling stress, and possibly, to improve animal welfare.

2. Materials and methods

2.1. Net-pen and logging of water current velocity, temperature, and dissolved oxygen levels

A salmon producer in central Norway has an array of waiting cages consisting of a net-pen with 8 units located next to the processing plant. Each unit has dimension 24 × 24 m and a sidewall and total depth of 15 and 21 m, respectively. The day before our study started, several data loggers (see below) were placed in the bulk volume of one of the net-pen units (NP#2), as well as within

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the part of NP#2 where the crowding operation was to take place (pump inlet side) the next morning when the slaughter process started. Dissolved oxygen (DO), temperature, salinity, net-pen depth and environmental current velocity (bulk volume only) were logged during the night before the experiment started as well as during two crowding operations the following day (experimental phase). In addition, DO and pH were measured sporadically with hand-held instruments during the crowding operations. Particular attention was given to address the assumed most severe crowding situations, such as among fish near the transfer hose inlet just before the sweep-net was completely emptied.

2.2. Fish, net-pen and sampling

Atlantic salmon were fasted for 144 day-degrees (12 days) at a fish farm before they were transported by a well-boat for 3.5 h at a fish density of 68 kg m^{-3}. The total biomass was 305,979 kg (69,383 fish with a mean weight of 4.41 kg). When the well-boat arrived at the processing plant, all fish were pumped to NP#2 between 01:00–03:00 a.m. on October 7th, 2014. About 30 h later, at 06:30 a.m., our study started. Notably, we later learned that about 10,000 fish were slaughtered the day before our arrival, namely between 16:45–18:25 p.m., that is, about 12 h before our first sampling of fish. This reduced the fish density in the net-pen from about 33 to 29 kg m^{-3}.

Our experimental plan was governed by the commercial production plan for NP#2. Two crowding operations from the net-pen were completed (fish pumped to plant). Our experimental design comprised of the following three groups: *Control* – fish from bulk volume of NP#2 sampled before the first crowding operation started. *Crowding 1 and 2* – fish sampled from sweep net at different time intervals during two crowding operations. The seawater temperature as measured just outside the net-pen was 12.2 °C. The timeline for crowding, sampling of fish and key incidents are shown in Table 1. Sampling of fish was carried out by rapid netting of single fish before they were killed by a sharp cranial blow within 5 to 10 s. Blood samples (cortisol, lactate, and pH) were collected within 5 to 10 s from caudal vessels followed by measurement of initial pH in white muscle along with body temperature before fish weight and fork length were recorded. The fish were labelled and placed in EPS boxes containing ice for later determination of time to rigor onset. The mean ($\pm$SD, n = 65) weight and fork length of the experimental fish from both crowding operations were 4.4 $\pm$ 0.3 kg and 64 $\pm$ 6 cm, respectively. During the first crowding operation, about 12,000 fish (52,920 kg) were pumped to the slaughter line in 2.5 h and approximately the same number of fish were subsequently crowded and processed in 2.2 h during the second crowding. According to the company's fish counter display, the fish were pumped to the plant at a highest rate of about 2 fish s^{-1}.

2.3. Analytical methods

2.3.1. Water depth, temperature, current velocity and salinity

Net depths were logged using Data Storage Tags (DSTs) from Star Oddi Ltd. (Gardabaer, Iceland). In the crowded volume, two DSTs were placed on the enclosing volume's net centreline. In the bulk volume, one DST was placed on the enclosing volume's net centreline running parallel to the crowded volume's centreline. Current velocity was logged at 5 m depth using a 2 MHz Nortek Aquadopp current meter (Oslo, Norway). Salinity and temperature were logged using a SonTek conductivity, temperature and depth (CTD) meter (Model: Castaway, San Diego, USA). The meter was suspended from the net pen's peripheral walkway and manually moved down and up in the water column in order to obtain salinity profiles.

2.3.2. Dissolved oxygen

DO was logged using three Aanderaa oxygen optodes type no. 3835 (Aanderaa Data Instruments AS, Bergen, Norway). Two optodes, equipped with DST's for depth measurement (see above), were placed in the centre of the crowded volume at 3 and 5 m depth whereas one optode was placed in the centre of the bulk volume at 5 m depth. The oxygen data from the optodes were logged every 5 min using an Aanderaa 3660 data logger. Sporadic measurements of DO during both crowding operations were also carried out by using a Handy Polaris 2 instrument from OxyGuard (Birkerød, Denmark).

2.3.3. Fish behaviour

Fish behaviour was monitored by means of direct and camera-based observations. The camera-based assessment was done periodically by watching the company's video screen located in a shed for controlling transfer of fish from net-pen to processing plant. All units in the net-pen are equipped with underwater cameras (SmartEye surveillance camera, AKVA group, Bryne, Norway) for routine monitoring of the fish transfer (crowding) process in real-time. Surface activity of fish was monitored using a camera (Panasonic WVSC385, Panasonic Corporation, Osaka, Japan) mounted to the handrail of NP#2 and by visual inspection during our work (sampling and measurements) at the net-pen throughout the experimental phase. A remotely operated underwater vehicle (ROV: Video Ray Pro 3S, Pottstown, PA, USA) was used for periodical monitoring of fish behaviour in crowded and bulk volumes. The internal camera of the ROV was a GoPro Hero 3 camera (GoPro Inc., San Mateo CA, USA). The ROV was launched and operated outside the net-pen where it recorded fish behaviour near the net. The over- and underwater videos were later used to evaluate fish behaviour.

2.3.4. Ventilation rates

The ventilation rates of fish were assessed from underwater videos from the GoPro camera mounted on the ROV. For each selected fish, the number of operculum movements was counted within the time

Table 1
Experimental groups (Control, first crowding and second crowding), as defined by exposure time to crowding in a sweep net, and timeline for sampling of Atlantic salmon during two consecutive crowding operations from the same cage.

n	Fish sampling time	Crowding interval (min)	Comments
Control			
8	06:38–07:13	–	Before crowding operations started. Fish undisturbed for 12 h after fish from same net-pen were slaughtered the day before
First crowding			
10	07:28–08:13	0–40	Start of pumping from sweep net to plant at 07:55
10	08:26–09:10	55–100	
6	09:25–10:04	115–155	Includes last fish pumped from sweep net to plant
Second crowding			
10	10:35–11:25	30–80	Start of second crowding in same net-pen (t = 0 min)
10	11:00	55	Percussion stunned fish collected from slaughter line
9	11:45–12:08	100–120	Includes last fish out from sweep net