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Skirt around a salmon sea cage to reduce infestation of salmon lice resulted in low oxygen levels

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ABSTRACT

Salmon fish farmers are seeking methods to reduce infestations of salmon lice. The highest concentrations of salmon lice copepodites are typically found in the upper meters of the water column and preventing this water from passing through the salmon cages has been proposed as a way to reduce salmon lice infestation. One simple implementation proposed by the industry is to place a permanent tarpaulin skirt around the upper part of the sea cages. Currently, there is little evidence that a skirt will block the entrance of surface water to the cages and thereby reduce infestation. However, this pilot study shows that putting a tarpaulin skirt around a full scale commercial sea cage may seriously decrease the oxygen saturation levels available for the fish inside the skirt. Further investigations into the effectiveness of skirts as a means of reducing the exposure of farmed salmon to sea lice must therefore take precautional measures.

1. Introduction

The salmon farming industry urgently needs new methods to prevent infestations of sea lice, i.e. *Lepeophtheirus salmonis* (salmon lice) and, to a lesser extent, *Caligus elongatus* (Costello, 2006). Salmon lice represent a substantial economic impact on the industry (Costello, 2009a; Rosenberg, 2008), both indirectly through negative effects on the fish and directly through the costs of purchasing and administering the delousing agents. A third, very important aspect is that sea lice in salmon farms increase the infestation pressure on wild salmon (Costello, 2006). The salmon industry is therefore under heavy public pressure to solve the salmon lice problem.

The ultimate solution to the problem of salmon lice is to prevent physical contact between the infective sea lice larvae (copepodites) and the salmon host. Management of water quality by pumping and filtering water into land-based rearing systems or fully enclosed sea cages will certainly prevent physical contact. However, both of these approaches are at an early development stage and depend on cost-effective technological solutions and methods to meet the biological needs of the fish. A simpler solution to this critical problem that can be implemented in conventional sea cages has recently been proposed. The salmon lice copepodites are typically found near the surface during daylight (Heuch et al., 1995; Costello, 2009b) and Hevrøy et al. (2003) found that salmon held at 0–4 m depth developed higher infestation than salmon held at 4–8 m and 8–12 m depth. The salmon lice copepodits position itself in the upper water column to increase encounter probability with a potential host (Johannessen, 1977; Heuch et al., 1995). It is therefore hypothesized that putting a tarpaulin around the upper few meters of a sea cage (a skirt) to block the surface water from entering the sea cage will reduce lice infestation rates on the farmed salmon.

It is said in the industry that the skirt method has been tried with great success (Norwegian magazine article: Tveit, 2012). The most relevant publications on the topic are a report on the use of very deep skirts (10-m deep) to reduce infestation of salmon lice (Næs et al., 2012); a report by Lien and Høy (2011) that modeled how a 5-m deep skirt affects the flow pattern of water through a sea cage (⌀ = 50 m) without fish or nets, a flume study of retention of sea lice therapeutants inside a skirt (Corner et al., 2011) and a study of oxygen levels inside a skirt with the bottom of cage pulled up to force the fish inside the skirt (master thesis: Vigen, 2008). Citing mathematical simulations and studies using models, the report by Lien and Høy (2011) shows that a large part of the water is, as hoped, diverted around the cage. However, a proportion of the water is also drawn under the skirt and up into the back half of the cage. This inflow may limit the ability of the skirt to

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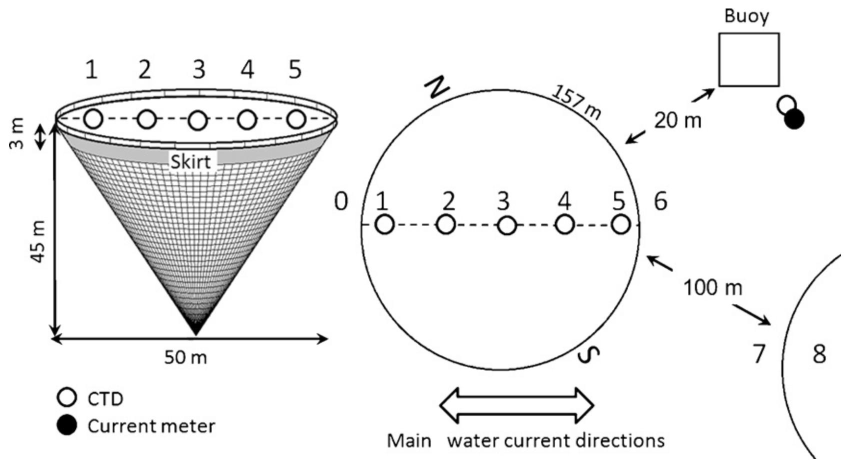

Fig. 1. Schematic drawings of the sea cage from the side and from above. The cage was 157 m in circumference (⌀ = 50, *C* = 157 m) and the cone shaped net was 45 m deep. Measurements positions 0–6 for water environment are indicated, as well as permanent positions for CTDs with oxygen sensors, main water current directions, distance to neighboring buoy with CTD with oxygen sensor and bundled current meter and distanced to neighboring sea cage with measuring positions 7 and 8, corresponding to measuring positions 0 and 1 in the sea cage with skirt.

prevent contact between the fish and the sea lice. Moreover, the flow of oxygen-rich water into sea cages must match the oxygen consumption of the fish inside the cage to avoid hypoxic conditions (Vigen, 2008). High stocking density of fish and increased oxygen consumption rates at high temperatures are of general concern in aquaculture (Johansson et al., 2006; Oppedal et al., 2011a, b), especially if devices that reduce the flow are used. The report by Næs et al. (2012) is very promising. They report significant less lice infestation in the sea cages with 10-m deep skirts compared to in the sea cages without skirt (0.20 vs. 0.6 lice $fish^{-1}$), but worryingly also incidence of significant lower oxygen saturation (as low as 67% compared to a minimum of 101% for the control cages). The depth of the skirts should, however, determine the need for technical prerequisites (e.g. extra oxygenation) in view of the increase in water exchange at the surface with decreasing skirt depth (Corner et al., 2011). A shallow skirt (<5 m deep) may function as a standalone solution without the need for extra circulation or oxygenation and may still cover the vertical range that is most important for controlling infestations of salmon lice. The salmon may also avoid any poor environmental conditions inside the skirt by occupying the much larger cage volume below the skirt.

The original goal of this study was to compare salmon lice infestation in two commercial sea cages with 3 m deep skirts compared to salmon lice infestation in four normal sea cages. To make sure that the skirts did not cause any harm to the fish, oxygen saturation were measured outside and inside one of the cages with skirt. The trial was carried out during midsummer, when lice abundance and water temperatures are expected to be high. Unfortunately it soon became clear after deployment of the first skirt that the skirt caused the oxygen concentration inside the cage to drop below levels acceptable for salmon welfare. The study was therefore stopped short, but since adequate oxygen levels are essential for fish welfare it is important to report the experimental setup and the effects on oxygen concentration recorded by the available instruments, particularly considering the number of animals (≈150,000 fish was involved in this study) that may be involved in future full scale studies on skirts to reduce infection with salmon lice.

2. Materials and methods

The commercial salmon farm site selected for the study was located in the Langenuen strait, south of Bergen, Norway (N60). It consisted of six circular sea cages (⌀ = 50 m, 45 m deep cone-shaped net, see Fig. 1) that were positioned in a diagonal row across the dominant current directions (Fig. 1). The farm staff began to mount the 3 m deep tarpaulin skirt on July 12, 2011 (Day 0), but the skirt was not fully in place until 3 pm on July 13 (Day 1). The cage chosen to have the first skirt, no. 4 in the row numbered from north east to south west, was supplied with five SD204 CTDs with SAIV205 oxygen sensors (Saiv AS, Norway, http://www.saivas.no) measuring salinity and temperature and oxygen saturation. The sensors were arranged in a line in the general direction of the main current (positions 1–5 in Fig. 1) at 1.5 m depth. A bundled current meter (Doppler Current Sensor 4100R) and CTD (SD204, Saiv AS, Norway) with oxygen sensor (Oxygen Sensor 4175, Aanderaa Data Instruments AS, Norway, http://www.aanderaa.com) were positioned 20 m outside the cage next to a mooring buoy at 1.5 m depth.

Due to the very low oxygen levels measured inside the cage after deployment of the first skirt, it was decided on Day 3 to use the available instruments to do additional measurements. Between 9 and 12 am, the bundled current meter and CTD with oxygen sensor were moved multiple times between positions 1 and 5 inside the cage with skirt (Fig. 1), positions 0 and 6 on each side of the cage and between positions 7 and 8 on the neighboring cage to the south east of the cage with the skirt (corresponding to positions 0 and 1, respectively). The measurements where performed for 5 min at each position. The cage with the skirt was also equipped with an underwater winch camera with oxygen and temperature sensors (Orbit 3300, Orbit GMT AS, Førresfjorden, Norway, http://www.orbitgmt.com) as part of the normal day-to-day management of the cage. Luckily this winch camera could be used to generate a vertical profile of temperature and oxygen conditions in the cage from the surface and down to 20 m depth.

The Atlantic salmon in the cage with the skirt had an average size of 0.92 ± 0.28 kg (SD) (sample of 20 individuals) and an estimated total biomass of 108 tonnes (≈150,000 fish) on Day 0. The neighboring cage to the south east had smaller fish and an estimated biomass of 76 tonnes (≈128,000 fish). The fish at the farm were diagnosed with pancreas disease (PD) on July 7. Owing to the very low oxygen values in the cage with the skirt (see below), the skirt was removed on July 19 (Day 7) rather than after six months as initially planned. The environmental data are reported below as the median and the 25–75-percentiles (interquartile range) in parentheses to give a description of the varying water environment. The median of the current direction data was calculated as the angle θ