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Review

Shielding skirt for prevention of salmon lice (*Lepeophtheirus salmonis*) infestation on Atlantic salmon (*Salmo salar* L.) in cages – A scaled model experimental study on net and skirt deformation, total mooring load, and currents

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ABSTRACT

Salmon lice are a serious threat to the Norwegian salmon aquaculture industry. Salmon have been found to develop higher infestation of salmon lice at the upper parts of the water column. The use of tarpaulin skirts for shielding the upper part of a salmon cage has therefore been used as a measure for reducing the salmon lice infestation. A tarpaulin skirt will however increase the effective solidity of the net, and it is necessary to study the cage mooring loads, the net deformation and the water flow through and around the cage to prevent damage to the structures and the fish. Experiments were conducted at the North Sea Centre Flume Tank in Hirtshals, Denmark, with a model salmon cage and skirt in scale 1:17. The experiments showed that the skirt sheet on the upstream side gets increasingly pulled back and up toward the surface as currents increase, and lice are likely to pass underneath and into the cage. The mooring load on the cage was also increasing with the current speed, and approximately 40% higher than that of a cage without skirt. Due to the increase in mooring loads applied by a shielding skirt it is important to include the effects of a skirt when calculating mooring loads on a farm system.

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1. Introduction

Infestation of salmon lice (*Lepeophtheirus salmonis*) is, together with escape (Naylor et al., 2005), currently the main challenge the salmon aquaculture industry in Norway is facing with respect to being environmentally sustainable. Salmon lice are a serious fish welfare problem, and are the most damaging parasite to the salmon farming industry in Norway (Costello, 2006). The consequences for the fish include damaged skin and compromised immunity (Skugor et al., 2008), and in some cases ultimately death (Finstad et al., 2000).

Salmon lice tend to multiply in fish farms because of the density of salmon individuals, and this also increases the infestation on surrounding wild fish (Bjørn et al., 2010). Along with the ecological impact the salmon lice negatively affect the industry's public reputation.

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With respect to economy, salmon lice infestations involve large expenses for the salmon farmers, approximately 1052 MNOK (131 MEUR or 164 MUSD) for the total production in Norway in 2006 (Costello, 2009), in which delousing contributes greatly (Høy, Unpublished results). Recent build-up of resistance caused by incorrect medication is making the treatment more complex, less effective and further increases the cost (Denholm et al., 2002).

Salmon have been found to develop higher infestation of salmon lice at the upper parts of the water column (Hevrøy et al., 2003). Because the swimming behavior of salmon lice is poor, and they are transported with the sea currents into the cages, shielding the upper part of a salmon cage might thus reduce the level of salmon lice infestations significantly. Tests with 10 m deep skirts have shown to reduce the salmon lice infestation on salmon in cages by a factor of four (Næs et al., 2012). Therefore, efforts such as tarpaulin skirts, or systems keeping the salmon below the salmon lice zone will likely reduce the number of delousing treatments needed, and thus reduce the fish farmers' production costs greatly, together with contributing to a more sustainable parasite control.

A tarpaulin skirt will increase the effective solidity of the net, and thus affect the cage mooring loads, the net deformation and the water flow through and around the cage. It is necessary to study these factors to prevent damage to the structures and the fish. Increased net solidity will increase the net deformation and the cage mooring loads which in turn can damage the net or the mooring lines, and can lead to escape of farmed fish (Lader et al., 2009; Jensen et al., 2010).

The forces on a flexible net cage are dependent on the deformation of the net, and using simple drag formulas derived from stiff net panel experiments give large errors compared to experimental measurements (Lader and Enerhaug, 2005). For a rigid body the drag force is proportional with the current speed squared, but because of the net deformation, this no longer applies. Therefore, if not corrected in relation to mooring calculations, the forces will be overestimated (Lader et al., 2009). Studies on how a skirt affects the mooring loads are needed.

CFD analyses of a rigid skirt in a laminar flow have shown that the flow partly is diverted around and partly underneath the skirt (Lien and Høy, 2011). This can result in decrease of water exchange inside the skirt volume. If the fish occupy this space the oxygen available inside the skirt may be seriously reduced (Stien et al., 2012).

The results from this study will contribute to validating numerical models for calculating fish farm structural loads and determine the technical and environmental limitations for the use of permanent skirts as a preventive disease control strategy.

2. Experimental description

2.1. Full scale starting point

The model was based on a 157 m circumference fish cage with 20 m deep cylindrical net with flat bottom, weighted with a sinker tube, which is a standard commercial fish cage for salmon farming in Norway. Shielding skirts for cages of this size are constructed as two sheets of tarpaulin of 95 m length overlapping each other on the diametric sides. The two sheets are not connected at the overlaps. The skirt is mounted outside the outer tube of the floating collar and hangs outside the sinker tube chains. The skirt is weighted with 26 single weights and by a lead line sewn in to the bottom of the tarpaulin.

2.2. Physical model

The model was constructed similar to the commercial cage in scale 1:17 (Fig. 1). The floating collar consisted of two 32 mm SDR 11 PE80 tubes attached together by 16 brackets evenly positioned around the circumference. The inner and outer diameters of the floating collar were 2940 mm and 3120 mm respectively. The net was attached to the inner tube and the skirt outside the outer. The net was made out of nylon, knotless Raschel type netting, with a nominal bar length of 7.3 mm and twine thickness of 0.7 mm, and had a solidity of 21%. The net was weighted and stretched by a sinker tube, having the same material and dimensions as the floating collar, with a weight chain inside. The sinker tube was secured to the outer floating collar by 20 chains evenly distributed along the circumference.

Fig. 1. Model cage with a floating collar consisting of two PE80 tubes, a nylon net with solidity 21%, and a skirt from waterproof parachute material.

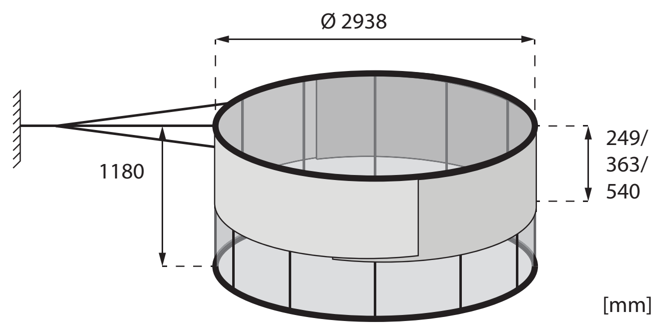

Fig. 2. Key dimensions for the model cage. The skirt was tested with three different depths, 249, 363 and 540 mm respectively.

The model skirt was made from a waterproof thin parachute fabric of nylon (type Ty-1) to imitate the behavior of a full scale skirt as close as possible. The skirt was attached as two pieces, overlapping without fixing where they connect. At the lower end a 1.2×10^{-5} kg mm^{-1} weight chain was sewn in and 26 single weights attached. Three different single weights were tested: w9, w18 and w36, at 9 g, 18 g and 36 g each respectively. 10 mm wide polyethylene bands were used for the straps, edge reinforcements and loops. Three different skirt depths were tested: d249, d363 and d540, being 249 mm, 363 mm and 540 mm deep respectively (Fig. 2).

2.3. Flume tank

The experiments were conducted in March 2012 at the North Sea Centre Flume Tank in Hirtshals, Denmark. The flume is a vertical circular water channel, driven by four impellers. The experimental section in the tank is 21.3 m long, 2.7 m deep and 8 m wide, and the maximum water speed capacity is 1 m s^{-1} (Fig. 3).