	Council ***Establishing barriers between farmed fish and sea lice – the only sustainable solution?***	**CNL(21)51rev** **Agenda Item: 5(a)**

Establishing Barriers Between Farmed Fish and Sea Lice – the Only Sustainable Solution?

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Introduction

Ectoparasitic sea lice present a major challenge to Atlantic salmon aquaculture (Coates *et al*. 2021) and a threat to fish welfare (Qviller *et al*. 2021). High infestation pressure of sea lice in the environment around commercial salmon farms has caused a critical increase in the mortality of wild salmonids (Krkosek *et al*. 2006; Ford and Myers 2008; Karlsen *et al*. 2020). Sea lice have also been described as a density-dependent constraint to salmonid farming (Jansen *et al*. 2012), where densities of farmed salmonids in an area have a strong effect on farm levels of sea lice and the efforts to control these infestations.

With widespread resistance towards all relevant delousing medications, other measures have been implemented such as mechanical and thermal delousing systems, freshwater baths (Overton *et al*. 2019) and a controversial increase in the use of cleaner fish (Overton *et al*. 2020; Sommerset 2021). Methods to prevent sea lice infestations have received little research effort, despite the many possible benefits of prevention over treatment-focused methods (Barrett *et al*. 2020). With effective prevention against salmon lice, the use of drugs which have a negative impact on non-target species around the farms (Urbina *et al*. 2019) and the ever-present challenge of drug-resistant parasites (Aaen *et al*. 2015) could be avoided. Further development of salmon farming will depend on the development and implementation of more efficient, fish-friendly and environmentally sustainable measures against salmon lice.

In this paper, I give a short presentation on semi-closed cage technology and the possible benefits and challenges of this farming technology.

What are semi-closed cages?

Semi-closed cages (SCCs) are floating, fish-farming systems with a barrier between the farmed fish inside the cage and the surrounding marine environment. Water is pumped from 20 – 35 m depth (Nilsen *et al*. 2017a; Balseiro *et al*. 2018) to create a single flow-through of sea water, with oxygen supplied through diffusers or ejector systems. In circular SCCs, water is released through a central outlet in the bottom; in some constructions, sea water is also released through several valves in the sidewall (Summerfelt *et al*. 2016). In tubular raceway systems, the water is circulated from inlet to outlet creating a constant one-way water current (Balseiro *et al*. 2018). The impermeable barriers that replace the nets used in open cages are made of flexible tarpaulin or constructions that are more rigid like composite, steel or concrete. With SCC technology, sedimentable particles can be collected and removed. So far, these systems are operated without any sophisticated cleaning or disinfection of water into or out from the cages, thus the term semi-closed or 'half'-closed.

Semi-closed cages – does it work?

In Nilsen *et al*. (2017a) and Nilsen *et al*. (2020), it was shown that effective prevention of sea lice infestation was possible with the use of semi-closed tarpaulin bags and an intake depth of 20 – 25 m. These studies were conducted between 2012 and 2017 at three different sea sites, with the same effect replicated at two new sites in the period from 2017 to 2021 (Nilsen, unpublished data). A study of a semi-closed raceway systems reported similar results (Balseiro *et al*. 2018). It is also possible to reduce salmon lice infestations with other barrier technologies such as skirts, submerged cages, or ‘snorkel’ cages, where the infestation levels will decrease when the barrier established between the farmed fish and the sea lice contaminated surface water is strengthened (Samsing *et al*. 2016).

Closing the cages leads to other possibilities and challenges. However, studies of fish welfare in commercial-scale SCCs are few and not conclusive (Calabrese 2017) and additional longitudinal studies of fish health and welfare are necessary to compare SCCs with other production systems. The most obvious management challenge in the first circular tank-prototypes has been the relatively low water exchange rates. Retention time in such tanks has been reported to be between 50 minutes (Summerfelt *et al*. 2016) and 150 minutes (Nilsen *et al*. 2017a), while the raceway study reported a retention time of only 5 minutes (Balseiro *et al*. 2018). Low specific water consumption may lead to accumulation of particles and metabolites (Fivelstad *et al*. 1999; Thorarensen and Farrell 2011; Nilsen *et al*. 2017b), to stress and impaired skin quality (Sveen *et al*. 2016) and slower wound healing (Sveen *et al*. 2019). Reduced water exchange and the use of deep water with higher possible levels of marine pathogens as *Moritella viscosa* could increase the probability of skin and gill infections, and increased mortality caused by complex or multifactorial infections affecting the body surface or the gills have been reported (Nilsen *et al*. 2017a; Nilsen *et al*. 2020; S. Handeland, pers. comm.). It has been suggested that fish welfare and production rates could be improved in SCCs because water temperatures and oxygen levels are more stable and water velocity can be regulated (Nilsen 2019). An increase in water velocity and swimming speed has been shown to enhance the development of skeletal and heart muscle (Balseiro *et al*. 2018; Nilsen *et al*. 2019; Timmerhaus *et al*. 2021) and positive effects on a broader range of metabolic variables and welfare indicators have also been documented (Nilsen *et al*. 2019). The use of deeper water layers may also reduce the likelihood of exposure to harmful algal blooms.

With SCCs, it is possible to reduce the output of organic nutrients from marine fish farms. A considerable fraction of the settleable particles can be collected and used for production of biogas and fertilisers (Bergheim and Nilsen 2017; Nilsen unpublished data), while soluble nutrients and smaller particles are released with the discharged (and untreated) outlet water. It is possible to combine SCC farms with integrated multitrophic aquaculture (IMTA). In pilot studies with the use of dissolved nutrients and small, organic particles discharged from SCCs with Atlantic salmon (Stedt 2018), it was shown how blue mussels (*Mytilus edulis*) could remove organic particles and that sugar kelp (*Saccharina latissima*) could utilise dissolved nitrogen to increase both growth rate (75 %) and nitrogen content of the leaves (72 %).

Sea lice biology and possible prevention strategies

Sea lice are marine copepods. In Norwegian salmonid farming the main concern is *Lepeophtheirus salmonis* (Qviller *et al*. 2021) with more sporadic problems reported with *Caligus elongatus* (Hemmingsen *et al*. 2020), whereas in Chile, the main sea lice species is *Caligus rogercresseyi* (Bravo 2003). All these have simple life cycles with juveniles, pre-adult, and adult stages on the host. Gravid females release egg strings and the eggs hatch to free-living planktonic stages. The newly hatched nauplii (0.4 – 0.7 mm long) disperse in the water column and drift with the current before they reach the final copepodid stage and settle on a new host (Boxaspen 2006). Copepodids (the infective stage) aggregate towards the surface during daytime and spread out into deeper layers at night (Heuch *et al*. 1995). Copepodids show no thermal preferences, while the smaller nauplii have been shown to avoid high water temperatures (Crosbie *et al*. 2020), interpreted as a strategy to combine increased geographical dispersion of the nauplii with optimal host-finding success for the copepodids. Sea lice larvae have an affinity for high salinities, but while copepodids display a relatively wide tolerance for brackish water and some individuals occur at salinities down to 16 to 20 ppt., nauplii almost completely avoid salinities below 30 ppt. (Crosbie *et al*. 2019). Both stages aggregate at, or just below, the halocline. For nauplii, the salinity is probably an important environmental cue for optimal vertical positioning, securing largest possible dispersion patterns (Crosbie *et al*. 2019). For copepodids, vertical positioning is probably also an important host-finding mechanism.

The copepod parasite *Caligus elongatus* is less host-specific than *L. salmonis* (Hemmingsen *et al*. 2020) and not a specialised salmonid ectoparasite. Still, it has been suggested as a possible challenge with the use of depth-based strategies compared to *L. salmonis,* because *C. elongatus* is found over a greater depth range, the parasites show a different seasonal variation than *L. salmonis* and fallowing has not been confirmed effective against *C. elongatus* (Hemmingsen *et al*. 2020). *C. elongatus* is also reported as a common ectoparasite on lumpfish (*Cyclopterus lumpus*) (Heuch *et al*. 2007), the most-used cleaner fish species in Norway. In salmon lice, development on the host is divided into the attached chalimus stage, moving pre-adult and finally moving adult lice. For *C. elongatus* the development is direct from chalimii to adult (Piasecki and MacKinnon 1995). The chalimii of *C. elongatus* are hard to distinguish from *L. salmonis* during routine lice-counts, especially the first two chalimii stages (S. Dalvin, pers. comm.), while the adult stages are small and relatively easy to identify. In both species, the copepodid is the infectious stage that locates and attaches to the host (Boxaspen 2006), but for *C. elongatus* it has also been speculated that adult lice could be capable of leaving their host and attaching to a new host (Hemmingsen *et al*. 2020). The effect of skirts and different versions of submerged cages on *C. elongatus* infestations is unknown. In closed-containment systems (CCS), there have been sporadic observations with a low abundance of *C. elongatus* (Nilsen *et al*. 2017a).

With the use of deeper water, it is possible to reduce or eliminate some parasitic infestations, others will be less affected. A reduction of tapeworm (*Eubothrium* sp.) infestation in Atlantic salmon was demonstrated with the use of snorkel cages (Geitung *et al*. 2021 in press). For important gill parasites like *Paramoeba perurans* (AGD), *Parvicapsula pseudobranchicola* and *Ichthyobodo* sp., there is no evidence of preventive effects from the use of depth-based technologies (Nilsen unpublished data).

Biofouling and biosecurity

Micro-organisms rapidly colonise all surfaces in marine waters. This formation of biofilm is important for the development and stability of marine ecosystems but is a challenge for design and management of fish farms (Dang and Lovell 2016). After the first microbiological colonisation, larger organisms like algae, hydrozoans, ascidiacea, bivalves and amphipods will settle, ending up with a complex ecosystem often referred to as biofouling. This is a perpetual process present in all fish farming units, and it comes with a significant economic impact (Fitridge *et al*. 2012). Biofilm and fouling organisms settle on all surfaces, with temporal and spatial gradients driven by variations of light and nutrients; the most rapid growth during spring and early summer and in the surface layers. Biofouling increases the weight of all underwater structures and reduces the flow of water through nets, filters and pipelines. With SCCs, the use of the copper-based antifouling chemicals that are frequently used on nets in open cages can be avoided (Grøsvik 2018); however, frequent cleaning is necessary to reduce the weight and possible negative impact on water flow from excess biofouling.

Biofilms are rich communities dominated by non-pathogenic organisms (Blancheton *et al*. 2013), however biofilms could also be reservoirs for pathogens (King *et al*. 2008), like *Aeromonas* sp. (Talagrand-Reboul *et al*. 2017) and *Peramoeba perurans* (AGD) (Tan *et al*. 2002). On the other hand, accumulations of sea lice in biofouling from salmon net pens and cleaner fish shelters have not been found (Jevne *et al*. 2020). It is also important to remember the importance of the microbiological processes in the water. In a study of land-based marine recirculating systems (RAS) and SCCs, both systems had a higher abundance of potential pathogens in the water than in the biofilm (Rud *et al*. 2017). With farming of Atlantic salmon, a significant microbiological footprint in the marine environment up to 1000 m away from the farm site was shown (Strand *et al*. 2020) and several pathogens were identified both inside the cages and in the water around the farm site.

Escaped fish

SCCs with a commercially developed and certified technology, combined with location at more sheltered sites, could be a way to reduce the risk of escapes. However, whether introduction of more SCCs will reduce or increase the risk of escaped fish is the subject of ongoing discussion. Tarpaulin bags are flexible and supplied with an extra net to prevent fish from escaping. Other materials are rigid, like solid-wall cages of composite, steel or concrete. These constructions are less vulnerable for wear and tear, but could be at risk of critical damage when exposed to heavy weather. For all technologies, SCCs are certified for less exposed sites (lower wave height) than open cages. At least three cases of accidents caused by storms are documented and a low number of escapes were registered in one of these. For open cages, the Norwegian Directorate of Fisheries (2021) report sea lice treatments with accompanying use of boats and handling of nets as a major risk factor for tearing of nets and thus escaped fish. Other new farming technologies, such as offshore farming, are less documented, but escaped fish caused by technical or human errors have been reported (Anonymous 2020).

The way forward

In recent years, we have seen high profit rates in salmon farming combined with increased biological challenges and accompanying strong regulatory limitations on growth in traditional farms. The value of the existing sea-farming licenses and the very limited new license volumes has increased dramatically, creating a strong incitement for investments in land-based production (fewer regulations) or offshore farms (new areas). Semi-closed farms have, until now, been regulated with the same legislative tools as open cage farms. This may change this year, as the Ministry of Trade and Fisheries are preparing a new policy document on future growth of salmon aquaculture in Norway.

Conclusions

SCCs introduce a solid barrier between the farmed fish and the surface water. Water is pumped from 20 – 30 m depth, thus effectively avoiding the infective sea lice copepodites. If open net cages are replaced with SCCs, the negative impact on wild salmonid populations from heavy sea lice infestations will be significantly reduced. With SCCs, sedimentable particles can be collected and removed, reducing the negative impact on the local benthic environment. In addition, there will be less need for environmentally controversial therapeutic measures such as chemical treatments or the use of cleaner fish. There will also be less negative impact on the welfare of farmed fish caused by the non-medical treatments frequently used in open cages.

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