

	<p>Council</p> <p><i>Establishing barriers between farmed fish and sea lice – the only sustainable solution?</i></p>	<p>CNL(21)51</p> <p>Agenda Item: 5(a)</p>
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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.* 2021). 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 infections.

With widespread resistance towards all relevant delousing medications, other measures have been implemented, as mechanical and thermal delousing systems and 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, it could be possible to avoid the use of drugs with 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). 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 of the technology of semi-closed cages and the possible benefits and challenges of this farming technology.

What are semi-closed cages?

Semi-closed cages (SCC) 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 to 35 m depth (Nilsen *et al.* 2017a; Balseiro *et al.* 2018) to create a single flow-through of seawater, with oxygen supplied through diffusers or ejector systems. In circular SCC, water is released through a central outlet in the bottom, in some constructions also 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, it is possible to collect and remove sedimentable particles. 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 also at two new sites in the period from 2017 to 2021 (Nilsen, unpublished data). A study of a semi-closed raceway system reported similar results (Balseiro

et al. 2018). It is possible to reduce salmon lice infestations also with other barrier technologies, as skirts, submerged cages, or ‘snorkel’ cages, where the infestation levels will decrease with the strength of the barrier established between the farmed fish and the sea lice contaminated surface water (Samsing *et al.* 2016).

Closing the cages leads to other possibilities and challenges. However, studies of fish welfare in commercial-scale SCC are few and not conclusive (Calabrese 2017) and additional longitudinal studies of fish health and welfare are necessary to compare semi-closed cages 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; Handeland pers.com.). It has been suggested that it is possible to improve fish welfare and production rates in semi-closed cages because water temperatures and oxygen levels are more stable, and it is possible to regulate water velocity (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 for exposure of harmful algal blooms.

With semi-closed cages, 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 fertilizers (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 semi-closed cages with Atlantic salmon (Stedt 2018), it was shown how blue mussels (*Mytilus edulis*) could remove organic particles and that sugar kelp (*Saccharina latissima*) could utilize 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 specialized salmonid ectoparasite. Still, it has been suggested as a possible challenge with the use of depth-based strategies against *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 (Dalvin pers.com.), 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 on the possibility that adult lice are capable to leave their host and attach 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 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 effect from the use of depth-based technologies (Nilsen unpublished data).

Biofouling and biosecurity

Micro-organisms rapidly colonize 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 colonization, 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 reduce the flow of water through nets, filters, and pipelines. With semi-closed cages, it is possible to avoid the use of the copper-based antifouling chemicals that are frequently used on nets in open cages (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 semi-closed cages, both systems had a higher abundance of potential pathogens in the water than in the biofilm (Rud *et al.* 2016). With farming of Atlantic salmon, it was shown a significant microbiological footprint in the marine environment up to 1000 m away from the farm site (Strand *et al.* 2020), and several pathogens were identified both inside the cages and in the water around the farm site.

Escaped fish

Semi-closed cages 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, it is an ongoing discussion whether introduction of more semi-closed cages will reduce or increase the risk of escaped fish. 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, semi-closed cages 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, as offshore farming, are less documented, but escaped fish caused by technical or human errors have been reported (Anonymous 2020).

The way forward

During the last 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

Semi-closed cages introduce a solid barrier between the farmed fish and the surface water. Water is pumped from 20 to 30 m depth, thus effectively avoiding the infective sea lice copepodites. If open net cages are replaced with semi-closed cages, the negative impact on wild salmonid populations from heavy sea lice infestations will be significantly reduced. With semi-closed cages it is possible to collect and remove sedimentable particles, 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.

References:

Aaen, S.M., Helgesen, K.O., Bakke, M.J., Kaur, K., and Horsberg, T.E. 2015. Drug resistance in sea lice: a threat to salmonid aquaculture. *Trends in Parasitology*, 31(2), 72-81. doi: 10.1016/j.pt.2014.12.006

Anonymous 2020. Sluttrapport Prosjekt Ocean Farm 1. Website: <https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Saertillatelser/Utviklingstillatelser/Kunnskap-fra-utviklingsprosjektene> (In Norwegian). Retrieved 2021 04 14.

- Balseiro, P., Moe, O., Gamlem, I., Shimizu, M., Sveier, H., Nilsen, T.O., Kaneko, N. *et al.* 2018. Comparison between Atlantic salmon *Salmo salar* post-smolts reared in open sea cages and in the Preline raceway semi-closed containment aquaculture system. *Journal of Fish Biology*, 93(3), 567-579. doi: 10.1111/jfb.13659
- Barrett, L.T., Oppedal, F., Robinson, N., Dempster, T. 2020. Prevention not cure: a review of methods to avoid sea lice infestations. In: Boxaspen, K. 2006. A review of the biology and genetics of sea lice. *ICES Journal of Marine Science*, 63(7), 1304-1316. doi: 10.1016/j.icesjms.2006.04.017
- Bergheim, A. and Nilsen, A. 2017. Slamproduksjon ved mekanisk behandling av avløp fra lukkede merder, Akva Future AS, avd. Sæterosen, 2017 (in Norwegian). Report IRIS – 2017/060.
- Blancheton, J.P., Attramadal, K.J.K., Michaud, L., d'Orbcastel, E.R., Vadstein, O. 2013. Insight into bacterial population in aquaculture systems and its implication. *Aquaculture*, 53, 30-39.
- Boxaspen, K. 2006. A review of the biology and genetics of sea lice. *ICES Journal of Marine Science*, 63, 1304-1316.
- Bravo, S. 2003. Sea lice in Chilean salmon farms. *Bulletin of the European Association of Fish Pathologists*, 23(4), 197-200.
- Calabrese, S. 2017. Environmental and biological requirements of post-smolt Atlantic salmon (*Salmo salar* L.) in closed-containment aquaculture systems. (Doctoral dissertation), University of Bergen, Bergen, Norway.
- Coates, A., Philips, B.L., Bui, S., Oppedal, F., Robinson, N.A., Dempster, T. 2021. Evolution of salmon lice in response to management strategies: a review. *Reviews in Aquaculture*, 1-26. doi: 10.1111/raq.12528.
- Crosbie, T., Wright, D.W., Oppedal, F., Johnsen, I.A., Samsing, F., Dempster, T. 2019. Effects of step salinity on salmon lice larvae behaviour and dispersal. *Aquaculture Environment Interactions*, 11, 181-190. doi 10.3354/aei00303.
- Crosbie, T., Wright, D.W., Oppedal, F., Dalvin, S., Myksvoll, M.S., Dempster, T. 2020. Impact of thermoclines on the vertical distribution of salmon lice larvae. *Aquaculture Environment Interactions*, 12, 1-10. doi 10.3354/aei00344.
- Dang, H. and Lovell, C.R. 2016. Microbial surface colonization and biofilm development in marine environments. *Microbiology and Molecular Biology Reviews*, 80, 91–138.
- Fivelstad, S., Bergheim, A., Kloften, H., Haugen, R., Lohne, T. and Olsen, A.B. 1999. Water flow requirements in the intensive production of Atlantic salmon (*Salmo salar* L.) fry: growth and oxygen consumption. *Aquacultural Engineering*, 20(1), 1-15. doi: Doi 10.1016/S0144-8609(99)00002-3
- Fitridge, I., Dempster, T., Guenther, J. and de Nys, R. 2012. The impact and control of biofouling in marine aquaculture. *Biofouling*, 28(7), 649-669.
- Ford, J.S. and Myers, R.A. 2008. A global assessment of salmon aquaculture impacts on wild salmonids. *PLOS Biology*, 6(2):e33, doi 10.1371/journal.pbio.0060033.
- Geitung, L., Wright, D.W., Stien, L.H., Oppedal, F. and Karlsbakk, E. 2021 (in press). Tapeworm (*Eubothrium* sp.) infestation in sea caged Atlantic salmon decreased by lice barrier snorkels during a commercial-scale study. *Aquaculture*, online 17 April 2021, doi: 10.1016/j.aquaculture.2021.736774

- Grøsvik, B.E. 2018. Fremmedstoff. In: E.S. Grefsrud, K. Glover, B.E. Grøsvik, V. Husa, Ø. Karlsen, T. Kristiansen, B.O. Kvamme *et al.* (Eds) 2018. Risikoreport norsk fiskeoppdrett (In Norwegian), Norwegian Institute of Marine Research, Fisken og havet, Særnummer 1-2018.
- Hemmingsen, W., MacKenzie, K., Sagerup, K., Remen, M., Bloch-Hansen, K. and Imsland, A.L.D. 2020. *Caligus elongatus* and other sea lice of the genus *Caligus* as parasites of farmed salmonids: A review. *Aquaculture*, 522, 735160, doi: 10.1016/j.aquaculture.2020.735160.
- Heuch, P.A., Parsons, A. and Boxaspen, K. 1995. Diel Vertical Migration – a Possible Host-Finding Mechanism in Salmon Louse (*Lepeophtheirus-Salmonis*) Copepodids. *Canadian Journal of Fisheries and Aquatic Sciences*, 52(4), 681-689.
- Heuch, P.A., Øines, Ø., Knutsen, J.A. and Schram, T.A. 2007. Infection of wild fishes by the parasitic copepod *Caligus elongatus* on the south east coast of Norway. *Diseases of Aquatic Organisms*, 77, 149-158, doi: 10.3354/dao01833.
- Jansen, P.A., Kristoffersen, A.B., Viljugrein, H., Jimenez, D., Aldrin, M. and Stien, A. 2012. Sea lice as a density-dependent constraint to salmonid farming. *Proceedings of the Royal Society B-Biological Sciences*, 279(1737), 2330-2338. doi: 10.1098/rspb.2012.0084
- Jevne, L.S., Øvrelid, M.S., Hagemann, A., Bloecher, N., Steinhovden, K.B., Båtnes, A.S., Olsen, Y., Reitan, K.I. 2020. Biofouling on Salmon Net Pens and Cleaner Fish Shelters Does Not Harbor Planktonic Stages of Sea Lice. *Frontiers in Marine Science*, 7, 727.
- Karlsen, Ø., Dalvin, S., Johnsen, I.A., Sandvik, A.D. and Serra-Llinares, R.M. 2021. Risiko knyttet til dødelighet hos utvandrende postsmolt laks som følge av utslipp av lakselus fra fiskeoppdrett. In: E.S. Grefsrud., Ø. Karlsen., T. Svåsand. (Eds.), Risikoreport norsk fiskeoppdrett. 2020 (in Norwegian). Norwegian Institute of Marine Research, Report. 2020-4.
- King, R.K., Flick Jr., G.J., Pierson, D., Smith, S.A., Boardman, G.D. and Coale Jr., C.W. 2008. Identification of Bacterial Pathogens in Biofilms of Recirculating Aquaculture Systems. *Journal of Aquatic Food Product Technology*, 13(1), 125-133.
- Krkosek, M., Lewis, M.A., Morton, A., Frazer, L.N. and Volpe, J.P. 2006. Epizootics of wild fish induced by farm fish. *Proceedings of the National Academy of Sciences*, 103(42), 15506-15510, doi: 10.1073/pnas.0603525103.
- Nilsen, A. 2019. Production of Atlantic salmon (*Salmo salar*) in closed confinement systems (CCS) – salmon lice, growth rates, mortality and fish welfare. Norwegian University of Life Sciences, Doctoral thesis 2019:48.
- Nilsen, A., Nielsen, K.V., Biering, E. and Bergheim, A. 2017a. Effective protection against sea lice during the production of Atlantic salmon in floating enclosures. *Aquaculture* 466, 41-50. doi: 10.1016/j.aquaculture.2016.09.009
- Nilsen, A., Nielsen, K.V. and Bergheim, A. 2017b. The impact of production intensity on water quality in oxygen enriched, floating enclosures for post-smolt salmon culture. *Aquacultural engineering* 78, 221-227. doi: 10.1016/j.aquaeng.2017.06.001
- Nilsen, A., Hagen, Ø., Johnsen, C.A., Prytz, H., Zhou, B., Nielsen, K.V. and Bjørnevik, M. 2019. The importance of exercise: Increased water velocity improves growth of Atlantic salmon in closed cages. *Aquacultural Engineering* 78, 221-227. doi: 10.1016/j.aquaculture.2018.09.057.
- Nilsen, A., Nielsen, K.V. and Bergheim, A., 2020. A closer look at closed cages: Growth and mortality rates during production of post-smolt Atlantic salmon in marine closed confinement systems. *Aquacultural Engineering* 91. doi: 10.1016/j.aquaeng.2020.102124

- Norwegian Directorate of Fisheries 2021. Website: <https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Roemningsstatistikk>. Retrieved 2021 04 14.
- Overton, K., Dempster, T., Oppedal, F., Kristiansen, T.S., Gismervik, K. and Stien, L.H. 2019. Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review. *Reviews in Aquaculture*, 11, 1398-1417. doi: 10.1111/raq.12299
- Overton, K., Barrett, L.T., Oppedal, F., Kristiansen, T.S. and Dempster, T. 2020. Sea lice removal by cleaner fish in salmon aquaculture: a review of the evidence base. *Aquaculture environment interactions*, 12, 31-44. doi: 10.3354/aei00345
- Piasecki, W. and Mackinnon, B.M. 1995. Life-Cycle of a Sea Louse, *Caligus-Elongatus* Von nordmann, 1832 (Copepoda, Siphonostomatoida, Caligidae). *Canadian Journal of Zoology-Revue Canadienne De Zoologie*, 73(1), 74-82. doi: Doi 10.1139/Z95-009
- Rud, I., Kolarevic, J., Holan, A.B., Berget, I., Calabrese, S. and Terjesen, B. F. 2017. Deep-sequencing of the bacterial microbiota in commercial-scale recirculating and semi-closed aquaculture systems for Atlantic salmon post-smolt production. *Aquacultural Engineering*, 78, 50-62. doi: 10.1016/j.aquaeng.2016.10.003
- Samsing, F., Johnsen, I., Stien, L.H., Oppedal, F., Albretsen, J., Asplin, L. and Dempster, T. 2016. Predicting the effectiveness of depth-based technologies to prevent salmon lice infection using a dispersal model. *Preventive Veterinary Medicine*, 129, 48-57. doi: 10.1016/j.prevetmed.2016.05.010
- Sommerset, I. 2021. In: I. Sommerset and E. Brun (Eds.), *Fish Health Report from the Norwegian Veterinary Institute (in Norwegian)*, Report 41a/2021.
- Stedt, K. 2018. *Integrated multi-trophic aquaculture: The Potential of Using Saccharina latissima and Mytilus edulis as Bioremediative Species in Sea-Based Aquaculture Systems*. (Masters thesis), University of Gothenburg.
- Strand, D., Sørum, H., Nielsen, K.V., Næss, A., Johnsen, T.O., Singdahlsen, J.O., Fjelldalselv, B. *et al.* 2020. Fiskehelse og mikrobielt miljø a lukkede merder (In Norwegian). Presentation at Norwegian Research Council annual meeting, HAVBRUK, June 12th 2020.
- Summerfelt, S.T., Mathisen, F., Holan, A.B. and Terjesen, B.F. 2016. Survey of large circular and octagonal tanks operated at Norwegian commercial smolt and post-smolt sites. *Aquacultural Engineering*, 74, 105-110. doi: 10.1016/j.aquaeng.2016.07.004
- Sveen, L.R., Timmerhaus, G., Krasnov, A., Takle, H., Handeland, S. and Ytteborg, E. 2019. Wound Healing in post-smolt Atlantic salmon (*Salmo salar* L.). *Scientific Reports*, 9. doi: Artn 356510.1038/S41598-019-39080-X
- Sveen, L.R., Timmerhaus, G., Torgersen, J.S., Ytteborg, E., Jorgensen, S.M., Handeland, S. Stefansson, S.O., *et al.* 2016. Impact of fish density and specific water flow on skin properties in Atlantic salmon (*Salmo salar* L.) post-smolts. *Aquaculture*, 464, 629-637. doi: 10.1016/j.aquaculture.2016.08.012
- Talagrand-Rebouol, E., Jumas-Bilak, E. and Lamy, B. 2017. The Social Life of *Aeromonas* through Biofilm and Quorum Sensing Systems. *Frontiers in Microbiology*, 8, 37.
- Tan, C.K.F., Nowak, B.F. and Hodson, S.L. 2002. Biofouling as a reservoir of *Neoparamoeba pemaquidensis* (Page, 1970), the causative agent of amoebic gill disease in Atlantic salmon. *Aquaculture*, 210, 49-58.

Thorarensen, H. and Farrell, A.P. 2011. The biological requirements for post-smolt Atlantic salmon in closed-containment systems. *Aquaculture*, 312(1-4), 1-14. doi: 10.1016/j.aquaculture.2010.11.043

Timmerhaus, G., Lazado, C.C., Cabillon, N.A.R., Reiten, B.K.M. and Johansen, L.H. 2021. The optimum velocity for Atlantic salmon post-smolts in RAS is a compromise between muscle growth and fish welfare. *Aquaculture*, 532, doi: 10.1016/j.aquaculture.2020.736076

Urbina, M.A., Cumillaf, J.P., Paschke, K. and Gebauer, P. 2019. Effects of pharmaceuticals used to treat salmon lice on non-target species: Evidence from a systematic review. *Science of the Total Environment*, 649, 1124-1136. doi: 10.1016/j.scitotenv.2018.08.334

Qviller, L., Helgesen, K.O. and Stige, L.C. 2021. Lakselus – *Lepeophtheirus salmonis*. In: I. Sommerset and E. Brun (Eds.), *Fish Health Report from the Norwegian Veterinary Institute (in Norwegian)*, Report 41a/2021.