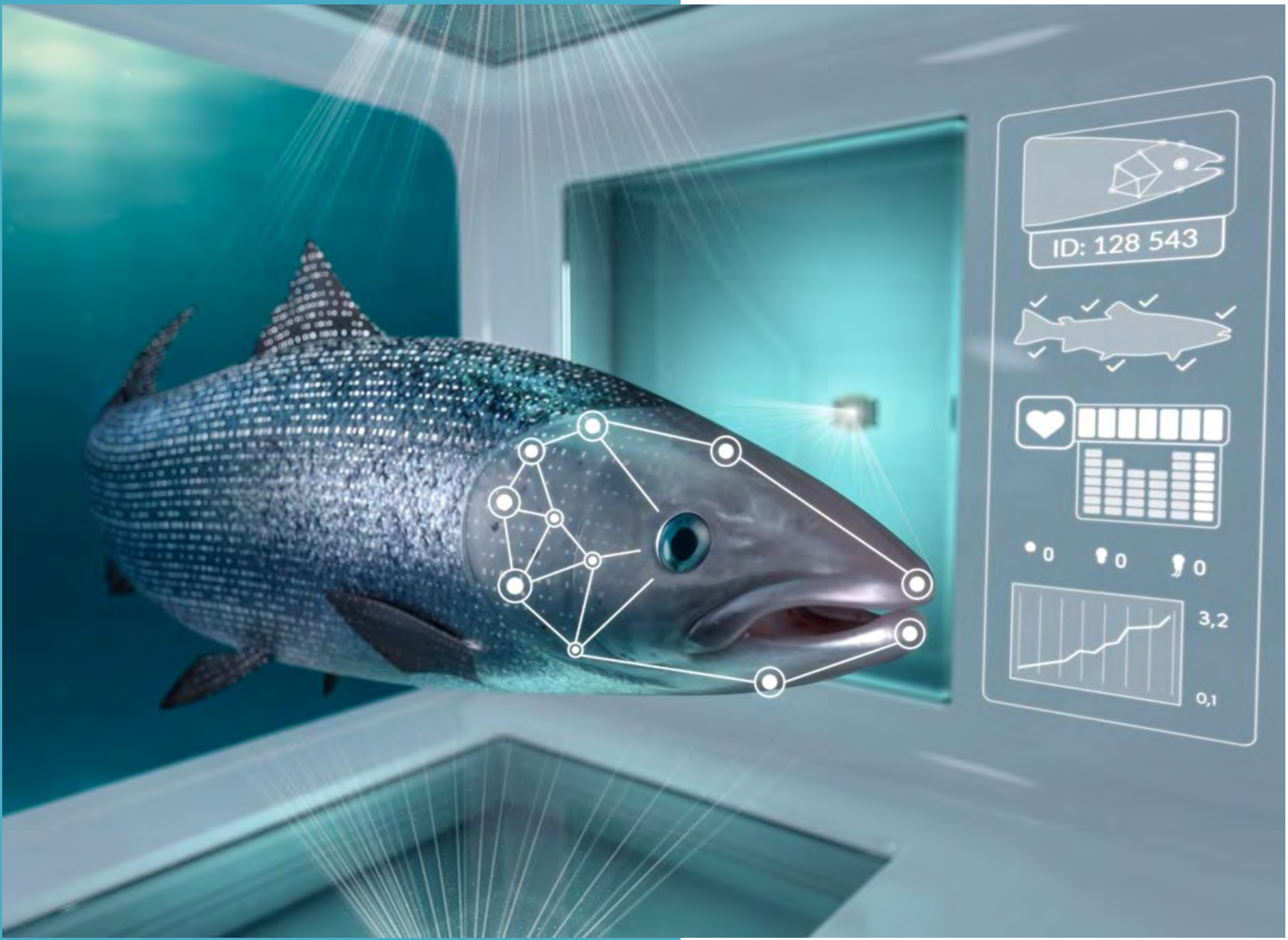
iFarm: Final report documenting the biological and technological results from Phase 3 (Prototype B) – Cermaq Utvikling avd Hellarvika



Cermaq Norway

16.05.2024

Innhold

CERMAQ

Summary

The iFarm aquaculture concept, being developed by BioSort AS in partnership with Cermaq Utvikling AS was granted four development licences by the Norwegian Directorate of Fisheries in June 2019. The iFarm concept aims to introduce individual-based Precision Fish Farming (Føre et al., 2018) to Atlantic salmon aquaculture. It aims to use advanced illumination/camera technologies and computer vision algorithms to identify individual fish, as well as counting lice on the fish and other parameters related to health, welfare and growth on individual salmon held within adapted aquaculture sea cages from smolt transfer to slaughter. The development licence project also aims to grade and sort fish based on their emaciation status or lethargy status (often termed 'loser fish'), their wound prevalence/severity and also their morbidity status.

The iFarm development licences in Phase 3 consisted of 9 cages. Three phases of the iFarm project were originally planned from 2020-2024 and a fourth phase has been added to supplement project data, which will run until 2025. This final report addresses Phase 3 from when the first cages were stocked on the 3rd June 2022 until slaughter. Spring 1-year smolts were stocked in on 3rd June 2022 (cages M5, M10 and M11) and 0-year smolts were stocked in two periods, a) 1st August 2022 (cages M1, M7 and M8), and b) 17th October 2022 (cages M2, M3 and M4).

This report summarises the technological developments that occurred during the report period in addition to results from the monitoring of biological (fish health and welfare) and production performance during the reporting period.

CERMAQ

Background

Cermaq's vision for the Age of Aquaculture

The Norwegian Atlantic salmon farming industry is over 50 years old, beginning in the late 1960's where annual production was very limited, amounting to ca. 100 tonnes in 1970 (Hersoug, 2021 and references therein). Steady growth, seeing annual production reach over 200,000 tonnes in the mid 1990's soon accelerated in the early and mid-2000's reaching an annual sales tonnage of over 1.0 million tonnes in 2011. However, growth has somewhat stagnated over the last decade, with annual sales ranging from 1.1 – 1.4 million tonnes per year (Norwegian Directorate of Fisheries, 2022).

The drivers for this stagnation are wide-ranging and multi-factorial, and also manifest themselves in other Atlantic salmon production regions around the world (e.g., Iversen et al., 2020). These drivers consider socio-environmental impacts of aquaculture addressing sustainability and co-existence, including the potential transfer of disease and pathogens to wild stocks, the potential genetic and ecological impacts of escaped farmed fish upon wild stocks amongst others (e.g., Young et al., 2019; Hersoug, 2021).

A central objective in Cermaq's operations is to continuously work to minimize the negative environmental footprint of the company while lifting Cermaq's own (and the industry's) standards. Farming salmon is an efficient way of producing healthy and nutritious food with a smaller ecological footprint compared with other animal proteins. Cermaq aligns its focus areas with the UN Sustainable Development Goals (SDGs) but growing sustainable salmon farming comes with challenges. Through dedicated R&D, Cermaq are always searching for new ways to improve animal welfare, salmon quality and make the task of farming more sustainable and take great interest in innovative ways to use new technologies to enhance nature and ensure salmon health and welfare.

Regulatory frameworks for promoting sustainable and innovative Norwegian salmon farming

The Norwegian Atlantic salmon farming industry is subject to a robust and far-reaching management and regulatory framework to promote sustainability, to regulate total production and address the concerns of interested parties and stakeholders (Young et al., 2019; Hersoug, 2021). The regulatory framework has been developed and adapted over the years, with two recent regulatory instruments, the 'Traffic Light System (TLS)' and 'Development licences' being recently introduced (Hersoug et al., 2021). Growth under the Traffic Light System is regulated by sea lice abundance on out-migrating wild salmon smolts and its potential mortality risk on these smolts within a specific salmon farming region (Young et al., 2021).

The Development Licence regulatory instrument is specifically designed to encourage innovation and help the aquaculture industry develop new and innovative production technologies (see Hersoug et al., 2021 and https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Saertillatelser/Utviklingstillatelser). The aim of the licence instrument is to reduce the risks connected to the development and implementation of large-scale innovation and are initially granted freely but do require the awardee to make significant investments in the projects (see Hersoug et al., 2021 for more details).

The iFarm concept

The iFarm aquaculture concept, currently being developed by BioSort AS and being brought to fruition in partnership with Cermaq Utvikling AS was granted four development licences by the Norwegian Directorate of Fisheries in 2019 (see https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Saertillatelser/Utviklingstillatelser/Status-ja-nei-antall-og-biomasse).

The iFarm aquaculture concept is a novel production system that aims to introduce individual-based Precision Fish Farming (Føre et al., 2018) to Atlantic salmon aquaculture. It aims to use advanced illumination/camera technologies and computer vision algorithms to identify individual fish (similar to facial recognition), as well as counting lice on the fish and other parameters related to health, welfare and growth on individual salmon held within adapted aquaculture sea cages from smolt transfer to slaughter. The iFarm prototype B production system consists of an adapted snorkel cage that holds fish 12 m below the ocean surface to limit their interactions with potential lice rich surface waters. Cages are also fitted with lice skirts around the main cage collar (not snorkel) down to a depth of 6 meters. Atlantic salmon must access the water surface to refill their swim bladder with air and have the opportunity to do so by swimming up through the snorkel to the surface (see Stien et al., 2016a). The aim is that each time the fish swims to the surface it must pass through the iFarm sensor which will then identify it and measure various performance, welfare and health parameters.

The iFarm development licence Phase 1, Phase 2 and Phase 3

Pilot and commercial testing of the iFarm concept

The iFarm concept was initially pilot-tested at the Institute of Marine Research and a report of the 2017 trials from January 24th – March 28th, 2017, was submitted to the Directorate on June 27th, 2017, as part of "tilleggsopplysninger til søknad", vedlegg 7.

Development of the iFarm concept for commercial scale cages, within the development licence project, was started in January 2020. In September 2020 a full-scale testing of two iFarm systems with a strong focus on operations, technology and fish health and welfare monitoring was carried out to initiate the first full-scale "proof of concept" for the iFarm system. This testing was also to instigate the initial full-scale implementation and application of the farming system and take the first steps to realise it as an innovative product. This testing was carried out in tandem with monitoring a third, adapted snorkel cage at the same farming site. Phase 2 involved full scale testing of eight adapted iFarm cages and one associate cage from the first stocking of fish in May 2021 until the slaughtering of the last cage in February 2023. All cages in Phase 2 were fed using adapted underwater feeding systems. Findings on the testing of Phase 1 and Phase 2 of the system have been outlined in the Phase 1 final report, submitted to the Norwegian Directorate of Fisheries on 25th July 2022 and the Phase 2 final report, submitted to the Norwegian Directorate of Fisheries on 28th September 2023.

This current report addresses the final Phase 3 reporting period of the iFarm development licence as outlined below.

Technical design and cage set-up Phase 3

Geographical location

This proof of concept commercialisation study was carried out at the Cermaq Utvikling AS Hellarvika production site 67.43602^{0} N, 15.22807^{0} E (see Figure 1).

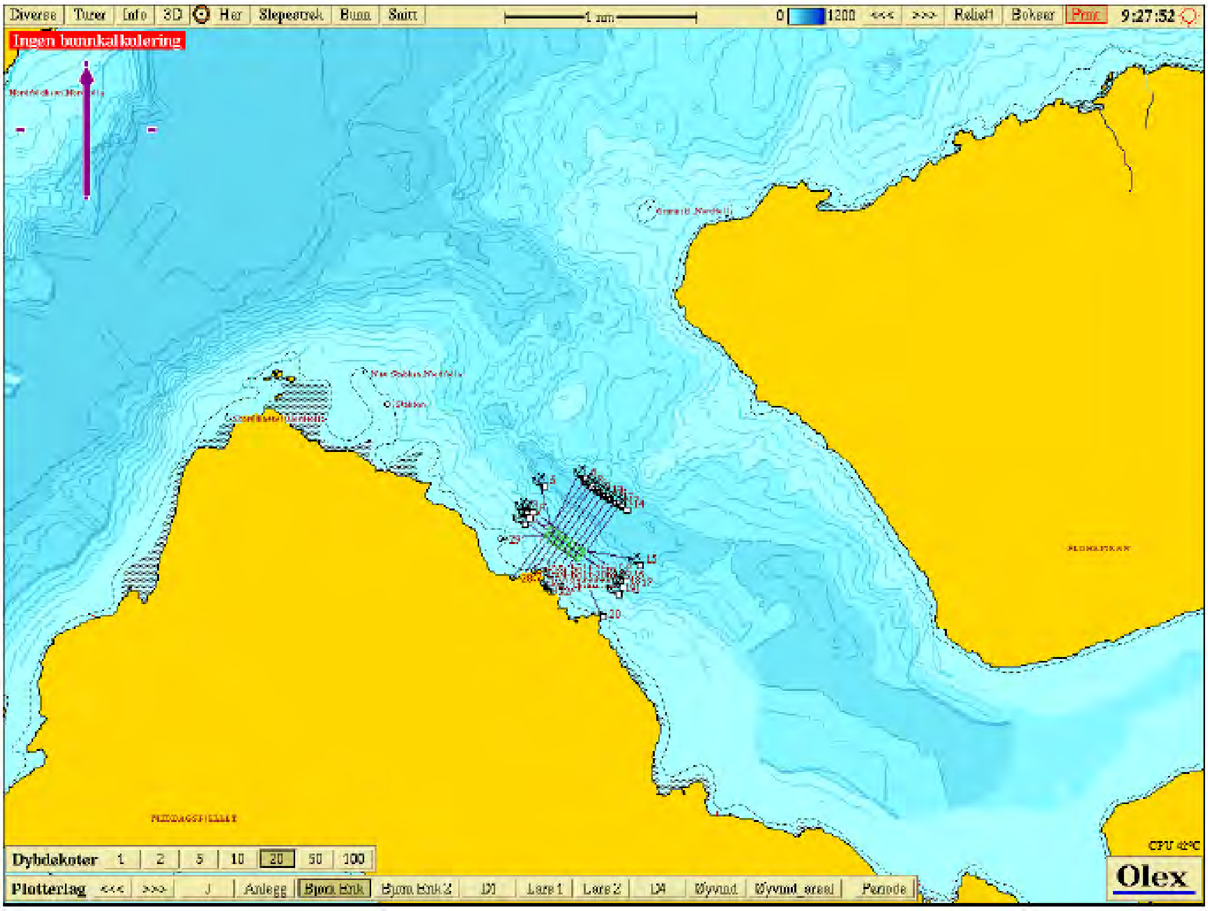


Figure 1 Map showing the Cermaq Utvikling AS facility Hellarvika, where the iFarm cages are located. Map courtesy of Olex AS and reproduced from the Hellarvika site report by Akvaplan-niva.

Phase 3 timeline and set up

Phase 3 of the project is currently underway and began when the fish were transferred to seawater on the 3rd of June 2022. Phase 3 uses spring 1-year and autumn 0-year smolts stocked in nine production cages at Hellarvika, where 1-year smolts were stocked i) in a cage that first had a traditional 90m circumference snorkel mounted for the first six months of production, before then becoming an open associate cage (M5) fed via an underwater feeder (Brattland Subfeeder, see feeding system section of the methods) and ii) two open cages fed with iFarm underwater feeding equipment (M10 and M11). The actual cage configurations for the first stocking of the 0-year smolts was i) a cage with an adapted iFarm snorkel that had a standard docking station for 4 months until this was replaced with a net-based docking station (cage M1), ii) a cage with a standard docking station from the time of smolt transfer (cage M7), and iii) a cage with a standard docking station and for periods an iFarm sensor house (cage M8). The actual cage configurations for the second stocking of the 0-year smolts was i) a cage with an adapted iFarm snorkel that had a standard docking station for ca. 7 months until this was replaced with a net-based docking station (cage M2), ii) a cage with a standard docking station and for periods an iFarm sensor house (cage M3), and iii) an open cage fed with iFarm underwater feeding equipment (cage M4).

Spring 1-year smolts were stocked on the 3rd of June 2022 (cages M5, M10 and M11). Fish in these cages were from a pooled hatchery AquaGen QTL-Innova SHIELD + HSMB stock. Because of logistical delays with the manufacturing, delivery and deployment of the adapted iFarm snorkel cages in M10 and M11, fish were originally transferred into open 160 m net cages at the time of seawater transfer. Autumn 0-year smolts were stocked in two periods: a) 1st of August 2022 (cages M1, M7 and M8) and b) 17th of October 2022 (cages M2, M3 and M4). Fish in cages M1, M7 and M8 were from a pooled hatchery AquaGen QTL-Innova SHIELD + HSMB stock, and fish in cages M2, M3 and M4 were from a pooled hatchery SalmoBreed SalmoSelect. The stocking details can be seen in Table 1 below.

Table 1 outlining the source hatchery, well boat, date of stocking and cage destination of fish for iFarm Phase 3 at the Cermaq Utvikling AS facility Hellarvika 11315. Also shown are water temperatures at time of transfer and fish size and stocking number.

Hatchery	Well boat	Date of stocking	Cage	Mean water temp. at seawater transfer	Mean weight	Number stocked
Hatchery 1	M/S Dønnland	03.06.22	M5	7. 0	83 g	128 674
Hatchery 1	M/S Dønnland	03.06.22	M10	7.0	88 g	127 376
Hatchery 1	M/S Dønnland	03.06.22	M11	7.0	78 g	130 448
Hatchery 2	M/S Dønnland	01.08.22	M1	13.4	68 g	123 380
Hatchery 2	M/S Dønnland	01.08.22	M7	13.4	77 g	129 336
Hatchery 2	M/S Dønnland	01.08.22	M8	13.4	90 g	143 112
Hatchery 3	M/S Dønnland	17.10.22	M2	9.5	112 g	128 032
Hatchery 3	M/S Dønnland	17.10.22	M3	9.5	108 g	127 859
Hatchery 3	M/S Dønnland	17.10.22	M4	9.5	97 g	127 997

Placement of the cages within the cage group at the Hellarvika site is shown in Figure 2 below.

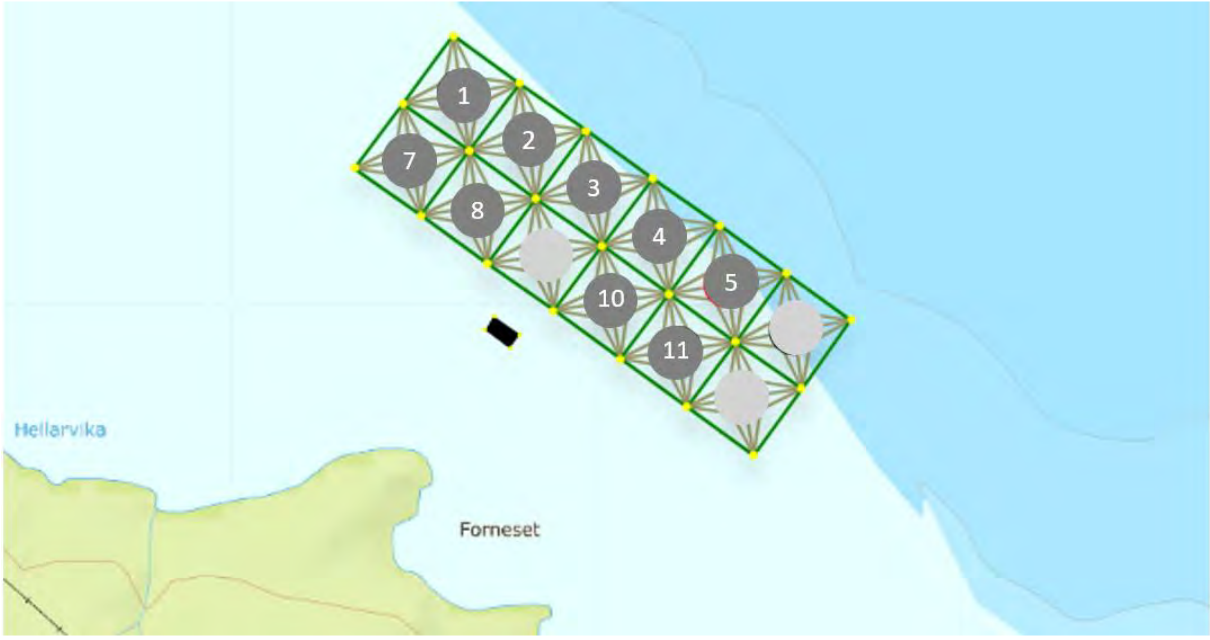


Figure 2 Figure showing the placement of the Phase 3 cages within the Cermaq Utvikling AS facility Hellarvika 11315.

Feeding systems

Fish are remotely fed from the Nordfold feeding center using existing Cermaq Norway AS feeding regimes for the Hellarvika locality. Eight cages at the site were fed by an underwater feeding system (AkvaGroup) that distributed water-borne feed via six feeding points below the snorkel at a depth of approximately 12 m. The feed distributer is a customized version of AkvaGroup`s "Sjøstjerna", and it has a distribution at the feed points of ca. 0.5 m (see Figures 3a-d). In addition, a special edition of the feed pipes was created to feed with this arrangement in open cages. A Brattland Subfeeder was used in cage M5 during the whole production period, and this had a 4 m spread. Investigating drivers for compromised production was an important objective in this Phase, and four cages were dedicated to feeding trials in open cages. Fish were fed a commercial diet from seawater transfer utilising: i) Intro 100 HH 50mg Q, 3.5 mm ii) Intro 100 HH 50mg Q, 4 mm, iii) Power 200 F1 50mg, 4 mm iv) Power 500 HO3 50mg, 6 mm, v) Power 2500 HO3 50mg, 9mm and vi) Power 100 HO3 50mg, 9 mm. In all open cages, feeding started at 4m depth after stocking before the feeding systems were moved deeper in the cages (10 m) later in the production cycle.

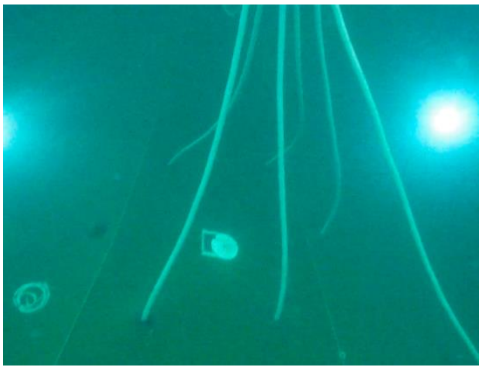


Figure 3a, Feed setup in cage M1 where one feed hose was moved to just under the net docking

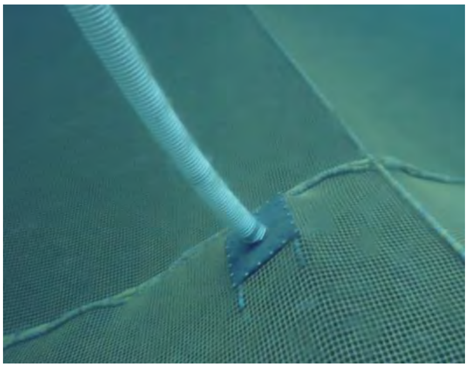


Figure 3b, Feed hose mounting in net roof

Figure 3c, iFarm subfeeder used in M10 with diameter 5 m

Figure 3d, Akvapartner (Brattland) subfeeder used in cage M5 with a 4-meter spread

Artificial lighting systems

Fish in each cage were subjected to artificial underwater lighting using existing plans for Cermaq Norway. Fish stocked before the 1st August 2022 has underwater lights from 1st November 2022 until 1st May 2023, and fish stocked after the 1st August 2022 has underwater lights on from stocking until the 1st May 2023. Underwater lighting was provided via four underwater lights (AkvaGroup, Akva Aurora SubLED Combi) placed in the feeding zone, under the net roof at a depth of approximately 15 m (see Figure 4a-b).

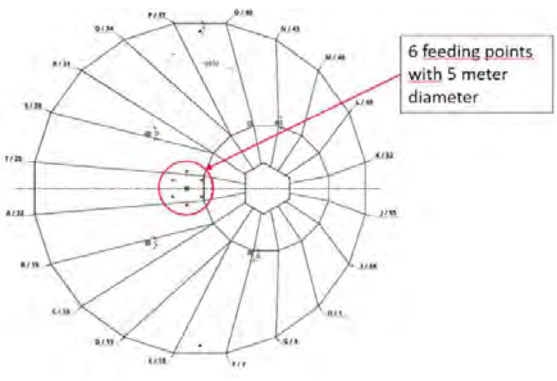


Figure 4a, showing feeding points within each cage

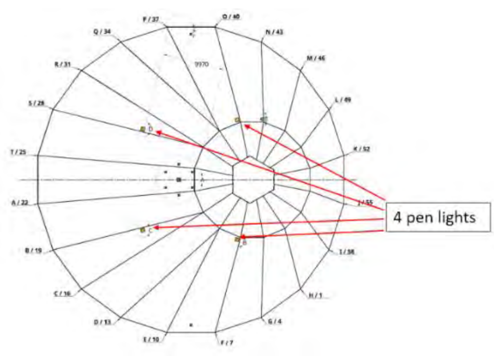


Figure 4b, showing the position of lights within each cage

Daily operations and husbandry

iFarm follow the standard procedures for daily operations at the Hellarvika site. Dead fish are removed from the cages daily using LiftUp. Moribund fish at the surface are removed from the cage every day and they are euthanised by an overdose of Benzoak vet. (30-40 ml/100l water). Lice are counted weekly by the farm personnel.

Net cleaning

Net cleaning followed the Hellarvika site's cleaning plan, and any extra cleaning was carried out when needed. Cleaning was carried out by a service boat using net cleaning robot rigs. The iFarm and associate cages were cleaned a total of eight times from stocking until slaughter (see Table 2) and the cleaning procedure included the cleaning of the main net, snorkel net and roof for iFarm cages, and the main net for the associate cages.

Table 2 showing the time of cage cleaning and service boat used.

Cleaning week	Service boat
2022 – 37	M/S Breidsund
2023 – 18	M/S Breidsund
2023 – 24	M/S Breidsund
2023 – 30	M/S Breidsund
2023 – 34	M/S Breidsund
2023 – 37	M/S Breidsund
2023 – 43	M/S Breidsund
2023 – 49	M/S Breidsund

Net changes

At Hellarvika, Midtgard smolt nets (ScaleAQ) were used in all cages from the time of sticking. Cages M5, M10, M11, M1, M7, M8 and M4 underwent a net change, where the smolt nets was changed to larger Midtgard post-smolt nets (ScaleAQ) in May 2023. The fish in M2 and M3 were moved from a smolt net to a larger post-smolt net in August 2023.

Project plan

The iFarm project goals and objectives will be addressed over three phases, and with an additional fourth phase to supplement project data which will run until 2025 (see Figure 5 below). This final report addresses Phase 3.

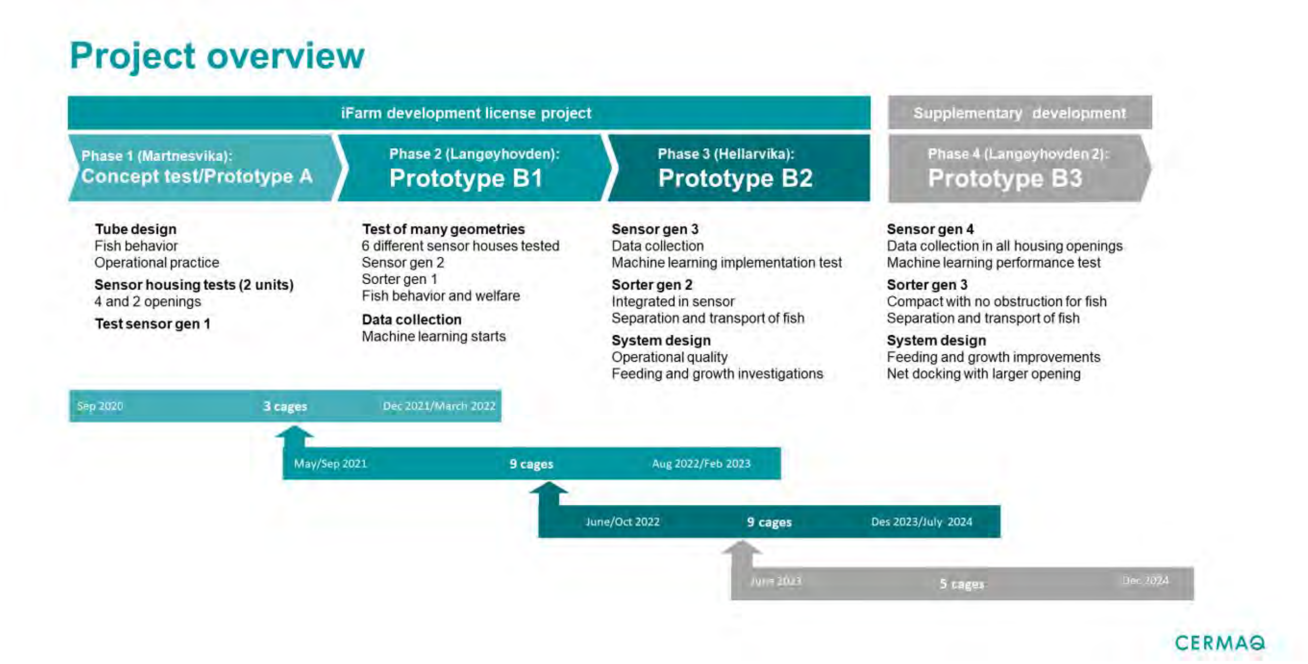


Figure 5 Overview of the iFarm project and Phase 1-4 timeline from 2020-2024. This final report addresses the Phase 3 period from 3rd June 2022 until slaughter.

Technical development

Cage design and rearing system characteristics

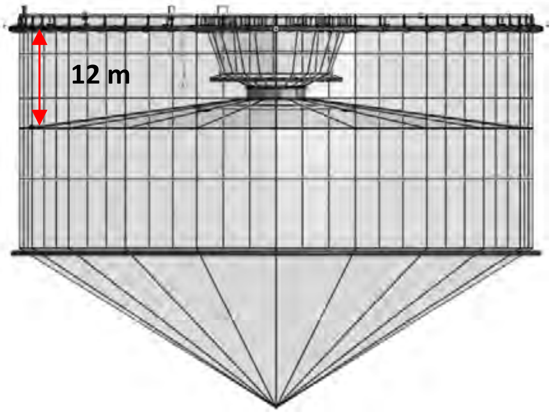
The iFarm production systems in Phase 3 were adapted snorkel cages with a net roof that starts 12m below the water surface to limit fish interactions with potential lice rich surface water (Figure 6). Cages were also fitted with commercial lice skirt around the edge of each iFarm cage structure to a depth of 6 m. Fish have the opportunity to access the ocean surface to refill their swim bladder with air by swimming through the adapted snorkel. Each iFarm snorkel was mounted at a depth of 6.5 m and within the snorkel a docking station was mounted. The circumference of the snorkel at the water surface was 44m. Two pens were not equipped with an iFarm snorkel but maintained as open associate cages, while one cage had a normal snorkel installed for the first six-month period in sea before this was removed for the remainder of Phase 3 cycle. These cages were however fed deep with either an Akvapartner (Brattland) subfeeder or with an iFarm feeding arrangement.

Phase 3 included several improvements in iFarm cage geometry, including introducing net dockings to investigate the effect of larger opening of the surface passage through the snorkel on production and feeding results. During the production cycle, two of the iFarm snorkel and docking constructions were replaced with two net dockings, a snorkel construction equal to before, but with no docking to mount an iFarm sensor on. These net dockings were 7 meter in diameter at the narrowest point while the standard docking diameter was 3 meters. Net dockings were installed mainly to examine growth and FCR (Feed Conversion Ratio) issues in greater detail. Additionally, anchors were introduced to the snorkel set-up to introduce a dynamic choice of depth of the snorkel, and for targeted periods the snorkel could be placed shallow. Both improvements were carried out with an aim of preventing fish spending extended time in the snorkel rather than below the net roof where feed is given. The anchors introduced to set the snorkel shallow facilitated for shallow initial feeding even when a snorkel was mounted. The upgraded docking stations were improved with new materials and designs to make them generally lighter, have higher precision geometrical tolerances, and to introduce a dead fish channel to handle potential moribund fish in the upper volume, amongst others.

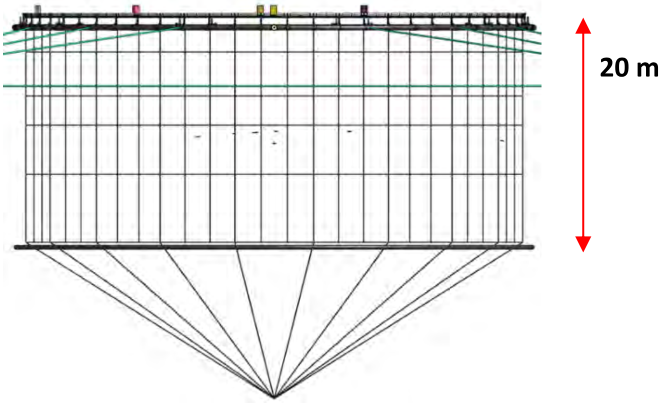
The snorkels were placed 10m off centre within the outer collar of the 160m circumference net to aid boat-crane access and staff access to the iFarm collar. This was the same/an update on Phase 2.

Cages M1, M2, and M7 (Figure 6) were either i) iFarm cages with a standard docking station (M7) or ii) iFarm cages that had a standard docking station mounted for between ca. 4 and 7 months before this was replaced with a net docking solution further outlined above (cages M1 and M2, respectively). No sensor houses were mounted on these cages for the entire Phase 3 reporting period, however these cages were important for fish behaviour analyses, and growth and FCR performance measurements. Cage M3 and M8 was cages with a standard docking station which also had a sensor house mounted between 18th February – 16th April 2023 and 13th May-27th December respectively

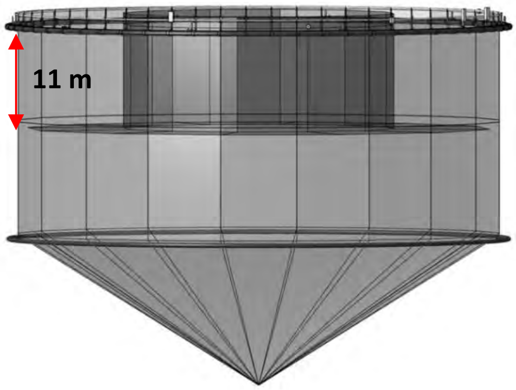
Cages M4, M10 and M11 (Figure 6) were open associate cages used for feeding experiments equipped with feeding arrangements as described above. Cage M5 (Figure 6) had a normal snorkel installed for the first six-month period in sea before this was removed for the remainder of Phase 3 cycle. This was a traditional 90m circumference adapted snorkel that started at 11 m deep for the first ca six months of stocking. After this point the snorkel was removed, and fish were held in an open cage. This cage was fed with a Akvapartner (Brattland) underwater feeding system. The other three open associated cages had open access to the surface and were fed with the same iFarm underwater feeding systems that were initially placed at 4 m deep after smolt transfer before being transferred deeper to 10 m later in the production cycle. These served as an important reference for fish growth and health/welfare analyses.



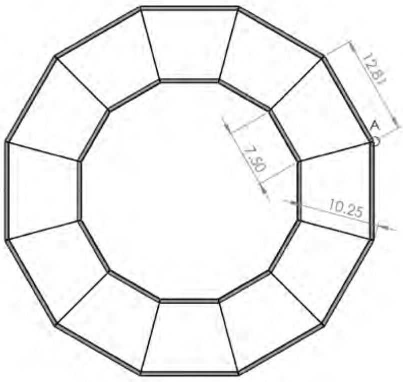
iFarm M1-M4 and M7-M8 with the roof net starting at 12 m depth



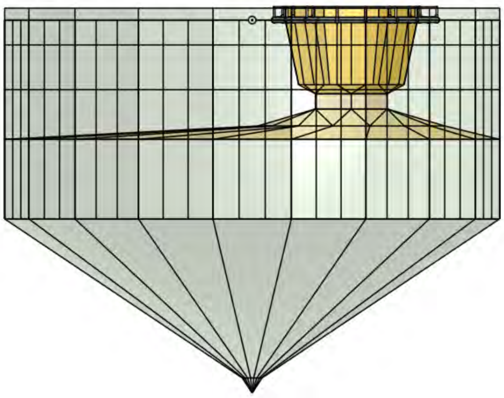
The associate cages, M10 and M11, open access to the surface with underwater feeding



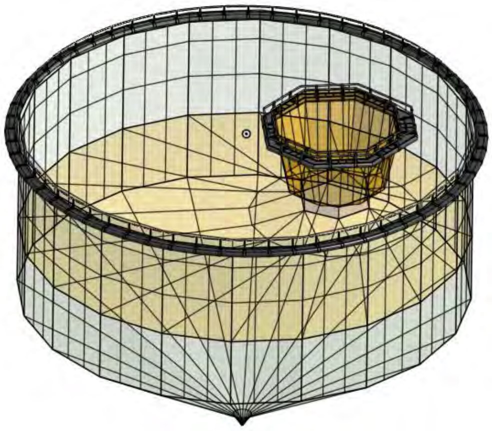
Associate cage M5 with roof net starting at 11m



Snorkel dimensions for M5



Net docking installed in December 22´ and May 23´ for M1 and M2



ISO view of net docking

Figure 6 Technical specifications and information for each of the iFarm and the associate cages utilised in Phase 3 of the iFarm project.

iFarm docking station housed within the snorkel

The iFarm docking station is both the structural connection between the upper part of the snorkel and the snorkel floor, and at the same time the mounting platform for the iFarm sensor unit (see Figures 7a and 7b). The docking stations are also fitted with internal air tanks designed to keep the docking station in a floating position at the time of installation or service. Improvements done in Phase 3 included material updates and introduction of a dead fish channel.

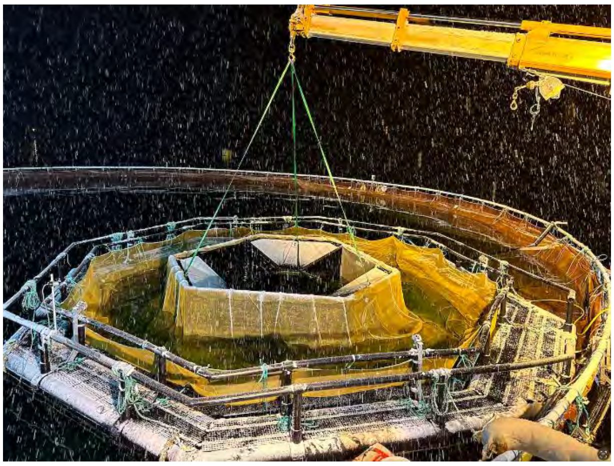
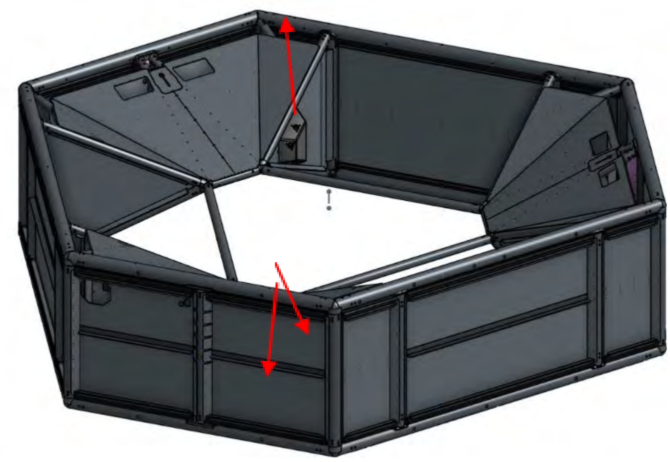


Figure 7 Technical specifications and information for the iFarm floater, snorkel, bottom ring and docking stations (Figure 5a, left) and a picture (Figure 5b, right) showing the installation of a docking station for Phase 3 in one of the iFarm cages. Note the inflated air tube at the base of the docking station.

Camera set-up for fish monitoring in and around the iFarm sensor housing

To be able to monitor fish behavior in and around each iFarm snorkel, docking station and sensor house, especially in relation to system design choices, the iFarm docking units are equipped with 3 (in periods 6) surveillance cameras. These cameras are used to e.g., monitor fish traffic through the iFarm docking station, the number of fish in the snorkel above the docking station and the behavior of the fish immediately below the snorkel (see Figure 8 for the placement of the cameras in the docking station). The footage from these cameras was also supplemented with footage from the feeding cameras installed in each cage and with overhead cameras mounted on the inner snorkel ring and outer cage ring for e.g., monitoring fish surfacing activity (see Figures 9 and 10 for an example of the camera output from each iFarm cage).



1 camera looking up into upper volume
1 camera looking down
1 camera looking across docking opening
1-3 cameras observing the housing openings
2 surface cameras
1 feed camera

Figure 8 Technical information regarding camera placement for each of the iFarm docking stations utilised in Phase 3 of the iFarm project.

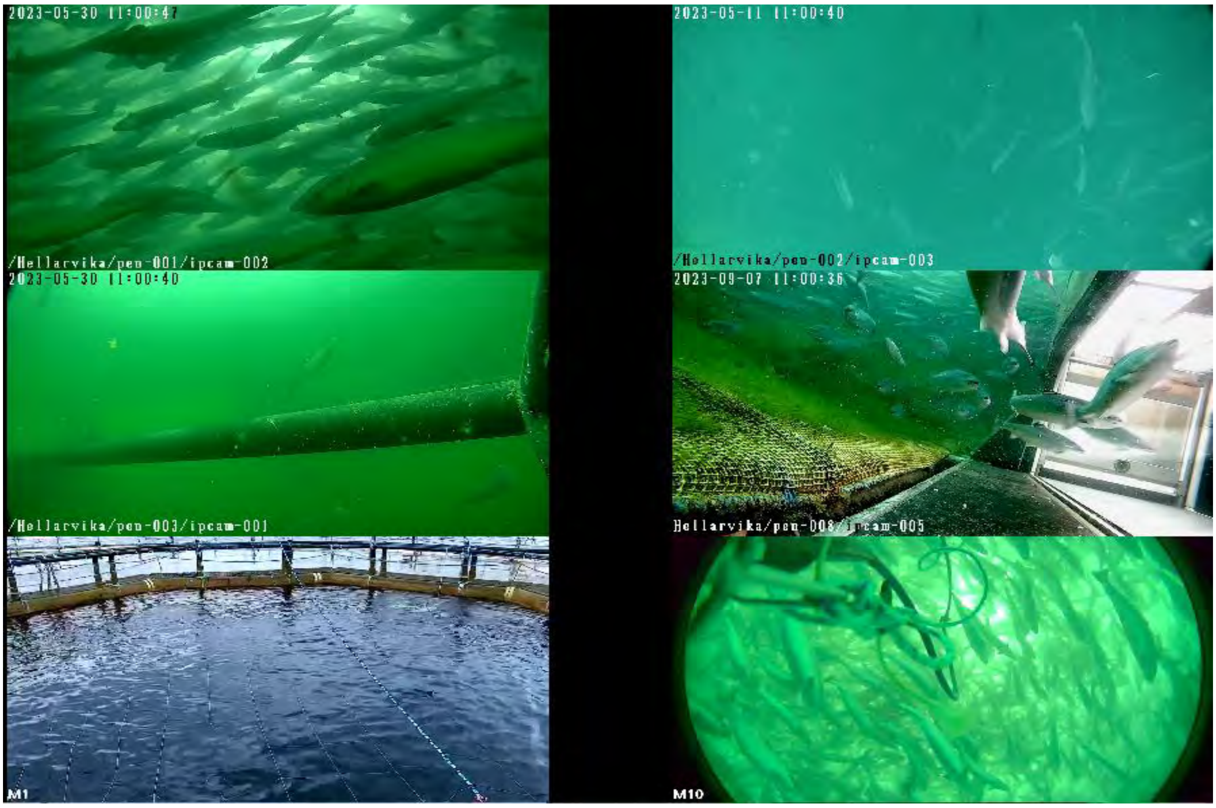


Figure 9 access to different IP and feeding cameras for fish monitoring in all iFarm cages.

Figure 10 extra cameras installed in cages with the iFarm sensor house for increased understanding and control

iFarm housings and sensor unit

The first- and second-generation sensor prototypes were tested in the two previous project phases and the experiences with camera and light placement and settings served as an important platform for the design of the third-generation sensor prototype. The third-generation design can be seen in Figure 11 and consists of a construction with three openings for fish movements.

Figure 11 a) iFarm docking, (b) and (c) iFarm house and docking Phase 3.

Two identical iFarm sensor house units were installed at Hellarvika in cage M3 and cage M8 in two consecutively time periods (cage M3: 18th of February-16th of April, cage M8: 15th of May-27th of December)-. The Phase 3 design utilised the experience gained in Phase 2 to design houses that resemble cages M1, M2 and M8 from Phase 2, but with only three openings and slightly greater angles of the opening.

A milestone was achieved in June 2023 when a complete iFarm sensor house with three sensor units installed (one in all openings) was mounted in cage M8 at Hellarvika (Figure 12 and 13). This is the first time it has been possible for complete population surveillance in an aquaculture cage, and this development marks a crucial advancement for iFarm technology, enabling comprehensive population surveillance when fish is utilizing the snorkel. Several improvements have been made to the Phase 3 sensor units compared to Phase 2, especially related to optimizing lamps, cameras, and sensor design (colours and reflections) to provide high-quality images where clear detections of fish features are now visible. Secondly, the introduction of an antifouling system to keep cameras clean has been crucial to both secure longer periods with data collection, but also with regard to husbandry operations and fish welfare, since the need for iFarm ascendance for maintenance is reduced.

Figure 12 showing the iFarm house installed in Hellarvika cage M3.

Figure 13 showing the iFarm house at the surface in M3.

Sorting and transporting of fish to the surface

A second-generation sorter was tested in Phase 3, where not only sorting itself were demonstrated, but also transportation of fish to the surface using vacuum suction. The sorter has evolved since Phase 2, but some key learning points will be relevant for the third iteration of the sorter solution.

Sorting and transporting test

Tests involving sorting and transporting fish were conducted at Hellarvika in cage M8, involving approximately 1.5-2 kilograms of fish over the period from 22.06.2023-28.06.2023. The objectives of the sorting test encompassed several key elements:

1. Catching fish with the iFarm sorter
2. Gently guiding fish towards one of the sensor opening sides (towards a suction channel)
3. Moving fish to the surface
4. Manual evaluation of sorted fish

Important insights and valuable experiences were garnered from the commercial sorting test and will be object for further sorter improvements:

- Control of the movement and range of raising walls proved to need upgrades, to prevent fish from escaping the sorting area, thereby mitigating potential risks of fish damage. Optimal movement speed of the sorter walls will be further investigated.
- Rigid sorting walls occupy space below the sensor house's docking, potentially disrupting fish beneath and complicating operational handling. This will be improved in future sorter iterations.
- Improvements to smoother surface design and openings between the sorter unit and transport channel are necessary. Ensuring adequate suction for moving fish to the surface is also a vital aspect that requires attention.

In summary, the sorter and transportation test were evaluated as a success by BioSort and Cermaq. Since the fish were bigger than in Phase 2 it has been demonstrated that sorting is possible even with bigger fish. The demonstration of both sorting and transportation of fish is a milestone on the way to a final goal of not only removing fish with certain traits, but having the infrastructure to handle them afterwards.

Developing of software infrastructure architecture and computer vision

The development of software infrastructure architecture and computer vision models was a big focus in Phase3. To handle the large amount of data collected, sophisticated software infrastructures are required, which has evolved greatly during Phase 3 with iFarm software systems running in the iFarm sensor itself, on the barge and the Cloud. Data was successfully collected during the time the sensor was mounted in either M3 or M8 and dedicated work was put into expert labelling of images, called annotation, and field trials to produce and collect material to further train computer vision models. Consequentially models have matured, and it was possible to display sensible population statistics on average weight, lice numbers and prevalence of selected welfare indicators over time in M8. Figure 14 shows predicted development of average weight and length in the population between May and October in 2023.

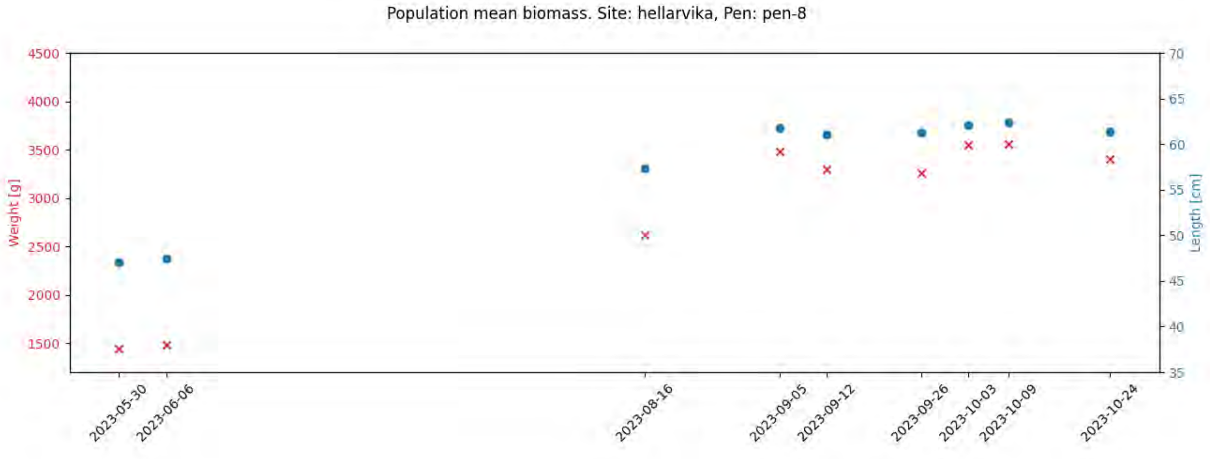


Figure 14: *Weight and length estimate of the population in cage M8 during a few select days from May to October 2023. Blue dots indicate iFarm estimated fish length and red crosses indicate iFarm estimated fish weight*

The computer vision models developed and improved throughout the project up until Phase 3 can be summarized as follows:

- Multi-camera image capture
- Fish head and bounding boxes
- Fish instance segmentation
- Fish tracker/multi view association
- Fish key points/stereo/biomass
    - 3D positioning and tracking
    - Biomass
    - Aggregation
- Lice detection
- Welfare indicators
- Fish ID and the Salmon Identification service

The great work with developing models for individual fish recognition has given high precision levels, meaning the model's ability to identify the correct fish, in addition to improving the performance of capturing all instances of a particular fish. Figure 15 gives an example of how individual fish recognition can facilitate monitoring of single individuals and their traits over time, giving insight which has not been available in the industry before. This may be understanding individual disease- or health development or revealing new correlations between, for example growth and physical abnormalities or lice infestation.

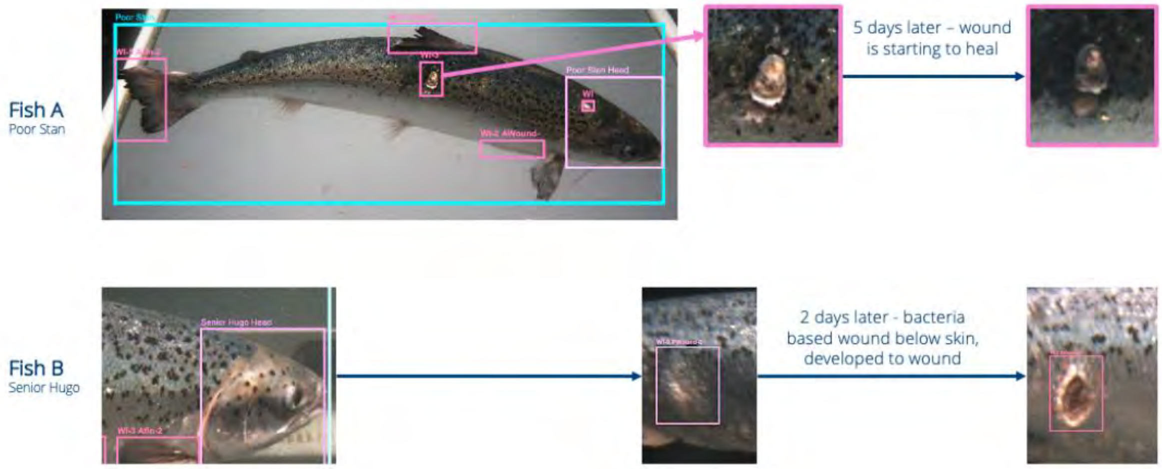


Figure 15: *The SID service allows for the tracking of the health and welfare of the fish over time. Here is an example extracted from initial SID trials where two different fish (A and B) are shown. For fish A, a wound was observed to start healing over time, while for fish B an abnormality in the skin was observed to develop into a wound two days later.*

Investigating and understanding feeding in iFarm

Efficient production is core to the economic aspects of the production, therefore have understanding feeding in iFarm been important in Phase 3, and several cages were dedicated to this purpose. The different variants of feeding arrangements gave interesting learning points, for example that the iFarm feeding system used in open cages, starting shallow and descending after a few months in the sea, seems to give improved growth results compared to other iFarm stockings with deep feeding since stocking. FCR is slightly higher in open cages fed with an iFarm feeding system which may indicate that it can be more challenging to maintain control when feeding with iFarm systems compared to a traditional subfeeding system.

When looking into the results from the cages with different surface passage configurations (net docking, docking, iFarm house) the eFCR results between cages differ. As these cages were fed in a similar manner, with deep feeding from stocking to harvest, the explanation for the difference is most likely due to surrounding elements in the geometry or other external factors. The main experiences from Phase 3 guiding the feeding arrangement and expecting to improve growth and FCR in the next Phase was the good growth results showed with shallow initial feeding in addition to the small-scale trial showing it was possible to have a feeding point in relation to the snorkel opening. In Phase 4 will all feeding points be placed below the snorkel opening and in the first period after stocking feeding will be shallow facilitated by dynamic shallow tube.

Fish health and welfare

Fish health monitoring plan

Cermaq Norway's fish health monitoring plan was applied throughout Phase 3 for the Cermaq Utvikling AS Hellarvika farming site. Compared to regular farming cages, the fish in the iFarm system have reduced/smaller openings to the surface. The purpose of fish health monitoring is therefore to assess the extent to which this affects the fish in the iFarm system.

The health of the fish is monitored in two ways:

1) As a part of operations all relevant production parameters were registered daily. This included environmental parameters, feed consumption, mortality and growth. There was also daily camera surveillance and recording of fish behaviour at multiple depths within the iFarm systems.
2) The fish health situation at the facility was followed up with monthly fish health visits by authorized fish health personnel. For a detailed description on the fish health situation in at Hellarvika, see the fish health report (attachment 1, not public).

The welfare monitoring program utilises a suite of OWIs (Operational Welfare Indicators) and LABWIs (Laboratory-based Welfare Indicators) based upon the environment the fish are subjected to (input-based OWIs) or the fish themselves (individual or group level outcome-based OWIs and LABWIs).

Fish health and welfare monitoring

The fish health situation at Hellarvika has generally been good, with low mortality and a low incidence of moribund fish throughout the midway reporting period. At the start of production there was increased mortality in the fish from Hatchery 1 and Hatchery 3 because of high variability in smolt size, especially in the Hatchery 3 group. Over the winter, there was an increase in ulcers at Hellarvika, especially in the iFarm cages, and this was the main reason for mortality during the first half of the reporting period in these cages. An increase in ulcers over the winter was also observed in Phase 1 and Phase 2. Screening and histology taken throughout this reporting period has shown *Piscine orthoreovirus 1* (PRV-1) and *Moritella viscosa* (winter ulcers). Disregarding the mortality associated with stocking, undersized individuals and ulcers, the mortality at Hellarvika was mostly related to handling and treatment against salmon lice. Similar to Phase 1, mortality was generally low, with the exception of increased mortality in one cage during a delousing incident in October 2023.

Input-based OWIs

Water temperature (° C) and dissolved oxygen values (DO, % saturation) were recorded at 5 m depth in all cages, and at 10 m and 20 m depth in cages M2, M5, M7, M10 and M11. Sensors at 5 m depth were installed for the duration of the monitoring period, whilst sensors at 10 m and 20 m were only installed during certain time periods. Overall trends were consistent over the study period for all cages, so we chose to report median daily values across all cages with valid data.

Dissolved oxygen saturation levels were generally over 80 % across the three reported depths of 5, 10 and 20 m for the entire reporting period and did not drop to levels that are sub-optimal in relation to water temperatures the fish were exposed to during the reporting period (Remen et al., 2016). This data is also comparable to that reported in Phase 1 and 2 of the development project.

Fish were subjected to water temperatures ranging from a peak during July-August in both 2022 and 2023 at ca. 12.5 - 14.5°C in 2022 and 8 - 16°C in 2023. The lowest temperatures were recorded in March 2023 at ca. 1.5 - 5.5°C depending upon depth. It has been suggested that temperatures outside 6 – 17 ° C can present potential welfare challenges e.g., temperatures below 6 - 7 °C increase the risk of winter ulcers (Noble et al., 2018 and references therein). Whilst fish were subjected to temperatures below 7 ° C during winter, this is a challenge all fish faced in Phase 3, irrespective of the rearing system they were farmed in.

It has previously been suggested that water quality in the snorkel can be compromised if there is e.g., a buildup of fish in the snorkel or restricted water flow into the snorkel. This was not the case in the iFarm cages.

Group-based OWI and LABWIs – Behaviour

Fish surfacing activity

Surface activity was somewhat variable in different cages. In the majority of cages, surface activity increased as winter and spring progressed and summer approached. Fish surface activity for 1-year smolts stocked in cage M5 (traditional 90 m snorkel cage/open cage) showed a similar trend to other cages at this time of year. The substitution of the snorkel with a standard docking station with a net docking station in cages M1 and M2 aappeared to have a minor positive effect upon surface activity as the observed increases in the cages were also noted in other cages to a lesser extent within each smolt group at similar times of the year. The deployment of the sensor houses in cage M3 and M8 had a marked reduction upon surface activity, although there was a short-term increase in surface activity in cage M3 upon its removal and in cage M8 just prior to the end of the reporting period. The trend for reduced surface activity during sensor house deployment was also noted in some iFarm cages in Phase 2 (either short- or long-term) and Phase 1. This suggests a reluctance for the fish to utilise the snorkel for accessing the surface after sensor house deployment.

Fish aggregating in the snorkel

It has been reported that fish can aggregate in the snorkel when held in snorkel cages and this may lead to reduced oxygen saturations in the snorkel (Kolarevic, Stien et al., 2018). Aggregation of fish in the iFarm cage snorkel did not seem to have a detrimental effect upon oxygen saturation levels at 5 m deep, which were generally above 80 %. This was also noted in Phase 1 and 2. There were some differences in the number of fish observed in the snorkel between the iFarm cages. Relatively high numbers of fish were observed in the snorkel just after smolt transfer in three of the iFarm cages and this generally decreased within a month of deployment. There were also some further peaks in the number of fish in the snorkel later in Phase 3 but this was not associated with sensor house deployment in cage M3 and M8. Any peaks in fish number in the snorkel did not occur in late winter/early spring when an increase in the frequency of wound related mortalities was detected in the iFarm cages. In Phase 2, an increase in fish number/density in the snorkel in one iFarm cage was believed to have contributed to the increase rate of ulcer/sore development (and associated mortalities) that led to the sensor house being removed. Phase 1 also saw a general increase in the number of fish in the snorkel during winter (and a corresponding increase in the incidence of mortalities related to wound/sores) and an increased winter aggregation of fish in the snorkel is considered a potential risk factor for ulcer/sore driven mortalities. A key lesson learned from the earlier Phase 2 was to act early on wound/sore developments, even if they are related to winter ulcer outbreaks, as increased fish number/density in the snorkel may be a risk factor for driving or exacerbating the problem.

Fish traffic

Trends in surface activity for each cage were generally reflected in the traffic data through the docking station/sensor house. The replacement of the standard docking station with the net docking station in cages M1 and M2 led to a marked increase in traffic up during winter in early 2023 in cage M1 versus M7 and M8, and a minor positive effect in cage M2 (see the surface activity data) and the deployment of the sensor houses on M3 and M8 led to a marked decrease in traffic for a) the majority of the deployment for cage M3 until just prior to removal and b) the majority of the deployment for cage M8 until just prior to the end of the reporting period. In Phase 2, the reduced surface activity of the fish after sensor mounting was not always reflected in the traffic data through the docking station/sensor house, unlike in Phase 1.

Swimming speed and cohesion

If fish are exhibiting problems with buoyancy, they can increase their swimming speeds to generate lift (Sievers et al., 2021). For the majority of the reporting period fish swam at medium/cruising speeds and there was little difference between feeding and non-feeding periods. The switching of the standard docking station to a net docking station in cages M1 and M2 generally led to more variable swimming speeds between low/slow and medium/cruising following the switch. Sensor house deployment in cages M3 and M8 generally led to no difference in swimming speeds in cage M3 and some variability in cage M8. Swimming speed in body lengths per second was also audited during weeks 22/23 (31st of May 2023 until the 5th of June 2023) and weeks 23/24 (13th of June 2023 until the 19th of June 2023) and neither the time of day (morning vs evening) or cage configuration had a clear effect upon swimming speeds. Differing smolt groups (and fish sizes at the time of auditing) lead to the formation of three main clusters of swimming speeds and average swimming speeds ranged from 1.07 ± 0.3 BL/sec to 1.18 ± 0.27 BL/sec in cages M2, M3 and M4, 0.83 ± 0.15 BL/sec to 0.86 ± 0.27 BL/sec in cages M1, M7 and M8, and 0.61 ± 0.15 BL/sec to 0.67 ± 0.19 BL/sec in cages M5, M10 and M11.

Cohesion in all cages generally varied between mixed behaviours and uniform schooling with some exceptions. There were incidences of erratic swimming immediately after smolt transfer for iFarm cages M8, M2 and M3. It is unclear whether this was related to the snorkel. Erratic swimming also occurred in the iFarm cage M8 when the sensor house was deployed. When the iFarm sensor house was deployed in cage M3, cohesion was initially uniform before varying between mixed behaviours and loose schooling. In Phase 2, swimming cohesion below the snorkel generally increased over time towards uniform circular schooling for the majority of iFarm cages, both for feeding and non-feeding periods, irrespective of whether the sensor house was deployed or not, with some minor exceptions. In Phase 1, different iFarm set-ups affected group cohesion in different ways and trends in cohesion data appeared to be also affected by water temperature in both Phase 1 iFarm cages and dropped when temperatures were at their lowest. This was not apparent in Phase 2. There are two things to consider when interpreting the Phase 3 swimming speed and cohesion results. Firstly, documentation of swimming speeds was mainly audited just below the snorkel and this documentation may not be representative for the whole group of fish under the snorkel. Secondly, if changes in swimming speed are minor, our operationalised scheme may be a little too crude to pick up these differences when compared to other methods (such as swimming speed expressed as body lengths per second).

Tilt angle

No tilted swimming behaviour > 25 ° was observed by Cermaq feed staff during a minimum of twice daily audits of fish behaviour at the bottom of the cage, both before and during feeding for all cages, with the exception of cages M2 and M3 where on a period of 5 days from 16th to 21st January 2023 there were a limited number of timepoints where a number of fish were observed during feeding exhibiting a swimming tilt angle of > 25 ° (and this was before the sensor house was mounted on the cage). This behavior was observed by the feeding staff outside the normal daily control points, and it subsided after 5 days and has not been observed again since. With regard to Phase 2, no tilted (head-up/tail down) swimming behaviour > 25 ° was observed aside from the observation of 1 fish exhibiting tiled swimming behaviour in cage M3 on July 26th 2022 (before the sensor house was mounted). Results on activity around feeding and swimming tilt angle are similar to those reported in Phase 1 and 2 of the iFarm project. However, it should be noted that even though tilt angle documentation was carried out in the area of the cage that we would expect that fish with buoyancy issues would aggregate (the bottom of the cage), tilt angle was only documented twice a day from a limited viewpoint from feed cameras and was not documented at night.

Group-based OWI and LABWIs – Appetite

Daily Feed delivery

Fish were remotely fed to apparent satiation using existing Cermaq Norway AS feeding regimes for the Hellarvika locality using mobile underwater feed cameras. No marked differences in daily feed delivery were observed between the associate open or iFarm cages for the majority of the reporting period and daily activity scoring of fish at the start and end of feeding was generally scored as similar by the Cermaq feed staff.

eFCR

eFCR values for the 1-year fish at the time of slaughter were at an acceptable range for cage M5 (traditional snorkel for 6 months after stocking before being an open cage) and a above the desired level for M10 and M11 (open cages), respectively. eFCR values for the 0-year summer transferred fish at the time of slaughter in cage M1 (standard docking/net docking), cage M7 (standard docking) and cage M8 (standard docking/iFarm sensor house) were higher than desired and higher than M10 and M11. eFCR values for the 0-year autumn transferred fish in cage M2 (standard docking/net docking) and cage M3 (standard docking station and iFarm sensor house) were higher than expected, and cage M4 (open cage) had eFCR at an acceptable level. Open cages had lower eFCR values compared to snorkel/iFarm cages. In Phase 1 and Phase 2, the associate open cages had lower eFCR values than the corresponding iFarm cages in each of these phases. In Phases 1 - 3 the effect of cage design/rearing system and operational decisions (such as the timing of the sensor house deployment in addition to its design) appears to have a marked effect upon feeding performance and feed conversion performance.

Group-based OWI and LABWIs – Growth

TGC

Growth rates for the 1-year fish at the time of slaughter were within an acceptable range for cages M5 (traditional snorkel for 6 months after stocking before being an open cage) and M10 and M11 (open cages), respectively. Growth values for the 0-year summer transferred fish at the time of slaughter in cage M1 (standard docking/net docking), cage M7 (standard docking) and cage M8 (standard docking/iFarm sensor house) were all <3, which is lower than desired. Growth rates for the 0-year autumn transferred fish in cage M2 (standard docking/net docking) and cage M3 (standard docking station and iFarm sensor house) and cage M4 (open cage) were within an acceptable range. The open cages had the highest TGC at slaughter. Cages with the iFarm installed all had TGC <3, except for M5 (traditional snorkel for six months) and M3 (iFarm docking installed for twelve months and the iFarm sensor housing for two months). These TGC results coincide with what has been seen in earlier phases of the project. Although the TGC results for the iFarm units are not at the desired level, a positive trend has been observed through the completed phases of the project. In the additional phase 4, mitigating measures have been taken and it is expected that the TGC results will reach an acceptable level. TGC values at the end of the Phase 1 and Phase 2 production cycle were lower than the results observed in Phase 3. As stated above, eight of the nine cages in Phase 3 were fed using the same underwater feeding system, *the effect of cage design/rearing system and operational decisions (such as the timing of the sensor house deployment in addition to its design) appears to have a marked effect upon growth performance and feed conversion performance. This was also the case for Phase 1 and 2*.

Whole body composition

No major significant differences in whole-body composition of salmon from the comparable net cages with respect to fat, protein, energy, ash and dry matter were observed from samplings taken throughout the production. However, the protein level of salmon from M8 was higher compared to M1, which correlates with a lower whole body fat level and a visceral fat score indicating a leaner fish. The differences in fish size can explain variation in whole body composition of salmon from the comparable net cages.

Group-based OWI and LABWIs – Mortality

Cumulative mortalities

Cumulative mortalities were generally low but a little variable during the Phase 3 reporting period. This is a marked improvement upon Phase 2, where the health situation at Langøyhovden was often challenging, and this contributed markedly to mortalities in Phase 2, as did isolated delousing events. Cumulative mortalities in Phase 3 were generally low for the majority of iFarm and associate cages and for the smolts held in the open cages. Sensor house deployment in iFarm cage M3 in late spring early summer for ca. 2 months led to slightly higher mortalities in this cage compared to its corresponding snorkel and open cages. There was also a trend for higher mortalities in early winter (from November 2023 until slaughter in early January 2024) in cage M8, a period where the sensor house had been deployed ca. 6 months in comparison to cage M7 (standard docking). In general, mortality levels in Phase 3 were similar to Phase 1, where cumulative mortality was generally low for both the associate and iFarm cages and was < 6% and less than in Phase 2 for the most part, where the health situation is Phase 2 was often challenging.

Cause specific mortalities

Mortalities in the 1-year smolts transferred in June 2022 and held in either open cages (M10 and M11) or a traditional 90 m snorkel cage/open cage (M5) were primarily driven by transfer related mortalities and elevated numbers of mortalities related to moribund fish, especially in cage M5. Mortalities in the summer 0-year smolts in cage M1 (standard docking/net docking), cage M7 (standard docking) and cage M8 (standard docking/iFarm sensor house) were primarily driven by wounds, moribund fish and mortalities attributed to HSMI/CMS. Mortalities in the autumn 0-year smolts in cage M2 (standard docking/net docking) and cage M3 (standard docking station and iFarm sensor house) and cage M4 (open cage) were driven primarily by wounds, moribund fish and transfer related. Mortalities in the open cage (M4) were the lowest on the farm and were driven by wounds, HSMI/CMS and handling.

However, wounds were a common cause of mortalities in all iFarm cages and the least number of wound related mortalities were registered in the associate cages. This was also the case for Phases 1 and 2, where there more wound/ulcer related mortalities in both iFarm cages than in the associate cage. It appears that potential mechanical trauma e.g., the fish coming into contact with the sensor house, or the increased fish aggregations in the snorkel in late winter/early spring may be a driver for developing ulcers. Snorkel cleaning routines have also been updated in relation to potential mechanical trauma risks from biofouling organisms.

Individual based OWIs and LABWIs

The morphological OWI situation was often better for Phase 3 than Phase 2, with a lower frequency of severe injuries at many timepoints. Specific attention was paid to three OWIs, snout damage, scale loss and fin damage as these are particularly relevant OWIs for fish raised in snorkel cages and can be indicative of fish colliding with aspects of the rearing structure such as the net roof (Stien et al., 2016a; Kolarevic, Stien et al., 2018; Oppedal et al., 2019). The prevalence of wounds and sores was also monitored as these can be exacerbated by collision/abrasion injuries. As the drivers for the prevalence of all of these OWIs are multi-factorial and can be linked to abrasive injuries during handling (Nilsson, Stien, Iversen et al., 2018), it cannot be discounted that the effects of the OWI sampling procedure itself may also have an impact upon the prevalence of at least minor scale loss and fin damage (see also Stien et al., 2016a). However, more extensive wounds/sores and snout damage are more likely to be evidence of problems the fish are facing within the cages and not the sampling procedure.

Snout damage

Severe snout damage was generally absent at all time points irrespective of cage type or time of year, with the exception of a low number of sampled fish at various timepoints. In Phases 1 and 2, it was generally the case that no fish had severe snout damage in either of the iFarm or associate cages and when they did it was a minor percentage of fish and no clear cage trend was apparent.

Scale loss

Severe scale loss was also often low at many time points irrespective of cage type or time of year. However, there was sometimes increased prevalence in some cages soon after smolt transfer or following mechanical delousing. In Phase 1, it was generally the case that no fish had severe scale loss in either of the iFarm or associate cages for the majority of Phase 1 and when they did it was a minor percentage of fish with no clear link to a particular cage. In Phase 2, there were sometimes cases of severe scale loss at various timepoints, especially in late winter/early spring.

Skin haemorrhaging

Severe skin hemorrhaging was not widespread in Phase 3 and when it did occur there was no clear link to a particular cage or treatment. This was also the case for Phase 2.

Fin damage

Severe fin damage was also often low at many time points irrespective of cage type or time of year. In Phase 2, the frequency was mixed and generally more severe than Phase 3. In Phase 1 only a minor percentage of fish exhibited severe fin damage until fish were subjected to mechanical delousing events.

Wound status

The frequency of severe wounds/sores was generally low but increased in some cages in late winter/early spring (which may be related to a seasonal outbreak of ulcers). A low number of healed wounds were also recorded in late summer 2023 in all cages of the autumn 0-year smolts. When considering wound status in relation to wound-linked mortalities in Phase 3 (see group-based OWI section above), wounds were a common cause of mortalities in all iFarm cages and the least number of wound related mortalities were registered in the open cages. This was also the case for Phase 1 and Phase 2, where there were more wound/ulcer related mortalities the iFarm cages than the associate cages. Adapted snorkel/iFarm production is a clear risk for wound development during late winter/early spring. It appears that potential mechanical trauma e.g., the fish coming into contact with the sensor house, or any incidences of increased fish aggregations in the snorkel in late winter/early spring (as seen in Phase 2) may be a driver for developing ulcers. In Phase 2, fish aggregations in the snorkel during low temperatures periods were identified as a risk factor for fish welfare and were monitored closely in Phase 3.

Opercular and gill damage

Severe opercular or gill damage was either absent or generally low, irrespective of cage for the entire Phase 3 reporting period.

Condition factor

Condition factor in the slaughtered cages in the Phase 3 reporting period were at an acceptable level. Cages with the large net docking mounted had a higher condition factor than open cages and cages with the iFarm sensor housing or just the iFarm docking installed. The mean condition factor in all cages were higher than the threshold considered to indicate emaciation in Atlantic salmon post-smolts (> 0.9, Stien et al., 2013), but were not at the desired level for all cages. It should be noted that the Condition factor estimates are done on 30 fish before slaughter. Condition factors of the fish in Phase 3 were similar to the condition factors from Phase 2 and Phase 1.

Internal OWIs

Liver colour is a multifactorial iceberg indicator and its exact drivers need further scientific evaluation. An orange liver is here viewed as a sign of normal liver. The number of fish sampled with a pale liver generally decreased as Phase 3 progressed, indicating reduced levels of fat accumulation in these fish irrespective of cage. Sampling in late winter and early summer in 2023 revealed increasing numbers of fish with dark livers in certain cages. Liver colour in fish sampled in August 2023 was more normal and there were an increasing number of pale livers in these cages compared to the earlier sampling points and this trend continued till slaughter. Interestingly, 1-year smolts (in open cages) and the 0-year smolts in the other open cage often had the darkest livers.

Scoring of visceral fat levels from November 2022 – July 2023 suggests all sampled fish in all cages generally became leaner until the summer 2023 before the proportions of fish with low/moderate visceral fat levels generally increased until slaughter. Fish from the open cages during these time points often had the highest visceral fat levels. Visceral fat levels began increasing in the remaining 1-year smolts (cage M5) and the summer transferred 0-year smolts in August 2023 and the increase in visceral lipid storage observed during sampling in July/August 2023 and just prior to slaughter may be a natural increase seen in farmed salmon prior to winter (Mørkøre and Rørvik, 2001, Alne et al., 2011, Dessen et al., 2017).

The digesta score was especially poor in February and June 2023, with the exception of some, but not all, of the open cages. There was a slight improvement in August 2023 and this trend continued until slaughter. No clear trends were observed in relation to cage type and signs of nephrocalcinosis, which was mainly observed in the autumn 0-year smolts (cage M2, M3 and M4) at between November 2022 and June 2023, with a few exceptions in June 2023 in the summer transferred 0-year fish. The higher number of fish with signs of nephrocalcinosis seen may be linked to the earlier hatchery rearing history of the fish. No fish were sampled with nephrocalcinosis from June 2023 until slaughter. A number of fish with fluid filled swim bladders were sampled in August 2023 in both the open cage M5 and also in two of the snorkel/iFarm cages (M2 and M3). The drivers for this are currently unclear. The presence of fluid in the swim bladder was monitored closely during sampling for the remainder of the study, but was not detected again.

Vertebral deformities

At the first sampling, the prevalence and severity of skeletal lesions in fish was low across stocking dates and cages, and the lesions observed were, with one exception, common for farmed salmon and of a low to moderate severity. The most conspicuous finding in the material was the development of a new set of lesions between first and final sampling, predominantly in fish stocked in June 2022 (M5 that was a traditional snorkel for the first six months of stokcing until becoming an open cage, and M10 and M11, open cages). The lesions, classified as atypical cross-stitch pathology, were found in 13-36% of fish in the three cages, and the average size of lesions was 7-9 affected vertebrae per fish. Morphologically, the lesions resembled cross-stitch pathology, which was first recognized as a specific type of pathology in 2016-17 (Holm et al., 2020), and which was linked to the use of some specific vaccine products (Thorarinsson et al., 2023). The fish in these cages, however, differed from the typical cross-stitch pathology as it was found almost exclusively in fish transferred to sea as 1+, and the lesions were unusually uniform in size and location, under the dorsal fin. The possibility remains that fish from the second and third stocking, which were between 1.6kg and 2.5kg at termination sampling, might have developed cross-stitch pathology with increasing size. In fact, three individuals with varieties of cross stitch pathology were recorded in M3, which was stocked in November 2022 and were 1.7kg at termination sampling. Thus, the question remains open whether or not more cross-stitch pathology might have developed with time. Fusions, which is by far the most common type of pathology in farmed salmon, was slightly increased in numbers and severity from the first sampling to termination. The trend was similar across cages and stocking dates, but the numbers remained low and probably of little significance to either fish welfare or product quality. At the terminal sampling, two fish with a prominent break of the vertical axis were observed. In both cases, a severe displacement of a single vertebrae was in the center of the axis deviation, and adjacent vertebra were affected. The two individuals were from the M10 (open cage) and M8 (iFarm snorkel with sensor house) same stocking group and same cage configuration. Although the numbers were practically insignificant, this type of lesion should be kept in mind in future.

Melanin spots in the fillets

Melanin spots were found in 4.5-15.8% of the sampled fish fillets and of these spots, 1.1-5.8% were classified as deep. The incidence of melanin spots was somewhat lower in the slaughtered cages in Phase 3 compared to Phase 2, where these spots were found in 7.5-21.5% of the sampled fish, and 2.6-5.0% were classified as deep. In Phase 1 melanin spots were observed in 11-24% of the sampled fish, and 5.0-10.0% were classified as deep. The proportion of fillets with melanin spots in Norway in 2014 was reported to be 19 % on average (Mørkøre et al., 2015) and Cermaq Nordland has an average of roughly 1/3 of that. Thus, the values reported here are not extraordinary and are lower than average in all cages slaughtered in Phase 3. Whilst the aetiology of melanin spots is difficult to determine and can be linked to handling and/or smolt robustness, both Bjørgen et al., (2019) and Malik et al., (2021) have reported that Piscine orthoreovirus 1 (PRV-1), the causative agent behind HSMI, has been related to their occurrence.

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