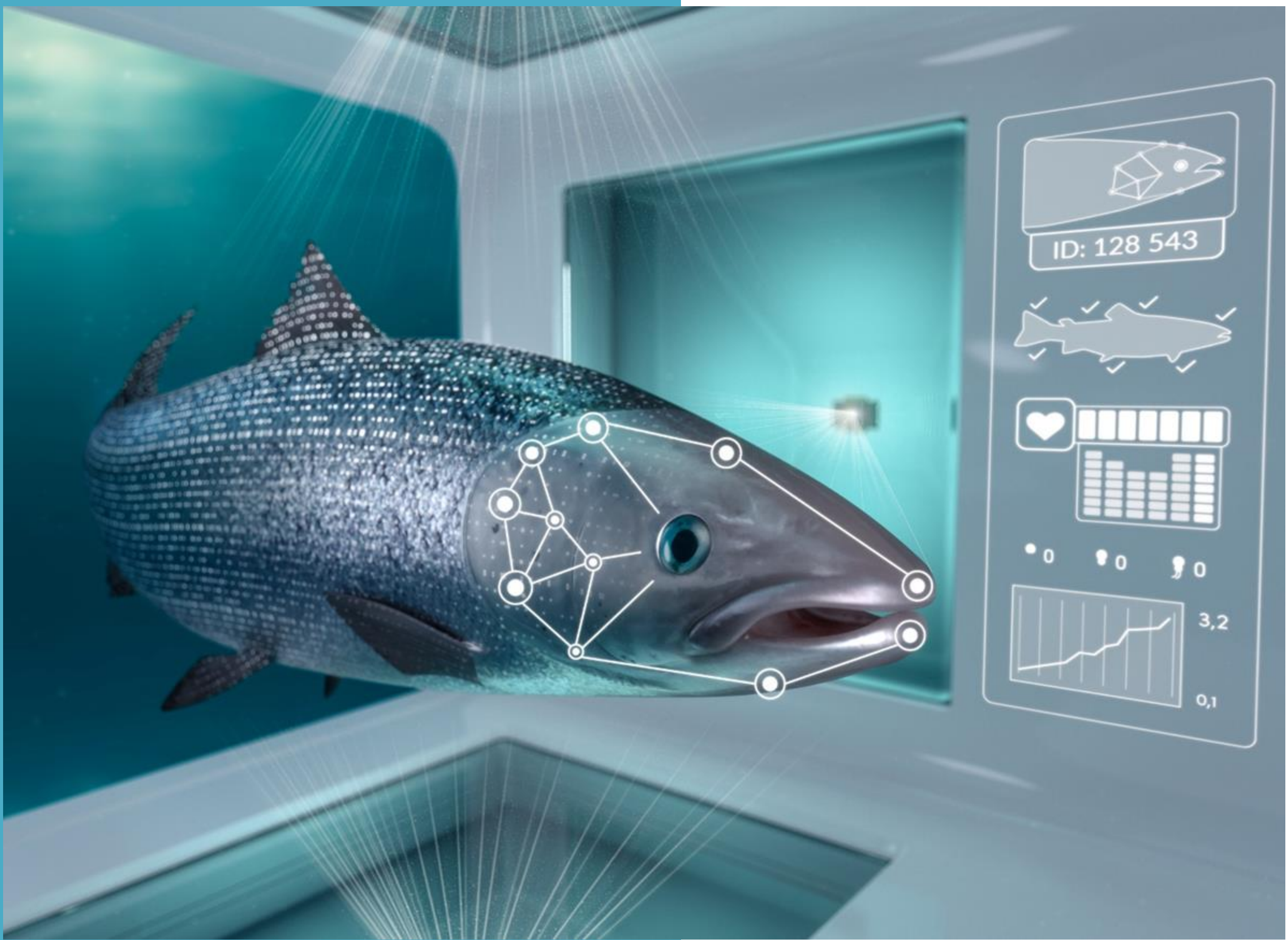
iFarm: Midway report documenting the biological and technological results from Phase 2 (Prototype A) – Cermaq Utvikling avd Martnesvika



Cermaq Norway

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Innhold

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 size and also their morbidity status.

The iFarm development licences in Phase 2 consist of 9 cages. Three phases of the iFarm project are planned from 2020-2024. This midway report addresses the first half of Phase 2 which started when the first cages were stocked on the 26th of May 2021 until the 1st of March 2022. Spring 1-year smolts were stocked in two periods: a) 26th of May 2021 (cages M1-M2) and b) 5th – 14th of June 2021 (cages M3 – M5). Autumn 0-year smolts were stocked on the 10th and 11th of September 2021 (cages M6 – M9).

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.

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 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 development licence project also aims to grade and sort fish based on their size. The iFarm prototype A 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. The fish must be able to access the ocean surface to refill their swim bladder with air and can do so by swimming up through the snorkel to the surface (see Stien et al., 2016a). 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

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 welfare and health monitoring was carried out to initiate the first full-scale "proof of concept" for the iFarm system and 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. Preliminary findings on the testing of Phase 1 of the system have previously been outlined in the Phase 1 midway report (covering data from seawater transfer on 14th – 16th September 2020 until 1st June 2021) and submitted to the Norwegian Directorate of Fisheries on 1st September 2021. The full report of Phase 1 testing will be submitted to the Norwegian Directorate of Fisheries on 25th July 2022.

This current report addresses Phase 2 of the iFarm development licence as outlined below.

Technical design and cage set-up Phase 2

Geographical location

This proof of concept commercialisation study was carried out at the Cermaq Utvikling AS Langøyhovden production site 68.48236⁰ N, 14.51975⁰ E (see Figure 1).

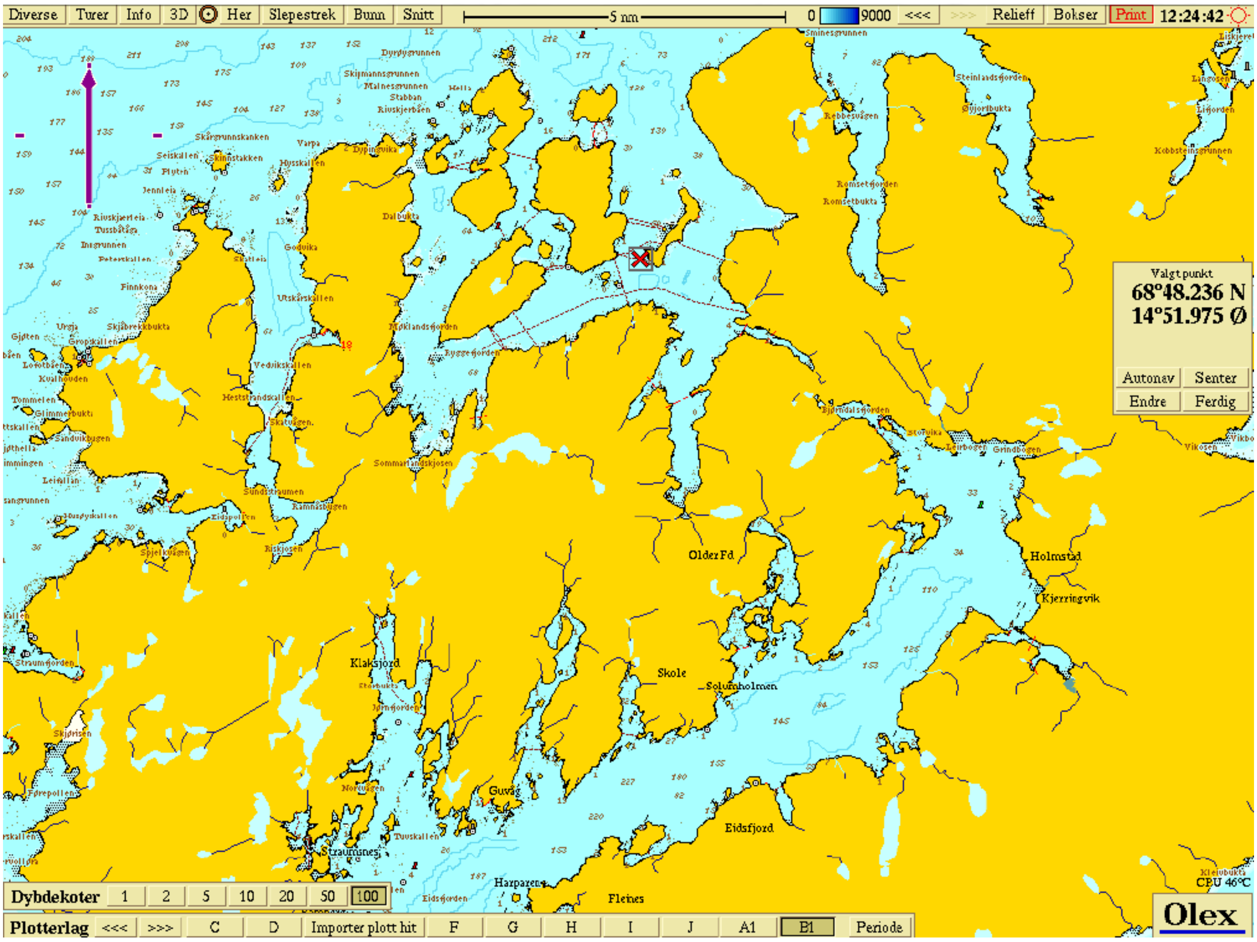


Figure 1 Map showing the Cermaq Utvikling AS facility Langøyhovden, where the iFarm cages are located (map location highlighted with a red boxed x). Map courtesy of Olex AS and reproduced from the Langøyhovden site report by Akvaplan-niva.

Phase 2 timeline and set up

Phase 2 of the project is currently underway and began when the fish were transferred to seawater on the 26th of May 2021. Phase 2 uses spring 1-year and autumn 0-year smolts stocked in nine production cages at Langøyhovden, including one associate cage (M5) and eight iFarm cages (M1-4 and M6-9), hereafter termed the associate cage/M5 and the iFarm cages termed by cage numbers above.

Spring 1-year smolts were stocked in two periods: a) 26th of May 2021 (M1-M2) and b) 5th – 14th of June 2021 (M3 – M5). Fish in cages M1 and M2 were from an internal Cermaq Norway smolt facility, and fish in cages M3 – M5 were from an external smolt producer.

Autumn 0-year smolts were stocked on the 10th and 11th of September 2021 (M6 – M9) and were from an internal Cermaq Norway smolt facility. Placement of the cages within the cage group at the Langøyhovden site is shown in Figure 2 below.

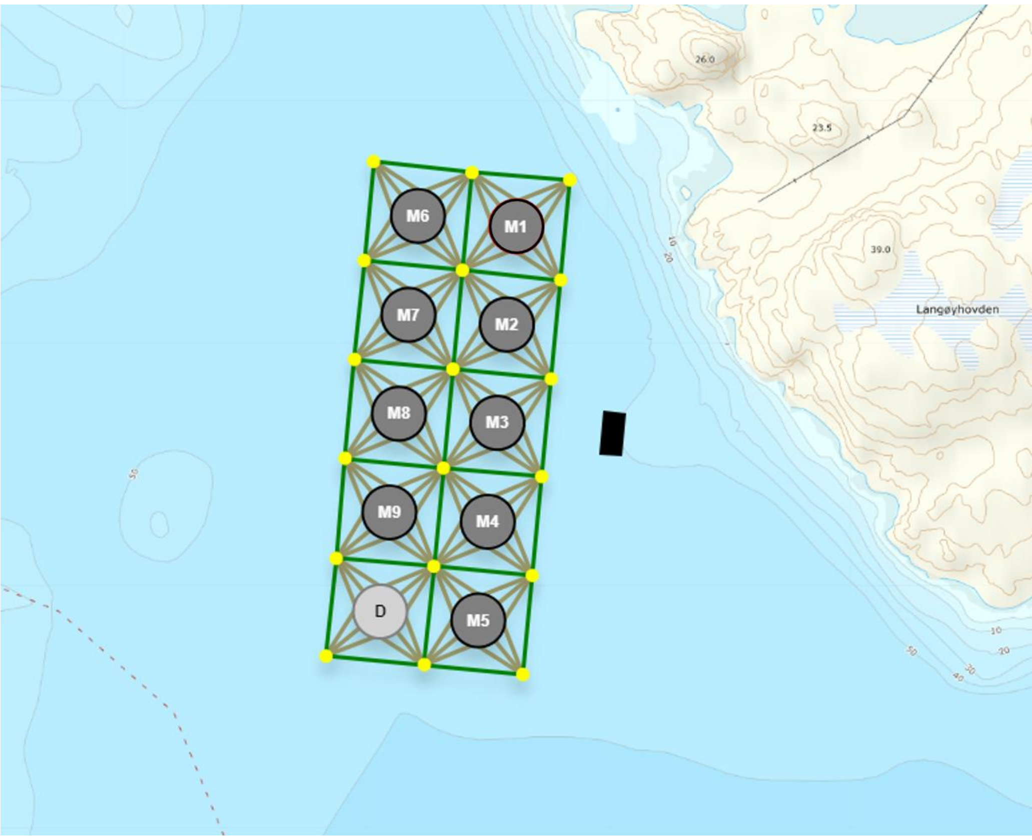


Figure 2 Figure showing the placement of the Phase 2 cages within the Cermaq Utvikling AS facility Langøyhovden 11238.

Feeding systems

Fish are remotely fed from the Sandset feeding center using existing Cermaq Norway AS feeding regimes for the Langøyhovden locality. All fish at the site are fed by an underwater feeding system that distributes feed via feeding points below the snorkel at a depth of approximately 15 m. Fish were fed a commercial diet from seawater transfer utilising: i) Ewos Rapid Asapt 50 40A, 3.5 mm (M3-5) ii) Intro 100 HH 50mg Q, 3.5 mm iii) Intro 100 HH 50mg Q, 4 mm, iv) Power 200 F1 50mg, 4 mm v) Power 500 HO3 50mg, 6 mm, vi) Power 2500 HO3 50mg, 9mm and vii) Power 100 HO3 50gm, 9 mm.

Artificial lighting systems

Fish in each cage have been subjected to artificial underwater lighting throughout the natural diurnal and nocturnal period from time of stocking. Underwater lighting is 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.

Daily operations and husbandry

iFarm follow the standard procedures for daily operations at the Langøyhovden 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 through the automatic lice counting-system CreateView every week.

Project plan

The iFarm project goals and objectives will be addressed over three phases (see Figure 3 below). This midway report addresses the first half of Phase 2.

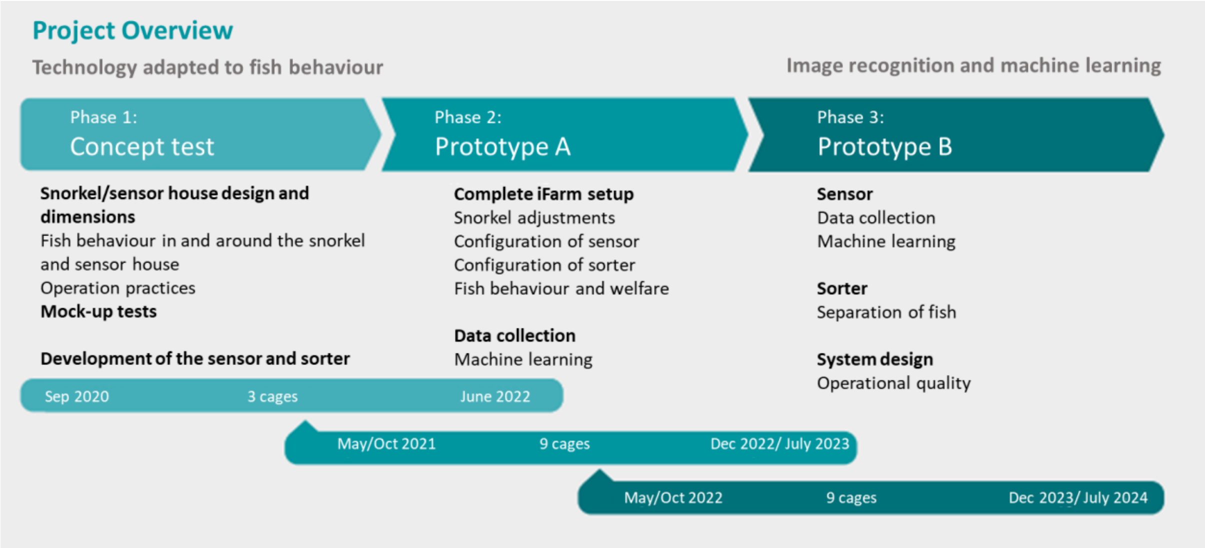
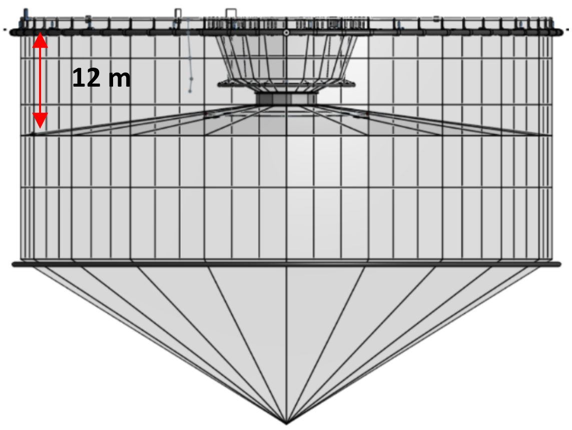


Figure 3 Overview of the iFarm project and Phase 1-3 timeline from 2020-2024. This midway report addresses the first half of Phase 2 from May 2021 until 1st March 2022.

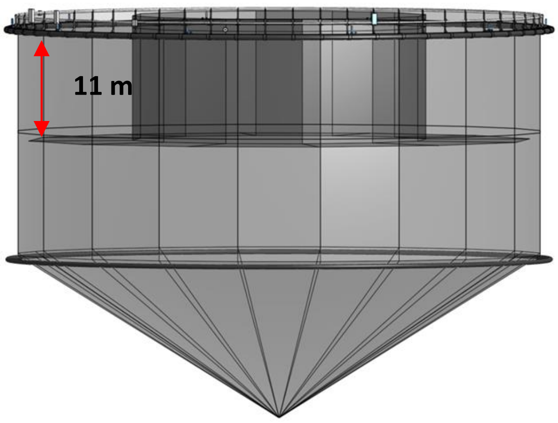
Technical development

Adapted snorkel cage

The eight iFarm production systems in Phase 2 are adapted snorkel cages with a net roof that starts 12 m below the water surface to limit their interactions with potential lice rich surface waters. Cages are also fitted with lice skirts around the main cage collar (not adapted snorkel) down to a depth of 6 meters. The fish can access the ocean surface to refill their swim bladder with air through the snorkel. Within each iFarm snorkel at a depth of 8 m is the iFarm docking station which has a circumference of 19 m and a diameter of 6 m. The circumference of the snorkel at the water surface is 44 m. The solitary associated cage design has a snorkel and net roof that starts at 11 m deep fed using underwater feeders (as are the rest of the iFarm cages).



iFarm M1-M4 and M6-M9 with the roof net starting at 12 m depth



The Associate cage, M5, with the roof net starting at 11 m depth

Figure 4 Technical specifications and information for each of the iFarm and the associate cages utilised in Phase 2 of the iFarm project.

With regard to the horizontal placement of the snorkel collar ring, the iFarm cages at Langøyhovden have the snorkel placed more off centre within the outer collar of the 160 m circumference, compared to the initial placement of the snorkel in Phase 1. This is to aid boat-crane access and staff access to the iFarm collar, which was somewhat difficult in Phase 1. The separate working platform that was used to access the snorkel in Phase 1 has now been replaced with a working platform that is integrated with the iFarm collar.

Phase 2 has utilised a less labour-intensive method than sewing to connect the net to the docking stations. A good design has been found that gives smooth transitions between net and structure and ensures that no fish can swim into the outer upper volume of the cage. The Phase 3 design will build on this experience but use other materials to cut cost, decrease weight and add functionality.

iFarm sensor houses

Different iFarm sensor housings will be tested during Phase 2 of the iFarm project (see Figure 5). The purpose of the different sensor housings is to study what works best to establish the desired quality of sensor images from a technical point of view and also how to manage fish traffic through the sensors (from a biological point of view).

So far, six different iFarm sensor housing units have been tested at Langøyhovden: the Spider (cage M1), the Dome (M2), the Two-way (M3), the Pyramid (M4), the Sorter (M8) and the Triangle (M9). These sensor houses differ both in their shape and number of openings. Cages M6 and M7 are iFarm cages that house the iFarm docking station within the snorkel but will not have sensor houses mounted for the entire Phase 2 period as these cages will be used as a comparison in terms of fish traffic and fish behaviour.

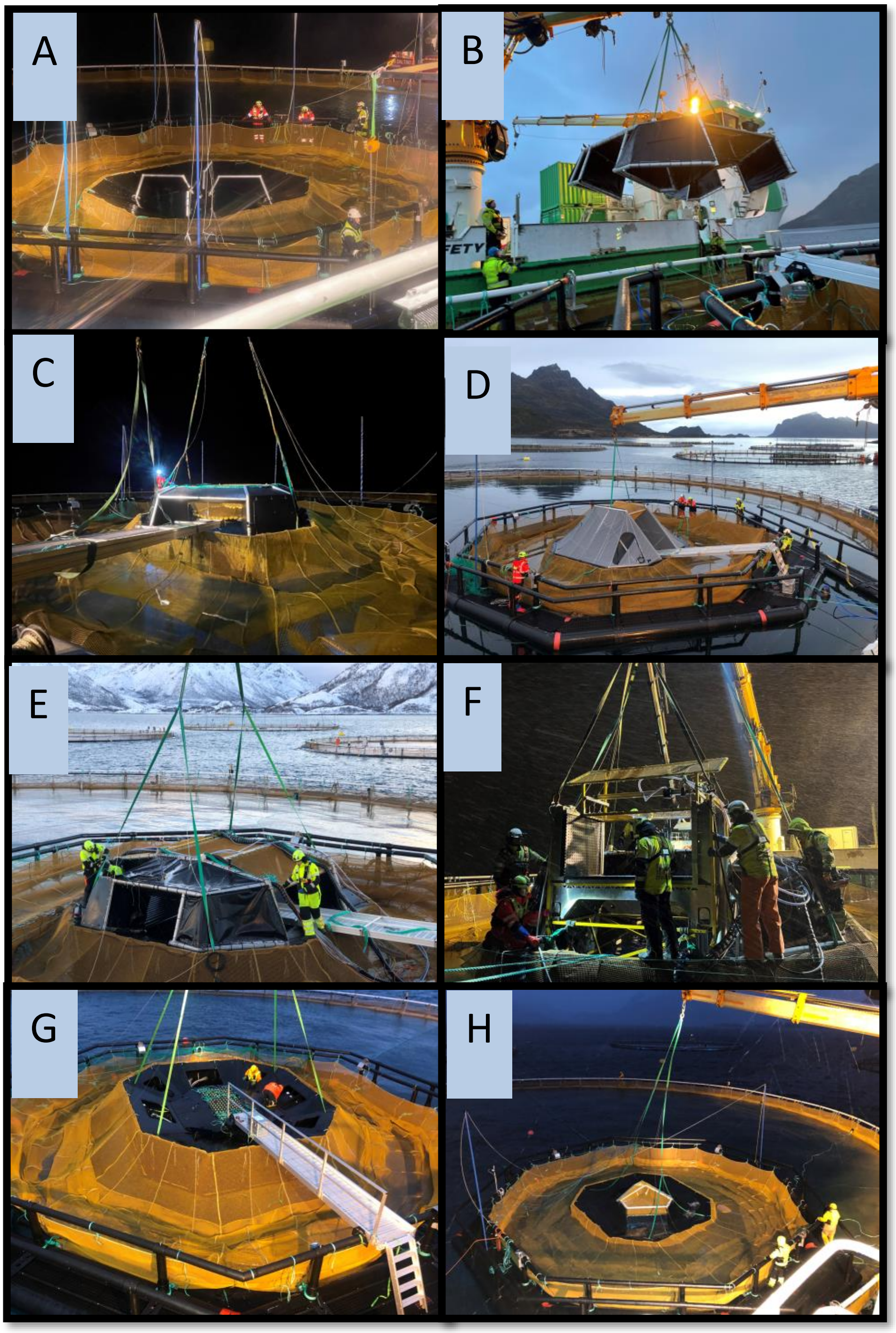


Figure 5 Photo collage showing the installation of the sensor houses to cages a) M1 – spider house, b) M2 – dome house, c) M3 – 2-way house, d) M4 – pyramid house, e) and f) M8– sorter house, g) and h) M9 – preparations and installation of the triangle house.

Sensor houses were deployed in cages M1-M4 between 9th - 12th of November 2021. Sensor houses were also deployed in cage M9 on the 17th of December 2021 and in cage M8 on the 8th of February 2022. Due to problems with surface activity/ traffic and the number of fish in the upper volume in three of the iFarm cages, a decision was taken to remove some of the sensor houses during the Phase

2 midway reporting period. Sensor houses were removed from cage M9 (7th of January 2022, after ca. 3 weeks), cage M4 (7th of January 2022, after ca. 9 weeks) and cage M3 (8th of February 2022, after ca. 13 weeks). This is a good learning experience, and the remaining test period can now be used to fine tune and investigate other potential operational challenges with regard to snorkel length, roof material, lighting etc. The Phase 3 design is now being finalized and the experience gained in Phase 2 is being used to design houses that resemble cages M1, M2 and M8 but with only three openings and slightly greater angles of the opening.

Operational routines

Regular operational routines, such as manual fish health monitoring and net cleaning operations are currently working well in all the iFarm cages. However, bringing the iFarm docking and sensor housing to the surface for cleaning is still a challenge since it is hard to get all fish in the upper volume down through the docking. Based on experiences with de-licing and harvesting of the fish in Phase 1, the docking stations of Phase 2 have been retrofitted with air tanks to aid buoyancy. A more permanent solution is being developed for Phase 3 and consists of regular cleaning under water, as well as a better solution to bring the iFarm unit to the surface at less frequent intervals. The crowding of fish for e.g., harvesting, net changing or other reasons, is manageable but still need further improvements. For example, getting a representative sample of fish from the cages may be challenging as it is not possible to sample fish below the snorkel with existing sweep nets or existing operational practices. This may mean that fish that aggregate at the surface e.g., moribund fish are over-represented in manual sampling events.

iFarm machine vision sensor arrangement

In Phase 1 of the iFarm development project, the first-generation sensor prototype was tested for close to one year at Martnesvika and the data collected and analysed during that period served as an important platform for the design of the second-generation sensor prototype. The second-generation sensor is expected to be installed at the Phase 2 farm site, Langøyhovden, in May 2022.

iFarm sorter

Operational in-cage testing of the first iFarm fish sorter was carried out at Langøyhovden during February 2022. The goal of this first sorter test was to see if it was possible to catch and sort fish in the cage and learn what needs to be improved to make a fully functional fish sorter. Important learning opportunities and experiences were gleaned from the sorting attempts:

- The majority of fish that entered the sorter did not appear to exhibit behaviours that were indicative of high stress (e.g., high speed swimming/panic behaviour) during sorting. In fact, in some scenarios, fish did not exhibit any escape type or stress related behaviours when the digits were moved sideways partly above the sorter floor. However, some fish that were in too close proximity to the sorter exhibited startle related behaviours. Some fish did come into contact with the digits/sorting door when the sorting process was initiated, although this contact was milder than what can be expected during the majority of normal handling procedures.
- The parabola shapes created by the digits are sometimes too small and the movement and deployment of the digits need to be faster. There also needs to be less space between the digits to prevent fish escaping from the sorter.

- In summary, the sorting test was deemed successful by BioSort and Cermaq. The test showed that it is possible to sort fish as they swim through the iFarm sensor house without touching them with no or minimal contact with the fish. The next step is to take all the experience from the current sorter and design the second-generation sorting prototype that will be tested out in the Phase 3 of the project.

Fish health and welfare

Fish health monitoring

Cermaq Norway's fish health monitoring plan has been applied throughout Phase 2 for the Cermaq Utvikling AS Langøyhovden farming site. With close monitoring, Cermaq aims to detect possible situations that may reduce fish health and/or welfare at an early stage. 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 daily operations all relevant production parameters are registered daily. This includes environmental parameters, feed consumption, mortality, growth. There is also daily camera surveillance and recording of fish behaviour at multiple depths within the iFarm systems (iFarm cages M1 – M4 and M6 – M9)
2) The fish health situation at the facility is followed up with monthly fish health visits by authorized fish health personnel. For a detailed description on the fish health situation in at Langøyhovden, see the fish health report (attachment 1, not public).

Health and mortality

Unlike during Phase 1, fish health has been a challenge on the Langøyhovden farm site. Fish health and welfare has in periods been reduced, mainly related to different health diagnoses or events in the specific fish groups. The main reason for mortality in the period covered by this report can be linked to IPN outbreaks in cages M3-M5, mortality following seawater transfer due to algae exposure during transport in cages M7-M9, and mortalities due to Tenacibaculosis and Parvicapsulosis in cages M6-M9. Over the winter there was an increase of ulcers, most likely winter ulcers in all cages at Langøyhovden and also some potential contact sores/wounds related to abrasion, which, together with other diagnoses, has led to increasing mortality. In Phase 1, increasing ulcer development was also observed over the winter, and this was the main reason for mortality at the Martnesvika site during Phase 1.

Cumulative mortalities were very variable during the midway Phase 2 reporting cages and with highest mortalities in cages M3-M5 and cages M7-M9. Mortalities in the 1-year smolt in cages M1 and M2 have been some of the lowest on the farm for the Phase 2 midway reporting period and reached ca. 3% in both cages. Sensor house configurations in these cages did not have a marked impact upon total cumulative mortalities during the Phase 2 reporting period. The primary causes of mortalities in these cages are wounds/sores, both related to common winter ulcers and also sores potentially due to contact/mechanical injuries.

Mortalities in 1-year smolts in cages M3-M5 were unfortunately the highest on the farm during Phase 2. Fish in cages M3-M5 initially had problems related to seawater transfer. Cumulative mortality then increased rapidly 8-10 weeks post seawater transfer due to a confirmed case of Infectious Pancreatic Necrosis (IPN). Mortalities following the IPN outbreak stabilised and were relatively low for cages M3 (two-way sensor house) and cage M5 (the associate cage), increasing 2-3% for both cages during the remainder of the Phase 2 midway reporting period. Moribund/loser fish also account for a portion of mortalities in cages M3-M5, as do wounds, both related to common winter ulcers and also sores potentially due to contact/mechanical injuries. Winter ulcer/sore driven mortalities was prominent in cage M4 between December 2021 and March 2022. In January 2022 there was a suspicion that a high number of fish in the upper volume of the snorkel was contributing to this mortality and the sensor house was consequently removed from cage M4 during the first week of January 2022. Unfortunately, mortalities continued to increase for the remainder of the midway reporting period for cage M4 and health screening revealed bacterial wound infection, skin infections and sepsis, suspected bacterial sepsis and a circulatory disorder of the spleen in the sampled fish. Fish numbers also increased in the upper volume of the snorkel in cage M3 in February 2022 the sensor house was removed as a precautionary measure. Fortunately, no increase in mortalities above normal was observed after the sensor house was removed. The associate cage (M5) reported the highest cumulative total mortalities on the farm and have been mostly driven by the IPN outbreak. Mortalities in the 0-year smolt in cages M6 and M7 (docking station only), M8 (sorter) and M9 (triangle) were low. Mortalities were also low in cage M6 (ca. 3%) but unfortunately higher in cages M7-M9. The high initial mortalities in cages M7-M9 were attributed to algal exposure during smolt transport. Mouth rot and wounds/sores also account for a relative high portion of the mortality in cage M7, M8 and M9. There has also been an outbreak of Parvicapsulosis in cages M6-M9 that has also contributed to the mortality situation in these cages.

When comparing the results of Phase 1 against Phase 2 there is a marked contrast in mortality data between each Phase of the project. Cumulative mortality during Phase 1 was generally low for both the associate and iFarm cages and was 0.7 % in the associate cage and 1.1-1.4 % in the iFarm cages for the Phase 1 midway reporting period. A high portion of late winter/spring mortalities in Phase 1 were driven by ulcers, especially in the iFarm cages and winter ulcer/sore problems also contributed to mortalities in Phase 2. Ulcerative disease disorders may become problematic in salmon farming especially when water temperatures are low (< 7 °C). They can be drivers for mortality and causative agents are suggested to be multifactorial, including pathogens (*Moritella viscosa, Tenacibaculum* spp. and *Aliivibrio (Vibrio) wodanis*) and mechanical trauma. As increased mortalities due to winter ulcer in the iFarm cages happened in both Phase 1 and Phase 2, it appears that potential mechanical trauma e.g., the fish coming into contact with the sensor house may be a driver/or at least exacerbate the risk of developing ulcers.

Fish welfare monitoring

The purpose of fish welfare monitoring in Phase 2 was to document the welfare of the fish at the Langøyhovden farming site. 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).

Environmental Operational Welfare Indicators

Environmental OWIs (Dissolved oxygen, DO and water temperature) were also monitored at three depths in all iFarm cages and the associate cage. DO saturations were generally over 80 % 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 (Remen et al., 2016). Water temperatures at all depths in all cages peaked at ca. 12 ^{o} C in late August 2021 and dropped to ca. < 4 ^{o} C at the start of March 2022. This was a similar trend to the input OWIs monitored during Phase 1.

Morphological Operational Welfare Indicators

Morphological OWIs were followed closely throughout Phase 1 using the Cermaq Welfare Scoring scheme for scoring 11 external injuries according to a 0-3 scale. 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. The prevalence of wounds and sores was also monitored as these can be exacerbated by collision/abrasion injuries. Morphological OWIs from a selection of cages were followed a minimum of every 2-3 months throughout Phase 2 using the Cermaq Welfare Scoring scheme for scoring 11 external injuries according to a 0-3 scale. In general, and in all cages, the range, frequency and severity of injuries increased as Phase 2 progressed. Some of these injuries were health related e.g., due to the outbreak of tenacibaculosis at various stages of the production cycle and the outbreak of winter ulcers during winter 2021. Other drivers were also health related, in particular related to the ongoing Parvicapsulosis problem on the farm in cages M6-M9.

In general, 1-year fish in all cages M1-M5 had limited or no severe morphological injuries for the first 2-3 months after seawater transfer. 0-year fish in cages M6-M9 also had no severe morphological injuries for the first 2-3 months after seawater transfer. In early winter as the temperatures dropped to below 7 ^{o}C the situation changed in all cages. In cages M1 and M2 in November, the sampled fish had a wider range of injuries than in August, and the frequency increased and was somewhat higher in cage M1 than M2. The majority of the injuries were mostly directed at the skins, fins, snout and eye, and the frequency of active wounds had also increased. None of these injuries appear related to the sensor house deployment or geometry of the sensor house as the OWIs were audited within one week of sensor house deployment. However, they may be related to the adapted snorkel cage structure. In March 2022, ca. 9-10 months after smolt transfer, and ca. 3.5-4 months after sensor house deployment, sampled fish had a narrower range of injuries than in November, and the frequency of injuries decreased, although it was still somewhat higher in cage M1 than M2. A similar trend was also observed in cages M3-M5. During November 2021 the sampled fish had a wider range of injuries than in July, and the frequency of injuries increased and was somewhat comparable in both the iFarm and associate cages. In fact, the frequency of severe scale loss was greatest in the associate cage at this sample point. Scale loss and fin damage increased markedly in cage M4 during March 2022, but not in cage M3 over the same period. This may have been related to the health problems associated with winter ulcers/sores the fish in cage M4 were experiencing from late December onwards. Cages M6-M9 also report similar trends, with a low frequency and severity of injuries in September 2021, followed by an increase in both the breadth and severity of injuries in November 2021. Injuries were once again observed on the fins and in relation to scale loss and skin haemorrhaging. In March 2022 the morphological OWI situation was worse in cages M6-M9, with an increase in the frequency of injuries to the skin (scale loss and haemorrhaging), active and healed wounds, snout, eye and fin damage. The higher number of fish with these issues may have been related to the outbreak of parvicapsulosis at the time of sampling. Wounds/sores were also increasing in their prevalence at this time.

In summary, injuries that are applicable to snorkel cages (snout damage, skin damage and fin damage) generally increased in frequency and severity during Phase 2, as did skin haemorrhaging. The drivers for skin haemorrhaging can be multifactorial such as disease outbreaks or due to mechanical/handling trauma and we suggest its use as a relevant OWI for adapted snorkel/iFarm cages, especially if it can be indicative of mechanical trauma/abrasion injuries or contact with the rearing unit. When comparing the morphological OWI situation during Phase 2 at Langøyhovden with that of the Phase 1 at Martnesvika, it is clear that the frequency and severity of the injury situation is worse during Phase 2 than in Phase 1. In Phase 1 there were generally no major differences between the range of OWIs measured in each cage for the duration of the reporting period, whilst the frequency and severity of injuries generally increased with time in Phase 2. In Phase 1, fish in the associate cage generally had more moderate snout damage than the iFarm cages and it was generally the case that no fish had severe snout damage in either of the iFarm or associate cages. In Phase 2, snout damage manifested itself in fish sampled in November 2021; this is most likely associated with an earlier outbreak of Tenacibaculosis. Levels of scale loss and fin damage were generally similar between the iFarm and the associate cages in Phase 1. In Phase 2 the associate cage had a higher frequency of scale loss than its corresponding snorkel cages, although other OWI frequencies and severities were comparable. In Phase 1, the prevalence of skin haemorrhaging increased in all cages, and this also happened in Phase 2.

Fish Behaviour

Fish behaviour was closely followed in Phase 2 using a suite of behavioural OWIs and LABWIs. Behavioural LABWIs included surface activity, fish traffic through the docking station/sensor house and the number of fish in the snorkel. Behavioural OWIs included swimming behaviour (speed and group cohesion), and the presence/absence freezing or group clumping behaviours of fish below the docking station. Tilt angle was also monitored by feeding staff each day before and during feeding in the lower portion of the cage. A further behavioural OWI was developed for feeding staff to frame how they interpreted fish activity using live footage from remote feeding cameras at two different depths at the start and end of feeding each day.

Surface activity was somewhat variable in relation to sensor house deployment in different cages. For the spider sensor house (cage M1), sensor house deployment led to ca. one-week increase in surface activity, before this activity decreased to a level of ca. 0.1-0.2 jumps/fish/hour for the majority of the reporting period. For the dome sensor house (cage M2) sensor house deployment did not appear to affect surfacing activity for ca. one week and then activity decreased to a level of ca. 0.1-0.2 jumps/fish/hour for the majority of the reporting period. There was also a one-two week decrease in fish surface activity and fish traffic through the sensor house unit when the sensor houses were mounted in the iFarm two-way sensor house (M3), the pyramid (M4) and the sorter (M8). Surface activity for the remainder of the reporting period was ca. 0.2-0.4 jumps/fish/hour in cages M3 and M4 and ca 0.1 jumps/fish/hour in cage M8. Surface activity in cage M9 dropped markedly and remained very low after sensor house deployment and the sensor house was therefore removed after three weeks. In cages M6 and M7, which only have the docking station in the snorkel for Phase 2, fish surfacing activity has stayed stable and consistent within and between both cages for the entire November – March auditing period at ca. 0.1 – 0.2 jumps/fish/hour, until it began decreasing in both cages at the end of February 2022. Interestingly in Phase 1, all fish in both iFarm cages were reluctant to use the snorkel after the sensor housing was mounted. Fish surface activity in Phase 1 averaged ca. 0.04 jumps/fish/hour when the sensor house was deployed, a figure that is much lower than that which has been observed in Phase 2 for the majority of iFarm cages. The reasons for this are unclear and will be investigated further. When comparing surface activity in the iFarm cages to other studies on standard and snorkel cages, surface activity frequencies the iFarm cages are somewhat similar (see Dempster et al., 2008; Dempster et al., 2009; Wright et al., 2018; Oppedal et al., 2019).

Trends in surface activity for each cage were generally also reflected in the traffic data through the docking station/sensor house. The number of fish aggregating in the snorkel was also documented from November 2021 until March 2022 in each of the iFarm cages. In cages M1 and M2, the number of fish observed in the snorkel during the entire sensor house deployment period were ca. 2-3% and similar between cages. The number of fish observed in the snorkel for cages M3 (two-way sensor house) and M4 (pyramid sensor house) was consistently higher in cage M4 than cage M3 until January 2022 (4-5% vs 2-3%). Sensor house removal in cage M4 led to a marked 2-3% drop in the number of fish in the snorkel, with fish numbers then remaining relatively stable until they began increasingly during February 2022 up to ca. 4%. The number of fish in the snorkel in cage M3 initially increased after sensor house deployment and remained relatively constant until February 2022, where fish numbers markedly increased from ca. 3% to ca. 6%. Fish numbers in the snorkel of cage M3 remained relatively stable at this level even after the sensor house was removed in February. In cages M6 and M7 (docking station only) there has been a general trend for an increased number of fish in the snorkel as Phase 2 progressed, increasing from ca. 1-2 % in November up to 6-7% at the end of February 2022. In cages M8 (sorter) sensor house deployment led to a drop in the number of fish in the snorkel from ca. 6% to ca. 3%, but numbers returned to pre-mounting levels within ca. 3 weeks. In cage M9 (triangle) fish numbers in the snorkel were approximately similar during the three weeks before and during sensor deployment. Upon removal of the sensor house from cage M9, there was a short-term increase in fish in the snorkel and numbers again increased during February to a level of ca. 9% at the end of February 2022. Increased aggregations of fish in the snorkel have also been noted elsewhere. DO saturations in the snorkel did not drop to suboptimal levels. However, the increase in fish number/density in the snorkel was believed to have contributed to the increase rate of ulcer/sore development (and associated mortalities) in cage M4 and led to the sensor house being removed in January 2022. A later, but acute increase in fish numbers in the snorkel of cage M3 also led to the removal of this sensor house in February 2022 to prevent a repeat of this problem. 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 emerging as a potential risk factor for ulcer/sore driven mortalities. A situation with escalating moribund fish in the upper volume will in a finished iFarm product be resolved by sorting out these fish. Phase 3 of the project will also investigate other methods to get the fish return down to the lower volume.

If fish are exhibiting problems with buoyancy, they can increase their swimming speeds to generate lift. In general, there were no differences in swimming speed between the periods before and after the sensor houses were mounted, and values remained steady at medium cruising levels. The swimming cohesion of 1-year smolt in cages M1 and M2 showed a similar trend throughout the study period with fish progressively increasing cohesion over time. The mean swimming cohesion for 1-year smolt in cages M3 and M4 was similar to that observed in cages M1 and M2 and increased over time. Visually, no differences in swimming cohesion between the periods before and after the installation of the sensor housings were observed. Swimming cohesion for 0-year smolt in cages M7 - M9 also seems to increase over time, especially in cages M8 and M9. For cage M6, there was little evidence of an increase in swimming cohesion as time progressed. For cage M7, swimming cohesion values were similar to cages M8 and M9.

Activity at the start and end of daily feeding was also closely matched between iFarm cages and did not appear to be markedly affected by the mounting of the sensor houses or the various geometries of the iFarm sensor housings. No tilted (head-up/tail down) swimming behaviour > 25 ^{o} was observed during a minimum of twice daily audits of fish behaviour near the bottom of each iFarm cage during Phase 2, by Cermaq feed staff both before and during feeding aside from the observation of 1 fish exhibiting tiled swimming behaviour in cage M3 on July 26th (before the sensor house was mounted). It currently appears that the surface activity expressed by the fish after the sensor houses were mounted in the snorkels is sufficient to maintain buoyancy. Results on activity around feeding and swimming tilt angle are similar to those reported in Phase 1 of the iFarm project. The pending analysis of vertebral condition in fish at Langøyhovden will also provide supplementary data on this. Sievers et al., (2018) reported this continuous submerged artificial lighting reduce the expression of tilted swimming behaviours when fish are held in submerged cages, by increasing their swimming speeds and compensating for negative buoyancy. Continuous lighting may therefore be beneficial for stimulating swimming behaviour and counteracting any potential negative effects of submergence upon buoyancy (Dempster et al., 2009).

No marked differences in daily feed delivery for the entire Phase 2 midway reporting period were observed between cages holding i) the 1-year smolt transferred in May 2021 (cages M1 and M2), ii) the 1-year smolt transferred in June 2021 (cages M3-M5) and iii) the 0-year smolt transferred in September 2021 (cages M6-M9) and daily activity scoring of fish at the start and end of feeding was generally scored as normal by the Cermaq feed staff. The deployment of the sensor housing did not have a marked effect on appetite in any of the iFarm cages. Interestingly, appetite in the iFarm cages M3 and M4 was also similar to the associate cage M5.

Sea lice monitoring

Sea lice monitoring in the iFarm systems (M1-M4, M6-M9), and the associate cage (M5) is an important part of this project. To have good control over the sea lice situation in all cages, automatic lice counting technology from CreateView AS has been used. In addition, lice are control counted once every month with sea temperatures over 7 ^{0}C and once every second month with sea temperatures under 7 ^{0}C. Sea lice are also counted as part of the Cermaq Welfare Scoring Protocol. All manual sea lice counts are carried out by Cermaq personnel with an approved lice counting course, or external fish health personnel.

After smolt transfer in 2021 there have generally been low sea lice levels in the fjord system. Sea lice infestation levels were generally low throughout Phase 2 up until the midway reporting period for the skirt equipped associate (M5) and skirt-snorkel equipped iFarm cages (M1-M4, M6-M9) at the Langøyhovden farm site. Lice levels required a single Slice intervention from week 36-37 (cages M1-M5, 1-year smolts) and week 40-41 (cages M6-M9, 0-year smolts) in 2021. The drivers for both treatments were high levels of *Caligus elongatus*. There has been an increasing trend of mobile salmon lice numbers in 2022, but this has required no intervention as of the date of the midway reporting period.

Production performance monitoring

Production performance monitoring (primarily growth performance) for each of the associate (M5) and iFarm cages (M1 – M4, M6 – M9) are based on the initial weight estimates of fish at the time of seawater transfer. Manual weighing of 40 – 60 fish per cage was also carried out in November 2021 in conjunction with OWI scoring. From seawater transfer in 2021 until 1st March 2022 biomass (and changes in biomass) were also monitored using data from "FISHTALK" (AkvaGroup AS, Norway)/Power BI(Microsoft) where stock weight estimates are modified in line with growth audits (after Imsland et al., 2017). Growth performance was calculated using TGC data from seawater transfer until 1st March 2022.

Reported production performance is similar between the cages holding i) the 1-year smolt transferred in May 2021 (cages M1 and M2), ii) the 1-year smolt transferred in June 2021 (cages M3-M5) and iii) the 0-year smolt transferred in September 2021 (cages M6-M9) during the first reporting period. TGC and eFCR values are closely matched at the end of the reporting period for all cages within each smolt transfer group. Mean condition factor of fish in all cages were higher than the threshold considered to indicate emaciation in Atlantic salmon post-smolts (> 0.9) but is not at the desired level for M3-M9. The low condition factor of some of the fish may have been due to the high number of moribund fish that were sampled during the March 2022 sampling event, especially in the 0-year smolt group (M7 to M9 especially) that are diagnosed with Parvicapsulosis. Irrespective of this, the condition factors of the fish for Phase 2 are lower than the first half of Phase 1.

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Collaborators

BioSort

Nofima