This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773330

Deliverable report for

GAIN

Green Aquaculture Intensification

Grant Agreement Number 773330

Deliverable D1.1
Title: Report on instrumentation of GAIN pilot sites

Due date of deliverable: 31/01/2019
Actual submission date: 01/04/2019

Lead beneficiary: AFBI
Authors: Service, M.; Grant, J., Icely, J.D., Lopez, M., Moore, H., Micallef, G., Panicz, R., Pastres, R., Rey Planellas, S , Zhu, C.

WP 1 – Production and Environment
Task 1.3 – Instrumentation of commercial aquaculture facilities.

Dissemination Level:		
PU	**Public**	**Y**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document log

Version	Date	Comments	Author(s)
Version 1	14/01/2019	Table of contents	Service, M., Moore, H.
Version 2	14/01/2019	First draft	Service, M., Moore, H.
Version 3.1	28/01/2019	Second Draft	All 1.3 Pilot sites' Partners
Version 4.1	07/02/2019	Third Draft	Moore, H., Service, M.
Version 4.4	28/02/19	Fourth Draft	Moore, H., Service, M.
Version 5	08/03/19	First revision	Pastres R., O'Donncha F.
Version 6	15/03/19	Fifth Draft	All 1.3 Pilot sites' Partners
Version 6.1	22/03/19	Additional info	All 1.3 Pilot sites' Partners
Version 7	27/03/19	Final Document	Pastres R.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Recommended Citation

Service, M.; Grant, J., Icely, J.D., Lopez, M., Moore, H., Micallef, G., Panicz, R., Pastres, R., Rey Planellas, S , Zhu, C.Report on Instrumentation of GAIN pilot sites. Deliverable 1.1. GAIN - Green Aquaculture INtensification in Europe. EU Horizon 2020 project grant nº. 773330. 63 pp.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

GLOSSARY OF ACRONYMS

Acronym	Definition
ABM	Aquaculture Biomass Monitor
AMS	Aquaculture Management System
CFC	Closed Fish Cage
Chl a	Chlorophyll a
CTD	Conductivity, Temperature and Depth
DO	Dissolved Oxygen
FCR	Feed Conversion Ratio
HABs	Harmful Algal Blooms
IoA	Institute of Aquaculture
NH4	Ammonium
ORP	Oxidation Reduction Potential
PFF	Precision Fish Farming
PLC	Programming Logic Controller
PSF	Precision Shellfish Farming
RAS	Recirculating Aquaculture Systems
SGR	Specific Growth Rate
SRP	Soluble Reactive Phosphorus
SST	Sea Surface Temperature
TSS	Total Suspended Solids

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table of Contents

1. Introduction 5

2. Methodology 6

3. Description of pilot sites instrumentation 8

3.1 Shellfish Aquaculture Pilot sites 9
3.1.1 Site 1. Dundrum bay – Northern Ireland 9
3.1.2 Site 2. Belfast Lough – Northern Ireland 13
3.1.3 Site 3. Sagres – SW of Portugal 15
3.2 Sea-cages pilot sites 20
3.2.1 Site 4. – Rossøya Nord– Norway 20
3.2.2 Site 5. Carness Bay Orkney- Scotland (UK) 25
3.2.3 Site 6. McNutt's Island Shelburne - Nova Scotia, Canada 30
3.2.4 Site 7. El Gorguel, Cartagena – Spain 34
3.3 Land based systems 38
3.3.1 Site 8. Preore– Italy 38
3.3.2 Site 9 Nowe Czarnowo – Poland 43
3.3.3 Site 10. Fenzhou Village – China 48

4. Conclusions 54

References 56

ANNEX 1 - GAIN Consortium and project structure 57

Annex 2 - Monitoring equipment installed at the pilot sites in the framework of the GAIN project. 59

List of Tables 61

List of Figures 62

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

1. Introduction

Green Aquaculture Intensification in Europe (GAIN) (www.unive.it/gainh2020_eu) is a project financed by the European Union under the Horizon2020 framework. The project is run by a consortium of 20 partners from a variety of professional backgrounds, spanning across 11 different countries, including Canada and China. The global scope of the consortium is enhanced by the involvement of a US national organization (NOAA) as a third party member. The composition of GAIN Consortium and the project structure are given in Annex 1. GAIN's primary aim is to assist the ecological intensification of aquaculture in the European Union (EU) and the European Economic Area (EEA), with the dual objectives of increasing production and competitiveness of the industry, while ensuring sustainability and compliance with EU regulations on food safety and environment.

Across the GAIN consortium and elsewhere various approaches have developed to instrument shellfish aquaculture sites, land-based finfish and offshore caged fish farms to obtain high temporal resolution, near real time data. This has developed across a range of drivers, for optimising productivity and for environmental monitoring. In GAIN WP1, Task 1.3, a survey of the state-of-the-art in commercial or close-to-market sensors which could provide real-time observations was carried out. Based on that, a plan for installing sensors at ten pilot sites was designed and carried out.

This deliverable describes the results achieved during the first 9 months in Task 1.3, which main goal was to design and install cost-effective monitoring systems at GAIN pilot sites, based on state-of-the-art sensors, with the ability to observe a set of relevant environmental variables and fish/shellfish bio-responses, i.e. animal variables, whenever possible in real time. Data collected by GAIN sensors will be complemented by the observation capacity already available at sites and by data available on public portals (e.g. remotely sensed data and data from operational oceanography freely downloadable from Copernicus Marine Environment Monitoring Service). Forthcoming Task 1.3 activities will be aimed at checking the quality of collected data and transferring them to Task 1.4 and Task 1.5: the comprehensive data sets concerning GAIN pilot sites will support the modelling activities aimed at implementing the emerging framework of Precision Fish/Shellfish Farming, as described in Section 2, which will be carried out in Task 1.4 and 1.5.

Data sets will be used to produce predictive models and, ultimately, software that is able to convert raw data into formats that are readily interpretable and meet stakeholder requirements, thus supporting decision-making on fish/shellfish farms. Furthermore, the results to be obtained in Task 1.3-1.5 will be used for developing "best practice guidelines" for data collection, quality assessment and management across the range of aquaculture typologies and species investigated in the ten pilot cases described in section 3. Concluding remarks are given in Section 4.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

2. Methodology

"Precision agriculture", introduced in the early 1990s, and "Precision Livestock Farming", introduced in early 2000, approaches are being rapidly implemented in the agrifood sector, due to three concurrent factors (Banhazi et al., 2012):

1) the development of sensors which can provide, at an affordable cost, large data sets, often in real time, concerning both environmental variables and crops and livestock bio-responses;

2) the decrease in computational costs and the development of AI algorithms and data driven model for extracting useful information from "Big Data" sets.

3) the development of "smart" management systems, based on IoT, Internet of Things.

Innovations and decrease in costs of sensors are now making possible to transfer these approaches to aquaculture, within the framework of "Precision Fish Farming" (PFF) (Fore et. al., 2018), which in GAIN will be extended to "Precision Shellfish Farming" (PSF).

According to (Fore et. al., 2018), PFF aims at improving accuracy, precision and repeatability in farming operations by providing reliable decision support to farmers, thus reducing subjective assessments. These goals are achieved by complementing decision making based on qualitative information collected by operators with decision support tools based on the processing of quantitative data provided by sensors. The management of an aquafarm can be viewed as the result of a cyclical set of operations, which can be divided into four phases:

1) Observe: Observation of bio-responses of farmed animals;

2) Interpret: Interpretation of the observations;

3) Decide: Decision making;

4) Act: Implementation of decisions, which should lead to an improvement in bio-responses.

In many aquaculture sectors, this sequence is mainly driven by the expert judgement of operators and actions are implemented manually. More mature sectors, i.e. Atlantic salmon farming in the EU and Canada, seabass and seabream farming in the Mediterranean region, are already switching to management systems in which the expert judgement is supported by software, e.g. Aqvaconnect, FishTalk. Based on input data concerning environmental variables, (e.g. water temperature), and bio-responses, (e.g. estimates of biomass/fish size distribution), these tools provides estimates of daily feed ration. However, biomass/fish size distribution are still obtained from small samples of a cage population, e.g. about 100 specimen out of a 1-3 hundred thousands, and, on average, a monthly sampling frequency or lower. As s result, the uncertainty in the assessment of feed ration can still be rather high, leading to: i) economic losses and unnecessary environmental pollution in case of over-estimation, ii) poorer growth performances in case of under-estimation.

In the case of land-based aquaculture systems such as RAS and raceways farms, one can measure and control some environmental variables, (e.g. Dissolved Oxygen). An approach based on the quantitative processing of environmental data and bio-responses makes it possible to optimise the feeding, oxygen supply, water temperature of farms. Intensive and semi-intensive aquaculture in ponds is a relevant sector in Central Europe and a major one in China. These systems offer large possibilities for optimization of feeding and co-culture, based on the analysis and forecasting of fish growth on the basis of predictive ecosystem modelling.

As regards shellfish, site selection and planning of husbandry operation (e.g. mussel re-socking in longline farms), are key to the success of the industry. Growth performance

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

and to an extent disease management depends on environmental variables, which are seldom monitored on site by farmers.

GAIN ambition is to contribute to the implementation of PFF/PSF across the systems mentioned above, collecting data from ten pilot sites and processing them using state-of-the-art mechanistic models, including data assimilation algorithms, and data driven models.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3. Description of pilot sites instrumentation

AFBI liaised with other Task 1.3 partners to ensure appropriate technology transfer and skills to ensure compatibility of systems and data management. GAIN pilot sites are listed below (Table 3.1). According to the methodological approach outlined in section 2, a variety of state-of-the art sensors were deployed on ten pilot sites, in order to detect both environmental and animal variables, whenever possible in real time. GAIN pilot sites cover the main aquaculture typologies, i.e. shellfish culture (oysters and mussels), marine finfish cages (Atlantic salmon, seabass), land based raceway (rainbow trout), RAS (common carp) and pond systems (common carp and shrimp) In the following subsections, shellfish sites are presented first in section 3.1, followed by sea cages, section 3.2, and land based systems section 3.3.

Each pilot description includes two Tables, summarizing, respectively, the main features of each site, and the instrumentation deployed. In the second Table, the terminology introduced in (Fore et al., 2018) is used, designating bio-responses of fish/shellfish as "animal variables". Modelling activities in Task 1.4 and 1.5 aim at quantifying relationships between environmental variables and animal variables, or specific functions of animal variables which are interesting for farmers, e.g. SGR, FCR, etc., which are called "target variables".

Table 3.1 - Summary of Pilot Sites

Pilot Site	**Country**	**Species**	**Type of Aquaculture**	**Partner**
1) Dundrum Bay	Northern Ireland - UK	Oysters (*Magellana gigas*)	Shellfish Aquaculture	AFBI
2) Belfast Lough	Northern Ireland - UK	Mussels (*Mytilus edulis*)	Shellfish Aquaculture	AFBI
3) Sagres	Portugal	Mussels (*Mytilus galloprovincialis*)	Shellfish Aquaculture	SGM
4) Rossøya Nord	Norway	Salmon (*Salmo salar*)	Sea cages	GIFAS
5) Carness Bay	Scotland	Salmon (*Salmo salar*)	Sea cages	UoS
6) McNutt's Island, Shelburne	Canada	Salmon (*Salmo salar*)	Sea cages	DAL
7) El Gorguel, Cartagena	Spain	Seabass (*Dicentrarchus labrax*)	Sea cages	LEBCH
8) Preore, Troticoltura Leonardi	Italy	Rainbow trout (*Oncorhyncus mykiss*)	Land-based raceways	UNIVE
9) FES NOWE Czarnowo	Poland	Carp (*Cyprinius carp*)	Land-based RAS/pond	ZUT
10) Fenzhou Village	China	Shrimp (*Litopenaeus vannmei*, *Macrobrachium roserbergii*)	Land-based pond	SCSFRI

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.1 Shellfish Aquaculture Pilot sites

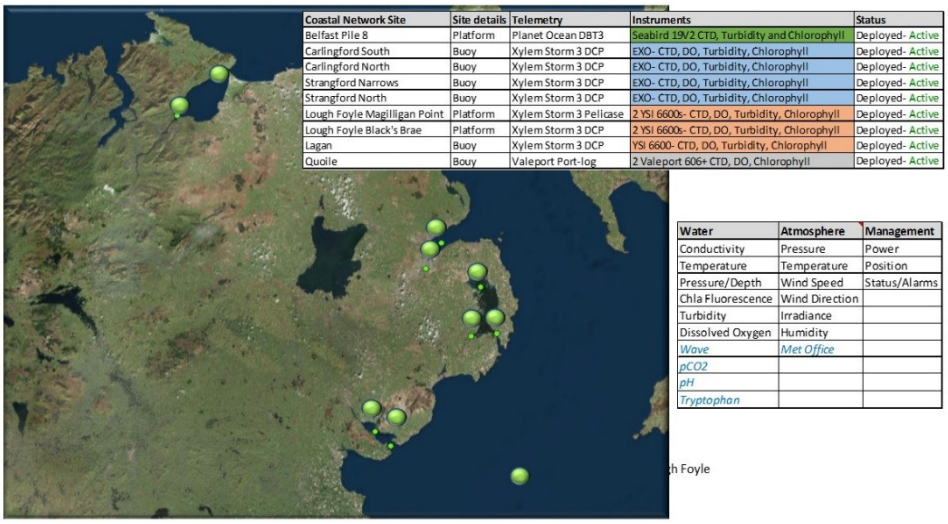
Three shellfish sites are considered in the GAIN project. Two sites are located in Northern Ireland (UK), where oysters are cultivated in intertidal trestles and blue mussel bottom culture is practised. The third site is an off-shore mussel farm located in Portugal.

3.1.1 Site 1. Dundrum bay – Northern Ireland

Authors: Heather Moore, Matthew Service

AFBI have maintained an Inshore Moored Instrument Network (Figure 1) in Northern Ireland's coastal waters for around 20 years. Moored instrument sites are located on or adjacent to some of the main shellfish growing areas. It is anticipated this will provide the core platform for setting reference conditions and will host the additional data flow from directly instrumented aquaculture sites. The per annum network typically provides:

- 259,588 multi-parameter records – each record typically generating around 7 parameters (estimate >2 million data points);
- Selected sites measure at 2 depths where stratification exists;
- Typically recording 20 minute interval – data telemetered in near-real time and is subject to 41 individual service and maintenance events.



Coastal Network Site	Site details	Telemetry	Instruments	Status
Belfast Pile 8	Platform	Planet Ocean DBT3	Seabird 19V2 CTD, Turbidity and Chlorophyll	Deployed- Active
Carlingford South	Buoy	Xylem Storm 3 DCP	EXO- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Carlingford North	Buoy	Xylem Storm 3 DCP	EXO- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Strangford Narrows	Buoy	Xylem Storm 3 DCP	EXO- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Strangford North	Buoy	Xylem Storm 3 DCP	EXO- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Lough Foyle Magilligan Point	Platform	Xylem Storm 3 Pelicase	2 YSI 6600s- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Lough Foyle Black's Brae	Platform	Xylem Storm 3 DCP	2 YSI 6600s- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Lagan	Buoy	Xylem Storm 3 DCP	YSI 6600- CTD, DO, Turbidity, Chlorophyll	Deployed- Active
Quoile	Bouy	Valeport Port-log	2 Valeport 606+ CTD, DO, Chlorophyll	Deployed- Active

Water	Atmosphere	Management
Conductivity	Pressure	Power
Temperature	Temperature	Position
Pressure/Depth	Wind Speed	Status/Alarms
Chla Fluorescence	Wind Direction	
Turbidity	Irradiance	
Dissolved Oxygen	Humidity	
Wave	*Met Office*	
pCO2		
pH		
Tryptophan		

Figure 1. AFBI's Inshore Moored Instrument Network

The first pilot aquaculture site instrumented by AFBI in the framework of the GAIN project is situated in Inner Dundrum Bay (Figure 2), a small, largely intertidal inlet on the east coast of Northern Ireland connected to the Irish Sea by a narrow channel. The main focus of aquaculture production at this site is for Pacific oysters (*Magallana gigas*) grown on intertidal trestles (Figure 2, Table 3.2).

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.2 - Description of Inner Dundrum Bay Oyster aquaculture site

Site	**Dundrum Bay**
Location	54.3 N 5.84 W
Size and layout	16 hectare Depth: intertidal +/- 5m
Species	*M. gigas*
Culture system	Intertidal trestles
Farming practice	Seeding, from hatchery: Seed size: 30-50 g
Harvest	Expected harvest after 18 to 30 months Standard harvest weight: 70-80 g
Mortality	Oyster mortality (%(): <10%

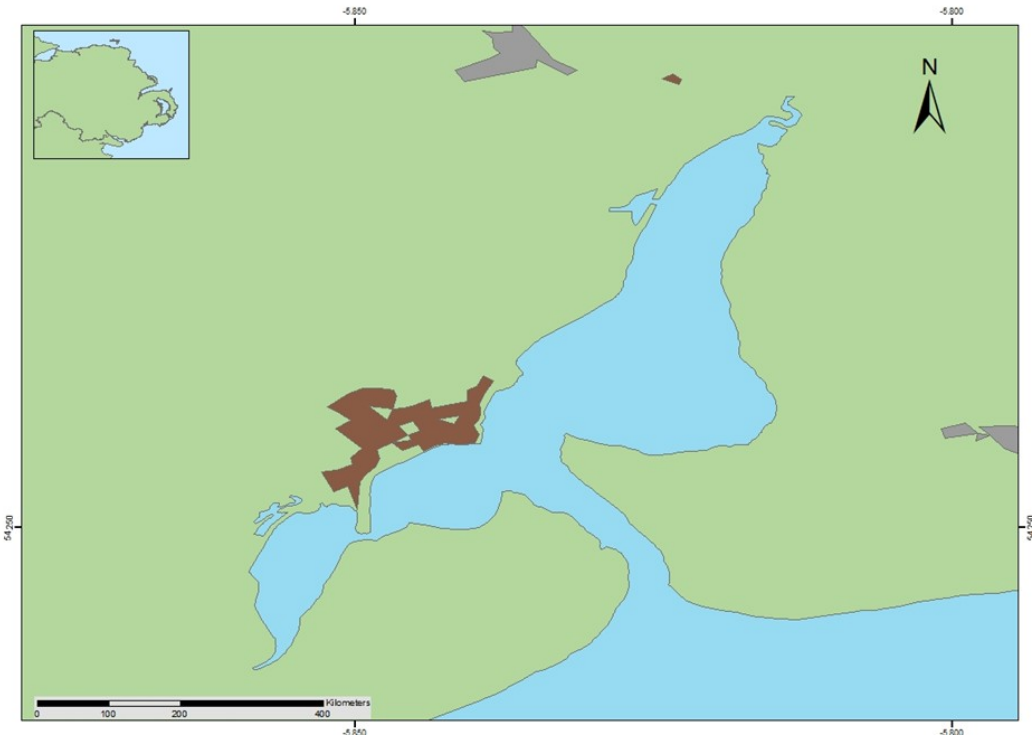


Figure 2. Map showing the location of Inner Dundrum Bay

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 3. Oyster trestles in Inner Dundrum Bay

Instrumentation and Data Collection

The Inner Dundrum Bay catchment is the subject of a long term monitoring campaign by AFBI, both in relation to fresh water loading and inputs from adjacent coastal waters.

Instrumentation of the site in Inner Dundrum Bay is summarised in Table 3.3. The system will allow for the establishment of a permanent moored installation adjacent to the oyster trestles carrying CTD, Turbidity (FTU), chlorophyll A, Dissolved oxygen and Tryptophan (bacterial) sensors. These will be incorporated into the existing network. This will be installed by the 30th of April 2019. AFBI have identified a low-cost solution to instrument the intertidal trestles and aim to install three temperature sensors across the oyster farm with long range Wi-Fi to a base-station, which will relay to the AFBI network.

Currently Oyster growth and quality are monitored monthly by AFBI. Development of simple but robust in-field growth measurements is being trialled during GAIN by AFBI staff, with the intention to transfer skills to the producer. This trial will provide bi-weekly growth data.

Table 3.3 - Environmental and animal variables sample "in situ" at Dundrum pilot site.

Environmental variables	**Sampling frequency**	**Biological variables**	**Sampling frequency**
Chlorophyll a	1/15 mins	Wet weight	1/2 weeks
Dissolved oxygen	1/15 mins	Length/height	1/2 weeks
Salinity	1/15 mins	Dry weight	1/month
Temperature	1/15 mins	Toxic algae	1/month
Turbidity	1/15 mins		
Tryptophan	1715 mins		

Reporting

AFBI is responsible to ensure that all the instruments are maintained in working condition and that the data is transferred to the GAIN hub. The environmental sensors will all be

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

connected to the Internet and will regularly transmit data to a storage Cloud. The project partners will be provided with the necessary passwords such that they can access and download the data at their own convenience. Shellfish growth data will be collected in a monthly report. The monthly report will be sent to the project leader and partners within a week from the end of each month.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.1.2 Site 2. Belfast Lough – Northern Ireland

Authors: Heather Moore, Matthew Service

The second pilot site instrumented by AFBI is Belfast Lough, the majority of bottom cultivation for mussels in Northern Ireland occurs on licensed sites in this lough. Seed mussels are dredged from offshore seed mussel beds and relayed on the licensed aquaculture sites in Belfast Lough (Figure 4, Table 3.4) for on-growing to harvestable size. Producers in Belfast Lough have been approached to participate in this project.

Table 3.4 - Description of Belfast Lough mussel farming site

Site	**Belfast Lough**
Location	54°41'27.2"N 5°47'07.1"W
Size and layout	952 hectare Depth: 5m
Species	*M. edulis*
Culture system	Bottom culture
Farming practice	Seed, wild seed: 20-30mm Seed size: 250 units/kg.
Harvest	Expected harvest after 18 - 24 months (e.g. M3-M4) Standard harvest weight: 80 units/Kg
Mortality	Average rate 10-50% any specific cause predation poor seed handling

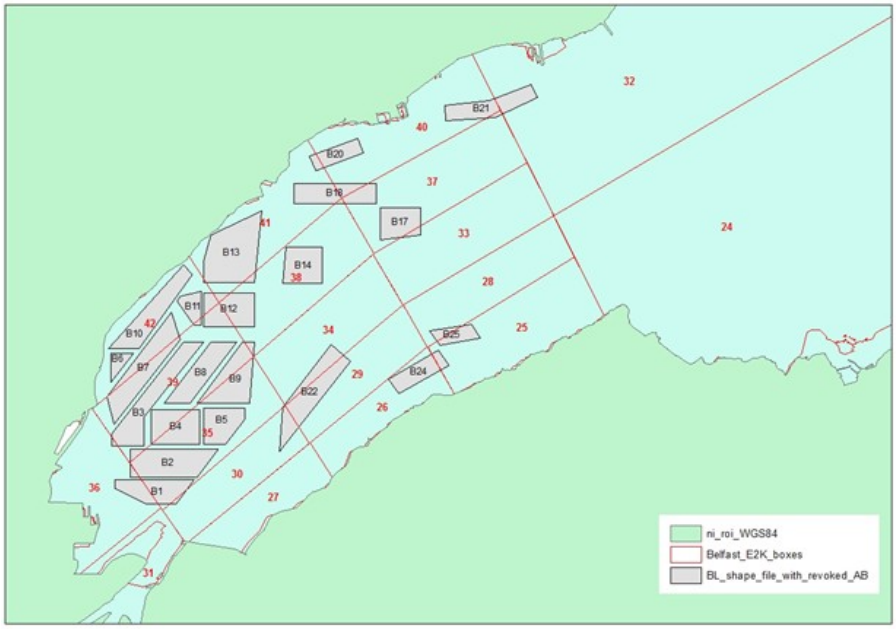


Figure 4. Location of sites for bottom cultivation of mussels in Belfast Lough

Instrumentation and Data Collection

The pilot site in Belfast Lough is entirely sub-tidal, the bottom cultivated mussel beds are maintained (mopped to remove predators, thinned, moved as required for on-growing) and harvested using a dredge.

Installing water quality monitoring directly on mussel plots will be challenging and initially an

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

existing AFBI Platform situated adjacent to the mussel plots will used to provided reference data. Technologies to be investigated will include; remote sensing, trawl safe moorings and short term moorings. Currently this location is subject to a high intensity field campaign to improve the management of waste water treatment plants which will provide additional instrumentation in the catchment. Focus here will be on turbidity, DO and particulate organic matter, key determinants impacting mussel growth and quality.

Mussel growth and quality is monitored monthly by AFBI, with length, width, height, total wet weight, wet flesh, dry flesh and shell weight recorded. Development of a simple but robust in-field growth monitoring system has been discussed with growers and pieces per kilo will be recorded during their routine site inspections, bi-weekly data should be recorded.

Table 3.5 - Environmental and animal variables sampled in situ at Belfast Lough Pilot site.

Environmental variables	**Sampling frequency**	**Biological variables**	**Sampling frequency**
Chlorophyll a	1/15 mins	Wet weight	1/2 weeks
Dissolved oxygen	1/15 mins	Length/height	To be decided
salinity	1/15 mins	Dry weight	1/month
temperature	1/15 mins	Toxic algae	1/month
Turbidity	1/15 mins	Algal Toxins	1/2 weeks
Tryptophan	1/15 mins	Chlorophyll a	1/2 weeks
NO3-N/NH3-N/SRP-P/SiO2	1/2 weeks		
POM	1/2 weeks		
SS	1/2 weeks		

Reporting

AFBI is responsible to ensure that all the instruments are maintained in working condition and that the data is transferred to the GAIN hub. The environmental sensors will all be connected to the Internet and will regularly transmit data to a storage Cloud. The project partners will be provided with the necessary passwords such that they can access and download the data at their own convenience. Mussel growth data will be collected in a monthly report. The monthly report will be sent to the partners within a week from the end of each month.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.1.3 Site 3. Sagres – SW of Portugal

Authors: John David Icely

The Sagres pilot site is located in the Finisterra Lda offshore concessions on the Algarve coast, SW Portugal, see Figure 5. These concessions are located east from the Sagres harbour and have been issued only for bivalve aquaculture. The production is using longline cultivation of *Mytilus galloprovincialis*. Figures 6 and 7 show deployment of mussel seed along a longline and Table 3.6 summarises information about the Finisterra concessions.

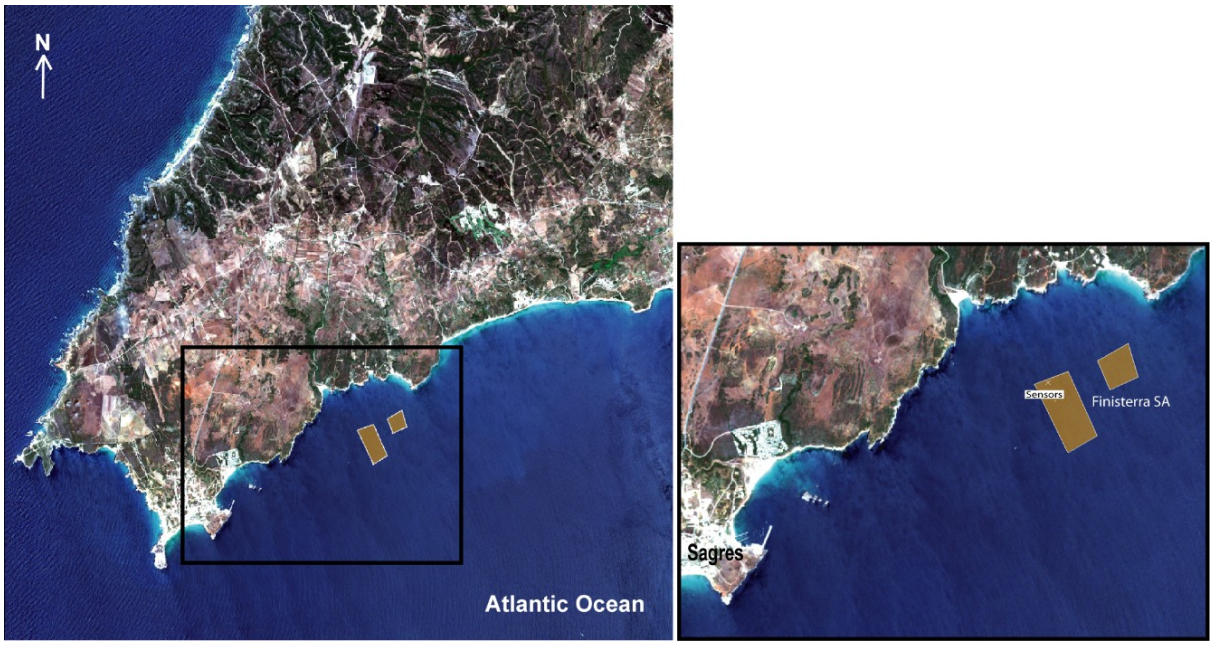


Figure 5. Geographic location of Finisterra offshore longline aquaculture in Sagres at the Southwest coast of Portugal (ESA - Sentinel-2 satellite image)

Figure 6. Detail of socking mussels. Portugal ©Gary Littler

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 7. Detail of socking and hanging mussels. Portugal ©Gary Littler

Table 3.6 - Description of Sagres mussel aquaculture site

Site	**Sagres**
Location	37° 1' N, 8° 53' W
Size and layout	3 current concessions (420m x 420m) with a further concession of 420 x 420m planned for the future. Depth: 17-36m
Culture system	Longline culture.
Farming practice	Seeding: Nov-Feb Seed size: 3-5gr (200-300 units/kg), 2-4kg linear metre.
Harvest	Expected harvest after 7 to 9 months (e.g. Jun-Sept) Standard harvest weight: 33-40gr (25-30units/Kg) dependent on the market Condition index: 16-22% cooked meat method
Mortality	Mussel mortality considered negligible. Mortality by fish grazing very important, with a requirement for anti-grazing nets.

Instrumentation and data collection

The observation capacity at the Sagres site is summarised in Table 3.7, which presents the set of environmental (with sensors) and animal variables which will be collected during the GAIN project and processed in Task 1.4 and 1.5.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.7 - Environmental and animal variables sampled "in situ" at Sagres pilot site.

Environmental variables	**Frequency**	**Animal variables**	**Frequency**
SST	1/30 minute	Total length	1/month
Salinity	1/30 minute	Width	1/month
Dissolved Oxygen	1/30 minute	Wet weight	1/month
Chlorophyll (Fluorescence probe)	1/30 min	Mortality	1/month
Chlorophyll (laboratory)	1/month	Condition index	1/month
Turbidity (Transmissometer)	1/30 minutes		
Secchi disc	1/month		
TSS (laboratory)	1/month		

Environmental variables

Instrumentation of the Finisterra site for the GAIN project is a two phase process starting with HOBO loggers for sea surface temperature (SST), salinity and oxygen. These were purchased in 2018, with the sensors for SST and salinity currently deployed at 37° 01' 51'' N / 8° 52' 51''W, see Figure 7. Data is recorded every 30 min and is normally downloaded on a monthly basis and uploaded to the IBM platform (https://app.box.com). An example of data recorded over a monthly period is shown in Figure 8.

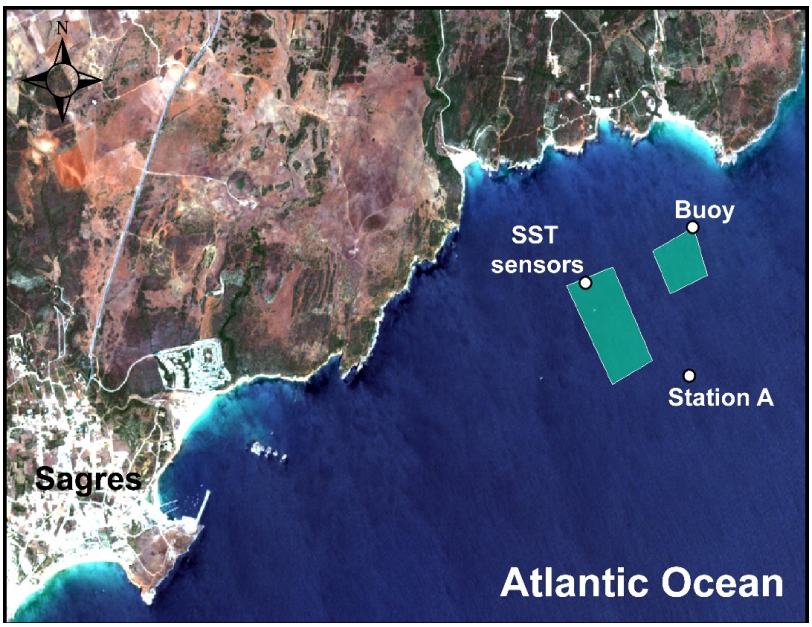


Figure 8. Sentinel-2 satellite image with the geographic location of the Finisterra longline aquaculture (green squares), the buoy, the different loggers of sea surface temperature (SST) sensors and the Station A that correspond to the station that has been used to extract satellite remote sensing data

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 9. Temperature and salinity data obtained from Hobo sensors (7-28 Nov 2018)

The second phase of instrumentation is to deploy the HOBO oxygen sensor in March 2019 on the longline, essentially to avoid the winter storms which can be severe off Sagres. In addition, more instruments will be attached to a moored marker buoy at 37° 02' 10'' N / 8° 52' 06''W in the NE corner of the mussel farm concession that acts as hazard warning system for the Finisterra concession (Buoy in Figure 8). This buoy will allow easy access without interfering with farming operations and avoiding entanglements from ropes in the system.

Data will be collected using a solar powered data logger with sensors for solar irradiance and acceleration (used to estimate wave height). There are sub surface sensors for chlorophyll fluorescence, transmission, and provisionally optical sensors at two depths. The optical sensors will measure temperature, depth and radiance at six visible wavelengths (450, 500, 550, 570, 600 & 650nm). Data will be transmitted in real time from the moored system to a local data logging and display system. This data will simultaneously be sent by mobile telemetry to the IBM platform for subsequent analysis and archive.

Finally, data collected *in situ* will be complemented by remotely sensed Earth Observations. A satellite pixel at37° 01' 21'' N / 8° 52' 08''W is the coastal site (Station A in Figure 8) used for *in situ* validation of the Ocean Land Colour Image (OLCI) sensor on Sentinel 3 and is the site from which satellite products produced by OLCI will be provided for GAIN.
Water products from the OLCI instrument on the Sentinel-3A instrument have been extracted between the dates 26 April 2016 until 31 January 2019 and have been made available to the Consortium. They include total chlorophyll a concentration retrieved by the two algorithms CHL_OC4Me and the CHL_NN, Total Suspended Solids (TSS), Coloured Dissolved Organic Matter absorption coefficient, as well as the diffuse attenuation coefficient and Photosynthetically Active Radiation. The near real time products acquired by the Sentinel-3 OLCI can be made available to users within three hours after the passage of the satellite, complementing the *in-situ* data and providing valuable information about the study site. Additional satellite data from Sentinal-3B should be provisionally available in March 2019.

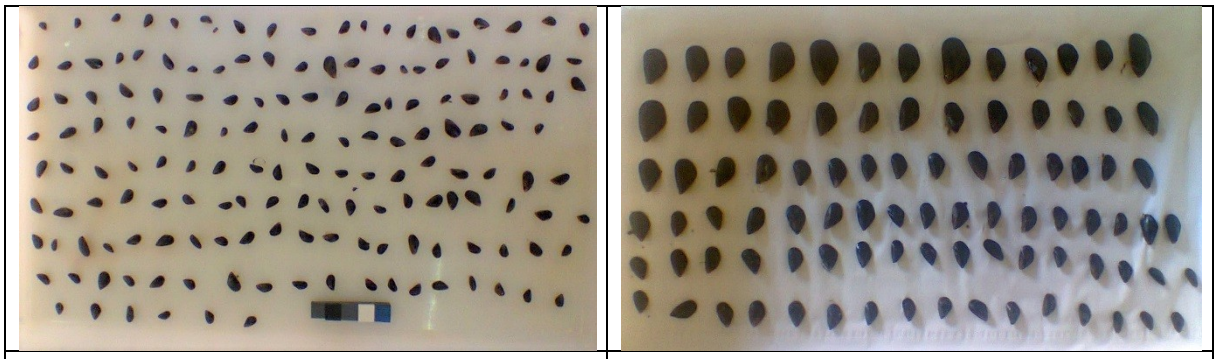
The data collected from sensors will also be related to data from sampling carried out on regular visits to the pilot site to maintain the sensors, including CTD profiles and water samples for laboratory analysis of nutrients, chlorophyll and other pigments, TSM (total suspended matter) and TOM (total organic matter). Samples are also collected for the identification of the microplankton community by microscopy and/or HPLC (high pressure

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

liquid chromatography.

Animal variables

Besides the data listed in Table 3.7, spat from the Mediterranean mussel *M. galloprovincialis* have been collected locally from the Sagres coast during June 2018 and deployed on a Finisterra longline (Fig. 10) in order to relate growth to the environmental data collected from June to date. This *in situ* data will be used to support modelling activities in the GAIN project. With the deployment of new instruments in March 2019, a mussel growth and mortality experiment of a single cohort will be reinitiated to accompany the more detailed *in situ* data that should become available.



13-07-2018	20-11-2018

Figure 10 Samples of mussels from the growth experiment Finisterra longline

Reporting

SGM is responsible for ensuring that all the instruments are calibrated and are working correctly. The company is also responsible for ensuring that all the data collected at the site is delivered to the Consortium and, in particular, to partners involved in Tasks 1.4 and 1.5.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.2 Sea-cages pilot sites

In order to cover both Atlantic and Mediterranean aquaculture, GAIN will investigate four sea-cages pilot sites, i.e. three Atlantic salmon farms and a Mediterranean seabass farm. The salmon farms are located in Norway, Scotland (UK) and Canada, thanks to the cooperation of Dalhousie University as non-European partners. These three sites presents different bathymetry and environmental conditions, as well as different current management practices, thus giving the possibility of testing the robustness of GAIN innovative tools. The seabass farm is located in Southern Spain: its management is keen of implementing PFF framework and fully cooperated to the instrumentation of the farm.

3.2.1 Site 4. – Rossøya Nord– Norway

Author: Giulia Micallef

Rossøya Nord farming site (67 4.380, 13 56.855) is one of the five commercial farming sites owned by GIFAS in Gildeskål municipality. The site has a mooring system with placements for 16 cages, (Figure 11,circumference 90 m; depth 27 m). The figure is oriented such that the top is the North. The arrow indicates the main water current at this site. The site is semi-exposed, with the southern cages partially sheltered by the island of Rossøya, while the northern cages are comparatively more exposed to wind and waves. The white cages are currently not in use, whereas the coloured cages contain approximately 150.000 fish in each. Yellow cages contain fish from SaltenSmolt AS, whereas green cages contain fish from Sundsfjord Smolt AS.

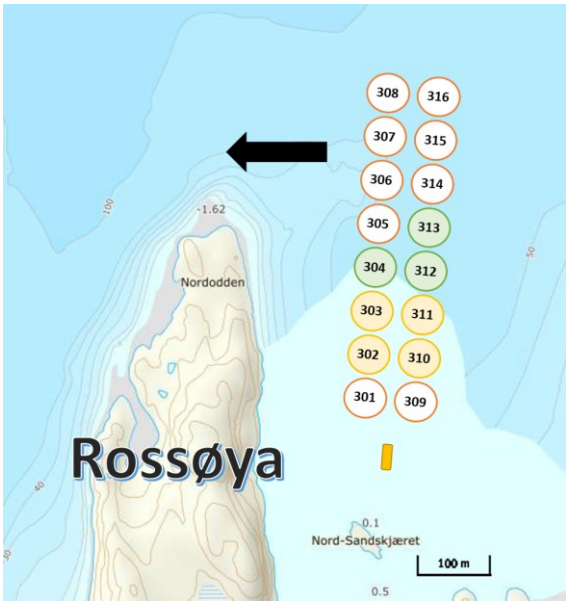


Figure 11. Rossoya Salmon Farming SITE.

All cages at Rossøya are equipped with a CFC (closed fish cage) system. CFC is a semi-closed cage system developed in-house at GIFAS to prevent sea lice infections in commercial cages. Briefly, CFC systems consist of 15 m long lice skirt and a propeller (2,5 m diameter), positioned just below the lice skirt. The length of the lice skirt may be adjusted with a winch. Both the winch and the propeller speed may be connected to an oxygen sensor and

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

programming logic controller (PLC). Hence, hypoxic conditions can be avoided by setting lower limit oxygen concentration thresholds.

The fish cohort which will be monitored in GAIN, 18G autumn salmon, was distributed into the four cages, i.e. 302, 303, 311, 312 in Fig. 3.10 in mid August 2018. The fish were delivered to the site Rossøya Nord as smolts by SaltenSmolt AS. All the fish used in this trial share the same genetic background. Table 3.8 shows a full description of the smolts used. Cage 303 will be equipped with instrumentation to measure environmental parameters, fish growth and behaviour: these data will be processed in Task 1.4. Cage 310 will have all the same conditions present in Cage 303 (CFC, approx. 150 000 fish), but not the same instrumentation. Welfare assessment and slaughter data from cage 310 will be used for comparative studies, if necessary.

Table 3.8 - Description of Rossøya site and of the smolt group to be monitored in GAIN.

Site	**Rossøya Nord**
Location	67 4.380, 13 56.855
Species	*Salmo salar* - Atlantic salmon
Culture system	Fish cages
Cage size	Circumference: 90 m; Depth: 27 m
Number of cages	16
Smolt Producer	Salten Smolt AS
Breed	Salmobreed
Smolt type, generation	First year, 18G
Delivery date	10.08.2018 (302, 303) 11.08.2018 (310, 311)
Average weight (on delivery)	61g
Number x cage	150.314 (302) 153.691 (303) 152.000 (310) 153.376 (311)
Cages monitored in GAIN	303310
Hatching date	20.11.2017
Start feeding (date / degree days / average weight)	15.01.2018 / 450 / 0,18 g
Vaccination (date / degree days / average weight)	19.07.2018 / 2759 / 39 g
Vaccine	AlphaJect Micro 6
Seawater acclimatisation (10ppt) (date / degree days / average weight)	02.08.2018 / 2954 / 50 g
Feed up to delivery	NutraOlympic 3, 3.0mm

Feeding practices

All cages are fed on a standard commercial diet (Salten X, Biomar). Feed is distributed to the fish cages from the hulls on the barge via an air-blowing system. Feeding is controlled by AkvaConnect software (AkvaGroup AS). Feeding starts at pre-determined times according to day length, most often with a meal duration of 2-3 hours. Feeding intensity is adjusted by

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

the staff members according to observed feeding behaviour from the camera and/or surface activity. For example, should the fish exhibit poor feeding activity, the feeding intensity will be decreased or stopped in the affected cages. Adjustments in the feeding intensity will be done daily according to requirement. The number of meals per day is also dependent on the day length. As soon as there is enough light, the first meal will be started (lasting 2-3 hours according to appetite), earliest at 06:00. Once the first meal is terminated, a new meal will be started after a pause of 4 hours on the condition that there is still enough daylight. A maximum of 3 meals will be administered per day. Daily feed amounts (kg) for each of the cages will be recorded and sent to the GAIN partners on a monthly basis.

Instrumentation and Data Collection

Cage 303 has been instrumented to observe environmental and animal variables, i.e. variables concerning fish behaviour, growth and welfare. These data will be used in Task 1.4 and Task 1.5 for the development of the GAIN Information Management System. The observation capacity is summarized in Table 3.9.

Table 3.9 - Environmental and animal variables measured "in situ" at Rossoya pilot site.

Environmental variables	System and frequency	Animal variables	System and frequency
Water temperature, 5m	Aanderaa 1/10 minute	Fish weight distribution, biomass, fish activity	ABM > 1/minute
Salinity, 5m	Aanderaa, 1/10 minute	Lice counting	1/week
Dissolved Oxygen, 5m and 17m	Aanderaa 1/10 minute	Welfare indicators (see list in text)	1/month
		Mortality	1/month
		Veterinary Report	6/year

Environmental variables

Environmental monitoring will be achieved using an Aanderaa system (Xylem Analytics, Norway). The system consists of a Smartguard datalogger, a salinity/temperature sensor, 4 oxygen/temperature sensors and a wind gauge. The datalogger may be equipped with either an SD card that stores average measurements over 10 minute intervals. The oxygen sensors will be distributed sensibly in the cage, for example one within the lice skirt (5 m) and one beneath the lice skirt (17 m). The feeding barge (AM 320 Comfort, AkvaGroup AS, Norway) has a temperature and current sensor at 5 m depth. A daily reading from these sensors will be recorded manually. These readings and the data saved on the SD card from the Aanderaa system will be sent to GAIN partners each month.

Animal variables

Total biomass, biomass distribution with depth, fish weight distribution and fish activity will be assessed using the Aquaculture Biomass Monitor (ABM) (Biometrics AS, Norway). ABM is a sonar mounted on a buoy and it can detect over 50.000 fish per day, enabling robust

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

assessment of the above variables. It can also monitor fish speeds and give out alarms if it detects sudden drop in signals or changes in behaviour. Observations from the ABM will be used to control feeding, assisted with occasional use of ROV footage. **Lice counting** will be carried out once a week or every second week, when the seawater temperature is below 4°C. Ten fish per cage will be collected, lightly sedated with benzocaine (Benzoak Vet, ACD Pharmaceuticals, Norway) and the lice will be counted in the following classes: Chalimus (stationary), Pre-Adult (mobile), Adult Female and *Caligus elongatus*, according to regulations set by the Food Safety Authorities. Lice counting will be recorded and sent to the GAIN partners each month. Once a month, in conjunction with lice counting, **welfare assessment** of the fish will be carried out. The welfare assessment will involve scoring of the following features:

- Condition factor
- Spinal deformities
- Maturation
- Fin damage
- Scale loss
- Eye damage
- Gill condition
- Operculum damage
- Snout damage
- Overbite and underbite deformities

Mortality. The dead fish haul will be pulled up daily, during the feeding break or once feeding is terminated. Should there be excessive uneaten pellets in the dead fish net, this will be noted and the feeding duration and intensity will be adjusted accordingly. The number of dead salmon will be recorded and mortality data will be sent to the GAIN partners each month.

Reporting

GIFAS is responsible to ensure that all the instruments are in the right working condition and that the data is transferred to the GAIN hub and ready to be processed. The ABM (sonar system), and SmartGuard (logger for the environmental sensors) will all be connected to the Internet via a 4G modem and will regularly transmit data to a storage Cloud. Footage collected by Trident OpenROV (OpenROV, California, USA), will be made available through an Android device via a Wi-Fi connection. Partners involved in Task 1.4 and Task 1.5 will be provided with the necessary passwords such that they can access and download the data at their own convenience. Feeding data (kg of feed per cage), daily readings from the barge sensors, mortalities, lice counting, welfare assessment and a diary of events concerning the trial cages (e.g. delousing, fish grading, net cleaning, etc) will be collected in a monthly report. The monthly report will be sent to the coordinator and partners involved in Task 1.4-Task 1.5 within a week from the end of each month.

The trial will end when the fish are slaughtered (est. January 2020) and an end report will be produced, for use in the preparation of publications and for progress reporting to the EU. GIFAS is legally obliged to provide a summary of project findings to the Norwegian Directorate of Fisheries, as part of the terms and conditions for R&D concessions.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.2.2 Site 5. Carness Bay Orkney- Scotland (UK)

Author: Sonia Rey Planellas

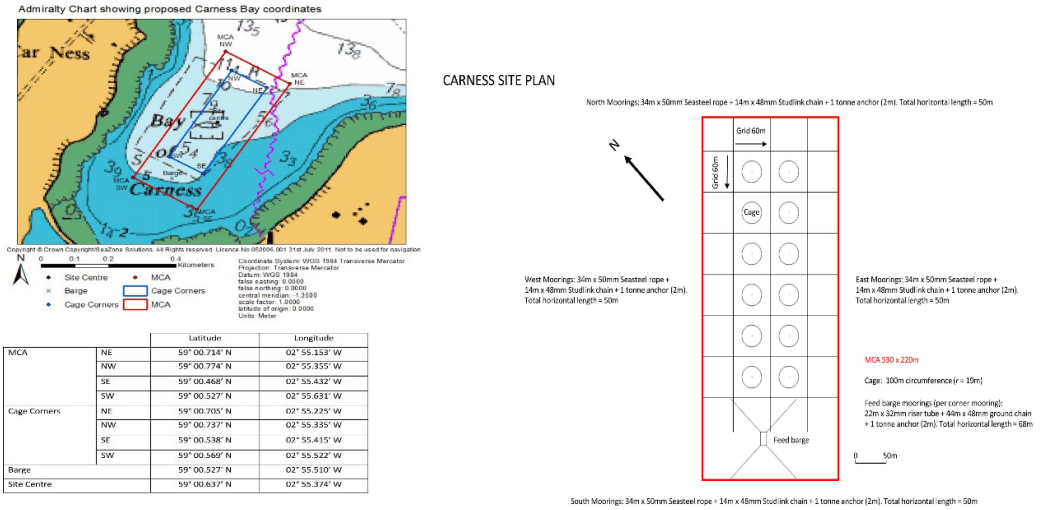
The Salmon sea farm where the study is going to be undertaken is Carness Bay and it is located in Orkney (Scotland, UK) and owned by Cooke aquaculture, a committed end-user of GAIN, which is also collaborating with Dalhousie University (see site 6 description). Table 3.10 provides a summary description of the site and the salmon cohort which will be monitored in GAIN. -This barge feed site includes a total of 12x100m circumference cages. Total number of fish stocked at the end of January 2019 was about 230.000, with a stocking density of 10.5 kg/m^3.

Fish are 18S1 smolts, which were moved from Meilbay to Carness Bay on the 27/01/2019. This stock is expected to be harvested by the end of September 2019. Each cage will have around 20.000 salmon. The site plan and cage positions are shown in Fig. 12. All cages are equipped with underwater cameras and fish is constantly visually monitored for feeding behaviour. AQVA Fishtalk is used for archiving environmental data, namely water Temperature, dissolved oxygen and Salinity as well as data concerning feed used per cage and mortality.

Table 3.10 - Description of Carness Bay site and of the smolt group to be monitored in GAIN.

Site	**Carness Bay**
Location	Geographical coordinates
Species	*Salmo salar* - Atlantic salmon
Culture system	Fish cages
Cage size	Circumference: 100 m; Depth: 6 m
Number of cages	12
Smolt Producer	CAS Loch Shin, CAS Haweswater
Breed	Aquagen, Mowi, Stofenfiskar
Smolt type, generation	S1 2018
Delivery date	24.02.2018 onwards
Average weight (on delivery)	100g – 2500g when moved to Carness Bay
Number x cage	20,000
Hatching date	2016
Start feeding (date / degree days)	1st Feb 2017, 464 degree days
Vaccination (date / degree days / weight)	21-27th November 2017, 4050 degree days, 40 g
Vaccine	AQUAVAC® PD7 Alphaject Micro 6 and Alphaject PD
Feed up to delivery	Ewos

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330



		Latitude	Longitude
MCA	NE	59° 00.714' N	02° 55.153' W
	NW	59° 00.774' N	02° 55.355' W
	SE	59° 00.468' N	02° 55.432' W
	SW	59° 00.527' N	02° 55.631' W
Cage Corners	NE	59° 00.705' N	02° 55.225' W
	NW	59° 00.737' N	02° 55.335' W
	SE	59° 00.538' N	02° 55.415' W
	SW	59° 00.569' N	02° 55.522' W
Barge		59° 00.527' N	02° 55.510' W
Site Centre		59° 00.637' N	02° 55.374' W

Figure 12. Carness Bay site plan and location. Cage 8 will be fully instrumented with environmental sensors and a sonar system.

All the cages are fed on a standard commercial diet (Biomar, power extreme). Feed will be distributed to the fish cage from the hulls on the barge via an air-blowing system. Feeding is controlled by AkvaConnect software (AkvaGroup AS). Feeding starts at pre-determined times according to day length, most often with a meal duration of 30-60 minutes. The stock is monitored by camera and feeding intensity is adjusted accordingly. For example, should the fish exhibit poor feeding activity, the feeding intensity will be decreased or stopped in the affected cages. Adjustments in the feeding intensity will be done daily according to requirement. The number of meals per day is also dependent on the day length. As soon as there is enough light, the first meal will be started (lasting 30min according to appetite), earliest at 06:00. Once the first meal is terminated, a new meal will be started after a pause of 4-6 hours on the condition that there is still enough daylight. A maximum of 2 meals will be administered per day. Daily feed amounts (kg) for each of the cages will be recorded and sent to the GAIN partners on a monthly basis and uploaded in a common BOX account for the project.

Instrumentation and Data Collection

Cage 8 will be instrumented to collect both environmental and animal variables i.e. variables concerning fish behaviour, growth and welfare data to be used in Task 1.4 and Task 1.5 for the development of the GAIN Information Management System. The observation capacity is summarized in Table 3.11.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.11. - Environmental and animal variables measured "in situ" at Carness Bay pilot site.

Environmental variables	**System and frequency**	**Animal variables**	**System and frequency**
Water temperature	PolarisPortable 1/hour	Relative biomass density	CageEye > 1/minute
Dissolved Oxygen	PolarisPortable 1/hour	Fish activity during feeding	Video camera > 1/minute
Turbidity	1/day	Gill Health	1/week
Salinity	1/day	Lice counting	1/week
		Welfare indicators (see list in text)	1/month
		Mortality	1/week

Environmental variables

Water Temperature, Dissolved Oxygen, turbidity and salinity are measured for each cage daily by the site management staff.

Cage 8 will be equipped for a year (12 months) with two underwater wireless sensors for DO and Temperature: one near the surface (1m depth) and one near the bottom (5m depth) (Oxyguard Handy PolarisPortable DO meter: http://www.oxyguard.dk/wp-content/uploads/2014/08/H01P-handy-Polaris-2-brochure-GB-2014-04.pdf). The sensors will record temperature and DO every hour. Polaris 2 has a memory that can contain 3000 complete sets of data - each with values of mg/l (ppm), % saturation, temperature, time and date. Values can be stored either automatically at pre-set time intervals, or manually. Stored values can be transferred to a PC using the Polaris Link, which connects to the PC via a USB cable. To fit the objectives of the project, environmental data will be uploaded daily by using the link for transfer of data to a PC (H10LINK: OxyGuard Polaris Link) and send to the cloud each week for data analysis.

Animal variables

All cages are equipped with underwater cameras and fish is constantly visually monitored for feeding behaviour). The **relative biomass distribution** within Cage 8 will be assessed using the beam sonar system CageEye This system is made up of an echosounder and two transducers. The transducers are placed in the cage, see Fig. 3.12, and connected to the echosounder cabinet, which is placed on the net ring and sends the data wireless to the base station. The two transducers will be placed as deep as possible, looking up at the whole (or big part of the) biomass of the cage, one in each side of the cage. The transducers have two angles that they switch between, about ~14 degrees (200kHz) and ~42 (50kHz) degrees: this allows one to get echogram recordings of both.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

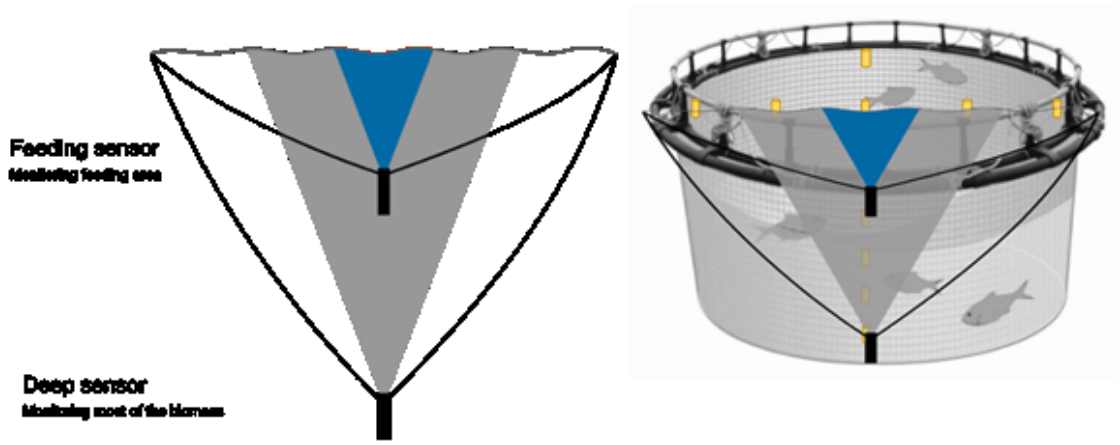


Figure 13. Positioning of transducers in a fish cage.

The image obtained by the transducers goes is sent in real-time to a dash board (see Figure 14), providing a 2D distribution of the biomass density within the cage.

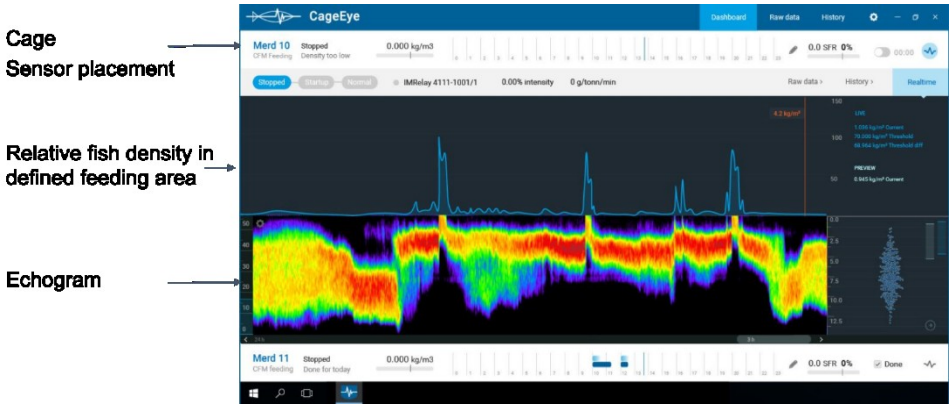


Figure 14. Dashboard obtained by the CageEye software system

Salmon **sea lice counting** will be carried out once a week. A total of 120 fish will be collected (10 x fish per cage) lightly sedated with Tricaine (from Pharmaq) and the lice will be counted in the following classes: Chalimus (stationary), Pre-Adult (mobile), Adult Female and *Caligus elongatus*, according to Marine Scotland regulations. Lice counting will be recorded and made available to the GAIN Consortium every month. Once a month, in conjunction with lice counting, **welfare assessment** of the fish will be carried out. The welfare assessment will involve scoring of the following features:

- Condition factor
- Spinal deformities
- Maturation
- Fin damage
- Scale loss
- Eye damage
- Gill condition

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

- Operculum damage
- Snout damage
- Overbite and under bite deformities

All cages will be sampled and data will be provided on individual cage basis and site average data. Indicators will be assessed in accordance with a scoring harmonized across the three GAIN salmon sites: the results will be made available to the Consortium within a week from the end of each month for further analysis. Occasional health assessments will be performed by the farm based on the health status of the fish. Data obtained on this assessment will be available for the project and send to the project partners each month for further analysis. A confidentiality agreement may be required pertaining to the sharing of information.

Mortality.

The dead baskets will be pulled up twice per week, and mortality also removed by divers once per week, in the feeding break or once feeding is terminated. Dead salmon will be recorded separately, and the salmon mortality values will be sent to the project owners each month. No other fish species (e.g. cleaner fish) are used on site.

Reporting

UoS GAIN team and Cooke Aquaculture Scotland are responsible to ensure that all the instruments are in the right working condition and that the data are made available to the GAIN Consortium. The CageEye (sonar system) will be connected to the Internet via a 4G modem and together with the OxyGuard Polaris meter (logger for the environmental sensors) will regularly transmit data to a storage Cloud. The project partners involved in data processing will be provided with the necessary passwords such that they can access and download the data at their own convenience.

Feeding data (kg of feed per cage), daily readings from the barge sensors, mortalities, lice counting, welfare assessment and a diary of events concerning the trial cages (e.g. delousing, fish grading, net cleaning, etc) will be collected in a monthly report. Standard Operational Procedures (SOPs) can be provided for all general activities that take place at the site. All non-routine activities will be noted in the site diary and written up as part of a monthly report. The monthly report will be sent to the project coordinator within a week from the end of each month.

The first trial will end when the fish are slaughtered (est. September 2019) and an end report will be produced by the concerned GAIN project partners, for use in the preparation of publications and for progress reporting to the EU. Next batch of animals will be placed two months later and monitored until the end of the CAgeEye lease period (12 months).

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.2.3 Site 6. McNutt's Island Shelburne - Nova Scotia, Canada

Authors: John Grant, Meredith Burke, Caitlin Stockwell

This pilot site, see Fig. 15, is located off McNutt's Island, near Shelburne in Southern Nova Scotia, Canada. This Atlantic salmon farm, see Fig. 16, is part of the Cooke Aquaculture Group, a committed end-user of the GAIN project. The main features of the site and of the smolt which will be monitored in GAIN are summarized in Table 3.12.

Table 3.12 - Description of McNutt's Island site and of smolt group to be monitored in GAIN.

Site	**McNutts Island**
Location	43.71889N, -65.2834W
Species	*Salmo salar* - Atlantic salmon
Culture system	Fish cages
Cage size	Circumference: 100 m; Depth: 12 m
Number of cages	19
Smolt Delivery date	Spring 2019
Average weight (on delivery)	50-60g
Number x cage	25 000

McNutts has 19 sea cages (100 m circumference with 12 m depth) stocked with *Salmo salar*. Figure 15 shows a site map of McNutts with open ocean located in the east corner. Waves and tides arrive from the southeast and move into the bay. McNutts island is located on the southwest side of the site. All 19 cages contain about 25 000 salmon. All cages are feed using an automated feeding system operated from on-land location with 2-3 cages being feed at once, and all cages feed twice daily.

Instrumentation and Data Collection

All 19 sea cages will be equipped instrumented as shown in Figure 15, in order to collect data concerning both environmental and animal variables. The observation capacity is summarized in Table 3.13.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.13 - Environmental and animal variables measured "in situ" at McNutt's Island pilot site.

Environmental variables	System and frequency	Animal variables	System and frequency
Water temperature	Real Time Aquaculture 1/ 3 minute	Relative biomass density	CageEye 1/second
Dissolved Oxygen	Real Time Aquaculture 1/ 3 minute	Biomass Average weight Mortality	Estimated using FishTalk 1/week
		Lice counting	1/month
		Welfare indicators	1/month
		Location	1/ 3 seconds

Environmental variables

Two dissolved oxygen and temperature sensors (Real-Time Aquaculture, InnovaSea Systems Inc., Canada) are placed in Cages 1-5, and 7-18 at 2m and 8m, in the centre of the cages. Cages 6 and 19 contained 9 sensors: 4 at 2m, and 4 at 8m (North, South, East, West configuration), and 1 at 5m, in the centre. The four corners of the site were also equipped with 2 sensors each, at 2m and 8m, as reference.

Animal variables

The **relative biomass distribution** within two cages will be assessed using the beam sonar system CageEye (CageEye AS, Norway): see the description of site 5 for details. CageEye operates in real-time with constant data collection of fish density in selected cages. CageEye is mounted on the side of the cages, with 3 transducers (hydroacoustic cameras) within the two cages allowing for high spatial resolution. All data is collected and stored within a computer on the barge, data is projected on the computer in a density heat map.

In one cage, 15 salmon specimens will be implanted with acoustic tags (Vemco, InnovaSea Systems Inc., Canada). **Location** within a cage is recorded every 3 seconds for about 5 months. A (x, y, z) coordinate will be provided allowing for an exact location within cage to be obtained as well as other factors such as speed and swim patterns determined from coordinates.

FishTalk database software provides information on **biomass**, **mortality**, **average weight, lice count**, and **feed amount** (Cooke Aquaculture, Canada). Mortality is calculated once a week in which divers haul dead fish to the surface and counts occur in every cage. Every week, average weight and length will also be recorded for each cage. FishTalk stores all information and provides weekly reports. Lice counts are recorded about once a month (process for counts are unknown). Total feed days per week, and amount of week per day are recorded within FishTalk.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 15. The location of Cooke Aquaculture's Atlantic Salmon farm (McNutt's Island), near Shelburne in Southern Nova Scotia, Canada

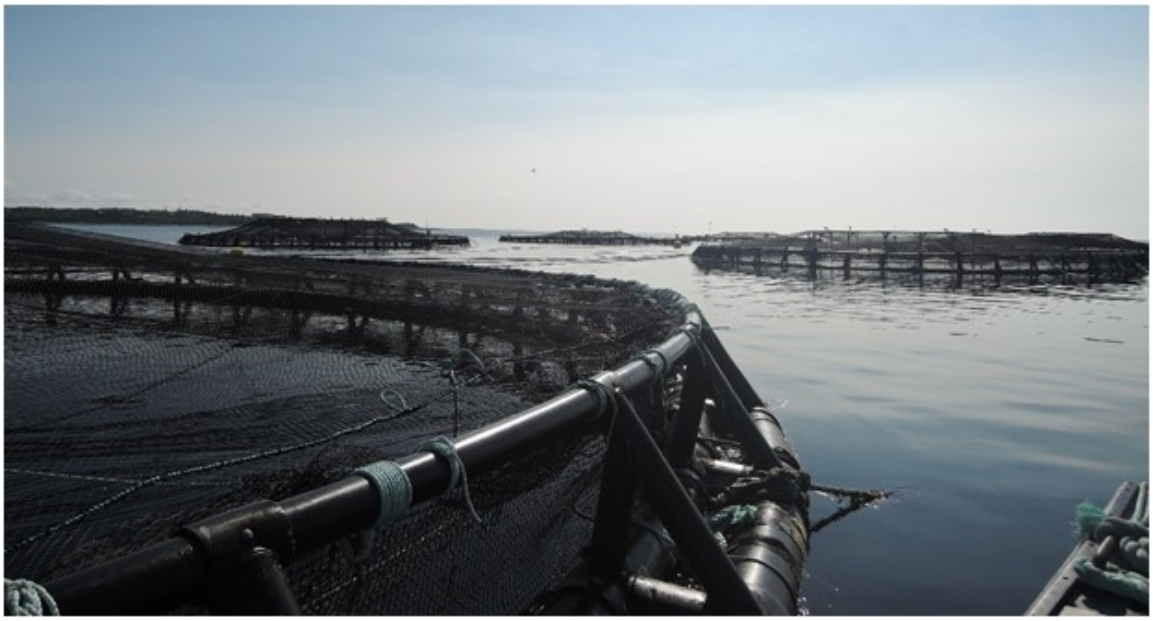


Figure 16. Salmon farm cages at McNutt's Island, Shelburne

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

RealTime Sensors					
Serial No.	Location	Serial No.	Location	Serial No.	Location
670216	CAGE-1-C-2M	670642	CAGE-8-C-8M	670508	CAGE-19-N-2M
670634	CAGE-1-C-8M	670603	CAGE-9-C-2M	670507	CAGE-19-E-2M
670583	CAGE-2-C-2M	670637	CAGE-9-C-8M	670505	CAGE-19-W-2M
670620	CAGE-2-C-8M	670218	CAGE-10-C-2M	670513	CAGE-19-S-2M
670544	CAGE-3-C-2M	670636	CAGE-10-C-8M	670511	CAGE-19-C-4M
670652	CAGE-3-C-8M	670562	CAGE-11-C-2M	670215	CAGE-19-N-8M
670579	CAGE-4-C-2M	670641	CAGE-11-C-8M	670509	CAGE-19-E-8M
670633	CAGE-4-C-8M	670584	CAGE-12-C-2M	670510	CAGE-19-W-8M
670600	CAGE-5-C-2M	670639	CAGE-12-C-8M	670512	CAGE-19-S-8M
670643	CAGE-5-C-8M	670580	CAGE-13-C-2M		
670517	CAGE-6-N-2M	670635	CAGE-13-C-8M		
670531	CAGE-6-W-2M	670078	CAGE-14-C-2M		
670506	CAGE-6-E-2M	670638	CAGE-14-C-8M		
670536	CAGE-6-S-2M	670590	CAGE-15-C-2M		
670515	CAGE-6-C-4M	670650	CAGE-15-C-8M	670645	CORNER-N-2M
670537	CAGE-6-N-8M	670300	CAGE-16-2M	670655	CORNER-N-8M
670542	CAGE-6-E-8M	670090	CAGE-16-5M	670646	CORNER-E-2M
670535	CAGE-6-W-8M	670301	CAGE-16-10M	670654	CORNER-E-8M
670543	CAGE-6-S-8M	670576	CAGE-17-C-2M	670653	CORNER-S-2M
670597	CAGE-7-2M	670651	CAGE-17-C-8M	670658	CORNER-S-8M
670644	CAGE-7-C-8M	670591	CAGE-18-C-2M	670657	CORNER-W-2M
670604	CAGE-8-C-2M	670648	CAGE-18-C-8M	670656	CORNER-W-8M

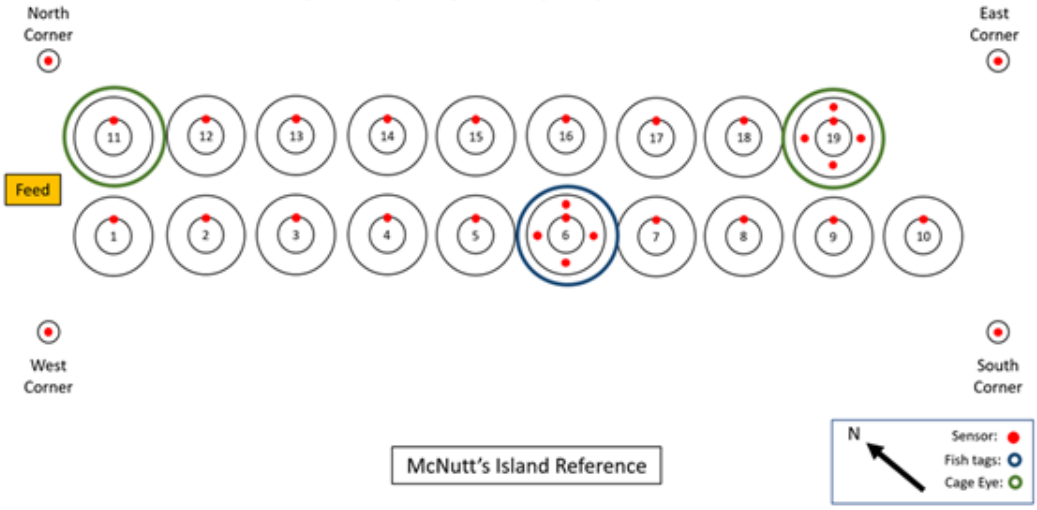


Figure 17. Overview of the instrumentation including: Real-Time Aquaculture dissolved oxygen and temperature sensors (60), Vemco acoustic telemetry fish tags (15), and CageEye (2).

Reporting

Dalhousie will provide partners with information on the use of technology in commercial farms and the data to be expected. The Dalhousie team coordinates all their activities with Cooke Aquaculture, since Cooke provides access to sites and logistics. In addition, the research is coordinated with Real Time Aquaculture, who is involved in instrument maintenance and troubleshooting, Vemco, who is involved in initial processing of fish tag data, and CageEye, coordination for experimental set up and troubleshooting of system. The interpretation of data is a joint effort and is ongoing at Dalhousie through graduate programmes in Oceanography. Initial results have been presented at several meetings including Aquaculture Canada and International Symposium on Aquatic Animal Health (ISAAH). A general new story on the technology at Cooke farms including using biosentinel mussel for HAB at Cooke farms can be found at:
https://www.cbc.ca/news/canada/nova-scotia/how-wired-mussels-are-predicting-toxic-algae-1.4896317

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.2.4 Site 7. El Gorguel, Cartagena – Spain

Authors: Mariló López Belluga

The pilot site is situated in Gorguel (Cartagena), in the South coast of Spain in Mediterranean Sea (Figure 18). In this off-shore site, Lebeche, GAIN partner part of the Culmarex grop, farms sea bass in cages. The fish in this trial were delivered to El Gorguel as juveniles (15-20 grams) by ABSA between February and July 2018. The main features of the site and of the fish stock to be monitored in GAIN are shown in Table 3.14.

Table 3.14 - Description of El Gorguel site and of the stock to be monitored in GAIN.

Site	**El Gorguel**
Location	37° 34' 03.211'' N 00° 52' 17.459 W
Species	*Dicentrarcus labrax* - European seabass
Culture system	Fish cages
Cage size	Circumference: 80 m; Depth: 15 m
Number of cages	32
Juvenile Producer	ABSA
Breed	CULMAREX GROUP FARMS, SEA CAGES
Juvenile type, generation	2018
Delivery date	Feb-July 2018
Average weight (on delivery)	15g – 20g
Number x cage	300,000
Hatching date	2016
Vaccination	Different protocols, from 60 days to 150 days from fingerlings delivery
Vaccine	*Aeromonas salmonicida+Photobacterium+Vibrio anguillarum*
Feed up to delivery	Sea bass commercial feed

Figure 18. Map showing the location of El Gorguel

All cages are equipped with Dyneema© or Nylon nets, covered with protection nets to avoid bird predation and equipped with feed spreaders (Figure 19). Feeding is controlled by

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

AkvaConnect software. The software provides as output the feeding speed, using as input water temperature, biomass per cage, fish average weight and behaviour.

Figure 19. Seabass cages covered with nets in the site El Gorguel

Instrumentation and Data Collection

Six out of thirty-two cages were instrumented to collect both environmental and animal variables, i.e. variables concerning fish behaviour, growth and welfare data to be used in Task 1.4 and Task 1.5 for the development of the GAIN Information Management System. The observation capacity is summarized in Table 3.15.

Table 3.15 - Environmental and animal variables measured "in situ" at El Gorguel pilot site.

Environmental variables	**System and frequency**	**Animal variables**	**System and frequency**
Water temperature	Real Time Aquaculture 1/5 minutes	Biomass	Fish counting. Once, during the on-growing phase.
Dissolved Oxygen	Real Time Aquaculture 1/5 minutes	Fish weight distribution	100 specimen are sampled and weighted . 2/year
Chlorophyll a	1/5 minutes	Feeding behaviour	Visually 1/day
		Parasyte counting	Fish are checked for parasite in case an increase in mortality is observed.
		Welfare indicators	Visually, daily
		Mortality	Fish counting

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

			1/day

Environmental variables

In August 2018, six selected cages out of thirty-two were equipped with sensors that measure water temperature and dissolved oxygen in real time. The installment of Chlorophyll a sensors is foreseen in the Spring 2019. The sensors were placed in the middle of each cage, hung 5 or 12 meters from the center of the cage.

The other cages are used as a control and only contain standard equipment (without sensors). Data are processed and visualized using a software, provided by RTA. It also measures other parameters such as tilt and battery voltage of the sensors. Sensors transmit the data every 5 minutes to a base-station via WiFi or 4G (Figure 20), which are plotted and made available through a website or app.

Animal variables

Fish response, in terms of feeding behavior and welfare indicators, is monitored by operators, by means of visual observation. Fish weight distribution is estimated from samples, 2-3 times during the on-growing phase. Biomass per cage is estimated on the basis of fish counting at stocking, mortality and fish weight distribution.

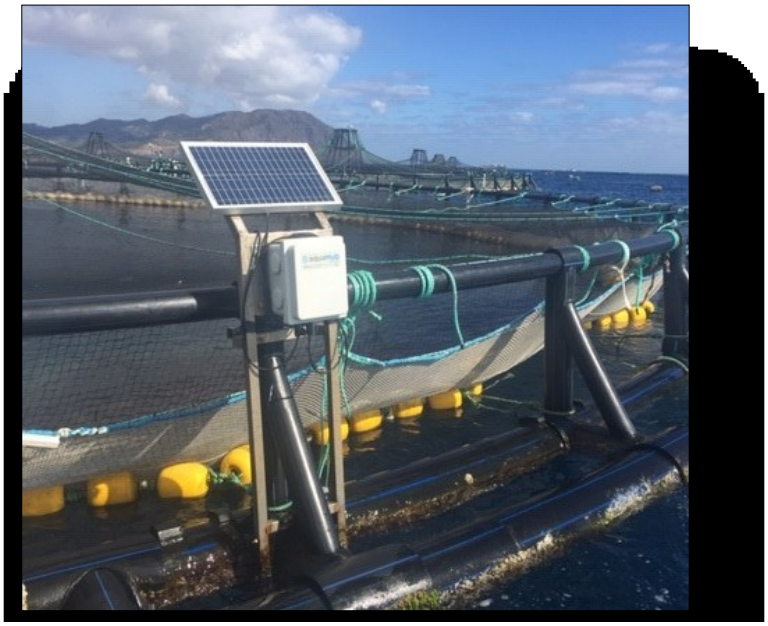


Figure 20. Base station of AquaHub system installed on one of the cages

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Reporting

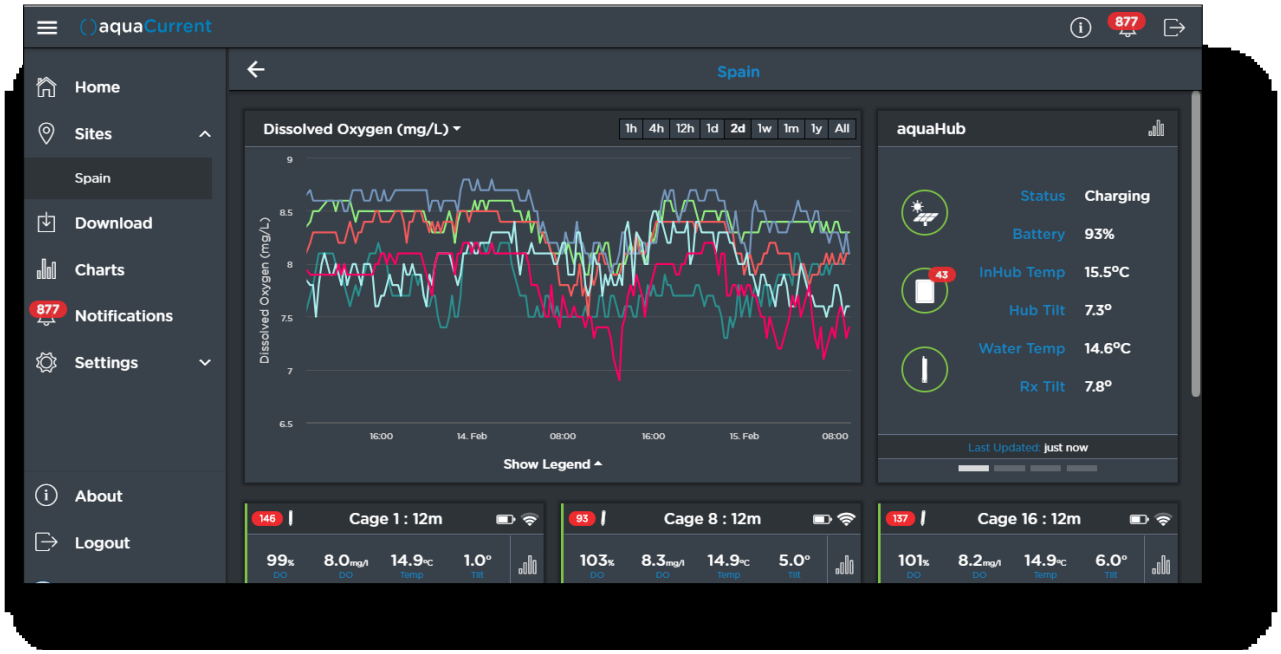


Figure 21. Screenshot of the dashboard and graphics displaying the time series of environmental data

Environmental data are uploaded on a website: an app allows users to plot the time series of each variable for different time windows, e.g. days, weeks, months: an example is shown in Figure 21. The app also allows operators to get by email alarm messages, concerning system failures and critical values of temperature/dissolved oxygen. Project partners are provided with passwords allowing them to access and download data. Oxygen, temperature, tilt and chlorophyll are collected in a weekly report. The report is sent to the project leader and partners by email.

The data collected at this pilot site will allow farmers to take decisions on:

- Net changes: a low level of oxygen in a given cage indicates that is necessary to change the net. This happens because of fouling, e.g. seaweed, mussels covering the mesh of the net, thus decreasing water renewal which, in turn causes a decrease in oxygen levels.
- Feeding: with very low level of oxygen, feeding is not recommended, as it may increase mortality or poor response to feeding: feed losses represent lead to both economic losses and higher environmental impact on the seabed.
- Animal health and welfare: the environmental variables can affect fish health and welfare. For example, low level of oxygen could produce hypoxia or high level of plankton could produce gill infection.

At present, real time data collected by DO and temperature sensors are used to make decisions regarding net operations. In GAIN, the goal is to use them for improving the feeding strategy and prevent some health problems.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.3 Land based systems

Three different land-based systems are investigated, in order to cover RAS, raceway, and pond culture. The first pilot case presented in this subsection is a raceway rainbow trout farm located in Northern Italy. The second, located in Poland, combines RAS, with hydroponic unit, and semi-intensive pond culture for reducing the time to market of common carp. The third presents a very interesting co-culture rice-shrimp system in China.

3.3.1 Site 8. Preore– Italy

Authors: Roberto Pastres, Filippo Faccenda, Andrea Alberto Forchino, Fernando Lunelli

This pilot site is located in the municipality of Preore, in Northern Italy, near the city of Trento. (Figure 22). In this area, the farming of rainbow trout (*Oncorhynchus mykiss*) is a well-established, traditional activity. The site is owned by "Troticultura Fratelli Leonardi" a GAIN committed end user. The company produces its own fingerlings, which are subsequently transferred to 6 100 m long and 7 m wide raceway basins (Figure 23). The main feature of the site are summarized in Table 3.16.

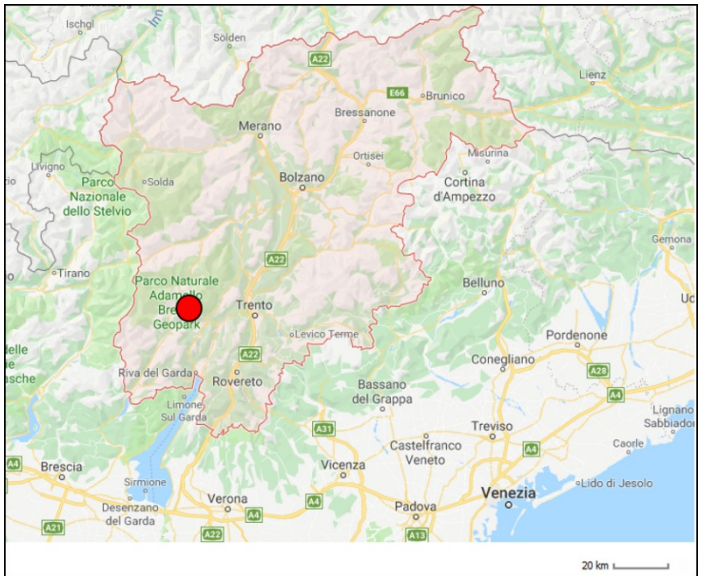


Figure 22. Location of the pilot site of Preore.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

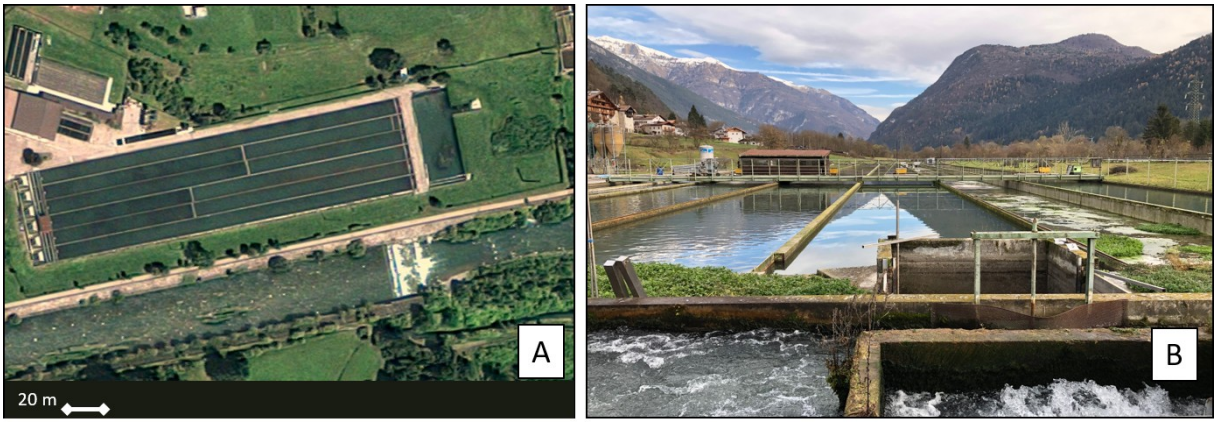


Figure 23. Arial (A) and side (B) view of the rainbow trout farm in Preore.

Table 3.16 - Description of Preore site

Site	**Preore**
Location	*46° 02' 41.04'' N, 10° 45' 31.19''E*
Species	*Oncorhynchus mykiss – Rainbow trout*
Culture system	Raceways
Raceways size	Length: 100 m; width: 7 m
Number of raceways	6

Instrumentation and Data Collection

Environmental variables

The farm, which is a committed GAIN end-user, is already equipped with sensors for real time monitoring of water temperature and dissolved oxygen. These parameters are measured in the input water and in the middle of each basins. Data are processed and visualized using a dedicated proprietary software: at present, operators decide when to activate the oxygen supply on the basis of this information. Other chemical parameters are monitored at the inlet and outlet once a year. A set of chemical parameters which could be potentially affected by fish metabolism were monitored by FEM in October 2018. The comparison between values detected at the farm inlet and outlet led to identify the following set of water quality variables:

- Temperature
- Dissolved oxygen
- ORP
- NH_4^+
- NO_3^-
- pH

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

- Conductivity

These variables will be measured at the water inlet and outlet, in order to: 1) quantify reduced nitrogen emissions and 2) correlate these emissions to fish metabolism. The sensors and automatic samplers for the detection of above variables will be installed in March 2019. Data will be collected with a daily frequency during 4 sampling periods of 1 month each (1 month per season).

Animal variables

Fish biomass will be determined on the basis of:

- 1. the number of stocked individuals
- 2. mortality
- 3. fish size distribution

Data concerning 1) and 2) will be provided by the company, starting from April 2019. Prior to that, the company will cover the basins with protection nets, in order to avoid bird predation: this will allow an accurate estimation of fish mortality. Fish size distribution will be sampled in real time by means of the Biomass Daily System, supplied by Pentair, installed by UNIVE. The core of the system is a frame (50 x 50 cm) containing LEDs that transmit infrared light rays both horizontal and vertical planes. These light rays are broken when the fish swims through the frame: data are processed by a specific software which estimate individual height and length: the weight is subsequently calculated through a regression. This consolidated technology have been thoroughly tested, with good results, on salmon cages, but its use in trout farming is not as widespread. These data will be complemented by periodic manual sampling of the above biometric parameters. The observation capacity is summarized in Table 3.17.

Table 3.17 - Environmental and animal variables measured "in situ" at Preore

Environmental variables	System and frequency	Animal variables	System and frequency
Temperature	Farm sensors 1/15 minutes	Fish size distribution	Biomass Daily System 1/day
Dissolved oxygen	Farm sensors 1/15 minute	Biomass	Biomass Daily System 1/day
NH_4^+	1/day	Mortality	1/day
NO_3^-	1/day		
ORP	1/day		
pH	1/day		
Conductivity	1/day		

Biomass Daily has been tested "*in situ*", in order to calibrate it and identify operational ranges of size and stocking density: see Figure 24.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 24. Biomass Daily System installation in one raceway of the Troticoltura F. lli Leonardi fish farm

The frame is connected to a sending box. The latter sends the information from the frame to a computer which is used as a control tool for the frame and to run the specific software for the data elaboration (Bio3000 frame management software) (Figure 25). Examples of outputs generated by the software are represented in Figure 26.

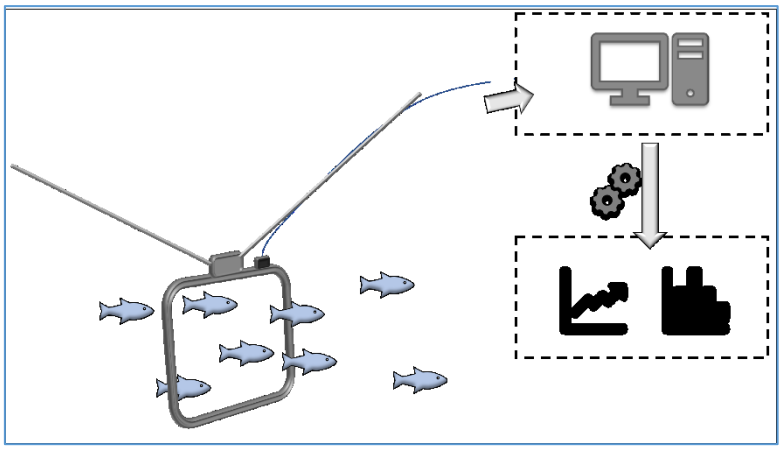


Figure 25. Biomass Daily System functioning

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

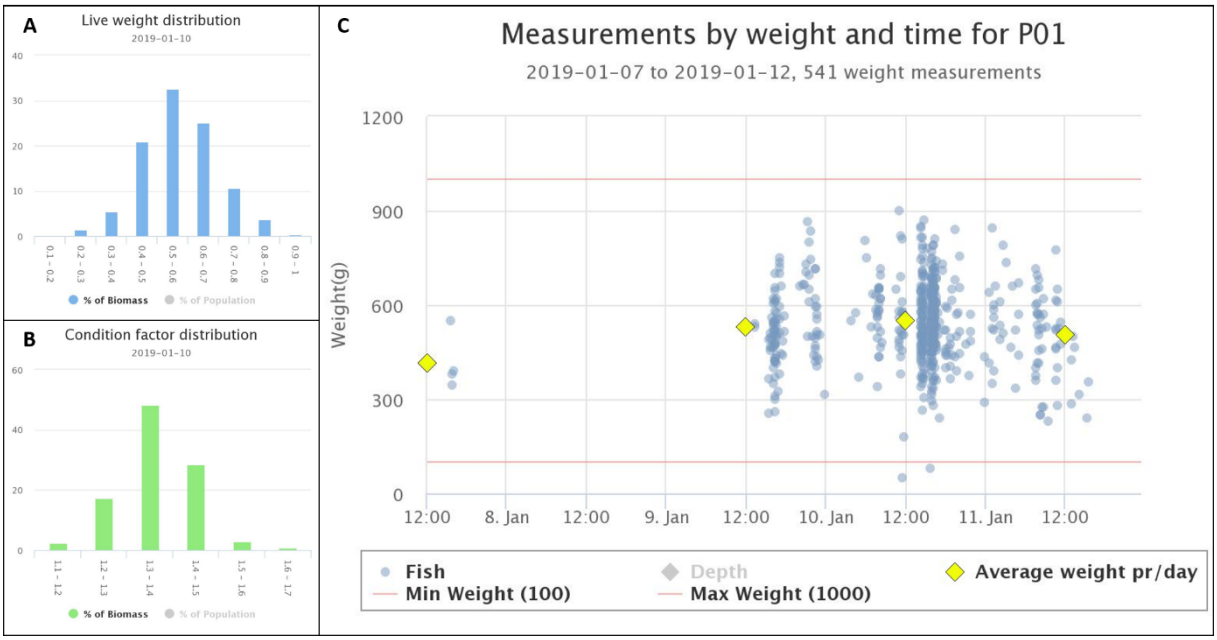


Figure 26. Example of outputs generated by the Bio3000 software. A) Live weight distribution; B) Condition factor distribution; C) Weight distribution vs time.

The whole system will become fully operational by April 2019, after the installation of the anti-bird predation cover. The comprehensive data set described above will be complemented with a set of data concerning feed composition and feeding time provided by the company.

Reporting

UNIVE is responsible for making the data collected available to the Consortium. Environmental and biomass data will be processed by a dynamic mechanistic model, including data assimilation algorithms, developed by UNIVE, which will be used for supporting operators in:

- optimizing oxygen supply
- estimating FCR and optimizing feed ration and feeding time, in relation to: water temperature, DO and fish biomass
- estimating farm emissions, in terms of Dissolved Inorganic Nitrogen

Data will also be used for correlating farmer observations about fish welfare to potential causes, e.g. high temperature, low DO, high ammonia concentration.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.3.2 Site 9 Nowe Czarnowo – Poland

Authors: Remigiusz Panicz, Jacek Sadowski

The pilot site is located in North Western Poland in the West Pomerania Province, approximately 35 km from Szczecin (Figure 27). The Fisheries Experimental Station (FES) in Nowe Czarnowo breeds and produces carp and other freshwater fish species. The main part of the facility consists of a triple tent with fully adjustable independent recirculating aquaculture systems (RAS), coupled with hydroponics units. Adjacent to the tent, 120 floating cages are submerged in the outlet channel of a power plant (Figure 27). The FES in Nowe Czarnowo also has a hatchery on site and a RAS for rearing fry, supplied by well water (Figure 27). Fish trials within GAIN will be performed in a RAS located in tents.

Figure 27 Location and key elements of the Fisheries Experimental Station in Nowe Czarnowo.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.18 - Description of Nowe Czarnowo pilot site and of fish coohort to be monitored in GAIN.

Site	**Nowe Czarnowo**
Location	53 12 35.5 N / 14 27 50.2 E
Species	*Cyprinus carpio*, common carp
Culture system	RAS coupled with hydroponic units
Tank volume	2.7 m^3
Number of tanks	8
Fingerling Producer	Maliniec pond farm
Breed	Maliniec line
Delivery date	September 2019
Average weight (on delivery)	35 g
Number x tank	100

The fingerlings for this trial will be produced in breeding ponds at Maliniec pond farm in April/May 2019. In late September 2019 carp fingerlings (approx. 35 g) will be transferred to the RAS at the FES where fish will be cultured up to 250 g and returned to Maliniec ponds in April/May 2020. Fish will be transferred to ponds, after tagging, until they reach market size, i.e. 1.2 kg: harvest is expected by the end of October 2020. All fish used in this trial share the same genetic background. Figure 28 shows the RAS designed for under-tent carp farming, which is made up of 8 rearing tanks 2.7 m^3, static mechanical filter with Kladnes media (2 m^3) and PolyGeyser® Bead Filter for biofiltration. Solid waste such as faeces, detritus and uneaten feed will be removed directly from mechanical filter through additional valve. Water circulation will be assured by Sparus™ Pump with Constant Flow Technology™ and aeration by Hiblow HP-200 air pump. The hydroponic unit, where watercress will be cultivated, includes 10 trays of 2.25 m^2 each, filled with vermiculite and perlite media. The total RAS volume will be 21.6 m^3 and the total surface of the hydroponic units 22.5 m^2: the system will become fully operational by September 2019.

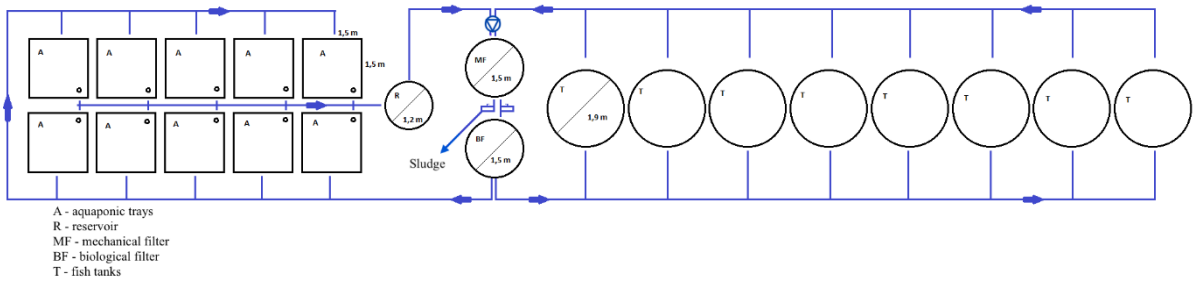


Figure 28 Carp aquaponic system consisting of a RAS directly connected to the hydroponic unit

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Instrumentation and Data Collection

The aquaponic system will been instrumented to observe environmental animal variables i.e. variables concerning fish behaviour, growth and welfare. These data will be used in Task 1.4 and Task 1.5 for the development of the GAIN Information Management System. The observation capacity is summarized in Table 3.19, which concerns the aquaponic system, and 3.20, which concerns the two grow out phases in pond.

Table 3.19 - Environmental and animal variables measured at Nowe Czarnowo site in the RAS.

Environmental variables	System and frequency	Animal variables	System and frequency
Water temperature	Pacific Oxyguard 1/ minute	Fish weight distribution and Total biomass per Tank	Weighting of all specimen in tanks. 1/week (above 18°C), every two weeks (14-18°C), monthly below 14°C
Dissolved Oxygen	Pacific Oxyguard 1/minute	Specific Growth Rate	Estimated from average fish weight 1/week (above 18°C), every two weeks (14-18°C), monthly below 14°C
pH	Pacific Oxyguard 1/minute	Fulton Condition Factor	Estimated from average fish weight 1/week (above 18°C), every two weeks (14-18°C), monthly below 14°C
$N\text{-}NH_4$	Spectrophotometry in lab. 1/week	FCR	Estimated from average fish weight 1/week (above 18°C), every two weeks (14-18°C), monthly below 14°C
$N\text{-}NO_3$	Spectrophotometry in lab. 1/week	Mortality	Daily

Environmental variables

Aquaponic system: concentration of O_2, level of pH and water temperature will be measured with Pacific OxyGuard every minute. Ammonium and nitrate concentrations in water samples will be measured weekly using standard methodologies.

Pond: concentration of DO, water temperature, and pH, will be measured with Pacific OxyGuard 3 times per day.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Animal variables

Aquaponic system: fish density, SGR, FCR and Fulton's condition factor will be assessed by weighting all fish in each tank. The sampling frequency will be related to water temperature, as detailed in Table 3.19. Mortality rate will be determined by direct fish counting.

Pond: fish density, SGR, FCR and Fulton's condition factor will be assessed from fish samples. The sampling frequency will be related to water temperature, as detailed in Table 3.20. Mortality rate will be determined by fish counting at harvest.

Table 3.20 - Environmental and animal variables measured at Maliniec carp farm.

Environmental variables	**System and frequency**	**Animal variables**	**System and frequency**
Water temperature	Oxyguard 3/day	Fish weight distribution and Total biomass in pond	Fish samples/once a month
Dissolved Oxygen	Oxyguard 3/day	Specific Growth Rate	Fish samples/once a month
pH	Oxyguard 3/day	Fulton Condition Factor	Fish samples/once a month
		FCR	Fish samples/once a month
		Mortality	Fish counting at harvest.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 29 Carp pond farm in Maliniec

Reporting

ZUT will ensure that all the instruments are maintained in working condition and that the data is easily available to the Consortium. ZUT will produce one report at the end of the RAS phase and a final one, after harvesting the carp.

.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.3.3 Site 10. Fenzhou Village – China

Author: Changbo Zhu

Fenzhou (113˚14’16’’E, 22˚19’9’’N) is a typical village located on the south-western plain of the Pearl River estuary, China, with more than 70% of the total village land area (530 Ha) covered by brackish water (salinity range: 1 - 5) ponds (Figure 29). Enclosed pond culture is the major shrimp farming method at present in China: this is the main economic activity in Fenzhou. Farmers pour fresh source water into the ponds at the beginning of the culture season, add a little water in the middle in case of evaporation and drain the ponds after shrimp harvest. Therefore, there is no water exchange between ponds and the environment during the whole cultivation period (3 to 6 months), which minimizes the risk of pathogen introduction from outside. The main features of the site and the farming practices are summarized in Table 3.21.

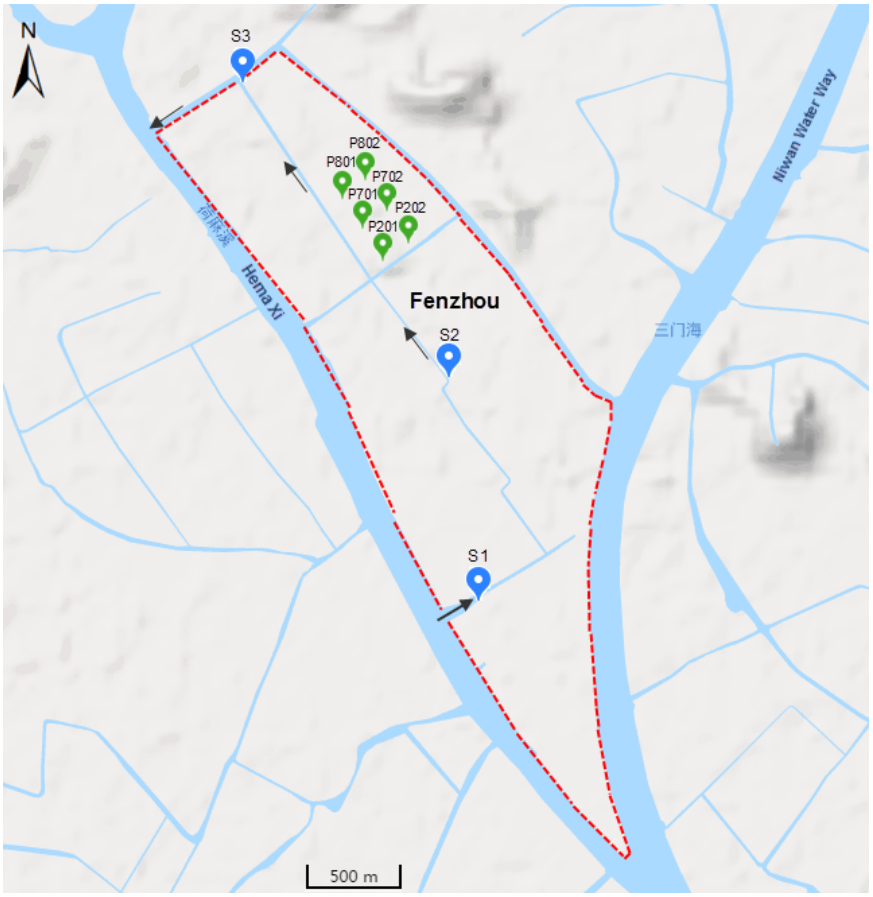


Figure 30 Observation stations for Fenzhou Village farming site.

The area within the red dotted lines is Fenzhou shrimp farm. Stations marked in blue (S1, S2 and S3) are the water quality observation stations on the water pathway. Stations marked in green are shrimp-rice co-culture ponds (P701, P702, P801 and P802) and shrimp monoculture ponds (P201 and P202). Arrows in black indicate the water pathway directions inside the farm when there is a spring tide at the river estuarine

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.21 - Description of shrimp pond farming

Farming Site	**Fenzhou Village, Guangdong, China**
Location	113˚14’16’’E, 22˚19’9’’N
Species	White Shrimp / Tiger Shrimp in Spring and Summer; Giant Freshwater Prawn in Autumn and Winter
Culture system	Intensive shrimp monoculture / Shrimp-rice co-culture in enclosed earthen ponds with aerators (and vinyl cover in winter)
Pond size	0.3 to 0.6 Ha
Juveniles	Initial body length 0.7 - 1 cm, all from commercial hatchery
Delivery date	April 2019 for white shrimp and tiger shrimp; September 2019 for giant freshwater prawn
Stocking density	450 000 per hectar for white shrimp and tiger shrimp; 300 000 per hectar for giant freshwater prawn
Feed	Tongwei Feed Ltd.
Feeding method	Manual feeding, 2 – 3 times a day

The main farming activity is intensive monoculture of White shrimp *Litopenaeus vannamei*, Tiger shrimp *Penaeus monodon* and giant freshwater prawn *Macrobrachium rosenbergii*. Farmers normally culture white shrimp and tiger shrimp in spring and summer, and giant freshwater prawn in autumn and winter with vinyl cover (Figure 30). However, the end water of most monoculture ponds is rich in nutrients and it potentially could be a heavy burden to the environment at the harvest season. Shrimp-rice co-culture (Figure 31) is a new trial farming style developed by SCSFRI, which takes the advantage of nutrient removal ability of rice and the economic benefit.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 31 Shrimp pond with vinyl cover

Brackish rice is planted in the shallow area and covering 40-60% of the whole pond, while shrimps can freely pass across the shallow and deep areas. There will be very little nutrients in the end water of ponds conducting co-culture style. In this study SCSFR is planning to collect data concerning both environmental and animal variables, in order to set up protocols and guidelines for optimizing this eco-friendly farming styles, in relation to the environmental carrying capacity.

Figure 32 Shrimp-rice co-culture style

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Instrumentation and Data Collection

The Fenzhou Village site was instrumented to observe environmental and animal variables, i.e. variables concerning shrimp behaviour, growth and welfare. These data will be used in Task 1.4 and Task 1.5 for the development of the GAIN Information Management System. The observation capacity is summarized in Table 3.22.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 3.22 - Environmental and animal variables measured "in situ" at Fenzhou Village, pilot site.

Environmental variables	**System and frequency**	**Animal variables**	**System and frequency**
Water temperature	Portable water quality analyser (YSI 556, USA) 2/day	Carapace length	1/week
Salinity	Portable water quality analyser (YSI 556, USA) 1/day	Body length	1/week
Dissolved Oxygen	Portable water quality analyser (YSI 556, USA) 2/day	Body weight	1/week
pH	Portable water quality analyser (YSI 556, USA) 2/day	Mortality	1/on -growing phase, at harvest
Concentrations of Ammonia-N, Nitrite-N, Nitrate-N, Phosphate-P, TN and TP	Auto discrete analyser Cleverchem Anna (Dechem-Tech, Germany) 1/week	SGR	1/ on -growing phase, at harvest
COD, POM, POC, TPM and Chl a	Laboratory analysis, standard methods 1/week	FCR	1/ on -growing phase, at harvest
Zooplankton and phytoplankton (Qualitative and quantitative analysis of plankton)	1/month		
Sediment oxidation reduction potential (ORP)	portable ORP meter SX712 (Sanxin, China) 1/week		
Carbon and nitrogen content in the sediment	(Vario EL III, Germany), 1/week		
Phosphorus concentration in sediment	Laboratory analysis, standard methodologies1/week		
Biogeochemical status in the water pathways	1/ month		

Based on the characteristics of pond aquaculture, environmental and biological parameters will be measured with portable instruments and laboratory procedures, as detailed in Table

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

3.22.

Environmental quality data of water pathways will be determined monthly. Environmental parameters of shrimp ponds will be measured and recorded daily, while chemical parameters and shrimp growth (carapace length, body length and body weight) will be measured weekly.

Phytoplankton and zooplankton sampling in water pathways and shrimp ponds will be conducted monthly and analysed for species composition and biomass estimation.

Reporting

SCSFRI is responsible to ensure all the observation and measurement work done on schedule. Data will be collected monthly, and it will be shared within the project partners as necessary.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

4. Conclusions

The achievement of GAIN Task 1.3 are summarized in Table 4.1, for environmental variables, and 4.2, for animal variables. The Tables shows which variables will be monitored at each site: data collection frequencies, f_d, are summarized as follows:

- H : $f_d \geq$ 1/hour
- D : 1/day $\leq f_d <$ 1/hour
- W: 1/week $\leq f_d <$ 1/day
- F: 1/2 weeks $\leq f_d <$ 1/week
- M: 1/month $\leq f_d <$ 1/week
- S: $f_d \leq$ 1/month and/or as a response to observed anomalies.

As one can see from the Tables and, in more detail, in Section 3, a diverse range of instrumentation is in place operating at a range of temporal and spatial scales, meaning a "one size" fits all solution of data management and dissemination is unlikely to be available. Nevertheless, data collected in GAIN will contribute to provide guidelines and set standards in monitoring fish and shellfish farms, besides providing a wealth central to this is an analysis of what the relevant questions are across the sectors.

Table 4.23 - Summary of environmental variables monitored on GAIN pilot sites.

	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**
Water Temperature	H	H	H	H	H	H	H	H	H/D	D
Salinity	H	H	H	H	D			H		D
Dissolved Oxygen	H	H	H	H	H	H	H	H	H/D	D
pH								D	H/D	D
ORP								D		W
Turbidity	H	H			D					
Chlorophyll a	H	H	H				H			W
Tryptophan										
N-NH4		F						D	W	D
N-NO3		F						H		D
P-SRP		F								
Si-SiO2		F								
POM		F								W
POC										W
TSS		F								W

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Table 4.24 - Summary of animal variables monitored on GAIN pilot sites.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Size (weight/length) distribution	F	F	M	H	S	S	S	H	W/M	W
Biomass	S	S	S	H	S	S	S	W	W/M	S
Relative biomass distribution in cages				H	H	H				
Feeding activity					H	H				
Fish speed and location						H				
Parasites				M	S	S	S	S		
Welfare indicators				M	M	M				
Mortality	S	S	S	D	W	W	D	D	D	S

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

References

Banhazi, T. M., H. Lehr, J.L. Black, H. Crabtree, P. Schofield, M. Tscharke, D. Berckmans. Precision Livestock Farming: An international review of scientific and commercial aspects. Int J Agric & Biol Eng. Vol. 5 N° 3 (2012): 1-9.

Føre M., K. Frank, T. Norton, E, Svendsen, J. A. Alfredsen, T. Dempster, H. Eguiraun, W. Watson, A. Stahl, L. M. Sunde, C. Schellewald, K. R. Skøien, M. O. Alver, D. Berckmans. Precision fish farming: A new framework to improve production in aquaculture. Biosystems engineering 173 (20 18): 176 -193.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

ANNEX 1 - GAIN Consortium and project structure

Table A 25 - GAIN Consortium

Participant Nº (leadership role)	Participant legal name	Country	Type
1 (Coordinator; WP5; WP7)	Università Ca' Foscari Venezia (UNIVE)	Italy	RTD
2 (WP3)	The University of Stirling (UoS)	UK	RTD
3 (WP1)	Alfred-Wegener-Institut Helmholtz- Zentrum für Polar- und Meeresforschung (AWI)	Germany	RTD
4	IBM Ireland Limited (IBM)	Ireland	CORP[1]
5 (WP2)	Agencia Estatal Consejo Superior de Investigaciones Cientificas (CSIC)	Spain	RTD
6 (WP4)	Longline Environment Limited (LLE)	Ireland	SME
7 (WP6)	Sparos Lda (SPAROS)	Portugal	SME
8	Salten Havbrukspark (SHP)	Norway	SME
9	Wageningen University (WU)	Netherlands	RTD
10	Johann Heinrich von Thuenen-Institut, Bundesforschungsinstitut Fuer Laendliche Raeume, Wald Und Fischerei (TI)	Germany	RTD
11	Agrifood and Biosciences Institute (AFBI)	UK	RTD
12	Zachodniopomorski Uniwersytet Technologiczny W Szczecinie (ZUT)	Poland	RTD
13	Asociacion Nacional de Fabricantes de Conservas de Pescados y Mariscos-Centro Tecnico Nacional de Conservacion de Productos de la Pesca (ANFACO)	Spain	NPO[2]
14	Multivector AS (MV)	Norway	SME
15	Gildeskal Forskningsstasjon AS (GIFAS)	Norway	SME
16	Lebeche (LEBCH)	Spain	CORP[1]
17	Sagremarisco-Viveiros de Marisco Lda (SGM)	Portugal	SME
18	Fondazione Edmund Mach (FEM)	Italy	NPO[2]
19	Dalhousie University (DAL)	Canada	RTD
20	South China Sea Fisheries Research Institute (SCSFRI)	China	RTD

GAIN is structured in 7 Work Packages, plus an Ethics Work Package, which was added by the EC during the negotiation (see Fig. A1). WP leaders are indicated in Table A1. The main objects of each WP are listed below.

WP1 - Production and Environment: will develop novel sustainable feeds and tools for enhancing aquaculture sustainable management of aquafarm based on Big Data analytics.

WP2 - Secondary products: will develop new co-products, in order to enhance circularity, sustainability and profitability of aquaculture supply chains.

WP3 - Policy and markets will analyse the state-of-the-art of EU and national legislations with respect to the valorisation and marketing of innovative GAIN products and co-products and provide suggestions to policy makers.

WP4 - Eco-intensification: will develop new approaches and tools for assessing the level of eco-intensification of GAIN innovative solutions, in comparison with standard

[1] Corporation (Not SME)
[2] Non-profit Organisation

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

practices.

WP5 - Professional development: will deliver both on-line and in presence courses, in order to facilitate the adoption of GAIN innovative solutions by aquafarm operators.

WP6 - Dissemination, Exploitation, Communication: will maximize GAIN impact, by careful matching communication&dissemination tools to targeted audiences and developing platforms for exploiting GAIN results beyond its life time.

WP7 - Coordination: will ensure the timely delivery of all GAIN contractual items.

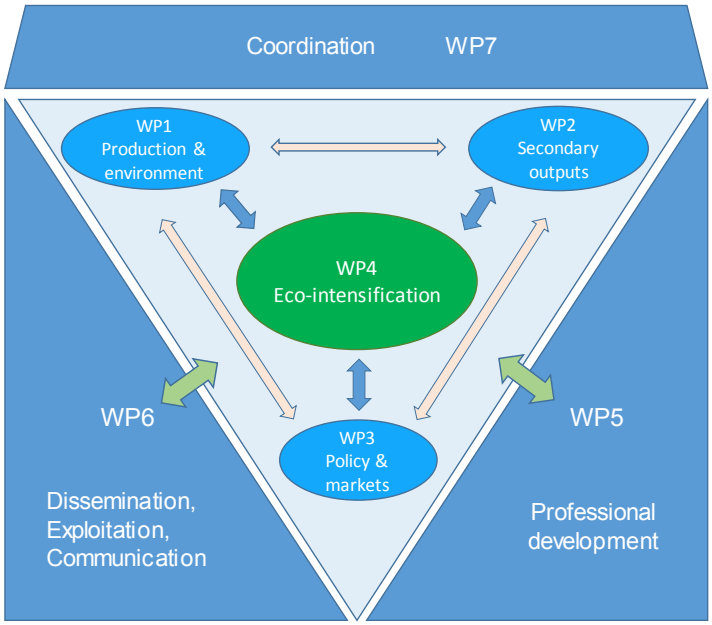


Figure 33 GAIN structure

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Annex 2 - Monitoring equipment installed at the pilot sites in the framework of the GAIN project.

Pilot site	Monitoring equipment	Short description
1) Dundrum Bay	YSI EXO2 probe	The buoy monitors conductivity, temperature, depth, Chl a and turbidity.
	Cyclops tryptophan	This sensor can be used for estimating the concentration of faecal bacteria
2) Belfast Lough	SEABIRD probe.	This buoy monitors turbidity and, Chl a.
3) Sagres	Marker buoy with automated sensors	The sensors monitor: chlorophyll-a (Chelsea fluorometer), turbidity, temperature, solar irradiance and optical light attenuation.
4) Rossøya Nord	Aquaculture Biomass Monitor – ABM	ABM is a buoy equipped with a split-beam sonar: it provides robust estimations of salmon average size, size distribution, vertical stratification of fish densities and fish sizes, swimming speeds.
	Aanderaa system (Xylem Analytics, Norway).	The system consists of a Smartguard datalogger, a salinity/temperature sensor, 4 oxygen/temperature sensors and a wind gauge.
5) Carness Bay	CageEye	Integrated software based on a sonar system, developed by CageEye AS, Norway, that allows to monitor the vertical position of fish in cages.
	Oxyguard Handy Polaris Portable DO meter	The sensors record temperature and DO every hour.
6) McNutt's Island, Shelburne	CageEye	Integrated software based on a sonar system, developed by CageEye AS, Norway, that allows to monitor the vertical position of fish in cages.
	Real-Time Aquaculture, InnovaSea Systems Inc., Canada	The sensors record temperature and DO in real time.
7) El Gorguel, Cartagena	Real-Time Aquaculture, InnovaSea Systems Inc., Canada	The sensors record temperature and DO in real time

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Pilot site	Monitoring equipment	Short description
8) Preore, Troticoltura Leonardi	Biomass Daily	This close-to-market system, produced by Vaki and distributed in Italy by Aquatrade LtD, allows the non invasive monitoring of rainbow trout weight distribution in real time.
	Automatic sampler and analyser provided by RT ENVIRONMENT	The system was leased for detecting every hour the following variables: temperature, pH, Dissolved Oxygen, Conducibility, Ammonia, Nitrate, Nitrite. Two probes were leased and installed at the farm inlet and outlet.
9) FES NOWE Czarnowo	OxyGuard® Pacific sensors	The sensors provide hourly data of O_2, pH and temperature at the water inlet and outlet of the aquaponic system,
10) Fenzhou Village	Portable water quality analyser (YSI 556, USA)	This probe records water temperature, dissolved oxyen, salinity and pH.
	Cleverchem Anna (Dechem-Tech, Germany)	This automatic analyzer measures Ammonia-N, Nitrite-N, Nitrate-N, Phosphate-P, TN and TP.

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

List of Tables

Table 3.1 - Summary of Pilot Sites..... 8
Table 3.2 - Description of Inner Dundrum Bay Oyster aquaculture site..... 10
Table 3.3 - Environmental and animal variables sample "in situ" at Dundrum pilot site..... 11
Table 3.4 - Description of Belfast Lough mussel farming site..... 13
Table 3.5 - Environmental and animal variables sampled in situ at Belfast Lough Pilot site. . 14
Table 3.6 - Description of Sagres mussel aquaculture site 16
Table 3.7 - Environmental and animal variables sampled "in situ" at Sagres pilot site..... 17
Table 3.8 - Description of Rossøya site and of the smolt group to be monitored in GAIN. 21
Table 3.9 - Environmental and animal variables measured "in situ" at Rossoya pilot site. 22
Table 3.10 - Description of Carness Bay site and of the smolt group to be monitored in GAIN. 25
Table 3.11. - Environmental and animal variables measured "in situ" at Carness Bay pilot site. 27
Table 3.12 - Description of McNutt's Island site and of smolt group to be monitored in GAIN. 30
Table 3.13 - Environmental and animal variables measured "in situ" at McNutt's Island pilot site. 31
Table 3.14 - Description of El Gorguel site and of the stock to be monitored in GAIN. 34
Table 3.15 - Environmental and animal variables measured "in situ" at El Gorguel pilot site.35
Table 3.16 - Description of Preore site..... 39
Table 3.17 - Environmental and animal variables measured "in situ" at Preore..... 40
Table 3.18 - Description of Nowe Czarnowo pilot site and of fish coohort to be monitored in GAIN. 44
Table 3.19 - Environmental and animal variables measured at Nowe Czarnowo site in the RAS..... 45
Table 3.20 - Environmental and animal variables measured at Maliniec carp farm. 46
Table 3.21 - Description of shrimp pond farming 49
Table 3.22 - Environmental and animal variables measured "in situ" at Fenzhou Village, pilot site. 52
Table 4.23 - Summary of environmental variables monitored on GAIN pilot sites. 54
Table 4.24 - Summary of animal variables monitored on GAIN pilot sites. 55
Table A 25 - GAIN Consortium..... 57

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

List of Figures

Figure 1. AFBI's Inshore Moored Instrument Network 9
Figure 2. Map showing the location of Inner Dundrum Bay 10
Figure 3. Oyster trestles in Inner Dundrum Bay 11
Figure 4. Location of sites for bottom cultivation of mussels in Belfast Lough 13
Figure 6. Detail of socking mussels. Portugal ©Gary Littler 15
Figure 5. Geographic location of Finisterra offshore longline aquaculture in Sagres at the Southwest coast of Portugal (ESA - Sentinel-2 satellite image) 15
Figure 7. Detail of socking and hanging mussels. Portugal ©Gary Littler 16
Figure 8. Sentinel-2 satellite image with the geographic location of the Finisterra longline aquaculture (green squares), the buoy, the different loggers of sea surface temperature (SST) sensors and the Station A that correspond to the station that has been used to extract satellite remote sensing data 17
Figure 9. Temperature and salinity data obtained from Hobo sensors (7-28 Nov 2018) 18
Figure 10 Samples of mussels from the growth experiment Finisterra longline 19
Figure 11. Rossoya Salmon Farming SITE. 20
Figure 12. Carness Bay site plan and location. Cage 8 will be fully instrumented with environmental sensors and a sonar system. 26
Figure 13. Positioning of transducers in a fish cage. 28
Figure 14. Dashboard obtained by the CageEye software system 28
Figure 16. Salmon farm cages at McNutt's Island, Shelburne 32
Figure 15. The location of Cooke Aquaculture's Atlantic Salmon farm (McNutt's Island), near Shelburne in Southern Nova Scotia, Canada 32
Figure 17. Overview of the instrumentation including: Real-Time Aquaculture dissolved oxygen and temperature sensors (60), Vemco acoustic telemetry fish tags (15), and CageEye (2). 33
Figure 18. Map showing the location of El Gorguel 34
Figure 19. Seabass cages covered with nets in the site El Gorguel 35
Figure 20. Base station of AquaHub system installed on one of the cages 36
Figure 21. Screenshot of the dashboard and graphics displaying the time series of environmental data 37
Figure 22. Location of the pilot site of Preore. 38
Figure 23. Arial (A) and side (B) view of the rainbow trout farm in Preore. 39
Figure 24. Biomass Daily System installation in one raceway of the Troticoltura F. lli Leonardi fish farm 41
Figure 25. Biomass Daily System functioning 41
Figure 26. Example of outputs generated by the Bio3000 software. A) Live weight distribution; B) Condition factor distribution; C) Weight distribution vs time. 42
Figure 27 Location and key elements of the Fisheries Experimental Station in Nowe Czarnowo. 43
Figure 28 Carp aquaponic system consisting of a RAS directly connected to the hydroponic unit 44
Figure 29 Carp pond farm in Maliniec 47
Figure 30 Observation stations for Fenzhou Village farming site. 48
Figure 31 Shrimp pond with vinyl cover 50
Figure 32 Shrimp-rice co-culture style 50

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Figure 33 GAIN structure 58

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330