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 in Europe

Grant Agreement Number 773330

GAIN Deliverable 4.6

Report and white paper for policy-makers with key findings and recommendations

Due date of deliverable: 31/10/2021
Actual submission date: 12/11/2021

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WP 4 – Eco-Intensification of aquaculture

Dissemination Level:		
PU	**Public**	**Y**

Document log

Version	Date	Comments	Author(s)
V1	26/10/2021	-	Pastres, R.
V2	10/11/2021	-	Ferreira. J.G, D. Little, R. Pastres

Recommended citation. Pastres, R., J.G. Ferreira, D. Little, S. Bricker, B. Buck, L. Conceição J. Grant, C.G. Sotelo, C. Zhu. Report and white paper for policy-makers with key findings and recommendations. Deliverable 4.6. GAIN - Green Aquaculture INtensification in Europe. EU Horizon 2020 project grant nº. 773330 21 pp.

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List of Acronyms

ABP – Animal By-products

CE – Circular Economy

EAA – European Economic Area

EMFAF – European Maritime Fishery and Aquaculture Funds

FPH – Fish Protein Hydrolysates

ICES – International Council for the Exploration of the Sea

PAP – Processed Animal Proteins

PFF – Precision Fish Farming

PSF – Precision Shellfish Farming

RAS – Recirculating Aquaculture System

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Executive Summary

GAIN, Green Aquaculture INtensification in Europe, was designed to support the ecological intensification of aquaculture in the European Union and European Economic Area. The project, funded by the Horizon 2020 EU research programme, aimed at increasing production volumes, the profitability and the competitiveness of this sector, while ensuring sustainability, fish welfare and compliance with EU regulation on food safety and environment.

This Deliverable is made up of two parts, namely a report and a white paper for policy-makers:

- the report supplies policy-makers with a blueprint of eco-intensification trends, based not only on the European situation, but on trends in the US, Canada, and China.
- the white paper focuses on the key messages of interest to high-level managers of key organisations, such as the EC, EU national governments: these messages could also be discussed in international for a, i.e. Galway meetings.

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Introduction and objectives

GAIN, Green Aquaculture INtensification in Europe, was designed to support the ecological intensification of aquaculture in the European Union and European Economic Area. The project, funded by the Horizon 2020 EU research programme, aimed at increasing production volumes, the profitability and the competitiveness of this sector, while ensuring sustainability, fish welfare and compliance with EU regulation on food safety and environment.

The GAIN vision of ecological intensification is based on two pillars, namely (i) implementation of Precision Fish and Shellfish Farming (PFF/PSF), and feed innovations; and (ii) reuse of aquaculture by-products and side-streams, in the framework of the circular economy. GAIN developed and tested innovative tools and processes to advance the state-of-the-art in these fields: however, the scientific and technological progress which were achieved in WP1 and WP2 alone cannot guarantee the achievement of the main goal, which is the increase in volume, quality, value, and sustainability of aquaculture in the EU/EAA.

In fact, the ecological intensification and, in perspective, the ecological transition of this sector requires a transdisciplinary approach which integrates scientific and technical innovations with:

1) new approaches to the assessment of the sustainability of innovative feeds, husbandry practices, and production processes;

2) an in-depth analysis of the value chains of the most important species produced in the EU/EAA;

3) changes in current legislation and policies, to remove barriers and exploit opportunities for enhancing aquaculture circularity, thus fostering its eco-intensification.

The importance of the aquaculture ecological intensification, as defined above, is confirmed by the results of the Value Chain Analyses (VCA), which were carried out in GAIN: the results are presented in detail in GAIN Deliverable D4.2. This methodology was applied to Atlantic salmon (*Salmo salar*) in Norway, common carp (*Cyprinus carpio*) in Poland, rainbow trout (*Oncorhynchus mykiss*) in Italy, blue mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) in the United Kingdom (UK). The species and culture system combinations were selected to reflect the full range of current system intensity. The salmon farming industry, by far the largest one, indicated major sustainability concerns about sea lice, feed ingredients, type of energy use (need for renewables) and regulations (medicine use and production limits). To overcome these challenges innovation is required: the improvement of farm management and fish welfare using big data was pointed out as very relevant, with high consensus, by value chain members which were interviewed. The potential contribution of novel feed ingredients, such as microalgae and insect to the sustainability of the aquaculture sector was also ranked high.

Common carp is carried out in extensive or semi-intensive ponds: therefore value chain members in Poland indicated climate-change-related extreme weather as main threats for this sector but also pointed out the opportunities related to fish processing and by-product valorization in food, feed and other sectors.

Value chain members from the Italian rainbow trout industry, which is based on intensive raceway systems, identified climate change and market aspects, i.e. loss of customer interest towards fresh products and low price of trout, as major challenges, which again points at the need on innovations in farm management, within the framework of the precision fish farming, and in fish processing and related valorization of by-products.

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For the bivalve sector in the UK the most important sustainability challenges identified by value chain members were governance, e.g. water classification, increase in public awareness of the low environmental footprint of shellfish farming and valorization of its ecosystem services : GAIN contribution to this issue is detailed in D2.9 and summarized in this report, section 1.6.

This Deliverable is made up of two complementary parts, namely a report and a white paper for policy-makers:

- the report presents eco-intensification trends in the EU/EAA, with reference to US, Canada, and China, based on the interaction with GAIN International partners and Third Party;
- the White Paper focuses on the key messages of interest to high-level managers of key organisations, such as the EC, EU national governments, and the EEA: these messages could also be discussed in international for a, such as Galway-themed meetings and EMFAF https://ec.europa.eu/oceans-and-fisheries/funding/emfaf_en, and shared with organisations representing different parts of farmed seafood value chains.

The report also presents the main GAIN contribution to eco-intensification. Key messages to policy makers take into account the main GAIN findings concerning the gap analysis of EU legislation and the Value Chain Analysis of selected supply chains.

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1. Towards the ecological intensification of aquaculture: main trends

This report summarizes the main trends in the aquaculture industry which, according to the GAIN vision, contribute to the ecological intensification of this sector and set the stage for the ecological transition of aquaculture. This vision closely parallels the strategic guidelines for a more sustainable and competitive EU aquaculture for the present decade, EC COMM(2021) 256, (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0236&from=EN), which sets the objectives listed below.

1) Building resilience and competitiveness.
2) Participating in the green transition.
3) Ensuring social acceptance and consumer information.
4) Increasing knowledge and innovation.

Tools and innovative processes which were developed and tested in GAIN are presented in detail in the project deliverable, publicly available at www.unive.it/gainh2020_eu. As shown in this report, these project outputs can foster the evolution of aquaculture envisioned by the GAIN Consortium, represented in Fig. 1, and contribute to the achievement of the above strategic objectives.

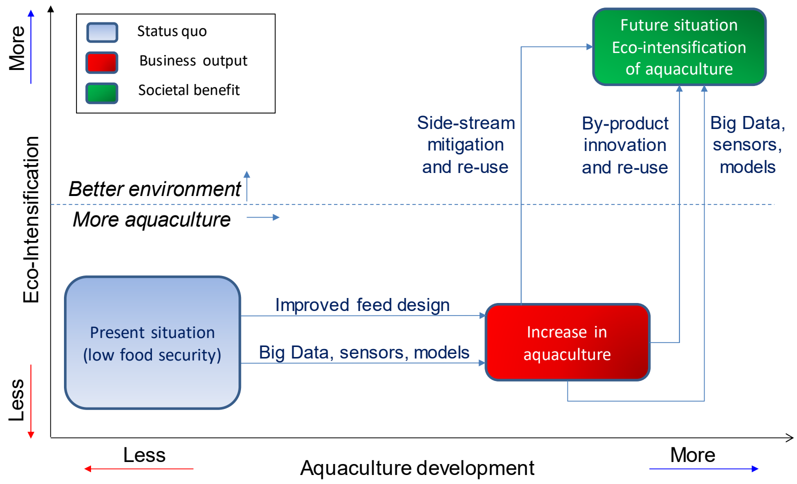

***Fig. 1**. Schematic representation of the GAIN vision of ecological intensification.*

1.1 Aquaculture digitalization: implementation of precision aquaculture

The aquaculture sector is rapidly evolving, driven by the increase in demand of more seafood. Furthermore, an increasing segment of consumers is asking for more sustainable, healthy, nutritious and traceable products and is also paying more and more attention at fish welfare. These drivers set new challenges for operators along the whole aquaculture supply chain: digitalization is one of the key approaches to meet the emerging consumer demands for more sustainable and higher quality 'blue food'. This trend is perceived as very relevant by major ICT corporations, such as Siemens (https://new.siemens.com/global/en/markets/food-beverage/aquaculture.html), and IBM, which engaged in the GAIN project and in the Canadian 'DeepSense' initiative (https://deepsense.ca), linked to GAIN through the Canadian International partners, Dalhousie University. The digitalization of aquaculture will contribute

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to the European Green Deal and, therefore, is high on the agenda of the European Aquaculture Technology and Innovation Platform (EATIP), which recently organized a dedicated webinar, see http://eatip.eu/?p=4854. The adoption of digital technologies, e.g. precision aquaculture, will both improve husbandry practices at production sites and facilitate data interoperability, enhancing transparency across aquaculture supply chains, e.g. block chain, as well as among supply chains of other sectors. As a consequence of better information and shorter supply chains, market stickiness would be reduced and relevant information delivered to consumers.

At the production stage, productivity can be enhanced and wastes reduced by exploiting the implementation of innovative, non-invasive observation systems and models for real time processing of data concerning environmental variables and fish physiological responses.

GAIN focused on this specific aspect of aquaculture digitalization, by developing tools for the implementation of Precision Fish and Shellfish Farming (PFF/PSF). Worldwide, aquaculture is a very diverse sector and even in the EU there are large differences in the technological maturity of different farming typologies. For this reason, GAIN developed an advanced prototype of a **scalable and flexible Information Management System** (IMS), represented in Fig. 2. The GAIN IMS combines a centralized cloud computing platform, including AI models, with peripheral nodes, addressing the requirements of open-water and land-based farms. This structure addresses the needs of large companies as well as those of small farms, since the nodes can facilitate a two-way communication with the platform.

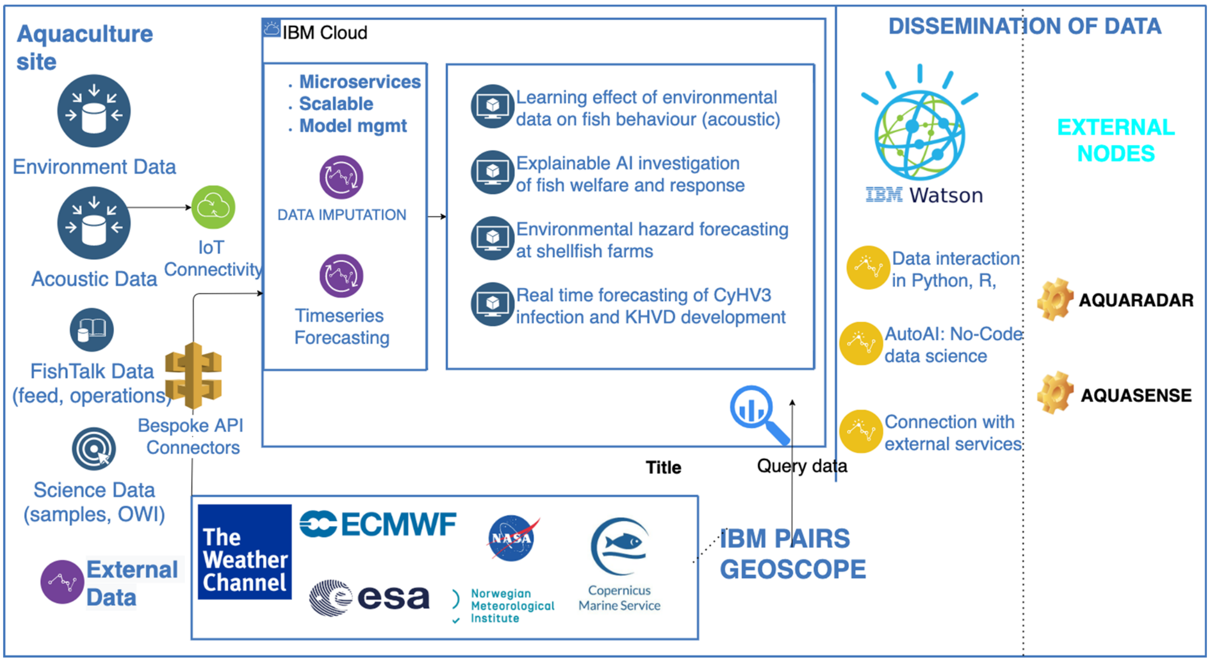

Figure 2: *Overview of the system presenting IoT data integration, connectors to external data, microservices and automated model training and scheduling, and user interaction with the system in terms of bespoke (species and farm specific) model development, and dissemination to end user. Interaction with the end user is outlined on the right-hand side and is supported by robust data science and enterprise tools. Python and R packages allow the user to interact using open-source (e.g. Jupyter Notebooks) or commercial tools (e.g. IBM Watson Studio, Google Collab). AutoAI provides a "no-code" approach to allow non-data scientists apply AI to their datasets. External nodes (AQUARADAR, AQUASENSE) can upload and download data to the cloud to enable different levels of connectivity between different services (i.e. one-way connection where data such as sensor or model forecasts*

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are downloaded from the cloud or two-way connection where data is downloaded and model forecasts uploaded and stored in the service).

The IMS was deployed at salmon farms in Norway, seabass and seabream in Spain, rainbow trout in Italy, mussel farming in Portugal and Northern Ireland (UK), oyster farming in Northern Ireland (UK). GAIN partner Dalhousie University applied a similar concept to salmon farming in Canada. In this case studies, a range of innovative tools were tested, namely:

- Dynamic models for smart management of oxygen supply, based on data assimilation algorithms;
- Dynamic models integrating financial analysis for predicting fish/shellfish growth, local environmental load and financial returns;
- Data driven models for short term predictions of environmental variables.

1.2 Aquaculture digitalization: connecting stakeholders of aquaculture supply chains

Interaction between buyers and sellers is a confidential commercial operation, and in supply chains (or more properly supply webs) the upstream and downstream links of the chain nodes (i.e. intermediaries) are known only to themselves. Adjacent nodes are deliberately excluded from this information, in order to avoid the potential elimination of the intermediary or 'middle-man': this generates long supply chains that dilute value and increase product cost. Platforms for vertical integration of data along aquaculture supply chains are emerging, e.g. https://www.cobalia.com/welcome.

In order to reduce market 'stickiness', which results in long supply chains and costly goods, GAIN relied on making public in a way that is easy to use, both the origin of different aquaculture products, and the pricing of aquafarming products. At present, there is, as far we were able to ascertain, no mapping solution to help a European buyer access this information. The SailFish web application, which builds on the 'META' platform developed by Longline Environment Ltd https://longline.co.uk/meta, represents the first attempt at undertaking a major step in connecting the opposite ends of the market. One key challenge for this platform is maintaining a database of producers, given the market is fluid with respect to consolidation, bankruptcies, new investments, and takeovers. We believe that producers will be interested in being represented on such a map, and will contribute metadata and correct wrong data, if for instance a company has been bought out or relocated.

1.3 Sustainable aquafeeds

Ensuring sustainable feed systems is indicated as one of the main issues for increasing the environmental performance of aquaculture and, therefore, participating to the green transition. These systems should use "ingredients that are sourced in the way which is most respectful of ecosystems and biodiversity and which, at the same time, are appropriate for ensuring the health and welfare of the animals. It also means limiting feed producers' reliance on fish meal and fish oil taken from wild stocks" (EC COMM(2021), 256).

The aquafeed industry is striving to achieve this goal and, in particular, to find alternatives to fish meal and fish oil derived from wild capture. The current shift towards land-

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based proteins could improve the situation in the short term but may not ensure the same nutritional (for instance with respect to PUFAs) and organoleptic properties.

GAIN designed and tested a **range of novel feeds**, which included emerging ingredients, i.e. insects, seaweeds, microalgae as functional ingredients, Processed Animal Proteins, and **Fish Protein Hydrolysates from aquaculture by-products:** the GAIN formulation concepts are presented in Fig. 3.

Feeds were trialled on Atlantic salmon, rainbow trout, European seabass, gilthead seabream and turbot. The comprehensive data sets concerning feed trials shows that the best new formulations do not appreciably change fish physiology and guarantee zootechnical performances very close to commercial formulations that include a higher percentage of fish meal and fish oil.

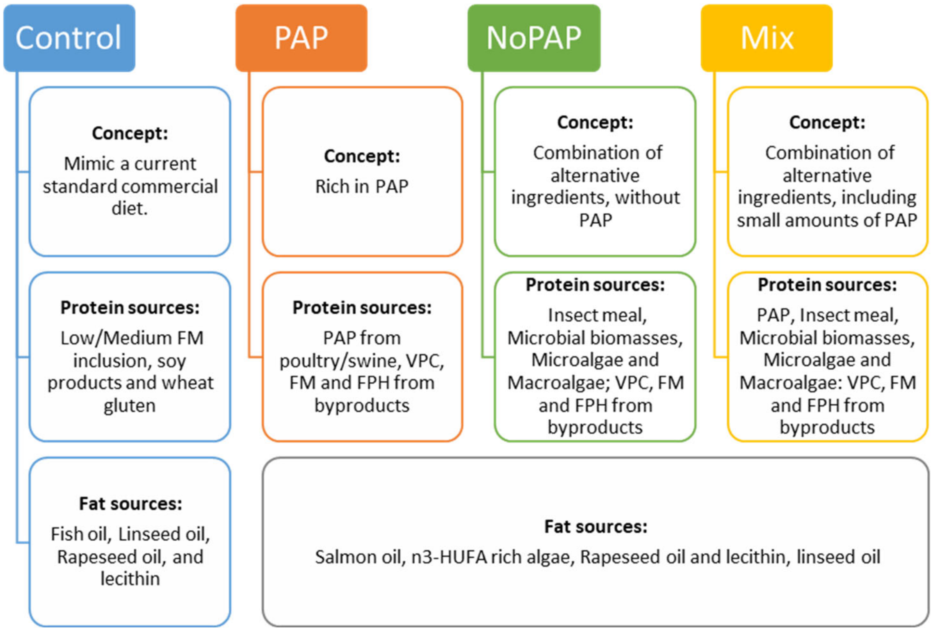

Figure 3. *Formulation concepts and main ingredients used in GAIN trials with novel aquafeeds. FM – fish meal; PAP – processed animal protein from farmed animals (e.g., poultry meal, feather meal and blood meal); VCP – vegetable (e.g., pea, rapeseed) protein concentrates from European origin; FPH - fish protein hydrolysates from fisheries and aquaculture by-products (e.g., fish trimmings, heads and frames); Salmon oil - by-product from salmon farming industry*

The 9 trials on fish novel feeds performed during the GAIN project confirmed that it is possible to produce fish using formulation concepts and ingredient baskets that fit into a circular economy framework. This was one the main objectives of the project and an outcome that can contribute to the green transition. We demonstrated that fish production can be achieved using eco-efficient feeds: for trout, the new formulations even increased production in a cost-effective manner, which may improve the competitiveness of the industry. Furthermore, the very good acceptance of fish fillets after sensorial analysis in salmon and trout reinforces the idea that consumer acceptance for alternative formulations and ingredients will not be a problem. The results of GAIN trials also demonstrated that fish protein hydrolysates (FPH) arising from aquaculture side-streams, as well as macroalgae and microalgae, can be used as effective aquafeed ingredients. FPH are valuable to stimulate feed

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intake, due to their high content in free amino acids, while containing peptides with putative bioactive substances. Micro- and macro-algae were also successfully used as a source of minerals, in particular selenium. Bioactive peptides from FPH, and pigments, phenolic, polysaccharide, and other compounds from algae, may explain the positive effect on fish immunity observed in some GAIN fish trials. In short, GAIN feed formulations, including ingredients using aquaculture and fisheries side-streams and other emerging ingredients adhering to circular economy principles, in perspective are going to be viable options for eco-efficient European fish farming. In fact, the results of economic analysis and LCA indicate that these novel feeds could become profitable environmentally more sustainable if: i) the cost of emerging ingredients would decrease, due to increase in demand and production volumes; ii) renewable energies would be used in rendering process. Given the high interest of feeding companies in emerging ingredients and the strong commitment of the EU in implementing the energy transition, it is reasonable to expect that these two conditions will be met in the present decade.

1.4 Enhancing aquaculture circularity

The European Green Deal (European Commission, 2019) sets a roadmap for making EU's economy environmentally sustainable, through actions targeted to move towards a Circular Economy, as a way to boost the efficient use of resources, to restore biodiversity and to cut pollution. As part of this agenda, a new Circular Economy Action Plan (European Commission, 2020) that aims to involve economic actors, consumers, citizens and civil society organizations in the dynamization of the regulatory framework has been recently published. Increasing aquaculture circularity was the second main pillar of the GAIN vision of ecological intensification. GAIN therefore anticipated the transition towards circular aquaculture, as a contribution to the EU green transition.

There are two ways of interpreting the circularity concept:

A) Co-farming different species, by implementing integrated systems, in which effluent from one compartment of the system can be used as influent from another one;
B) Developing processes leading to the reuse of aquafarming wastes and by-products not only within the aquaculture sectors but also elsewhere in the food or industrial sectors.

GAIN explored both alternatives but focused more on the second one, which has a much higher potential for decreasing the environmental footprint of aquaculture, since it can be applied to current mono-production farming systems. Co-farming through Integrated Multi-Trophic Aquaculture was investigated in detail by GAIN sister project IMPAQT (https://impaqtproject.eu/).

In GAIN, co-farming of shrimp and rice in pond systems was investigated by the Chinese International partner, the South China Sea Fisheries Research Institute (SCSFRI): results showed that shifting towards this co-culture system would both reduce the environmental loads of shrimp farming and increase profit. GAIN also investigated the potential use of open pond aquaponics for capturing dissolved nitrogen and phosphorus from RAS waste waters.

GAIN EU/EAA partners developed innovative processes for **reusing and valorizing**:

1) **side-streams**, i.e. fish sludge, waste waters from Recirculating Aquaculture Systems, and mortalities;

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2) **by-products** from fish and shellfish processing.

The main results are summarized below.

- Two processes for drying and sanitizing fish sludge from RAS and a process for drying and sanitizing mortalities went beyond the pilot stage (TRL8) during the project lifetime: their commercialization is due to start in 2022.
- The end product of these processes, a sanitized dried powder high in organic matter and caloric content, could be reused as fertilizer, insect meal, or biofuel.
- The results of a Life Cycle Assessment (LCA) Analysis show that these innovative ways of reusing side streams have a lower carbon footprint, compare with main stream processes: for example, the carbon footprint of the GAIN process for treating mortalities is only 10% of the one currently used in Norway, i.e. ensilage of mortalities in an acid solution.
- The reuse of mussel shells from the canning industry as filler medina in RAS biofilter was developed up to TRL 5: the results are promising and shells seem to be a good candidate for substituting plastic filler media.
- Processes for extracting valuable secondary products, namely FPH, peptones, collagen, gelatine, from Atlantic salmon, rainbow trout, European seabass, gilthead seabream and turbot were optimized, at pilot scale.

However, the full exploitation of GAIN innovations, as well as those which are being investigated in other on-going H2020 projects, e.g. iFishIENCi (http://ifishienci.eu/) and ASTRAL (https://www.astral-project.eu/), **may require changes in the current EU legislation**, as highlighted in the White Paper presented in the second part of this deliverable.

1.5 Meeting the demand for traceable and sustainable products

Throughout Europe, consumers only have access to the following information at a fresh fish counter: species name, type of origin (aquaculture/capture) and geographic origin (country, ICES region), which is extremely limiting. In this situation, the third objective stated in EC COMM(2021) 256, i.e. "ensuring social acceptance and consumer information" seems still far from being achieved. Improving communication towards consumers is, nevertheless, essential to increase the understanding of ecological intensification, as the cost of more sustainable products, farmed in the EU/EAA in compliance with high food safety and environmental standard regulations, could be compensated by a premium market price. Therefore, to be competitive, eco-intensified products should be compared with those coming from intensive farming using a set of objective indicators and, on the other, this information should be communicated to consumers in a simple and appealing way.

GAIN pioneered both avenues by:

- developing and testing a comprehensive composite indicator for benchmarking eco-intensified products, namely the **EISI Eco-Intensification Sustainability Index** and
- prototyping a web-based application, **GoodFish**, for informing consumers about the fish they eat and allowing them to provide feedback on their culinary experience.

The aims of the EISI are to provide a sustainability index that covered the whole value chain of different aquaculture production but goes beyond the narrow and uncontextualized scope of Life Cycle Assessment. LCA, in conjunction with Value Chain Analysis and targeted aquaculture specific indicators, can provide a better method to assess the overall

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sustainability of aquaculture value chains in Europe, including environmental, socio-economic and animal welfare indicators that provides a 'One Health' perspective on sustainability. The index is data-demanding but allows the characterisation of a supply chain based on indicators belonging to four categories: social, economic, environmental sustainability, and fish welfare.

The EISI was applied to the salmon supply chain in Norway: the results are summarized in Fig. 4: the ratings were defined based on acceptability thresholds for each indicator and the number of operators who comply with the thresholds. Overall, the salmon industry performs well, with medians in either the excellent or acceptable areas of the index for all four categories. However, there are quite a lot of extremes with around 10% to 25% of the industry rated as poor for welfare, environmental or social standards. Economic indicators appear to be less variable, with the bulk of the industry in the "acceptable" range and no poor performers as would be expected within a growing and well established industry.

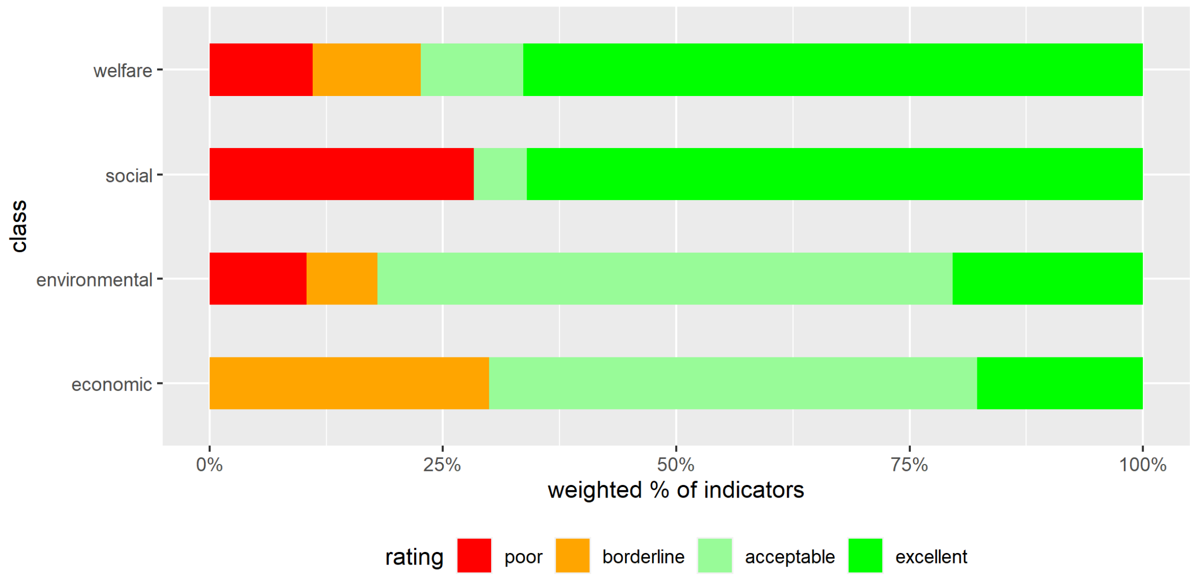

Figure 4. *EISI indicator results for Norwegian salmon production*

The GoodFish web application was designed as a tool to improve the traceability of farmed aquatic products and aim at giving consumers more information about aquaculture products. GoodFish was launched in the final phase of the project in a public virtual conference in the World Food Day, organized by GAIN in collaboration with the 2030 cities H2020 project. The virtual conference was held in October (16.10.2021) on World Food Day, and had the participation of the GAIN community, as well as invitees from other projects, institutions as well as a celebrity chef.

The application was presented to users and a trial run was conducted. A demonstration of the features (detailed in D4.5) was done in the presentation, and a Q&A was held. A lot of effort was put into the design and functionality of GoodFish to make it appeal not only to consumers but also to retailers themselves. This is a fundamental aspect of retailer onboarding since supermarkets and other targets will only deploy this application if they see a clear benefit to their business.

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Figure 1 shows an example of this functionality. The nomenclature of the items shown is that of the nutritional database referred in D4.5, and businesses are able to see detailed information on each product and to download the respective QR code.

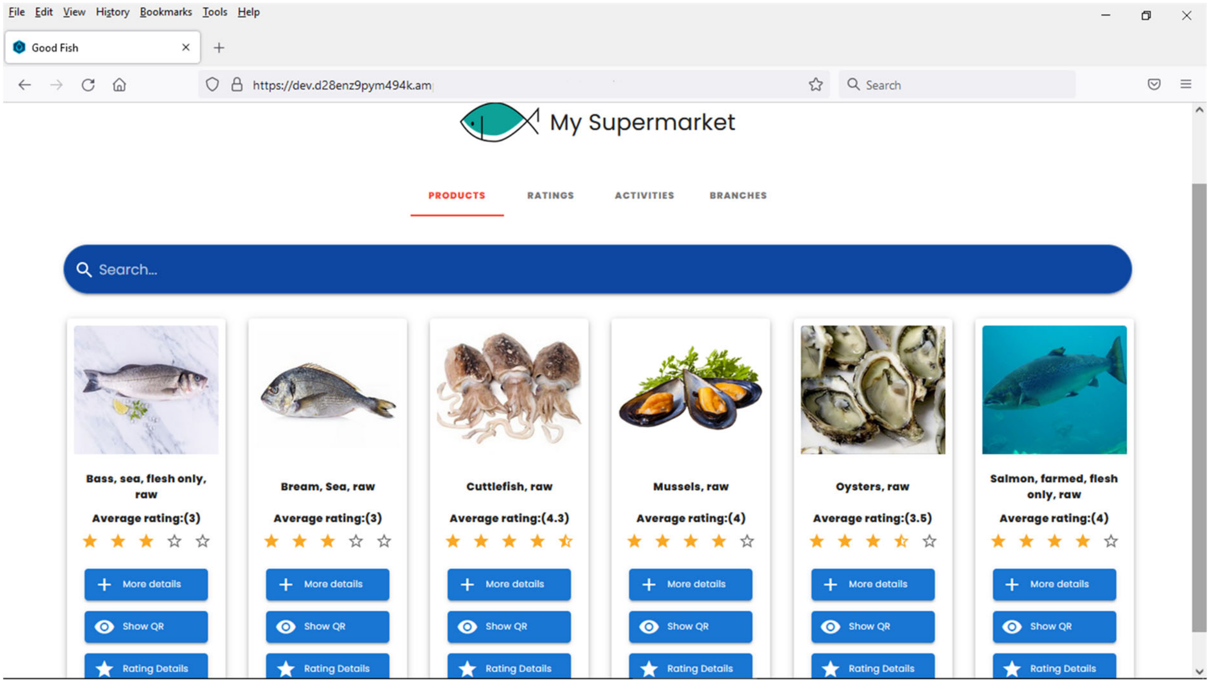

Figure 1*. View of business intelligence platform (cloud backend) of the GoodFish app.*

1.6 Fostering low environmental footprint aquaculture

The LCA literature provides overwhelming evidence that proteins from seafood have, in general, a lower environmental footprint, compared with terrestrial ones. Moreover, extensive or semi-intensive fish farming in ponds and low trophic aquaculture, i.e. shellfish and seaweed farming, can also provide relevant regulatory ecosystem services, contributing to mitigate climate changes and to preserve biodiversity. Fostering the development of these aquaculture typologies is an essential component of the ecological intensification and is also clearly indicated as one the action required to fulfill the strategic vision of the EU by 2030.

The (e)valuation of the benefits provided by these aquaculture typologies is a very important step, which could provide policy makers objective data for defining policies supporting farmer. GAIN looked in detail at the valuation of **shellfish farming bioextraction of nitrogen and phosphorus**, as an additional tool for contrasting the eutrophication of coastal water bodies, due to non-point sources. This key regulatory ecosystem service has not been used in Europe as part of a management framework. In the US, nutrient credit trading schemes where bivalves form a part of the overall nitrogen budget as a part of integrated catchment management are already implemented. GAIN lower estimates show that, considering only **nitrogen removal by shellfish, the average overall value totals almost 18 billion €.**

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2. White Paper: policies for fostering the ecological intensification of aquaculture.

2.1 Facts & figures

1) The EU aquaculture sector has a large potential to grow and meet the increasing demand for more sustainable seafood. According to the EUMOFA 2020 report, the self-sufficiency rate for fisheries and aquaculture products was about 42%. Aquaculture products, including imports, represent 25% of EU seafood consumption: of these, less than half came from EU aquaculture.
2) Aquaculture is strictly regulated in the EU and EAA, guaranteeing that farmed products Made-in-Europe comply with high food safety and quality standards. This comes to a price, i.e. EU products are often less competitive, pricewise, compared with those imported from other economic areas. Actions for turning this weakness into a strength are required.
3) The economic structure of the aquaculture sector in the EU/EAA is extremely diverse: Atlantic salmon production, by far the largest in volume and value, involves multinational corporations; large companies are also responsible for seabass and gilthead bream production, although the sector is still consolidating. By contrast, traditional extensive or semi-intensive aquaculture, e.g. carp farming in Poland, mussel, oyster, and clam farming in Italy, France, Spain, Ireland, Portugal and other countries, is carried out by small, often family-run, companies.
4) Consumer demand for sustainable, healthy locally produced, seafood is increasing: EU aquaculture has the potential to meet this demand by increasing production volumes while ensuring adequate quality standards and sustainability.
5) Consumer demand for ready-made meals is on the rise: these value-added products, besides generating higher profits, could also stimulate the creation of new value chains, based on the reuse of by-products, i.e. shells, fish heads, trimmings, bones and viscera, which, at present, are under-utilized.
6) Modern intensive aquaculture is a relatively new industry, which is little-known to most consumers. In this situation, misleading information about welfare of farmed fish and the impact of aquafarming on the environment has already led to high profile criticism of the sector, reduced social acceptability of aquaculture products and difficulties in implementing science-based spatial plans for allocating new areas to aquaculture activities.
7) Low trophic aquaculture, such as the farming of shellfish and seaweeds, provides a range of ecosystem services, such as the bio-extraction of nitrogen and phosphorus and, in certain conditions, the sequestration of CO_2, which can contribute to improve the environmental quality of marine and freshwaters and to mitigate climate change.

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8) There is a large communication gap to be filled: throughout Europe, consumers only have access to the following information at a fresh fish counter: species name, type of production (aquaculture/capture) and geographic origin (country, ICES region, FAO zone).

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2.2 Challenges & solutions

9) In order to meet EU consumer demands, **it is necessary to increase both production volumes and values, without increasing (and, if possible, decreasing) the environmental footprint of aquaculture**. These multiple goals cannot be achieved by intensifying aquafarming: instead, the **ecological intensification (or eco-intensification) of aquaculture is required.**
10) Aquaculture intersectoral diversity, point 3, generates opposite demands for improving the overall socio-economic and environmental performances, as was demonstrated by the GAIN Value Chain Analysis. Mature supply chains, such as for Atlantic salmon, have already achieved a high optimization level at the production stage, and are already supported by digital tools, but need to find more sustainable solutions concerning feeds and to reduce the local environmental impact by improving the treatment of waste i.e. fish sludge and wastewaters from smolt production, organic emissions from cages, and mortality. At the opposite end, extensive or semi-intensive farming typologies, such as carp farming in ponds and shellfish farms need technological innovations for enhancing the productivity, reducing risks due adverse meteorological events and climate change and optimizing the use of space.
11) Results obtained by the Horizon 2020 project GAIN – Green Aquaculture Intensification in Europe, indicate that it is possible to achieve better economic and environmental performances by: 1) rapidly bringing the aquaculture sector into the digital age, in order to implement more cost-effective management practices based on Precision Fish and Shellfish Farming (PFF/PSF); 2) decreasing the demand for primary resources such as fish meal and fish oil from wild fish stocks, by enhancing aquaculture circularity and connecting it to other bio-based industries, e.g. biofuels, cosmetics, and nutraceuticals.
12) **Enhancing the digitalization of SMEs** is a mandatory step for applying PFF/PSF to the whole aquaculture sector PFF/PSF: this could radically change the way in fish and shellfish farms are managed. From the technological point of view, state-of-the art process-based and data-driven models for predicting fish and shellfish response (e.g. growth, oxygen demand) to controllable inputs, e.g. feed quality and quantity, and non-controllable ones, e.g. water temperature, are already available for the most important farmed species. Low-cost sensors for monitoring basic environmental variables, e.g. water temperature, dissolved oxygen, chlorophyll, are also on the market. The use of control devices based on the Internet of Things (IoT) is increasing as well. Therefore, more efficient decision-making processes based on real-time predictive models can be implemented, at reasonable costs, also in medium size rainbow trout, European seabass, gilthead seabream farms, as was demonstrated in the GAIN project. Cloud computing could make decision support systems based on PFF principles affordable and accessible through smart phones, thus enhancing the social inclusion of operators, who could manage farm sites remotely. This becomes increasingly relevant as aquaculture expands offshore.
13) By contrast with the linear economy production pathway, i.e. take, make, consume, and dispose, **Circular Economy (CE)** processes aim to close loops in industrial ecosystems and minimise waste. CE pursues minimization of raw material inputs, valorisation of process waste or side streams, preservation of the resource value of a

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product as long as possible during its life cycle, redesign of processes and reintegration of used products at their end-of-life for the same or other applications. Therefore, the enhancement of circularity in the aquaculture sector is one of the key strategies towards ecological intensification, as a better use of resources and the reduction of the environmental load would enable an increase in production volumes and values without further deteriorating the environment.

14) A set of CE solutions are mainly related with the use of aquaculture effluents by other cultured species, as in Integrated Multi-Trophic Aquaculture systems and in Aquaponics. These are clear examples of industrial symbiosis, which can increase overall biomass production, mitigating environmental drawbacks at the same time. An ecological intensification pathway based on IMTA was fully investigated in GAIN sister project, IMPAQT (https://impaqtproject.eu/).
15) At present, however, the commercial success of IMTA and Aquaponics n EU/EAA is still limited, compared to Asia. This could be due to the possible risks related for reducing the water exchange and compromising fish health but can also be related to the difficulties in obtaining licenses for co-cultivating different species.
16) The GAIN approach to CE, complementary with that investigated in IMPAQT, looked at ways of reusing and valorising: i) sidestreams, namely fish sludge, waste waters and mortalities, ii) by-products, i.e. shells, fish heads, trims, bones, viscera. Innovative processes developed during the project tested the reuse of secondary products within the aquaculture sector, i.e. in aquafeeds, but also in other ones, such as agriculture, the cosmetic and nutraceutical industry.
17) The current regulatory framework regarding aspects of health and safety, commercialisation and environmental protection, however, sets some limitation to the development of CE in the aquaculture sector. Gaps and barriers were thoroughly investigated in GAIN, suggestions for removing some of them are given in the third section of this White Paper.
18) Expanding low trophic and low environmental footprint aquaculture typologies, such as seaweed farming, shellfish farming and pond culture, and extracting more value out of these productions is one of the goals of the ecological intensification that is perfectly aligned with one of the objectives of the EU strategic guidelines for a more sustainable and competitive EU aquaculture. To be competitive, these production systems need to be supported by strong information and marketing campaigns, aimed at explaining the extra benefits they provide, such as ecosystem services. However, proper communication and marketing may not be sufficient to create remunerative market niches for low environmental footprint products and policies for adequately compensating ecosystem services could be the key for maintaining and fostering the diversification of aquaculture.

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2.3 Policies for supporting the ecological intensification of aquaculture

19) The EU launched the European Green Deal (European Commission, 2019), the roadmap for making EU's economy environmentally sustainable, through actions targeted to move to a CE which boosts the efficient use of resources, to restore biodiversity, and to cut pollution. As part of this agenda, a new Circular Economy Action Plan (European Commission, 2020) has been published recently, which aims to involve economic actors, consumers, citizens, and civil society organizations in the dynamisation of the regulatory framework. This opens a new horizon for the implementation of CE in aquaculture production.
20) According to the European Green Deal, the **green and digital transformation are twin challenges**.
21) In many aquaculture typologies, the digital transformation is still incipient in its infancy: setting it as a priority in the national strategic plans for the development of aquaculture is a prerequisite for unleashing the potential of Precision Aquaculture.
22) Technology transfer of the most advanced and best management practices could be fostered by recommending to Member States the allocation of EMFAF to digitalization and innovations in supply/value chains, aimed at enhancing circularity.
23) The **current regulatory framework in aquaculture is complex and sets barriers to the adoption of CE processes**. The lack of measures to regulate or incentivise the reinjection of side streams into productive schemes may pose a burden for the development of circular processes, with the exception of the valorisation of animal by-products (ABP), which is well developed and ruled by Regulation (EC) No 1069/2009 (European Parliament, 2009a). According to the exhaustive analysis carried in GAIN, there is scope for removing some obstacles without affecting food safety, as summarized below.

- The ban of the use of meal from the same species in fish feed may affect the efficient valorisation of aquaculture ABPs, e.g. when more than one species is processed at the same facility and by-products are mixed. As this restriction does not apply to fishmeal from wild catches, the ban could be revised, in light of scientific evidence to confirm or discard issues concerning food and feed safety.
- The current Regulation on APB could be revised, to allow the use of certain types of Category 2 fish by-products as fish feed ingredients, provided their safety (e.g. microbiological) is demonstrated and supported by scientific evidence. In this case, the economic benefits for the EU fish farms and feed manufacturers would be considerable.
- Aquaculture side streams are not efficiently valorised as yet, due to gaps in legislation. Only recently has the use of aquaculture sludge, i.e. particulate, organically rich matter from faeces and uneaten feed that deposit at the bottom of aquaculture facilities (tanks, cages), as fertilizer been allowed, as part of the implementation of the 2015 Action Plan, the Regulation (EU) 2019/1009 (European Union, 2019) that harmonises requirements for fertilisers produced from organic primary or secondary raw materials. It is expected that this new regulation will increase the interest in organically rich side streams such as aquaculture sludges: an interesting process for

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turning mortalities into fertilizer was developed in GAIN but authorization from the Norwegian authorities is still pending.

- **Integrated farming systems: IMTA**. In an IMTA system, two additional trophic levels can be added to high trophic-level fish or shrimp: a filter-feeder or a detritivore to feed on particulate matter and seaweeds to uptake dissolved nitrogen and phosphorus. Faeces and uneaten feed are rich in organic matter, and in the wild both constitute part of the natural diet of filter feeders and deposit feeders; nevertheless, Regulation (EC) No. 767/2009 on the placing on the market and use of feed, prohibits the use of animal waste to feed any other animal, both for food producing and non-food producing animals. This prohibition *de facto* could **invalidate IMTA schemes including bivalves, sea urchins or other groups.** However, current limitations to the full implementation of IMTA at commercial scale in the EU are also due to the complexity of licensing regulations at the national level. Harmonisation and simplification are issues that were supposed to be dealt with in the previous planning cycle (2014-2020) but is still one of the main objectives of the strategic development of EU aquaculture in the 2020-2030 decade.

- **Seaweeds** bioextract dissolved minerals and trace elements from the surrounding waters and, therefore, could present high concentrations of these potentially harmful chemicals. EU Regulations on the content of contaminants in seaweeds and their derivatives are still recent, and, in some cases, only a risk assessment is available, with a recommendation for the establishment of maximum levels.
- **Integrated farming systems: Aquaponics.** At present**, there is no clear legal status and regulation in the EU.** The EU regulatory framework for this combination of fish farming and plant cultivation would apply both to the Common Fisheries Policy (CFP) and the Common Agricultural Policy (CAP), together with regulations on food safety, animal health and welfare, plant health, and the environment. Additionally, national regulations may apply to specific aspects of this activity. Even though research and technological innovations are quite advanced, this situation is an obstacle to large private investments.

24) **Nutrient trading policies**. Eutrophication due to anthropogenic nutrient enrichment of marine and estuarine waters is a major issue in European seas. These water bodies are susceptible to the direct and indirect effects of excessive nutrient loading, and although point-source emissions are currently better controlled, diffuse emissions that end up in the coastal zones are a more complicated and expensive issue to solve. Due to the origin of such emissions, substantial changes might well be required to agriculture and livestock management, leading to high social and financial burdens to communities. The bioextraction capacity of bivalve shellfish is a key regulatory ecosystem service that contributes to eutrophication control, but to date it has not been used in Europe as part of a management framework. In other parts of the world, such as the USA, there are examples of working nutrient credit trading schemes where bivalves form a part of the overall nitrogen budget as a part of integrated catchment management. GAIN estimated the nitrogen loading to European regional seas and, whenever possible, source apportionment. Subsequently, nutrient removal by the five main species of bivalve shellfish grown in Europe was evaluated, based on both a

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laboratory analysis of shellfish composition and a mathematical model of growth, the well-established FARM model. The role of shellfish in top-down control of eutrophication as a complement to the well-established bottom-up approach of emission control was also assessed. In financial terms, the benefits of incorporating cultivated shellfish into a catchment-scale nutrient management scheme are significant, as summarized in Table 1. The remediation costs of different measures such as stormwater control or agricultural best practices.

Table 1. Financial benefits of an EU-wide nutrient credit trading framework to include shellfish farmers.

Nitrogen removal		Minimum (analytical)	Maximum (FARM)
Nitrogen removed by shellfish (tonnes per year)		4922	13425
Population-Equivalents (PEQ @ 3.3 kg N per ind.)		1490000	4068076
Value of eco-intensification	Remediation cost (€ kg-1 N)	Credit valuation (Millions of €)	Credit valuation (Millions of €)
Stormwater control measures	3388	16601	45483
Approved agricultural BMP	435	2132	5840
Wastewater treatment upgrades	7047	34530	94604
Average credit valuation (millions of €)		17754	48642

If we consider only the lower estimate of nitrogen removal by shellfish, the average overall value of nutrient removal **totals almost eighteen billion €.** The maximum estimates are considerably higher, and it is recognised that the potential valuation is associated to nutrient loading that is for the most part diffuse and is therefore challenging to reduce in many rural areas in Europe without severe social consequences. Nutrient management at the catchment scale is in line with other policy instruments such as the WFD, which aim to manage watersheds in an integrated manner across the various types of waterbodies. **Top-down control of eutrophication via shellfish aquaculture is recognised in qualitative terms but there has been no associated policy development at a European or national level**. The draft of policies to control eutrophication should have at the core an ecosystem approach to manage human activities that impact the marine environment. This can be accomplished through the promotion of a sustainable use of ecosystem goods and services and by a stronger coupling of policies at the land-water interface. Services provided by shellfish are not limited to nutrient removal: there are other major societal benefits including greater food security, local employment and cleaner waters, beneficial for local populations and for tourism, and a range of ecosystem engineering services.

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