



Portfolio Analysis Horizon 2020 Aquaculture Projects

Supporting the implementation of the
“Strategic guidelines for a more sustainable and competitive EU
aquaculture for the period 2021 to 2030”
and the
“EU Mission Restore our Ocean and Waters by 2023”

Independent
Expert
Report

Portfolio Analysis Horizon 2020 Aquaculture Projects

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Portfolio Analysis

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and the
“EU Mission Restore our Ocean and Waters by 2023”

Report on R&I Project Cluster Analysis

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Table of Contents

1.	EXECUTIVE SUMMARY	4
2.	INTRODUCTION.....	6
3.	STRATEGIC CONTEXT	7
4.	ANALYSIS OF THE PROJECT PORTFOLIO	9
	4.1. Portfolio description.....	9
	4.2. Methodology applied	10
	4.3. Project relevance and results	12
	4.4. Knowledge gaps	24
5.	CONCLUSIONS AND RECOMMENTATIONS.....	26
6.	LIST OF PROJECTS	28
7.	SOURCES OF INFORMATION	32

Abbreviations

AIS	Incubation System
ARS	Automated Release System
CFP	Common Fisheries Policy
IMTA	Integrated multi-trophic aquaculture systems
LTA	Low trophic aquaculture
RAS	Recirculating aquaculture systems
RIA	Research and innovation actions
TRL	Technology readiness level

1. EXECUTIVE SUMMARY

Aquaculture can alleviate food insecurity and promote sustainable production methods while contributing to community health and well-being and economic growth in coastal and rural areas. The main goal of the “*Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030*”¹ is to enable the EU aquaculture industry to grow into a more competitive and resilient sector as well as boost its environmental performance and reduce its impact on climate. The “*EU Mission Restore our Ocean and Waters by 2030*” will foster the establishment of a digital ocean and water knowledge system with the aim of restoring and protecting the marine and freshwater ecosystems.

This report supports the implementation of the Strategic guidelines and the Mission by analysing 53 Horizon 2020 projects related to aquaculture and identifying tangible results that may be beneficial to the aquaculture community and readily used by various stakeholders and end-users. The information on each project in the portfolio is collected from CORDIS and, where available, from the project websites. Based on information on its objectives and activities, the relevance of each project to the main headings that stem from the Guidelines and the Mission is assessed. The main headings are: *Environmental performance*, *Climate change adaptation and mitigation*, *Animal health and welfare*, *Diversification of species*, and *Low trophic aquaculture*. An auxiliary category “*Other*” has been added to cover projects relevant to other important aquaculture-related topics that are not explicitly covered in the main headings. The tangible results (products/outcomes/results that can be measured or put into exploitation by end-users) identified per project are put into four categories, most of which are based on their assessed technology readiness level - early stage (feasible) technology (TRL 1 to 4), validated technology (TRL 5 to 7), complete technology (TRL 8 and 9) and other ready-to-use results (mainly document-type results and deliverables as well as web-tools or repositories). Based on information on the number of results and projects, relevant to each of the five headings and the categories of the identified tangible results, a knowledge gap analysis has been performed to identify headings that are most or least frequently associated with project results and the common categories of results for each heading.

In some cases, no active web links or public repositories where the project results could be accessed have been found.

The assessment reveals that almost half of the projects are relevant to the *Animal Health and Welfare* heading (25 projects), followed by the *Environmental performance* heading (22 projects) and the *Diversification* heading (15 projects). The *Climate change mitigation and adaptation* (7 projects) and *Low trophic aquaculture* (8 projects) headings are covered by a small number of projects. The identified tangible results are presented in Table 2. In general, a total of 7 projects demonstrate *Complete technology readiness*, or tangible results that are ready for commercial use. Twenty-eight projects are classified as *Other ready-to-use results* whereas there have been no project results delivered in the *Early stage (feasible) technology* category. Knowledge gaps are identified in two aspects. Some headings (*Climate change* and *Low trophic aquaculture*) are covered by a limited number of portfolio projects, but there are also headings with a relatively low technology level of the results. For *Diversification* and *Low trophic aquaculture*, the results are mostly document-type ones with a small number of projects reporting *Validated technology* deliverables. The gaps in *Climate change adaptation and mitigation* are similar - only one project has yielded *Complete technology* results, two projects reported *Validated technology* results while the rest of the projects have document-type results. For the *Environmental performance* and the *Animal health and welfare* heading, a significant share of the projects delivered results classified as *Validated technology* or *Complete technologies*.

In conclusion, most of the tangible results under almost all headings fall into the *Other ready-to-use results* category and are document-type ones that focus on spreading knowledge through guidelines, methodologies, documents, platforms, etc. However, there are some differences in the other result categories within the main headings. Projects reporting *Validated technology* or *Complete technology* results are limited and concentrate on *Environmental performance* and *Animal health and welfare* action. Results relevant to the *Diversification* and *Low trophic aquaculture* headings are mainly low TRLs. There is an underrepresentation of the technology readiness results that contribute to the *Climate change adaptation and mitigation* heading.

¹ COM(2021)236 final

To close the identified knowledge gaps, a more focused support to projects providing high technology level and/or ready-to-use solutions in the underrepresented areas (*Climate change adaptation and mitigation* and *Low trophic aquaculture*) is suggested. Communicating the potential of low trophic aquaculture (shellfish, micro-algae, and seaweed) for application in fish farming is recommended. Also, projects in all themes that intend to deliver results close to the market should be preferred. The adoption of a standardised framework with information on project results, and their transferability that is to be regularly filled in and updated by the project coordinators (within CORDIS) can bolster the commercialisation of results.

2. INTRODUCTION

According to FAO (1990)², aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants. It could alleviate food insecurity and promote sustainable production methods while contributing to community health and well-being and economic growth in coastal and rural areas. Aquaculture has drawn the attention of the EU policymakers as they recognise the potential of the Blue economy development and the role of the aquaculture industry in achieving environmental policy goals and solving challenges such as overfishing, ocean and sea acidification, climate change, water level-rise, loss of biodiversity, loss of natural resources, environmental pollution, coastal erosion, and GHG emissions. The European aquaculture industry produced over 2.57 million tonnes³ of fish in 2020 (FEAP), 70% of which were marine cold water species while marine Mediterranean and freshwater species accounted for 16% and 14% of the production⁴ (FEAP), respectively. Norway, the largest European producer with a share of 58% of the total supply, cultivates mostly salmon and trout.

In 2021 the European Commission presented the **Strategic guidelines for further development of the European aquaculture sector**⁵. The guidelines support the resilience and competitiveness of and contribute to the EU aquaculture sector while ensuring the latter's participation in the green transition. In addition, they foster social acceptance and improved consumer information on EU aquaculture activities and products and aim at increasing knowledge and innovation in the EU aquaculture sector. The Strategic guidelines contribute to the goals of the European Green Deal and the various strategic documents associated with it. Another major initiative that is highly relevant to aquaculture is the [EU Mission Restore Our Ocean and Waters by 2030](#), launched in 2021. The objective to restore the health of oceans and waters complements the Green Deal goals for biodiversity, zero pollution, and decarbonisation with greenhouse gas emissions reduction.

The aim of the report is to support the implementation of the Strategic guidelines and the EU Mission to Restore our Ocean and Waters by 2030. This aim has been achieved on the basis of an in-depth analysis of a portfolio of 53 aquaculture-related Horizon 2020 projects and classification of their relevance into five main headings (themes) and subheadings as well as identification of the projects' tangible results, where available.

The report is structured as follows: Section 3 presents an overview of the strategic documents and guidelines related to aquaculture. Section 4 describes the project portfolio and methodology applied. An assessment of the project relevance to the five main headings as well as a presentation of the identified tangible results can be found in Subsection 4.3. Subsection 4.4 summarises the identified knowledge gaps while Section 5 contains the findings reported and conclusions made.

² FAO

[https://www.fao.org/3/T0697E/t0697e02.htm#:~:text=FAO%20\(1990\)%20defined%20aquaculture%20as,%2C%20crustaceans%2C%20and%20aquatic%20plants.](https://www.fao.org/3/T0697E/t0697e02.htm#:~:text=FAO%20(1990)%20defined%20aquaculture%20as,%2C%20crustaceans%2C%20and%20aquatic%20plants.)

³ FEAP <https://feap.info/index.php/data/>

⁴ FEAP <https://feap.info/index.php/data/>

⁵ COM(2021)236 final Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030.

3. STRATEGIC CONTEXT

The [Farm to Fork Strategy](#) is one of the key strategies that complements the European Green Deal as it addresses the issue of climate change and the challenges related to resilient and sustainable food systems. The Strategy highlights the importance of the much-needed transition to more innovative, carbon-neutral, and pesticide/antibiotic-free food production methods, including the adoption of advanced technological and digital solutions that will meet the emerging demand for nutrition. The strategy emphasises new methods to ensure that agriculture, fisheries, aquaculture, and the food value chain have all made their contribution to the process of transition. Blue farming is part of the Farm to Fork Strategy and aims at helping producers in aquaculture and fisheries to increase seafood production with a low environmental footprint. It also supports them to become pioneers in the supply chain by providing alternative use of high protein food, low trophic species, and high animal welfare standards, and thereby how to add economic value.

The [Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030](#) address the need to develop a sustainable and competitive EU aquaculture sector that will directly contribute to the European Green Deal. The Strategic guidelines outline four inter-related objectives that provide the conditions to achieve resilient aquaculture in the EU without compromising its climate and environmental performance: **building resilience and competitiveness, participating in the green transition, ensuring social acceptance and consumer information, and increasing knowledge and innovation.** In particular, these guidelines are growth-conducive to an EU aquaculture sector that: (i) is competitive and resilient; (ii) ensures the supply of nutritious and healthy food; (iii) reduces the EU's dependency on seafood imports; (iv) creates economic opportunities and jobs; and (v) becomes a global reference for sustainability. They should also help EU consumers make informed choices of sustainable aquaculture products and ensure a level playing field for aquaculture products marketed in the EU. The guidelines recommend specific actions in a number of areas such as **facilitating access to space and water, human and animal health management, environmental performance, climate change, animal welfare, regulatory and administrative framework, and communication on EU aquaculture.**"

[Restore our Ocean and Waters by 2030](#) is among the five EU Missions launched by the European Commission. The 5 EU Missions underpin the EC's priorities such as the transformation of the continent into a greener, resilient Europe and provide solutions to the most pressing and challenging issues; they also set out goals and aims whose results have to be delivered by 2030. The Mission **Restore our Ocean and Waters by 2030** will enable a digital ocean and water knowledge system along with the preparation and integration of the Digital Twin of the Ocean Destination Earth initiative of the Digital Europe Programme. The Mission will pilot and test R&I to carry out all activities from monitoring to mapping and overall managing and restoring the ocean and waters whenever climate change-related issues occur. It will serve as an asset to the existing and planned EU infrastructures and services such as Copernicus.

[The Implementation Plan of Mission Ocean and Waters](#) outlines the objectives and targets and provides an operational plan to achieve the Mission goals. The Mission's overall strategic objective is to restore the good health of the oceans and all water systems (from rivers to seas and the ocean) by 2030 by achieving three specific objectives: **(1) protect and restore marine and freshwater biodiversity and ecosystems, (2) prevent and eliminate pollution of our ocean, seas, and waters (achieve zero pollution), and (3) transform the traditional blue economy into a climate-neutral circular economy (develop zero-carbon and low-impact aquaculture and focus on maritime energy renewable sources such as offshore wind, etc).** The Mission also aims to **"accelerate the twin green and digital transition across EU marine and freshwater"**. New technology, social and business innovation, transition and governance, knowledge, and research and innovation all play a key role in the restoration and conservation of marine systems, including aquaculture. The use of new technologies will enable the remote and accurate monitoring of aquatic species, prevention of bycatch, improve litter management in the river basins that pollute waters and seafood, as well as the full traceability of fisheries and aquaculture products from net to fork. The Mission will also deliver on key EU policies and regulatory initiatives in synergy with other funding streams.

The following strategic documents are also taken into consideration as they are relevant to certain aspects of aquaculture and sustainability:

[Food 2030](#), 3rd pathway for action: Food from the oceans and freshwater resources highlights crucial R&I steps in the transition to a resilient blue economy, and inclusive affordable food systems. It also points out how vital the path of sustainable seafood production through fisheries and aquaculture is. The pathway focuses on the following Food 2030 co-benefits related to aquaculture:

- **Nutrition and health**, including food safety of aquaculture products and their traceability.

- **Climate and environmental sustainability** by reducing carbon footprints through energy-efficient fishing vessels, managing all marine and freshwater activities, and keeping the integrity and safety of the marine ecosystems intact.
- **Circularity and resource efficiency** by promoting diversification, recirculation, and seafood waste management.
- **Innovation and empowering communities** by adopting new digital technology and AI that will lead to innovation, also job creation on the coast, marine biotechnology, maritime eco-tourism and blue economy growth.

„Transforming the EU's Blue Economy for a Sustainable Future” is a Communication that addresses the transition from “blue growth” to a “sustainable blue economy”. It provides a systematic approach through which ocean policy is integrated into the new European Economic policy. The oceans and waters are the drivers of the blue economy; hence, they are vital elements for the blue transformation, as set among the goals of the EU Green Deal. Examples of developing the blue growth sectors' potential include promoting a circular economy, reducing pollution, tackling greenhouse gas emissions, maritime protection, and conservation, increasing biodiversity, streamlining the connection between blue and green policies, coastal resilience, sustainable and organic food supply, and production, as well as efficient management of water space.

4. ANALYSIS OF THE PROJECT PORTFOLIO

4.1. Portfolio description

The portfolio comprises **53 Horizon 2020 projects related to aquaculture** both complete and ongoing. The total cost of the portfolio is € 304,8 million, of which € 263,3 million worth of EU support. These projects were selected by DG RTD as most promising to deliver tangible results starting from an initial list of 198 potentially relevant projects that were identified using the CORDA tool (COMmon Research DATA Warehouse) from the interface available to European Commission officers. The projects included in the analysis have an EC contribution of 140 000 Euros or more and have been completed, or if ongoing started no later than 2019, or to be completed in 2022.

Table 1. Number of projects by funding scheme

Funding scheme	No. of projects	Total funding, €	EU contribution, €
Research and innovation actions (RIA)	18	139 280 322,54	134 304 574,50
Marie Skłodowska-Curie Actions ⁶	12	9 247 069,08	9 247 069,08
SME2	9	18 821 189,73	13 174 832,33
Innovation actions (IA)	9	101 837 378,23	88 584 600,03
Coordination and support actions (CSA)	4	9 961 822,13	9 956 322,63
ERA-NET-Cofund	1	25 649 263,15	8 014 646,64
Total	53	304 797 044,86	263 282 045,21

Source: CORDIS

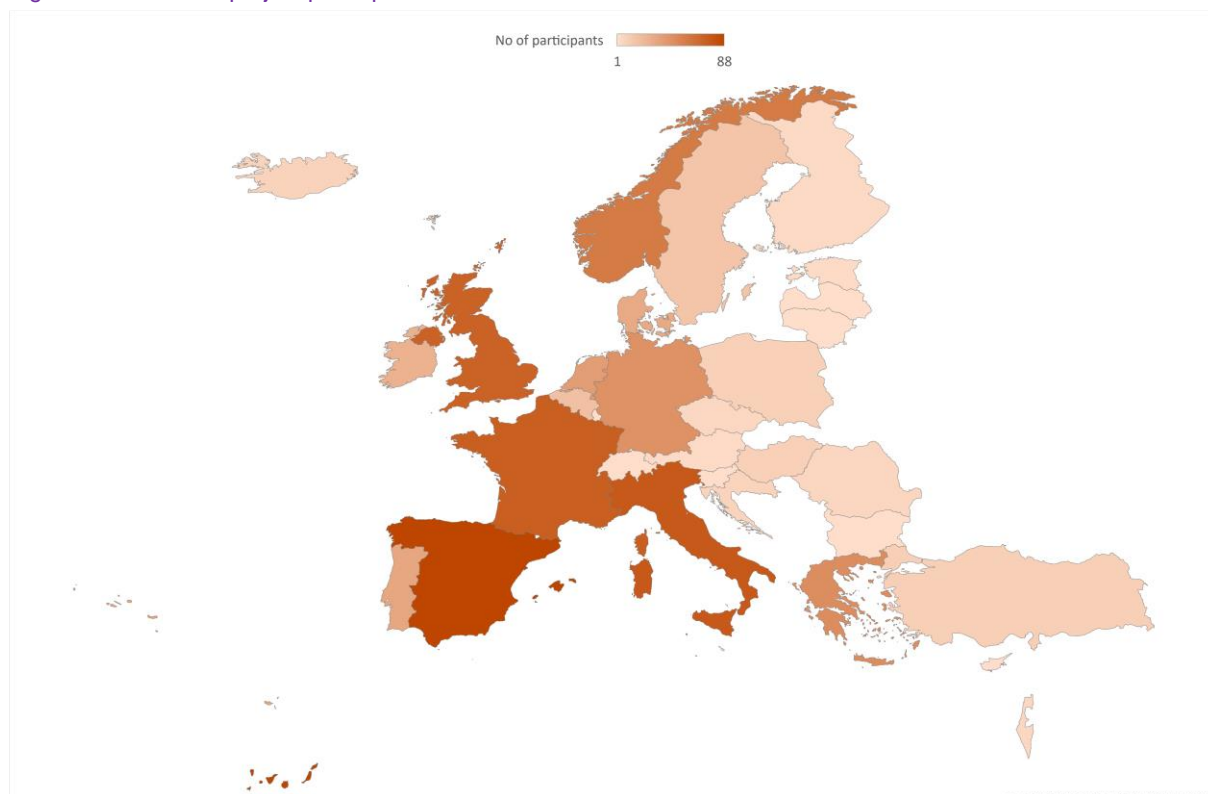
Most projects, 18, are research and innovation actions (RIA), followed by Marie Skłodowska-Curie actions covered by 12 projects. In terms of budget, RIA (€ 139,3 million or 45,7% of the total portfolio budget) and innovation actions (IA) (€ 101,8 million, 33,4%) enjoy the highest shares in the budget total. The share of projects supported by Marie Skłodowska-Curie actions amounts to only 3%, the smallest budget in the portfolio. The ERA-NET-Cofund project in the portfolio is [BlueBio](#).

In terms of work programme, 30 projects were funded under Societal Challenge 2 (on Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy) and 12 under various Marie Skłodowska-Curie actions (mainly Individual fellowships and research and innovation staff exchange). The rest of the work programmes herein dealt with encompass Innovation in SMEs, European research infrastructures (INFRAIA, INFRADEV, EINFRA), Leadership in Enabling and Industrial Technologies - Space (EO), and Information and Communication Technologies.

A total of 759 participants from 52 countries took part in the projects. Nevertheless, there is some geographical concentration in the portfolio, as nearly half of the participants came from 5 European countries (Spain, Italy, France, the UK and Norway). The distribution of project coordinators, who manage 33 of the projects, is also concentrated in 5 countries (France, Spain, Norway, Portugal and Ireland).

⁶ Standard European Fellowship, Innovative Training Networks, Research and Innovation Staff Exchange, and Individual Fellowships Reintegration Panel

Figure 1. Number of project participants from EU and Horizon-associated countries



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Source: CORDIS

4.2. Methodology applied

The information on each project in the portfolio is collected from CORDIS and, where available, the project websites. The relevance of every project to the **five main headings (themes)** that stem from the Guidelines and the Mission is assessed based on information on their objectives and activities. Each theme is further divided into several subcategories for the purposes of more precise classification. The themes and subcategories are as follows:

- **Environmental performance**

- Monitoring and assessment: environmental monitoring of aquaculture sites, including water quality, discharges and emissions; use of life-cycle approaches in environmental impact assessment of aquaculture.
- Mitigating the impact of aquaculture: sustainable feed systems; reducing the use of veterinary products and other substances (e.g., anti-fouling agents); applying management practices for mitigating impacts (e.g., management of predators, prevention of escapees); limiting the contribution of aquaculture activities to marine litter.
- Promoting aquaculture with a lower environmental impact: development of organic aquaculture; use of energy-efficient recirculating aquaculture systems (RAS) and integrated multi-trophic aquaculture systems (IMTA); use of renewable energy sources; use of waste management systems to minimise the environmental footprint of aquaculture activities; promoting forms of aquaculture that offer ecosystem services, incl. in ponds, wetlands, and brackish water.

- **Climate change adaptation and mitigation**

- Reduction of energy consumption and carbon emissions: practices leading to reduced energy consumption and/or reduced carbon emissions from transport, production, and processing.

- Climate-mitigation services: promotion of types of aquacultures that provide climate-mitigation services (such as carbon sequestration).
- Climate-adaptation services: promotion of types of aquacultures that provide climate-adaptation services (such as nature-based coastal protection).
- **Animal health and welfare**
 - Husbandry practices: use of good husbandry practices and technologies tailored to each aquaculture species.
 - Disease prevention: prevention of diseases and parasite infestation; reducing the use of pharmaceuticals, including antimicrobials and anti-parasitic substances; increasing the availability of veterinary medicines (incl. vaccines) for use in aquatic animals; prevention of noroviruses in mollusc farming.
 - Improving animal welfare: developing good practices on fish welfare during farming, transport and killing; setting common, validated, species-specific, and auditable fish-welfare indicators throughout the production chain; providing knowledge and skills on fish welfare to aquaculture producers and other operators that handle live farmed fish.
 - Research on animal health and welfare: filling in research gaps (e.g., on fish microbiome, the impact of climate change on fish health, and the impact of stress on the fish immune system); more consistent and thorough investigation of aquatic diseases in certain EU Member States and within certain sectors; introducing codes of good practices in EU legislation for the early detection, prevention and control of aquatic diseases; further research on animal welfare, in particular on species-specific parameters.
- **Diversification (species, products, production methods)**
 - Diversification of species: diversification into non-fed and low-trophic species with a lower environmental footprint.
 - Diversification of production methods: applying polyculture practices in pond aquaculture; promoting integrated multi-trophic aquaculture.
 - Diversification of products: processing and packaging aquaculture products into new value-added products (e.g., fillets and ready-to-use products) which are attractive to consumers.
- **Low trophic aquaculture**
 - Diversification to lower-trophic species: promotion of lower-trophic species such as molluscs, other invertebrates, algae, and herbivore fish.
 - Use of low-impact feed sources: introducing feed sources from algae production, which have a smaller carbon footprint than land-based animal proteins.

Due to the limited availability of information on some of the analysed projects (e.g., on projects which have started recently, projects which have not been implemented as planned, etc.), project coordinators have been contacted and asked to provide the information required.

In some cases, a project is assigned to more than one heading depending on its activities and results or it is not assigned at all to either of the themes.

An auxiliary heading, “Other”, has been introduced so that the analysis can make use of all the available information on the projects in the portfolio. The “Other” category is based on the [‘Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030’](#), as it covers the **communication process on EU aquaculture** (including proper labelling and marketing standards of sea products, increasing consumer awareness, collaborations between different parties involved, etc), **integration of local communities, boosting competitiveness, and increasing knowledge, innovation, and research**. The heading also covers the topic of **blue economy** (including the renewable energy

transition), which is introduced as a key element in the Communication document [Transforming the EU's Blue Economy for a Sustainable Future](#) and addresses the transition from “blue growth” to a “sustainable blue economy”.

Tangible results are defined as products/outcomes/results that can be measured or put into exploitation by end-users (i.e. prototype technology, ready-to-work sensing-tool technology, etc. but also policy papers, guidelines and methodologies). The identified tangible results are grouped into 4 categories most of which are based on the technology readiness levels (TRLs)⁷ currently used in EU policy. The categories are:

- **Early stage (feasible) technology:** Results in this group encompass initial early-stage technology model formulation or product in development or early validation phase. It includes TRL levels 1 to 4, which embody the following technology progress: Basic principles observed, Technology concept formulated, Experimental proof of concept and Technology validated in lab.
- **Validated technology:** Results in this group include technology (prototype) that is partially or fully validated in a relevant environment. It covers TRL 5 to 7, namely Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies, Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) and System prototype demonstration in an operational environment.
- **Complete technology:** Technology developed and ready for commercial exploitation. It includes TRL groups 8 and 9: System complete and qualified and Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).
- **Other ready-to-use results:** Those will be mainly document-type results and deliverables (such as policy papers, methodologies, guidelines) as well as web-tools or repositories that could be used by relevant stakeholders (e.g., fish producers,) including policymakers, and citizens.

It should be noted that tangible results have not been identified for all projects. In some cases, no active web links or public repository where the project results could be accessed were identified. In those instances, the team contacted the project coordinators asking for further clarification and additional information to fill-in the gaps. Only projects that have distinct tangible results are presented in Table 2 in Section 4.3.

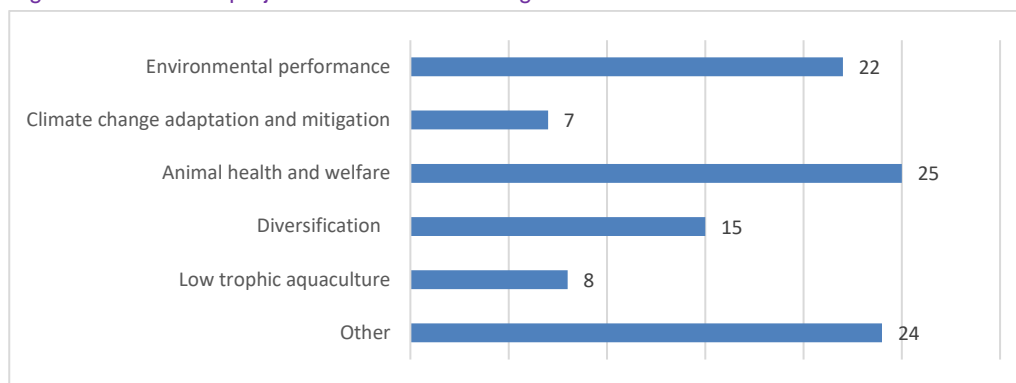
Knowledge gaps are identified in Chapter 4.4 based on information of the number of results and projects, relevant to each of the five headings and the categories of the identified tangible results. Headings that are most or least frequently associated with project results are highlighted. The most common categories of results for each heading have also been analysed.

4.3. Project relevance and results

An overall assessment of the project relevance to the predefined themes is presented in Figure 2 below. 25 projects proved to be relevant to the *Animal Health and Welfare* theme, and another 22 projects to the *Environmental performance* heading. Least covered are the *Climate change adaptation and mitigation* and the *Low trophic* headings with 7 and 8 projects, respectively. 22 projects were identified to have activities and/or results that are relevant to the overall communication or development of R&I infrastructure and collaboration outside or beyond the five main headings.

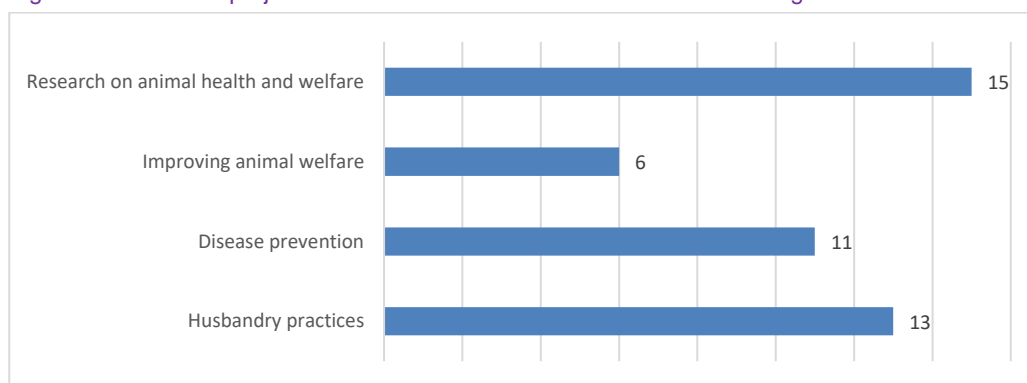
⁷ Technology Readiness Level (TRL) unified scale which was introduced into the EU-funded projects as part of the Horizon 2020 framework program. The scale was originally created by NASA in the 1990's; however, due to the technology advancement in time, the scale was modified by the EU to match the current state of the technology emergence. The scale will enable the stakeholders to align with the EU's expectations depending on the number of the TRLs (i.e. pilot technology system, demonstrated technology, etc.).

Figure 2. Number of projects under main headings



The **Animal Health and Welfare** heading lays emphasis on fish welfare that has the potential to contribute to high-quality products manufactured with fewer or without pharmaceuticals and applying husbandry practices and technologies that are animal- and environment-friendly. The main activities for 15 of the projects relevant to the theme include filling in research gaps through research and innovation (i.e. climate change effects on aquaculture, stress impacts on the fish population, etc.). These projects are relevant to the *Research on animal health and welfare* subheading (see Figure 3 below). For example, the [GTHREG](#) project concentrates on scientific advancements through studies and experiments related to fish reproduction and its regulators. Fish mortality and the process of farming, culturing and breeding of a healthy aquaculture population are covered by 13 projects, as classified in the *Husbandry practices* subheading. The projects often focus on research that is relevant to reducing the use of antibiotics and other harmful substances such as anti-fouling agents when managing aquaculture. The Norwegian-led project [SPG](#) has developed an innovative chemical-free technology based on electric pulses that tackles the problem of sea lice infection in salmon while not harming it. Eleven projects cover *Disease prevention* techniques to improve animal health and welfare. For example, [ParaFishControl](#) works on a unique tool that can enable farmers to identify the risk of parasite infection and outlines the most appropriate and effective management strategy of parasite disease prevention in terms of site characteristics and husbandry practices. Six projects work on improving fish welfare during farming, transport and killing under the *Improving animal welfare* subheading. An example of the aforementioned action is [CLAIM](#). The project developed, designed, and tested a prototype filtering system in a coastal sampling station and on board a Research Vessel and a pilot for the removal of microplastics, employing visible light (sunlight) photocatalysis with green nanotechnology-based coatings that can be potentially used to remove microplastics from the water in aquaculture installations and prevent them from impacting farmed fish and shellfish.

Figure 3. Number of projects under Animal Health and Welfare subheadings



Five projects under the *Animal Health and Welfare* heading have ready-to-use tangible results in the *Complete technology* readiness level category. These are [SELAM](#), [SPG](#), [NEPTUN](#), [eForcis](#) and [BeForcis](#), [VicInAqua](#) and their results and application can be seen in **Error! Reference source not found.**. All of them contribute to better *Husbandry practices* while others contribute to *Animal Health and Welfare*.

Another five projects, [The Blue Growth Farm](#), [CLAIM](#), [OCEANFISH](#), [ELOXIRAS](#), [CryoPlankton2](#), reported results that fall into the *Validated technology readiness level* group as the technologies developed are demonstrated in a relevant environment. For example, the Subflex Classic system, developed within [OCEANFISH](#), allow fish farming in deeper waters and harsh weather conditions. Its smart hi-tech technologies enable better management tools, and livestock monitoring systems within the fields of Biomass Monitoring, Control of Feed Delivery, Parasite Monitoring, and Management of Crowding Operations.

Projects delivering *other ready-to-use* results are [COLUMBUS](#), [FutureEUAqua](#), [BlueBio](#), [ParaFishControl](#), [VIVALDI](#), [Performfish](#), and [MEDAID](#). They have mainly document-type results and deliverables that can be used by a variety of stakeholders. [VIVALDI](#) created a manual for bivalve disease management and biosecurity incorporating solutions, lessons learned and management techniques, as well as a guidance report on optimal husbandry practices to be used for cultivation practices to reduce or avoid mortalities among oysters during cultivation, a study report on bivalve mortality data on oyster, mussel, and clam production related to different environmental factors/parameters such as temperature and salinity, and Guidelines containing recommendations related to reducing mortalities and management of shellfish diseases.

No tangible results have been identified for the following MSCA projects: [ResisGal](#), [GTHREG](#), [SAFE-Aqua](#), [PROTECTA](#), [HappyFish](#), [EVOMA](#), [ShrimpLLH](#).

The **Environmental performance** heading encompasses projects focusing on sustainable protein production from aquaculture that reduces carbon and environmental footprint on the planet. They also seek to bring additional benefits from aquaculture management such as mitigating impacts, reducing marine litter, minimising excess nutrients, organic

SELAM is a project at a commercial stage. The Norwegian Lobster Farm AS company, which initially started as a project (SELAM), is currently producing environmentally-friendly lobsters and delivering them to restaurants, bars, and other relevant high-end customers worldwide. The project developed a unique technological concept for land-based juvenile lobster farming by keeping animal welfare as a priority. The company uses separate cages which prevent cannibalism and fighting amongst lobsters. Due to its in-land Recirculating Aquaculture Systems (RAS) of production, many issues such as contamination, feed waste, escapees, and diseases are managed. The company has become a pioneer and the first in the world to raise lobsters from eggs to plate size using only formulated feed, including the larval stages. The project has also boosted the market for lobsters because wild individuals can be caught in Norway only during the months of October and November while the Norwegian Lobster Farm AS provides lobsters all year round.

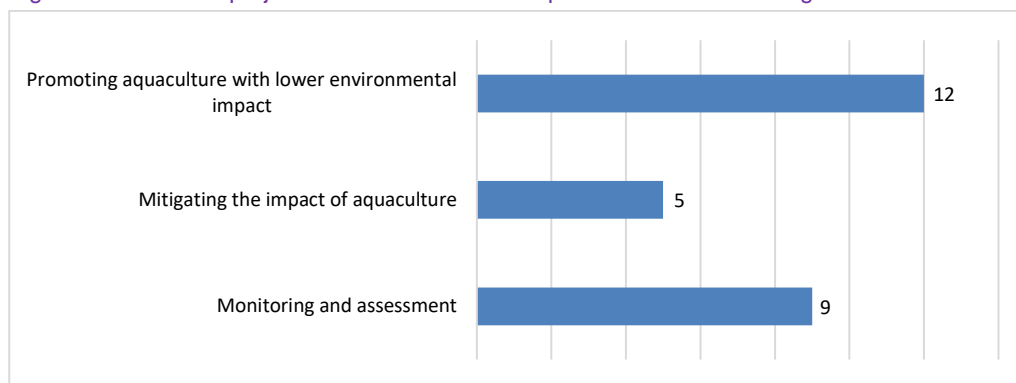
[eForcis and BeForcis](#) is a project based in Spain that shows good practices in energy efficiency. The project developed a unique technology that uses kinetic energy and converts it into electricity while collecting data for oceanographic research. The BeForcis wave generator converts wave energy into electricity through a simple off-grid mechanism, while the BeForcis buoy contributes to boosting business security in offshore fish farms due to the use of surveillance cameras. The technology feasibility solves issues and inconveniences related to temporary energy supply such as battery systems, or solar panels and provides renewable energy sources. The sustainable energy source also directly contributes to the Blue economy and marine aquaculture sectors as well as boosts employment in coastal areas.

matter and restoring marine biodiversity through life-cycle approaches, mollusc, and algae farming, and managing ponds and wetlands. Twelve projects are relevant to the *Promoting aquaculture with lower environmental impact* subheading (see [Figure 4](#)). Subheading *Monitoring and Assessment* is covered by 8 projects that deal with environmental monitoring of aquaculture sites and use life-cycle approaches to impact assessment in aquaculture. [CLAIM](#), a project, falling under the above subheading, developed innovative modelling and monitoring tools to assess marine litter pollution in the Mediterranean and Baltic Seas. The technology quantified and mapped the main sources of plastic litter; hence the initial source of contamination can be identified and treated in order to achieve a cleaner marine environment. It also focuses on performing MP biota analyses on main commercial aquaculture species to investigate any potential impact

due to ingestion on ecosystem services. The project contributes to cleaning the waters from polluting materials which can be ingested by aquaculture species; thus preventing contamination from small particles from getting into food to fall in people's diet as well.

Five projects have activities and results that are relevant to the *Mitigating the impact of aquaculture* subheading. [CryoPlankton2](#) demonstrates a novel technique that cryopreserves the marine crustacean nauplii in large user-friendly entities and revitalises them after thawing. The process is efficient: it replaces conventional live feeds and is also eco-friendly as it seeks ways to limit the amount of plastics normally associated with the process. The project has also had a positive impact on sea bass and sea bream production in South Europe.

Figure 4. Number of projects under Environmental performance subheadings



Six projects under the *Environmental performance* heading have results that have been assessed to belong to the *Validated technology readiness level* - [Space at Sea](#), [The Blue Growth Farm](#), [CLAIM](#), [OCEANFISH](#), [ELOXIRAS](#), [CryoPlankton2](#). [Space at Sea](#) has developed a standardised multi-use modular floating island with a low ecological impact that will contribute to offshore activities and the expansion of coastal areas in an efficient and sustainable way. It demonstrated the economic feasibility of floating islands and provided a comparison between the modular floating hub (T&L@Sea, developed in the project) and respective container terminals situated onshore. The project qualifies for the *Validated technology* level as the integrated Space@Sea island was tested and demonstrated in the Offshore Basin of the Maritime Research Institute Netherlands (MARIN).

Four projects have demonstrated tangible results in the *Complete technology level* category: [SABANA](#), [SPG](#), [NEPTUN](#), [VicInAqua](#).

Twelve projects have *Other ready-to-use results*, namely [COLUMBUS](#), [ClimeFish](#), [SEAFOODTOMORROW](#), [FutureEUAqua](#), [CoastObs](#), [AQUACOSM](#), [GAIN](#), [IMPAQT](#), [AquaVitae](#), [PerformFish](#), [MEDAID](#) and [ECOFISH](#). For example, [COLUMBUS](#) collected information and created 53 easy-to-read success stories of marine and maritime Knowledge transfer activities, which are shared with end-users (companies, stakeholders, governmental bodies). It produced newsletters, conference papers, presentations, guidelines, a methodology with an emphasis on Blue Growth, describing technical and non-technical barriers and socio-economic trends. The papers cover a broad spectrum of marine topics such as ocean acidification, fisheries environmental impact, coral health, and marine litter, among others.

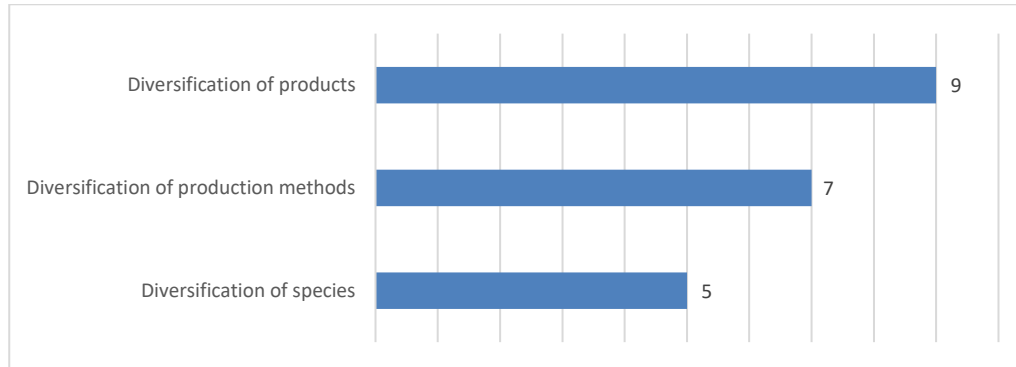
[VOPSA2.0](#) is a project for an innovative extraction technology. It extracts omega-3 fatty acids and astaxanthin (Carotenoid red pigment used for fighting oxidant stress) from algae containing 90% pure oil packed with vitamins, minerals, and antioxidants. The oils can be used in a wide range of industries, including food, pharmaceuticals, and cosmetics. Neoalga is a biotech company that coordinated the project and delivered a green solution to the traditional extraction of fish, or krill which affects marine resources and causes overfishing. Another collaboration [VOPSA2.0](#) has been involved in is with the partner company Bicosome. The collaboration led to two products ready for commercial use called Bicoalgae® Xanthin and Bicoalgae® for treating acne, atopic skin issues, and wrinkle prevention. There is a global demand for omega-3 and astaxanthin in a number of industries, including cosmetics and human consumption; hence, the project demonstrates good practice by developing sustainable and eco-innovative technologies delivering tangible results.

The **Diversification** heading is covered by 15 projects that foster farming of new species, labelling, quality schemes, production methods (for example, polyculture in pond aquaculture), processing, packaging aquaculture products, and geographical promotion of aquaculture. Nine projects focus on activities under the *Diversification of products* subheading. [Blue Iodine II](#) developed and produced a seaweed iodine product for human consumption which is extracted from seaweed biomass using cold press extraction and filtering techniques. The end result is a purified extract that provides the human body with a wide range of healthy nutrients, vitamins, and minerals (i.e. iron, calcium, magnesium, amino acids, etc). The project promotes product diversification by specialising in the creation/design of high-quality seaweed products, rich in iodine and protein. There is a gap in the market for high-quality pure aquaculture supplements packed with essential micronutrients that play a vital role in the human body; hence, the project contributes to a sustainable, contamination-free source of nutrient rich products that are part of a healthy diet.

Seven projects are associated with the *Diversification of production methods* subheading. Some of the results reported by [SEAFOODTOMORROW](#) are the optimised protocols to support improved seafood production by using an Integrated Multi-Trophic Aquaculture system, a diversifying production method. The project also tested and validated methods to remove or reduce contaminants in seafood produce and ready-to-eat products. Hence, it ensures a sustainable safe production system and processing of aquaculture and

increase the profitability of the marine industry. Additionally, [SEAFOODTOMORROW](#) has developed a DNA database for identification of sea species in regular and highly-processed products. Only five projects have been assessed to be relevant to the *Diversification of species* subheading. [GENIALG](#) is a project that designed high-yielding seaweed cultivation systems and published a number of research reports with results on seaweed aquaculture (thus, it contributes to the diversification of farmed species). The project created a platform, held a training course, and focused on increasing the production and sustainable exploitation of two high-yielding low trophic species of the EU seaweed biomass (the brown alga *Saccharina latissima* and the green algae *Ulva spp.*). [GENIALG](#) also has showed interest in boosting the Blue Biotech Economy.

Figure 5. Number of projects under Diversification subheadings



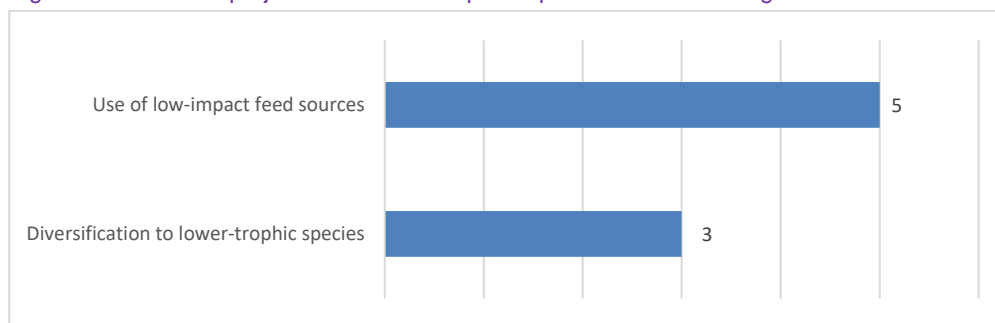
Only one project, [VOPSA2.0](#), has results that are assessed to belong to the *Complete technology readiness level*.

Three projects, [ELOXIRAS](#), [CryoPlankton2](#), and [Blue Iodine II](#), have results that are classified as having a *Validated technology readiness level*. [ELOXIRAS](#) created water-treatment systems for recirculating aquaculture systems (ELOXIRAS® HYBRID, ELOXIRAS® MINI, ELOXIRAS® LOGISTIC, ELOXIRAS® BIO), which constitute a controlled setting to optimise production growth and fish survival and increase the efficacy of removing pollutants from the water. [Blue Iodine II](#) has been validated in a relevant environment as well, as it has developed and produced the seaweed iodine product – IODOBEM.

The results of another nine projects, [COLUMBUS](#), [SUCCESS](#), [CERES](#), [MUSES](#), [GENIALG](#), [SEAFOODTOMORROW](#), [FutureEUAqua](#), [GAIN](#), and [AquaVitae](#), have been classified in the *Other ready-to-use results* category. [MUSES](#) developed a platform with 7 case study-based ready-to-use analyses and an Action Plan that will help users to identify multi-use potentiality, opportunities and limitations of the European sea basins; therefore, it is expected to lead to a number of local benefits while reducing barriers, impacts, and risks. Its scientific documents will contribute to increasing the competitiveness and economic performance of Europe's aquaculture sector. The results of two MSCA projects, [IntegraSea](#) and [GHaNa](#), were not assigned to any tangible result category.

Low trophic aquaculture (LTA) covers topics such as marine species such as macroalgae, clams, seaweed, unfed shellfish, and species that feed on plant products. Five projects, [SABANA](#), [SEAFOODTOMORROW](#), [FutureEUAqua](#), [CryoPlankton2](#), [Blue Iodine II](#), are relevant to the *Use of low-impact feed sources* subheading. The subheading focuses on incorporating feed sources from algae, which have a reduced carbon footprint vis-a-vis land-based animal proteins. One of the results of [FutureEUAqua](#) is the development of commercially relevant tailored-made aquafeeds with a low environmental impact. The *Diversification to lower-trophic species* subheading, which promotes lower-trophic species such as molluscs, other invertebrates, algae and herbivore fish, is covered by three projects: [GENIALG](#), [SEAFOODTOMORROW](#) and [AquaVitae](#). [SEAFOODTOMORROW](#) has promoted an advanced production technology for ready-to-use sea products that first, detects contaminants, and then reduces/removes them leading to cleaner, high-quality aquaculture products of higher social, economic and environmental value added.

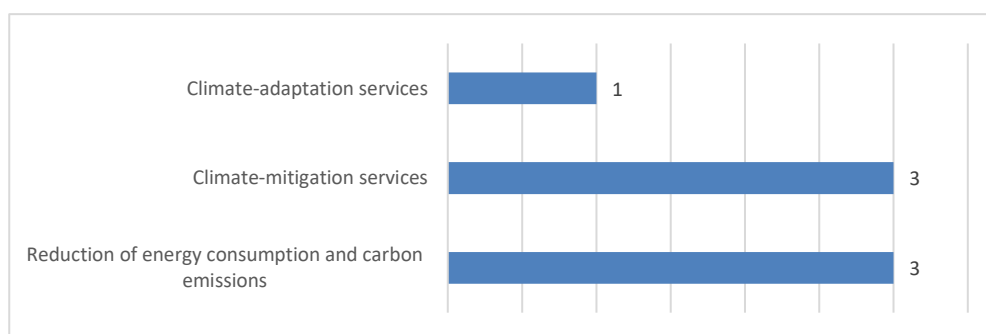
Figure 6. Number of projects under Low trophic aquaculture subheadings



One project, [SABANA](#), has reported tangible results in the *Complete technology readiness level* category and another two, [CryoPlankton2](#) and [Blue Iodine II](#) belong to the group of projects with *Validated technology readiness level* results. The results of five projects are included in the group of *Other ready-to-use results*. These are [COLUMBUS](#), [GENIALG](#), [SEAFOODTOMORROW](#), [FutureEUAqua](#), and [AquaVitae](#).

The **Climate change adaptation and mitigation** heading aims at improving the resilience of aquaculture in the sense of mitigating the effect of climate change and adapting to its impacts. Climate mitigation measures and services include nature-based coastal protection, carbon sequestration, effective management of sea-level rise and floods, reduced energy consumption and carbon emissions from production, transport, and processing. Subheading *Reduction of energy consumption and carbon emissions* is covered by three projects, [SABANA](#), [Space at Sea](#), [The Blue Growth Farm](#). The [Blue Growth Farm](#) has built an automated, modular, multi-functional platform that is environmentally-friendly. It has been designed to cater for open sea farm installations of the Blue Growth Industry and its purpose, which is directly linked to minimising energy consumption levels, is to adapt large storage and deck areas to host commercial 10 MW wind turbines and several wave energy converters. [CERES](#), [AQUACOSM](#) and [ClimeFish](#) are relevant to the *Climate-mitigation services* subheading. [AQUACOSM](#) measured the different effects of multiple stressors on the whole ecosystem (climate, pollution) and how they impact aquatic ecosystems through mesocosm experiments in both freshwater and marine facilities to fill in the existing research and infrastructure gap. It has created 37 mesocosms facilities around Europe and a Transnational Access platform – an online portal for application and provision to the mesocosm facilities, data handling, announcements of collaborative activities, teaching, social networks, and newsletters. One project, [ClimeFish](#), goes under the subheading *Climate-adaptation services*. The project produced Climate adaptation guidelines, and an e-learning course that provides an overview of practices related to “Climate Change Adaptation and Mitigation in Fisheries and Aquaculture”. [COLUMBUS](#), is another project included in this heading due to its broad spectrum of marine topics covered. The project serves as a Knowledge Transfer platform for Blue Growth that gathers success stories. The project’s database plays a vital role in raising/ awareness, knowledge, and skills to end-users such as policymakers, industry, science and the wider society.

Figure 7. Number of projects under Climate change adaptation and mitigation subheadings



The results of [SABANA](#) have been categorised in the *Complete Technology readiness level* group, while [Space at Sea](#) and [The Blue Growth Farm](#) projects have validated their technology. *Other, ready-to-use results* have been delivered by [COLUMBUS](#), [ClimeFish](#), [AQUACOSM](#), and [CERES](#).

The additional category “Other” encompasses 24 projects divided in two subcategories:

- Projects that fall into one, or more of the main headings, and in addition, are relevant to other vital topics (such as organising training events, spreading knowledge and skills on aquaculture, etc.) related to aquacultures that are not explicitly covered in the 5 main headings. This subcategory includes 17

projects. For example, [GAIN](#) is classified under the main headings of *Environmental performance* and *Diversification* but the project also lays emphasis on eco-intensification (increasing production and competitiveness of the industry; sustainable production; circular economy). [VIVALDI's](#) work includes shellfish farming in addition to the heading *Animal health and welfare*. [EVOMA](#) is classified under *Animal health and welfare* but its activity also extends to ocean acidification. The other projects in this subcategory are [SUCCESS](#), [MUSES](#), [FutureEUAqua](#), [BlueBio](#), [EMBRIC](#), [AquaSpace](#), [MEDAID](#), [eForcis and BeForcis](#), [VicInAqua](#), [ECOFISH](#), [SAFE-Aqua](#), [ALGAE4A-B](#), [IntegraSea](#), [PROTECTA](#).

- Projects that are not relevant to any of the 5 main headings, but are still related to aquaculture. This subcategory encompasses seven projects whose topic of interest is on improving the competitiveness and economic performance of Europe's aquaculture sector and increasing consumer awareness, challenges and recommendations, training activities, increasing knowledge and innovation, marine biotechnology, EU aquaculture research facilities, collaboration between academia and industry, increased production of aquaculture and spatial planning, and protection of the ocean. For example, [EURASTIP](#) is focused on building international cooperation in industry and trade between the EU and Asia, and organises workshops, training activities, exchange programs and brokerage events. The project compiled a database based on stakeholder mapping in Asia and their respective aquaculture production/value chain. [PrimeFish](#) is concerned with improving the competitiveness and economic performance of Europe's aquaculture sector and increasing consumer awareness and does not fall into any of the five main headings. [BlueBRIDGE](#) focuses on improving the competitiveness and economic performance of Europe's Blue growth sector as it developed 66 web-based platforms, referred to as 'Virtual Research Environments' (VREs), each giving access to tailored data and services providing a better understanding of the marine and maritime environments, their living resources, and economies. The project also provided a report on best practices and socio-economic performance analysis on aquaculture and has thus increased knowledge and supported capacity building to boost the Blue Growth sector while not demonstrating relevance to any particular main heading. [AquaSmart](#) strives to increase knowledge and innovation by delivering results on a variety of themes including enhancing innovation capacity and improved business performance that are marine related. Designed to increase knowledge and underpin innovation, [AQUAEXCEL2020](#) deals with EU aquaculture research facilities. The [TAPAS project](#) is focused on sustainable growth and increasing knowledge and innovation as it has developed a web-based Aquaculture toolbox containing tools to support the planning and licensing of aquaculture in Europe as well as modelling and guidance tools. [MARIBE's](#) main topic is the Blue Growth arena, seen as the main driver of growth for sustainable aquaculture which is indicated as a driver for sustainable aquaculture. The project produced a range of reports and databases that will promote a deeper understanding of the Blue Growth arena and, in particular, of the potential for multi-use of space and multi-use platforms.

No tangible results that can be applied by end-users have been identified for eleven MSCA projects. The latter are mainly focused on scientific research, reports, innovation, and scientific advancements through studies. In addition, they are still ongoing, and most have not yet reported any results. Nevertheless, several of them have outcomes that contribute indirectly to society such as books, trainings, workshops, etc. An example of this is [SAFE-Aqua](#), an MSCA-RISE project that focuses on building up collaboration(s) between academia and industry in the area of animal health and disease prevention. Seminars, workshops, participation in conferences, staff exchange experiences, publication of peer-reviewed articles and a book chapter are among the results delivered. Another example is [ShrimpLLH](#) that supports scientific experiments and the results described in CORDIS are two publications on shrimp immunology.

Table 2 provides information on the projects with identified specific tangible results that are publicly accessible and ready to use by end consumers. As some of the projects are still ongoing, the availability of information on some of the tangible results is rather limited. Most of these H2020 projects are led by organisations from Norway and Spain and their technology readiness level is considered complete technology.

Table 2. Presentation of project portfolio tangible results

Project acronym	Description of results	Category of results	Application/Relevance	Link to the project result
Presentation of portfolio tangible results with technological advancement				
SELAM	The project developed an automated production system for juvenile lobsters, which consists of an Automated Incubation System (AIS), and an Automated Release System (ARS).	Complete technology	The project improves the hatchery technology and shellfish sea/ocean ranching, resulting in sustainable and high-quality farmed EU lobsters that are to reach end customers. Animal health and welfare: Husbandry practices	https://norwegian-lobster-farm.com/production
SABANA	The project developed the first fully microalgae-driven wastewater treatment plant in Europe. It also sparked a number of innovations including biomass harvesting and processing technologies by GEA Westfalia, and microalgae biomass processing of feed additives by AIA, which boosts production of algae feed sources.	Complete technology	The technology (built by Biorizon Biotech) produces clean biomass for high value applications, while the technology (built by FCC Aqualia) is used for wastewater treatment through microalgae producing biomass for low-value applications. Environmental Performance: Mitigating the impact of aquaculture. Diversification: Diversification of production methods and Low trophic aquaculture: Use of low-impact feed sources	http://www2.ual.es/sabana/
SPG	The project developed an innovative chemical-free technology based on electric pulses to prevent sea lice infection (in salmon) and improve fish farming. The technology has been patented. The company delivers the technology to customers and currently has a few customers on the coast of Norway.	Complete technology	The SPG system will provide the industry with a solution to a number of major environmental challenges, including exploitation of aquaculture, boosting the sustainability of existing locations and allowing access to new areas. Animal health and mitigation: Husbandry practices and Disease prevention	https://harbor.no/fisk_ehelse
VOPSA2.0	The project developed a novel extraction technology that obtains pure omega-3 fatty acids and astaxanthin pigment from microalgae. The production system does not affect the marine ecosystem (fish and krill populations) and tackles overfishing issues since the marine ingredients are not extracted from fish but are produced from vegetable sources (microalgae). The technology also contributes to reducing the ecological footprint since the extraction bioprocess is characterised by low energy consumption.	Complete technology	The project relevance is vital for nutraceutical, cosmetic and pharmaceutical applications (i.e. human consumption, topical creams for skincare). The extracted Omega-3 and astaxanthin oils provide healthy nutrients, support human health and add value to the diversification of products (processing and packaging aquaculture products). Due to its plant-based origin, the product is also considered vegan friendly. Diversification: Diversification of products	https://neoalgae.es/divisions/rd-division/?lang=en

	<p>The following products are at commercial stage: For human consumption: astaxanthin (which is characterised as an organic red pigment called Carotenoid and prevents the cells from oxidant stress and has powerful antioxidant properties⁸), omega 3 oils; capsules of Spirulina and astaxanthin; Also, the development of the advanced systems Bicomage3 and Bicoxanthin led to the new BICOSOME skinline H creams (with H. Pluvialis extract) composed of two products: Bicoalgae® Omega 3 and Bicoalgae® Xanthin that treat wrinkles, atopic skin disorders and acne due to its anti-inflammatory and high antioxidant properties.</p> <p>Both companies BICOSOME and NEOALGAE had reached a commercial pre-arrangement about the supply of omega 3 and Astaxanthin oil for the production of the products.</p>			
NEPTUN	<p>The project developed a Closed-Cage Aquaculture System [CCAS] creating an environmentally- friendly, biosecure habitat for raising Atlantic salmon, so that the fish avoid contact with the surrounding marine environment. This minimises pollution and disease outbreaks and therefore, reduces mortality and improves the feed factor. It significantly reduces the risk of salmon lice and the release of organic nutrients and wastes into the surrounding environment.</p>	Complete technology	<p>The project has applications in the marine industries (e.g. farming). Animal health and welfare: Husbandry practices and Disease prevention. Environmental performance: Promoting aquaculture with a lower environmental impact.</p>	https://aquafarm.no/what-we-do/
eForcis and Beforcis	<p>The project developed wave energy generators. The eForcis WAVE POWER ELECTRIC GENERATOR extracts energy from sea waves and transforms it into electricity to supply power to offshore devices. The BeForcis technology is a Data buoy which allows fish farms to increase the use of feeding or surveillance cameras and many other sensors, which can contribute to the</p>	Complete technology	<p>The project has application in the energy efficiency wind sector and in boosting the blue economy as well as in the offshore aquaculture industry. For example, the BeForcis technology improves productivity, profitability, and sustainability in the offshore aquaculture industry. While the BeForcis technology delivers constant and reliable energy supply and can be used as a substitute for or as an addition to power sources in off-grid marine devices.</p>	https://www.eforcis.com/project/technology/

⁸ Webmd: <https://www.webmd.com/vitamins/ai/ingredientmono-1063/astaxanthin>

	improvement of the conversion ratio factor (fish produced against feed delivered) and reduce mortality.		Other: Generation of renewable and clean energy from the wind – Blue Economy Animal health and welfare: Husbandry practices and Improve animal welfare	
VicInAqua	The project partners developed an integrated approach to aquaculture and water management in the Lake Victoria region that will simultaneously protect the environment, enhance fish productivity and increase freshwater availability. The single solution water treatment (sanitation) presents a small technical self-cleaning membrane bio-reactor (MBR) which will be integrated into a domestic wastewater treatment system (DWTS), a pilot RAS and a fish processing industry. The project also empowers local stakeholders in the agriculture and aquaculture sectors. VicInAqua developed a tilapia hatchery in Kisumu, Kenya that runs using the RAS. The hatchery can produce 25,000 fingerlings per month to supply pond aquaculture in the area.	Complete technology	The developed technology can be applied in the effective sanitation of wastewater treatment and water supply facilities (aquaculture, households, fish processing industry), solid waste management and utilisation. It can also be used in agriculture- in case of extraction and use of natural by-products (nutrients can be used as fertilisers). Environmental performance: promoting aquaculture with a lower environmental impact Animal health and welfare: Husbandry practices	http://www.vicinaqua.eu/resources/
Presentation of portfolio tangible document-type results				
VIVALDI	The project created a manual for bivalve disease management and biosecurity incorporating solutions, a study report, as well as guidelines with recommendations, lessons learned and management techniques.	Other ready-to-use result	A guidance report on optimal husbandry practices that can be used for cultivation practices to reduce or avoid mortalities among oysters during cultivation. Also, a study report has been created on bivalve mortality data for oyster, mussel, and clam production related to different environmental factors/parameters such as temperature and salinity. Guidelines containing recommendations related to reducing mortalities and management of shellfish diseases are ready to use by relative stakeholders. Animal health and welfare	https://www.vivaldi-project.eu/Activities
Performfish	The project developed a tool called FEEDEST - PerformFISH Tool to Estimate Feeding Rates. The tool aims to help Mediterranean marine fish farmers' operations and performance become efficient in economic and environmental conditions as well as to ensure that the operations are socially and culturally responsible. It will also foster modernisation	Other ready-to-use result	The PerformFISH benchmark tool was developed to give an account of a system based on 55 Key Performance Indicators (KPIs) to be used by the Mediterranean Fish Farming industry to get information about the differences between the technologies and production systems used by the industry. Animal health and welfare: Disease prevention and Research on animal welfare and health Environmental Performance: Monitoring and Assessment	http://performfish.eu/raining/ www.webtools.sparos.pt/feedest

	through capacity building of the Mediterranean aquaculture workforce. The results of the project include the development of new more efficient vaccines for sea bass and gilthead sea bream protecting them against diseases. The vaccines were validated in commercial environments.			
CERES	The project developed a set of online tools providing stakeholders with invaluable data and suggestions for mitigation measures on climate change such as the type of fish and shellfish that will be profitable to farms, or which fish to breed, or sea plant to grow best in certain environmental conditions.	Other ready-to-use result	The project submitted a number of different reports including Industry- and policy-driven conceptual frameworks of climate change impacts based on stakeholder engagement, a MET database with data on the cultivation thresholds of aquatic animals and plants on the Maritime and Environmental Thresholds for Aquaculture database to be used by stakeholders. Also, CERES developed 4 potential socio-political scenarios that might occur in the future and discussed them with stakeholders, which is fostering knowledge and experience exchange. Environmental performance: Monitoring and assessment Diversification: Diversification of species Climate change adaptation and mitigation: Climate-mitigation services	https://ceresproject.eu/wp-content/uploads/2016/10/CERES-glossy-card-on-future-scenarios.pdf https://longline.co.uk/meta/
ParaFishControl	The project developed a unique tool that enables farmers to identify the risk of parasite infection and indicates the most appropriate and effective management strategy for parasites in terms of site characteristics and husbandry practices.	Other ready-to-use result	The project developed Fish Farmer's Guides to Combating Parasitic Infections in Salmonid, Turbot, Common Carp, European Sea Bass, and Gilthead Sea Bream Aquacultures that are ready-to-use by end-users. Animal health and welfare, encompassing different aspects of the sub-categories (e.g., prevention of diseases and parasite infestations, providing knowledge and skills on fish welfare to aquaculture producers, filling in research gaps on parasites; husbandry practices for particular species).	http://libros.csic.es/product_info.php?products_id=1407 http://libros.csic.es/product_info.php?products_id=1408 http://libros.csic.es/product_info.php?products_id=1409 http://libros.csic.es/product_info.php?products_id=1410
SUCCESS	The project explores new policies and innovations that have the potential to boost the European seafood sector by creating a number of reports that include cost-benefit analyses,	Other ready-to-use result	The project results have possible applications in the production sectors by providing scientific support to EU seafood producers and in the wider value chain by providing an overview of the current state of affairs and anticipated long-term developments, new	https://cordis.europa.eu/project/id/635188/results

comparative reports, impact assessment of technological and regulatory innovations and a paper on identification and quantification of non-market values.

products and packaging methods. They contribute to raising awareness as to product quality and organic labelling as well as the development of EU policies and regulations.

Diversification: Diversification of products

Auxiliary: Improving the competitiveness and economic performance of Europe's aquaculture sector and increasing consumer awareness

4.4. Knowledge gaps

Table 2 summarises the classification of the portfolio projects with respect to the five main headings and the tangible result categories. The numbers in the table show the number of projects associated with the respective heading or subheading and technology readiness of the tangible results identified. For example, nine projects have been found to be relevant to subheading *Monitoring and assessment*, of which one project reported a *Validated technology* result, another one - a *Complete technology* result, and six others - *Other ready-to-use* results. When considering the numbers in the table, one should take note of the fact that a project may be relevant to more than one heading or that a project may be relevant to a heading but for which no tangible results have been identified. A total of seven projects in each TRL category have qualified for both the *Validated and Complete technology* levels while *Other ready-to-use results* have been delivered by a total of twenty-eight projects. The number of projects under all headings totals forty-two.

Generally, most of the tangible results in almost all headings fall into the *Other ready-to-use results* category. However, there are some differences in the other result categories within the main headings. No project results have been classified as *Early stage (feasible) technology*.

Table 2. Technology readiness level per heading

Heading	Early stage (feasible) technology	Validated technology	Complete technology	Other ready-to-use results	Number of projects per heading
Environmental performance		6	4	12	22
Monitoring and assessment		1	1	6	9
Mitigating the impact of aquaculture		3		2	5
Promoting aquaculture with lower environmental impact		3	3	6	12
Climate change adaptation and mitigation		2	1	4	7
Reduction of energy consumption and carbon emissions		2	1		3
Climate-mitigation services				3	3
Climate-adaptation services				1	1
Animal health and welfare		5	5	8	25
Husbandry practices		4	5	4	13
Disease prevention		2	2	4	11
Improving animal welfare		3	1	2	6

Research on animal health and welfare				7	15
Diversification (species, products, production methods)		3	1	9	15
Diversification of species		1		4	5
Diversification of production methods		2		5	7
Diversification of products		2	1	4	9
Low trophic aquaculture (LTA)		2	1	5	8
Diversification to lower-trophic species				3	3
Use of low-impact feed sources		2	1	2	5
Total		7	7	28	42

Under the **Environmental performance** heading, 10 projects or nearly half of the projects relevant to this heading, have delivered results that are *Validated technologies* or *Complete ready-to-use technologies*. This relatively sound performance reflects mainly the concentration of higher technology level results in the *Promoting aquaculture with lower environmental impact* and *Mitigating the impact of aquaculture* subheadings. Only one project reporting *Validated technology* level results and a project yielding *Complete technology* level results account for the *Monitoring and assessment* subheading.

The **Animal health and welfare** heading, which encompasses the largest number of projects, has a relatively good project coverage, delivering on the two high-tech categories: *Validated* and *Complete ready-to-use* technologies, accounting for approximately 40% of the relevant projects. The latter cover mostly areas like *Husbandry practices* and *Improving animal welfare*. On the other hand, the *Disease prevention*, and especially the *Research on animal health and welfare* subheadings fall short of results with higher TRLs and report mainly document-type results and deliverables. There is a notable knowledge gap discerned in the *Research on animal and welfare* subheading that lacks technological results and shows no projects with validated or complete technology levels.

There is a significant knowledge gap in **Climate change adaptation and mitigation**. On the one hand, the number of projects relevant to this heading is limited. At the same time, only one project has yielded *complete technology* results (in the area of *Reduction of energy consumption and carbon emissions*), two projects delivered *Validated technology* results, whereas the other tangible results identified are document-type. *Reduction of energy consumption and carbon emissions* is the only area reporting *Validated technology* results. Overall, there is an underrepresentation of technology readiness in the heading.

The tangible results identified for the projects under the **Diversification** heading are skewed towards the *Other ready-to-use results* category. They are the prevailing type of results in all subheadings. The limited number of projects reporting *Complete* or *Validated technology* results are relevant to *Diversification of species and of products*. *Diversification of production methods* reported only *Other ready-to-use* tangible results. As the number of projects relevant to this heading is rather large (within the portfolio), the lack of technologically advanced results is alarming.

The knowledge gaps identified under the **Low trophic aquaculture** heading demonstrate a similar trend. The total number of projects is smaller. Furthermore, most of them do not report technologically advanced results. Only three projects, relevant to the *Use of low-impact feed sources* subheading, report *Complete* or *Validated technology* results.

Combining the information in Section 4.3 on the number of projects per theme and sub-theme and the type of results, it can be concluded that the widest gaps are to be found within the *Diversification*, *Climate change adaptation and mitigation* and *Low trophic aquaculture* themes. A comparatively small number of projects (within the portfolio) are relevant to the above headings and most of the identified tangible results are with low TRLs or document-type ones. It follows that supporting projects that deliver ready-to-use and focused solutions in, for example, the areas of farming species with a lower environmental footprint, polyculture practices in pond aquaculture, practices that lead to reduction in energy consumption and/or carbon emissions, carbon sequestration or nature-based coastal protection and introduction of feed sources from algae production, may result in narrowing down the gaps.

In conclusion, the results most commonly delivered by the projects are document-type ones that focus on spreading knowledge through guidelines, methodologies, documents, platforms, etc. Projects delivering validated or complete technology results are limited and clustered in the *Environmental performance* and *Animal health and welfare* headings. Results that qualify for the *Diversification* and *Low trophic aquaculture* headings are mainly low TRLs. The *Climate change adaptation and mitigation* heading can be said to be marked by an underrepresentation of the technology readiness results.

5. CONCLUSIONS AND RECOMMENDATIONS

Most projects are relevant to the *Animal Health and Welfare* (25) main heading followed by projects covering the *Environmental performance* heading (22). Projects making contributions to the *Diversification* heading amount to 15, followed by the smallest number of projects covering *Low trophic aquaculture* (8) and *Climate change adaptation and mitigation* (7). Although there is a number of portfolio projects under both the *Low trophic aquaculture* and *Climate change adaptation and mitigation* headings that meet the tangible results requirement, their coverage is relatively small compared to the other 3 headings. Therefore, these two areas need special attention. Lastly, the *Auxiliary “other” category* that has been specifically created for the purpose of this study covers a total of 24 projects focusing on a variety of aquaculture-related areas.

Almost half of the projects under the *Environmental performance* heading demonstrate *Validated technologies* or *Complete ready-to-use technologies* results. The *Animal health and welfare* heading displays a good coverage of project results in the *Complete ready-to-use* and *Validated technology levels* that focus mainly on *Husbandry practices* and *Improving animal welfare*. However, knowledge gaps are found in the *Disease prevention* and *Research on animal health and welfare* subheadings. The project results under these two subheadings illustrate primarily document-type results and a lack of technological advancement. There is a noticeable knowledge gap in the *Climate change adaptation and mitigation* heading as only one project reports technological progress with identified *Complete technology* deliverables. *Reduction of energy consumption and carbon emissions* is the only area accelerating its activities in the *Validated technology* category. Overall, there is an underrepresentation of technology growth in the Climate change area. The *Diversification* heading represents the most results in the *Other ready-to-use results* category. The subheading *Diversification of production methods* has delivered only *Other ready-to-use* tangible results and no technological advancement, which can be identified as a knowledge gap. Also, *Diversification to lower-trophic species* can increase aquaculture production and boost the Blue Economy by bringing in revenue in an environmentally-friendly and energy-efficient way; hence there should be more projects covering this area. Similar knowledge gaps have been identified for the *Low trophic aquaculture* heading pointing to a lack of technological advancement in the results.

Overall, a total of 7 projects show a technological breakthrough and are identified under *Complete technology readiness level* covering different headings. Most of the tangible results in almost all main headings fall into the *Other ready-to-use results* category and are document-type ones (i.e., knowledge transfer platforms, data collection platforms, written guidelines, methodologies, reports, scorecards, etc.) focused on aquaculture that can help farmers, authorities, investors, regional and coastal communities to manage sustainable and resilient fish farming processes. No project outputs have been identified in the initial stage of their technology advancement, or *Early stage (feasible) technology level*. Projects delivering *Validated technology* or *Complete technology* results are limited in number. Projects demonstrating technological advancement fall mostly under the *Environmental performance* and *Animal health and welfare* headings. The most knowledge gaps are identified in the *Diversification*, *Climate change adaptation and mitigation* and *Low trophic aquaculture* headings. A relatively small number of projects are covered by the above headings (within the portfolio) and most of the identified tangible results have low TRLs or are document-type ones.

A number of recommendations can be drawn from the analysis of the project portfolio such as:

- It is recommended that advanced technological systems to monitor and assess the environmental performance of aquaculture activities should be built up.
- Gaps related to *Diversification, Climate change adaptation and mitigation* and *Low trophic aquaculture* can be filled in by employing ready- to- use solutions in the areas of farming species with a lower environmental footprint, polyculture practices in pond aquaculture, practices that lead to a reduction of energy consumption and/or carbon emissions, carbon sequestration or nature-based coastal protection, and introduction of feed sources from algae production.
- It is recommended that more investments in projects covering specific areas of expertise such as *Climate change adaptation and mitigation, Disease prevention* and especially *Research on animal health and welfare* and *Diversification* be made as they lack technological advancement that can be directly put in use.
- There is a need for improving the understanding of the aquaculture market since there is lack of accessible databases and information materials regarding diversification and low trophic species aquaculture (shellfish, algae and seaweed) application in fish farming (i.e., salmon feeding with kelp); hence, improving the communication activities as to the quality and safety of aquaculture products and their importance is essential to reach end-customers.
- There is a need to assess and examine the potential impacts of aquaculture on ecosystems and other organisms.
- There is a need to invest in real-time surveying technology for offshore marine aquaculture fisheries that will help the latter become an environmentally responsible source of aquaculture and commercial products. Also, there is a need for priority investment that augments and/or fosters synergies with other missions and EU initiatives to the EU Mission themes.

There is a need for in-depth research contributing to controlling emerging diseases in fish and developing organic non-antibiotic medications that fight parasitic infections and pathogenic bacteria in order to apply safety measures and precautions prior to the occurrence of any infection.

6. LIST OF PROJECTS

Project Acronym	Title	Programme / type of action	Total budget, €
MARIBE	Marine Investment for the Blue Economy	SC Food	1 977 951,25
COLUMBUS	COLUMBUS - Monitoring, Managing and Transferring Marine and Maritime Knowledge for Sustainable Blue Growth	SC Food	3 997 488,00
SUCCESS	Strategic Use of Competitiveness towards Consolidating the Economic Sustainability of the European Seafood Sector	SC Food	5 207 821,75
PrimeFish	Developing Innovative Market Orientated Prediction Toolbox to Strengthen the Economic Sustainability and Competitiveness of European Seafood on Local and Global Markets	SC Food	15 826 278,75
ClimeFish	Co-creating a decision support framework to ensure sustainable fish production in Europe under climate change	SC Food	5 195 216,25
CERES	Climate change and European aquatic RESources	SC Food	5 586 851,25
MUSES	Multi-Use in European Seas	SC Food	1 987 603,88
SABANA	Sustainable Algae Biorefinery for Agriculture and Aquaculture	SC Food	10 646 705,00
GENIALG	GENetic diversity exploitation for Innovative macro-ALGal biorefinery	SC Food	36 672 712,50
SEAFOODTOMORROW	Nutritious, safe and sustainable seafood for consumers of tomorrow	SC Food	7 516 875,48
Space at Sea	Multi-use affordable standardised floating Space@Sea	SC Food	7 629 927,50
The Blue Growth Farm	Development and demonstration of an automated, modular, and environmentally friendly multi-functional platform for open sea farm installations of the Blue Growth Industry	SC Food	9 854 077,50
CLAIM	Cleaning Litter by developing and Applying Innovative Methods in European Seas	SC Food	6 185 612,75

FutureEUAqua	Future growth in sustainable, resilient and climate friendly organic and conventional European aquaculture	SC Food	7 083 501,25
BlueBio	ERA-NET Cofund on Blue Bioeconomy - Unlocking the potential of aquatic bioresources	SC Food	25 649 263,15
BlueBRIDGE	Building Research Environments for Fostering Innovation, Decision making, Governance and Education to Support Blue Growth	EINFRA	15 887 261,25
CoastObs	Commercial service platform for user-relevant coastal water monitoring services based on Earth observation	EO	6 920 733,75
AquaSmart	Aquaculture Smart and Open Data Analytics as a Service	ICT	9 327 232,50
EMBRIC	European Marine Biological Research Infrastructure Cluster to Promote the Blue Bioeconomy	INFRADEV	9 041 611,00
AQUAEXCEL2020	AQUAculture infrastructures for EXCELlence in European fish research towards 2020	INFRAIA	9 708 867,00
AQUACOSM	Network of Leading European AQUAtic MesoCOSM Facilities Connecting Mountains to Oceans from the Arctic to the Mediterranean	INFRAIA	9 999 806,57
AquaSpace	Ecosystem Approach to Making Space for Aquaculture	SC Food	3 625 581,25
ParaFishControl	Advanced Tools and Research Strategies for Parasite Control in European Farmed Fish	SC Food	8 104 133,75
TAPAS	Tools for Assessment and Planning of Aquaculture Sustainability	SC Food	6 918 512,50
VIVALDI	Preventing and mitigating farmed bivalve diseases	SC Food	5 414 417,50
EURASTIP	Promoting Multi-Stakeholder Contributions to International Cooperation on Sustainable Solutions for Aquaculture Development in South-East Asia	SC Food	1 998 779,00
GAIN	Green Aquaculture Intensification in Europe	SC Food	6 109 648,75
IMPAQT	Intelligent management system for integrated multi-trophic aquaculture	SC Food	6 218 180,00
OCEANFISH	Open Ocean Fish Farms	SC Food	3 354 000,00

SELAM	Large-scale piloting and market maturation of a novel process for sustainable European lobster aqua- and mariculture	SC Food	1 673 283,75
ELOXIRAS	Electrochemical Oxidation in the Recirculating Aquaculture Systems Industry	SC Food	2 030 633,48
CryoPlankton2	Cryopreservation of marine planktonic crustacean nauplii for innovative and cost-effective live feed diet in fish juvenile aquaculture	SC Food	2 004 250,00
Blue Iodine II	Boost BLUE economy through market uptake an innovative seaweed bioextract for IODINE fortification II	SC Food	1 147 826,25
AquaVitae	New species, processes and products contributing to increased production and improved sustainability in emerging low trophic, and existing low and high trophic aquaculture value chains in the Atlantic	SC Food	8 748 035,00
PerformFish	Consumer-driven Production: Integrating Innovative Approaches for Competitive and Sustainable Performance across the Mediterranean Aquaculture Value Chain	SC Food	7 690 393,72
MEDAID	Mediterranean Aquaculture Integrated Development	SC Food	6 999 996,25
VOPSA2.0	Value Omega 3 and Astaxanthin products from SeaAlgae	SME	1 980 665,00
SPG	Seafarm Pulse Guard	SME	2 516 250,00
NEPTUN	Novel closed-cage system for high-value marine aquaculture	SME	2 686 875,00
eForcis and BeForcis	Wave Energy Generators for Marine Buoys and Aquaculture Fish Farms	SME	1 427 406,25
VicInAqua	Integrated aquaculture based on sustainable water recirculating system for the Victoria Lake Basin (VicInAqua)	WATER	2 997 710,00
ECOFISH	Research on the potential conversion of conventional fish farms into organic by establishing a model and good practice guide	MSC-RISE	580 500,00
ResisGal	Ostreid herpesvirus 1: Genetic selection of resistant strains and environmental interaction in the Atlantic coast of Spain (Galicia)	MSC-IF	170 121,60

GTHREG	Differential regulation of gonadotropins	MSC-IF	185 076,00
SAFE-Aqua	SustainAble Farming for Effective Aquaculture	MSC-RISE	900 000,00
ALGAE4A-B	Development of Microalgae-based novel high added-value products for the Cosmetic and Aquaculture industry	MSCA-RISE	972 000,00
IntegraSea	Integrated offshore cultivation of high value seaweed and their potential use in controlling harmful algal blooms.	MSCA-IF	148 635,60
PROTECTA	Pathogen-informed Resistance to Oomycete diseases in Ecosystems, Agriculture and Aquaculture	MSC-ITN	3 992 284,44
OPTIMAR	OPTical Imaging of Molecular and signalling Activity in Real-time: application to flatfish metamorphosis	WF (widening fellowships)	147 815,04
HappyFish	Understanding the role of the rainbow trout metagenome on growth and health in aquaculturally farmed fish	MSC-IF	212 194,80
EVOMA	The influence of Environmental Variability On Mussel Aquaculture and adaptation in the context of global ocean change	MSC-IF	158 121,60
GHaNA	The Genus Haslea, New marine resources for blue biotechnology and Aquaculture	MSC-RISE	1 602 000,00
ShrimpLLH	Role of non-phagocytic, lymphocyte-like haemocytes in the antiviral and antibacterial defence of shrimp	MSC	178 320,00

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This report supports the implementation of the Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030 and the EU Mission Restore our Ocean and Waters by 2030 by analysing 53 Horizon 2020 projects related to aquaculture and identifying tangible results that may be beneficial to the aquaculture community and readily used by various stakeholders and end-users. The information on each project in the portfolio is collected from CORDIS and, where available, from the project websites. Based on information on its objectives and activities, the relevance of each project to the main headings that stem from the Guidelines and the Mission is assessed.

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