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AQUASPACE

Ecosystem Approach to making Space for Aquaculture

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Deliverable 5.1

Synthesis of the lessons learned from the development and testing of innovative tools to support ecosystem-based spatial planning to aquaculture

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Executive Summary

This document synthesises the process, results and main outcomes obtained in the project entitled "Ecosystem Approach to making Space for Aquaculture (AquaSpace)". AquaSpace is funded by the EU Framework Programme for Research and Innovation (Horizon 2020; Grant agreement nº: 633476); corresponding to the research topic of optimizing space availability for European Aquaculture (SFS-11a-2014).

The central goal of the AquaSpace project is to optimise and increase the available area for aquaculture, in both marine and freshwater environments, by adopting the Ecosystem Approach to Aquaculture (EAA), and spatial planning for aquaculture in the wider context of the most relevant European legislation and policies: Maritime Spatial Planning Directive (MSP Directive), Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD), Birds and Habitats Directives, Integrated Marine Policy (IMP) and other policy mechanisms. AquaSpace aims to contribute to: (i) increased production; (ii) employment opportunities; and (iii) economic growth of the aquaculture sector.

This report is Aquaspace Deliverable 5.1, a synthesis of the key project results and outcomes from four project work packages:

1. The identification of industry-wide issues and options presented as the key points constraining or strengthening the growth of aquaculture in Europe (WP2).
2. Mapping a wide variety of tools and methods against the constraints identified in WP2 and testing and development of tailored tools (WP3).
3. Tools validation working collaboratively with stakeholders, in 17 aquaculture case study sites spanning a variety of scales, species, different trophic levels and different environmental interactions, and most importantly, with a range of key space-related development constraints as defined by local stakeholders (WP4).
4. Evaluation of tested tools and recommendations based on lessons learned and development of guidance (WP5).

The main outcomes of AquaSpace are based on cross case study comparison and experiences gained during the implementation of tools and methods supporting ecosystem-based spatial management of aquaculture (EB-SMA). The present synthesis document assesses current issues, needs and recommendations to spatial planning for aquaculture in Europe, along with Norway, the United States of America, Canada, China, and Australia, leveraging the AquaSpace partnership and the Galway Statement.[1] The analysis covers both marine and freshwater environments, which benefit from integration because, on one hand, more useful information is provided to policy-makers and managers through the analysis of countries as a whole; and on

[1] Galway Statement on Atlantic Ocean Cooperation Launching a European Union – Canada – United States of America Research Alliance.

another, there is a mutual learning process resulting from the comparison of the two environments.

In **Section 1**, the main context and drivers for spatial management under the Ecosystem Approach to Aquaculture is presented; which in turn was used to define the objectives of AquaSpace (**Section 2**).

In **Section 3**, a brief description of the 17 case study areas is presented regarding the location, environment for aquaculture development, production system and cultivated species; as well as the local relevance and trends in production. Moreover, current progress in the implementation of Spatial Planning and the Ecosystem Approach to Aquaculture is given. The main research topics tackled in AquaSpace within the case studies are summarised at the end of this section.

The engagement of regional and local stakeholders has been pursued from the very beginning of the project. During AquaSpace, 43 communication actions were undertaken with aquaculture-related stakeholders, which has allowed the project to reach up to 665 people (**Section 4**). This enabled the identification of the main issues that the stakeholders are facing related to aquaculture activity (**Section 5**).

AquaSpace has developed new and innovative tools to try to overcome some of those issues and to contribute to spatial management of aquaculture. The detailed description of four new tools, together with a review of previously existing tools, are described in **Section 6**.

An evaluation of existing tools and methods was performed by their implementation and testing in case studies (**Section 7**). The solution capacity and existing gaps for ecosystem-based spatial management of aquaculture are given.

The lessons learned during the previously described process, allowed the AquaSpace consortium to provide the vision and recommendations for further growth of aquaculture from stakeholder perspectives (**Section 8**) and the present and future needs and recommendations regarding the further development of tools and methods, to support the implementation of the EAA and develop spatial planning for increased production (**Section 9**). Finally, conclusions that have been extracted from AquaSpace are given in **Section 10**.

A set of Case Study fact sheets is annexed as **Section 14**.

1 Introduction

Currently, the EU aquaculture sector produces about 1.2 million tons of fish and shellfish with a total value of around EUR 4 billion (EC, 2016a). This is little over 1% of the global aquaculture production. The sector is composed almost entirely of micro-enterprises and provides employment to approximately 85,000 people (EC, 2016b). The EU demand for fish is met by EU aquaculture (10%) and EU fisheries (30%), with the remaining 60% of wild and farmed fish consumed imported from third countries. The estimated projection for aquaculture production in 2020 is an increase of over 300,000 tons (25%) to a total of more than 1.5 million tons (EC, 2016a).

At present, the most important farmed species in the EU are mussel, oyster, salmon, trout, carp, seabass and seabream (EC, 2016a), using various techniques such as e.g. on-bottom as well as off-bottom (rafts and long-lines) cultures for shellfish farming. Relatively small quantities of other species are also produced in freshwater (EC, 2016a).

The Strategic Guidelines for Aquaculture produced by the European Commission (EC, 2013) identified the need to increase aquaculture across Europe, and considered development of spatial planning for aquaculture as a key enabler of that activity. The reformed Common Fisheries Policy (CFP; Regulation (EU) 2015/812) places an increased emphasis on the sustainable development of aquaculture; including rules on aquaculture and stakeholder involvement. Thus, recognising that sustainable solutions should be achieved through integrating the social, economic and environmental dimensions.

In general terms, and as common conditions for aquaculture expansion globally, aquaculture requires access to sufficient space to fulfil favourable operational characteristics; minimise conflicts with existing or planned uses, including protected areas, and utilise locations that could support maximum production within acceptable limits of environmental impact. Hence, spatial planning for aquaculture is receiving increased attention globally, due to the need to optimise the use of space in the context of other uses—the aim is to increase global production of aquatic products, while maintaining environmental sustainability.

It is recognised that the allocation of new space and the increase of aquatic products, in both marine and freshwater environments, while maintaining environmental sustainability, requires adopting the Ecosystem Approach to Aquaculture (EAA), and spatial planning for aquaculture in the wider context of Maritime Spatial Planning (MSP), as required by the new Directive 2014/89/EU (European Union, 2014). Moreover, the spatial management of aquaculture should be developed under the framework of other environmental legislation such as the Water Framework Directive (WFD; 2000/60/EC) (Boyes *et al.*, 2016; Katsanevakis *et al.*, 2011).

In 2009, the International Council for the Exploration of the Sea (ICES) launched a strategic initiative on area-based science and management to examine the linkages between MSP and the ecosystem approach to management (Cormier *et al.*, 2015).

Ehler and Douvere (2009) describe MSP as "*a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process*". The EU define maritime spatial planning as: "*…the planning and regulating all human uses of the sea, while protecting marine ecosystems*" (European Union, 2014). The overarching scope is that the marine or maritime spatial planning should contribute to the effective management of marine activities and the sustainable use of marine and coastal resources, by creating a framework for consistent, transparent, sustainable and evidence-based decision-making (European Union, 2014).

Thus, to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources, the European policies promote the adoption of an ecosystem-based approach. Therefore, increasing and choosing optimal spaces for aquaculture usually faces many issues or constraints, given that they are understood as risks to full development and good management of aquaculture. One such constraint is the lack of space in coastal areas due to existing maritime activities, thus there has been a conscious move to explore moving aquaculture further offshore. This will have implications for implementation and compliance with the framework of Ecosystem-based Maritime Spatial Planning (Ansong *et al.*, 2017; Katsanevakis *et al.*, 2011).

Most EU Member States highlight the need to improve spatial planning for aquaculture, and some propose how this might be achieved, e.g. through better mapping, use of technologies such as GIS, and undertaking studies to identify potential new areas. Few (if any) countries commit to increasing the amount of space allocated to aquaculture in any definitive way.

The EAA is defined as "*a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity and resilience of interlinked socio-ecological systems*" (FAO, 2010; Soto *et al.*, 2008). The EAA is viewed as the main instrument for guiding the planning of aquaculture. There is compatibility between the current approaches of the EU and the more global approaches advocated by EAA through the UN Food and Agriculture Organization (FAO), but there remains a significant amount to do in terms of implementation.

In supporting the application of the EAA and spatial planning, spatially explicit methods and tools are needed to assess both, the environmental risks and benefits of management options with aquaculture (Aguilar-Manjarrez *et al.*, 2017; Stelzenmüller *et al.*, 2013). Due to this, attention is presently turning to the processes, methods and tools that allow practical implementation of the EAA (Aguilar-Manjarrez *et al.*, 2010) and spatial planning (Pınarbaşı *et al.*, 2017); as many of the steps in spatial planning and the EAA processes require or are facilitated by the use of software tools or other well-defined spatially-explicit methodologies (collectively referred to as "tools") (Ehler and Douvere, 2009).

2 Objectives

The central goal of the AquaSpace project is to optimise the available area for aquaculture, in both marine and freshwater environments, by adopting the EAA, and spatial planning for aquaculture, within the wider context of European legislation, such as the Marine Spatial Planning, Water Framework, and Marine Strategy Framework, Directives, and policies like the Integrated Marine Policy. The core objectives of AquaSpace are to: (i) support increased production; (ii) provide employment opportunities; and (iii) promote economic growth of the aquaculture sector. The project therefore set out to:

1. Identify key space-related development constraints experienced by aquaculture development as defined by regional and local stakeholders in a wide range of contexts and aquaculture types.

2. Review existing tools and methods supporting the implementation of the EAA and spatial planning and, the evaluation of tools capacity to overcoming some of the highlighted constraints.

3. Develop new tools to assist management plans and overcome key space-related development constraints.

4. Implement and test identified tools and newly developed ones across 17 case studies.

5. Provide lessons learned from case studies (across scales, socio-economic contexts, environmental conditions, and aquaculture types).

6. Develop guidance to assist specific user types (e.g. planners, farmers, public) in the selection of the tools most appropriate to their needs.

7. Develop an interactive web-based platform to provide access to the tools.

8. Establish an effective knowledge exchange to maximise the impacts of the project outputs.

3 AquaSpace approach

The AquaSpace project approach relies on four main pillars: (i) a detailed identification of the main issues highlighted by regional and local stakeholders, related to aquaculture activity from a multi-sectoral perspective; (ii) the implementation and testing of existing and newly developed tools in order to try and solve or partially overcome such issues; (iii) the evaluation of such tools to assess their capacity to partially/totally overcome these issues, the remaining gaps in functionalities, and the identification of good practice; and, finally, (iv) establish guidance and good practices for users and practitioners. ***Figure 1*** shows the project Work-Package (WP) structure set to work on these topics.

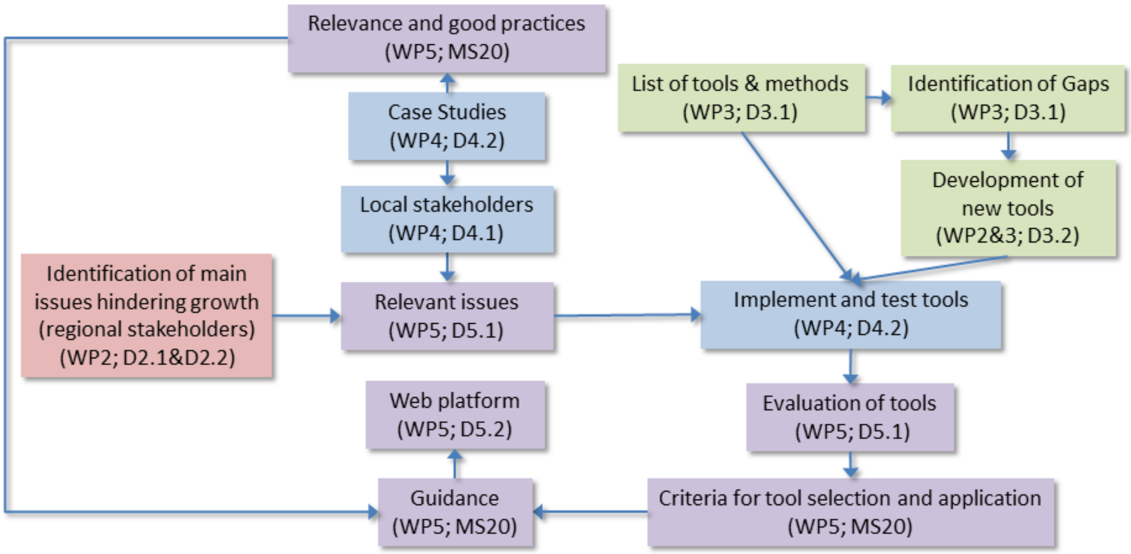


Figure 1. AquaSpace project approach towards the identification of increased space for aquaculture under EAA and Spatial Management. WP: Work Package; D: Deliverable; MS: Milestone.

The remainder of this section describes the Case Study approach, briefly describes the Ecosystem Approach to Aquaculture (EAA) and summarises the main research topics studied during Aquaspace.

3.1 Approach based on representative case studies

Within AquaSpace a cross-case study comparison methodology was used for the identification of commonalities and differences regarding the observed issues, the evaluation of solution capacity of implemented and tested tools and the identification of the remaining unsolved issues, together with guidance on good practices. Importantly, the adopted methodology includes qualitative knowledge (“soft” information) coming from stakeholders involved in aquaculture activities (mainly, private companies, administrations, and research bodies). The

AquaSpace project included 17 case study areas with broad geographical distribution and representative of different aquaculture types, including both marine and freshwater aquaculture, with differentiated characteristics in terms of aquaculture scale, production technologies, and species; as well as different management levels and characteristics of aquaculture activity in Europe, along with Norway, the United States of America, Canada, China, and Australia (***Figure 2***). Case studies are representative of key aspects of the implementation of spatial planning and management. The main characteristics of each case study area can be found in the case study fact sheets (see Annex); and a detailed description of the research and outcomes of the case studies are provided in Strand *et al*. (2017).

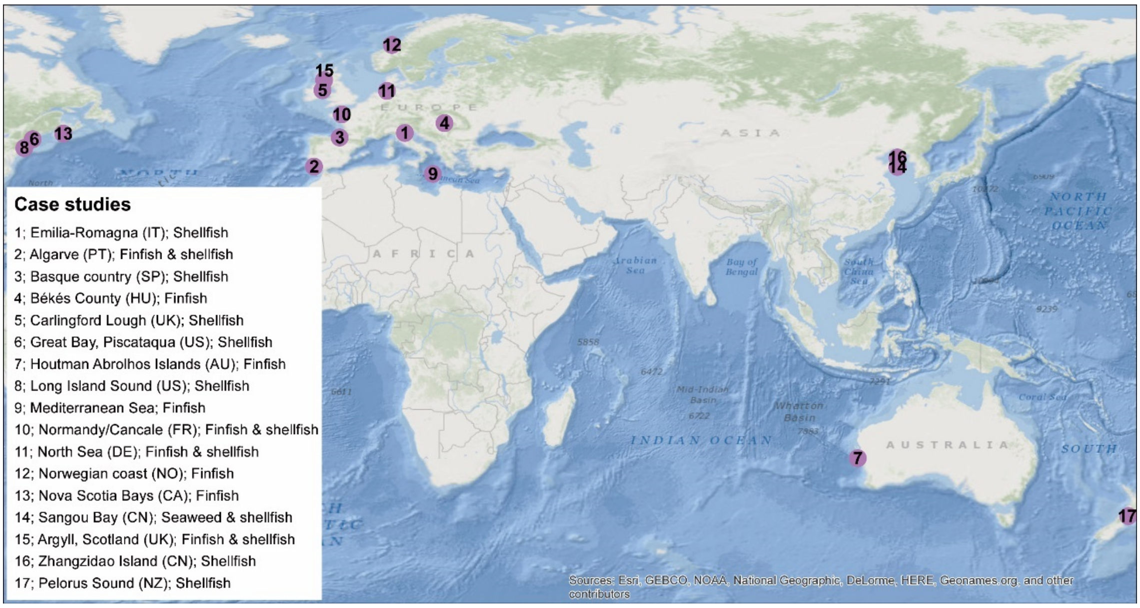


Figure 2. Geographical location of the 17 case studies and aquaculture type.

The case studies are representative of nine different aquaculture environments (***Figure 3***). The most commonly studied area is the open sea or offshore environment. These cases are representative of: (i) the present research needs for the expansion of aquaculture to new zones; (ii) the expected promotion for demand of new technologies; (iii) the assessment of environmental and production capacity; and (iv) the possibility for new conflicts that might arise from this expansion.

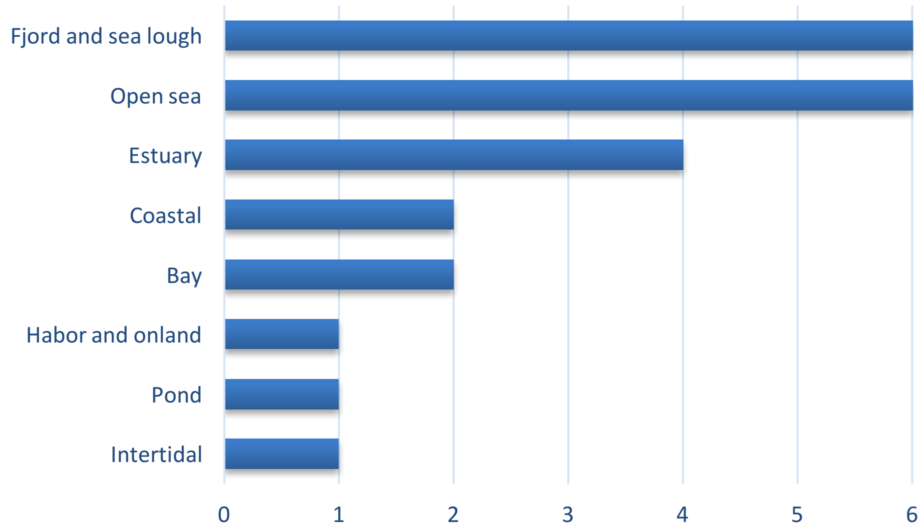


Figure 3. Number of aquaculture site environments analysed in AquaSpace.

Six production systems have been analysed in the AquaSpace case studies. The most common ones were long-lines mainly for bivalves and seaweed cultivation; followed by cages for finfish and integrated within Integrated Multi-Trophic Aquaculture (IMTA) systems, and rack and bag systems for bivalve cultivation in sheltered intertidal zones (Figure 4).

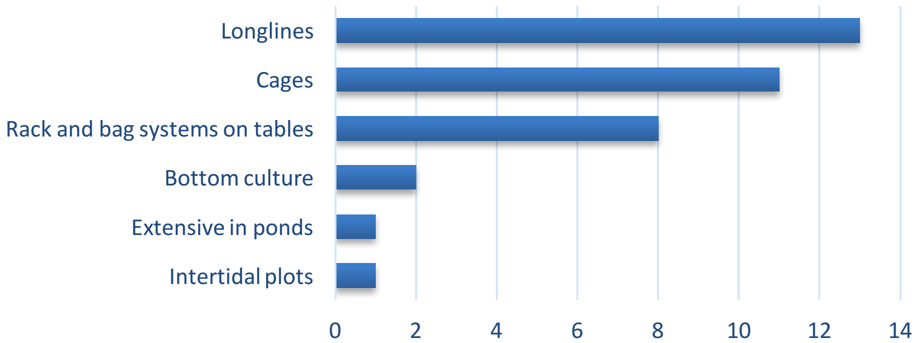


Figure 4. Number of cultivation technologies analysed in AquaSpace.

Case studies were also representative in terms of the cultivated species. A total number of 27 species of aquaculture interest have been studied corresponding to 5 groups (Figure 5):

Bivalves (13 species): Blue mussel (*Mytilus edulis*), Clam (*Ruditapes decussata*), Eastern oyster (*Crassostrea virginica*), Greenshell mussel (*Perna canaliculus*), Mediterranean mussel (*Mytilus galloprovincialis*), Oyster (*Ostrea edulis*), Pacific oyster (*Crassostrea gigas*), Yesso scallop (*Patinopecten yessoensis*)， Quahog clam (*Mercenaria mercenaria*), King scallop (*Pecten maximus*), Queen scallop (Ae*quipecten opercularis*), and two scallops (*Chlamys farreri* and *Patinopecten yessoensis*).

Finfish (8 species): Atlantic bluefin tuna (*Thunnus thynnus*), Atlantic salmon (*Salmo salar*), Carp (*Cyprinus carpio*), European seabass (*Dicentrarchus labrax*), Gilthead seabream (*Sparus aurata*), Rainbow trout (*Oncorhynchus mykiss*), Sea bass (*Lateolabrax maculatus*), and Yellowtail kingfish (*Seriola lalandi*).

Seaweed (3 species): Kelp (*Laminaria japonica*), and two seaweeds (*Alaria esculenta* and *Saccharina latissima*).

Echinoderm (1 species): Sea cucumber (*Apostichopus japonicus*).

Gastropod (1 species): Abalone (*Haliotis discus*).

The most commonly studied **species** were Pacific oyster, Blue mussel, Atlantic salmon and the Mediterranean mussel.

Differences in Aquaculture **production capacity** are also very large, mainly because of the geographical scale of the case study sites, as well as traditional and established aquaculture industry.

In terms of the **occupied area**, significant differences are observed across the case studies, with individual farms ranging from some tens of hectares (mainly due to space limitations in confined areas) in bays, fjords or estuaries up to many hundreds of square kilometres for extensive aquaculture production for freshwater aquaculture in ponds or bays in China.

In general terms, the **trends in production** for the case studies producing the most, such as China, is to maintain the present production. In others, the tendency is to increase the production of existing species, mainly by increasing the production area, or by introducing new species. Finally, a global decrease of 16% on production was reported in the Mediterranean international case study (FAO, 2015).

In most case studies, expected increases in production are mainly for oysters and mussels, both by increasing production through expanding the areas available or promoting it as a new activity or even by establishing this production in offshore areas.

Only three case studies plan new species cultivation. These are seabass and blue mussel in the North Sea, tuna production in Portugal and yellowtail kingfish in Houtman Abrolhos archipelago.

Only in China has **IMTA** been reported as being fully implemented; meanwhile, in other case studies, this approach is being analysed as a diversification and growth opportunity.

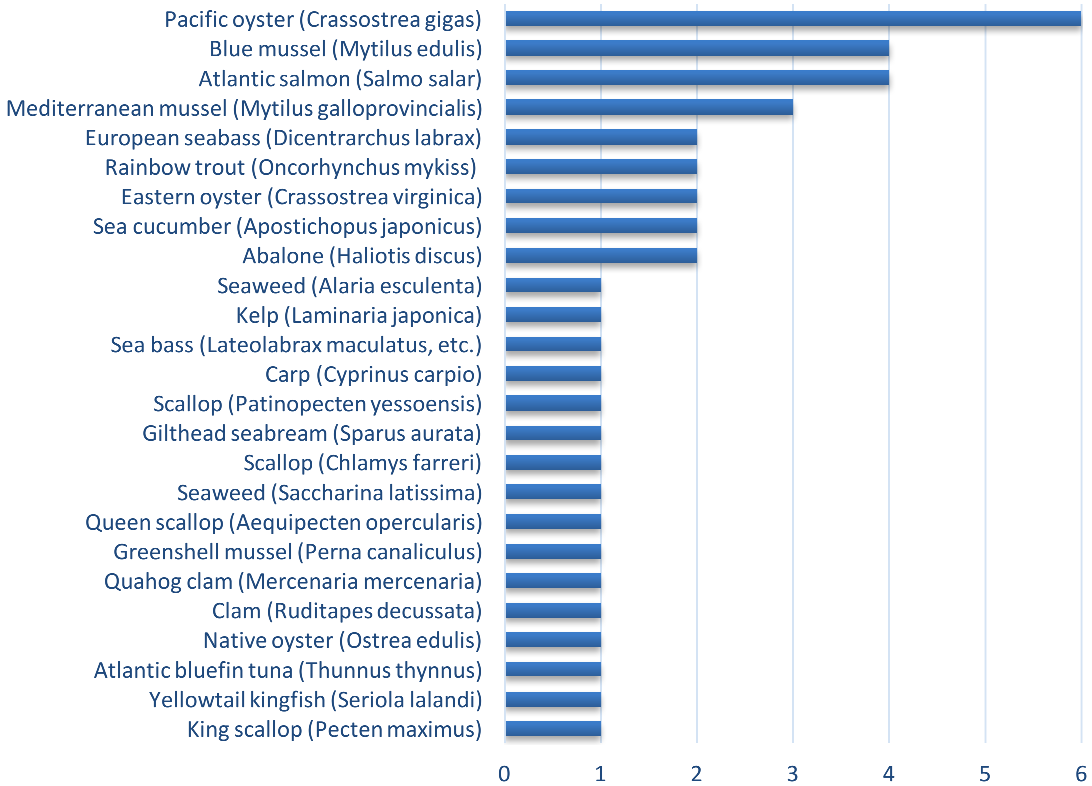


Figure 5. Number of case studies in which a particular species has been analysed.

Maritime Spatial Planning is implemented in three case study areas (Germany and, in China, Sangou and Zhangzidao island) and one pilot plan implemented in Algarve Coast (PT). In addition, another eleven case study locations have partially implemented MSP, it is forthcoming or has been implemented at sub-national level or at an administrative level (i.e. Emilia-Romagna, Adriatic Sea (IT); Basque Country (SP); Carlingford Lough (UK); Normandy/Cancale (FR); Argyll, Scotland (UK); Great Bay, Piscataqua (USA); Houtman Abrolhos Islands (AU); Long Island Sound (USA); Norwegian Coast; Nova Scotia Bays (CA); and Pelorus Sound (NZ)). Mediterranean Sea Multinational case study reported the existence of a zoning systems for aquaculture activity. Békés County (HU) reported that there are no spatial management measures in place. This means that for more than three quarters of the case study areas spatial management for aquaculture and other activities is in place or is expected to be in place soon (Figure 6).

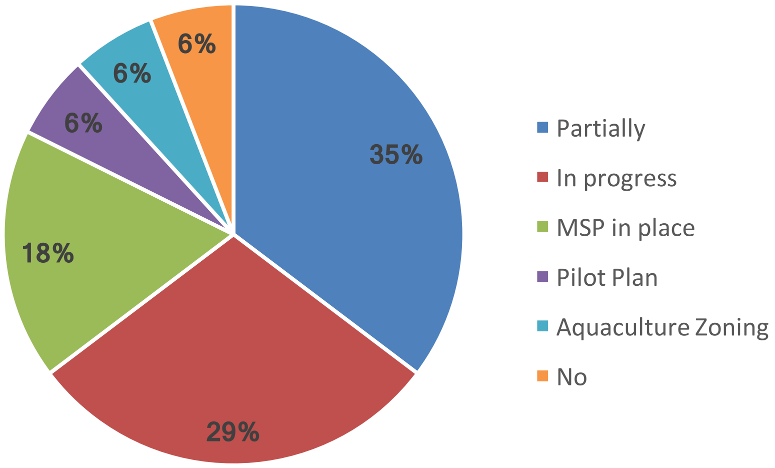


Figure 6. Maritime spatial planning or spatial management measures implemented in AquaSpace case studies.

3.2 The Ecosystem Approach to Aquaculture

The development of aquaculture should follow an EAA which comprises six steps (FAO and World Bank, 2015). Scoping (i) includes the establishing of the relevant geographical scales or ecosystem boundaries and the relevant stakeholders and institutions within each. The Identification of issues and opportunities (ii) integrates the selection of criteria thresholds to address the issues including considerations of risks (risk assessment and risk mapping). Subsequently, the maximum production is determined during carrying capacity estimation (iii), whereas the allocation of area/user access (iv) and/or management rights (consultation with stakeholders and setting operational and management objectives) are conducted according to this agreed production. Based on the results, the final management plans are developed (v). Their implementation and compliance are monitored (vi) and evaluated regularly, leading to planning and implementation adjustments – within the scope of the initially assessed opportunities and risks. Regarding EAA implementation, none of the case studies located in Europe reported it as being fully implemented; the USA and Canadian case studies are the only areas where specific progress towards EAA implementation was reported. Nevertheless, it must be noted, that in all case studies, analogous processes that could be linked to EAA steps were performed. This means that even if the EAA itself is not implemented at national level (the Italian National Strategic Aquaculture Plan, is the only such plan to mention the EAA), different national programmes for aquaculture management and development have already considered different steps of the EAA. In general terms, it could be observed that the EAA, or at least some of the steps, have already been implemented, but that in practice, is not explicitly cited in policy. National strategic plans have gone through the scoping process, by identifying opportunities for aquaculture growth and consultation with relevant stakeholders. Assessments of carrying capacity is another step of the EAA that has been undertaken, and other progress is mainly related to EIA that is required to fulfil the licensing process.

3.3 Main research topics

Each case study identified specific research topics according to specific realities and needs of the aquaculture sector in the studied area. The main research topics studied during AquaSpace, in order of frequency in Case Studies, were:

- Analysis of the opportunities to promote the sustainable development of new aquaculture activities in combination with other maritime uses. This point mainly refers to an analysis of conflict resolution and avoidance, and optimisation of resources and space. These studies included more specific topics:
    - Identification of new locations for offshore aquaculture as nearshore areas are already heavily used. This refers to a site selection analysis for the establishment of new aquaculture sites away from the more crowded coastal fringe.
    - Promote the coexistence of aquaculture with other strategic uses, such as tourism, wind energy, marine traffic; conservation and Marine Protected Areas (MPA). These case studies refer to areas where aquaculture activity already exists but, its increase and development is constrained by spatial conflict with other prioritised activities.
- Analysis of ecosystem services provided by aquaculture. To assess and value the benefits that aquaculture activities may provide to the ecosystems. This includes water purification, nutrient removal and habitat conservation (among others).
- Environmental carrying capacity and production capacity. This topic refers to models that are usually used to estimate how much biomass production could be expected in a certain location or region, which is of particular interest for economic assessments; as well as the environmental carrying capacity, needed to estimate the maximum production that could be conducted without adverse environmental effects.
- Disease risk: outbreaks, dispersion and connectivity. This topic relates to disease problems that could compromise the production and the costs of production; as well as the effects on wild fauna.
- Increasing production by optimising culture density and layout. This refers to studies that aim to increase production by increasing the density as well as the quality of the final product.
- Licensing process. This refers to the main problems that the industry or promoters encounter during the process of obtaining licences. Here, it should be highlighted that tools are usually not specifically designed for such purposes, but they could support or assist in the different stages of the licensing process.
- The potential of IMTA systems for increasing aquaculture carrying capacity.

It should be noted that each of the aforementioned research topics were analysed under the context and scope for which the tools and methods were implemented and tested.

4 *Involvement of stakeholders*

AquaSpace is focused on the assessment and development of integrated tools and methods to fulfil the needs and requirements of a range of aquaculture-related stakeholders, including managers, promoters, farmers, scientists, etc. For this purpose, stakeholder involvement was crucial to AquaSpace. The stakeholder consultation process included four main phases: (i) to identify the main issues regarding aquaculture growth; (ii) to consider the vision and needs of the stakeholders; (iii) to include their recommendations on more effective management of aquaculture; and (iv) to gather their opinions on existing tools and newly developed tools from the AquaSpace project. This assisted the consortium with the development and refinement of the tools and methods.

During the AquaSpace project 43 workshops, meetings and communication actions were utilised, reaching up to 665 stakeholders (Table 1), from which 34% were from industry or promoters, 25% from government, 34% from research, 4% from conservation and NGOs, and the remaining 3% were attached to other sectors, such as education and fishermen associations (Figure 7). Each stakeholder reported their perspective, identified issues and their own recommendations, which were collated, interpreted and categorised. Further details on the local case study workshops can be found in Bergh *et al*. (2016), Aquaspace Deliverable 4.1; and a regional review of policy-management issues in marine and freshwater aquaculture can be found in O´Hagan *et al.* (2017), Aquaspace Deliverable 2.1 (available at: http://www.aquaspace-h2020.eu/).

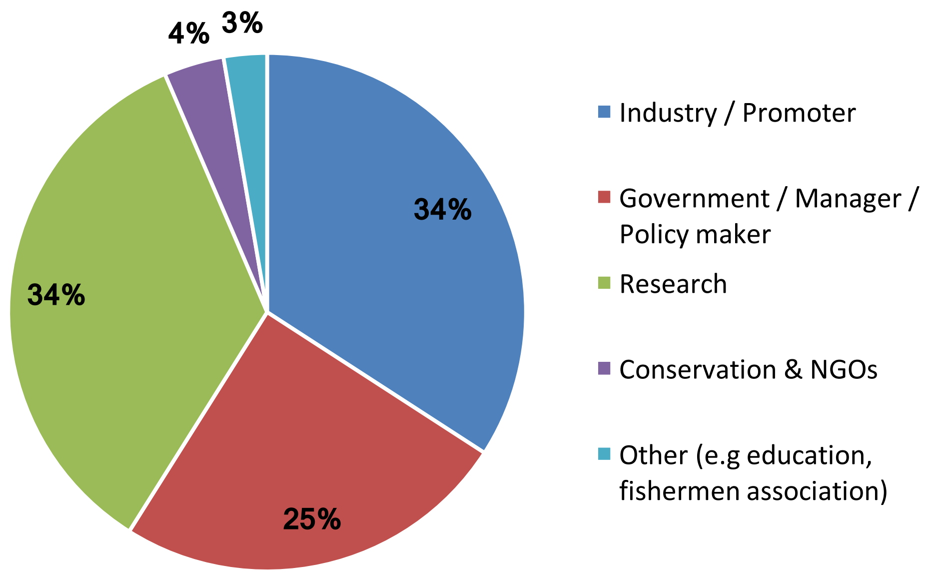


Figure 7. Composition of stakeholder types that attended the AquaSpace workshops.

Table 1. Total number of workshops held, number of participants and type of stakeholders involved in the project. NA: not available.

Case study	Number of workshops	Stakeholder type					Total number attendees
		Industry / Promoter	Government / Manager / Policy maker	Research	Conservation & NGOs	Other (e.g. education, fishermen association)	
01. Shellfish culture in Emilia-Romagna, Adriatic Sea, IT	1	19	18	10			**47**
02. Algarve Coast, PT	5	18	17	12			**47**
03. Basque Country, SP	2	14	16	6	3	5	**44**
04. Békés County, HU	2	33	34	16	3	5	**91**
05. Carlingford Lough, UK	Delayed						
06. Great Bay, Piscataqua, USA	1 workshop + phone call dialogue	60	3	14		2	**79**
07. Houtman Abrolhos Islands, AU	17 (meetings and dialogue)	1	8	3		2	**14**
08. Long Island Sound, USA	Phone call dialogue	1	1	14		1	**17**
09. Mediterranean Sea Multinational	1	1	4	8			**13**
10. Normandy/Cancale, FR	2	9	10	11	3		**33**
11. North Sea, DE	1	5	6	8	3		**22**
12. Norwegian Coast, NO	3	10	13	44	13		**80**
13. Nova Scotia Bays, CA	2						**NA**
14. Sangou Bay, China	3	23	3	38			**64**
15. Argyll, Scotland, UK	1	8	5	9		3	**25**
16. Zhangzidao Island, China	1	5	1	22			**28**
17. Pelorus Sound, New Zealand	1						**NA**
Mediterranean region stakeholders workshop	1	20	26	15			**61**
TOTAL	**44**	**227**	**165**	**230**	**25**	**18**	**665**

A total of 65 needs or measures for better management and aquaculture growth were reported. These were classified into 10 different categories according to their nature:

Governance: management, planning and policies: one of the common points raised was the need for better integration of national policy, local planning, and industry needs. The need to develop specific spatial planning for aquaculture activity and the identification of areas where aquaculture has priority over other uses was also identified. Spatial planning is seen as an opportunity to allow for the coexistence of aquaculture with other uses of the sea, not overemphasizing zoning. This relates to the adoption of measures for resolving conflicts with other uses, and should consider social, environmental and economic aspects, aiming to develop consensus among users. The previously cited needs rely on the political willingness to develop aquaculture at global and local scales, and the establishment of committees who meet on a regular basis to create a successful vision for aquaculture plans and to discuss new and emerging issues.

Administrative procedures / licensing: this refers to national or local governance processes needed to establish aquaculture activity. The most commonly highlighted needs here were to streamline licensing approvals and simplify administrative procedures.

Environmental research: This refers to the scientific research and knowledge that is required to promote aquaculture management within the EAA. The main needs or concerns from the aquaculture sector in this is the identification of potential areas for aquaculture growth, further investigation of the impacts caused by pollution on shellfish, the assessment of positive farm-ecosystem interactions (e.g. ecosystem services provided by certain aquaculture activities), and to investigate the present and future impacts that climate change will have on finfish and shellfish.

Technology: This refers to the technical developments required to promote and improve different aspects of the aquaculture industry. The most common needs identified include: modernisation and improvement of the activity, the need to diversify production including new cultivated species, enhance the quality and safety of aquaculture products, increase productivity per unit area/labour, and the adoption of measures to solve environmental issues thereby reducing negative impacts; as well as the development and implementation of new culture technologies for offshore areas.

Monitoring: This refers to the promotion of regional programmes for environmental monitoring provided by the state (e.g. for Harmful Algae Blooms - HAB); as well as the need to improve and update the monitoring regulations.

Management of farm activity: The need for developing better biosecurity and contingency plans.

Promotion: Make information on the different aspects of aquaculture activity visible and available to support knowledge transfer, exchange of best practices, support newcomers (e.g. marketing) and educate consumers (about the sustainability of aquaculture products and prices), with the final aim of increasing public awareness, acceptance and support for aquaculture activity and derived products.

Economic and market: This refers to the need to improve the sector's performance and competitiveness. This includes the need to diversify production in order to increase competitiveness in the market, enhance productivity and cost-benefit efficiency, address the price competitiveness with imports, and the need for a better post-harvest value chain; as well as the adoption of measures to increase business certainty.

Tools/models/methods: This considers the developments related to software, algorithms, methods or protocols that could support the fulfilment of some of the previously cited needs.

Given the varying nature of the identified issues, not all the needs could be fulfilled by the tools considered in AquaSpace. However, the tools and methods could help to achieve some of these needs. Some of the specific needs identified were related to the following topics: tools for site selection, the need for flexible tools concerning the estimation of potential biomass yield to be integrated within more comprehensive planning instruments and tools to assess disease outbreak, dispersion and exposure.

5 Observed issues hindering aquaculture development

Given that the issues are understood as risks for full development and good management of aquaculture, their identification represents an opportunity for understanding the context and limitations of aquaculture activity growth and development. Experience during the Case Studies has provided a highly relevant source of information for both the successful implementation of a spatial planning process under the EAA, and the development of fit for purpose operational tools and methods supporting the process.

This section concerns the key constraints experienced by aquaculture development in the wide range of contexts and aquaculture types that comprised the Case Studies. This analysis of constraints will later link to the account of tools implemented and tested in the case studies, in order to evaluate their capacity to overcome some of the constraints either partially or completely (see section 7), and to identify needs for future development (see sections 8 and 9).

In this section, the issues raised during the regional and local stakeholder workshops, as well as during the running of case study and internal workshops and discussions held in the AquaSpace consortium, are presented. A total of 146 issues were reported during this process. The list of issues was interpreted, filtered and classified resulting in 35 different types of issues (Figure 8). These were then further classified according to four dimensions: (i) Policy and management, (ii) Environmental, (iii) Economic and market, and (iv) Other sectors (which integrates the social dimension) (**Error! Reference source not found.**). In general, these are the four dimensions/pillars to consider in terms of aquaculture sustainability, which is a multidimensional concept. To ensure that aquaculture development contributes to Blue Growth the activity should be sustainable, which requires achieving certain objectives from all four dimensions. The institutional dimensions, that is, policy and management, are the most important to reach the objectives under the remaining dimensions.

The way in which each of the dimensions has been interpreted is shown below:

Policy and management:
Aquaculture activity is subject to different legal frameworks at international, national and local scales. At the EU scale, the MSP Directive requires Member States to develop integrated planning and management approach to maritime activities through the creative of Maritime Spatial Plans. Moreover, other requirements relating to environmental and conservation policies must be fulfilled (i.e. WFD, MSFD, Habitats and Birds Directives). These legal instruments can have direct effects on the implementation of EAA and availability of space for aquaculture. Specifically, a main concern commonly found within all the AquaSpace case studies (according to the stakeholders) is the complexity and timelines associated with administrative and licensing processes in order to gain permission for aquaculture activity; as well as regulation and planning issues which are seen to be hindering the expansion and growth of aquaculture. Conflicts with other users are also seen as a limiting factor. Other issues of less importance are also included in Figure 10.

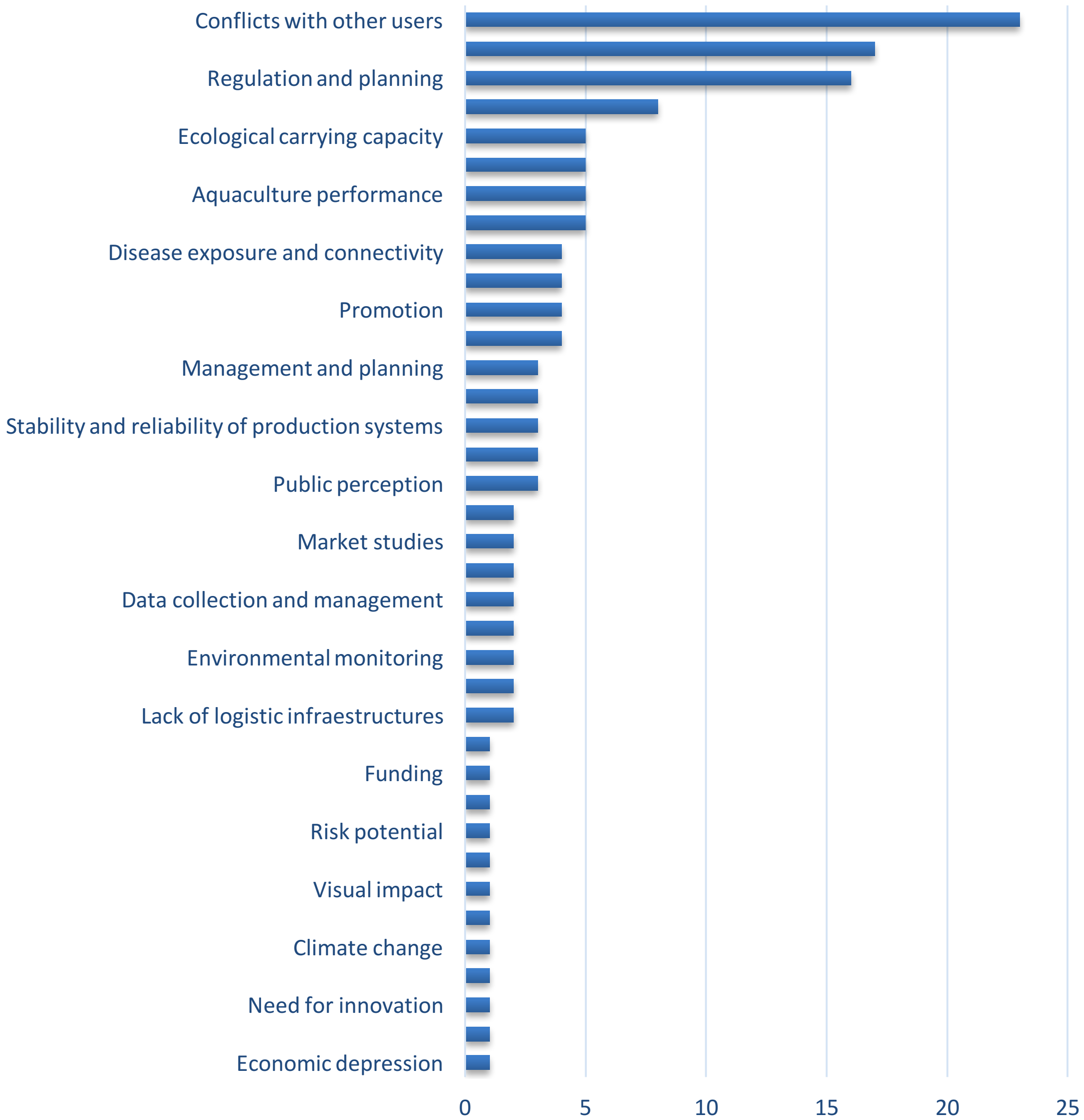


Figure 8. Most frequently reported issues by local and regional stakeholders, and number of citations.

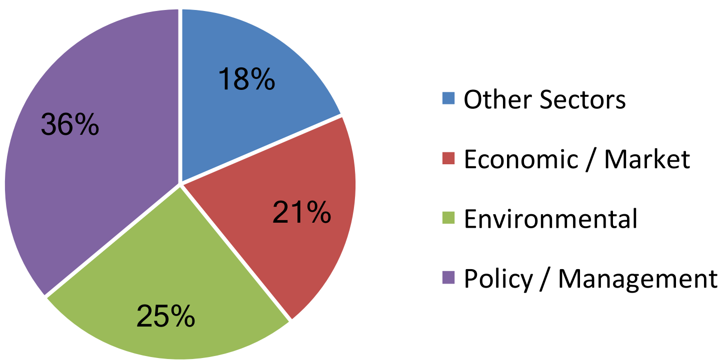


Figure 9. Proportion of the number of issues reported for each of the four dimensions considered in AquaSpace.

Figure 10. Frequency of reported issues with a policy and management dimension.

Environmental:

This dimension considers the effect of environmental conditions in both directions; limitations that the environmental conditions may pose to aquaculture as well as the potential effect of aquaculture on the environmental conditions. Environmental considerations in spatial planning of aquaculture should be considered at different stages and scales of zoning, site selection and area management. Environmental issues related to aquaculture arise from the effects of its waste products and associated human activities, together with disease outbreaks that depend on connectivity between farms for their spread. Regarding environmental conditions, issues relate to carrying capacity, limited areas of suitability for aquaculture production, HAB events and water quality. The complete list of identified issues is shown in Figure 11.

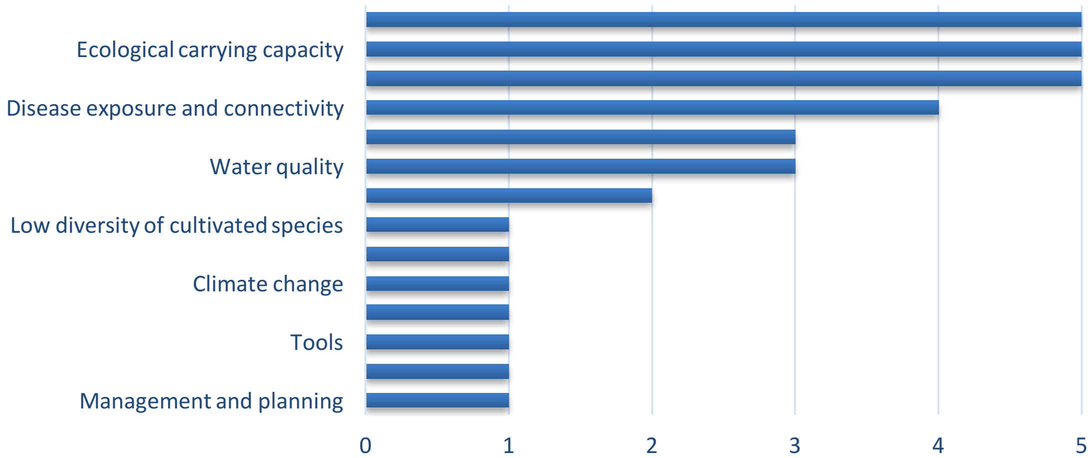


Figure 11. Frequency of reported issues with an environmental dimension.

Economic and market:

While numerous 'space' related factors constrain EU aquaculture expansion, the production cost is also seen as a limiting factor. This has a direct effect on international market competitiveness of European aquaculture products. The stability and reliability of production systems and the lack of market studies with price structure analysis, (particularly export-focused), coupled with the inability for small-scale producers to develop the sales and logistical platforms required, presents a significant market-related bottleneck. These are issues mainly related to the amount of fish or shellfish produced, while there are also others with less importance such as the level of consumer demand, or public perception. Finally, it is also important to consider that the economic sector, even locally, is strongly dependent on the global economy which affects market stability in general. Issues are listed in Figure 12.

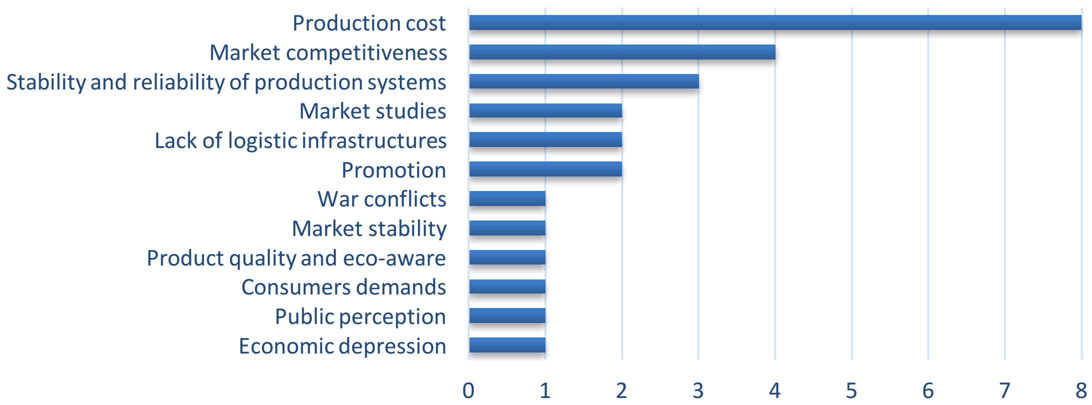


Figure 12. Frequency of reported issues with an economic and market dimension.

Other sectors:

Conflicts with other users are seen as the main issue for aquaculture expansion or for the allocation of new space for aquaculture production. Interactions between aquaculture and other activities are perceived as competition for space and may be either synergistic or antagonistic, but these effects are not always predictable and may be cumulative, so they need to be included in any assessment of aquaculture under maritime spatial planning and the EAA. Moreover, social perception and social licence are also factors to be considered. Conflicts between aquaculture and other sectors/uses are probably not yet fully realised, but their potential impacts must be considered in current planning processes as this will impact future planning and development of aquaculture areas (Figure 13).

The overarching driver is the scale of farming, as this affects the magnitude of the remaining issues. The issues presented here could be grouped and when they coincide in the same space and timescale, this could have a synergetic or antagonistic effect. Some of the issues are interconnected and it is not possible to solve them by acting solely in one dimension. Some of them are caused by underlying reasons that are outside the scope of the tools implemented and tested in AquaSpace. It is calculated that 43% of the issues listed above have a spatial component.

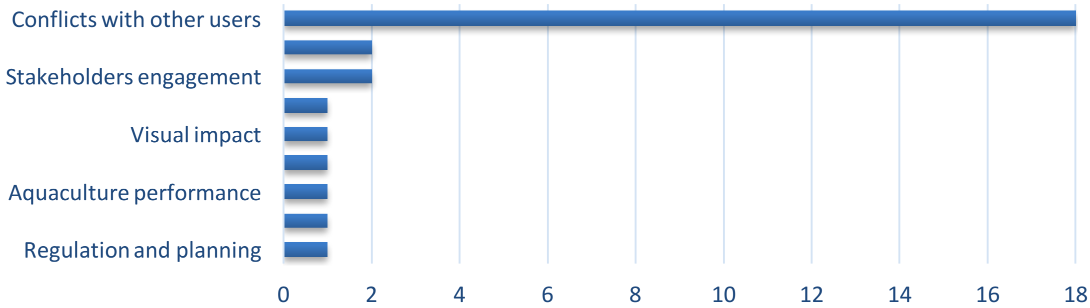


Figure 13. Frequency of reported issues with an ‘other users’ dimension.

6 Innovative tools developed and tested in AquaSpace

An essential element for the implementation of the EAA and spatial planning is the support that can be provided by tools and methods including Geographic Information Systems (GIS), remote sensing and mapping for data management, analysis, modelling and decision-making (Aguilar-Manjarrez *et al.*, 2010). A review of the tools and methods that can be used to facilitate and inform the spatial planning and EAA implementation process was developed in Aquaspace. In particular, a review was performed to target existing methods, models, tools and toolboxes used to scope for the spatial allocation of aquaculture activities in terms of environmental and economic costs and benefits (such as e.g. environmental potential and risks). The outcomes of the review can be found in Gimpel et al. (2016), AquaSpace Deliverable D3.1 available at: http://www.aquaspace-h2020.eu

When referring to tools and methods in this section, we use the following definitions adopted by Corner and Aguilar-Manjarrez (2017):

'Tool' has a very wide definition, and is considered to include any legal instrument (laws, regulations, guidelines), process (such as stakeholder engagement), computer model application (such as GIS, or computer models to assess impacts of aquaculture), or other approaches that can be used or be implemented to help and support the development of aquaculture; and the gathering, analysis and presentation of data to aid decision making.

'Model' is regarded as a predictive tool, mainly developed by numerical modelling specialists, using state-of-the-art equations to describe specific actions (e.g. fish growth), interactions (e.g. cage aquaculture wastes into the environment), and consequences (e.g. setting of local carrying capacity) of aquaculture. Models provide information to enable understanding of sometimes complex activities and interactions that would otherwise not be possible. Outputs from models, by definition, cannot provide definitive "answers", but do support decision making by giving outcomes (e.g. species growth, aquaculture waste deposition, changes to water quality from aquaculture activity) that improve understanding. Models generally require calibration to local conditions and validation through data collection.

Subsection 6.1 provides an overview of all tools applied in AquasSpace case Studies, and subsections 6.2 through 6.7 describe the new tools developed during AquaSpace.

6.1 Implemented and tested tools and methods

At each case study, different tools and methods were selected and implemented to evaluate their usability for different purposes related to aquaculture planning. Some of the analysed tools (25) were corresponding to existing, customised or adapted tools for the purposes of each case study; six other tools, were newly developed in the framework of AquaSpace (Table 2).

Table 2. List of tools analysed in AquaSpace. The table indicates if it is a newly developed, customised, adapted or further developed or an implementation of an existing tool.

Tool name	Tool development status
BLUEFARM-2	New tool
Stakeholder consultation (EAF)	Implementation of existing tool
GIS based tools (multicriteria analysis)	Implementation of existing tool
Remote sensing. Sentinel Application Platform (SNAP). Earth Observation	Implementation of existing tool
Hydrodynamic modelling	Implementation of existing tool
Multi-layer GIS mapping	Implementation of existing tool
Bayesian Belief Network	Custimised, adapted or further developed tool
Aquaculture Planning Decision Support: AquaSpace tool	New tool
Hydrodynamic modelling (Norkyst800)	Implementation of existing tool
Assessment of ecosystem services (e.g. MEA)	Implementation of existing tool
Stakeholder meetings	Implementation of existing tool
Public comment analysis and interviews	Implementation of existing tool
SMILE (Ecological carrying capacity model)	Implementation of existing tool
Web-based Aquaculture Planning Decision Support System (SISAQUA)	Customised, adapted or further developed tool
FARM (FARM Aquaculture Resource Management)	Implementation of existing tool
ASSETS	Implementation of existing tool
Avoided Cost approach - a cost-based economic analysis method	Implementation of existing tool
EcoWin	Implementation of existing tool
Disease connectivity analysis («fire break» positioning)	Customised, adapted or further developed tool
Aquaculture Planning Decision Support System (AkvaVis)	Implementation of existing tool
Virtual reality (visual preference surveys)	New tool
ArcGIS Visibility Analysis	Customised, adapted or further developed tool
Web-based Aquaculture Planning Decision Support System (APDSS)	Implementation of existing tool
Forecasts of mussel meat yield (NIWA Website)	Implementation of existing tool
Web-based Aquaculture Planning Decision Support System (sinoAkvaVis)	Customised, adapted or further developed tool
Aquaculture Investor Index	New tool
Where can Aquaculture Thrive in EuRope (WATER)	New tool
Maritime and Environmental Thresholds for Aquaculture (META)	New tool
WestLice (connectivity)	Customised, adapted or further developed tool

Each case study, implemented a set of tools to assess the different objectives stablished (Table 3).

Table 3. List of tools and methods implemented in each of the case studies.

Case study	Implented tool or method
01. Shellfish culture in Emilia-Romagna, Adriatic Sea, IT	BLUEFARM-2
02. Algarve Coast, PT	Stakeholder consultation (EAF)
	Remote sensing (STEP)
03. Basque Country, SP	Hydrodynamic modelling
	GIS based tools (multicriteria analysis)
	Bayesian Belief Network
	Aquaculture Planning Decision Support: AquaSpace tool
04. Békés County, HU	Multi-layer GIS mapping
	Assessment of ecosystem services (e.g. MEA)
	Stakeholder meetings
05. Carlingford Lough, UK	GIS based tools (multicriteria analysis)
	SMILE (Ecological carrying capacity model)
	Web-based Aquaculture Planning Decision Support System (AkvaVis)
06. Great Bay, Piscataqua, USA	FARM (FARM Aquaculture Resource Management)
	ASSETS
	Avoided Cost approach - a cost-based economic analysis method
07. Houtman Abrolhos Islands, AU	Modelling (EcoWin)
08. Long Island Sound, USA	GIS based tools (multicriteria analysis)
	EcoWin
	FARM (FARM Aquaculture Resource Management)
	ASSETS
	Avoided Cost approach - a cost-based economic analysis method
09. Mediterranean Sea Multinational	GIS based tools (multicriteria analysis)
10. Normandy/Cancale, FR	Web-based Aquaculture Planning Decision Support System (SISAQUA)
11. North Sea, DE	Aquaculture Planning Decision Support: AquaSpace tool
12. Norwegian Coast, NO	Hydrodynamic modelling (Norkyst800)
	Disease connectivity analysis («fire break» positioning)
	Existing industry structure
	Aquaculture Planning Decision Support System (AkvaVis)
13. Nova Scotia Bays, CA	GIS based tools (multicriteria analysis)
	Hydrodynamic modelling

Case study	Implented tool or method
14. Sangou Bay, China	Aquaculture Planning Decision Support System
15. Argyll, Scotland, UK	Public comment analysis and interviews
	Disease connectivity analysis («fire break» positioning)
	GIS based tools (multicriteria analysis)
	Virtual reality (visual preference surveys)
16. Zhangzidao Island, China	Web-based Aquaculture Planning Decision Support System (sinoAkvaVis)
17. Pelorus Sound, New Zeland	Forecasts of mussel meat yield (NIWA Website)

The analysed tools were classified into seven large groups according to the main function or purpose of its use even if there are tools that could be used for more than one purpose. Main uses of the tools and methods implemented in AquaSpace case studies were site identification (15); modelling (12); mapping (6); stakeholder engagement and consultation (3); economic analysis (2); Ecosystem services assessment (1); and scenario analysis (1) (Figure 14 and Figure 15).

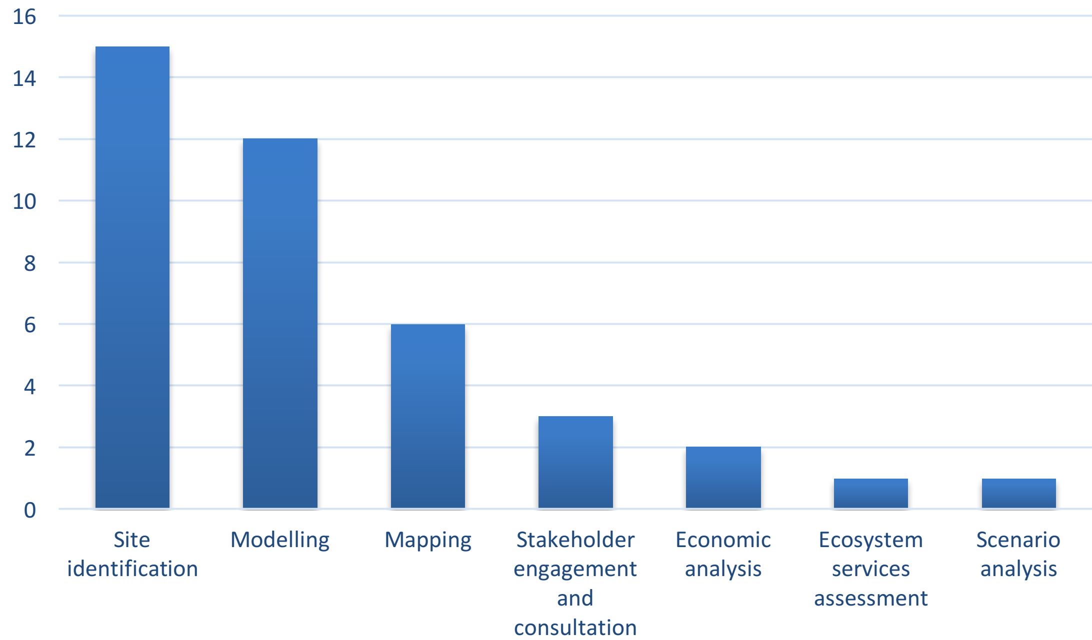


Figure 14. Number of times that tools and methods have been implemented and tested in AquaSpace case studies as a function of their main objective.

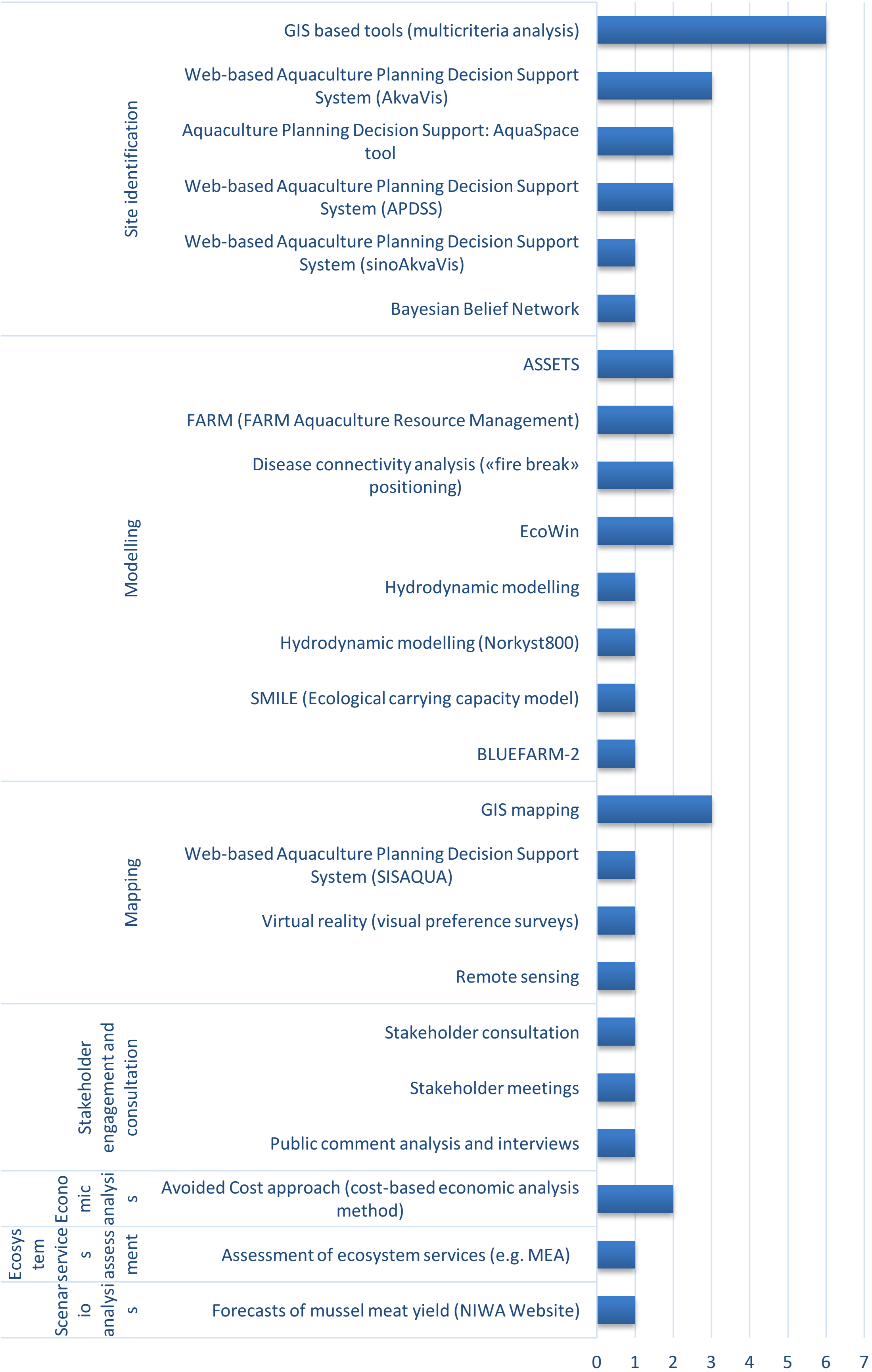


Figure 15. List of tools implemented and tested in AquaSpace.

Usually, the implemented tools and methods aimed at studying different dimensions of sustainable aquaculture management (i.e. considering environmental, economic and market, interactions with other users and policy and management) (). This demonstrates that when tools are implemented they were done so with the intention of analysing different aspects of aquaculture as a whole. The most commonly used tools were in relation to site identification and mapping; hence, indicating the awareness of considering all the relevant aspects, in this early stage of allocating new space for aquaculture growth, (Table 4).

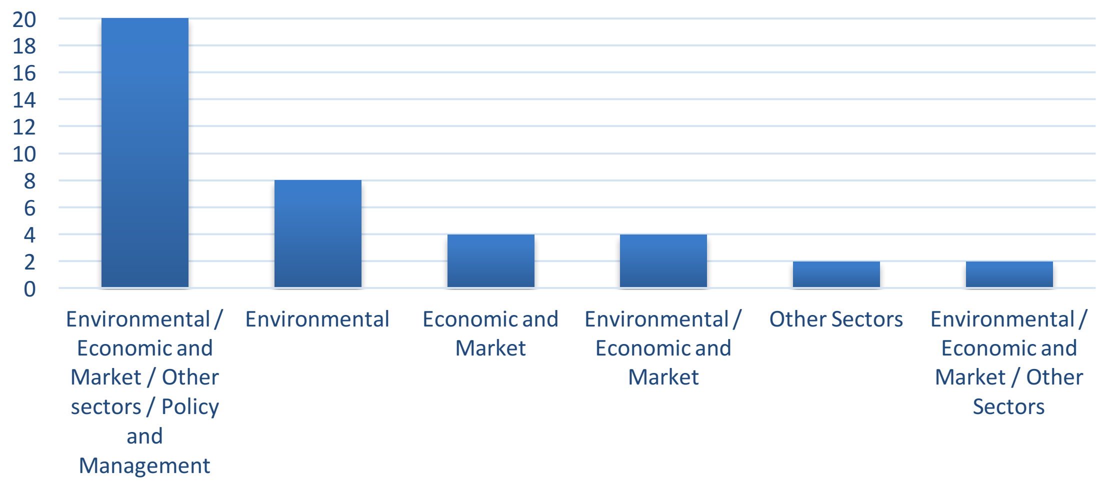


Figure 16. Number of tools implemented and tested for the sustainability dimension in AquaSpace case studies.

Table 4. Tool type implemented and tested for the sustainability dimension.

Environmental / Economic and Market / Other sectors / Policy and Management	**20**
Site identification	14
Mapping	4
Stakeholder engagement and consultation	2
Environmental	**8**
Modelling	7
Mapping	1
Environmental / Economic and Market	**4**
Modelling	4
Economic and Market	**4**
Economic analysis	2
Ecosystem services assessment	1
Scenario analysis	1
Other Sectors	**2**
Mapping	1
Stakeholder engagement and consultation	1
Environmental / Economic and Market / Other Sectors	**2**
Site identification	1
Modelling	1

6.2 AquaSpace Tool

Reflecting stakeholder needs, the AquaSpace tool is meant to allow for a spatial representation of opportunities and risks of a proposed aquaculture activity at a specific marine location in a multi-use context. Specifically, opportunities relate to socio-economic assessments of the added value of an activity, food security or expected revenues; while risks relate to an evaluation environmental effects of the additional pressure contribution of a new aquaculture activity when combined with the overall human pressures in a management area.

The AquaSpace tool is one of the first Geographic Information System (GIS)-based spatial planning tools that allows for a spatially explicit and integrated assessment of indicators reflecting the economic, environmental, inter-sectorial and socio-cultural risk and opportunities for proposed aquaculture systems (Figure 17). Its technical concept and development was based on a bottom-up approach. Tool outputs (i.e. AquaSpace tool Assessment Report) comprise detailed reports and graphical outputs which can facilitate planning trade-off discussions hence allowing key stakeholders (e.g. industry, marine planners, licensing authorities) to proactively communicate effects of alternative scenarios and take more informed, evidence-based decisions on proposed aquaculture. A typical scenario involves a choice of site location amongst other considerations.

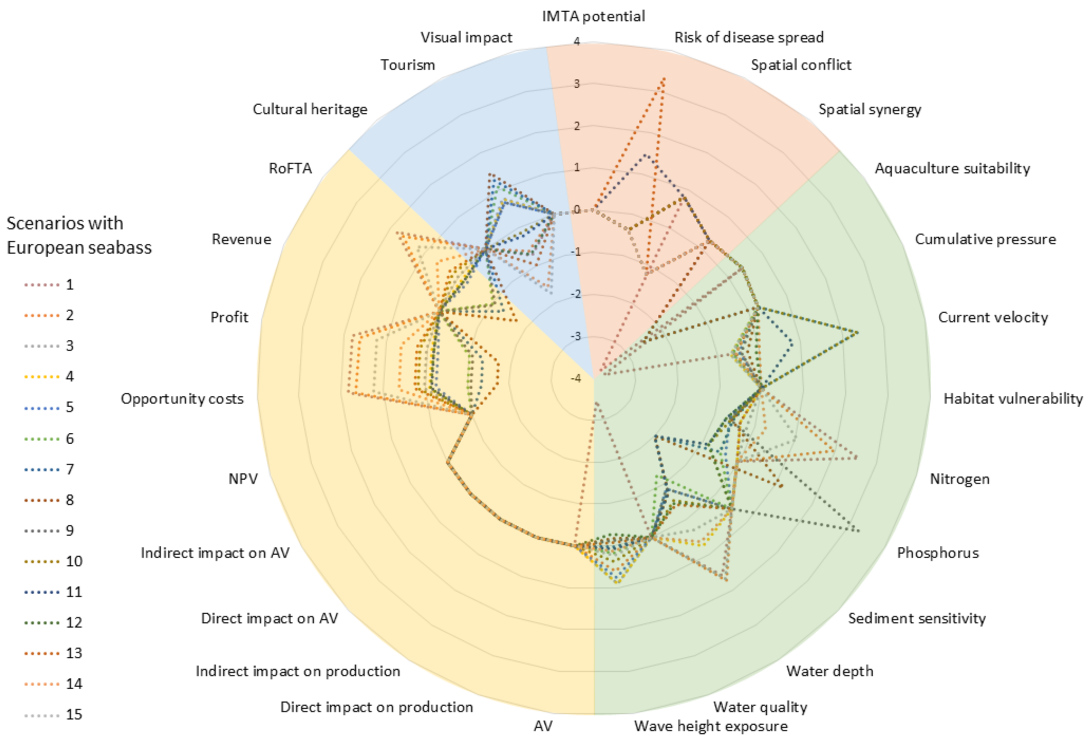


Figure 17. Spatially explicit performance of inter-sectorial, environmental, economic and socio-cultural indicators for 15 different aquaculture planning scenarios with European seabass. Shown are potential trade-offs in between the AquaSpace tool indicators by comparing data normalised in application of a z-transformation. Indicators required merely to assess the growth performance of a species (i.e. chlorophyll a concentration at surface, temperature and salinity) are not included (AV = Added Value, IMTA = Integrated Multi-Trophic Aquaculture, NPV = Net Present Value, RoFTA = Return on Fixed Tangible Assets).

Such a transparent visualisation technique facilitates i) an effective implementation of MSP for aquaculture, enabled by using spatially explicit methods and tools, ii) the implementation of a spatially explicit (GIS-based) multi-use context, addressing the functionality for cumulative risk assessments and conflict analysis, and iii) the implementation of an Ecosystem Approach to Aquaculture (EAA), explicitly considering economic and market issues. Further, the GIS AddIn is freely available and builds on open datasets at European scale (incl. suitability layers extracted from the WATER tool), improving reproducibility and collaboration in aquaculture science and research. Ultimately, this integrated approach would support the licensing process and facilitate investments.

For further information see the detailed description and user manual for the AquaSpace Tool in Gimpel *et al*. (2017), Aquaspace Deliverable 3.3 (available at: http://www.aquaspace-h2020.eu/) and online resources at: https://gdi.thuenen.de/geoserver/sf/www/aqspce.html.

6.3 Aquaculture Investor Index

The Aquaculture Investor Index was developed to provide a broad view of the relative appeal of different European countries to aquaculture investors. That is, it relates to an industry and not to individual farms. To ensure a wide dissemination and maximum visual impact, both to investors and the public, the index was deployed as a smartphone application, available in the Google Play Store (Figure 18).

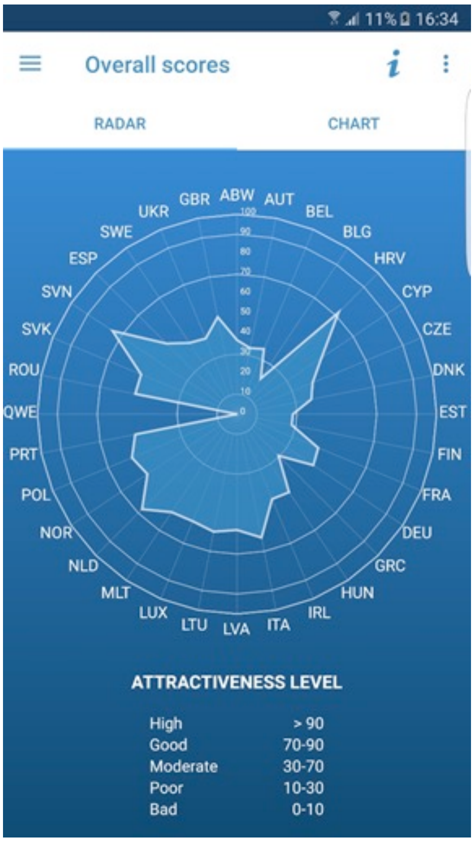


Figure 18. Smartphone screenshot of the appearance of the Aquaculture Investor Index app.

The aquaculture investor index ranks 20 indicators into five categories (market, production, regulatory, environment and social), which are diverse in nature, but account for connectivity in the aquaculture industry. The attraction of investment into aquaculture is conditioned by the viability of developing aquaculture for each country. The index benchmarks and tracks countries' progress, aggregated across five categories: market, production, regulatory, environmental, and social. The index is designed to rank aquaculture competitiveness for each country, by producing a quantitative, scalable assessment, for stakeholders to assess and monitor aquaculture attractiveness.

The index scores calculated for Europe range from moderate to good. Countries with well-established aquaculture sectors in northern Europe score well, whereas countries in southern Europe tend to score moderately. Countries with developing aquaculture sectors tend to score moderately. High scores within single categories can be achieved, but to provide the highest general appeal for stakeholders, the index rewards countries with high scores across the five categories.

No countries within Europe rank below the middle of the moderate range. The index identifies several countries with high scores that do not have significant aquaculture industries (e.g. Sweden and Finland), and further research is warranted to identify why aquaculture has not developed. It is expected that as the index is expanded to lower income countries spanning other geographic regions, countries with lower quality indicator scores will have lower overall scores.

The index provides a broad-scale approach, across a range of categories, and must be interpreted in this context. Appropriate due diligence for specific circumstances should be exercised by all stakeholders, who must gain additional, more detailed local knowledge before making important investment decisions. The Aquaculture Investor Index is designed to provide high-level guidance, of the general attractiveness for aquaculture in each country, and to our knowledge provides the first integrated approach in this regard. It is freely available to investors, stakeholders and the public, through the Google Play Store.

For further information see Smartphone 'Investor Appeal' application in Ferreira *et al.* (2017) (available from the AquaSpace website at www.aquaspace-h2020.eu/) or Longline Environment website at www.longline.co.uk/site/products/aquainvestor/. The app can be obtained from Google Play.

6.4 Where can Aquaculture Thrive in EuRope (WATER)

WATER is an on-line application, developed to assess broad-scale suitability of European waters to grow specific species, or to determine what might be grown within the jurisdiction of specific countries. The application is underpinned by reliable parameters that provide environmental and ecological limits for species, with outputs in the form of georeferenced suitability maps, with synthesis data aggregating total areas, percentage of Economic Exclusive Zone (EEZ), and other statistics (Figure 19). It does not take account of potential constraints such as the effects of aquaculture on the environment.

WATER is a complex product that combines big data (e.g. GEBCO, Copernicus Marine Environment Monitoring Service, WFD) with online processing to provide information for industry, management, and the public. It is written in SQL (Structured Query Language) used to query a database. The software uses mapping tools, species and parameter thresholds and individual growth models to identify the environmental potential for aquaculture with an emphasis on sites, both on land and in open waters, where different cultivated species can be grown. Each parameter is divided into 5 classes (score 1 (unsuitable) to 5 (highly suitable)) per 1 km^2 grid cell across the entire European EEZ, which are then normalised to give a single precautionary minimum score per grid cell that forms the basis for the mapping output and synthesis data. The system is implemented on a dedicated server, which can be queried through any web browser, and provides a response based on the question asked and the data retrieved by crossing the species requirements with the environmental conditions.

WATER was designed to support the analysis of available areas for farming and will be maintained and extended as part of the AquaSpace legacy programme, to include other kinds of models, such as dynamic growth and environmental effects simulations.

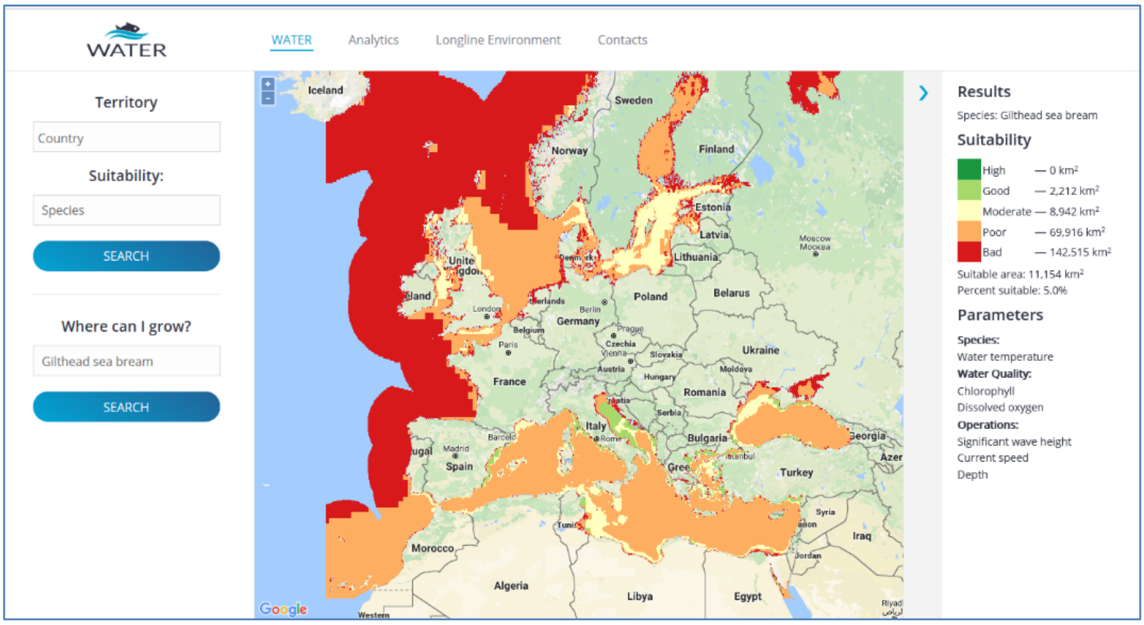


Figure 19. Appearance of the on-line WATER application (Where can Aquaculture Thrive in EuRope), to assess broad-scale suitability of European waters to grow specific species.

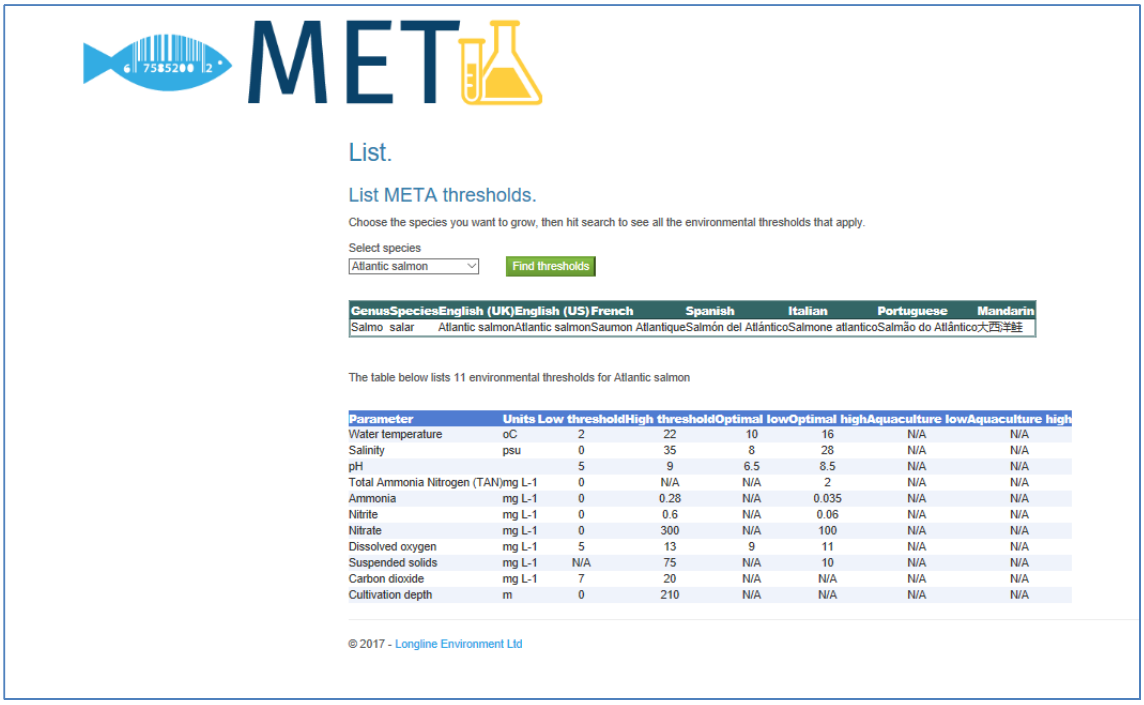
Shapefiles of outputs can be, and were in some Case Studies, made available as an input to the AquaSpace tool, which imposes other constraints including sectoral competition and co-use as well as the way in which the environment limits or is affected by aquaculture.

Further information and online resources could be found in: http://www.longline.co.uk/water/

6.5 Maritime and Environmental Thresholds for Aquaculture (META)

META is a web-based database-driven website that provides data on environmental thresholds for cultivation of aquatic animals and plants, for users to explore. Data are available on 14 parameters covering 45 existing and emerging aquaculture species grown in Europe. The database is searchable via species names and provides a series of upper and lower thresholds for survival, and upper and lower optima for each species, derived from more than 700 research references and other data sources assessed through a literature review, which are also listed within the database should the user wish to investigate further. The database is also searchable via each one of the 14 parameters, where lowest and highest values can be set by the user, to determine which species meet those requirements (Figure 20).

The database is limited by currently available information and not all parameters have the same level of detail at present, but this also points to areas where future research may be appropriate.



List.

List META thresholds.

Choose the species you want to grow, then hit search to see all the environmental thresholds that apply.

Select species

Atlantic salmon

Find thresholds

Genus	Species	English (UK)	English (US)	French	Spanish	Italian	Portuguese	Mandarin
Salmo	salar	Atlantic salmon	Atlantic salmon	Saumon Atlantique	Salmón del Atlántico	Salmone atlantico	Salmão do Atlântico	大西洋鲑

The table below lists 11 environmental thresholds for Atlantic salmon

Parameter	Units	Low threshold	High threshold	Optimal low	Optimal high	Aquaculture low	Aquaculture high
Water temperature	oC	2	22	10	16	N/A	N/A
Salinity	psu	0	35	8	28	N/A	N/A
pH		5	9	6.5	8.5	N/A	N/A
Total Ammonia Nitrogen (TAN)	mg L-1	0	N/A	N/A	2	N/A	N/A
Ammonia	mg L-1	0	0.28	N/A	0.035	N/A	N/A
Nitrite	mg L-1	0	0.6	N/A	0.06	N/A	N/A
Nitrate	mg L-1	0	300	N/A	100	N/A	N/A
Dissolved oxygen	mg L-1	5	13	9	11	N/A	N/A
Suspended solids	mg L-1	N/A	75	N/A	10	N/A	N/A
Carbon dioxide	mg L-1	7	20	N/A	N/A	N/A	N/A
Cultivation depth	m	0	210	N/A	N/A	N/A	N/A

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Figure 20. Snapshot of the web-based database-driven META website (Maritime and Environmental Thresholds for Aquaculture), providing data on environmental thresholds for cultivation of aquatic animals and plants.

For further information, see Boogert *et al.* (2017) Online Environmental Feasibility Application, corresponding to Deliverable 2.5, and http://www.longline.co.uk/meta/

6.6 BLUEFARM-2

BLUEFARM-2 is a plugin for the open source software Q-GIS, designed to guide the user towards the steps required by the application of a Spatial Multi Criteria Evaluation Analysis, SMCE, methodology to the selection of aquaculture sites. SMCE is based on an analytic hierarchical process: as other Multi Criteria methodologies, it allows one to deal with complex decision problems, through the combination of different criteria, which need to be grouped, standardized, and weighted. Being spatially explicit, it requires as input maps of criteria: therefore, its implementation can be greatly facilitated by appropriate GIS tools. The application of this methodology to finfish farming is presented in detail in Depueto *et al*., (2015). In AquaSpace, Bluefarm developed a specific application of SMCE to shellfish aquaculture, which was tested on the Adriatic Sea case study: see Brigolin *et al*. (2017) for a summary of the theoretical background and a detailed description of the results, which can also be found in AquaSpace Deliverable D4.2 (Strand *et al.*, 2017). The plugin BLUEFARM-2 tool facilitates the application of SMCE to other cases, taking into account both a set of spatially explicit suitability criteria and constraints: on this basis, BLUEFARM-2 computes and maps a suitability index ranging from 0 (not allowed) to 1 (highly suitable. Input maps of criteria are grouped in three classes: (i) optimal growth conditions (OG); (ii) environmental interactions (EI); (iii) socio-economic evaluation (SE). A set of constraints is added to criteria: the user is guided in the input process. Maps of criteria and constraints should be provided by the users, who can easily upload end-users, through a user-friendly interface. Users can also define the weights for each criterion. Once the input layers are uploaded, the suitability maps are produced very quickly, thus allowing users to rapidly explore different scenarios of weighting: this feature can be very useful in the implementation of the MSP Directive, which requires the participation of stakeholders. On a consultancy basis, Bluefarm could provide site-specific input maps concerning potential biomass yield indicators (e.g. average individual weight at harvest, time to reach the market size) for the main Mediterranean species (seabass, seabream, mediterranean mussel, manila clam). The tool was implemented by using Phyton language, and instructions are provided to facilitate its set up as a plug-in of Q-GIS, which is a free and open-source Geographic Information System. At present, the tool can be downloaded at: http://bluefarmenvironment.com/project/aquaspace/. Demo input layers are also provided, based on the input maps produced within the Northern Adriatic case study of Aquaspace (Figure 21). Bluefarm will upload BLUEFARM-2 on the QGIS plug-in repository and keep improving it, as part of the exploitation of AquaSpace, as described in the Deliverable D6.4.

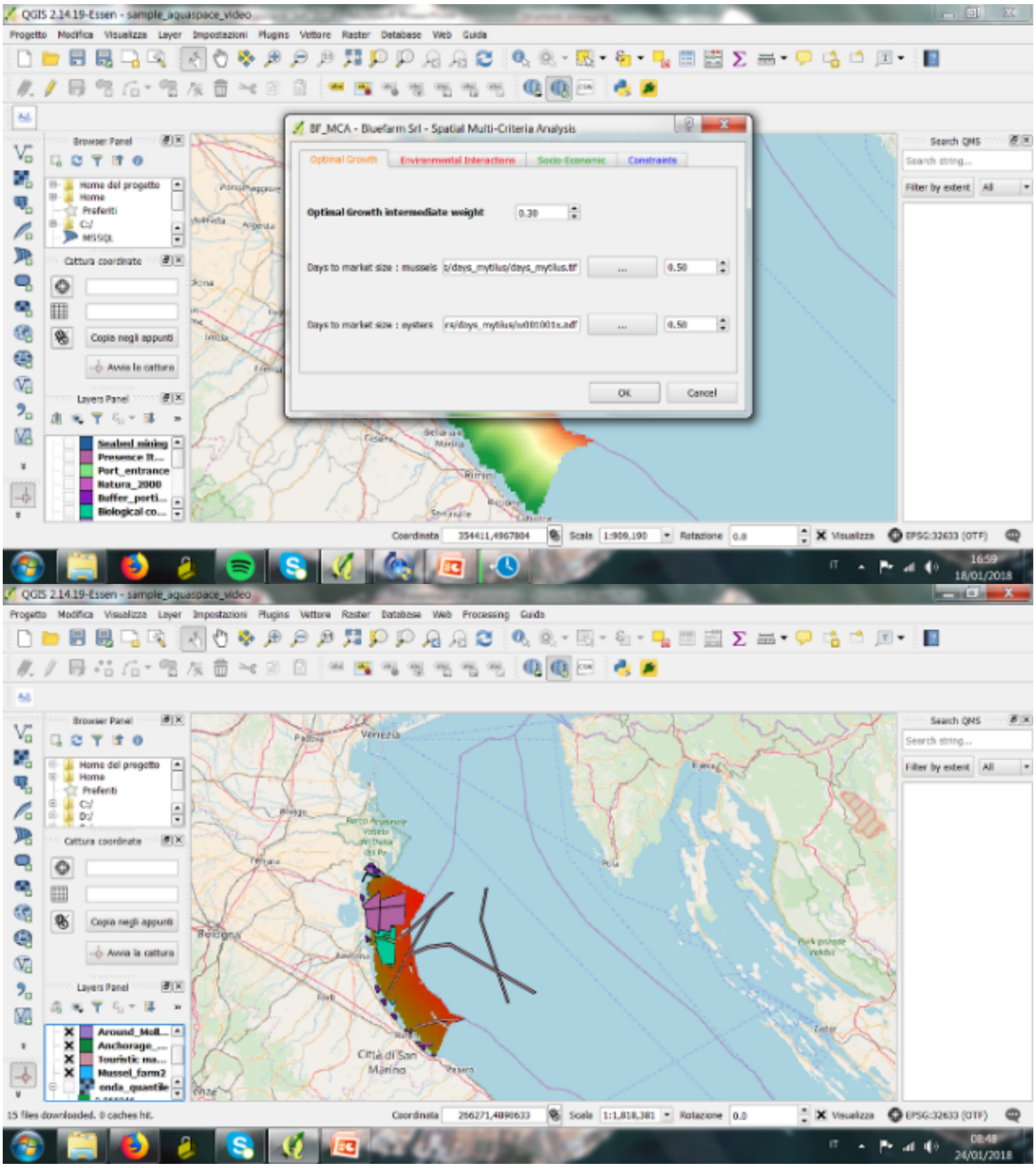


Figure 21. Screenshots of the Bluefarm-2 plugin for QGIS: input data menu (upper), output maps for the Northern Adriatic case study (bottom).

6.7 Aquaspace Virtual Seascapes

The Virtual Reality toolset enables policy, industry and public stakeholders to interpret aquaculture developments with respect to visual indicators of landscapes, or site landscape and seascape features (e.g. aquaculture, renewable energy, leisure, transport).

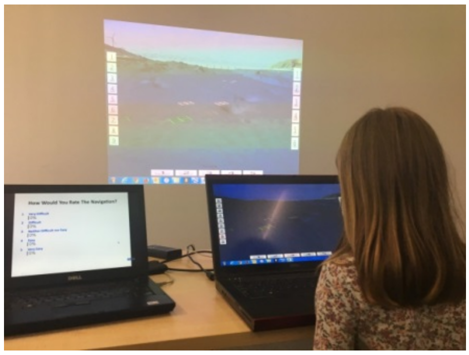
- **i)** **Seascape creation** by users who can interactively add and relocate features in landscapes and seascapes, in an Augmented Reality environment, explain their reasons for siting and design, and report preferences with respect to seascapes.
- **ii)** **Site level** exploration of, and learning about, aquaculture developments using a simulator (from the Norwegian University of Science and Technology), implemented in a Virtual Reality environment that enables the user to navigate around and within a set of fish cages, populated by moving fish, and feeder systems.
- **iii)** **Regional level** identification of natural heritage designations, landscape characteristics, spatial data on cumulative visibility of aquaculture sites, and development guidance for spatial planning, and to explore and discuss consistency between terrestrial and marine environments, in a Google Earth interface.

They have been used: i) to explore socio-economic and environmental scenarios and develop options for development, raising public awareness, and scientific experimentation on public preferences and attitudes; ii) at strategic, local, and site specific geographic levels; iii) with symbolic and photorealistic levels of detail; iv) as static or navigable models; v) in an interactive mode, enabling features to be changed, or only for viewing.

a. Virtual tour of aquaculture cage in site level simulator: public audiences looking up through cage.

b. Exploring 3D features in seascape creation model of sea and land use: with public audiences.

c. Virtual Landscape Theatre, with virtual reality model of seascape, with fish cages viewed from below.



d. Designing uses of land and sea with interactive 'drag and drop' tools in seascape creation model.

The models can be experienced using personal headsets (as in figures a and b, above), in a virtual reality theatre (c), or on a PC (d). The tools have been used in engagement with stakeholders from policy, industry and the public (of all ages, and living locally and remotely from the area represented).

Several sources of software and hardware have been used, listed below.

Hardware and infrastructure -

- Virtual Landscape Theatre: James Hutton Institute
- Virtual Reality headsets: Oculus Rift.

Software -

- Interactive visualisation software (commercial source): Presagis
- Interactive visualisation software (bespoke software): coded in VRML, played in Octaga Panorama
- Google Earth

Data –

- Digital Terrain Model (e.g. for Scotland, OS Terrain 5, 5m x 5m raster)
- Aerial imagery (commercial vendors, e.g. Getmapping, Bluesky).

Environmental designations (marine and terrestrial) (e.g. Scotland's Environment Web)

7 SWOT analysis of tools and methods

A generic evaluation of tools and methods implemented and tested in the case studies () was performed to bring together the diverse experiences obtained in the case studies. Factsheets describing specific technical characteristics and capabilities of the different tools are contained in the AquaSpace Guidance document, which will be made available in the AquaSpace ToolBox (at www.aquaspace-h2020.eu). The over-arching objective of the evaluation of tools and methods was the analysis of the tools' performances in supporting spatial planning and EAA by providing solutions to the identified issues in a variety of production environments, of different geographical, production and governance scales, and different ecosystems. To perform the analysis, the contribution to Aquapsace's first objective of identifying optimal space through EAA was assessed. Then, the internal and external factors that support or limit the ability of the tools to achieve the objective were identified.

The methodology used is based on a SWOT analysis, which is a qualitative method intended for strategic planning and decision-making. The name is an acronym for Strengths, Weaknesses, Opportunities and Threats. The tool-related SWOT analysis is produced to provide a better understanding of the external and internal factors affecting the capacity of the tools to contribute to the agreed objective. The strengths and weaknesses are internal factors (aspects related to the tool itself) while opportunities and threats are external to the tool. Main weaknesses and threats to the implemented and tested tools in case studies will limit their solution capacity, and thus, limit their application in spatial planning and EAA.

It must be noted that the tools and methods evaluated in AquaSpace are very diverse, showing different characteristics and capacities. We have performed a general evaluation of the tools to highlight those topics that are common to all the tools and methods implemented and tested. A specific SWOT analysis of the tools will be provided in the tool factsheets in the Aquaspace toolbox (http://www.aquaspace-h2020.eu). This analysis highlighted the improvements needed in the tools and new functionalities to be developed, which leads to the recommendations in Section 9.

7.1 Strengths: advantages of the tools

Since the evaluated tools and methods are diverse in terms of their initial aim, underlying approach, technical characteristics and functionalities, identified strengths are distinct. In general, it has been observed that the underlying approach is multidisciplinary with the integration of different sources of data and criteria (e.g. multi-criteria analysis in GIS-based tools or Aquaculture Planning Decision Support Systems (APDSS). The strong background research and the integration of knowledge from different scientific fields were considered as noteworthy characteristics of the modelling tools. They are found to be useful to explore ecosystem functioning and processes, and responses of the ecosystem to changes. Moreover, outcomes obtained from tools, can promote consultation with stakeholders by facilitating the integration of social, environmental and economic factors in the decision-making process and the co-creation of solutions.

From a more technical point of view the inherent capacity to manage and integrate_large volumes of data and information were shown as an important advantage of the tools (e.g. GIS and AquaSpace). Moreover, the flexibility and possibility to add new data to an analysis was also identified as an important advantage of the tools. The possibility of customisation and adaptation of the tools is perceived as a good characteristic; thus, tools based on a modular approach, which allows the development of additional functionalities, is valued.

From the users' perspective, a positive point is that some of the most commonly used tools (e.g. GIS) are broadly used with accepted and standardised methods. Some of such tools are free, which promotes their use among wider stakeholders and decision makers. Some of the tools were found to be user friendly and interactive (e.g. web-based APDSS).

The most valued characteristic of the output is the visual representation of information layers (e.g. spatial overlap, visualization of scenarios) and the consultation and analysis of information. Also, a variety of output metrics for different questions is possible. Modelling approaches provide relevant information for different scenarios, different levels of aquaculture production and a variety of aquaculture species. Future forecasts and necessary information to evaluate grower requests are included. In general terms, the application of the tools enables one to take a systematic approach to calculating and comparing opportunities and risks of a proposed aquaculture site in a multi-use context (e.g. AquaSpace tool).

One of the most interesting outcomes is related to the identification of new areas suitable for aquaculture. Potential production, socioeconomic outputs, and environmental effects can be estimated through the application of models, including scenarios, without the cost or time required for actual implementation. Estimation and maximisation of sustainable harvest of shellfish, as well as an assessment of long-term socio-economic profits and negative and positive environmental externalities can be obtained through these tools.

The main strengths identified are shown in Table 5.

7.2 Weaknesses: room to improve tools

The weaknesses experienced during the implementation and testing of the tools, were grouped into 12 main topics. Specific weaknesses associated with each of the implemented and tested tools are given in Tools Factsheets of the Guidance document available in the AquaSpace toolbox.

The most frequently cited weakness, common to all tools, related to the data requirements. This weakness is inherent to the multidisciplinary and multidimensional approach of the tools. As more integrated and complex tools and methods are being implemented, larger amounts of data from different sources are required, which need to be maintained constantly. A direct link to Web Feature Service (WFS) datasets, which allows a download of the latest datasets available would decrease the maintenance costs of data. Nevertheless, the response of the WFS currently still needs a high amount of time delivering those data, which slows down tool performance as usually models are data demanding and computationally intensive. While individual runs are relatively quick, new site locations require several model runs to compare different scenarios. This results into an increased processing time.

The implementation of modelling tools might be constrained by the fact that they are too species-specific and because they are based on certain assumptions and physical and biological information as proxies.

Among the most frequent weaknesses mentioned was the fact that the tools are not yet fully developed. New functionalities and capabilities are planned for more integrated tools, but they are still under development. A lack of functionalities such as prediction of HABs and climate change effects were found as weaknesses for the broader use of tools.

Spatial resolution of resulting maps was also an issue. The maps produced often have low spatial resolution and do not always satisfy the level of detail required for site selection or management plan development. This is particularly relevant for local management plans within estuaries or bays. Thus, outcomes are found to be informative but not sufficient for planning individual farms at an operational scale. In most cases, this limitation is related to the spatial and temporal resolution of available input data and not always related to the technical capabilities of the tools and methods. This issue is particularly evident when performing social and economic analysis, for which the available input data do not show sufficient spatial resolution or require certain assumptions and proxies for their calculation: for example, distance to ports as a proxy for farm maintenance costs.

The cost associated with tools and model implementation was highlighted as the most frequent weakness. This cost refers both to the software licence cost; as well as to the human resources and time needed to get enough technical skills and training to use the tools.

Tools are usually developed for implementation in a certain place or case study and thus, many are case specific and hard to upscale and generalise. In other cases, tools showed insufficient flexibility in adaptability to other scenarios. Moreover, comparison of data from different sites and different years may give an incorrect determination of the most desirable site. Thus growth, harvest and water quality data should match with respect to timeframes to provide an accurate analytical result that can be used with certainty in policy decisions. This would also be useful in promoting the use of these tools elsewhere.

From the user perspective, it was found that many tools are complex to use, requiring some level of knowledge or training and thus, can only be used by several trained people. These may hinder a broader use of tools, especially in the case of administrators or managers, who may be unable to use and interpret the results obtained in a simple way. The main weaknesses identified are shown in Table 5.

7.3 Threats: external factors constraining tools and methods usability

The most frequently reported topic here was data availability and quality. High resolution spatial data are needed. Data uncertainties, data quality, availability and accessibility certainly limit the operational use of tools for decision-making. In fact, this is clearly the most frequent and common threat to all tools. As more integrated and complex tools and methods are being implemented, larger amounts of data from different sources are required. Thus, the lack of data can constrain the applicability of the tools; as well as the reliability of final results. In turn, this has a direct effect when informing managers or decision makers. Nevertheless, it should be appreciated that threats are external to the capabilities of the tools themselves. A tool might be operational for certain functionalities but fail to be implemented successfully at some sites due to the lack of input data for those sites. For example, environmental data are mostly presented in average values with low spatial and temporal resolution; while inter-sectoral data (i.e. marine activity patterns) are based on the *status quo*. In most cases, the functionality of the tool exists but the required data quality is not always enough for full potential exploitation of the tools. Furthermore, data needed to extend the geographical analysis area could be unavailable or hard to access. This is especially relevant if tools and methods are going to be used for new site identification in offshore areas. The limited information and data relevant to aquaculture activity were identified as an important hindrance to the development of management plans at regional level and therefore, it could still produce problems in the future.

The complexity of ecosystem functioning is also affecting the performance and reliability of tools. The variability of environmental conditions or extreme events are difficult to predict with enough reliability by modelling tools. This is also valid for the effects of climate change and invasive species. Regarding aquaculture related effects, both biological and environmental factors become more complicated as aquaculture is up scaled, so that the modelling of carrying capacity and spatial planning becomes more difficult. Thus, the development of tools is hampered by the lack of scientific knowledge and data or by the scientific disagreement on methodologies and model background assumptions (e.g. concerning the causal link between salmon lice from farmed fish and the lice's impact on wild salmonid populations).

From the stakeholders' perspective, different interests among producer groups for some issues (production volume, technology type) or the industry resistance to accept the zoning principle affect usability of the tools. They might not trust the outcomes from the tools and methods implemented, in other cases, they find them useful, but do not have the resources to invest in the application of the tools.

An additional threat is related to the managers' concerns about the feasibility to use model outcomes where the model is to them a kind of a "black box".

It was found that resources are usually dedicated to the development of new tools. However, the maintenance of tools continues to require work, which is affected by the lack of continuous funding.

The main threats identified are shown in Table 5.

7.4 Opportunities: new perspectives for the tools

New opportunities and beneficial prospects for the development of tools and methods have increased because of the present acknowledged need to implement ecosystem-based spatial management. Among others, Blue Growth requires the diversification of maritime activities and their promotion under sustainable conditions. The implementation of the MSP Directive might therefore be supported by tools. Moreover, food security, and the expansion of aquaculture activity requires promotion. Government policies and Strategic Plans advocate more coordinated spatial planning of aquaculture. This underpins the need for diversification of activities, site identification, mitigation of conflicts and the optimisation of space. These initiatives and requirements can be considered as opportunities to develop new tools, to standardise procedures, and to support authorities. Scientific and technical advice to support management plans requires the development of tools. Tools and methods might support management plan design and the decision-making process at different stages of spatial planning implementation and integrated assessments.

Outputs from research studies of species growth and carrying capacity can be used to assess the trade-offs to decision makers and inform local communities and non-profit organisations wanting to ensure that aquaculture operations benefit local communities. The application of the tools informs a systematic process for calculating and comparing opportunities and risks of a proposed aquaculture site in a multi-use context. Tool applications can assist in determining if aquaculture is a sound investment, how it compares with alternative projects, and for spatially representing all opportunities and risks. Stakeholder related tools, such as questionnaires, online participatory tools, and virtual reality tools, can provide an opportunity to identify the issues and facilitate good communication. Tools can be used to facilitate discussions that seek to harmonise different stakeholder interests and to bring about social acceptability of aquaculture. Tools can define meaningful indicators and present them graphically. Moreover, the use of tools by public authorities could improve the licensing process, which is one of the main constraints reported by aquaculture stakeholders. Tools can assist in the identification and representation of existing uses, the spatial and temporal pattern of uses, the identification of stakeholders that might be affected by establishing new aquaculture activities; as well as management measures implemented in a certain area.

Nevertheless, data availability plays a major role in using the tools to obtain meaningful results. Existing information layers do not always meet the required spatial and temporal resolution for local management plans. Tools that could perform analysis at various scales would be beneficial to solve such an issue. Access to open source data repositories could solve this problem. Guaranteeing stable accessibility to public environmental data could fulfil the needs of getting near-real time results from operational modelling methods (i.e. HABs events or sea-lice re-infection). New Information Technologies developments can assist with the performance of tools (online data access). This, in turn, would require standard formats and protocols that would promote intercommunication and data exchange between different platforms to use the latest datasets available. Access to open source data presents an opportunity to promote integration of diverse data.

The main opportunities identified are shown in Table 5.

Table 5. Summary of the SWOT analysis of tools and methods analysed in AquaSpace.

Strengths:	Weaknesses:
Approach - Promotes multidisciplinary analysis and the integration of different sources of knowledge - Strong background research of modelling tools - Useful to explore ecosystem functioning and processes, and responses of the ecosystem to changes **Technical** - Manage and integrate big volumes of data - Possibility to add new data - Possibility to customise and adapt tools **Outputs** - Visual representation - Identification of suitable new sites - Information on different scenarios for aquaculture production and species - Provide future forecasts and necessary information to evaluate grower requests - Potential production, socioeconomic outputs, and environmental effects can be estimated **User** - Some tools are broadly used with accepted and standardised methods - Free licences - Friendly: simple to use and interactive	**Approach** - Data requirements - Simplicity of certain assumptions to operationalise tools **Technical** - Lack of functionalities of interest (HABs, predicted climate change effects) - Development costs - Computationally intensive - Not always fully developed **Outputs** - Outcome does not always satisfy required detail - Low spatial resolution **User** - Implementation cost and effort - Hard to upscale and generalise - Insufficient flexibility - Difficult to use - Technical skills and scientific knowledge needed
Threats:	**Opportunities:**
Data - Uncertainties relating to data quality, availability and accessibility - Low spatial and temporal resolution of input data - Lack of continued funding for development and maintenance of tools **Approach** - Complexity of ecosystem functioning - Lack of scientific knowledge - Lack of consensus on methodologies and models - Variability of environmental conditions and extreme events **Users** - Different interests among producer groups - Resistance to zoning - Managers concern about feasibility to use operational model outcomes to manage production regulation	- Need for ecosystem-based spatial management - Blue Growth advocates growth of marine activities - MSP Directive implementation - Food security - Government policies and Strategic Plans - Sound investment - Need to improve licensing process **Technical** - IT developments - Access to open source data repositories - Promotion of standard formats and protocols

8 Stakeholders´ vision for aquaculture growth and ecosystem-based spatial management

Understanding stakeholders' visions and needs is essential to properly develop management plans and also the supporting tools and methods. Stakeholders were consulted through regional and local stakeholder workshops organised during the AquaSpace project, as reported in Section 4. The points made by stakeholders were grouped into eight main topics: (i) management and planning; (ii) stakeholder engagement; (iii) administrative procedures / licensing; (iv) economy and market; (v) networking, cooperation and communication; (vi) promotion; (vii) monitoring; and (viii) tools. Although not all the needs and recommendations that are reported here are related to the main research aim of AquaSpace (developing and evaluating tools supporting ecosystem-based spatial planning of aquaculture), additional information provided by stakeholders has been included here for cases win which tools and methods could contribute to achieve such needs indirectly.

The 8 topics are:

- Ideas for improving the **management and planning** of aquaculture. The recommendations were diverse, and, in general, the development of areal management plans are seen as an opportunity for this sector. The present process for the implementation of the MSP Directive is perceived as well timed to bring scientific knowledge into the public debate. Aquaculture should be considered as a highly important sector that should be properly managed by appropriate spatial planning. MSP should promote the identification of suitable areas for aquaculture, including the development of indicators for the areas for which management plans are already implemented. The aquaculture sector is aware of the need to share the marine environment with other users and sectors/industries, mainly because of awareness that the space available for marine activities is finite. Spatial planning could also be a means to modify negative public perception about potential environmental impacts, especially those associated with marine fish farming, and on access to and use of coastal resources. Among more specific recommendations, it was suggested that sites for bivalve longlines with low environmental impact, could be allocated to the surroundings of strictly protected areas (non-take areas) as a way of limiting fishing access to the protected area. Recommendations were also made for management plans to include adequate buffer zones between adjacent farms, to prevent spreading of disease.

- Related to the previous points, the need was identified to adopt participatory processes to get meaningful and productive **stakeholder engagement**. More involvement of local communities in identifying opportunities for aquaculture was recommended. The process of participation must be transparent, and the results should be shared with other marine actors.

- **Administrative procedures / licensing** was the issue that was most frequently reported in all the case studies independent of the country, species or cultivation method. The standardisation and simplification of regulatory frameworks and authorisation procedures is highly recommended. This would reduce the time and cost of establishing new aquaculture industries and reduce uncertainty for investors.

- Regarding the **economy and market**, some stakeholders highlighted the need to impose duties for imported products in cases where it is known that production is undertaken with low environmental, consumer or hygiene standards. Moreover, it is recommended that the traceability of products should be improved, and that demand-orientated aquaculture products should be developed. Finally, enlarging enterprises/farms would bring benefit associated with economies of scale.

- **Networking, cooperation and communication** should be improved. National governments should establish and maintain cooperation mechanisms between industry, environmental management, governance and scientific research. Enhancement of cooperation between producer associations was also seen as necessary to improve competitiveness and reduce production costs (monitoring, biosecurity plans, etc.).

- More actions to **promote** aquaculture and increase its local acceptance (social licence) are recommended. Public perception towards aquaculture activities should be improved, and awareness increased of certain types of aquaculture (e.g. ponds) in terms of its maintenance of ecosystems (e.g. wetlands). Governance should be improved (e.g. between administrative authorities and private sector). Staff training should be guaranteed and promoted by government and industry. Research results should be widely disseminated, including to the public, and used by industry and environmental management: this is seen as a measure to promote the growth of the industry in a sustainable way and get support from the public.

- The implementation of improved **monitoring** procedures would benefit this sector in several ways, from early prediction of HABs to other aspects of food safety; as well as in the farm management to reduce environmental effects from organic waste, nutrients, impact on the seabed, and spread of diseases and parasites.

- Further **development and implementation of tools**, especially those with ecosystem-basis, is recommended, with the main aims of optimising the space based on hydrodynamic studies and assessments of carrying capacity.

9 Needs and recommendations for improvement of tools

This section identifies needs for improvements in tools to support the provision of new space for aquaculture growth under the EAA and spatial planning.

The AquaSpace project has identified the main issues that aquaculture-related stakeholders are facing. Newly developed and existing tools have been implemented and tested under real conditions, across case studies representing different production scales and management levels. This has allowed: an updated vision of what has been achieved and what is still needed (from the tool development perspective) to support ecosystem-based spatial planning of aquaculture and therefore sustainable growth of aquaculture; and to maximise the social, economic and environmental benefits of aquaculture.

Ecosystem-based spatial planning of aquaculture integrates a set of principles which consider that growth of the aquaculture industry should be achievable and technically feasible, economically viable, socially desirable, culturally inclusive and environmental/ecologically sustainable. Underlying knowledge relies on understanding the interactions of aquaculture with the surrounding environment. These interactions have economic and social components as well as physical, biological, and biochemical components. This understanding is critical to focus the research and technological developments that are needed to inform spatial planning. The relevant needs and recommendations identified in AquaSpace are grouped into seven main themes: (i) management and planning; (ii) stakeholder engagement; (iii) monitoring; (iv) data collection and management; (v) technical development of tools; (vi) funding; and (vii) promotion.

- Regarding **management and planning** aspects, the implementation of tools and methods, for the identification of the most suitable areas for aquaculture, could support aquaculture zoning. The multi-criteria GIS approach is a very useful method for aquaculture site selection, but it should be also combined with other approaches to serve management purposes and result in integrated decisions. According to the principles of the EAA, the needs and characteristics of other maritime socio-economic sectors should be considered. A holistic ecosystem approach can contribute significantly. Aquaculture management plans should be developed in conjunction with the use of different tools and methods that have demonstrated their utility in other places (see examples of good practices in the Guidance document of AquaSpace). Moreover, tools can add transparency to the MSP implementation process by facilitating access to geographical information that can be easily interpreted by stakeholders.

- Considering the implementation of an EAA, this might facilitate the adoption of measures and strategies to increase aquaculture production. In turn, the EAA needs to be supported by spatially explicit tools and be informed and validated by the real world in an interdisciplinary way. In general, it has been observed that most of the principles and stages of **MSP and EAA implementation** have been already considered in the management and strategic plans of the studied countries. It means that even if the EAA or MSP is not fully implemented, significant progress has already been undertaken and thus, it is not a process starting from zero. Given that, at present, more than three-quarters of aquaculture production in the EU occur along the coast, where WFD and land-planning regulations apply, it is possible that MSP will not immediately to be applied to aquaculture development. Nevertheless, aquaculture should be considered as potential future stakeholder in MSP implementations, because it is likely to move offshore once technical challenges are solved. It will be important point to seek a continuous **interaction with stakeholders** at regional and local level to guarantee the quality and reliability of input information layers for GIS tools. Consultation with relevant stakeholders should be increased and promoted to allow sustainable development of aquaculture in the framework of other activities requirements and Blue Growth. The consultation and participatory processes with the involvement of different stakeholder groups can eliminate false assumptions and increase awareness towards aquaculture industry efforts. Stakeholders could be brought together to develop aquaculture plans development and recommendations based on clear and transparent list aquaculture requirements and needs. This approach requires the identification of the relevant stakeholders and the implementation of mechanisms and incentives to promote and guarantee their effective involvement. Stakeholders could significantly contribute to public awareness, aquaculture development, water and habitat quality, and regulations and management. All of which would help to improve the perception and thus, the social license that would then support growth of aquaculture new operations and would remove obstacles to expansion of existing operations. New tools, methods, standard protocols and definition of indicators are still needed to facilitate and guarantee that the process is conducted properly.

- Continuous **monitoring** and online accessibility to environmental data are needed to feed the models as well as a reduction of time to give results and outcomes from these models (e.g. environmental Monitoring Program (EMP) calibrated variables for all areas and farmed species). Data collection should be extended and monitoring efforts should consider environmental variables and biodiversity. Additionally, more sources of unbiased information on the **social-ecological** systems around aquaculture are needed to mitigate misinformation and aid host communities in their debate about the acceptability of aquaculture activities in their area.

- Main recommendations regarding to further implementation and use of tools are related to **input data** needed to feed the tools and models. This point refers to **data collection and management.** High-resolution information and locally relevant data sets are needed to improve the accuracy of reports, particularly for regions with complex topographies. The public authorities should promote and enable public **open access** to data repositories, which can guarantee the quality and reliability of results. The databases should be maintained updated (e.g. for operational models and to give near-real time results). This would help to keep the tools and models updated with the latest data. Future analyses need to be based on latest data available (e.g. by linking the tool to WFS data sources which will again decrease data maintenance costs). Spatial multi-criteria evaluation methodologies and tools have demonstrated their utility (i.e. BLUEFARM-2, GIS approaches), but the guarantee of their continuous update is needed including additional layers of information and publicly available new functionalities.

- **Tools and methods** have demonstrated their usability at different stages of spatial planning and EAA implementation. There are many examples in which tools have been used successfully for the identification of most suitable areas for aquaculture, aquaculture zoning and management. It is expected that broader use of existing tools, as well as the developed tools, will contribute to further integrated assessments supporting and informing spatial planning with aquaculture.

  Newly developed tools (e.g. AquaSpace tool) have been built to take account, in an integrated way, of different environmental, social and economic components of the ecosystem. They typically promote the coexistence of marine activities (e.g. windfarms and aquaculture), but this relies on the integration of intersectoral information, environmental, and socio-cultural and economic conditions and effects. Aquaculture objectives should be consistent with other sectors' objectives. This means that a consensus and trade-off should be found between the different sectors operating in a managed area. The objective is to fulfil the socio-economic targets for the area as well as the protection and conservation goals. Nevertheless, more efforts on such balanced information integration are still needed. One measure to achieve this is collaboration in developing tools with functionalities fit for purpose. In this way, the development process, as well as the analysis of the obtained results, can promote collaboration among stakeholders as well as best-informed decision making.

  It was observed that while environmental-related tools are more common, there is a continuing need for the development of tools to assist social and economic analysis. More specifically, new tools and standardized methods to assist, guarantee and assess the representativeness of stakeholder participation within a participatory process should be developed. In general, and to guarantee the development of fit for purpose tools, transparency is needed in the requirements of the aquaculture sector and of its regulators. There will be an end-user driven need to customize or further develop operational tools, allowing industry more informed, evidence-based decisions (e.g. by providing market commentary) on aquaculture development. and policy-makers a risk-based analysis of spatial management options as suggested in this report. Based on this, it should become possible to assess the vulnerability of ecosystem components to aquaculture and to define buffer distances to sensitive marine ecosystems. Additionally, environmental benefits from aquaculture could be assessed for vulnerable ecosystems. Such an integrated approach would support the licensing process and facilitate investments.

  There are specific modelling approaches that have already been used (e.g. SMILE (Ferreira *et al.*, 2007)) to determine optimal stocking densities (e.g. mussels and oysters) and to estimate production capacity. This functionality is of high relevance when trying to reduce the uncertainties for development of aquaculture in new locations and attract new industry and investors. Such assessment could be done at regional scale. For that, further developments on hydrodynamic modelling and environmental characterization (availability of higher temporal and spatial resolution information of environmental parameters) are essential for reliable assessments of carrying capacity. Modelling approaches have produced valuable information on the spread and connectivity of disease and pathogens. This has important implications for the aquaculture industry, but also for environmental effects on wild fish, thereby influencing which precautionary measures should be adopted. Tools have also been implemented as part of individual site application processes to assess changes to the cumulative impacts of networks of farms. Tools can generate scenarios of future conditions as well as the outcomes of different management plans. Nevertheless, there a need for further development of models capable of predicting extreme environmental events which may affect cultured species and aquaculture infrastructures. Such extreme events are becoming more frequent in recent years due to the effects of climate change.

- The previously cited recommendations, and promotion of the use of tools, requires the development of user-friendly tools. Better interface and internet platforms would make such tools more accessible to a broader spectrum of stakeholders. This can only be achieved by promoting tools that are durable and stable in time. For the benefit of further development of tools, long-term strategies and **funding mechanisms** should be defined and agreed to maintain well-established teams and promote software development.

- The tools that have demonstrated success should be transferred to different case studies and needs. Existing tools usually require adaptation time and cost and the new developed tools should be designed, as much as possible, in a way that could be easily transferred to other areas. Existing tools and methods as well as outcomes from projects and assessments and implemented tools should be adequately **promoted** and updated. The AquaSpace Toolbox is intended to assist this. Additionally, new projects and new studies should encourage the promotion and further development of existing tools. This also relates to transparency and know-how transfer. Results from research projects such as AquaSpace should be properly promoted and made accessible through different national and international platforms supporting MSP implementation; especially governmental institutions playing a role in MSP implementation process. Transparency and effective knowledge transfer regarding successful implementation of policy and management could provide a basis for establishing good practice principles and adopting common standards for environmental sustainability in other parts of the world.

10 Concluding remarks

The EAA and spatial planning for aquaculture are the framework under which aquaculture growth should be supported. The aquaculture growth objectives should be achievable and technically feasible; and they should seek to be economically viable, socially desirable/tolerable, culturally inclusive and environmental/ecologically sustainable. The tools tested, including those developed during AquaSpace, could support the application of ecosystem-based spatial planning to aquaculture.

No single tool or method can overcome all the issues constraining increases in aquaculture production, or provide an optimal spatial management of aquaculture under ecosystem approach. Nevertheless, the solution capacity, demonstrated by the tools, make them essential during the implementation process of the different stages of MSP and EAA. Moreover, it is expected that improvement of scientific knowledge, data availability, stakeholder participation and development of new functionalities will make the tools more and more valuable for effective and optimum decision making and management plans development.

Although scientific and technological gaps remain, AquaSpace has produced substantial advances in this field by testing existing tools and by developing innovative tools when a lack of functionalities was identified. The project has produced up-to-date knowledge that contributes to best-informed management measures towards an operational ecosystem based spatial planning of aquaculture. Tools can support managers and other stakeholders when defining achievable strategic plans and during their implementation towards a sustainable growth. Case Studies have shown tools and method supporting many of the steps during the development of spatial plans and implementation of the Maritime Spatial Planning Directive. They have promoted, and can promote, integrated intersectional analysis. More specifically their implementation during site licensing processes could significantly reduce the economic cost, time frame and uncertainty of these processes. Tools and models dedicated to forecast production capacity and ecological carrying capacity and environmental effects as well as trade-offs with other socio-economic activities, might help developers, facilitating investments, as well as increasing the social acceptability of aquaculture by communities.

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12 List of partners

1. THE SCOTTISH ASSOCIATION FOR MARINESCIENCE LBG (SAMS). Coordinator
2. AGRIFOOD AND BIOSCIENCES INSTITUTE (AFBI)
3. FUNDACION AZTI - AZTI FUNDAZIOA (AZTI-Tecnalia)
4. BLUEFARM SRL (BLUEFARM) SRL
5. CHRISTIAN MICHELSEN RESEARCH AS (CMR) AS
6. AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS (CSIC)
7. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS FAO (FAO)
8. NEMZETI AGRARKUTATASI ES INNOVACIOSKOZPONT (NARIC)
9. INSTITUT FRANCAIS DE RECHERCHE POUR L'EXPLOITATION DE LA MER (IFREMER)
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19. YELLOW SEA FISHERIES RESEARCH INSTITUTE, CHINESE ACADEMY OF FISHERY SCIENCES (YSFRI)
20. THE UNIVERSITY OF WESTERN AUSTRALIA (UWA)
21. BIHARUGRAI HALGAZDASAG MEZOGAZDASAGI TERMELO ERTEKESITO ES TERMESZETVEDELMI KFT (BHG) KFT
22. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)
23. NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH (NIWA)

13 List of AquaSpace deliverables

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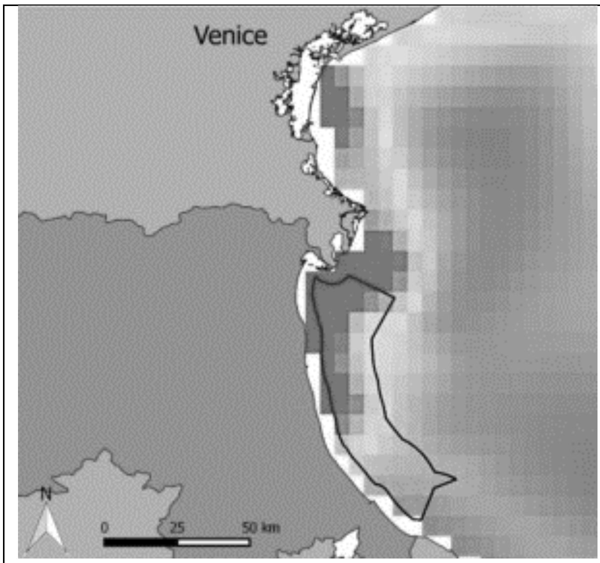
14 Annex. Case studies outcomes

14.1 Shellfish culture in Emilia-Romagna, Adriatic Sea



Region: Emilia-Romagna	**Country:** Italy	**Location:**	
Partner: BLUEFARM SRL (BLUEFARM)			

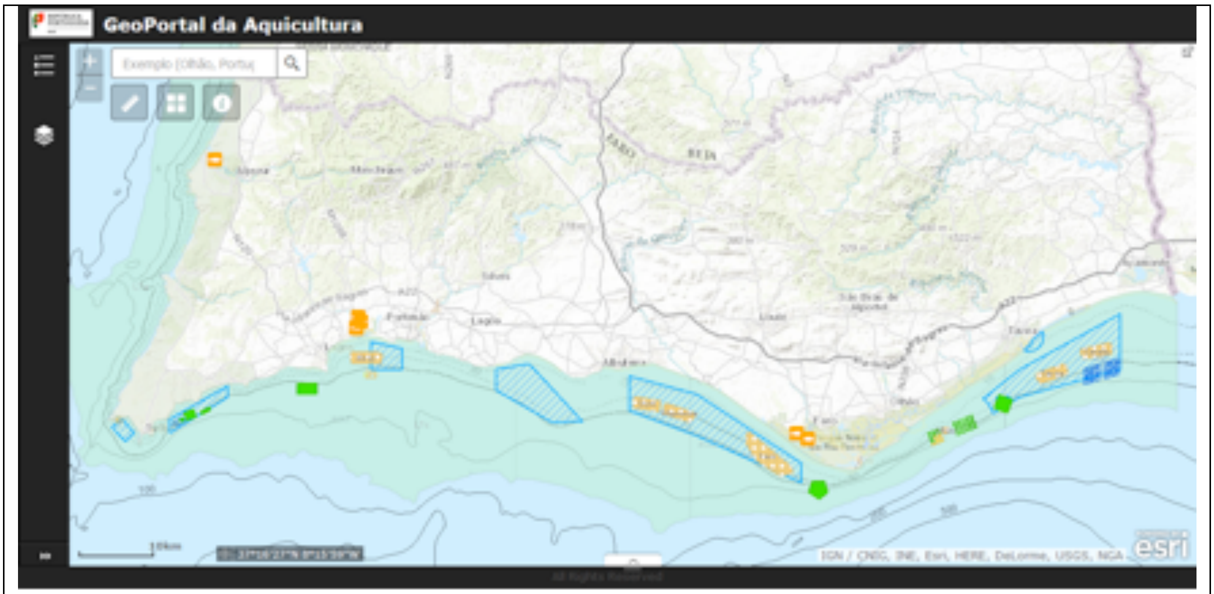
Management level:	
MSP in place at national level? Yes/No	No, in progress. The Legislative Decree n. 201/2016 has recently set the framework for the MSP implementation in the Italian Seas. The regulators are represented by a Committee lead by the Italian Ministry of Infrastructure and Transports and including 1 delegate of Italian region for each reference maritime area and 4 Ministries: (i) Environment, Land and Seas; (ii) Agriculture and Forestry; (iii) Economic Development; (iv) Cultural Heritage and Activities and Tourism. http://www.msp-platform.eu/countries/italy
Any spatial management in the case study area?	Spatial management plans for aquaculture are not in place in this area. Regione Emilia Romagna is involved in the delivery of new leases for shellfish aquaculture. GAC (Coastal Action Groups) are in place in the area. At the national level, since 2010 trawling is prohibited within the three nautical miles from the coast.
Any other spatial planning measures/ordination of space? (including sectoral plans)	Emilia Romagna Region published in 2005 the Regional guidelines for the integrated management of coastal zones (GIZC). Projects Shape (Shaping an Holistic Approach to Protect the Adriatic Environment between coast and sea) and Adriplan (ADRiatic Ionian maritime spatial PLANning) investigated the theme of the multi-use of space along this coastal area.
How were the principles of EAA addresses in your case study?	EAA not implemented. However, the EAA concept was cited in the National Strategic Plan for the development of aquaculture in Italy. Pilot studies were carried out to assess bivalve carrying capacity in the area, by applying numerical models.

Aquaculture activity:			
Main environment: Open Sea	**Extension of aquaculture (occupied area in km^2)** 1561	**Culture system:** Longline	**Species:** Mediterranean mussel (*Mytilus galloprovincialis*) Oysters (*Crassostrea gigas*)
Number of farms:	**Production capacity:** Mussels: 40000 t	**Aquaculture relevance (importance for the region)** Highly relevant activity	**Incomes or economical aspects:**

Relevance of the Case Study within AquaSpace	Saturation of the area within 3 nm of the shore Need for product diversification Diversification of production technology
Relevance of the case study	Need to diversify the production Tools for site selection Need of flexible tools concerning the estimation of potential biomass yield, to be integrated within more comprehensive planning instruments Disease exposure Positive farm-ecosystem interactions Measures for climate change Establishing a unique point of contact for assisting farmers in complying with the current legislation concerning licensing, environmental monitoring and food safety (diseases.) Identification of areas where aquaculture has a priority on other uses
Main issues identified for further development of aquaculture	Too long to get new licenses, aquaculture zoning not in place in this region (it would facilitate the process of site selection, if used) Hydrodynamic conditions (wave exposure) HABS (Harmful Algal Blooms) Predicted trends in water temperature and river outflow Disease exposure Two sets of conflicts with other users were identified: For mussel production: 1) ports and navigation; 2) underwater pipes; 3) touristic traffic For oyster production: 1) conservation zones; 2) presence of Italian Navy; 3) anchorage areas; 4) seabed mining; Low selling price for mussels Lack of insurance against risk of damage to fam structures and loss of product

Implemented tools: BLUEFARM-2
Required data (environmental/socioeconomic data) Sea surface temperature; Chlorophyll-a concentration; wave height time series; water current velocity time series; bathymetry; constraints in place in the area: maritime traffic; presence of Italian navy, biological conservation zones; underwater pipes; seabed mining; sand deposits
Lessons learned, conclusions and recommendations Identification of the most suitable areas for aquaculture could help aquaculture zoning. We therefore recommend that Aquaspace results should be taken into account by the WG of the ITAQUA platform supporting the Ministry (MiPAF) in the MSP implementation. The BLUEFARM-2 tool is based on a flexible spatial multi criteria evaluation methodology, which will allow to upgrade it, by including additional layers of information. In order to do this, a continuous interaction with stakeholders at the regional level will be required. Access to public environmental data repositories will be highly important in order to keep the analysis up to date.

14.2 Algarve Coast



Region: Algarve	**Country:** Portugal	**Location:**	
Partner: Sagremarisco-Viveiros de Marisco Lda.			

Management level:	
MSP in place at national level? Yes/No	A pilot MSP plan. http://www.msp-platform.eu/countries/portugal
Any spatial management in the case study area?	There is a National Strategy for the Sea 2013-2020. With regards to aquaculture, it was updated in 2015 and it is based on 3 action plans. #1 Valuing aquaculture (value chain), #2 Management tools (Zoning), #3 Gears, Means, Methods (Sustainable aquaculture). Within action plan # 2 areas of potential offshore aquaculture have been defined.
Any other spatial planning measures/ordination of space? (including sectoral plans)	Maritime spatial planning *(*Plano de Ordenamento do Espaço Maritimo -http://www.msp-platform.eu/practices/plano-de-ordenamento-do-espaco-maritimo-poem) Some coastal areas are also under the regulations of natural parks and protected areas. For example, the PNSACV (Natural Park of the SW Alentejo and Vicentine Coast) affects an area upto 2km of the coast.
How were the principles of EAA addresses in your case study?	Within the action plan # 3, the National Strategy for the Sea 2013-2020 considers that sustainable aquaculture should take an ecosystem approach to promote the activity. Although the government have defined large areas with potential for the implementation of aquaculture, there has not been a proper stakeholder consultation, as required for the EAA strategy, resulting in recent conflicts; clearly a top-down approach. With regards to the MSP, there is a pilot process which is preparing and developing a Situation Plan, for the Portuguese MSP. The expansion to offshore aquaculture is a new activity in Portugal,

	and in the Algarve several conflicts have arisen with fishermen and tourism; this is expected to increase as more areas are occupied for aquaculture. Most of these problems are due to lack of consultation with relevant stakeholders, as well as the poor perception that aquaculture industry has with the public. SWOT analysis for global Portuguese aquaculture have been done by government (see Del.4.2). Carrying capacity and regular monitoring of environmental parameters are the responsibility of the lease owner.

Aquaculture activity:			
Main environment: Open sea	**Extension of aquaculture (occupied area in km^2)** Offshore active establishments with production (n=26, 3053ha) (source: INE/DGRM)	**Culture system:** Intertidal plots (inland). Longlines and Tuna traps (offshore)	**Species:** Clam (*Ruditapes decussata*) Mediterranean mussel (*Mytilus galloprovincialis*) Pacific oyster (*Crassostrea gigas*)
Number of farms:	**Production capacity:** Clam: stable production; mussel: 7240 oyster: 2405 Fattening of wild tuna, with an expected production of 4760 tons.	**Aquaculture relevance (importance for the region)** High strategic priority for the government	**Incomes or economical aspects:** 1521 licensed production establishments

Relevance of the Case Study within AquaSpace	There is a clear incentive for the development of offshore aquaculture in order to increase significantly the production. There are limitations with space for expansion in the inland waters of lagoons and intertidal areas, although there are incentives to recover/reconvert unused saltpans for aquaculture purposes. Pre-establishment of new offshore areas mainly for bivalves; these are considered to have a lower environmental impact compared to fish. Mandatory monitoring for environmental parameters (monthly for water parameters; yearly for sediment). Carrying capacity studies are not mandatory, but those might be requested in the future by the government.
Relevance of the case study	There is a need for contingency and biosecurity plans, with surveillance plans required by the veterinary authorities (DGAV- Food and Veterinary General Directorate). Although the Portuguese state currently monitors Harmful Algal Blooms (HABS), there is also a need for regional programs of environmental monitoring. Also, there is a need for industry to receive more rapid information of toxin levels in shellfish due to HAB events. Furthermore, the spatial range of the current toxin monitoring zones are considered too large (ex. area L7c from St Vincent to Portimão approx 50km).

	The cost of environmental monitoring of aquaculture on farms in the Algarve is supported by the owner. There is a need to develop a specific spatial planning for the activity, in the context of the general MSP currently under implementation in Portugal. There is a need for specific insurance for aquaculture and there is currently legislative efforts to support this activity in Portugal.
Main issues identified for further development of aquaculture	Difficulty/slowness to obtain permissions Ineffective/Undeveloped regulations Marine protected areas/ Natural parks regulations Disease connectivity Harmful Algal Booms Low chlorophyll values (i.e. poor food availability for shellfish) especially during periods of upwelling relaxation. Conflicts between activities (Fishing, Conservation, Tourism) Space and infrastructure on land to support offshore activity. Seasonality of tourism and consumers demand. Problems in siting farms in peripheral areas, away from logistic platforms. Price for bivalves, particularly mussels is low.

Implemented tools:

Stakeholder consultation done both with aquaculture farmers and as we all as the regulators of the activity.

Required data (environmental/socioeconomic data)

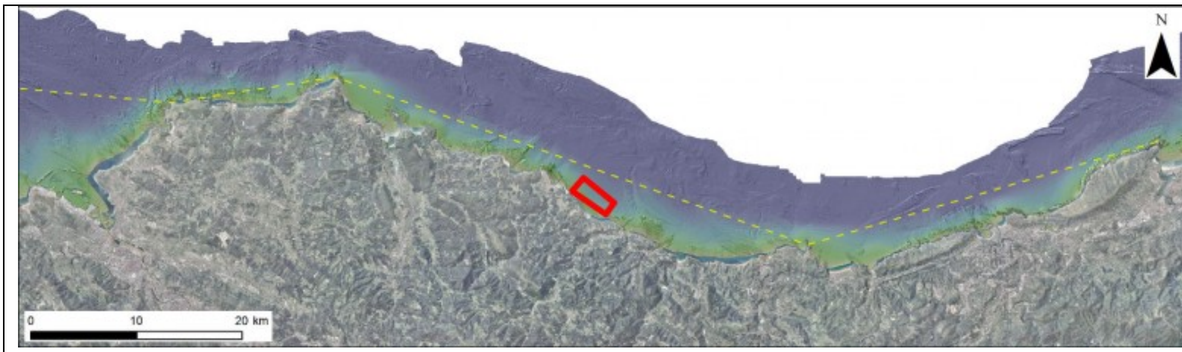
Lessons learned, conclusions and recommendations

All processes related to the implementation and management of aquaculture activities in the Algarve between the stakeholders and the managers, representing the government, need to be improved.

The main recommendations, are to increase consultation with the relevant stakeholders involved in aquaculture to ensure sustainable development.

Ensure that the public is properly informed about the aquaculture industry and its important contribution to the society. Indeed, the current perceptions of aquaculture activity and its products in the Algarve are very negative, although most consumers already consume a lot of imported aquaculture products such as mussels from New Zealand, catfish from Vietnam, salmon from Norway.

14.3 Basque Country



Region: Cantabrian sea (Bay of Biscay)	**Country:** Spain	**Location:** Basque Country	
Partner: Fundación AZTI - AZTI Fundazioa (AZTI-Tecnalia)			

Management level:

MSP in place at national level? Yes/No	No. In progress.
Any spatial management in the case study area?	No
Any other spatial planning measures/ordination of space? (including sectoral plans)	Yes. Sectoral plan for aquaculture
How were the principles of EAA addresses in your case study?	Not explicitly but the strategic Plan for Aquaculture already considers main steps of EAA

Aquaculture activity:

Main environment: Open sea	**Extension of aquaculture (occupied area in km^2)** 5.7 (52 plots of 1ha each)	**Culture system:** Longline	**Species:** Mediterranean mussel (*Mytilus galloprovincialis*)
Number of farms: 1 (experimental)	**Production capacity:** 2080 t per year (expected)	**Aquaculture relevance (importance for the region)** Low at local scale but promoted by national and local government as a way of diversification of maritime activities.	**Incomes or economical aspects:** N/A

Relevance of the Case Study within AquaSpace	Identification of areas for the establishment of aquaculture as a new activity. Diversification of marine activities and minimisation of conflicts of use, mainly with artisanal fishery.

	Analyse the conflicts between the maritime users within the new defined aquaculture zone. Analysis of option for optimisation of space. Economic assessment. Declaration of zones of aquaculture interest in which this activity would be prioritized.
Relevance of the case study	Main interest is that open sea shellfish aquaculture has not been developed in the region (Cantabrian sea), and the aquaculture testing site in the Basque Country represents the first aquaculture experience at regional level. Thus, the outcomes from this case study will lead to define proposals focused on some local aspects (i.e. socioeconomics, spatial planning, regulation, user conflicts, ecological tools, etc.) of high relevance and clearly related to the cost-effective and profitable development of aquaculture in the open ocean waters of the Bay of Biscay.
Main issues identified for further development of aquaculture	Licensing process is long and complex. Different roles of management authorities. Production capacity is limited due to environmental conditions (growth conditions). Limitations regarding to cultivated species (only common ones). Aquaculture activity should be located away from ports and recreational zones where they can interfere with bathers. Lack of infrastructure for an optimal management of the aquaculture products.

Implemented tools:

Hydrodynamic models: analysis of suitable areas for installing the longlines.
GIS (multicriteria analysis): avoid excluding factors (legal) and minimization of conflicts with artisanal fishery.
Bayesian Belief Network: analysis of fishing effort reallocation options.
AquaSpace tool: trade-off analysis of different aquaculture locations.

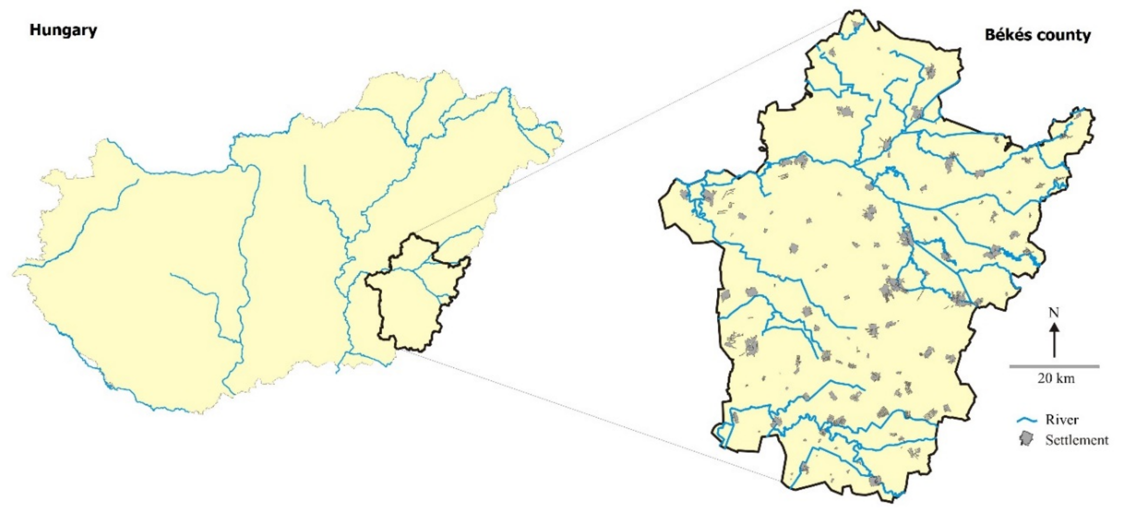
Required data (environmental/socioeconomic data)

Environmental data: Oceanographic characteristics, wave exposition, depth, seafloor types, benthic habitats types.
Socioeconomic data: Fishing activity data (effort and revenues), aquaculture production information (biomass, market price).

Lessons learned, conclusions and recommendations

Long-term strategies and funding mechanisms are needed to develop well established teams and for software developments.
Development of new tools needed to assist social and economic analysis.
Development of new tools needed to assist in the stakeholders' participation and involvement.
More transparency of the needs of aquaculture industry to develop fit to purpose planning tools.
Development and implementation of new management strategies (MSP or EEA), requires a better scientific knowledge of ecosystem functioning that could be transferred into reliable ecosystem models to be implemented in management tools.

14.4 Békés County



Region: Southern Great Plain	**Country:** Hungary	**Location:**	
Partner: Nemzeti Agrarkutatasi Es Innovacioskozpont (NARIC)			

Management level:

MSP in place at national level? Yes/No	No
Any spatial management in the case study area?	No
Any other spatial planning measures/ordination of space? (including sectoral plans)	Development plans at national, regional and municipal levels integrating economic, social and land use etc. aspects
How were the principles of EAA addresses in your case study?	No. Lack of integrated watershed management (surface and subsurface water use, waste water treatment/disposal, urban runoff, excess water, draft, etc.)

Aquaculture activity:

Main environment: Pond	**Extension of aquaculture (occupied area in km^2)** 2010	**Culture system:** Extensive	**Species:** Carp (*Cyprinus carpio*)
Number of farms: 10 companies	**Production capacity:** 1430 t	**Aquaculture relevance (importance for the region)** Economic relevance is limited. Significant role in water management and landscape formation.	**Incomes or economical aspects:** 3 million euro turn over/year

Relevance of the Case Study within AquaSpace	The CS concerns problems and needs of inland aquaculture (proper site selection tools, modernization, diversification, knowledge transfer, exchange of best practices, post-harvest value chain)

Relevance of the case study	Access to water resources Analysis of ecosystem services provided by aquaculture: (1) surveying how local people are aware of ES provided by fish ponds and how important are these for them. 2) biophysical quantification of provisioning and regulating Ecosystem Services Conflict mediation
Main issues identified for further development of aquaculture	Legal uncertainty i.e. not clearly defined the priority in water use Regulatory approach on aquaculture as a water user industry (there are questions on to what extent the aquaculture competes with other sectors (i.e. AQ uses water - in Feb March - when it is not needed by other sectors) Conflicts between natural conservation and aquaculture producers (Compensation system of the damage caused by predatory animal is not elaborated) Ecosystem services provided by fish ponds (promote their conservation as a source of other new activities: tourism, fishing, etc.) Regulation on water service fee

Implemented tools:

Multi-layer GIS mapping

Millennium Ecosystem Assessment Framework for biophysical and sociocultural valuation of ecosystem services

Stakeholder meetings (cross-sectoral)

Required data (environmental/socioeconomic data)

Open access maps and databases: (e.g. land cover database: CORINE), the M: 1:10000 topographic map, land register maps, settlement maps, hydrological and water use data;

Biodiversity data (flora, birds, reptiles, amphibians), water quality data on discharged water from fishponds, technological parameters and fish production data

Lessons learnt, conclusions and recommendations

Multi-layer GIS mapping is a proper tool to select sites not only for aquaculture but for water retention, storage or natural water treatment (wetlands) sites as well

The importance of consultation and participatory processes with the involvement of different stakeholder groups can eliminate false assumptions and increase awareness towards aquaculture industry efforts

Recommended:

- To adopt EAA principle: consider other sectors aspects and use a holistic ecosystem or watershed approach
- To establish open access databases
- To extend scope of data collection, monitoring efforts on environmental factors and biodiversity

14.5 Carlingford Lough

Region: Irish Sea	**Country:** United Kingdom/Republic of Ireland	**Location:** Carlingford Lough is a sea lough at the mouth of the Newry (or Clanrye) River on the east coast of Ireland, bordering both the Republic of Ireland and Northern Ireland.
Partner: Agrifood and Biosciences Institute (AFBI)		

Management level:	
MSP in place at national level? Yes/No	Yes. http://www.msp-platform.eu/countries/united-kingdom
Any spatial management in the case study area?	The Department of Agriculture, Environment and Rural Affairs (DAERA) are currently in the process of producing a Marine Plan for the Northern Irish Inshore and Offshore region. There are not currently any spatial management plans in place for Carlingford Lough.
How were the principles of EAA addressed in your case study?	The Ecosystem Approach to Aquaculture (EAA) is a strategy which has been summarised into six main steps (FAO and World Bank 2015). These steps and how this case study relates to them are outlined below. ***1) Scoping to understand broader issues:*** Within the Carlingford Lough Case Study, the Geographic Information System (GIS) ArcGIS v10.3 has been exploited to enable us to build a comprehensive picture of the multiple stakeholders involved within the area. Meetings have been carried out with various users to highlight the main issues affecting aquaculture development within Carlingford Lough.

	2) Identification of opportunities and assessment of Risks: Through this Case Study a demonstrator of the AkvaVis model has been developed for Carlingford Lough. This demonstrator version of the model allows the user to identify areas suitable for aquaculture production and applies a risk assessment scoring system (using predetermined parameters) to the areas selected. ***3) Carrying capacity:*** Within the Carlingford Lough Case Study, the SMILE model has been applied to determine both the ecological carrying capacity and the production carrying capacity of the study area. ***4) Allocation of user/areas access:*** This stage within the EAA process still needs to be addressed within Carlingford Lough. The work undertaken on this area within the AquaSpace project (such as the development of the Carlingford Lough AkvaVis demonstrator model) will help progress towards this. ***5) Development of management plans and 6) Monitoring of management plans:*** These two stages of the EAA process have yet to be undertaken within Carlingford Lough. Utilising the Carlingford Lough GIS project and the SMILE carrying capacity model AFBI have produced a cumulative impact assessment report for Carlingford Lough. This report, which analysed the cumulative impacts of current aquaculture activities on the marine designated features within Carlingford Lough, will be a vital component in the development of a Management Plan for the area.

Aquaculture activity:

Main environment: Sea lough (intertidal/subtidal)	**Extension of aquaculture (occupied area in km^2)** The total area of Carlingford Lough occupied by licensed aquaculture sites is 11.87 km^2.	**Culture system:** Off-bottom culture (trestle) Bottom culture	**Main species:** Pacific oyster (*Crassostrea gigas*) Blue mussel (*Mytilus edulis*)
Number of farms: 14 licensed aquaculture sites within the area of Carlingford Lough within Northern Ireland and 41 licensed aquaculture sites within the area of Carlingford Lough within the Republic of Ireland	**Production:** Due to the trans-boundary nature of the case study area a total production figure for Carlingford Lough is not available at this time.	**Aquaculture relevance (importance for the region):**	**Income or economic aspects:** Due to the trans-boundary nature of the case study area the total economic value for aquaculture within Carlingford Lough is not available at this time.

Relevance of the Case Study within AquaSpace	Trans-boundary sea Lough, with complex management issues.

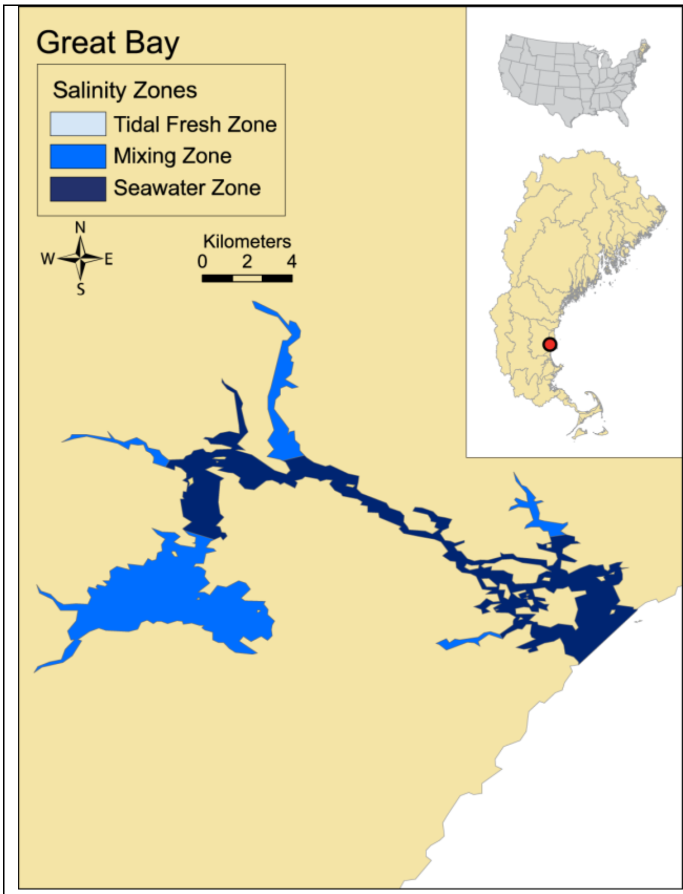
<table>
<tr><td></td><td>Expansion of the industry is seriously hampered by nature conservation legislation. There is the need to identify areas for future aquaculture development which do not conflict with nature conservation designations or other users.
Lengthy licensing process</td></tr>
<tr><td>Relevance of the case study</td><td>The Key issues identified within Carlingford Lough include conflicts between industry expansion, nature conservation, and the multiple other users of Carlingford Lough. These issues are confounded by the existence of a least six different regulatory authorities in two different national jurisdictions. There is therefore a requirement for regional aquaculture spatial planning tools.</td></tr>
<tr><td>Main issues identified for further development of aquaculture</td><td>Different Government bodies responsible for licensing in different jurisdictions.
Lengthy licensing process
Spatial conflicts with nature conservation
Ecological carrying capacity
Competition for space with other users/industries.</td></tr>
<tr><td colspan="2">Implemented tools:
GIS (ArcGIS V10.3)
Ecological Carrying capacity model (Sustainable Mariculture in northern Irish Lough Ecosystems - SMILE)
AkvaVis (Demonstrator model for Carlingford Lough developed)</td></tr>
<tr><td colspan="2">Required data (environmental/socioeconomic data)</td></tr>
<tr><td colspan="2">Lessons learned, conclusions and recommendations
The Carlingford Lough GIS project should continue to be updated (once new data sets become available) and utilised when undertaking aquaculture impact assessments.

The SMILE model should be run to enable the determination of optimal stocking densities for mussels (Mytilus edulis) and oysters (Crassostrea gigas) within the different model boxes and should also be used to determine the production carrying capacity of Carlingford Lough.

A fully operational version of the AkvaVis model should be developed for the Northern Ireland inshore region.

The Carlingford Lough GIS should be utilised in conjunction with the SMILE model and the AkvaVis demonstrator model of Carlingford Lough, for the development of an Aquaculture management plan for Carlingford Lough (step 5 in the EAA framework).</td></tr>
</table>

14.6 Great Bay, Piscataqua



Region: North Atlantic	**Country:** USA	**Location:** Piscataqua. The water body is shared by New Hampshire and Maine and the watershed is also shared by these two states	
Partner: National Oceanic and Atmospheric Administration (NOAA)			
Management level:			

MSP in place at national level? Yes/No	Each state has a plan for aquaculture and most now have the GIS decision support tools to help with siting and expansion
Any spatial management in the case study area?	An analysis was made for potential maximum area that could support shellfish leases (http://slideplayer.com/slide/7280199/) and a plan made for expansion and diversification of shellfish aquaculture (https://www.des.nh.gov/organization/divisions/water/wmb/shellfish/red-tide/documents/102012-jel-oysteraqfinal.pdf)
Any other spatial planning measures/ordination of space? (including sectoral plans)	A shellfish siting tool is being used and there is research being done to try to show the importance to water quality – as well as seafood product – of the oyster and clam aquaculture that is being conducted - one thing about that is that some of the growers (not the 'old school', more the new cage growers) are getting involved in the research to push the expansion.

<table>
<tr><td colspan="2">How were the principles of EAA addresses in your case study?</td><td colspan="2">Yes, the study of potential areas for potential use by aquaculture and the study of the diversification and expansion are designed to facilitate more aquaculture while minimizing conflicts in this small multiple use estuary</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Aquaculture activity:</td></tr>
<tr><td>Main environment:
Estuary</td><td>Extension of aquaculture (occupied area in km²)
0.1</td><td>Culture system:
Primarily rack and bag systems on bottom, mesh bags inserted into cages</td><td>Species:
Crassostrea virginica (Eastern oyster)</td></tr>
<tr><td>Number of farms:</td><td>Production capacity:
About 4.8 million oysters</td><td>Aquaculture relevance (importance for the region)
New and is growing rapidly but rate is unknown
Plans to expand aquaculture operations in the future, most likely bottom culture due to concerns (described as 'social carrying capacity</td><td>Incomes or economical aspects:</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="2">Relevance of the Case Study within AquaSpace</td><td colspan="2">Assess current status, processes and practices for aquaculture siting, site selection and area management

Benefits to water quality of shellfish aquaculture.
Potential impact of oyster filtration on reduction of nitrogen pollution in the estuaries at current and expanded oyster cultivation</td></tr>
<tr><td colspan="2">Relevance of the case study</td><td colspan="2">1) Increase public awareness and support

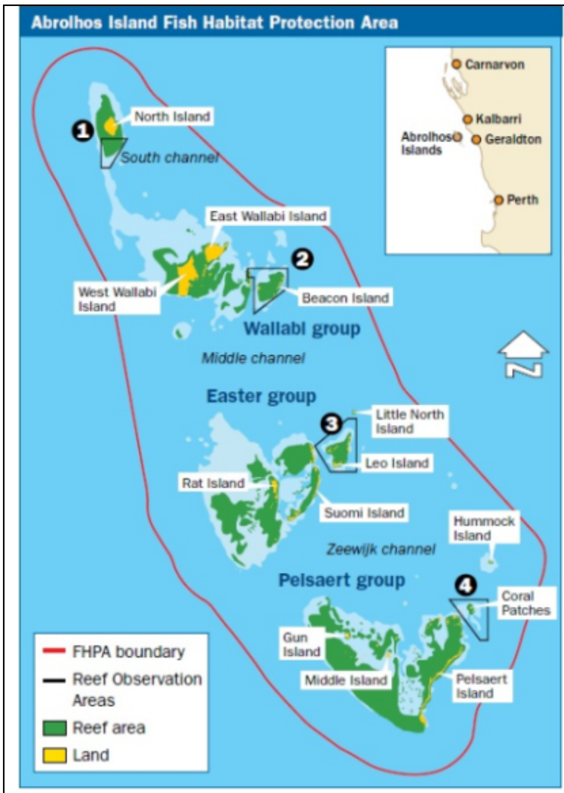
2) Promote expansion of aquaculture giving more space to farm

3) Investigate impacts of pollution and climate change on shellfish

4) Streamline regulations and management</td></tr>
<tr><td colspan="2">Main issues identified for further development of aquaculture</td><td colspan="2">Oyster and clam aquaculture are a benefit in that they improve overall water quality and reduce nutrient degradation, and which is a very serious concern in this waterbody. No negative impacts are anticipated since the oysters are not fed.
'Social carrying capacity' in relation to visibility of farms to land owners, and their obstructions to other users of the waterbody</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Implemented tools: Modeling (FARM) Modeling (ASSETS) Avoided Costa approach - a cost-based economic analysis method
Required data (environmental/socioeconomic data)
Lessons learned, conclusions and recommendations A modeling study has shown the benefit to water quality and the economy in Great Bay Piscataqua Region Estuaries where the aquaculture industry is small but growing. The economic benefits to water quality via nutrient removal vary from a minimum of $1.1 million under current aquaculture production to more than $5 million if aquaculture were expanded to maximum suitable areas. And it provides a sustainable domestic source of seafood in a country that imports more than 90% of the seafood consumed.

14.7 Houtman Abrolhos Islands



Region: Western Australia	**Country:** Australia	**Location:** Houtman Abrolhos Islands	
Partner: University of Western Australia (UWA)			
Management level:			
MSP in place at national level? Yes/No	Yes. http://msp.ioc-unesco.org/references/		
Any spatial management in the case study area?	While no spatial management plans have been implemented at the case study region specifically, spatial management has been implemented at a state level. The government of Western Australia (WA) has committed to ensuring that maintenance and development of existing aquaculture industries within WA are considered in marine planning processes (including development of new marine reserves). This also includes the establishment of aquaculture development zones in suitable areas which provide competitive advantages through streamlined environmental approval processes (Statement of Commitment 2015).		
Any other spatial planning measures/ordination of space? (including sectoral plans)	The Houtman Abrolhos Islands has also been declared a Fish habitat protected area (Fish Resource Management Act 1994) which serves to		

	protect fish (and other organisms) and their habitats through regulation of anthropogenic activities.
How were the principles of EAA addresses in your case study?	At the case study level, no EAA has been implemented. However, baseline samples for monitoring programs are expected to begin shortly. At the state level, an EAA has been considered. Due to the unique marine biodiversity of Western Australia (WA), the WA Department of Fisheries have put particular importance on monitoring fish health and potential for disease spread in aquaculture systems. This includes an emphasis on recognizing and diagnosing a range of disease threats (Industry Overview 2015).

Aquaculture activity:			
Main environment: Open Sea	**Extension of aquaculture (occupied area in km^2)** 30 (planned)	**Culture system:** Open water finfish cages	**Species:** Yellowtail Kingfish (*Seriola lalandi*)
Number of farms: Not yet implemented	**Production capacity:** 24000t estimated potential (Production of yellowtail kingfish at the Abrolhos Islands is just starting and therefore there are currently no annual production statistics)	**Aquaculture relevance (importance for the region)** Currently a total of 3000 ha of suitable space is being designated for the aquaculture of yellowtail kingfish around the Pelsaert group of islands (southern area of the archipelago).	**Incomes or economical aspects: NA**

Relevance of the Case Study within AquaSpace	Research to understand potential impacts of aquaculture implementation
Relevance of the case study	Need to: Streamline licensing approvals and site selections; Reduce impacts on natural conservation features
Main issues identified for further development of aquaculture	Streamlining the licensing approvals and ongoing management of activities Link governmental policy to expand aquaculture to conditions of sustainable production Methods for assessment of site suitability and carrying capacity to reduce compliance costs Need for improved spatial planning to enable better targeting and monitoring requirements in order to ensure sound environmental protection Need for development and use of tools to assist the assessment of suitability and carrying capacity of new sites and zones Defining best principles of operation to account for interaction of multiple users (industry, recreational purposes, etc.) and biosecurity Describing best strategies for reducing the risk of disease emergence, containment in the event of a disease outbreak, and prevention of spread of disease to the wider industry.

	Improving spatial planning of leased areas within planned zones to optimize production

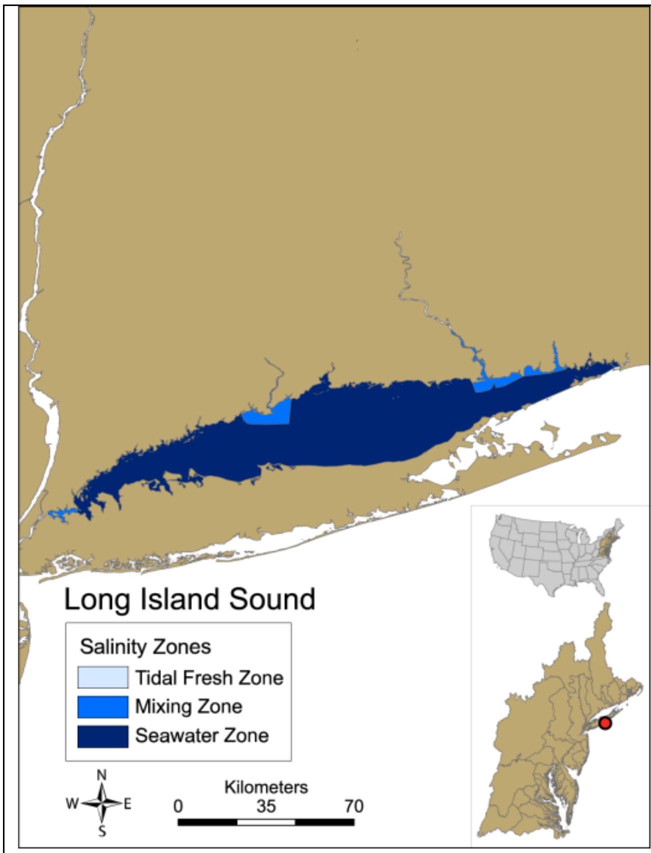
Implemented tools: Previous to AquaSpace, two models were implemented: TuFlow hydrodynamic model for particle transport and biochemical processes, and FABM-AED model for sediment diagenesis (e.g. turbidity, nutrients, general ecosystem interactions etc.). As part of the Aquaspace toolbox, EcoWin was identified as the most suitable tool to address the issues identified above.
For the application of EcoWin to the study site, integration of multiple models is needed, including a hydrodynamics model and a fish physiology model. We have adapted an existing fish growth and physiology model to yellowtail kingfish which could be incorporated in Ecowin. However, due to lack of funds we were unable to outsource hydrodynamic modelling outputs in the format as required for EcoWin.

Required data (environmental/socioeconomic data)

Lessons learned, conclusions and recommendations

Application of an ecosystem-based modelling approach to the study site could be beneficial to address the identified issues while aiming at increasing aquaculture production. Because disease control is an important issue, utilization of other models such as AkvaVis could also be beneficial.

14.8 Long Island Sound



Region: Mid-Atlantic	**Country:** USA	**Location:** Long Island Sound The waterbody is shared by New York and Connecticut. The water shed includes area in Connecticut, New York, Massachusetts, Rhode Island, Vermont, New Hampshire, and Canada.	
Partner: National Oceanic and Atmospheric Administration (NOAA)			

Management level:	
MSP in place at national level? Yes/No	Each state has a plan for aquaculture and most now have the GIS decision support tools to help with siting and expansion
Any spatial management in the case study area?	There is a shellfish siting tool to facilitate the expansion
Any other spatial planning measures/ordination of space? (including sectoral plans)	A shellfish siting tool is being used and there is research being done to try to show the importance to water quality – as well as seafood product – of the oyster and clam aquaculture that is being conducted - one thing about that is that some of the growers (not the 'old school', more the new cage growers) are getting involved in the research to push the expansion.

How were the principles of EAA addresses in your case study?	Yes, using the shellfish siting tool (http://clear2.uconn.edu/shellfish/) and study of current and potential production and nutrient removal (https://www.coastalscience.noaa.gov/publications/detail?resource=O0hdKo2k2hSWOxLGFRcu/feoeR4U4RM469gysLLrINQ=) are attempts to manage space and to reduce conflicts in this multi-use system.

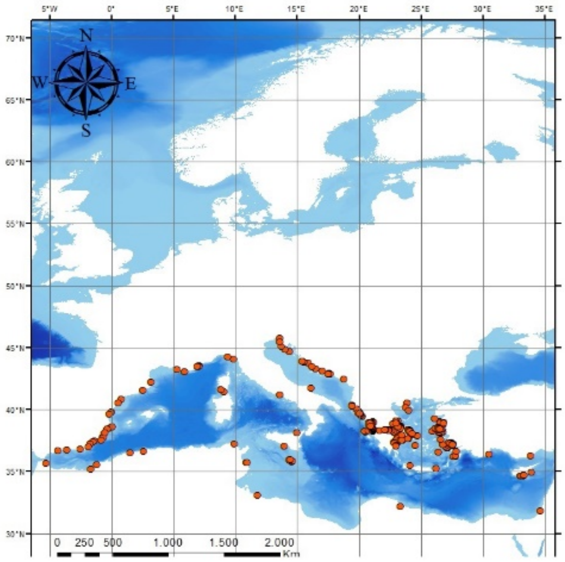
Aquaculture activity:

Main environment: Estuary	**Extension of aquaculture (occupied area in km^2):** 267	**Culture system:** "Primarily spat on shell culture planted directly on bottom with no gear (90% of the industry) Floating cages/gear (10% of the industry)"	**Species:** *Crassostrea virginica* (Eastern oyster) *Quahog clam* (Mercenaria mercenaria)
Number of farms:	**Production capacity:** About 52 million oysters About 833 million clams	**Aquaculture relevance (importance for the region)** Well-established. Aquaculture will increase in the future most likely through cage culture while bottom culture with no gear has to this point been the standard practice. There is a shellfish siting tool to facilitate the expansion (http://clear2.uconn.edu/shellfish/)	**Incomes or economical aspects:** CT shellfish harvests (primarily clams and oysters) have provided over 300 jobs and \$30 million in farmgate revenue (where farmgate price is the sale price of oysters that is received by the grower) annually, with oyster harvest exceeding 40 x 10^6 oysters

Relevance of the Case Study within AquaSpace	Benefits to water quality of shellfish aquaculture. Potential impact of oyster filtration on reduction of nitrogen pollution in the estuaries at current and expanded oyster cultivation Improve an existing GIS aquaculture siting decision support tool
Relevance of the case study	It has identified a need to: 1) Increase public awareness and support; 2) Promote aquaculture development; 3) Investigate impacts of pollution and climate change on shellfish; 4) Streamline regulations and management; 5) Develop a standing committee to meet on regular basis to assure success of aquaculture vision plan and to discuss new and emerging issues.
Main issues identified for further development of aquaculture	Nutrient degradation of water body quality is very serious, oyster and clam culture would benefit / improve this, without negative impacts of food waste since shellfish are not artificially fed 'Social carrying capacity' in relation to land owners and other users of the waterbody.

Implemented tools: GIS-based tools Modeling (EcoWin) Modeling (FARM) Modeling (ASSETS) Avoided Costa approach - a cost-based economic analysis method
Required data (environmental/socioeconomic data)
Lessons learned, conclusions and recommendations A study has been done where stakeholders were brought together to develop a plan based on the needs of aquaculture. The recommendations fall into 4 categories organized around themes: 1. public awareness, 2. aquaculture development, 3. water and habitat quality, 4. regulations and management, all of which would help to improve perception and thus the social license that would then support growth of aquaculture new operations and also would remove obstacles to expansion of existing operations. Details can be found in the report: http://shellfish.uconn.edu/wp-content/uploads/sites/62/2016/10/execsumm.pdf A modeling study has shown the benefit of oyster aquaculture to water quality and the economy in LIS and will be used to promote and facilitate the expansion of aquaculture. The economic benefits to water quality via nutrient removal vary from a minimum of $8.5 million under current aquaculture production to more than $470 million if aquaculture were expanded to maximum suitable areas. And it provides a sustainable domestic source of seafood in a country that imports more than 90% of the seafood consumed.

14.9 Mediterranean Sea Multinational (Multiple EEZ)



Region: Mediterranean Sea	**Country:** Multinational	**Location:**	21 countries have coastal areas bordering on the Mediterranean Sea
Partner: Panepistimio Kritis (University Of Crete) (UOC).			

Management level:	
MSP in place at national level? Yes/No	MSP implementation varies in content and in administrative authority between the different EU Mediterranean Member States and non-Member States.
Any spatial management in the case study area?	Varies by country. Allocated Zones for Aquaculture (AZA) have been implemented in a number of countries.
Any other spatial planning measures/ordination of space? (including sectoral plans)	Most countries in the case study area apply zoning systems for the placement of fish farms. IUCN and FAO have made a series of recommendations regarding aquaculture site selection and monitoring (IUCN, 2009; Ross et al., 2013).
How were the principles of EAA addressed in your case study?	Since the majority of fish farms are in coastal waters their placement and management has to comply with the WFD and achieve good ecological status as well as good environmental status under the MSFD. Also, the major producers have adopted the ICZM guidelines for aquaculture placement (Mediterranean Integrated Coastal Zone Management strategy plan (ICZM, EU Official Journal L34/19, 4 Feb 2009).

Aquaculture activity:			
Main environment: Coastal and offshore	**Extension of aquaculture (occupied area in km^2)**	**Culture system:** Floating cages (plastic circular or	**Species:** Gilthead seabream (*Sparus aurata*)

		metal square) with mooring system	European Seabass (*Dicentrarchus labrax*) Atlantic Bluefin tuna (*Thunnus thynnus*)
Number of farms: 21000 farms in 2000	**Production capacity:** 755,649 t (2013)	**Relevance of Aquaculture (importance to the region)**	**Incomes / Economic aspects:**

Relevance of the Case Study within AquaSpace	Historical trend and current state of Mediterranean fish farms with respect to spatial extent, depth and cage technology.
Relevance of the case study	Need to simplify administrative procedures and to clarify the decision-making process. Also need to improve and update the monitoring regulations. Operation of the GFCM and its Committee on Aquaculture (CAQ) provides strategic guidance on aquaculture management.
Main issues identified for further development of aquaculture	No common criteria and standards for all countries and even between the different regions of some countries (Too many regulations) No general policy/directives for spatial planning of aquaculture Complicated and lengthy licensing process Pressures on sensitive habitats (e.g. seagrass meadows) Harmful micro algal species Lack of monitoring standards Conflict with other stakeholders and social acceptability issues, (incompatibility with tourism, fisheries, less space for marine cultures due to increasing trends in other activities (offshore platforms, maritime traffic) Market issues: no market stability Lack of diversification in cultured finfish Economic issues: expensive fish feed High maintenance costs Economic depression Potential for civil unrest in certain countries e.g. Tunisia, Turkey

Implemented tools: GIS-based tools

Required data (environmental/socio-economic data)

Lessons learned, conclusions and recommendations

The Mediterranean Case Study can be used as an example of successful implementation of policy and management in order to act as a basis for establishing good practice principles and adopting common standards for environmental sustainability in other parts of the world.

The AZA concept has been adopted by most of the GFCM participating countries, though it is known under different names in different places and is also implemented in different ways e.g. "poligonos" in Spain, "POAY" in Greece, designated offshore sites in Turkey, Malta, Cyprus, etc. Tunisia, Montenegro, Italy and Croatia also use the AZA concept for site selection. In Turkey aquaculture zones are concentrated in only a small part of the coastline to protect the tourism industry and others were made to move offshore; a minimum distance of 0.6 miles from the land and located in a minimum water depth of 30 metres. In Greece, aquaculture zones are distributed along the coastline. Spatial planning of the fish farms is based on the carrying capacity of the installation area, determined by parameters such as distance from shore, depth and currents.

The Mediterranean example illustrates the adoption of a common framework in a multi-national context by using (a) scientific expertise, (b) stakeholder involvement and (c) political decisions. The main processes followed can be used as a tool and guide for aquaculture policy making in other regions of world.

14.10 Normandy / Cancale

Region: Atlantic	**Country:** France	**Location:** Northern France	
Partner: Institut Francais de Recherche Pour L'exploitation de la Mer (IFREMER)			

Management level:	
MSP in place at national level? Yes/No	In development
Any spatial management in the case study area?	No. Initiative under development (DSF)
Any other spatial planning measures/ordination of space? (including sectoral plans)	Sectoral plans: Departmental Structure Plans (SDS) Regional Plans for Marine Aquaculture Development (SRDAM – without enforcing value)
How were the principles of EAA addresses in your case study?	Partially in Departmental Structure Plans (SDS) which take into account carrying capacity and environmental impacts

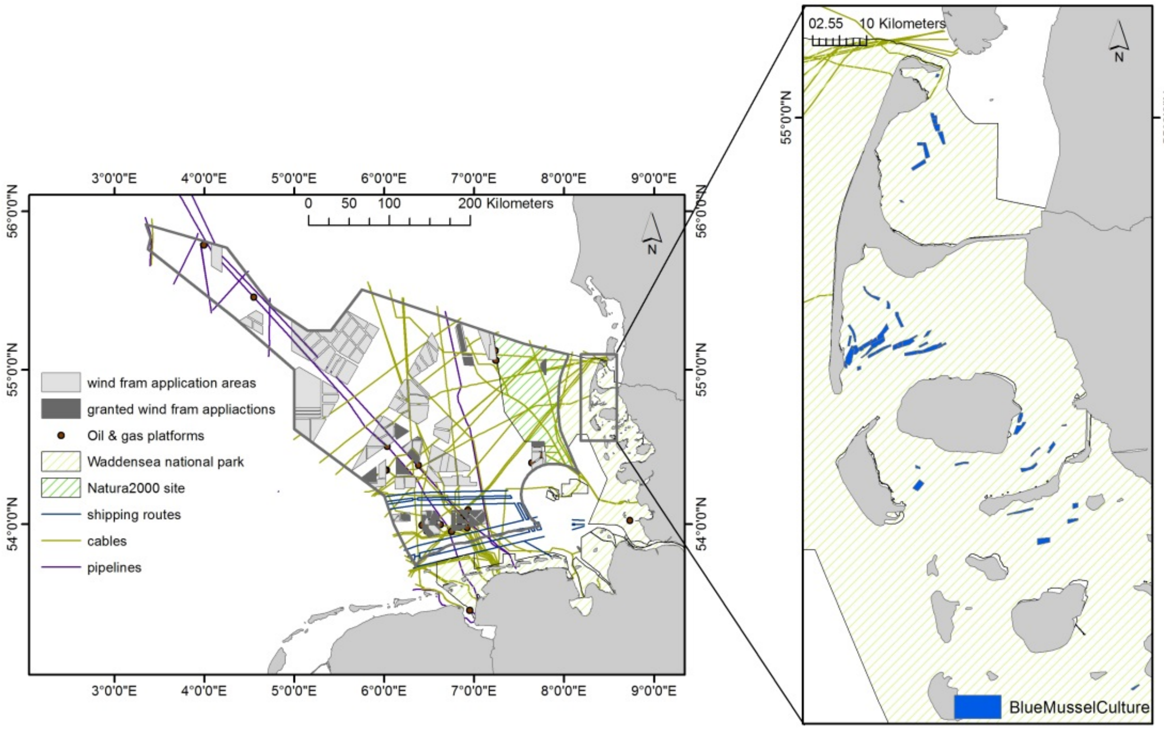
Aquaculture activity:			
Main environment: Intertidal area Harbour and on land	**Extension of aquaculture (occupied area in km^2)** ca. 65	**Culture system:** Plastic bags fixed on metallic tables moored in the sediment (oysters) On wooden poles or in bags on tables (mussels), Cages and sea water recirculation system (salmon)	**Species:** Pacific oyster (*Crassostrea gigas*) Blue mussel (*Mytilus edulis*) Salmon (*Salmo salar*)
Number of farms:	**Production capacity (per year):** 34000 t, Pacific oyster 29000 t, Blue mussel 2000 t, Salmon	**Relevance of aquaculture (importance for the region):**	**Income / Economic aspects:** At the national level, total revenue of aquaculture companies

		Normandy presents an important coastline and traditions regarding sea use (fisheries, aquaculture) are old. The total number of direct and indirect employments exceeds 24 000 for the region including aquaculture and fisheries.	reached €876 million in 2012. The major part of revenues is represented by shellfish production itself (89%, €781 million). The rest is represented by fish aquaculture. Pacific oyster: About 250 companies Blue mussel: About 200 companies Salmon: 2 companies

Relevance of the Case Study within AquaSpace	Maintain existing aquaculture activities and promote the sustainable development of new aquaculture activities in cohabitation with other usages. Huge shellfish aquaculture activity Numerous other activities High patrimonial value Scientific and legal approaches are developing in parallel: it is interesting to create communication and confrontation.
Relevance of the case study	Need to simplify administrative procedures and to clarify the decision-making process Need to make information visible and available Need to improve communication with society: social licence Need political willingness to develop aquaculture at national and local scales
Main issues identified for further development of aquaculture	Need to comply with environmental protection requirements Usage conflicts and difficulties to communicate with civil society related to social licence Set up a unique regulatory tool for a quick diagnostic and integration of a maximum of aquaculture types Increase water quality (oysters and mussels) Decrease disease outbreaks (oysters) Identify new suitable sites based on various and recognised data and indicators Potential conflicts of use with recreational fisheries on intertidal areas, and with other uses in open waters Need to balance aquaculture activities with respect to ecosystem services provided by coastal ecosystems (patrimonial issues) Social acceptability of aquaculture activity by society (even stronger for fish aquaculture) Need to become more familiar with the international market (competitiveness issues) and need for market studies (consumer expectation)

	Need to develop an industry based on high quality products and eco-aware Need stability and reliability of the production system
Implemented tools: SISAQUA	
Required data (environmental/socioeconomic data) Environmental data describing physical and biological properties of the ecosystem functioning are required as well as data concerning other usages and environmental protections.	
Lessons learned, conclusions and recommendations Stakeholders and mainly civil society raised the question of the continuous updating of data and tools developed for spatial planning in order to make them durable. This represents an important point that should not be forgotten from the process of tool development. These tools should also be designed to be user-friendly in order to facilitate their transfer to several categories of users (e.g. aquaculture investors, public institutions and civil society).	

14.11 German Case Study



<table>
<tr><td colspan="4">German EEZ of the North Sea with adjacent coastal waters, embedded between Denmark and the Netherlands with a maximum depth of 60 meters. The map shows the main offshore activities managed by the maritime spatial plan. Blue mussel license areas are located 20 km of the coast close to the island of Sylt within the Wadden Sea national park.</td></tr>
<tr><td>Region: German EEZ and Coastal waters</td><td>Country: Germany</td><td>Location: North Sea</td><td></td></tr>
<tr><td colspan="4">Partner: JOHANN HEINRICH VON THUENEN-INSTITUT, BUNDESFORSCHUNGSINSTITUT FUER LAENDLICHE RAEUME, WALD UND FISCHEREI (TI-SF)</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Management level:</td></tr>
<tr><td>MSP in place at national level? Yes/No</td><td colspan="3">Yes.
http://www.msp-platform.eu/countries/germany</td></tr>
<tr><td>Any spatial management in the case study area?</td><td colspan="3">Yes, Integrated Coastal Zone Management (ICZM) in Schleswig Holstein
Yes, Maritime Spatial Planning (MSP) at national level (German EEZ)</td></tr>
<tr><td>Any other spatial planning measures/ordination of space? (including sectoral plans)</td><td colspan="3">Yes, zoning for specific activities such as shipping and offshore wind farms.</td></tr>
<tr><td>How were the principles of EAA addresses in your case study?</td><td colspan="3">Although not yet implemented, some of the EAA framework steps are already addressed (Scoping = National Strategy for Aquaculture; Management plan development = MSP, ICZM)</td></tr>
</table>

Aquaculture activity:			
Main environment: Coastal; Open sea	**Extension of aquaculture (occupied area in km^2)** Not known	**Culture system:** Longline Free standing cage	**Species:** Blue mussel (*Mytilus edulis*) European seabass (*Dicentrarchus labrax*)
Number of farms: Blue Mussel: 10 companies European seabass: No production so far	**Production capacity:** 40000 tons (Blue Mussel) 4000 tons (European seabass)	**Aquaculture relevance (importance for the region):** Blue mussel production (approx. 5000t/y) relevant in terms of jobs and profits, not relevant in terms of food provision (mussels are mostly sold on Dutch auctions), European seabass production not relevant	**Incomes or economical aspects:** Blue Mussel: 10 companies European seabass: No production so far

Relevance of the Case Study within AquaSpace	Increase production within existing areas licensed for blue mussel. Promote coexistence of wind energy farms and finfish aquaculture. IMTA systems discussed (European seabass & blue mussel).
Relevance of the case study	Simplify and standardise authorisation procedures (for the federal states and the national state as well as in-between the federal states). Ease regulations. Support modernization. Support newcomers (e.g. marketing issues). Address price competitiveness with imports. Educate consumers (about the sustainability of aquaculture products and prices).
Main issues identified for further development of aquaculture	Conflict with conservation (Wadden Sea National Park). Plurality and complexity of authorisation procedures. Regulations (contradictions between consumer expectation towards the sustainability of aquaculture products and consumer willingness to pay) perceived as too strict (in comparison to e.g. Agriculture). High risk potential.

	No quantification of emissions. Current offshore wind energy plans cover, together with NATURA 2000 sites, approximately 30% of the German EEZ. Synergies (co-location) with offshore wind farms. No competitiveness (price) with imports (difficult marketing for newcomers & lag in modernisation).

Implemented tools:

AquaSpace tool

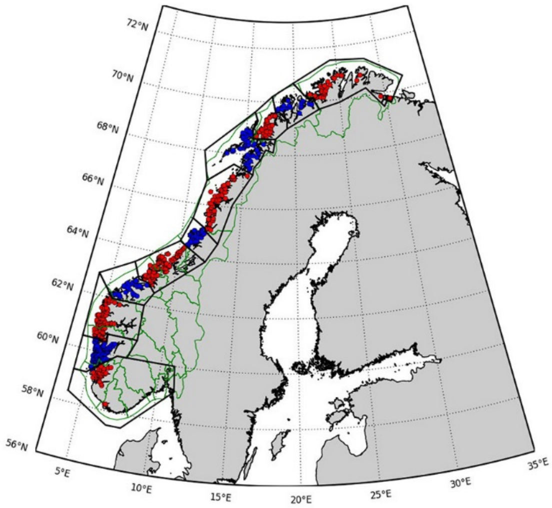
Required data (environmental/socio-economic data):

Specifications (e.g. related to investment costs, average fuel costs market price, the cage size in m³, the stocking density per m³, and the amount of production in kg/tons) need to be made to enable an economic impact assessment.

Lessons learnt, conclusions and recommendations

On the German scale, measures or strategies adopted to increase aquaculture production should allow for a priori consideration of aquaculture in spatial planning processes. Considering the implementation of an EAA might facilitate such an approach and needs to be supported by spatially explicit tools while being informed by the real world in an interdisciplinary way. Future analyses need to be based on latest data available (e.g. by linking the tool to Web Feature Service (WFS) data sources which will again lower data maintenance costs). Regarding the co-existence of windfarms and aquaculture, the AquaSpace tool could be developed further (incl. inter-sectorial, environmental, socio-cultural and economic effects from e.g. wind farm development). The outcomes of the German case study, as well as the application of the AquaSpace GIS Add-In, constitute an effort to make an integrated assessment of spatial planning operational and to aid spatial planning of aquaculture (considering the EAA framework steps).

14.12 Norwegian Coast



Region:	**Country:** Norway	**Location:**	
Partner: Havforskningsinstituttet (IMR)			

Management level:

MSP in place at national level? Yes/No	Yes. http://msp.ioc-unesco.org/references/
Any spatial management in the case study area?	Mostly. The aquaculture policy and planning process which is the basis for the Norwegian case study mostly complies with MSP steps.
Any other spatial planning measures/ordination of space? (including sectoral plans)	Yes
How were the principles of EAA addresses in your case study?	Mostly. Several elements of the EAA process implemented; Scoping Identification of opportunities and assessment of main risks Estimation of carrying capacity Allocation of user/area access and/or management rights Development of management plans for the zone/site/AMA Monitoring of the plan

Aquaculture activity:

Main environment: Coast and fjord	**Extension of aquaculture (occupied area in km^2)** 40 (in 2011)	**Culture system:** Open water cages/net pens	**Species:** Atlantic salmon (*Salmo salar*) Rainbow trout (*Oncorhynchus mykiss*)

Number of farms:	**Production capacity:**	**Aquaculture relevance (importance for the region)**	**Incomes or economical aspects:**
1067 licenses in operation, 162 companies (2015)	1,400,000 tonnes (2015)	High and the importance of aquaculture to the Norwegian economy is expected to increase	first hand value of about 5 billion euro. 6730 persons employed in aquaculture industry (2015)

Relevance of the Case Study within AquaSpace	Implementation of production zones in order to mitigate environmental issues and to manage allocation of space for aquaculture in the coastal zone. Regulate spatial planning/allowance for space. Governmental policy to allow growth of the industry on condition of sustainable production. Development of production regulation based on tools used in a traffic light system as an indicator for salmon-lice impact on wild salmon
Relevance of the case study	Solve environmental issues to allow for production growth
Main issues identified for further development of aquaculture	Government White Paper “Predictable and environmental sustainable growth of the Aquaculture industry” Salmon-lice impact on wild salmon and sea trout Competition for space The salmon lice issue impacts, motivates and drives research and industry to develop new technology that mitigate that problem. The imposed actions on mitigation and development of new technology affects the economics of the industry. Regulated production as a consequence of zoning has already had effects on the market.

Implemented tools:

Norkyst800 – hydrodynamic model for the entire coastal zone
Salmon-lice dispersion model (Ladim)
Connectivity analysis for «fire break» positioning
Existing industry structure
Web based DSS - IMR.no, Barentswatch and mapservice at Directorate of Fisheries

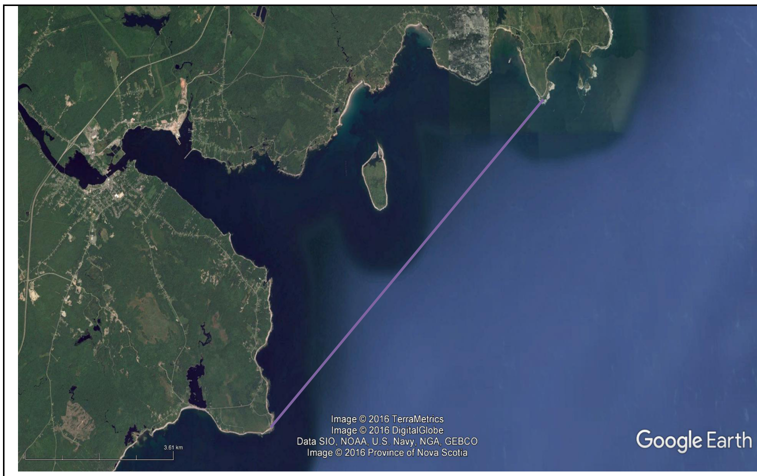
Required data (environmental/socioeconomic data)

Required data for the implementation of the production zones are salmon lice dispersion from Norkyst800 and Ladim, lice concentration on salmon and salmon biomass estimates from farms in operation reported by the industry and obtained through the Directorate of Fisheries.

Lessons learned, conclusions and recommendations

There is a need for wider collaboration between management, research and industry to amend efficient decision making. This include improved mechanisms for stakeholder interactions
The national process demonstrated in this case study includes elements of all stages of MSP and EAA. There is a need to further develop governance systems for more efficient decision making.

14.13 Nova Scotia Bays



Region: North America	**Country:** Canada	**Location:** Eastern Canada	
Partner: Dalhousie University (DAL)			

Management level:	
MSP in place at national level? Yes/No	Important initiatives are Canada Oceans Act (1996) and Eastern Scotian Shelf Integrated Ocean Management Plan (2007) and there are several local level plans.
Any spatial management in the case study area?	Marine spatial planning is not advanced in coastal Canada, and there are ongoing efforts to make progress on integrating aquaculture into MSP, along with other coastal resource issues such as fishing.
Any other spatial planning measures/ordination of space? (including sectoral plans)	Acoustic habitat surveys are completed and bottom type is mapped. Indices of lobster abundance have been assessed using drones to count traps. Connectivity matrices will be calculated from hydrodynamics. AquaModel will be used to predict spatial distribution of sediment sulfides
How were the principles of EAA addresses in your case study?	Yes. This study is consistent with EAA in assessing ecosystem scale components of habitat and attempting to accommodate other resource uses in aquaculture development.

Aquaculture activity:			
Main environment: Bay/Estuary	**Extension of aquaculture (occupied area in km^2)** 0.05	**Culture system:** Cage; polar circles	**Species:** Salmon *(Salmo salar)*
Number of farms: 2 (2 more are planned)	**Production capacity:** 2000 tonnes	**Aquaculture relevance (importance for the region)**	**Incomes or economical aspects:** Farm value €15 million Rural employment is always problematic in coastal communities of eastern

			Canada. Liverpool once had a thriving pulp and paper industry that has since closed.

Relevance of the Case Study within AquaSpace	The case study incorporates disease risk by determining connectivity between any set of points in the bay. Exploration of how aquaculture could be incorporated into MSP as well as with other marine activities. Aquaculture concepts used: Disease risk, carrying capacity, habitat mapping, marine spatial planning
Relevance of the case study	An example of how models can be used to generate GIS layers used in MSP (e.g. disease connectivity) A focus on the interaction between fisheries and aquaculture Generation of tools that can be used for future culture siting
Main issues identified for further development of aquaculture	Public opposition based on concerns about wild salmon, waste impacts, and disease Lobster fishery

Implemented tools:

GIS - ArcGIS
Hydrodynamic model
Acoustic Doppler and CTD Moorings
AquaModel (http://www.aquamodel.net/)

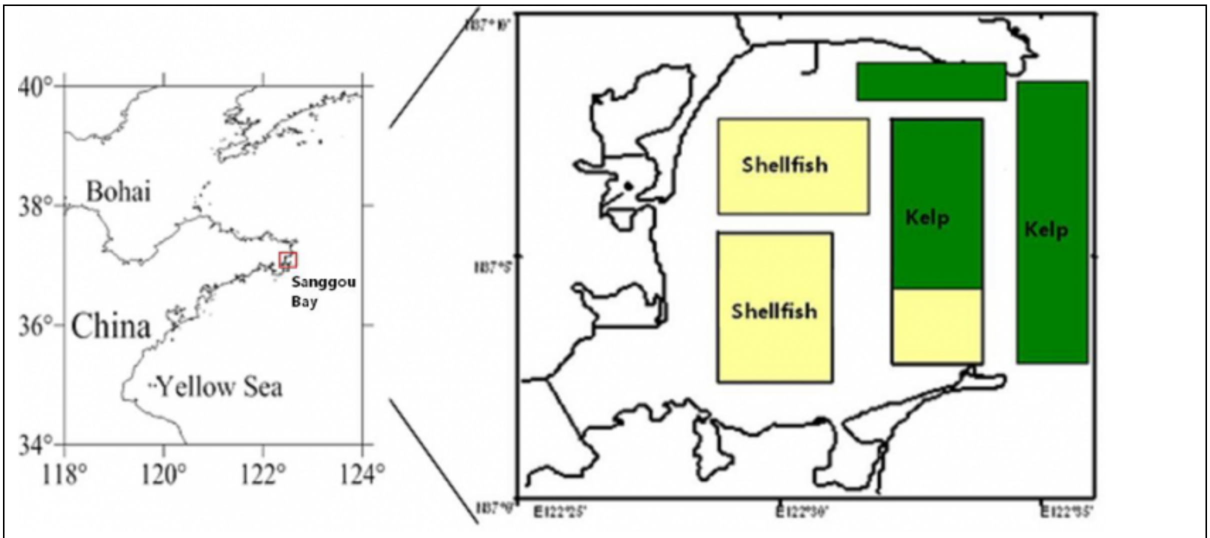
Required data (environmental/socioeconomic data)

Calibrated hydrodynamic model
Maps of bottom type

Lessons learned, conclusions and recommendations

Because aquaculture is still evolving here, the planning challenges are ongoing. New research programs will allow the work to continue including the large Ocean Frontier Institute project emphasizing marine technology applied to aquaculture. Given sensor data generated at farms, what is their role in coastal information management and planning? Specific additional studies targeting social license will implement an aspect of community participation in the MSP. Finally, AquaModel software will allow much of the spatial modelling to come together in predictive scenarios including the impacts of organic loading.

14.14 Sangou Bay



Region: Shandong Province	**Country:** China	**Location:**	
Partner: Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences (YSFRI)			

Management level:

MSP in place at national level? Yes/No	Yes (http://msp.ioc-unesco.org/references)
Any spatial management in the case study area?	National Marine Functional Zoning (2011-2020) (MFZ)
Any other spatial planning measures/ordination of space? (including sectoral plans)	MFZ is the key measure for ocean governance in Shandong Province, which was recently supplemented by the Marine Ecological Red Line System (the Red Line). The Red Line refers to a special marine spatial planning focusing on very strict ecological protection of sensitive or vulnerable marine habitats; it has been promoted following a 2011 decision of the Chinese State Council to strengthen environmental protection.
How were the principles of EAA addresses in your case study?	Not fully implemented now but future trend towards better implementation of EAA

Aquaculture activity:

Main environment: Bay	**Extension of aquaculture (occupied area in km^2)** 133.3	**Culture system:** Longline for seaweed shellfish, net cages for finfish	**Species:** Kelp (*Laminaria japonica*) Oyster (*Crassostrea gigas*) Scallop (*Chlamys farreri*) Abalone (*Haliotis discus*) Finfish （*Sea bass Lateolabrax maculatus* etc.） Sea cucumber (*Apostichopus japonicas*)

Number of farms:	**Production capacity:** Kelp: 80,000 t in dry weight Abalone: 2,000 t in fresh weight with shell Oyster: 120,000 t in fresh weight with shell Scallop: 10,000 t in fresh weight with shell Finfish: 100 t Sea cucumber: 100 t in fresh weight	**Aquaculture relevance (importance for the region)** More than 20 seaweed/bivalve/fish farms or companies	**Incomes or economical aspects:** Total marine aquaculture production in Sanggou Bay is over 260,000 t, covering an area of about 10,000ha, generating a total value of 4.6 billion Yuan RMB. The aquaculture industry employed slightly more than 11000 people in the bay.

Relevance of the Case Study within AquaSpace	Identifies the key environmental limiting factors for aquaculture carrying capacity in both Zhangzidao Island and Sanggou Bay areas, and sets up management tools based on ecological models and the aquaculture policy framework
Relevance of the case study	It has identified a need to: Increase of the production by optimizing culture density and lay out Promote coexistence of MPA, tourism, habour and aquaculture activity The potential of IMTA systems for increasing aquaculture carrying capacity (increase production capacity) discussed (finfish, shellfish and seaweed)
Main issues identified for further development of aquaculture	Solving sea use conflicts Optimizing aquaculture site selection Modulate aquaculture layout and species (combination) based on carrying capacity assessment

Implemented tools:

AkvaVis, and Aquaculture Planning Decision Support System (APDSS)

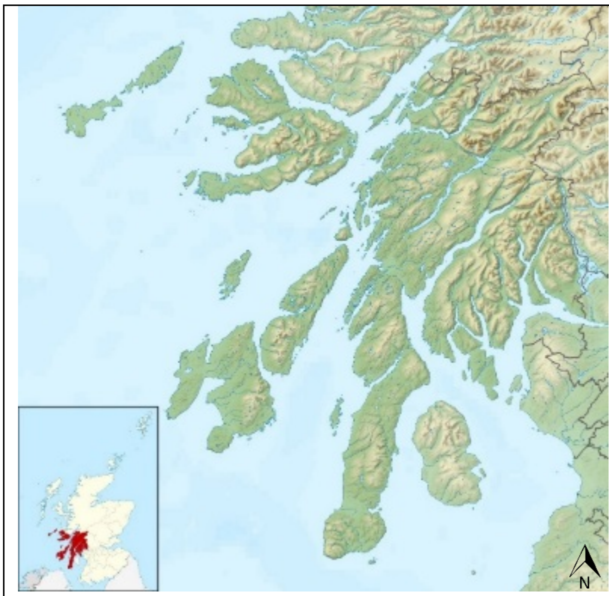
Required data (environmental/socioeconomic data)

Environmental data: temperature, nutrients, dissolved oxygen, salinity, currents and water exchange
Socioeconomic data: culture species, productivity, cost and benefits

Lessons learned, conclusions and recommendations

New study on hydrodynamics and aquaculture carrying capacity;
Data collection on current practice, i.e. species, layout, production, etc.
Application of modeling tools for future spatial planning in the bay

14.15 Argyll



Region: West Scotland	**Country:** Scotland	**Location:** UK	
Partner: Scottish Association For Marine Science LBG (SAMS)			

Management level: National/ regional	
MSP in place at national level? Yes/No	Yes. http://www.msp-platform.eu/countries/united-kingdom
Any spatial management in the case study area?	Scottish national marine plan and future regional marine plans (forthcoming)
Any other spatial planning measures/ordination of space? (including sectoral plans)	Leases of sites by the Crown Estate (who manage the seabed)
How were the principles of EAA addresses in your case study?	Yes, but in practice, not explicitly in policy

Aquaculture activity:			
Main environment: Bay and Fjord	**Extension of aquaculture (occupied area in km^2)** 9890.49	**Culture system:** Floating open cages (salmon and trout) Net pens (salmon and trout) Trestle tables (oyster) Suspended lines and/ or lanterns (mussels, scallop and seaweed)	**Species:** Atlantic Salmon (*Salmo salar*) Rainbow Trout (*Oncorhynchus mykiss*) Blue mussel (*Mytilus edulis*) Pacific oyster (*Crassostrea gigas*) Native Oyster (and *ostrea edulis*) Queen Scallop (*Equipecten opercularis*) King Scallop (*Pecten maximus*) Seaweed (*Alaria esculenta*) Seaweed (*Saccharina latissima*)

Number of farms:	**Production capacity:** For reasons of commercial confidentiality, it's not possible to obtain public figures for production in this region.	**Aquaculture relevance (importance for the region)** Scottish Government supports Scotland-wide growth in salmon aquaculture to 210,000t by 2020. (Effectively 50% increase in salmonid production and 100% increase in shellfish) Shellfish aquaculture target of 13,000t	**Incomes or economical aspects:** There are 49 shellfish farming enterprises in Argyll.

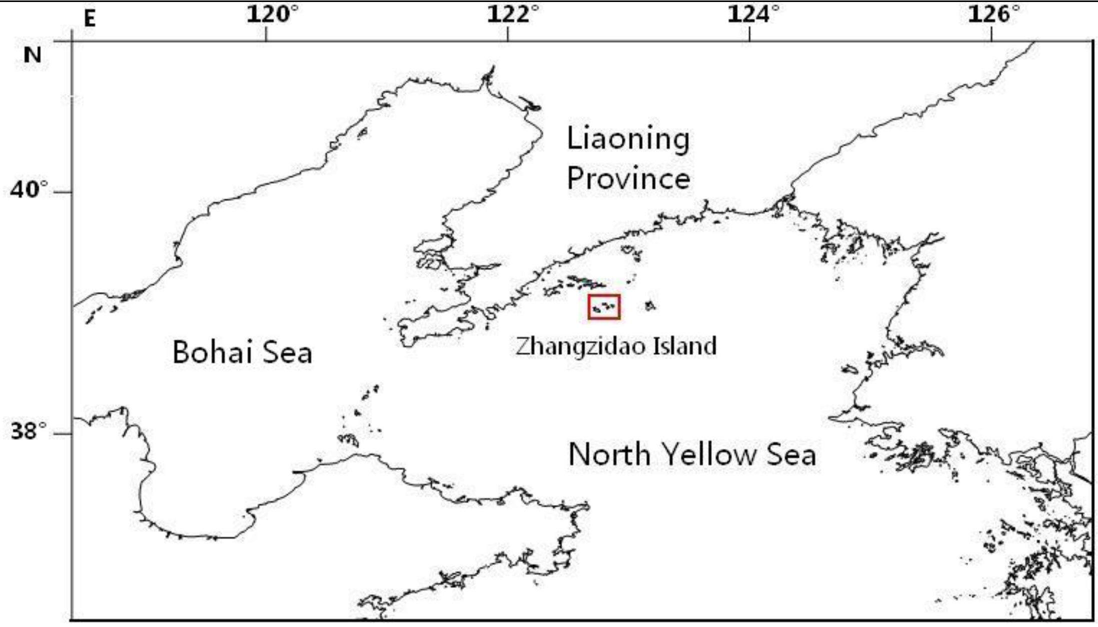
Relevance of the Case Study within AquaSpace	Long coastline and suitable waters for aquaculture development Difficult to identify areas where expansion is acceptable and desired due to current management, planning and social constraints The aquaculture industry spends a lot of time and money attempting to expand to new sites or change use on current sites, with varying outcomes. Complexities involved in whether the industry gets their licences and planning relate to ecological/environmental and social suitability. Challenges created by lack of full awareness of environmental and social issues relating to aquaculture.
Relevance of the case study	Better integration of national policy, local planning, and industry needs. Better spatial planning, allowing aquaculture to co-exist with other sectors, and not overemphasizing landscape/seascape issues. Develop accountability of developers, planners, policy-makers. Improve (and understand) public perception of aquaculture. Reduce business uncertainty Improved technologies
Main issues identified for further development of aquaculture	Planning and regulation procedures – duplication of effort Managing sea lice – cost, time and poor image Competition for marine space: Tourism, Fisheries, between aquaculture sectors

Implemented tools:

Public comment analysis and interviews
Sea lice connectivity modelling
GIS multi-criteria evaluation tool
- (i) Mapping of farm visibility
- (ii) Virtual reality visualisation of aquaculture
- (iii) visual preference surveys

Required data (environmental/socioeconomic data)
Publically available planning applications and community consultations Hydrodynamic data (current, temperature, salinity, bathymetry) Farm locations Aquaculture management area definitions Other licensed activities/ area definitions Landscape data
Lessons learned, conclusions and recommendations
Public comment analysis and interviews: More sources of unbiased information on the social-ecological systems around aquaculture are needed to mitigate misinformation and aid host communities in their debate about the acceptability of aquaculture activities in their area. Sea lice connectivity modelling: Sites should be located with due regard to the spread of parasites and pathogens both to and from them, applying caution where dispersal is predicted to take these between sites and/or into areas where wild fish are known to move or stay. Sea lice connectivity modelling tool should be used as part of individual site application process to assess changes to cumulative impacts of site network. GIS multi-criteria evaluation tool: Further work is underway to resolve some issues relating to the application of the AquaSpace and MaRS tools. Specifically, some of the MaRS data layers are being updated with the latest data and sense checked with stakeholders (wild salmonid sensitivity) and some of the European data sets provided with the AQUASPACE tool are being updated with higher resolution, locally relevant datasets to improve the accuracy of reports, particularly for regions with complex topographies.

14.16 Zhangzidao Island



Region: Liaoning Province	**Country:** China	**Location:**	
Partner: Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences (YSFRI)			

Management level:	
MSP in place at national level? Yes/No	Yes (http://msp.ioc-unesco.org/references)
Any spatial management in the case study area?	National Marine Functional Zoning (2011-2020)
Any other spatial planning measures/ordination of space? (including sectoral plans)	At the regional and local level, it is governed by the local MFZ and, by judiciary and administrative means, controlled by the Sea Use Permit and Aquaculture Permit systems. According to the production plan of the company, longline culture of juvenile shellfish is carried out at inshore water and grow out of scallops by seabed culture offshore.
How were the principles of EAA addresses in your case study?	Not fully implemented now but future trend towards better implementation of EAA

Aquaculture activity:			
Main environment: Open sea and inshore	**Extension of aquaculture (occupied area in km^2)** 1600 km^2 deep water area	**Culture system:** Sea-ranching (bottom culture) in deep water (>20m) and longline IMTA in shallow inshore waters (<20m)	**Species:** Scallop (*Patinopecten yessoensis*) Sea cucumber (*Apostichopus japonicus*) Abalone (*Haliotis discus*)
Number of farms:	**Production capacity:** Scallop: 20000 tonnes Sea cucumber, Abalone: 200 tonnes	**Aquaculture relevance (importance for the region)**	**Incomes or economical aspects:** Zhangzidao (Zoneco) Sea Ranch employs 1200 people and had

<table>
<tr><td></td><td></td><td>Zoneco Group is the main operator of the sea ranch</td><td>a total production value of 901 million Yuan RMB in 2016.</td></tr>
<tr><td colspan="2">Relevance of the Case Study within AquaSpace</td><td colspan="2">Identifies the key environmental limiting factors for aquaculture carrying capacity in both Zhangzidao Island and Sanggou Bay areas, and sets up management tools based on ecological models and the aquaculture policy framework.</td></tr>
<tr><td colspan="2">Relevance of the case study</td><td colspan="2">It has identified a need to:
Increase of the production by optimizing culture density and lay out.
Promote coexistence of MPA, tourism, habour and aquaculture activity.
The potential of IMTA systems for increasing aquaculture carrying capacity (increase production capacity) discussed (finfish, shellfish and seaweed).</td></tr>
<tr><td colspan="2">Main issues identified for further development of aquaculture</td><td colspan="2">Solving sea use conflicts.
Optimizing aquaculture site selection.
Modulate aquaculture layout and species (combination) based on carrying capacity assessment.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Implemented tools:
AkvaVis, and Aquaculture Planning Decision Support System (APDSS)</td></tr>
<tr><td colspan="4">Required data (environmental/socioeconomic data)
Environmental data: temperature, nutrients, dissolved oxygen, salinity, currents and water exchange
Socioeconomic data: culture species, productivity, cost and benefits.</td></tr>
<tr><td colspan="4">Lessons learned, conclusions and recommendations
New study on hydrodynamics and aquaculture carrying capacity;
Data collection on current practice, i.e. species, layout, production, etc.
Application of modeling tools for future spatial planning in the bay.</td></tr>
</table>

14.17 *Pelorus Sound, New Zealand*

Region: -	**Country:** New Zealand	**Location:** Pelorus Sound

Partner: National Institute of Water and Atmospheric research (NIWA)

Management level:	
MSP in place at national level? Yes/No	No
Any spatial management in the case study area?	No
Any other spatial planning measures/ordination of space? (including sectoral plans)	Yes: sectoral plans – by region either preselected for potential investment or more usually allocation on application. Hauraki Gulf: http://msp.ioc-unesco.org/references/
How were the principles of EAA addresses in your case study?	Approval for new farms and farm extension require Fisheries Resources Impact Assessment and regional/environmental court hearings.

Aquaculture activity:			
Main environment: Estuary	**Extension of aquaculture (occupied area in km^2)** -	**Culture system:** Long-line farms, suspended culture	**Species:** Greenshell Mussel (*Perna canaliculus*) Chinook salmon (*Oncorhynchus tshawytscha*) Pacific oyster (*Crassostrea gigas*)

Number of farms: Greenshell Mussel: About 645 licenses (farms) spread along the coast Salmon: About 13 licenses (marine farms) and 2 in freshwater Oyster: About 230 licenses	**Production capacity:** 75,000 tonne green weight annually	**Aquaculture relevance (importance for the region)** Pelorus Sound is predominately on farming the mussel for *Perna canaliculus*. New Zealand's largest salmon aquaculture farms are also located in Marlborough Sounds.	**Incomes or economical aspects:** Pelorus Sound accounts for about 68% of New Zealand's production, where generating around 170 million Euro per year in revenue.

Relevance of the Case Study within AquaSpace	This case study was included in the Aquaspace project on request from the governmental institute NIWA, after their participation at a stakeholder meeting held in month 20, hosted by partner number 20, YSFRI. The case study has relevance as contributing to the non-EU partners, reflecting the global expertise garnered for this project. The case study demonstrates the development of a predictive tool using information from climatic and environmental phenomena at global scale, for assessing use of space at regional scale. This is unique within the Aquaspace project. The case study involves industrial stakeholders from an aquaculture farming of national importance.
Relevance of the case study	Fluctuations in the per-capita meat yield of Pelorus Sound mussel farms have resulted in substantial economic impacts and distortions within the industry. NIWA have produced a website application that produces forecasts of mussel meat yield for the Pelorus Sound Greenshell™ mussel industry. The tool is implemented on a password-protected web application for farmers. The forecasts were created from the NIWA research, made in conjunction with the mussel industry, which has found that climate influences mussel yield.
Main issues identified for further development of aquaculture	Management Issues: Variable production/yield, uncertain spat supply/survival Biosecurity, Biotoxin-producing microalga Environmental Issues: Plankton depletion, benthic effects Habitat creation

Implemented tools:
NIWA Website: Forecasts of mussel meat yield
Required data (environmental/socioeconomic data)
Historical data set of yields measured on the harvesting vessels Mussel yield observations and the coincident climate values
Lessons learnt, conclusions and recommendations
Combined with the knowledge of conditions in the recent past, these may help farmers plan stocking and harvest rates and improve business projections over coming months. Further investigation showed that climate is a main driver of the variation in seston availability. Case study found that climate conditions occurring in the summer and winter halves of the year affected mussel yields differently.