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AQUASPACE

Ecosystem Approach to making Space for Aquaculture

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Deliverable 3.1

Tools and methods supporting EAA: Finding the gap towards an environmental Cost Benefit Analysis

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EXECUTIVE SUMMARY

The central goal of the AquaSpace project is to provide increased space for aquaculture by adopting the Ecosystem Approach to Aquaculture (EAA). Both, the environmental risks and benefits of such a management option need to be considered across cultivated organisms at different trophic levels, types of aquaculture, and key European ecosystems and their surroundings. One solution identified to be promising is the development of an environmental Cost Benefit Analysis (CBA) toolkit. A CBA toolkit refers to a collection of methods, tools or concepts to allow assessing the effects (i.e. costs and benefits) of a planned aquaculture venture in relation to the overall spatial planning context. Thus deliverable 3.1 addresses a review and a gap analysis of existing tools and methods aiming to support EAA.

In order to characterise existing tools for assessing spatial issues in relation to aquaculture and its environment, a targeted review of existing methods, models, tools and toolboxes was performed. The focus was on tools which can be used to scope for the spatial allocation of aquaculture activities in terms of environmental and economic costs (e.g. risks) and benefits. The identified solutions (tool functions) were categorized according to the economic, ecologic and social issues and objectives they address. In the next step, a gap analysis was performed: targeted stakeholder workshops organized by AquaSpace case studies were held, aiming to retrieve the opinions, needs and expectations of relevant stakeholders regarding the spatial allocation of aquaculture with regards to other uses. The key issues and objectives identified were compared with the tool functions already available, matched according to principles of an EAA. Those tools suitable to fill those gaps were further examined with regard to their technical components: input data, training, expertise and equipment required to run those tools.

Summarizing the results from the tool review, the stakeholder workshops and tool evaluation produced a well-resourced CBA toolkit which includes several promising tools for facilitating Marine Spatial Planning (MSP) with aquaculture. Nevertheless, development requirements have been identified when accounting for constraints identified in respective case studies: there are several tools assessing environmental factors, but tools assessing economic and market issues are few. The stakeholder consultation confirmed this gap and revealed a clear demand for tools allowing simultaneous analysis of economic and market issues. Hence, no practical tools designed to consider all key issues simultaneously were found. However, there are approaches and GIS-based tools such as SISAQUA, the SMILE Model or FARM, addressing up to three key issues, hence pointing the way towards holistic assessments of costs and benefits. Regarding the EAA framework, the majority of constraints could have been classified as being part of the Opportunity and Risk Assessment step. This highlights precisely the step in the framework, where the cost benefit trade-off has to be analysed, informing decision makers about the opportunity cost of a choice, and the value of the best management alternative forgone.

Next steps in AquaSpace (led by WP3) include a definition of standards for both the customisation of operational tool functions, allowing industry and policy-makers more informed decisions on aquaculture development, and the use of data related to aquaculture planning and management in EU waters. AquaSpace GIS experts could provide geospatial standards for hydrographic, maritime and related issues, based on project outcomes.

1. INTRODUCTION

The central goal of the EU Horizon 2020 project AquaSpace is to provide increased space of high water quality for aquaculture by adopting an Ecosystem Approach to Aquaculture (EAA) to support Marine Spatial Planning (MSP) and to deliver food security and increased employment opportunities through economic growth with a long-term view. The main objectives to achieve this comprise:

1) Accurately identify industry-wide issues and options
2) Develop and deliver tailored tools
3) Work collaboratively with stakeholders on validation of tools
4) Synthesise outcomes for post-project legacy and impact
5) Assess impacts through effective Knowledge Exchange.

In the AquaSpace context, industry-wide issues and options are widely defined as factors constraining or strengthening the growth of aquaculture in Europe. Identified in WP2, global issues can be listed as followed: policy management issues, social, economic and market issues, other sector issues and environmental issues. In order to put a finer point on those issues, constraints experienced by 16 case study sites having a variety of spatial scales, aquaculture at different trophic levels with different environmental interactions, and most importantly with a range of key space-related development constraints as defined by local stakeholders were identified in WP4.

Effective implementation of an EAA is enabled by using spatially explicit methods and tools. One promising solution is the development of an environmental Cost Benefit Analysis (CBA) toolkit. An environmental CBA toolkit refers to a collection of methods, tools, and concepts to allow assessing the effects (i.e. costs and benefits) of a planned aquaculture venture in relation to the overall spatial planning context.

Thus D3.1 outlines tools and methods to assess the costs and benefits of such spatial management options in a wider spatial planning context. It contains a review of existing tools and methods supporting EAA and comprises an evaluation and gap analysis of tools for facilitating the aquaculture planning process by overcoming present constraints. This includes the mapping of a wide variety of tools and methods against the constraints identified in WP2 and informed by the real world of the case studies (WP4). Some of those tools have already been developed in national and EU projects for spatial planning purposes, including the ones which have been designed specifically for aquaculture.

The synthesis and presentation of information gathered in the AquaSpace project is acquired by WP5. Outcomes will be published on an interactive web-based platform with tailored entry points for specific user types (e.g. planners, farmers, public) to enable them to navigate e.g. to the tools most appropriate to their application. Further, in WP6 the development of an on-line module at Master's Degree Level is envisaged. This will also be developed into a short Continuing Professional Development (CPD) course aimed at aquaculture planning professionals while engaging the public by various dissemination initiatives, including Web 2.0 materials, and an innovative school video competition.

1.1. Role of aquaculture in EU waters

An expansion of European aquaculture as a future management objective addressing sustainable use is currently a matter of debate. Further steps towards the Europe 2020 strategy should involve efforts to create a stable environment attractive to investors. MSP, contributing to the aims of ecosystem-based management and the development of land-sea links, should facilitate the development of aquaculture (EC, 2011; EC, 2014b). In art. 51 of EU regulation no 508/2014 “the identification and mapping of the most suitable areas for developing aquaculture” is fostered. The regulation establishes the European Maritime and Fisheries Fund (EMFF) in support of MSP, promoting a balanced and inclusive territorial development of fisheries and aquaculture areas (EC, 2014c). In the course of the EU Horizon 2020 Framework Programme the need for an optimization of contributions of fisheries and aquaculture to food security was raised (EC, 2015). (Maritime) aquaculture production may contribute to food security and relieve some of the pressures on wild stocks. Considering the current race for space, further attention needs to be paid to the increasing requirements for water resources.

1.2. Marine Spatial Planning (MSP) and the Ecosystem Approach to Aquaculture (EAA) as a management tool

MSP was identified by the European Commission as the cross-cutting policy tool that contributes to “sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources” while “applying an ecosystem-based approach as referred to in Article 1(3) of Directive 2008/56/EC with the aim of (...) achievement of good environmental status” (EC, 2014a). As a management tool, MSP can allocate space for upcoming activities such as aquaculture at sites with both favourable operational characteristics (economic and ecological) as well as lower potential for conflict with other sectors (Guerry et al., 2012; FAO, 2013; Christie et al., 2014; Stelzenmüller et al., under review). MSP aims to integrate ecological, social, and economic interests, interactions between human activities, regardless of whether cross-border or inter-sectorial nature, whether conflict or synergy (Halpern et al., 2008; Ehler and Douvere, 2009; Foley et al., 2010). Since MSP is a public process, the implementation of strategic plans integrates greater accountability and transparency of decision-making by including a wide range of stakeholders from all sectors (Gilliland and Laffoley, 2008; Ehler and Douvere, 2009; Stelzenmüller et al., 2013b; Wever et al., 2015). The MSP process is characterized as dynamic and evolving, integrating multiple feedback loops and permanent revisions (Ehler and Douvere, 2009). Due to continuous monitoring and evaluation performances it speeds up decision-making. Consequently, it increases the effectiveness of investments.

Environmental health is of particular importance to the pressures human activities already exert on the marine environment. MSP is concerned with the use of various spatial strategies such as the EAA to aid the integration of aquaculture within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems. Integrating the participation of stakeholders increases the account for the needs and impacts of other sectors (FAO, 2010). The respective EAA framework supporting the planning and management of sustainable aquaculture development includes six steps (Fig. 1). 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 is monitored (vi) and evaluated regularly, leading to planning and implementation adjustments – within the scope of the initially assessed opportunities and risks (FAO and World Bank, 2015).

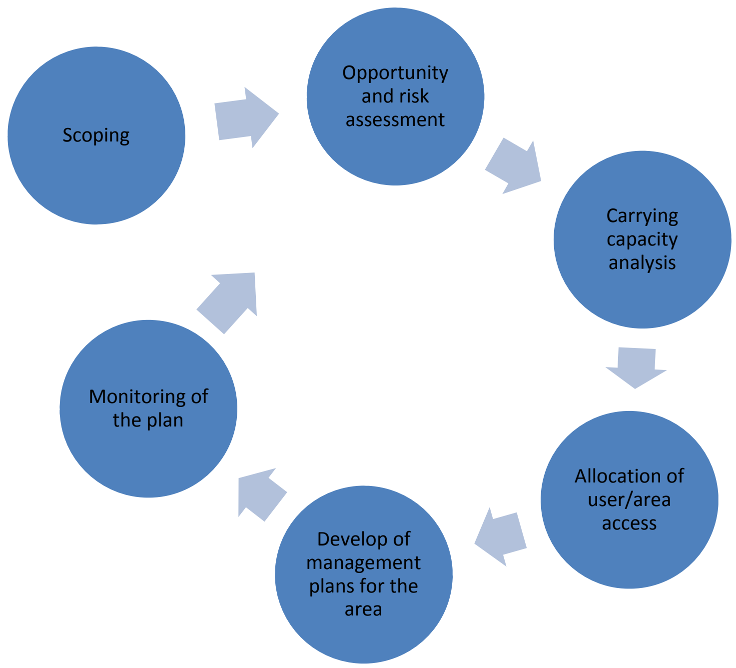

Figure 1: EAA framework supporting the planning and management process (FAO and World Bank, 2015).

In order to implement such a strategy, specific tool functions are needed to support the planning and management of sustainable aquaculture development. Each step in an EAA framework can benefit from tool functions addressing the key issues constraining or strengthening the growth of aquaculture. Therefore, we transferred the global issues identified by WP2 to structure the consequential tool function categories (Tab. 1).

Table 1: Framework matrix showing the generic steps of an EAA framework and the tool function categories that can add value to each of the steps. Redrawn from Foley and Prahler (2011) and Ocean Solutions (2011).

	Framework step					
	Scoping	Opportunity and risk assessment	Carrying capacity analysis	Area allocation	Management plan development	Monitoring
Tool function categories						
Policy and management	✓	✓		✓	✓	✓
Environmental	✓	✓	✓	✓		✓
Other sectors	✓	✓		✓		✓
Economic and market		✓		✓		

1.3. *Integrating aquaculture in MSP processes – some European examples*

Spain

Spanish marine aquaculture in the Mediterranean Sea is dominated by seabream and seabass farms, while in the Atlantic region of Spain, mussels and oysters are the major species.

Marine Spatial Planning has not yet been implemented in Spain and the transposition of this directive has not yet being conducted by the National Authorities. The national marine regulation and legislation related to the spatial management of activities in the marine area, are sectorial and don't consider the interactions between different activities. Spanish regions may have different regional social and economic interests and also regulations affecting their territory and specially their littoral and marine space. These differences often manifest in a north-south division, i.e. in regions located on the North-Atlantic, the Mediterranean coastline of Spain and the Canary Islands (Tab. 2). Thus in this context a considerable administrative effort is required of the regions to match their strategies with regulation at different scales (regional, national, European). The main instruments used in Spain for the management of the littoral space are:

- Littoral Management Plans
- Guidelines for the management of the territory
- Sectorial plans or Aquaculture Strategic Plans
- Others; Director Plans of Natura Net, Network of protected natural areas, etc.

The inter-connected regulations link to three main objectives:

- Guaranteeing the preservation of the environmental value that could be affected by an uncontrolled development of aquaculture
- Timely adaptation of regulation to the requirements derived by developers
- Guaranteeing the harmonic integration of aquaculture into the relevant socio-economic context.

Spanish regional initiatives to develop marine management plans and aquaculture strategic plans are shown in table 2. In this context, regions such as Galicia, Cataluña, the Basque Country, the Principado de Asturias and the Canary Islands have been very active in the development of regional strategic plans and specific instruments for spatial management and also for the guides or studies for zoning of their marine space for aquaculture.

The development of all these plans and studies related to the management of the littoral and marine space for aquaculture still demands significant coordination by the central Administration, which has to ensure equality for all the regions and demand of them the implementation of regulation. In this context, a "Guidelines of criteria for site selection and establishment of zones of interest for aquaculture in Spain" was developed and annexed to the Spanish Aquaculture Pluriannual Plan. This was intended to be used as a tool by the regional administrations and aquaculture industry investors in the selection of suitable sites for aquaculture and, therefore, to track the definitive expansion of aquaculture production in Spain. On the other hand, a study conducted for the Mediterranean region of Spain, entitled "Guidelines for the sustainable development of the Mediterranean Aquaculture. 2. Aquaculture: site selection and management" (https://cmsdata.iucn.org/downloads/acua_en_final.pdf), is perhaps the closest to a marine spatial planning approach. However, this is more a guideline for spatial planning rather than the regulation adopted by the Spanish Government or the regional Government for the implementation of the

European MSP Directive. This guideline is specific for the development of marine aquaculture in the Mediterranean regions of Spain. This could not be translated directly to the Atlantic regions due to major differences between the Mediterranean and Atlantic regions (e.g. environmental and socio-economic characteristics, production systems and species, etc.). Thus, there is an evident need to conduct marine spatial planning for the Atlantic region.

In the regional context, the Basque Country has been one of the pioneer regions in the elaboration of an Aquaculture Director Plan and territorial and sectorial management plans linked to the littoral zone. In 2015 the Aquaculture Strategic Plan 2014-2020 was developed, where studies for the zones of interest for marine aquaculture were extended from those of the previous plan. Currently the Basque Government is developing a study to determine appropriate sites for the development of terrestrial aquaculture.

Table 2: Sectorial planning and marine spatial ordination in Spanish regions (Pluriannual Plan of Aquaculture. Autonomic strategic planning document, 2015. http://www.magrama.gob.es/es/pesca/participacion-publica/documento_planes_autonomicos_plan_estrategico_tcm7-337108.pdf).

Division	***Regions***	***Sectorial/ Strategic Plans***	***Specific Instruments for Spatial Ordination***	***Guides or studies for zoning***
NORTH-ATLANTIC	PRINCIPADO DE ASTURIAS	Strategic Plan for the Aquaculture in Asturias	Ordination Plan for Asturian Coast	Identification of the suitable areas for fish cages in the Asturian coast (JACUMAR 2001-2003).
	CANTABRIA	Strategic Plan for Cantabria	No	No
	GALICIA	Galician Strategic Plan for Aquaculture	Master plan for Coastal Aquaculture	Sustainability and landscape integration criteria guideline for the establishment of facilities.
	BASQUE COUNTRY	Strategic Plan for Aquaculture	Sectorial Territorial Plan for Coastal Protection and Management (2007)	Yes
MEDITERRANEAN	COMUNIDAD VALENCIANA	Strategic Plan for the Development of the Aquaculture in Valencian Community	No	No
	CATALUÑA	Action Plan for the development of the Aquaculture	Map of Locations of Aquaculture Facilities of Catalonia (BOPC, no. 385 de 03.02.2003)	Suitable areas for cage aquaculture: location maps of aquaculture facilities in Catalonia (2003).
	CEUTA	No	No	-
	BALEARIC ISLANDS	Strategic Plan for the Balearic Islands	Coastal Aquaculture Master Plan	Potentially suitable areas for the installation of floating structures (2001).
	MELILLA	No	-	No
	REGION OF MURCIA	Sectorial Plan	Aquaculture Technical Paper	Studies for the establishment of aquaculture polygons (2002-2005). Feasibility studies for new areas of interest (2013).
	ANDALUCIA	Andalusian Strategy for the Development of the Marine Aquaculture 2014-2020 (EADAM 2014-2020)	No	Suitable location for the development of marine aquaculture in Andalusia (2010).
CANARY ISLANDS	CANARIAS	Strategic Plan for the Aquaculture in Canary Islands (PEACAN) *In progress.*	Regional Plan for Aquaculture in Canary Islands (PROAC)	Basic coastal planning document for aquaculture in the Canary Islands. Unsuitable areas.

Hungary

Aquaculture in Hungary is based on inland freshwater production, in extensive traditional pond farms. They play an important role in food safety and support rural employment. Their non-productive functions contribute to water management and the maintenance of biodiversity. The main freshwater species commercially cultured in Hungary are the common carp, bighead carp, silver carp, grass carp, European catfish and pikeperch. The policy and administrative framework of the aquaculture sector is managed by the Ministry of Agriculture through the Department of Angling and Fisheries Management and by the Prime Minister's Office through the State Secretariat for Agricultural and Rural Development. The Hungarian National Aquaculture Strategic Plan 2014–2020 is the current policy framework. The Hungarian Fisheries Operational Programme forms the basis of aquaculture development with several strategic objectives including:

- Boosting the competitiveness of traditional pond farming, besides conservation of biodiversity,
- Enhancing the sustainability of aquaculture by using alternative energy sources and reducing environmental load,
- Promoting aquaculture diversification and production of new species,
- Increasing fish consumption,
- Supporting monitoring, data collection and control.

A number of administrative agencies are involved in regulating aquaculture. The National Directorate General for Disaster Management (Ministry of the Interior) licences the establishment and operation of fishponds and management of water resources. The National Food Chain Safety Office is responsible for regulating the movement of aquaculture species, disease control, drugs and pesticides, feed and food safety. In addition to central governmental authorities, regional and local level authorities are also involved in managing aquaculture. Spatial planning is realized through regional and local spatial development plans and the siting of aquaculture ponds is depending on the adequacy of surface water resources. The regional water authority department brings a decision on the plans submitted based on the water demands, considering the available water volume at low flow season in the affected water catchment area.

Licences for establishing and operation of fishponds are primarily issued according to the Ministerial Regulation for water rights authorisation procedure (18/1996. KHVM (VI. 13.)) and several other Ministerial Regulations, Laws, Government Regulations, Community legislations and Community Directives. The Wild Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC) have also been adopted into the Hungarian law and they prohibit the construction of aquaculture farms in areas of high natural value.

One of the major difficulties, faced in particular by Hungarian fish farmers and small and medium-sized enterprises (SME), is the complexity, length, costs and legal uncertainty of administrative procedures during licencing of new aquaculture facilities. The fish producers must comply with numerous conditions laid down in many relevant laws and regulations.

Scotland

Scottish marine aquaculture is dominated by salmon, which at 163,000 tonnes production (http://www.scotland.gov.uk/Publications/2014/10/7776) is the world's third largest and is the United Kingdom's largest single food export. Salmon producers share marine waters with a smaller production of marine farmed trout and other fish species such as halibut, together with shellfish production which is of mostly of mussels and oysters. Fish farming is a mature industry in Scotland with a long history of Regulation to ensure production is sustainable from an environmental and fish health perspective. As such it operates a fairly complex, but effective system of planning and licensing, strategically managed using area management principles in order to protect both production and the environment. Area management is used to control the spread of diseases and to ensure aquaculture production is in unpolluted waters, while at the same time ensuring waste products such as excess nutrients and organic wastes do not pollute the environment, keeping production levels within carrying capacity of the relevant water body. Landscape and conservation issues can also influence the siting of aquaculture especially in sensitive zones.

Suitable sites such as sea lochs are defined geographically. Sea lochs are fjordic estuaries along the Scottish coast that have been systematically catalogued and described by oceanographers since the 1970s. Information on the volume and turnover time of the waters in these lochs, together with biological models of fish metabolism, are used to categorise sea lochs into categories 1, 2 or 3 dependent on how much environmental stress the sea loch is subjected to. This status informs these areas' suitability for further aquaculture development. Aquaculture is absent from large zones of the Scottish coastal environment. There is a policy presumption against further marine finfish farm development on the north and east coasts. Aquaculture is excluded from other zones for purposes such as shipping, naval activity, offshore energy production and conservation purposes. Site specific carrying capacity thresholds are determined through the licensing process, where benthic impact modelling is used to set peak biomass thresholds on the basis of predicted impacts on seabed infaunal diversity. At a water body level (sea lochs), simple models are employed to predict a precautionary threshold for assimilative capacity based on the predicted nutrient enhancement and benthic impacts arising from cumulative discharges from multiple developments in the water body (Fig. 2).

Finfish aquaculture developments need several permissions in order to produce fish in Scottish marine waters. These include planning consent, a Marine Licence for placing equipment and point source discharge and business authorisation. The statutory authorities issuing these permissions must do so in light of various strategic planning guidance, such as the objectives in the National Marine Plan, Scottish Planning Policy, Locational Guidelines, and any current Local Development Framework Plans containing spatial guidance on the siting of new farms. Aquaculture production in areas is co-ordinated through a number of different routes. Areas have e.g. moved towards synchronised fallowing, which is now widespread. All farms within an area wait until the last farm in that area is empty before restocking. This is an important tool for disease control and in the management of sea lice. In the event of notifiable disease, synchronised fallowing may be legally enforced across the affected area of the disease management area (DMA). Controls on aquaculture at a site or area level require monitoring and enforcement to be effective. These include inspections by fish health inspectors from Marine Scotland and environmental inspectors from Scottish Environment Protection Agency (SEPA). The EAA will require spatial analysis in order to ascertain those marine areas where these activities can optimally thrive or areas whereby conditions could be improved in order that natural benefits could be increased. These areas will be important to designate as potential areas that, wherever possible, should be reserved for aquaculture.

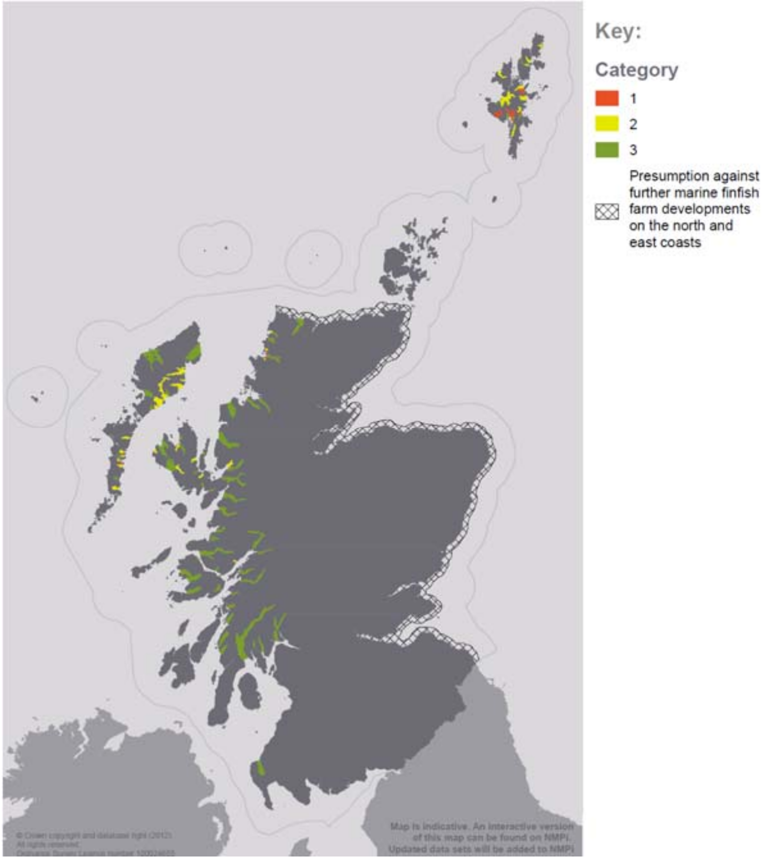

Figure 2: Spatial planning policy for aquaculture as laid out in the Scottish National Marine Plan. Finfish aquaculture is excluded on the North and East coasts. Inshore water bodies on the west coasts and islands are categorised according to their capacity potential to accommodate more finfish aquaculture.

1.4. Need for practical tools and role of GIS

Integrating aquaculture in MSP processes constitutes a challenge for European countries. Required instruments for spatial management (Sec. 1.3, Spain) or support for monitoring, data collection and control (Sec. 1.3, Hungary) are just a few examples demonstrating the need for practical tools supporting this process. In support of EAA, spatially explicit methods and tools are needed to assess both the environmental costs and benefits of spatial planning options within important European ecosystems types. In the AquaSpace context, costs are defined as environmental risks, cumulative impacts or spatial use conflicts with other sectors. Benefits are defined as environmental and social benefits, economic returns and synergy potential with other sectors. Practical tools to explore such (spatial) interactions need to incorporate multiple functions. Spatial human (cumulative) impact assessment, vulnerability analyses of ecosystem components or the evaluation of external factors such as climate change are just a few examples.

Some practical solutions are already available to support cumulative effect assessment, decision support and allocation of space, all of which form integral parts of the development of a regional spatial plan. However, such tools often represent tailored Geographic Information System (GIS) solutions for individual case studies, rather than generic tools that could be applied directly in MSP (Stelzenmüller et al., 2013a). The number of spatially explicit tools highlights the usefulness of GIS for MSP. Many workflows can be translated into a connected series of process steps to produce a tool for use by planners. Nevertheless, many of the recent tools are technically complex and could only be used by scientists or programmers. The use of generic GIS software or in-house tools, and perhaps the development of custom tools would be best for future efficiency (Stelzenmüller et al., 2013a).

1.5. Review of tools to identify practical needs

The final choice of methods and tools to support EAA has to be based on several criteria. Such tools have to be appropriate to (e.g.) the data available or the technical ability of the user. The uncertainty of the outputs is a result of the quality of the data used and the assumptions made for the assessment. Tool selections and developments have to result from a transparent and participatory process combining a selected review of tools with the views of stakeholders on the needs for practical tools. Such a gap analysis supports the identification of lacking tool functionalities and even more important, a lack of tools in general. In this way, routine tasks in the development of EAA towards MSP can be supported (Stelzenmüller et al., 2013a).

There is a great base of work to build on. Several toolboxes already exist which offer methods to scope for the multi-stakeholder context in which aquaculture might develop, the identification of economic costs and benefits, the estimation of environmental costs and benefits (such as e.g. environmental potential and risks), the allocation of other (aquaculture) activities, the suitability mapping and the related monitoring. Further, the review builds on material from the AquaSpace case studies and any tools currently in use and on methods applied by AquaSpace partners.

2. A REVIEW OF TOOLS AND METHODS TO SUPPORT AQUACULTURE IN A SPATIAL PLANNING CONTEXT

Several toolboxes already exist which provide a broad overview of tools and methods that support EAA. Those were examined according to their purpose, their design and content and their application. The tools applied by AquaSpace partners were examined according to several criteria. To address the specific focus on costs and benefits resulting from aquaculture activities, a dedicated step in this review process was on the tool functions. Here, the tool capabilities to assess all kinds of environmental costs and benefits were evaluated. Further, their software type (if applicable), the environment in which they are meant to be applied in, their potential operators, if they are management related, their strengths and weaknesses as well as references of applications were of interest.

In preparation for the gap analysis, technical components were examined with respect to the character of the tool (if it is about e.g. geospatial analyses, modelling or decision-support), information on the type of data needed (authoritative legal, physical, ecological or cultural data) and their spatial and temporal resolution. The skills needed to operate the tool were of the same interest as the costs related to it. Those data provided information about the general requirements to run the tool. In addition, existing tools were evaluated regarding their participative elements as well as their power in quantifying ecosystem services or valuing ecosystems or marine areas, as knowledge on the spatial scales of aquaculture-derived environmental impacts is crucial to EAA (Tab. 3).

Table 3: AquaSpace method review table.

REVIEW SECTION	**REVIEW QUERY**	***QUERY DESCRIPTION***
TOOL	Method/Model	*name of model*
APPLICATION	Aim/Nature of Issue addressed	*policy-management; aquaculture-environment; aquaculture-other sector interactions; economic and market issues*
	Regularity of use	*on a daily basis; once; not applied yet*
	Environment	*freshwater; coastal; offshore*
	Operational	*yes; not*
	Geographical component	*yes; not*
OUTCOMES	Data output	*general outcomes*
	Impact assessment	*e.g. impact, future risk, vulnerability*
	Ecosystem Services addressed	*e.g. water retention, microclimate improvement, habitat provision, landscape formation*
GENERAL REQUIREMENTS	Nature of software	*model; tool; toolbox; web-based application*
	Capacity	*Capacity needed*
	Equipment	*e.g. Arc GIS, Microsoft Excel, Access*
	Input data types	*e.g. authoritative legal; physical; ecological; economic, social; and/or cultural*
	Data requirements	*low; moderate; high*
	Skills needed to operate the tool	*e.g. programming skills*
	Usage level	*easy; medium; hard; very hard*
	Operators	*e.g. Industry, NGOs, governmental agencies*
	Costs	*low; moderate; high (software costs, training courses)*
	Source	*e.g. website*
INDIVIDUAL FEEDBACK	Strength	*e.g. considers different trophic levels or types of aquaculture (mono/polycultures)*
	Weakness	*e.g. complexity of the tool*
	Management related	*e.g. applied to any MSP, ICZM or land-based management decisions*
	Level of community participation	*low; moderate; high*
LITERATURE	References	*complete bibliographic reference*

2.1. *Existing toolboxes at a glance*

ECASA - The ECASA toolbox (http://www.ecasatoolbox.org.uk/) is the key deliverable of the three yearlong EU FP6 project "ECASA" (ECosystem Approach to Sustainable Aquaculture), which ended in November 2007. The main goal of the project was the development and testing of tools for the implementation of an ecosystem approach to aquaculture. It was developed by the "ECASA" Consortium and funded by the European Union, 6th Framework Programme, Grant Agreement 006540.

The virtual toolbox contains indicators and simulation models for supporting owners and operators of finfish and shellfish farms in selecting farm sites and operating farms, so as to minimize environmental impact and ensure the environmental sustainability of aquaculture activities. The toolbox includes five cross-referenced subject categories:

- Informative: provides background information concerning the project and the main theoretical principles and concepts in sustainable aquaculture; it also includes a book of protocols, describing in detail how to determine each indicator tested in the project.
- Indicators: gives a detailed list of potential indicators for assessing the environmental and economic sustainability of finfish and shellfish aquaculture activities, presents the methodology adopted to select the most reliable indicators and the results of the selection process and testing of the indicators in ECASA case studies.
- Models: contains an inventory of the model developed or tested in ECASA, as supporting tools for site selection, monitoring optimization and environmental impact assessment. Each model is described in detail and the results of tests performed in ECASA are summarized in terms of Goodness of Fit indices. The models are not available on the ECASA website but contacts for getting in touch with model developers are given.
- Study Site Environmental Impact Assessment by species: includes the reports on field work carried out at a range of representative sites across Europe, where the models and indicators were tested.
- Study Site Environmental Impact Assessment by countries: the same reports are arranged according to the geographical distribution of the ECASA case studies.

The ECASA toolbox was tested during the project at thirteen sites, in Croatia, France, Greece, Italy, Norway, Portugal, Scotland, Slovenia, Spain, covering the following types of culture: salmon, seabass, seabream, tuna, cod, mussel, oyster, clams.

COEXIST - The COEXIST toolbox (http://www.coexistproject.eu/coexist-results/tool) was compiled as one of the main deliverables of the multidisciplinary project "COEXIST" (Interaction in European coastal waters: A roadmap to sustainable integration of aquaculture and fisheries), which started in April 2010 and lasted for 39 months. The project team faced the challenge of balancing competing activities to avoid potential conflicts for space allocation. The consortium included thirteen partners from ten European countries, coordinated by the Norwegian Institute of Marine Research. COEXIST was funded by the European Commission Seventh Framework Programme.

The toolbox includes 13 tools which provide basic knowledge for a comprehensive assessment of the conflicts and synergies between fisheries, aquaculture and other activities in the coastal zone. Addressing economic, ecological and social dimensions in marine spatial planning, their application enables the provision of important information for decision makers in spatial management processes.

The tools were tested in six case study areas (Hardangerfjord, Atlantic coast Ireland, Atlantic coast France, Algarve Coast, Adriatic Sea, Coastal North Sea, Archipelago Sea and Bothnian Sea), which varied in size and focus and represented northern and southern European sea areas. A detailed description of the methods used and results addressing 16 key questions in spatial management, organised around three main topics:

- Assessment of status quo (legislation, activities, conflicts and synergies
- Monitoring and evaluation of spatial management options
- Integration of aquaculture, fisheries and other sectors

is given within the document "Guidance on a Better Integration of Aquaculture, Fisheries, and other Activities in the Coastal Zone: From tools to practical examples" (Stelzenmüller et al., 2013b).

MESMA – The MESMA toolbox (http://www.mesmacentralexchange.eu/tools.html) was developed within the project "MESMA" (Monitoring and Evaluation of Spatially Managed Areas), which started in November 2009 with a project duration of 48 month. The project team has focused on marine spatial planning and aimed to produce integrated management tools (concepts, models and guidelines) for the Monitoring, Evaluation and implementation of Spatially Managed marine Areas, based on European collaboration. The consortium included 21 partners from 13 countries, coordinated by the Dutch research institute IMARES. MESMA was funded by the European Commission Seventh Framework Programme.

The toolbox was structured around the MESMA framework. This framework explores in a logical way how the management initiatives in a certain area were established, so that they can be evaluated and monitored. In cases where no management plans are available, following this framework leads to recommendations for future plans. The framework includes the following steps:

1a) Context setting: temporal and spatial boundaries for Spatial Managed Areas (SMA) assessment
1b) Context setting: goals and operational objectives for SMA
2a) Existing information, collation and mapping: ecosystem components
2b) Existing information, collation and mapping: pressures and impacts
2c) Existing information, collation and mapping: management measures
3) Indicators
4) Risk analysis and state assessment
5) Assessment of findings against operational objectives
6) Evaluation of management effectiveness
7) Adaptation to current management

The toolbox includes several tools which provide basic support in the categories Data, Decision Support, Fisheries Analysis, Governance, Impact Assessment, Mapping, Numerical Model, Spatial Analysis, Spatial Planning, Visualization and Others.

The MESMA framework has been tested in nine case studies in in North- and Southern Europe. Together with the toolbox its high flexibility enables a standardized assessment of management, even though the data structure is complex or the management implementation difficult. Further, guidance is provided for governmental analysis, the data structure needed and the interactive web-based evaluation concept.

2.2. *Existing tools at a glance*

The tools and methods submitted by AquaSpace partners and reviewed during gap analysis are summarized in Table 4, further details are given in Annex I. Such tools predominantly focussed on environmental issues, which was followed by tools and methods to address policy-management issues and other sector issues. Tools considering economic and market issues were rarely mentioned. Consequently, the input data types have been in most of the cases of physical and ecological nature. Again, economic data constituted the smallest amount of input data (Fig. 3).

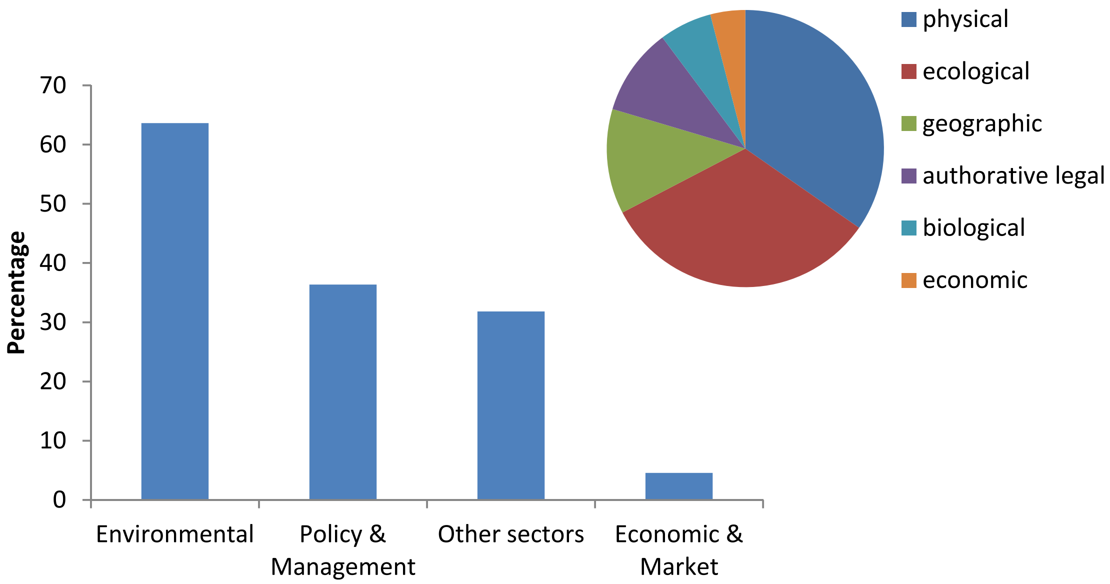

Figure 3: Nature of issue addressed and input data types of AquaSpace tools.

Geographically, 100% of the tools reviewed have their focus on the coastal environment, whereas less than 20% can be applied in offshore areas as well. While 73% have been rated as being "operational", only 32% are applied on a daily basis. More than half (59%) address the assessment of Ecosystem Services (ES).

Generally, the outputs are diverse and include maps, models, indicators or parameters to enable efficient management, at least in 90% of the cases. Nevertheless, the majority of tools reviewed require a high amount of technical skills and training.

Table 4: Tools and methods considered during the AquaSpace method review. Background information and further descriptions are provided in Annex I.

Tools/Methods	Background and further descriptions
AkvaVis	AkvaVis is a web-based application that provides indices of sea lice pressure given as relative concentration from dispersion from a source, and exposure given as wave height and current velocity for finfish farms. Further, its output provides recommendations related to distances to other farms, sewage etc., and suitable places for mariculture. The tool is meant to be applied mainly by management, but also by farmers, industry or researchers focussing on the major sustainability issues in national aquacultures.
BLUEFARM-2	The tool combines different models to assess the suitability of areas for shellfish farming and the preliminary assessment of the farm zone of effect in coastal and transitional waters. It shall be used by academics, farmers, managers or researchers for allocating best aquaculture zones, also considering distance from conservation hotspots.
Coupled ecosystem model	The tool combines different models to assess production carrying capacity and environmental carrying capacity for various aquaculture types in order to provide sustainability criteria for coastal environments. The tool shall to be used by coastal academics and governmental agencies on a daily basis for MSP and the management of aquaculture (stocking density, risk assessment, sustainability criteria).
Connectivity model	The tool combines different models to assess the connectivity between finfish aquaculture farms in the coastal and offshore environment. It is meant to be applied by academics, governmental agencies and people from industry and be applied to fish farms.
DEPOMOD/MERAMOD	The model provides contour maps of benthic effects for finfish aquaculture in coastal and offshore environments and shall be used by governmental agencies or industry on a daily basis as a fish farm planning siting tool.
Dispersion model	The model provides recommendations about the abundance of infective salmon lice for finfish aquaculture along the Norwegian coast weekly. It is meant to be used by governmental agencies on a daily basis to provide input to future management of Norwegian aquaculture (planned implementation 2017).
FARM	The model supports species selection, an ecological and economic optimisation of culture practices and the search for prospective shellfish aquaculture locations. Further, it supports the environmental assessment of farm related effects (i.e. potential nitrogen credits) in coastal environments. It shall be applied by researchers to support the management and planning of aquaculture.
GIS-based MCA/MaRS system	The model provides maps of opportunity and constraint for various types of aquaculture development in coastal areas. It shall be applied by public bodies and planners for sectorial planning.
GISFish	The web-based application provides relevant publications (i.e. references and abstracts) for the management of various types of aquaculture in coastal environments. It is meant to be applied by farmers, governmental agencies, industry or Non-Governmental Organisations (NGOs) on a daily basis.
GIS model	The tool provides maps showing the location of existing and proposed shellfish aquaculture sites in relation to conservation features such as habitats (e.g. Spatial Areas of Conservation (SAC) and Spatial Protected Area (SPA) designated features). Further, heat maps are showing

Tools/Methods	Background and further descriptions
	activities (in terms of density processed black box data) on subtidal bottom culture sites in coastal environments. The tool shall be applied by researchers.
GR_CC	The tool supports the calculation of maximum allowable production for finfish aquaculture in coastal areas using a simple set of variables (depth, distance from shore, exposure) setting also avoidance criteria for sensitive habitats. It shall be used by people from governmental agencies or industry and has been applied once in aquaculture management (GR).
Locational Guidelines	The model provides techniques to make room for expansion of biomass of finfish aquaculture on a water body basis in coastal environments. The model shall be used by managers a daily basis and is used routinely to inform planning and licensing in Scotland.
Empirical seagrass deterioration model	The tool is meant to assess buffer distances between a fish farm and a seagrass meadow in coastal areas. The outcomes are particulate organic or phosphorous thresholds to trigger ecosystem decline as well as sedimentation models. The tool shall be used by farmers, governmental agencies and managers
POM Kelp Production Simulator	The model provides physical parameters of the selected domain and a simulated Kelp production under different situations for coastal environment (i.e. Sanggou Bay, YSFRI case study site). The model shall be used by people from NGOs or researchers.
Seascape	The tool provides quantitative indicators of views of sea from land, land from sea and vertical angles to horizon (identifying visual enclosure). Further, it appropriates spatial data layers of quantitative indicators of visual impacts of all kinds of aquaculture development and interactive and immersive 3D models for coastal areas. The tool is meant to be used by governmental agencies and public bodies in any relevant environment.
SISAQUA	The web-based application provides indicators of suitability for the development of new potential shellfish aquaculture sites in coastal and offshore environments. It is meant to be applied by governmental agencies, industry, researchers or NGOs for MSP for shellfish cultures.
SMILE model	The model provides management recommendations and conservation advice by scenario testing for different types of shellfish aquaculture in coastal areas. It shall be applied by researchers who need to consider wild species at different trophic levels, including several aquaculture species.
Unity 3d / Oculus Rift	The interactive and immersive 3D model enables the user to do strategic assessments of visual impacts of various kinds of aquaculture in coastal environments. It is meant to be used by governmental agencies and public bodies in any relevant environment.
Visibility terrain model	The model provides contour maps of visibility of fish and shellfish farms from houses in coastal and offshore areas. It shall be used by governmental agencies and industries to any MSP, Integrated Coastal Zone Management (ICZM) or land-based management decisions.

2.3. General tool functions to support EAA

One essential step to identify where those tools can be applied (alone or in tandem) to support aquaculture in a spatial planning context was to define the tasks that need to be completed to deliver any kind of solution. In the AquaSpace context, those tasks are defined as tool functions. The Framework Matrix in section 1.2 (Tab. 1) provides a visual representation of the steps in an EAA framework that can benefit from tool function categories addressing the main issues constraining or strengthening the growth of aquaculture.

In this chapter, the actual tool functions of the tools reviewed (Tab. 4) are extracted, characterized and listed according to their tool function category (Tab. 1) and described in more detail (Tab. 5).

Table 5: Tool functions already existing and used in AquaSpace.

Categories	***Detailed description***
Policy and management	
Interactive activity mapping	Provides (3D) information about multiple uses of coastal areas (e.g. fishing and offshore oil operations) or impacts of aquaculture infrastructure itself. Supports participatory planning with stakeholders.
Cumulative effect assessment	Offers information about cumulative pressures coming from multiple human activities.
Risk identification	Provides information about the risks multiple uses of coastal areas (e.g. fishing and offshore oil operations) pose to the marine environment or even conserved areas (conservation impact). Such risks can refer to a degradation of natural seascapes and coastal landscapes or impacts of aquaculture infrastructure. Function supports scenario testing and the determination of thresholds.
Inventory and monitoring of aquaculture	Provides aquaculture site (heat) maps and information about unregistered or illegal farms, farm related effects or cumulative impact. Outputs can be sustainability criteria, impact parameter on sensitive ecosystems, sensitive ecosystem and habitat maps or conservation advice.
Guidance from around the globe	Information based on literature (related to GIS), remote sensing and mapping from 1980's to date.
Environmental	
Impact assessment (on Aquaculture)	Given are techniques to assess thresholds related to exposure (i.e. wave height), minimum distance to sewage or minimum distance to other farms.
Environmental carrying capacity analysis	Provides techniques to assess eutrophication risk (e.g. nutrient emissions in the water column, dissolved oxygen consumption, buffer distance between a fish farm and a seagrass meadow), benthic impacts (e.g. Organic Carbon, Nitrogen and Phosphorus fluxes and concentrations at the seabed and their effect on benthic keystone species) and biosecurity.
Production carrying capacity analysis	Provides techniques to assess the connectivity in between farms to avoid disease risk or infestation pressure (sea lice), the cultivation density (e.g. kelp) and dissolved oxygen consumption.
Site selection	Supports suitability mapping for mariculture, finfish aquaculture or aquaculture in general.
Ecological optimisation of culture practice	Function supports scenario testing to enable best available (ecological) culture practice.
Other sectors	
Interactive mapping	Mapping of multiple uses of coastal areas (e.g. fishing and offshore oil operations) and/or their visual impact.
Site selection	Supports participatory planning with stakeholders.
Economic and market	
Economic optimisation of culture practice	Function supports (economic) optimisation by facilitating a selection of the prospective culture location and the species and by production predictions.
Ecosystem service valuation	Provides techniques to evaluate ecosystem services or assess ecosystem service trade-offs.

3. GAP ANALYSIS

This chapter comprises the evaluation of tools for the CBA toolkit, which should facilitate the aquaculture planning process by overcoming present constraints. Being aware of tool competencies and how they could be used in a wider spatial planning context forms the baseline for the final choice of methods and tools to support EAA. As mentioned in section 1.4 and following the approach of Foley and Prahler (2011) and Ocean Solutions (2011), the evaluation of a tool has to result from a transparent and participatory process combining a selected review of tools with the views and needs of stakeholders. Further, such an evaluation can support the identification of missing tool functionalities and even more important, a lack of tools in general. Consequently, the AquaSpace CBA toolkit evaluation contained a gap analysis and consisted of the following three steps:

1. Map existing tools to EAA
2. Consult stakeholders to identify gaps in applying the EAA
3. Evaluate tools to bridge those gaps.

This includes the mapping of tools and methods (section 2.2) against identified tool functions (section 2.3). Aiming to generalize those core competencies (Tab. 6a,b), the number of specific functions within each broad function category was summed up for each tool function category and mapped against the EAA Framework steps (Tab. 7). Further, stakeholders were consulted in order to retrieve their opinions, needs and expectations regarding the spatial allocation of aquaculture next to other uses. Being informed by the real world of the case studies, constraints and issues (Fig. 4 and 5) could have been extracted and applied to the most promising tools (based on the tool core competencies; Tab. 7). Referring to technical capacities queried during the review (Tab. 9), the tool which matches the users' needs most closely can be identified. The general outcome of chapter 3 is a transparent CBA toolkit, referring to a collection of methods, tools, or concepts which allow assessing the effects (i.e. costs and benefits) of a planned aquaculture venture in relation to the overall spatial planning context.

3.1. Existing tools vs. EAA

In order to document the current tool core competencies in assessing costs and benefits in a wider spatial planning context, the tool functions (section 2.3) were mapped to the twenty tools and methods listed in section 2.2 (Table 6a,b). The tool function matrix gives a first overview about those tools and tool functions available addressing the key issues identified by WP2 constraining or strengthening the growth of aquaculture.

In the next step, the EAA framework steps were used to structure this wide variety of tool functions categorized by the main issues identified in WP2. The tool rubric matrix combines the Framework matrix (section 1.2) with the Tool function matrix (Tab. 6a,b) into one tool rubric, providing decision support for the final choice of tools applied at each step of MSP with aquaculture (Tab. 7). The different symbols reflect the number of specific functions within each broad function category that the tool is capable of performing. The symbols do not, however, evaluate how well each tool performs these specific functions. This rubric should be reviewed alongside the tool function matrix to ensure that the tools selected include the specific tool functions required in a process.

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Table 6a: Tool function matrix documenting core competencies of tools and methods (part 1), redrawn from Foley and Prahler (2011) and Ocean Solutions (2011).

		AquaSpace tools and methods									
		Seascape	NASO maps collection	GISFish	GR_CC	Coupled ecosystem model	Connectivity model	Minimum distance model	AkvaVis	Dispersion model	DEPOMOD/ MERAMOD
Tool function	**Policy and management**										
	Interactive activity mapping	✓							✓		
	Cumulative effect assessment										
	Risk identification	✓			✓					✓	
	Inventory and monitoring of aquaculture		✓		✓	✓	✓	✓	✓	✓	
	Guidance from around the globe			✓							
	Environmental										
	Impact assessment (on Aquaculture)				✓				✓		
	Environmental carrying capacity analysis				✓	✓	✓	✓	✓	✓	✓
	Production carrying capacity analysis					✓	✓			✓	✓
	Site selection						✓	✓	✓	✓	✓
	Ecological optimisation of culture practice										
	Other sector										
	Interactive mapping	✓									
	Site selection	✓			✓						

Economic and market				
Economic optimisation of culture practice				
Ecosystem service valuation	✓	✓	✓	✓

Table 6b: Tool function matrix documenting core competencies of tools and methods (part 2), redrawn from Foley and Prahler (2011) and Ocean Solutions (2011).

Tool function	Unity 3d / Oculus Rift	Locational Guidelines	POM Kelp Production Simulator	GIS-based model	BLUEFARM-2	FARM	SISAQUA	SMILE model	Visibility terrain model	GIS-based MCA/MaRS system
Policy and management										
Interactive activity mapping	✓			✓						
Cumulative effect assessment						✓		✓		
Risk identification	✓							✓	✓	
Inventory and monitoring of aquaculture	✓	✓	✓	✓	✓	✓	✓		✓	✓
Guidance from around the globe										
Environmental										
Impact assessment (on Aquaculture)										
Environmental carrying capacity analysis		✓		✓	✓	✓		✓		
Production carrying capacity analysis			✓		✓			✓		

Site selection		✓			✓	✓	✓			✓
Ecological optimisation of culture practice			✓			✓				
Other sectors										
Interactive mapping	✓			✓					✓	
Site selection					✓		✓			✓
Economic and market										
Economic optimisation of culture practice						✓				
Ecosystem service valuation	✓				✓	✓		✓	✓	

Table 7: Tool rubric combining the EAA framework and the tool function categories for tool selection (blank performs 0% of the functions, o performs < 50% of the functions, x performs 50 – 75% of the functions, ✓ performs > 75% of the functions), redrawn from Foley and Prahler (2011) and Ocean Solutions (2011).

	Framework step	Scoping			Opportunity and risk assessment				Carrying capacity analysis	Area allocation				Management plan development	Monitoring		
	Tool function categories	*Policy and management*	*Environmental*	*Other sectors*	*Policy and management*	*Environmental*	*Other sectors*	*Economic and market*	*Environmental*	*Policy and management*	*Environmental*	*Other sectors*	*Economic and market*	*Policy and management*	*Policy and management*	*Environmental*	*Other sectors*
Tools	Seascape	o		✓	o		✓	x		o		✓	x	o	x		✓
	NASO maps collection	o			o					o				o	o		

	GISFish	o			o					o				o	o		
	GR_CC	o	o	x	o	o	x	x	o	o	o	x	x	o	o	o	x
	Coupled ecosystem model	o	o		o	o		x	o	o	o		x	o	o	o	
	Connectivity model	o	x		o	x			x	o	x			o	o	x	
	Empirical seagrass deterioration model	o	o		o	o		x	o	o	o		x	o	o	o	
	AkvaVis	o	x		o	x			x	o	x			o	o	x	
	Dispersion model	o	x		o	x			x	o	x			o	o	x	
	DEPOMOD/MERAMOD		x			x			x		x					x	
	Unity 3d / Oculus Rift	x		x	x		x	x		x		x	x	x	✓		x
	Locational Guidelines	o	o		o	o			o	o	o			o	o	o	
	POM Kelp Production Simulator	o	o		o	o			o	o	o			o	o	o	
	GIS-based model	o	o	x	o	o	x		o	o	o	x		o	x	o	x
	BLUEFARM-2	o	x	x	o	x	x	x	x	o	x	x	x	o	o	x	x
	FARM	o	x		o	x		✓	x	o	x		✓	o	o	x	
	SISAQUA	o	o	x	o	o	x		o	o	o	x		o	o	o	x
	SMILE model	o	o		o	o		x	o	o	o		x	o	o	o	
	Visibility terrain model	o		x	o		x	x		o		x	x	o	x		x
	GIS-based MCA/MaRS system	o	o	x	o	o	x		o	o	o	x		o	o	o	x

3.2. Stakeholder consultation process

From the outset of AquaSpace, the choice of tools applied, any tool customisation or development should be undertaken with close stakeholder involvement to reflect their needs and expectations. The latter has been ensured though targeted stakeholder workshops, which brought together relevant stakeholders engaged in aquaculture processes within the respective case study areas (Annex II). The overall goal was to retrieve stakeholder opinions, needs and expectations regarding the spatial allocation of aquaculture next to other uses. These case study stakeholder workshops were facilitated through WP2 to ensure that comprehensive information was obtained from stakeholders. Most of the information was gathered by group discussions.

The stakeholder feedback (issues) has been synthesized in close collaboration of WP3 and WP4. Those issues which could be addressed by science were extracted and categorized as predetermined by WP2. The final selection was structured around the framework of EAA as described in section 1.5 (see Annex III for details).

3.3. Identify key issues

The outcomes of the local stakeholder workshops (given in detail in Annex III) have been generalized and ranked (number of case studies mentioning the same issue) to highlight gaps and stakeholder preferences on a regional level. The ranking of issues was followed by a synthesis of (ranked) issues by EAA framework step (Fig. 4) and key issues category coming from WP2 (Fig. 5).

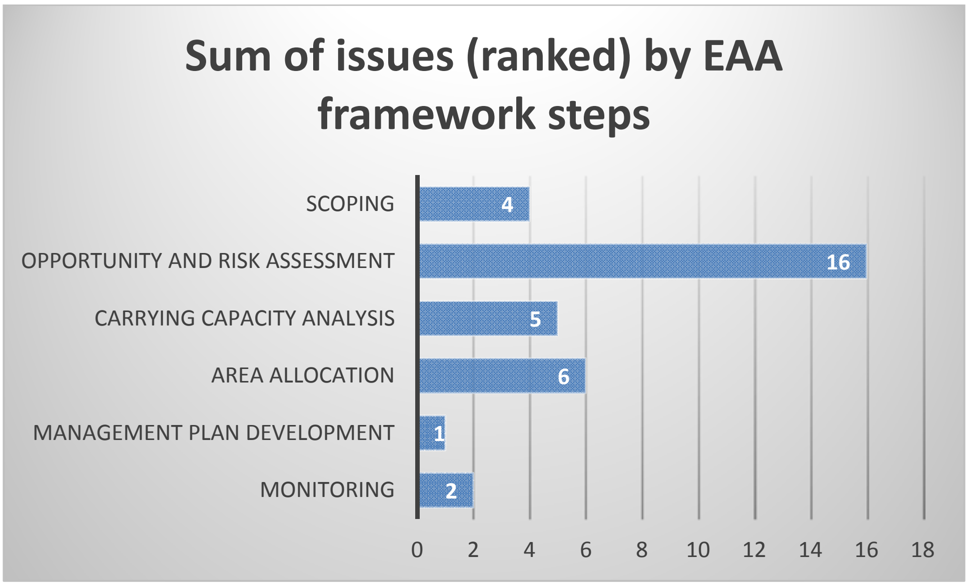

Figure 4: Ranked issues from local stakeholder workshops by EAA framework step.

The majority of constraints, barriers or issues could have been classified as being part of the Opportunity and Risk Assessment step. Nevertheless, uncertainty appeared even at the step of allocation of area/user access and/or management rights (consultation with stakeholders and setting operational and management objectives). Subsequently, the determination of maximum production as well as the scoping for e.g. ecosystem boundaries or relevant stakeholders was mentioned as being an issue.

Summing those constraints and barriers mentioned at the stakeholder workshops by the WP2 key issues, the majority were related to economic and market concerns. Unfavourable production conditions or a negative image of both aquaculture production and aquaculture products push back potential farmers and investors. Environmental threats such as high potential of pollution e.g. through faecal contamination were issued as being of nearly equal importance. This was followed by policy and management issues (mostly related to low accountability in aquaculture) and other sector issues (e.g. insufficient marine spatial management).

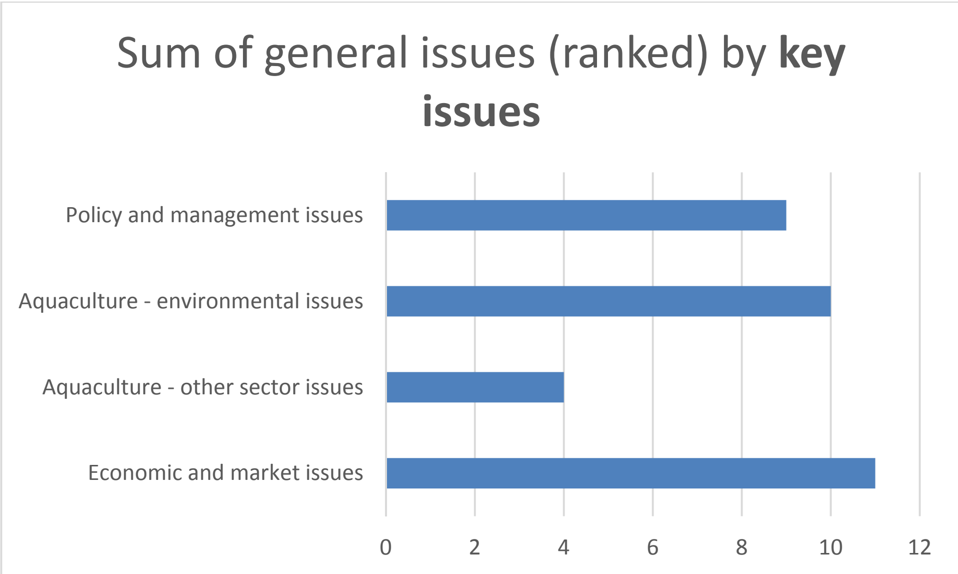

Figure 5: Ranked issues from local stakeholder workshops by key issue category.

3.4. Evaluation of tools to bridge the gap

In order to identify tools which have the potential to support MSP towards EAA, the issues identified during stakeholder workshops can be compared with the selection of tools and methods acquired during the method review, the tool rubric (Tab. 7). The utilisation of the tool rubric is exemplified in table 8 by using the top 5 issues mentioned during the stakeholder workshops. Taking for instance the issue "Insufficient marine spatial management", which is part of the EAA Framework step 'Scoping' and classified as being an issue of 'Aquaculture – other sectors' (Tab. 8 and Annex III) could be solved by searching in the tool rubric using the key words 'Scoping' and 'Other sectors'. The most suitable tool performing > 75% of the searched functions would be Seascape, followed by several other tools performing 50 – 75% of the searched functionality (Tab. 7 and 8). It has to be mentioned, that the symbols do not, however, evaluate how well each tool performs these specific functions. This rubric should further be reviewed alongside the tool function matrix (Tab. 6a,b) to ensure that the tools selected include the specific tool functions required in a process.

Although each of the tools reviewed show a wide variation of tool functions, none of them fits all stakeholder demands equally. If one would choose e.g. the tool FARM, as promoted by the tool rubric, to solve economic and market issues, the tool matrix would highlight the functions 'Economic optimisation of culture practice' and 'Ecosystem service valuation'. These functions might be helpful at the stage of improving aquaculture techniques or regarding their evaluation, but not when it comes to external factors such as fish feed. Here, it is advocated to use different tools in tandem rather than just to focus on one single tool.

In order to select the most promising tools, their technical capacities were evaluated. This includes the mapping of tools against (i) data requirements, (ii) training and expertise required to run those tools and (iii) costs expected to unfold their entire spectrum of functionality (Tab. 9). Based on this information, a final choice can be made. Coming back to one of the top 5 issues, for instance the issue "Production impediments", one might have to choose between FARM or GR_CC in order to avoid potential constraints. Managing aquaculture in data poor environments potentially lead to select GR_CC for support. Being well equipped and working independent of monetary limits might lead to a selection of FARM. Finally, guidance is provided towards the identification of tools, which have the potential to facilitate the aquaculture planning process by overcoming present constraints.

Table 8: Top 5 issues identified during local stakeholder workshops compared with final tools available based on tool rubric (Tab. 7). First choice tools (based on the overall tool functionality) are highlighted in bold.

EEA	**Category**	**Issues/Gap identified**	**Tools recommended to address those gaps**
Framework steps	*Defined by WP2*	*Constraints identified by stakeholders*	*Tool selected from table 7 that could address those gaps*
Opportunity and risk assessment	Economic and market	Production impediments	**FARM**, Seascape, GR_CC, Coupled ecosystem model, Empirical seagrass deterioration model, Unity 3d / Oculus Rift, BLUEFARM-2, SMILE model, Visibility terrain model
	Economic and market	Unfavourable image of aquaculture products	**FARM**, Seascape, GR_CC, Coupled ecosystem model, Empirical seagrass deterioration model, Unity 3d / Oculus Rift, BLUEFARM-2, SMILE mode, Visibility terrain model l
	Economic and market	Lack of product diversification & innovation	**FARM**, Seascape, GR_CC, Coupled ecosystem model, Empirical seagrass deterioration model, Unity 3d / Oculus Rift, BLUEFARM-2, SMILE model, Visibility terrain model
Scoping	Aquaculture - other sectors	Insufficient marine spatial management	**Seascape**, GR_CC, Unity 3d / Oculus Rift, GIS-based model, BLUEFARM-2, SISAQUA, Visibility terrain model, GIS-based MCA/MARS
Opportunity and risk assessment	Policy and management	Low accountability in aquaculture	**Unity 3d / Oculus Rift**

Table 9: Decision support for tool selection based on technical capacities. The squares are highlighted according to the tools' requirements: red = high, orange = medium, green = low).

	Data	**Training & Expertise**	**Funds & Equipment**
AkvaVis	red	green	green
BLUEFARM-2	orange	orange	orange
Connectivity modell	orange	red	orange
Coupled ecosystem model	orange	red	orange
DEPOMOD/MERAMOD	orange	orange	green
Dispersion model	red	red	red
FARM	orange	orange	orange
GIS-based MCA/MaRS system	red	red	red
GIS-based model	red	orange	orange
GISFish	green	green	green
GR_CC	green	green	green
Locational Guidelines	green	green	green
Empirical seagrass deterioration model	green	green	green
NASO maps collection	green	green	green
POM Kelp Production Simulator	red	red	orange
Seascape	orange	orange	orange
SISAQUA	red	green	green
SMILE model	red	red	orange
Unity 3d / Oculus Rift	orange	orange	orange
Visibility terrain model	red	red	orange

4. GAPS AND DEVELOPMENT REQUIREMENTS OF SELECTED TOOLS

The results based on the tool review, the stakeholder workshops and tool evaluation revealed several tools for the AquaSpace CBA toolkit, promising to be chosen for facilitating MSP with aquaculture. Nevertheless, development requirements have further been identified concerning the applicability or functionality of existing tools when accounting for constraints identified in respective case study needs (Annex III and Tab. 8).

The majority of tools reviewed were developed to solve environmental issues, followed by tools and methods to address policy-management issues and other sector issues. Tools considering economic and market issues were lacking. This gap becomes more obvious when plotting the tools according to their WP2 key issue classification prompted during review (Annex I). Indeed, the stakeholder consultation showed a clear demand for tool competencies solving economic and market issues (Fig. 5) when reaching the EAA framework step of Opportunity and Risk Assessment (Fig. 4). Further, the stakeholder consultation emphasized a need for tools focussing on environmental issues. Tool functions supporting environmental assessments have been valued as being crucial, especially when it comes to the EAA framework step of carrying capacity analysis and the subsequent area allocation.

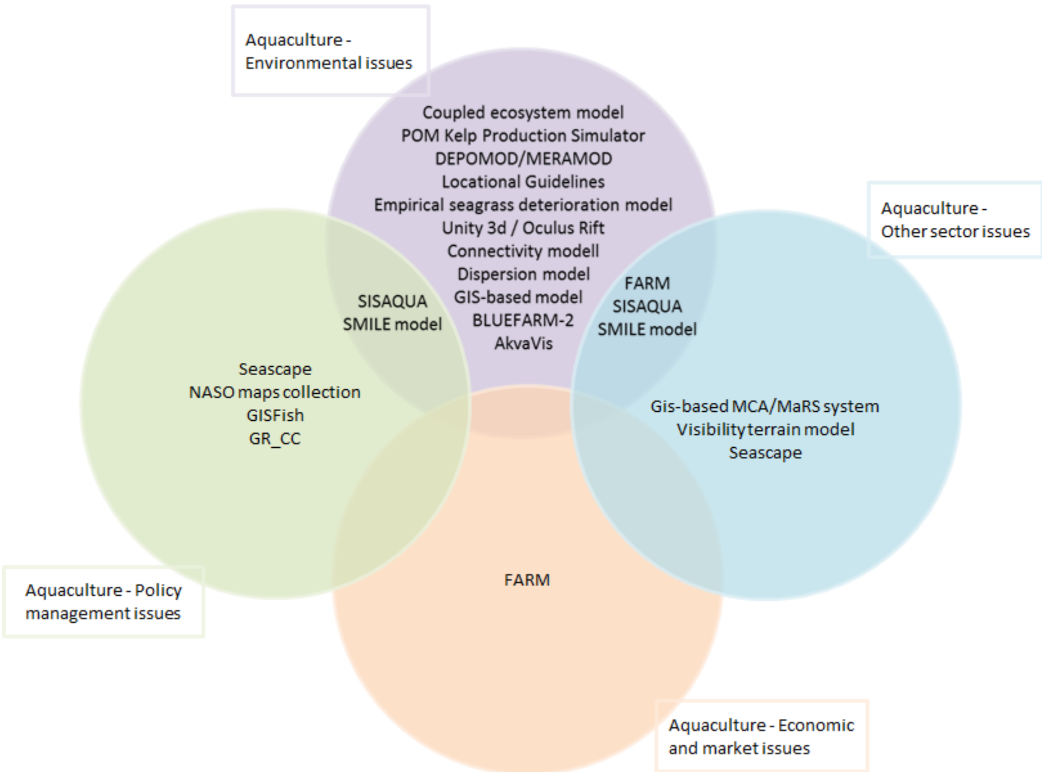

Figure 6: Overview of tools classified by AquaSpace partners as being applied to solve aquaculture-environment issues, aquaculture – other sector interactions, economic and/or market issues or policy-management issues.

The results revealed (Fig. 6) that no practical tools were found which considered all of the listed key issues. However, a few tools could address some key issues simultaneously. For example GIS-based tools such as SISAQUA, the SMILE Model or FARM addressed up to three key issues, hence pointing the way ahead to identify optimal locations, based on multiple defined constraints and targets.

Thinking about a tool allowing a holistic assessment of all costs and benefits of planning options in a wider MSP context, a GIS-based solution would be advantageous. Further, one of the critical components is a clear definition of the objectives for the development of such a tool. Ideally, it should be end-user driven (e.g. by using custom screeners), allowing industry to make better informed, evidence-based decisions (e.g. by providing market commentary) on aquaculture development and policy-makers a risk-based analysis of spatial management options.

Comparing the tools reviewed and evaluated with the gaps raised on the stakeholder workshops (Annex III), some kind of mismatches appeared. It seemed that a wide range of stakeholders are not aware about tools and functions already implemented or at least not able to operate them.

One future task mentioned to counteract a lack of designated areas for aquaculture was for instance the development and use of tools to assist the assessment of suitability and carrying capacity of new sites and zones for aquaculture. Nevertheless, considering the tool function matrix in section 3.1, several tools already do address environmental carrying capacity analysis or site selection. Another constraint emphasized the insufficient competence in regulators as difficulties in accessing and using supporting tools for monitoring, management and site selection.

Tools developed to support EAA should be promoted to a broad stakeholder community to enable them to navigate to the tools most appropriate to their application.

4.1. Recommendations Tools

It would be useful to identify standards for the customisation or development of operational tool(s) allowing a holistic assessment of costs and benefits of planning options in a wider MSP context. Such tools could further bring together spatially explicit information from tools and methods already applied. Recommendations for the customisation and (further) development comprise:

- The implementation of an ecosystem approach incorporating the functionality required to support an EEA implementation, explicitly considering economic and market issues
- The implementation of a spatially explicit (GIS-based) multi-use context, addressing the functionality for cumulative risk assessments and conflict analysis
- The intuitive design of the interface, which is meant to be end-user driven, allowing industry and policy-makers for more informed, evidence-based decisions
- A tool dissemination strategy to facilitate and support licensing processes and investment decisions.

The expertise of the AquaSpace consortium could contribute to implement tool functionality in relation to stakeholder requirements, case study issues, and current state of the art of the assessment of risks and opportunities of planned aquaculture activities. Further, they could develop a work plan for the amendments of the tool functionalities, the test phase by case studies, the tool manuals (framework) and the promotion of the tools.

4.2. Recommendations Data

To promote tool exchange and its general applicability it would be useful to also define standards for the use of data related to aquaculture planning and management in EU waters. This would include recommendations regarding:

- The type of data required for the designation of suitable sites (e.g. topography, current velocity, wave height etc.)
- The type of data required for the monitoring of aquaculture activities (e.g. pelagic and benthic nutrient and oxygen concentration, benthic keystone species etc.)
- The visualisation of spatially explicit data (geographic representation, object categories, symbols etc.)
- The data format required to enable free data access.

AquaSpace GIS experts could contribute geospatial standards for hydrographic, maritime and related issues for the International Hydrographic Organisation (IHO) Standard 100 (https://www.iho.int/iho_pubs/standard/S-100_Index.htm), based on project outcomes. S-100 provides the data framework for the development of the next generation of Electronic Navigational Charts (ENC) products, as well as other related digital products required by the hydrographic, maritime and GIS communities.

5. CONCLUDING REMARKS

Deliverable 3.1 reviewed existing CBA tools and methods to ultimately compile a CBA toolkit to support spatial planning with aquaculture in a multi-use context.

Several toolboxes or toolkits already exist which provide a broad overview of tools and methods that support a practical implementation of MSP. Nevertheless, none of them were structured around the EAA framework while being informed by a wide range of case studies. Based on the AquaSpace CBA toolkit, which consists of:

- a tool function matrix documenting core competencies of tools and methods,
- a tool rubric combining the EAA framework and the tool function categories for tool selection and
- decision support for tool selection based on technical capacities,

the best available tool (function) which completes the task of solution finding can be found. The use of stakeholder feedback collected through the case studies to finally evaluate both, selected tools and development requirements, proved to be powerful to identify major gaps where new or modified methods are needed. Being aware of gaps and missing tool functionalities, promising tools can be fine-tuned and developed further to extend their maximal utility and to fill those gaps. Future developments should address the following points:

- A facilitation of licensing is required when investments are made. A market-economy investor will invest only if the investment permits a higher return for a lower risk compared with the next-best alternative use of capital. Transferring this statement to the CBA toolkit, all kinds of costs and benefits, including economic ones, have to be considered.

- The valuation of ecosystem services might be one step forward to expand the technical capabilities in evaluating environmental benefits. Nevertheless, although being part of the review, the outcomes of methods and tools addressing ecosystem services were rare.

For several EU countries the designation of aquaculture sites means making space for a completely new sector leading to additional human pressure, increased conflict potential and therefore to increased management effort. With the CBA toolkit, guidance from around the globe as well as methods and tools tested by aquaculture experts are available supporting EAA, its planning, implementation and management.

Finally, D3.1 provides guidance towards the identification of tools, which have the potential to facilitate the aquaculture planning process by overcoming present constraints, contributing to increase sustainable EU aquaculture by supporting an EAA.

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ABBREVIATIONS

CBA	Cost Benefit Analysis
COEXIST	Interaction in European coastal waters: A roadmap to sustainable integration of aquaculture and fisheries
Connectivity model	Connectivity modelling
Coupled ecosystem model	Coupled physical-biogeochemical ecosystem model of aquaculture
CPD	Continuing Professional Development
Dispersion model	Operational salmon lice dispersion model
DMA	Disease Management Area
EAA	Ecosystem Approach to Aquaculture
ECASA	ECosystem Approach to Sustainable Aquaculture
EMFF	European Maritime and Fisheries Fund
ES	Ecosystem Services
GIS	Geographic Information System
GIS-based MCA/MaRS system	Multi-Criteria GIS analysis - MaRS system
GIS-based model	Arc GIS
GISFish	Global Gateway to Geographic Information Systems, Remote Sensing and Mapping for Fisheries and Aquaculture
ICZM	Integrated Coastal Zone Management
LOP	Littoral Ordination Plans
MESMA	Monitoring and Evaluation of Spatially Managed Areas)
Empirical seagrass deterioration model	Empirical model of seagrass deterioration with distance or organic matter inputs
MSP	Marine Spatial Planning
NASO maps collection	National Aquaculture Sector Overview (NASO) maps collection
NGO	Non-governmental Organization
POM Kelp Production Simulator	Princeton Ocean Model-based Kelp Production Simulator
SAC	Spatial Areas of Conservation
SEPA	Scottish Environment Protection Agency
SMA	Spatial Managed Areas
SME	Small and Medium-sized Enterprises
SPA	Spatial Protected Area
WFD	Water Framework Directive

RESPONSIBILITIES

This report was compiled by work package 3 at TI. The contents under each section reflect a synthesis of the work carried out across the work packages 2, 3 and 4 as well as within the case studies research.

ANNEX I. METHOD REVIEW TABLE

Annex 1a: Review table assessing tools and methods supporting aquaculture in a spatial management context. Those were examined according to their outcomes, individual feedback and general requirements (part 1).

Method/ Model	Key issue	Regularity of use	Environ-ment	Data output	Impact assessment addressed	Ecosystem Services (ES) addressed	Strength	Weakness	Management related
AkvaVis	Aquaculture-environment	On a daily basis	Coastal	Indices of sea lice pressure (relative concentration from dispersion from a source) and exposure (wave and currents), distance to other farms, sewage etc.; Suitability mapping for mariculture (incl. production predictions)	Siting and risk assessment related to sea lice and exposure, distance to other farms, sewage etc.; Biosecurity of siting a new farm; future risks of existing farms	No	Web based tool, immediate response, approach supported by robust science, site assessment; Given field data and mathematical models, AkvaVis can give the best location for cultivation site rapidly	Not updated, not maintained, demonstration; Requires long-term observation data	Yes, focus on the major sustainability issues in national aquaculture
BLUEFARM-2	Aquaculture-environment; aquaculture-other sectors interactions	Once	Coastal; transitional waters	Suitability of different areas for aquaculture (yes/no/ranking); Preliminary assessment of the farm zone of effect	Organic carbon, nitrogen and phosphorus fluxes and concentrations at the seabed; Macronutrients emissions in the water column; Dissolved oxygen consumption	Yes, for shellfish: nitrogen and phosphorous budgets of the farm	Considers environmental suitability; Applicable with both cage farming and longline aquaculture	Facility of usage: currently the user interface is still under development	Yes, allocating best aquaculture zones, considering distance from conservation hotspots
Connectivity model	Aquaculture-environment	N/A	Coastal; offshore	Connectivity	Risk with respect to diseases and parasites	No	Provides tool for deciding disease risk of different locations for new production	Complexity and computing requirements	Yes, applied to fish farms
Coupled ecosystem model	Aquaculture-environment	On a daily basis	Coastal	Production carrying capacity; environmental carrying capacity; sustainability criteria	Impact; Future risk; Eutrophication risk; Disease risk	Yes, habitat integrity, benthic health, shellfish filtration	Various types of aquaculture, many types of impact, extremely flexible	Complexity, needs expertise	Yes, MSP, stocking density, risk assessment, sustainability criteria
DEPOMOD/ MERAMOD	Aquaculture-environment	On a daily basis	Coastal; offshore	Contour map of benthic effects	Risk with respect to benthic impacts	No	Very well documented in literature	Requires good bathymetry and current data	Yes, fish farm planning siting tool

Method/ Model	Key issue	Regularity of use	Environ-ment	Data output	Impact assessment addressed	Ecosystem Services (ES) addressed	Strength	Weakness	Management related
Dispersion model	Aquaculture-environment	On a daily basis	Coastal	Abundance of infective salmon lice weekly along the Norwegian coast	Infestation pressure for wild fish; Siting of farms; Allowed production of salmon lice	NA	Will present a geographical overview of real infestation pressure from sea lice on wild fish weekly	Need specialized models and super-computer access	Yes, input to future management of Norwegian aquaculture (planned implementation 2017)
FARM	Aquaculture-environment; aquaculture-other sectors interactions; economic and market issues	N/A	Coastal	Prospective culture location and species selection; Ecological and economic optimisation of culture practice; Environmental assessment of farm related effects (nitrogen credits)	Nitrogen credit; Optimise site location; Conservation impact	Yes, ES trade-off; Reduce impact; Water Framework Directive (WFD) water quality guidelines	Physical, biogeochemical, shellfish growth models as screening models for eutrophication assessment	Model requires expert knowledge and large database	Yes
GIS model	Aquaculture-environment	N/A	Coastal	Aquaculture mapping (existing and proposed) in relation to conservation features/habitats (e.g. SAC and SPA); Human activity heat maps (in terms of Density processed black box data) on subtidal bottom culture sites	Impacts of aquaculture on conservation features	No	Takes account of a large variety of factors; Can map spatial overlap between aquaculture activities and conservation features/habitats	Requires large volumes of data	Yes
GIS-based MCA/MaRS system	Aquaculture-other sector interactions	Once	Coastal	Maps of opportunity and constraint to new development	All types of impact can be assessed depending on the availability of spatial data	No	Can account for a wide variety of factors to find optimum locations for new sites	Depends on expert judgement to weight data layers and must have spatially complete data sets	Yes, sectorial planning
GISFish	policy-management	On a daily basis	Coastal	Relevant publications (i.e. references and abstracts)	Collection of publications on GIS, remote sensing and mapping from 1980's to date	Yes, any relevant publications and information sources	Valuable compilation of applications from across the globe	Lack of funds have limited its development	Yes
GR_CC	policy-management	Once	Coastal	Calculation of max allowable production	Overall impact assessment	Yes, overall ES	Enables rapid diagnostics (with little amount of data needed); Applicable to a wide range of situations while being consistent and transparent	For fish farming only	Yes, already used in management

Method/ Model	Key issue	Regularity of use	Environ-ment	Data output	Impact assessment addressed	Ecosystem Services (ES) addressed	Strength	Weakness	Management related
Locational Guidelines	Aquaculture-environment	On a daily basis	Coastal	Room for expansion of biomass of finfish aquaculture on a water body basis	Current predicted impact from discharges and carrying capacity	No	Simple, precautionary; Gives an estimate of capacity	Simple, doesn't account for in situ primary production, or non-tidally driven exchange; Only works in fjordic inlets	Yes, used routinely to inform planning and licensing in Scotland
Empirical seagrass deterioration model	Aquaculture-environment	Once	Coastal	Buffer distance between a fish farm and a seagrass meadow	Protection of benthic keystone species; Impact assessment; Aquaculture site selection; Fish farm production planning	Yes, habitat structure	Spatial planning or fish load; Tool supported by robust science	Currently only developed for the Mediterranean seagrass species *Posidonia oceanica*	Yes
NASO maps collection	policy-management	On a daily basis	Coastal	Inventory and monitoring of aquaculture	Potential impacts on sensitive ecosystems, can also be linked to the licensing process to identify unregistered or illegal farms	Yes, the farm locations can be used to asses ES	User-friendly tool with a broad range of potential for numerous applications	Lack of funds and/or knowledge from countries to provide inputs	Yes
POM Kelp Production Simulator	Aquaculture-environment	Once	Coastal	Physical parameters of the selected domain and a simulated Kelp production under different situations	Provision of a proper cultivation density of kelp	No	Based on scientific principles and field data from selected region, polyculture can be considered and added to the model	Need strong background, Computational resource required	No

Method/ Model	Key issue	Regularity of use	Environ-ment	Data output	Impact assessment addressed	Ecosystem Services (ES) addressed	Strength	Weakness	Management related
Seascape participatory planning	Aquaculture-other sector interactions; policy-management	Once	Coastal	Spatial data layers of quantitative indicators of views of sea from land, land from sea and vertical angles to horizon (identifying visual enclosure); Spatial data layers of quantitative indicators of visual impacts of aquaculture developments; Interactive and immersive 3D Model; Interactive mapping	Landscape and visual assessments of impacts of aquaculture infrastructure on seascapes; Multiple uses of coastal areas (e.g. fishing and offshore oil operations); Visual impacts of changes in sea and land use on seascapes and coastal landscapes	Yes, landscape/ seascape character; Sea use	Strategic assessments of areas of potential visual sensitivity to development in coastal areas and of visual impacts of aquaculture developments with respect to landscape character; Environmental Impact Assessments of developments for site specific applications; Raising awareness of stakeholders of sea and land uses; derive stakeholder preferences for seascapes; develop collaborative plans for coastal management; Participatory planning, stakeholder engagement in raising awareness of issues relating to seascape/coastal areas; develop collaborative plans for coastal management	Sensitive to temporal aspects (i.e. changes in operational aquaculture sites), so reruns of calculations required; Time for mobilising the Theatre (i.e. ensure size of event is commensurate with time for running); Time for mobilising the Touch table and preparing the background data; Outputs require extensive computational time, but are only run once unless there are significant changes in physical structures	Yes, applicable in any relevant environment
SISAQUA	Aquaculture-environment; aquaculture-other sectors interactions; policy-management	Not applied yet	Coastal; offshore	Indicators of suitability for the development of new potential aquaculture sites	No	No	Easy to use, approach supported by robust science, high potential in terms of functionalities development; The application is still a prototype and needs to be evaluated	The application is still a prototype and needs to be evaluated	Yes, MSP for shellfish culture

Method/ Model	Key issue	Regularity of use	Environ-ment	Data output	Impact assessment addressed	Ecosystem Services (ES) addressed	Strength	Weakness	Management related
SMILE model	Aquaculture-environment; aquaculture-other sectors interactions; policy-management	N/A	Coastal	Management recommendations, conservation advice, scenario testing	Production capacity impact; Ecosystem capacity impact; Cumulative impact	Yes, WFD water quality guidelines (Chlorophyll a)	Considers wild species at different trophic levels, includes several aquaculture species. SMILE is a 3D model which can account for different types of aquaculture e.g. trestle, bottom or suspended	Complex multifaceted tool requiring large data sets for adequate validation	Yes
Unity 3d / Oculus Rift	Aquaculture-environment	Once	Coastal	Interactive and immersive 3D Model	Landscape and visual assessments of impacts of aquaculture infrastructure on seascapes	Yes, landscape/seascape character	Strategic assessments of visual impacts of aquaculture developments with respect to landscape character; Environmental Impact Assessments of aquaculture developments for site specific applications	Oculus Rift is a single user tool	Yes, applicable in any relevant environment
Visibility terrain model	aquaculture-other sector interactions	Not applied yet	Coastal; offshore	Contour map of visibility of farms from houses	Visual impact	Yes, visual amenity	Unique	Unique	Yes, could be applied to any MSP, ICZM or land-based management decisions

Annex 1b: Review table assessing tools and methods supporting aquaculture in a spatial management context. Those were examined according to their outcomes, individual feedback and general requirements (part 2).

Method/ Model	Nature of software	Equipment	Input data types	Data requirements	Skills needed to operate the tool	Usage level	Operators	Costs	Source	References
AkvaVis	Web-based application	Web access; WMS, Java; AkvaVis Console-based software (Windows)	Authorative legal, ecological, physical	High	No training required; basic training needed	Medium	Farmers, industry, manager	Moderate	http://insitu.cmr.no/akvavis2/akvavis.html	(Ervik et al., 2008; Ferreira et al., 2012a; CMR, 2016)
BLUEFARM-2	Coupled models	Quantum GIS (Qgis); Studio; BLUEFARM-1 web-based application	Ecological, physical, socio-economic	Moderate	Yes, knowledge of GIS at introductory level; capability of executing windows-based applications	Medium	Academics, farmer, manager, researcher	Moderate	NA	(Brigolin et al., 2015)
Connectivity model	Coupled models	PC to Cluster	Ecological, geographic, physical	Moderate	Yes, programming skills	Hard	Academics, governmental agencies, industry	High	service only	(Adams et al., 2015)
Coupled ecosystem model	Coupled models	MATLAB, Arc GIS, Finite-Volume, primitive equation Community Ocean Model (FVCOM)	Ecological, socio-economic	Moderate	Yes, MATLAB and physical oceanographic modelling	Hard	Academics, governmental agencies	Moderate	many published papers	(Filgueira et al., 2013)
DEPOMOD/ MERAMOD	Model	PC	Ecological, physical	Moderate	Yes, numerate	Medium	Governmental agencies, industry	Low	SAMS	(Cromey et al., 2012)
Dispersion model	Model	Super computer, web-based presentation of results	Ecological, physical	High	Yes, programming skills	Very hard	Governmental agencies	High	NA	(Asplin et al., 2015)
FARM	Model	Specialist model software	Biological, ecological, physical	Moderate	Yes, training required	Medium	Researcher	Moderate	Longline Environment (LLE) and freeware	(Ferreira et al., 2012b)
GIS-based MCA/MaRS system	Model	ArcGIS and access to the plug-in which is not for sale	geographic	High	NA	Hard	Public body, planners	High	The Crown Estates	(Davies et al., 2012)
GIS-based model	Tool	Arc GIS, Access	Biological, ecological, geographic	High	Yes, training required	Medium	Researcher	Moderate	AFBI	(Boyd and Service, 2014)
GISFish	Web-based application	Excel	Authorative legal, physical	Low	No training required	Easy	Farmers, governmental agencies, industry, NGOs	Low	www.fao.org/fishery/gisfish/index.jsp	(FAO, 2016b)

Method/ Model	Nature of software	Equipment	Input data types	Data requirements	Skills needed to operate the tool	Usage level	Operators	Costs	Source	References
GR_CC	Tool	Excel	Physical	Low	No training required	Easy	Governmental agencies, industry	Low	NA	(Karakassis et al., 2013)
Locational Guidelines	Model	Excel	Ecological, physical	Low	NA	Easy	Manager	Low	http://www.gov.scot/Resource/0048/00480659.pdf	(MSS, 2015)
Empirical seagrass deterioration model	Tool	PC	Ecological	Low	Yes, basic computer skills	Easy	Farmer, governmental agencies, manager	Low	NA	(Díaz-Almela et al., 2008)
NASO maps collection	Web-based application	Excel	Authorative legal, physical	Low	No training required	Easy	Farmers, governmental agencies, industry, NGOs	Low	www.fao.org/fishery/naso-maps/naso-home/en/	(FAO, 2016a)
POM Kelp Production Simulator	Model	Super computers and POM (Princeton Ocean Model)	Ecological, physical	High	Yes, programming skills, physical and biological oceanography knowledge	Hard	NGOs, researcher	Moderate	http://www.ccpo.odu.edu/POMWEB/	(Shi and Wei, in press)
Seascape	Tool	Hardware - Virtual Landscape Theatre; Software - spatial data handling (ArcGIS), visualisation viewer and development tools (Octaga, Vega Prime); Hardware - touch table; Software - Bespoke software implemented	Authorative legal, geographic, ecological, physical	Moderate	Yes, training in model design and creation, and operational training for use of 3D model and facilitating engagement activities; Operational training for use of touch table and software, facilitating engagement activities and in data and processing chain	Medium	Governmental agencies, industry, public bodies	Moderate; low	Software - commercially available; data - free for use by Scottish Government and public agencies; Software - optionally freeware (QGIS) or bespoke development	(Miller and Morrice, 2002; Ball et al., 2008; Wang et al., 2013)
SISAQUA	Web-based application	Web access	Authoritative legal, ecological, physical	High	Yes, training can be desirable; a video tutorial has been developed	Easy	Governmental agencies, industry, researcher, NGOs	Low	website	(Gangnery et al., 2014; Gangnery et al., 2015a; Gangnery et al., 2015b; Gangnery et al., 2015c)
SMILE model	Model	Specialist model software	Biological, ecological, physical	High	Yes, training required	Hard	Researcher	Moderate	LLE and freeware	(Ferreira et al., 2007; Ferreira et al., 2008)

Method/ Model	Nature of software	Equipment	Input data types	Data requirements	Skills needed to operate the tool	Usage level	Operators	Costs	Source	References
Unity 3d / Oculus Rift	Model	Visual Nature Studio, AutoCAD, Rhino 3d, Unity 3D	Ecological, geographic, physical	Moderate	Yes, operational training for initial software modelling. None needed for Oculus Rift operation. Stakeholder event facilitation skills	Medium	Governmental agencies, public bodies	Moderate	Software - commercially available; data - free for use by Scottish Government and agencies	(Schroth and Zhang, 2014)
Visibility terrain model	Model	PC to Cluster	geographic, physical	High	Yes, programming skills	Hard	Governmental agencies, industry	High	SAMS	Not yet published

ANNEX II. STAKEHOLDER WORKSHOPS AT CASE STUDY LEVEL

Annex II: Participants (given by affiliation) of those stakeholder workshops (organised at case study level), which have been considered in D3.1 gap analysis. Workshops were conducted in order to identify the key issues hindering aquaculture expansion. The stakeholder feedback (issues) has been synthesized in close collaboration of WP3 and WP4 in Annex III.

CASE STUDY	STATE	INDUSTRY	PUBLIC	MANAGEMENT	RESEARCH	NGO	OTHER	TOTAL
ADRIATIC	ITA	17	18		10			45
BASQUE	ESP		2		3	5		10
BEKES COUNTY	HUN	13		10	21		11	55
GREAT BAY/LONG ISLAND	USA	x	x		x			86
HOUTMAN ABROLHOS	AUS			x	x			1
MEDITERRANEAN	Multi	x		x	x			44
NORMANDY	FRA	x		x	x	x		18
NORTH SEA	GER	x	x	x	x	x		22
ARGYLL	UK	x		x	x	x		24

ANNEX III. ISSUES IDENTIFIED AT CASE STUDY LEVEL

Annex III: Issues identified at case study stakeholder workshops which could be addressed by science/research - structured around the EAA Framework steps and categorized by WP2 key issues. Attached are the tasks that need to be completed to overcome such issues and to deliver best solution as well as the authority which should take the lead on this task.

EAA framework steps	***Issue category identified***	***Issues***	***Explanations***	***Future task to ensure best available practice***
Scoping	*Policy and management*	Insufficient authorization competence in authorities	Lack of knowledge of existing and inexpensive data	Short training courses on specific subject, supported by public authorities
	Aquaculture - environment	Untapped scientific frontiers	Development of novel techniques and approaches (improve fish health, advance offshore technologies, reduce chemical usage)	Ecosystem and environmental modelling
	Aquaculture - other sectors	Insufficient marine spatial management	Optimizing space allocation to coordinate existing activities and minimisation of conflicts	Implementation of MSP, involving all relevant stakeholders
			Need for spatial planning and co-existence of aquaculture with other sectors and interests	Marine Spatial Planning, stakeholder and community engagement, co-development/ co-location planning
Opportunity and risk assessment	*Policy and management*	Low accountability in aquaculture	Negative public perception of aquaculture	Explore industry accountability
				Include conditions of accountability in licenses and plans

EAA framework steps	*Issue category identified*	*Issues*	*Explanations*	*Future task to ensure best available practice*
				Explore the root causes of conflicts (public and marine users) with the industry, identify barriers and potential solutions
		Insufficient perception of aquaculture	Pushback 'social carrying capacity'	Social science research to help with the perception of aquaculture
	Aquaculture - environment	High potential for pollutions	Accidental release of macro plastic litter (longline mussel culture)	Screening of technological solution for reducing the use of plastic socks
			Problems with faecal contamination and bio-toxins (shellfish production)	
		Climate change	Fish feed mostly imported from Chile and Peru (mainly Anchovies), which production is depending on El Nino conditions	Develop alternative feed sources (no anchovies included)
	Aquaculture - other sectors		NA	NA
	Economic and market	Unfavourable image of aquaculture products	Loss of income resulting from the maintenance of ecosystem goods and services is not compensated	Valuation of ecosystem services
				Potential valorisation of shellfish farms in terms of ecosystem services
				Traceability of aquaculture products
		Lack of product diversification & innovation	Need of diversifying the production introducing more cultured species, beside mussel	Diversification and analysis of the profitability of new cultivated species (potential biomass yield, marketing, expected revenues)
			Lack of business development to overcome stagnation	Review of planning and licensing, Marine Spatial Planning, stakeholder and community engagement, development funding (to make investment in the area viable)

EAA framework steps	*Issue category identified*	*Issues*	*Explanations*	*Future task to ensure best available practice*
		Production impediments	Quality of juveniles and the quality of fish feed prohibit the performance improvement	
			Inaccurate feed specific growth rates	
			Increased prices of petrol/ fish feed and declining market prices	
			Increased costs due to stricter regulations of monitoring, hygiene and safety	
			Unsuitable sites for increased production and/or reduction disease management	Improve spatial planning of leased areas within planned zones to optimise production
Carrying capacity analysis	*Aquaculture - environment*	Eutrophication risk	Lacking nutrient management (water quality issues)	Develop nutrient management programs
				Develop policies and procedures for crediting of nutrient removal
			No quantification of emissions	Identify 'low emission' production locations
				Assess overall (European-wide) emissions
		Disease risk	No quantification of risk potential	Assess of disease- and parasite potential
				Defining best principles of operation to account for biosecurity
				Describe best strategy for the prevention of spread of disease to the wider industry
				Development and use of tools to assist the assessment of suitability and carrying capacity of new sites and zones for aquaculture
		General risks		Assess interactions of culture species (IMTA, Aquaponics etc.)
				Assess risk of submersion and coastline erosion

EAA framework steps	***Issue category identified***	***Issues***	***Explanations***	***Future task to ensure best available practice***
Area allocation	*Policy and management*	Lack of designated areas for aquaculture	Lack of spatial planning and AZA, in particular in off-shore areas, where shellfish culture could expand	
		Insufficient suitability analysis due to limited data access	Environmental impact at unsuitable areas limits the establishment and further development of aquaculture	Historical data access for suitable areas identification
	Aquaculture - environment	Risk of exposure offshore	New technologies to avoid macro plastic release may require the reallocation of farms in deeper areas	
	Aquaculture - other sectors	Lack of space	Space issues of expansion of aquaculture in the intensely used/multi use estuaries	Development plans to support the management of Aquaculture expansion
	Economic and market		NA	NA
Management plan development	*Policy and management*	Insufficient authorization competence in authorities	Difficulties in accessing and using supporting tools for monitoring, management and site selection	Continued Professional Development (CPD) courses to address gaps in skilled capacity for planning and management of aquaculture
Monitoring	*Policy and management*	Lack of designated areas for aquaculture	High compliance costs by stakeholders	Development and use of tools to assist the assessment of suitability and carrying capacity of new sites and zones for aquaculture
				Assessment of site suitability and carrying capacity to reduce compliance costs
		Insufficient environmental monitoring	Improve spatial planning to enable better targeting and monitoring requirements in order to ensure sound environmental protection	Streamline the process for ongoing monitoring and management of aquaculture activities
	Aquaculture - other sectors		NA	NA

EAA framework steps	***Issue category identified***	***Issues***	***Explanations***	***Future task to ensure best available practice***
	Aquaculture - environment		NA	NA