Mediterranean Aquaculture Integrated Development

Deliverable 8.5

Recommendations for promoting new aquaculture systems to reduce environmental impacts

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Executive Summary

The MedAID project (Mediterranean Aquaculture Integrated Development) aims to increase the competitiveness and sustainability of the Mediterranean marine fish aquaculture sector throughout its value chain, by improving its technical productivity and economic performance with a market- and consumer-oriented approach, as well as achieving higher social and environmental acceptability and better governance (Aguilera *et al.,* 2019). The development of aquaculture will necessarily involve an increase in the spaces devoted to this activity, due to the expansion of existing businesses and/or the creation of new ones. Conflicts pertaining to the use of marine space and the implementation of existing policies and legislation are two of the main factors hindering aquaculture growth (Galparsoro *et al.,* 2020). Marine spatial management must be improved to facilitate site selection processes, alongside the establishment of transparent procedures and licencing processes, thus reducing the length of time and investment needed to develop new aquaculture activities. In addition, the increase in production will generate a proportional increase in the amounts of feed, which are often produced outside the countries concerned. If aquaculture is to double its production by 2030, the sector must improve its productivity, without compromising environmental performance (Lotze *et al.,* 2019). Aquaculture can affect ecosystems (socially, economically and environmentally) positively or negatively, and aquaculture can be impacted by other human activities. Environmental impacts vary greatly depending on the type of farming in question (inland open flow, RAS, cages in protected areas or offshore) and husbandry practices (species, stocking density, feed composition, etc ...). As for marine fish, whereas fry production takes place in inland hatcheries, as well as many pre-ongrowing farms, most ongrowing production takes place in sea cages, where the carrying capacity of the surrounding environment (hydrodynamic circulation, sediment characteristics etc...) is a critical constraint. To ensure sustainable development, ecological carrying capacity should be considered and environmental impacts of aquaculture should be minimized by either improving farm management or production systems, site selection, etc... Furthermore, all other uses of water and natural resources must also contribute to ensuring a sustainable ecosystem. The objective of this report (D8.5) is to review inputs and recommendations from international organizations and recent EU projects on environmental impact assessments, environmental monitoring procedures, as well as to discuss technical solutions to reduce the environmental impacts of Mediterranean fish farming and promote environmentally sustainable development.

After a brief introduction on Mediterranean fish farm production based on MedAID results, the "Ecosystem Approach to Aquaculture" (EAA) framework and general aquaculture constraints at different spatial scales (farm, waterbody and regional scales) are described. We then focus on the key steps of the EAA: Marine Spatial Planning (MSP), Site Selection, Environmental Impact Assessment (EIA) and the Environmental Monitoring Procedure (EMP) before explaining how recent EU projects have developed tools and methods to facilitate these different steps. We reviewed decision support tools and methods tested and developed to facilitate spatial planning (AQUASPACE), site selection and licencing procedures (TAPAS). We have then listed key indicators selected by stakeholders for Environmental Impact Assessments (EIA) and Environmental Monitoring Procedures (EMP) during different projects (including Indam and PerformFISH).

Finally, the local (eutrophication) and global (use of fishery resources, carbon footprint) environmental impacts related to feed and fish faeces are discussed. The main strategies and recommendations for minimizing the impact of feed are: improving feed use through improvement of FCR, feed composition or best management practices, implementing innovative farming systems such as recirculating aquaculture systems (RAS) and Integrated Multi-trophic Aquaculture (IMTA) to improve the treatment and recovery of waste. Finally, prevention of fish escapees is reviewed (Prevent-Escape project).

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Acronyms

AZA: Allocated Zones for Aquaculture
AZE: Allowable Zone of Effects
CC : carrying capacity
CESE : Conseil économique, social et environnemental (Economic, Social and Environmental Council)
CCRF: Code of Conduct for Responsible Fisheries
EAA: ecosystem approach to aquaculture
EIA: environmental impact assessment
EMP: environmental monitoring programme
EQS: environmental quality standards
EU: European Union
FAO: Food and Agriculture Organization of the United Nation
FCR: food conversion rate
GFCM: General Fisheries Commission for the Mediterranean
IMTA: integrated multitrophic aquaculture
IUCN: International Union for Conservation of Nature
LCA: life cycle analysis
NGO: non-governmental organization
OM: organic matter
SEA: strategic environmental assessment
SHoCMed: Siting and Holding Capacity in the Mediterranean
WFD: Water Framework Directives
WGSC: Working Group on Site Selection and Carrying Capacity
WHO: World Health Organization

1. Introduction

In the Mediterranean, the demand for fishery products has been rising steadily over recent decades, due to significant population growth and an increase in human per capita consumption (CIHEAM, 2010). These developments have led to growing pressure on Mediterranean fish stocks, most of which (about 78%) are currently being fished at biologically unsustainable levels, according to the FAO-GFCM (FAO, 2018). Thus, as in other areas, Mediterranean countries are facing a major and growing seafood supply deficit that can only be compensated by aquaculture. However, aquaculture has not been developed in northern Mediterranean countries as may have been expected (Massa *et al.,* 2017). This report focuses primarily on finfish aquaculture.

Stagnant marine fish aquaculture production in European Mediterranean contrasts with observed development in neighbouring countries (i.e. Egypt, Tunisia and Turkey). Multiple direct and indirect factors may explain this stagnation, including limited competitiveness, low zootechnical productivity, lack of genetically improved fish, poor feed performance, inadequate health management or a combination of these and other environmental factors (Aguilera *et al.,* 2019). The lack of market strategies and an insufficient knowledge of consumer preferences have also been highlighted. Increased competition for coastal uses (Galparsoro *et al.,* 2020), a poor public perception of aquaculture and a complex administrative framework also constitute major challenges for aquaculture development.

In this context, the MedAID project (Mediterranean Aquaculture Integrated Development) aims to increase the competitiveness and sustainability of the Mediterranean marine fish aquaculture sector throughout its value chain, by improving its technical productivity and economic performance with a market- and consumer-oriented approach, as well as achieving higher social and environmental acceptability and better governance (Aguilera *et al.,* 2019).

Aquaculture development will require an increase in the space devoted to this activity, due to the expansion of existing businesses and/or the creation of new ones. In addition, increased fish production will generate a proportional demand in the amounts of feed needed, which are often produced outside the countries concerned. Aquaculture can therefore affect ecosystems (socially, economically, environmentally and globally) positively or negatively, and aquaculture can be impacted by other human activities (CESE, 2017). Environmental impacts vary greatly depending on the type of farming (inland open flow, recirculating aquaculture system (RAS), fish cages in sheltered areas or offshore) and husbandry practices (species, stocking density, feed composition, etc.). As for marine fish, whereas fry production takes place in inland hatcheries, as well as many pre-ongrowing farms, most ongrowing production takes place in sea cages, where the carrying capacity of the surrounding environment (hydrodynamic circulation, sediment characteristics, etc.) is a critical constraint. To ensure sustainable development, ecological carrying capacity should be considered and the environmental impacts of aquaculture should be minimized by improving farm management, production systems, site selection, etc. In addition, all other uses of water and natural resources must ensure that they have a minimal impact on ecosystems (CESE, 2017).

1.1. Mediterranean aquaculture

The Mediterranean has 46,000 km of coastline and potential spaces for aquaculture. Since the beginning of the 1980s, both intensive and extensive aquaculture farming practices have been implemented, including cage farming, initially in protected bays and later off-coast and off-shore, onshore facilities in open flow systems and, more recently, recirculation (RAS) farms that produce medium- to high-value species. Many species of fish (seabass, seabream, meagre, sole, eel, trout, sturgeon and tench) and molluscs (clams, oysters and mussels) are produced. Although the main species-group produced in terms of volume (tonnes) is freshwater fish (trout, tilapia, carp), the main group produced in terms of value (USD) is marine fish, mainly seabass and seabream (Figure 1) (Aguilera *et al.,* 2019).

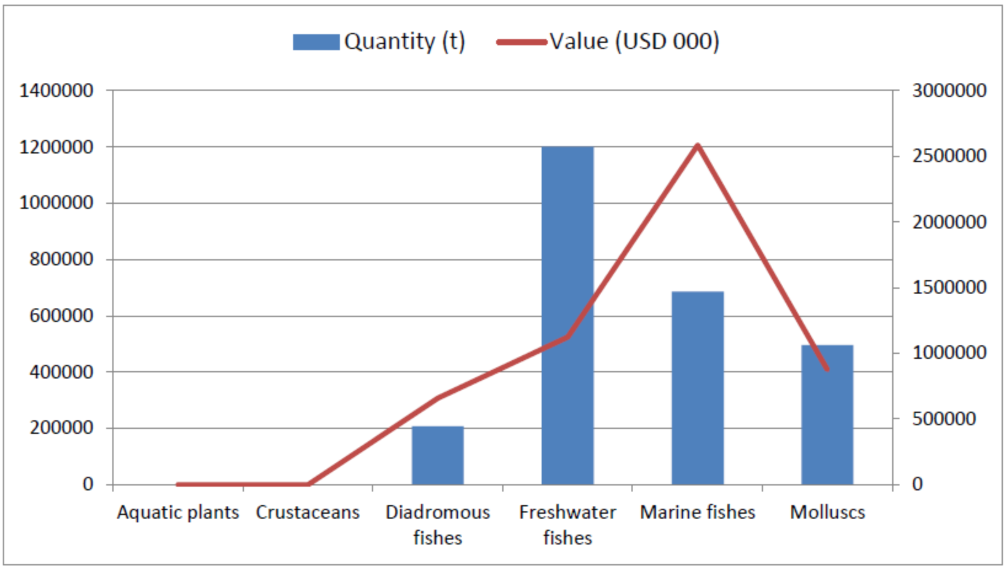

Fig 1. Aquaculture production and value in GFCM countries by species group (source: FAO fishstat, 2019, Aguilera *et al.,* 2019).

Mediterranean farmed marine fish sales amounted to 373,000 metric tons and 1.3 billion juveniles in 2016 (MedAID compilation data; various sources). Turkey (37%), Greece (25%), Egypt (14%), Spain (9%), Tunisia (4%) and Italy (4%) produced practically all of the seabass and seabream (tonnes) in the Mediterranean in 2016. Likewise, EU Mediterranean seabass and seabream on-growing production represents 44% of the total, while non-European production is equivalent to 56% of Mediterranean on-growing production. As regards hatcheries, the production of seabass and seabream juveniles (is mainly concentrated in 5 countries: Greece (33%), Turkey (32%), Spain (10%), Italy (9%) and France (9%). These five countries represent 93% of total production. In other words, EU Mediterranean aquaculture juvenile production represents 64% of the total while the juvenile production in non-EU countries accounts for only the remaining 36% (Aguilera *et al.,* 2019).

The distribution of aquaculture is not homogeneous throughout the Mediterranean. The causes of this heterogeneous growth are environmental (length of coastline or availability of potential suitable locations (such as in Croatia, Greece and Turkey), political and financial (Giannetto *et al.,* 2014). On the other hand, many EU countries have not adequately supported the development of the sector, and give priority to other coastal activities (e.g. tourism). Thus, some analysis reports existing difficulties behind authorization and licensing procedures, which often take around 2-3 years to complete, or even substantially longer (COM/2013/229).

1.2. Objectives of this report

The objectives of MedAID WP8 are to bring together outcomes from MedAID WPs to design and propose innovative management practices in order to improve the overall competitiveness and sustainability of the whole Mediterranean marine aquaculture sector value chain. The specific objectives of WP8 are: (i) to integrate the holistic assessment from WP1 and the outputs from all technical and socio-economic WPs, and to validate them in selected case studies through modelling; (ii) to develop best practice guidelines and recommendations with regards to zootechnical and socio-economic aquaculture development; (iii) to develop specific feasible business plans for the improvement of Mediterranean aquaculture's economic performance; (iv) to propose policy and social and environmental recommendations to support stakeholder engagement and co-construction of projects for sustainable aquaculture development.

The objective of this report (D8.5) is to review inputs and recommendations from the MedAID project, international organizations (FAO, GFCM [more specifically the ShoCMed and Indam projects], IUCN) and other recent EU projects (AQUASPACE, TAPAS, PerformFISH, PREVENT-ESCAPE) on environmental impact assessments, environmental monitoring procedures and solutions (precision fish farming, RAS, IMTA) aiming to reduce the environmental impact of Mediterranean fish farming and promote environmentally sustainable development. See Table 1 for details on the projects reviewed for elaborating the present report.

1.3. Methodology

The "Ecosystem Approach to Aquaculture" framework is initially described (part 1) as well as general aquaculture constraints at different spatial scales (farm, waterbody and regional scales). Following this, the outputs of EU projects are described, including tools and methods for spatial planning (Aquaspace), Site selection and licencing procedures (TAPAS). Then, relevant indicators selected for the Environmental Impact Assessment (EIA) and Environmental Monitoring Procedure (EMP) are presented (Indam, PerformFISH) (part 2). Finally, solutions to prevent or minimize the main environmental impacts of fish farming are discussed (Prevent-Escape) (part 3).

Table 1. Projects reviewed for the elaboration of the report.

Project name and logo	Objectives
	MedAID (2017-2021) aims to increase the competitiveness and sustainability of the Mediterranean marine fish aquaculture sector throughout its value chain, by improving its technical productivity and economic performance with a market- and consumer-oriented approach, as well as achieving higher social and environmental acceptability and better governance
	Aquaspace (2015-2018) was a research project aiming to understand spatial and socio-economic constraints on the expansion of aquaculture, and to test tools to help overcome these constraints. Its full title was 'Ecosystem Approach to making Space for Aquaculture'.
	TAPAS (Tools for Assessment and Planning of Aquaculture Sustainability) was a four-year EU Horizon 2020 collaborative research project which began in March 2016 and finished in February 2020. It aimed to promote and consolidate the environmental sustainability of European aquaculture by developing tools, approaches and frameworks to support EU Member States in establishing coherent and efficient regulatory frameworks.
	PerformFISH works to ensure sustainable growth of the MMFF industry, based on consumer perceptions and real market requirements. It aims to support fish farms to operate not only in optimal economic and environmental conditions, but also in a socially and culturally responsible manner.
ShoCMed	Developing site selection and carrying capacity for Mediterranean aquaculture within aquaculture-appropriate areas. The specific objectives of the SHoCMed project were to: i) produce site selection criteria in order to enhance the integration of aquaculture into coastal zone management through the use of AZAs and ii) provide a basis for the harmonization of standards, aquaculture policies and legal frameworks across the Mediterranean region to ensure equal terms of competition and minimal environmental impact. This project benefitted from the support of the European Union (EU) and was concluded in 2016.
Indam	"Indicators for Sustainable Development of Aquaculture and Guidelines for Use in the Mediterranean" (InDAM project) was carried out in support of the GFCM CAQ Working Group on Sustainability in Aquaculture (WGSA) and was funded by the European Union. Objectives: to meet the need for a decision support tool for monitoring the sustainable development of aquaculture in all its dimensions, based on a set of practical indicators and reference points.
	Prevent-Escape (2009-2012) was a research project aimed at assessing the extent and causes of escapes and generating new knowledge through research to help mitigate the effects of escapees on wild populations on a pan-European scale. Its full title was 'Assessing the causes and developing measures to prevent the escape of fish from sea-cage aquaculture'.

2. Ecosystem Approach to Aquaculture (EAA)

2.1. The EAA strategy

An ecosystem approach to aquaculture is a strategy for the integration of the activity within the wider ecosystem so that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems (FAO, 2010). "Great care is required in promoting specific mechanisms to implement the ecosystem approach, as optimal solutions depend on context. Guidance must be flexible and adaptable. The principles are far more important than any specific mechanisms, and the latter are a matter for local ingenuity and choice" (FAO, 2010). The three relevant scales for implementing EAA are the farm, the waterbody (or watershed or aquaculture zone) and the global scale (Figure 2).

Fig 2. The three relevant scales to implement the EAA approach: the farm, the waterbody (or watershed or aquaculture zone) and the global scale.

At each scale, the main issues and solutions differ. A synthesis of relevant good practice in environmental and aquatic health at farm level & waterbody level, based on EAA (FAO, 2010) is presented in Table 2. At the farm scale, major issues include mitigating negative impacts of nutrient emissions, limiting escapes, controlling the spread of disease, increasing productivity and ensuring farm profitability (see review by Chary *et al.,* submitted). Priorities at the waterbody scale are largely related to the planning and organizing of aquaculture development in a context of space and resources shared with other activities (Sanchez-Jerez *et al.,* 2016). More specifically, a significant planning challenge is the definition of appropriate locations within the waterbody for siting (zoning and site selection) and determining the adequate number of farms that would not lead to significant change in ecological processes and services (Aguilar-Manjarrez *et al.,* 2017), i.e. respecting the ecological carrying capacity of the host ecosystems (McKindsey *et al.,* 2006). Core issues at the global scale include reducing the pressure on wild stocks (Naylor *et al.,* 2000); reducing energy use, water use and carbon emissions (Reid *et al.,* 2019) and the development of circular and integrated aquatic food systems to recycle and reuse nutrients (Campanati *et al.,* 2021).

Table 2. Synthesis of relevant good practice in environmental and aquatic health at farm, waterbody and global scale. Principles adapted from FAO, 2010 (see ANNEX I).

Farm	Waterbody	Global
Optimize feed conversion rates (FCRs) to decrease nutrients and organic matter losses	Plan and organize aquaculture development in a context of shared space and resources (Spatial planning)	Reduce pressure on wild stocks in the aquaculture feed production process (improve feed composition)
Reduce nutrient emissions and impacts on ecosystems (best management practices, treatment, recovery**)**	Evaluate and minimize impact of escapees and wild population	Reduce energy use, water use and carbon emissions
Improve Environmental Impact Assessment and Monitoring Procedure (to respect Ecological carrying capacity)	Harmonization and simplification of Environmental Impact Assessment and Environmental Monitoring Procedure (to respect Ecological carrying capacity)	Anticipate and prevent Climate change's impact on aquaculture
Prevent Escapees	Mitigation plan for escapees	Develop circular and integrated food production
Control spread of diseases		
Reduce medicine, antifouling		

2.2. Spatial planning : Scoping, zoning and site selection

Conflicts with the use of marine space and the implementation of existing policies and legislation are two of the **main factors hindering aquaculture growth** (Galparsoro *et al.,* 2020). **Marine Spatial Management** must be improved to facilitate site selection processes, establish transparent procedures and licencing process and thus reduce the length of time needed for and cost incurred by developing new aquaculture activities. Marine Spatial Planning (MSP) is a management tool used to allocate space for upcoming activities such as aquaculture at sites with both favourable operational characteristics as well as **lower potential for conflict with other sectors** (Stelzenmüller *et al.,* 2017, Gimpel *et al.,* 2018). MSP aims to integrate **ecological, social and economic interests** as well as **interactions among human activities**, regardless of whether cross-border or inter-sectorial nature, whether there is conflict or synergy (see review in Gimpel *et al.,* 2018). 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, 2014). In Art. 51 of EU regulation no 508/2014 “the identification and mapping of the most suitable areas for developing aquaculture” is fostered (Gimpel *et al.,* 2018). Two recent projects aimed at improving spatial management at the regional scale are the SHoCMed project (for the Mediterranean and Black Seas) and the EU’s AquaSpace project.

The SHoCMed project (2012-2016) (Developing site selection and carrying capacity for Mediterranean aquaculture within aquaculture-appropriate areas) aimed to: i) produce site selection criteria in order to enhance the integration of aquaculture into coastal zone management through the use of allocated zones for aquaculture (AZA) and ii) provide a basis for the harmonization of standards, aquaculture policies and legal frameworks across the Mediterranean region to ensure equal terms of competition and minimal environmental impact (Sanchez-Jerez *et al.,* 2016). The AZA concept is defined as “a marine area where the development of aquaculture has priority over other uses, and therefore will be primarily dedicated to aquaculture. AZAs can be considered as a spatial planning system or zoning carried out at the local or national level, aimed at integrating aquaculture activities into coastal zone areas, where aquaculture should have priority over other activities and uses of marine space and resources, and where negative interferences with these activities and uses are minimized or avoided. It involves coordination among different authorities and is based on a participatory approach. Based on ShoCMed project, a guide for the establishment of coastal zones dedicated to aquaculture in the Mediterranean and Black Seas is now available (see Macias *et al.,* 2019). It includes recommendations for all phases including: Phase 1: Contextualization of the establishment process, Phase 2: Information and data collection, Phase 3: Pre-selection of the AZA, Phase 4: Consultations and validations of proposed areas, Phase 5: Analysis of aquaculture potentiality, Phase 6: Carrying capacity and monitoring plans, Phase 7: Integration of AZAs into the legal framework. The different steps are summarized in Figure 3. The Environmental Impact Assessment and Environmental Monitoring Procedure will be outlined in the next sections.

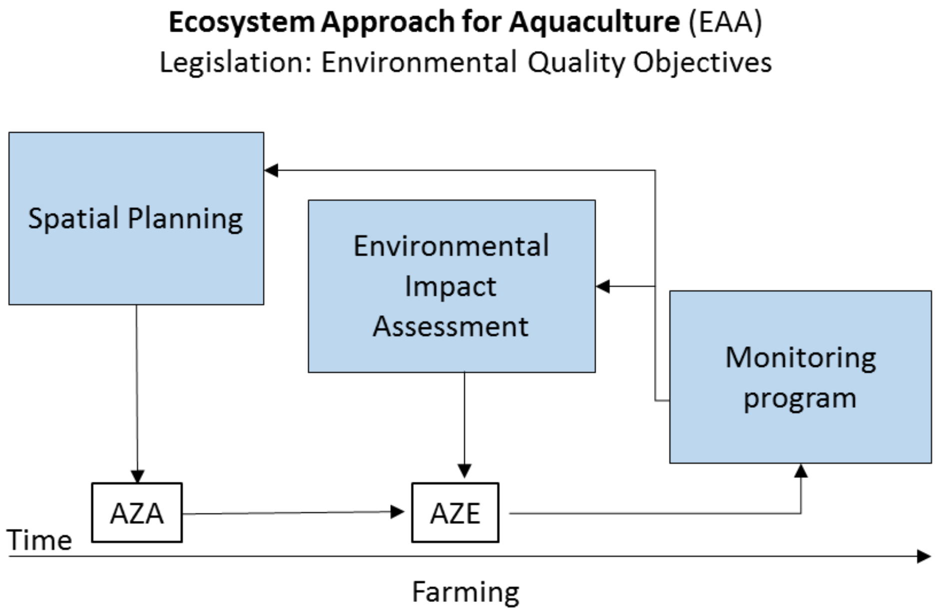

Fig 3.The different steps of an Ecosystem Approach to Aquaculture (adapted from Sanchez-Jerez & Karakassis, 2012 and Macias *et al.,* 2019). "National and/or regional legislation should define the Environmental Quality Objectives (EQO). A technical procedure of site selection must define the Allowed Zone for Aquaculture (AZA). For each AZA, an Environmental Impact Assessment will define the spatial magnitude of the Allowed Zone of Effect (AZE) for a determined level of production. When farming starts, monitoring programs should check that the Environmental Quality Standards (EQS) do not exceed maximal levels" (Sanchez-Jerez & Karakassis, 2012).

The AquaSpace project (Ecosystem Approach to making Space for Aquaculture, 2015–2018) aimed to (1) understand spatial and socio-economic constraints on the expansion of aquaculture, (2) test tools to help overcome these constraints. The project applied a case study approach. In 17 case studies, key planning issues for aquaculture development were identified and Marine Spatial tools were developed, fine-tuned and/or evaluated. The tools were reviewed in AquaSpace Deliverable 5.1, Galparsoro *et al.,* (2018) and are described in detail in a set of factsheets in the AquaSpace ToolBox ((http://www.aquaspace-h2020.eu/). The tools' application to case studies is presented in detail in AquaSpace Deliverable 4.2, Strand *et al.,* (2018). The main features of the tools and their potential exploitation beyond the project's lifetime were presented in Pastres *et al.,* (2018).

Among the tools developed/used during AquaSpace were:

- A decision support tool named AkvaVis, based on Geographic Information Systems (GIS) (Ervik *et al.,* 2008) used and adapted in 4 case studies (Hardangerfjord in Norway, Sanggou bay in China, Carlingford Lough in Northern Ireland and Normandy in France) (Gangnery *et al* 2021). The AkvaVis tool performs suitability analysis on proposed aquaculture areas through the use of a series of indicators and can create virtual farm objects to display and interact with models and environmental data. The tool provides a user friendly interface and can produce reports of the analysis undertaken for use by a variety of users with differing requirements with regards to aquaculture management, for example governing bodies, farmers and researchers.
- The AquaSpace Tool (Fig 4) was also developed during Aquaspace. This tool is an open source product and builds in the prospective use of open source datasets at a European scale. The

Tool outputs comprise detailed reports and graphics, allowing key stakeholders such as planners or licensing authorities to evaluate and communicate alternative planning scenarios and to take more informed decisions. This tool was tested in the German North Sea case study.

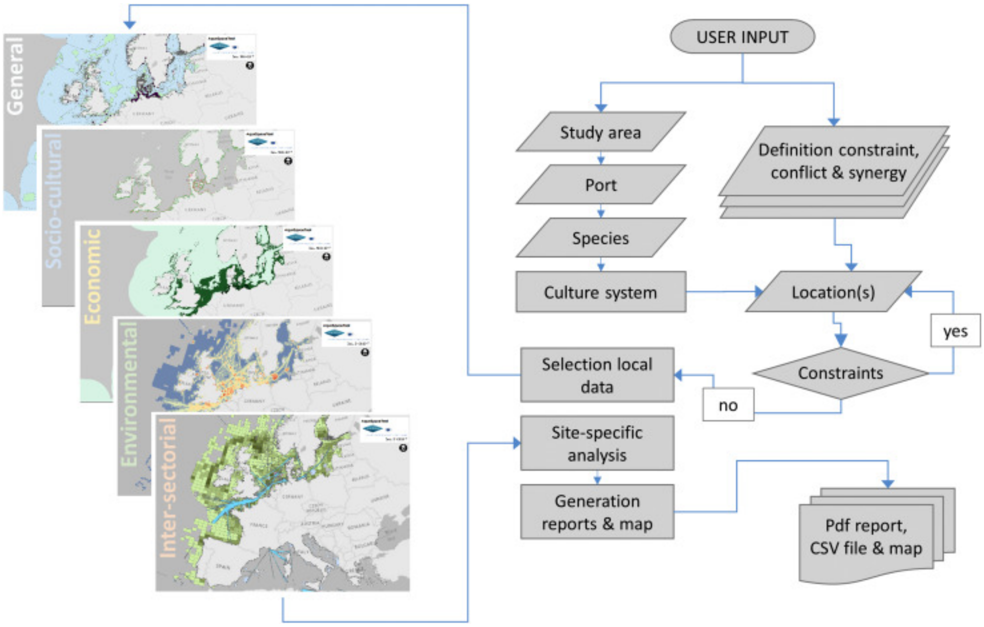

Fig. 4. Source: Gimpel *et al.,* 2018. " AquaSpace tool conceptual overview. The user input defines the study area (e.g. country), the port, the culture species, the culture system, the set of constraining, conflicting or synergistic human uses and the aquaculture locations to be tested. Alongside general input data (e.g. management area or culture system to be assessed), inter-sectorial, environmental, economic and socio-cultural data are processed".

The Mediterranean case study differs from the other AquaSpace case studies as it covers a multi-national economic zone, consisting of the Mediterranean and Black Seas respectively. The tool "BLUEFARM-2" was designed for identifying AZAs, i.e. areas to be allocated to aquaculture, in particular in coastal areas. Although BLUEFARM2 was tested only for shellfish farming, the methodology can be easily applied to fish farm site selection after a testing phase in a real world case study.

2.3. Environmental impact assessment (EIA)

EIA is a tool that was developed for the farm level and should be used for aquaculture projects that have the potential to cause significant impact on the environment or an ecosystem (FAO, 2010). "Small-scale farms or farms with low potential impact on the environment or ecosystem should be exempt, although the cumulative impacts of clusters of small farms should be assessed collectively by a programmatic EIA" (FAO, 2010). "**One of the main outputs of the EIA is an environmental management and monitoring plan that the farm or the cluster of farms should follow during and after operation and that would lead to corrective actions and decisions** (an extensive overall review, analysis and recommendations on EIA for aquaculture can be found in FAO/FIMA, 2009)".

The EU project TAPAS (Tools for Assessment and Planning of Aquaculture Sustainability) developed a Toolbox. The Environmental Impact Assessment is defined in this toolbox (https://www.aquaculturetoolbox.eu) as a process by which environmental and production information is gathered and assessed for the environmental impacts of a development (both positive and negative). Under EU regulations, national authorities decide if an aquaculture development(s) requires an EIA. This decision is reached through a “screening procedure” using thresholds of aquaculture activity and potential impacts to assess projects on an individual basis. The thresholds vary between countries and types of aquaculture (see Chapela and Ballesteros, 2011 for the Mediterranean region). No published papers about the regulation/licensing issue are available from TAPAS for the moment. Once it has been decided that an EIA is required, the developer may request the competent licensing and governance authority to identify the content of the EIA, the areas to be addressed and information required from the developer. This is known as scoping. The information identified by the scoping statement is then presented as a final report, known as an Environmental Statement (ES) which then goes out for consultation with statutory consultees and stakeholders (TAPAS, toolbox, see ANNEX II).

2.4 . Modelling tools to support EIA

Modelling plays an important role in determining acceptable limits of aquaculture (FAO 2010). “Without predictive models, we cannot assess whether the impacts are acceptable until they have occurred and been observed, which is almost always too late” (Silvert and Cromey, 2001). Effective licensing and regulation require industry and planners to have access to good guidance and support through provision of environmental modelling tools for site selection, assessment of carrying capacity, and prediction of the fate of nutrient and chemical waste to aid better decision-making (TAPAS 2018). **Aquaculture production facilities should adjust their production to the physical, ecological and social carrying capacity**. Each ecosystem has a different capacity to absorb and assimilate excess loading of organic compound nutrients (Assimilative capacity), this is particularly important in areas with low water exchange such as shallow, inshore and sheltered areas. A breakdown of different sustainable carrying capacities was described by McKindsey *et al.,* (2006). There are **different types of models**: ecological, GIS, etc which should be selected in accordance with the specified objectives and scales.

One objective of TAPAS was to create and test tools and models for regulation in different case studies, including Mediterranean case studies. First, a review of relevant models for European aquaculture systems with near-field models (defined as farm level to water-body scale) used for either regulatory or scientific purposes to assess nutrients/waste was done (Falconer *et al.,* 2016). Then, TAPAS focused on a selection of the models (due to limited access or because some models were no longer used by regulators and due to time/resource limitations) (Falconner, pers. Comm.). Table 3 presents the list of models used with a focus on Mediterranean case studies. Other CC models not listed in the table have been implemented or are currently being implemented at national level (e.g. in France with the MOCAA project, Callier *et al.,* 2020)

Table 3. Selected tools for EIA reviewed in TAPAS (adapted from Falconer *et al.,* 2016 and TAPAS toolbox)

Name of model	Origin/Country of development/First application/key reference	TAPAS summary	Application in the Mediterranean
FARM- SCALE			
DEPOMOD	DEPOMOD was developed by the Scottish Association for Marine Science (SAMS) (Cromey *et al.,* 2002ab). DEPOMOD (or the more locked down version autoDEPOMOD) has been the regulatory model for Scottish salmon aquaculture. In recent years it has been revised and redeveloped as NewDEPOMOD, although NewDEPOMOD was not used in TAPAS.	In TAPAS, the University of Stirling used DEPOMOD to simulate waste dispersion at Scottish and Norwegian salmon sites (Falconer *et al.,* 2019a, c). DEPOMOD relies on older software and newer operating systems cannot run this. However, DEPOMOD is being phased out and NewDEPOMOD is now the regulatory model. In Scotland there is also a move towards modelling approaches that use hydrodynamic models to consider far-field (>1km) effects.	DEPOMOD has been adapted for the Mediterranean (Cromey *et al.,* 2012). It is likely that NewDEPOMOD could also be used or adapted for use in the Mediterranean.
MERAMOD	MERAMOD was developed by the Scottish Association for Marine Science (SAMS) (Cromey *et al.,* 2012). It is an adaptation of the original DEPOMOD model that can be used for the Mediterranean. The main difference is the addition of a module that considers waste eaten by wild fish populations.	In TAPAS, the University of Murcia used MERAMOD together with the RAC package from R. RAC, which provided data on waste generated through the production cycle, and then MERAMOD was used to simulate waste dispersion .The MERAMOD software is sold under license but is not easily available to the public. It is necessary to use old versions of Windows because algorithms run better on XP.	Designed for the Mediterranean (Cromey *et al.,* 2012).

Name of model	Origin/Country of development/First application/key reference	TAPAS summary	Application in the Mediterranean
RAC (R package for AquaCulture)	RAC was developed by Baldan *et al.,* (2018) and is available from the CRAN repository RAC was designed for aquaculture in the Mediterranean and can simulate the production cycle of European seabass, Gilthead seabream, Manila clam, and Mediterranean mussel, at the individual and population level.	In TAPAS, the University of Murcia used RAC to simulate the growth of European seabass and gilthead seabream in a case study site in the South of Spain (Falconer *et al.,* 2019c). The model simulated fish growth and waste. This was then used in the MERAMOD model to simulate waste dispersion.	Designed for the Mediterranean (Baldan *et al.,* 2018)
CAPOT	The Cage Aquaculture Particulate Output & Transport (CAPOT) model is a spreadsheet model developed at the University of Stirling for salmon in Scotland (Telfer, 2006).	In TAPAS, the University of Stirling used CAPOT to simulate waste dispersion at farm sites in Norway, Ireland and Malta (Falconer *et al.,* 2019a,2019c). CAPOT is a simple model designed to be used for use as a scoping tool to determine if it is worth expending more resources to investigate the site further with more complex models. It is designed to be used by non-experts. It is not intended to be used for regulatory decision making. It is not species-specific and is easily adaptable.	In TAPAS, CAPOT was used to simulate waste dispersion at a farm in Malta that produced gilthead sea bream and greater amberjack (Falconer *et al.,* 2019a). In TAPAS, this site was also used for an IMTA trial and CAPOT was used to identify suitable places to locate sea cucumber containers to ensure exposure to waste.
BROM/2DBP	Bottom RedOx Biogeochemical model (Yakushev *et al.,* 2017) coupled with 2-dimensional Benthic-Pelagic transport model (BROM/2DBP)	In TAPAS, NIVA used BROM/2DBP for the case study in Hardangerfjord, Norway (see Yakushev *et al.,* (2020)). The model was used to quantify the effects of fish farm emissions on water column and sediment biogeochemistry. Oxygen depletion is an issue in some deep Norwegian fjords which is why models that consider vertical and horizontal distribution of waste are important.	n/a

Name of model	Origin/Country of development/First application/key reference	TAPAS summary	Application in the Mediterranean
DEB	Dynamic Energy Budget (DEB) theory (Kooijman, 2010) is a mechanistic approach to describing organism growth and reproduction. It is popular for modelling bivalve growth.	DEB models were used in several case studies in TAPAS. In France, UN was used alongside the DEB to earth observation data to evaluate potential production of Pacific oysters (C. gigas) (Palmer *et al.,* 2020) and was also used together with other socio-economic and administrative factors in a spatial multi-criteria evaluation (MCE) to evaluate potential opportunities to move production offshore (Barille *et al.,* 2020).	DEB models have been used in other studies for Mediterranean sites.
WATERBODY SCALE			
AIM	The Aquaculture Integrated Model (AIM, Tsagaraki *et al.,* 2011), developed at Hellenic Centre for Marine Research (HCMR), is based on a complex generic biogeochemical model, coupled with a 3-D hydrodynamic model and has been applied to study the effect from aquaculture waste in different areas of the Mediterranean Sea (Tsagaraki *et al.,* 2011; Petihakis *et al.,* 2012).	In TAPAS, HCMR used AIM to simulate aquaculture production in an Aquaculture Allocated Zones (AAZ) (Falconer *et al.,* 2019c). AIM was used to investigate different scenarios of production and assess potential impact in terms of good environmental status.	

Name of model	Origin/Country of development/First application/key reference	TAPAS summary	Application in the Mediterranean
Hydrodynamic and biogeochemical models	Hydrodynamic models can simulate physical processes in open ocean and coastal environments. Biogeochemical models simulate the nutrients in the ecosystem. Models can be developed for specific areas at varying levels of resolution depending on the intended application. The models can be used with some farm level models (e.g. in TAPAS PML used FVCOM and ERSEM with ShellSim to simulate shellfish farm production potential and effects on the wider environment. ROMS, FVCOM, and MIKE software have been used to develop hydrodynamic models for aquaculture purposes. ERSEM is a biogeochemical model that has been used for aquaculture applications.	In TAPAS, models were used to prepare spatial layers of important aquaculture parameters for different ecoregions (e.g. Mediterranean Sea, North Atlantic and Nordic Seas, Baltic Sea, Northeast Atlantic) (Ciavatta *et al.,* 2019). A GIS portal with some model outputs can be found here: https://tapas.eofrom.space/ Examples of applications in TAPAS case studies include: PML used the FVCOM to develop a hydrodynamic model for Hardangerfjord and then simulated the dispersion of organic matter from fish farms in an area of the fjord (Falconer *et al.,* 2019c). PML also used FVCOM and ERSEM with ShellSim to simulate shellfish farm production potential and effects on the wider environment (Falconer *et al.,* 2019a). DHI used MIKE software as part of a meta-modelling approach for use as a screening tool which ranked potential aquaculture sites based on environmental impact (Møhlenberg *et al.,* 2018). Hydrodynamic and biogeochemical modelling can be complex and require considerable time and resources to implement. However, such models are useful for understanding impacts beyond the farm scale and cumulative effects.	

2.5. Licencing procedure

In TAPAS, a decision support system hosting tools and guidance for regulation has been developed to improve the efficiency and transparency of aquaculture licensing in Europe (www.aquaculturetoolbox.eu). The advantages and disadvantages of existing licensing practices were used as a starting point to develop a strategy for improved and flexible governance with regard to European aquaculture. Eleven key recommendations were made by the project to streamline licensing in line with identified “bottlenecks” and, through consultation, included in a policy document to contribute to the new Strategic Guidelines for the Sustainable Development of EU Aquaculture. The web-based Aquaculture Toolbox (Figure 4) provides a broad overview of the main steps and approaches that can be used to provide information to support license applications and decisions. The Toolbox can be used to obtain information on the different stages in the licensing process for marine and freshwater aquaculture by both inexperienced and experienced operators and provide tools or guidance as needed (TAPAS website). The toolbox is designed to be high-level and can be used as an example for countries developing or revising their own licensing approaches.

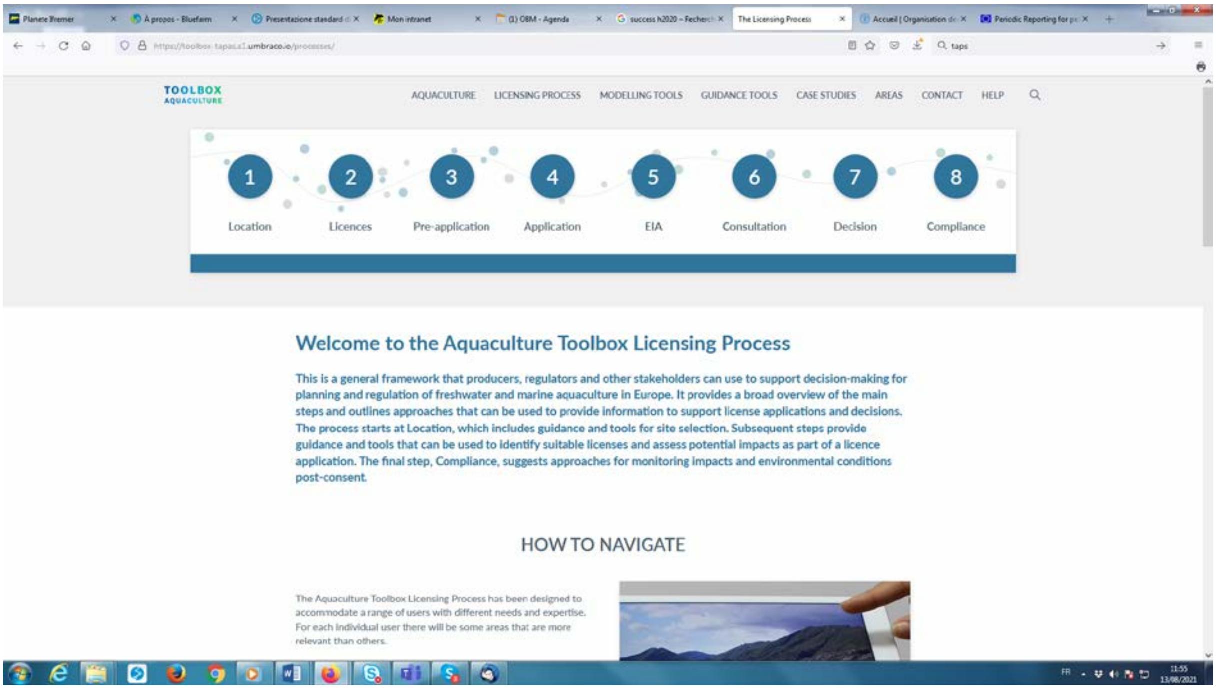

Fig 4. Licensing process presented in TAPAS toolbox (TAPAS).

2.6. Monitoring

The description of the recommended monitoring programme is often an output of the Environmental Impact Assessment (EIA) initially carried out at the outset of a fish farming project (FAO, 2010). **The monitoring programme includes sampling to quantify the effect of aquaculture activities on the ecosystem over time**, by comparing current data collected at various locations during operation with data obtained in the EIA, the baseline environmental survey or before development (see recommendations in FAO, 2009). The monitoring protocol proposes types of indicators that should be used to monitor the impact of the farm during operation and the **acceptable levels of impact**. It is essential to monitor **the aquaculture zone, watershed or waterbody.** Often this is more important than monitoring individual farms, especially when these are individually small, although their cumulative impact can be large. Typically, monitoring should include: (i) impacts on water and sediment quality, including physico-chemical and biological indicators; (ii) eutrophication condition and impacts on sensitive habitats such as mangroves, seagrass beds, etc.; and (iii) other impacts on fauna and flora. Monitoring should always take place at the potentially impacted site, as well as at a reference site in order to account for impacts of other factors beyond aquaculture.

2.6.1 Environmental monitoring procedures (EMP) in the Mediterranean

EIA procedures in the Mediterranean were described in Chapela and Ballesteros (2011). In some countries, such as in Spain, aquaculture policymaking is devolved to regional level. There is not one single EMP. Lack of EMP harmonization has been pointed out as a constraint in many EU countries.

In Macias *et al.,* 2019, a guide for EMP in Mediterranean and Black Seas is provided, and it includes some recommendations summarized below: Environmental monitoring should take place outside and inside the allowable zone of effect (AZE) (Figure 5). The AZE can be delineated when estimating the environmental carrying capacity and the nutrient flux emanating from the cages. However, when information is not sufficient or available to perform such an estimate, the concession area or leased area can be used as an AZE for the purpose of environmental monitoring. Implementing AZEs, including reaching a consensus on its definition, is essential in order to identify the source and level of impact of aquaculture on the environment and/or vice versa (Macias *et al.,* 2019). The EMP requires the collection of a range of information on the particular area, and of data considered as most appropriate to describe the environmental conditions of the water and sediment (frequency of sampling, physical and chemical variables, number of locations and sampling stations relative to the locations of the fish cages).

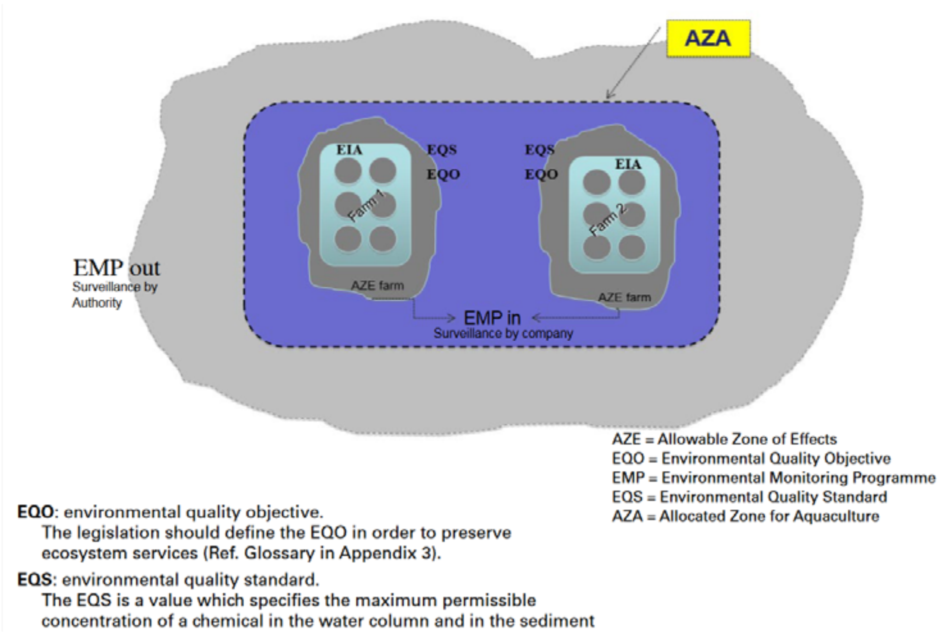

Fig 5. The Allowable Zone of Effect within the Allocated Zone for Aquaculture (AZA, see spatial planning section).

The Monitoring logbook (named Logbook2 in Macias *et al.,* 2019) should contain information that will be recorded during monitoring activities. This information should be collected according to a typology classification that is based on the production category and the mean sea current speed. It is suggested that monitoring be performed twice a year, during the two contrasting seasons or once a year, when there is maximum biomass in the cages. The distance between the stations and the cages will depend on the characteristics of each site. The EMP should be accompanied by a sampling plan and design (see examples in Macias *et al.,* 2019 and Aguado Giménez *et al.,* 2012). It should be noted that numerous studies in EU and the Mediterranean on the impacts of fish farming have evaluated the extent of influence on benthic communities <25m from the fish cages (Mazzola *et al.,* 2000, Nickell *et al.,* 2003, Kutti *et al.,* 2007b, Callier *et al.,* 2013).

2.6.2 State-of-the-art monitoring approaches

IN TAPAS, more efficient, in-situ and real-time monitoring technologies (Ntoumas *et al.,* 2019), earth observation methodologies, and vehicles for automated inspection (Palmer *et al.,* 2019), have been developed to assist in monitoring aquaculture facilities. Far field models improve on existing approaches for Earth Observation (EO) data use and provide indicators for operational practice. Regional physical-biogeochemical models, EO techniques and long term in-situ time series measurements were employed to develop novel EO-Model products for pan-European assessment of marine aquaculture capacity.

In situ or real-time operational tools for cost-efficient environmental monitoring of aquaculture production were created and evaluated, including novel bio- and optical sensors for water quality, and fish cage monitoring systems including a small-sized autonomous underwater vehicle architecture for regular periodic fish-cage net inspection (Chalkiadakis *et al.,* 2017). Methods for quality control of the large data streams produced by automated real time measurement stations were established as early detection systems. Algorithm sets for Sentinel-3 OLCI relevant to a range of aquaculture environments were developed (Laanen *et al.,* 2019). Methods were also developed for monitoring water quality impacts using Copernicus Sentinel-2 MSI data.

See also 3.2.1 Precision Fish Farming section.

2.7. Indicators

The EU-funded project "**Indicators for Sustainable Development of Aquaculture and Guidelines for their Use in the Mediterranean (InDAM)**" was initiated by the Working Group on Sustainability in Aquaculture (WGSA) of the GFCM-CAQ. InDAM addressed sustainability issues for finfish marine aquaculture in the GFCM region and, through a multi-stakeholder, participatory and multi-disciplinary methodology, aims at providing countries with a comprehensive decision support tool for the sustainable development of aquaculture with regards to economic, social and environmental dimensions as well as governance. InDAM presents the **use of indicators** in aquaculture within a sustainability analysis framework and describes the participatory process to identify, select and use indicators as well as the methodology applied for assessing and displaying the values of the indicators. The InDAM Project took advantage of the outputs of several other projects and initiatives dealing with European/Mediterranean aquaculture sustainability, with the identification of indicators at different levels (EVAD , Evaluation of sustainability of aquaculture systems; the IUCN initiative in the preparation of guidelines for sustainable aquaculture in the Mediterranean Region; SEACASE, Sustainable extensive and semi-extensive coastal aquaculture in Southern Europe; ECASA, An ecosystem approach for sustainable aquaculture; CONSENSUS, Defining indicators for sustainable aquaculture development in Europe). The different scales of Indicators, level of applicability and target users are presented in Table 4. Table 5 and 6 present the indicators at regional level and farm level respectively (Fezzardi *et al.,* 2013).

Table 4. Different scales of Indicators, level of applicability and target users (Fezzardi *et al.,* 2013)

Scale	Level of applicability	Target users
Regional	➢ E.g. for the whole Mediterranean and Black Sea area	Regional fishery management organisations/international organisation
National	➢ Entire country Describe the state and trends of aquaculture sustainability in a given nation giving a holistic picture of the aquaculture sector and its environment.	National governments
Local	➢ Homogenous cluster of farms or group of aquaculture operations (e.g. in close proximity to each other) These indicators are more linked to the local communities and could be changed according to the requirements and conditions for the sustainable development of aquaculture in a specific area. This set of indicators could also be considered as a communication tool between farmers and local communities.	National governments/local authorities/Aquaculture farmer organizations/farmers
Farm	➢ Single aquaculture operations and their close surroundings Farms can operate in isolation from other farms or be part of a homogenous cluster of farms (i.e. polygon). Some indicators are only applicable at farm level and can provide an operational as well as strictly managerial tool.	National governments/local authorities/aquaculture farmer organizations/farmers

The regional indicators should be adopted at regional level and considered as a tool at the disposal of GFCM countries for planning and monitoring the development of sustainable aquaculture at Mediterranean and Black Sea level, and should be regularly monitored within a regionally harmonized strategy and framework.

Table 5. Indicators at regional level for Mediterranean and Black Sea aquaculture (Fezzardi *et al.,* 2013).

Principle	Criteria	Indicator	Reference value
Minimize the global impact of aquaculture	Needs of natural resources for food production (pelagic fish and plants)	FCR feed conversion ratio (kg food/kg fish)*	Seabass (350- 400 gr): > 2.2/2.2- 1.8/<1.8 Seabream (300- 350 gr): >2.1/2.1-1.6/<1.6
Maintain the ecological services of ecosystems	Reduction of benthic environmental impact	Existence of criteria for the depth (m) of cage applied to site selection. Related to density. Ratio of depth and density (depth (m)/ density (kg/m^3)	< 1.5 / 1.5 –2 / >2**
Minimize the local impact on environmental conditions and biodiversity	Use of chemical Products	Existence of a national monitoring programme to monitor antibiotics and other chemical residues	Yes/No
	Impact on benthic habitats and communities	Implementation of a monitoring system for the evaluation of the level of impact on benthos	Yes/No
	Biological impact on communities	Reporting of escapees (number of escape events)	Number of escape events

Note: * = The FCR Ref. Values vary according to the farmed species
** = Higher fish density results in increased organic matter sedimentation, and higher depth would increase dispersion

Table 6. Selected key EQS variables for EMP in Mediterranean countries (Fezzardi *et al.,* 2013).

Monitoring EQS
Total Organic Matter in Sediments (%)
Total Nitrogen in Sediments (%)
Redox Potential Eh (mV)
Percentage of Capitellid polychaetes over macrofaunal biomass (%);
Gas bubbles
Dissolved Oxygen (mg/l)
Turbidity (m)
Percentage of silt/clay in sediments (%)
Litter in surrounding area.

More recently, during the EU project PerformFISH (http://performfish.eu/), an iterative and participatory process was implemented in collaboration with Fish Producers Associations and R&D partners to select KPIs. Twenty-seven Environmental KPIs were presented based on general principles of the FAO Code of Conduct for Responsible Fisheries (CCRF, 1995) FAO and Principle-Criteria-Indicators approach (Evad, Rey-Valette *et al.,* 2008) & Indam project (Fezzardi *et al*, 2013) see above. The objective of the Environmental KPIs are to assess the impact of farming practices on the preservation of biodiversity and habitats, the use of natural resources, water, space and energy use, and its ecological footprint. Three phases were considered (hatcheries, pre-ongrowing, and ongrowing). On the 27 KPIs presented, 14 were selected by the stakeholders and validated by the PerformFISH consortium in 2018, see Table 7 (PerFormFISH D7.1, 2018).

Table 7. PerformFISH Env KPI's (modified from PerFormFISH D7.1, 2018)

Preservation of biodiversity and habitats KPIs
Oxygen depletion persistence days
Escapes – Number of episodes
Escapes – Estimated number of escaped fish (confidential ISAB)
Endangered marine mammals, reptiles, fishes and birds - lethal incidents (confidential ISAB)
Phosphorous accumulated in sediment
Nitrogen accumulated in sediment

Use of resources
Marine space use for farming
Land use
Freshwater use
Energy used
Fuel (Diesel) used for transport
Fuel (Diesel) used for other uses
Total emission of CO2
Use of renewable energy

It should be noted that other environmental variables such as total free sulphides or polychaeta assemblages have been selected from other projects at national level (see for example Aguado-Gimenez *et al.,* 2012 for Spain).

3. Impacts related to feed and escapees: strategies for Mediterranean fish farming aquaculture

One of the main causes of the environmental impact of cage fish farming is the use of feed. At local (farm) level, the release of faeces and uneaten feed may induce organic enrichment, decrease water quality (Figure 6) and induce modification of benthic and pelagic ecosystems (Hargarve 2005). At global scale, as feed relies on fish oil and fish meal, aquaculture has an impact on fish stocks as carnivorous fish rely on fish oil and other fish. The main strategies and recommendations are described in this report, and included : 1) zoning and site selection (see part I), 2) improving feed use through improvement of FCR, feed composition or best management practices, and 3) developing innovative farming systems such as RAS and IMTA to improve the treatment and recovery of waste.

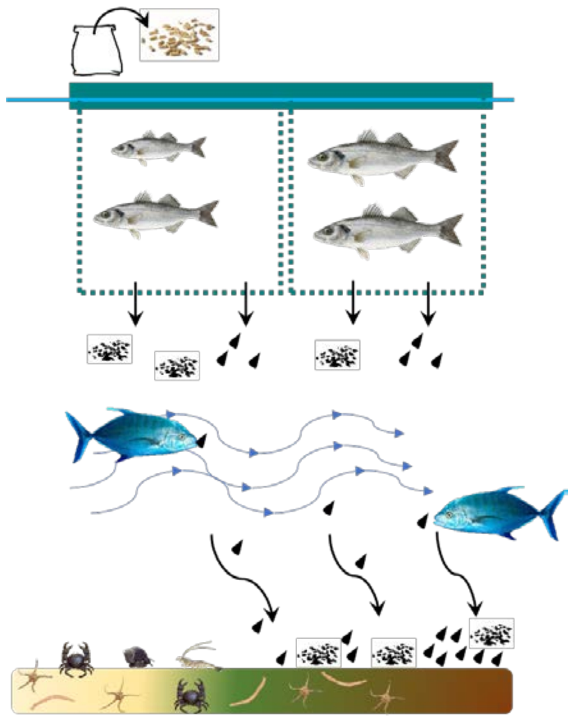

Fig. 6. The main environmental effect of fish farming in the Med MFF (modified from Callier *et al.,* 2020)

3.1. Feed: global impacts

When evaluating the environmental impacts of finfish production systems, both regional impacts (e.g. eutrophication) and global impacts (e.g. climate change) should be taken into account. The life cycle assessment (LCA) method is well suited for this purpose (Aubin *et al.,* 2009). In MedAID, LCA analysis was performed in WP1 (Ref: Cidad *et al.,* Del. 1.2). Overall, 19 farms have been inventoried as presenting a high diversity of farming systems (and consequently FCR, water use etc.). This explains the high variability in the results. The ratios of feed consumption per kg of fish for the farm studied in MedAID varied between 1 and 3.5 kg of feed/kg of fish. The main conclusion of the LCA analysis of seabass and seabream production was that feed production was the main cause of environmental impact. A high correlation between environmental impact categories of **climate change** (kg CO_2 eq./kg fish) and **marine eutrophication impact** (Kg N eq.) and **feed consumption** (kg feed/kg fish) was found. Juvenile production and diesel consumption for boat labour were the next most significant aspects in terms of the environmental impact of MFF. According to Cidad *et al.,* 2018, future action in terms of environmental improvements should be focused on reducing the requirements for feed or finding new sustainable sources of ingredients as well as implementing sustainable mobility strategies. Due to high diversity in farming systems, further analysis (comparing impacts of similar systems, simar technology and species) are still needed to fully interpret the environmental results. Moreover, as mentioned in (D8.2), one of the major criticisms is the absence of specific impact categories and methodologies for the marine environment. In this sense it would be necessary to regionalize the category of marine eutrophication impact. The Mediterranean sea has its own characteristics which mean that the emission of nitrogen or phosphorus does not have the same consequences as if it were emitted in another marine environment.

That being said, the conclusions of Cidad *et al.,* 2018 (MEDAID) are consistent with previous LCA analysis of Mediterranean fish farming (Aubin *et al.,* 2009, Wilfart *et al.,* 2013, Abdou *et al.,* 2017, Abdou *et al.,* 2018, Konstantinidis *et al.,* 2020, Konstantinidis *et al.,* 2021). We give some examples below. Aubin *et al.,* 2009, determined, based on LCA analysis, that the specific environmental objectives of seabass cage systems were: the limitation of nutrient loading by reducing feed spill through better feeding management, reduction of nutrient and solid loading of cage systems through management or technical solutions (e.g., stock assessment, feed intake control) to preserve the oligotrophic ecosystem and economic grounds. Wilfart *et al.,* 2013 compared environmental impact through LCA of a farm producing salmon in a recirculating system (RAS) in a semi-extensive and an extensive polyculture pond. They showed that the RAS had a low feed-conversion ratio (FCR = 0.95), and lower environmental impacts per tonne of live fish produced than did the two pond farms, however the RAS was clearly disconnected from the surrounding environment and depended highly on external resources (e.g. nutrients, energy). This study highlighted key factors necessary for the successful ecological intensification of fish farming, i.e., minimization of external inputs, lowering the FCR, and increasing the use of renewable resources from the surrounding environment. Assessing the environmental impacts of sea bass cage farms in Greece and Albania, Konstantinidis *et al.,* (2020) demonstrated that **feed**, and **accordingly feed conversion ratio**, followed by fry were the two predominant factors mostly affecting the eighteen ecological impact categories assessed. Feed impact is related to resource use, but also to impacts during processing, transportation and to its distribution throughout the farmed stocks. Fry production resulted in a major contribution to the 'water consumption' impact category, which is related to the hatchery operation. In their study, Konstantinidis *et al.,* (2021) identify environmental hotspots in fish feeds of various granulations in seabass and meagre farming, by using Life Cycle Assessment (LCA). They suggested that improvements in cultivation methods of raw materials, optimized reductions in the inclusion of marine-origin raw materials and improved feeding management could contribute to the overall ecological sustainability of the sector.

Feed is one the main causes of environmental impacts on a global and local scale, as well the main production cost in finfish aquaculture. Different Strategic decisions exist based on economic, quality, environmental and social criteria. Luna *et al.* (2019) proposed a model that allows managers to include their own considerations in the task of exploring the whole range of possible feeds to find the most suitable one (Figure 7). The methodology developed by Luna *et al.* (2019) has been tested by a gilthead seabream farm, which faces the task of selecting the optimal feeding strategy.

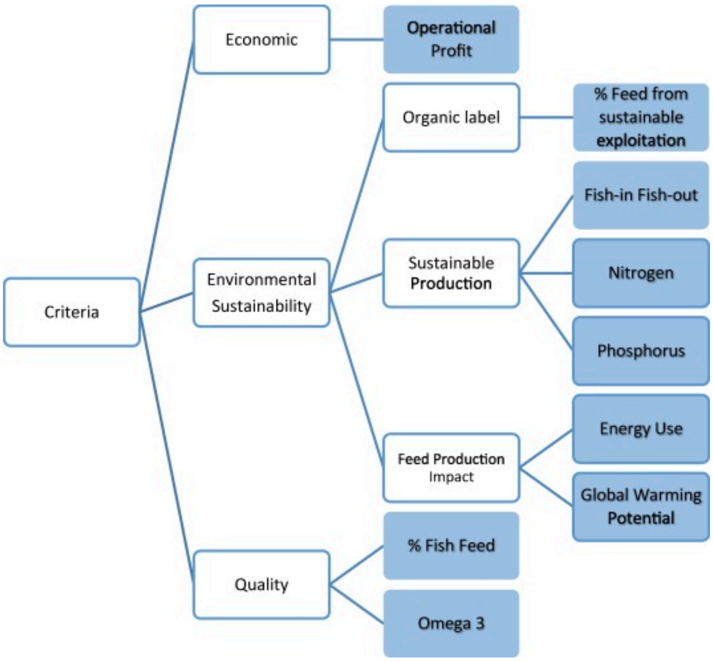

Fig 7. Criteria hierarchy tree structure: highlighted boxes correspond to finally included criteria (Luna *et al.,* 2019)

3.1.1 Feed conversion improvement

Numerous factors influence the used of feed and subsequent environmental impact and could be improved. MedAID studied the effect of feed composition and temperature on fat deposition, early larval rearing conditions to improve juvenile quality and fish welfare, the optimal water current-inducing swimming behaviour during the inland ongrowing cycle and the effects on activity and production in sea cages. The project also looked at the effects of fish density and daily feeding frequency on various KPIs, and the feeding strategies needed during unfavourable farming conditions, including the development of functional feeds. The results are available in WP2 and MedAID D8.2.

3.1.2 Feed loss

Feed loss is quite variable between farms and is difficult to estimate. The proportion of uneaten feed/feed loss could vary from 3% (e.g. set for seabream farm by (Ferreira *et al.,* 2012) to 38% for seabass; 33-50% for seabream (when estimated by models, see Brigolin *et al.*, 2010,2014)). For cage fish farming, the feed wastage rate is difficult to evaluate experimentally as it depends on feeding strategies, environmental conditions (e.g. hydrodynamics) or fish behaviour (see review by Chary *et al*, in prep) and could vary in space and time in the same farm and between farms. For instance, Ballester-Moltó *et al.* (2017) measured *in situ* feed loss ranging from 9 to 52% over different trials on the same farm. There is high uncertainty around feed loss estimations, which may have potential consequences on environmental impact assessments. A feed wastage of 3% could represent 12% of the total particulate waste of a salmon farm (Reid *et al.,* 2009). When feed wastage is above 15-20%, total particulate waste is composed mostly of wasted feed (Ballester-Moltó *et al.,* 2017). Better recovery and management of feed wastage is required. The use of farm scale models that consider individual behaviour (e.g. searching for food) and collective behaviour (e.g. competition for resources) could potentially help to better understand how feed wastage occurs and to reduce uncertainty surrounding this parameter and better estimate the environmental impact of fed fish farming (see Chary *et al*, in prep). Better management practice and precision fish farming should be promoted.

3.1.3 Improvement of feed composition

Local and quality feed is a major issue for aquaculture farms. Research on the sustainability of raw materials based on alternative resources (including algae, insects, etc.) still require substantial experimental work. The territorial ecosystem approach to agri-food chains and the circular economy needs to be strengthened. The IUCN guide promotes a "glocal" approach: a global reflection for local and sustainable responses (see review by Le Gouvello and Simard, 2017).

3.2. Technological solution and new production systems

3.2.1 Precision fish farming PFF

The PFF system is made up of a real-time observation component, a dynamic model, and a "control" component, providing support to the farmer in making optimal husbandry decisions (see review by Chary *et al.,* submitted): "Observation components can include: different real-time sensor networks (detection of temporal and spatial variability of dissolved oxygen throughout cage farms (see e.g., Burke *et al.* (2021), telemetry measurements of heart rate and swimming activity (Svendsen *et al.,* 2021). Fish behaviour monitoring and analysis (An *et al.,* 2021). Camera systems for automated monitoring (Føre *et al.* (2018). Hydroacoustic systems, single and multi-beam active systems to provide information about fish speed, direction, 3D movements, while passive systems can be adopted to monitor behaviour of some target species." Within TAPAS, improved environmental modelling tools, enhanced Earth Observation scenarios and methods, and development of in situ and real-time monitoring have been implemented. Such outcomes can be further applied as part of a "precision farming" approach to aquaculture regulation and management.

3.2.2 RAS

Access to sufficient quality water is often a limiting factor to the development of aquaculture. Recirculating aquaculture systems are designed to control all environmental aspects of production by continually filtering, treating, and reusing water, and thereby increasing operational efficiency and reducing risks from pathogens and climate change (Naylor *et al.,* 2021). In the Mediterranean, as in other region, RAS are usually used in hatcheries. Recently, RAS is being developed for high market value species and/or large production models that are large enough to generate profits (Naylor *et al.,* 2021). Indeed, RAS enable higher stocking densities but require high energy requirements, have high production costs and waste disposal challenges, and bring a risk of catastrophic disease failures (Badiola *et al.,* 2012). RAS could provide flexible, secure and controlled solutions in the future. Indeed, the installation of production units only close to shores has the double advantage of avoiding possible conflicts of use with other activities (fishing, tourism, energy production, etc.) while getting closer to consumers. However, difficulties in obtaining authorizations due to their significant water needs and the significance of waste treatment and assessment is still debated. The competitiveness of recirculating aquaculture systems for full roll-out relative to other production systems remains uncertain, however, and there have been several failures in North America and Europe and few large-scale, commercial successes over many years (Naylor *et al.,* 2021). In the Mediterranean, research has been carried out in France. Recently, RAS-IMTA have been tested as a promising approach and solution for the assessment of RAS waste (Li *et al.,* 2019).

3.2.3 IMTA

Integrated multi-trophic aquaculture (IMTA) can be considered a mitigation approach against the excess nutrients/organic matter generated by intensive aquaculture activities. In this context, integrated multitrophic aquaculture refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system (Chopin and Robinson, 2004). IMTA can be used to improve the environmental sustainability of fish farming industry, increase profitability and be a source of employment in coastal regions. IMTA has been practiced for centuries in Asia, but is not established in Europe and in the Mediterranean region. IMTA systems in open water or inland have been tested in several Mediterranean countries. In the present report, we will not review studies on IMTA as it is outside the scope of this deliverable, but recent projects on IMTA with application in the Mediterranean are listed below:

IDREEM (2012-2016) (Increasing industrial resource efficiency in European mariculture) (http://www.idreem.eu/) "was a EU framework 7 project launched in 2012 with 15 partners which ended in September 2016. The IDREEM project has "supported fish farmers across Europe, in developing different systems to introduce Integrated Multi-trophic Aquaculture in their existing farming facilities.". Three pilot sites in the Med were studied:

- Italy – Lavagna (Monoculture: Seabream, Sea bass, IMTA: Oysters) (Partners: AQUA, University of Genova): Read more: http://www.idreem.eu/cms/2015/07/01/oysters-in-oligotrophic-waters-integrated-multi-trophic-aquaculture
- Cyprus - Vasiliko/Zygi, Monoculture: Seabream, Sea bass, sea urchins, crabs and oysters; IMTA: mussels, abalones, sponges; (Partners: Seawave, Mer Lab)
- Israel – Ashdod; Monoculture: Seabream, Sea bass; IMTA: Ulva spp., mullets (Partners: Suf-Fish, Univ. Haifa)

IMTA-Effect (2016-2019) (Integrated Multi Trophic Aquaculture for Efficiency and Environmental Conservation), was funded by EU ERANET COFASP (www.cofasp.eu). "It associated 9 partners from public research and private companies, in 6 countries. The project aimed to develop IMTA strategies for fish farmers to develop new production systems that were efficient, economically attractive, robust, and environmentally friendly. For this purpose, the project aimed to provide scientific references on the nutrient and energy efficiency gains generated by bringing together different aquatic species of different levels in the food web". Mediterranean IMTA systems were implemented in two water types:

- seawater pond (fish + filter-feeders+ deposit feeder or macroalgae) studied by IPMA in Portugal and by HCMR in Greece,
- and RAS (compartmented fish and macroalgae IMTA) in Greece by AUA , and in France, by Ifremer (marine fish, phytoplankton, oyster, and ragworm) (Li *et al.,* 2019).

The SIMTAP project (2019-present) (https://www.simtap.eu/) "aims at developing self-sufficient IMTA systems in several Mediterranean countries (France, Italy, Malta, and Turkey) to improve nutrient recycling. The project will also assess their sustainability performance. Assessment of food-system sustainability needs to consider multiple criteria and multi-disciplinarity. In this context, environmental, social and economic impacts should be evaluated together. Assessing sustainability also depends on the context and the issues that impact those involved. Therefore, multiple stakeholders from the regions concerned need to participate, as shown previously in the aquaculture sector."

Project funded by JACUMAR In Spain. This project was launched in 2007. The overall objective was "to evaluate the application of integrated multi-trophic farming systems in aquaculture in Spain. "The goals were to improve the environmental management of farms and to promote the economic bolstering of companies by diversifying their production. Six regions with diverse conditions for farming were considered. A report is available for the Galician region (Guerrero and Cremades, 2012).

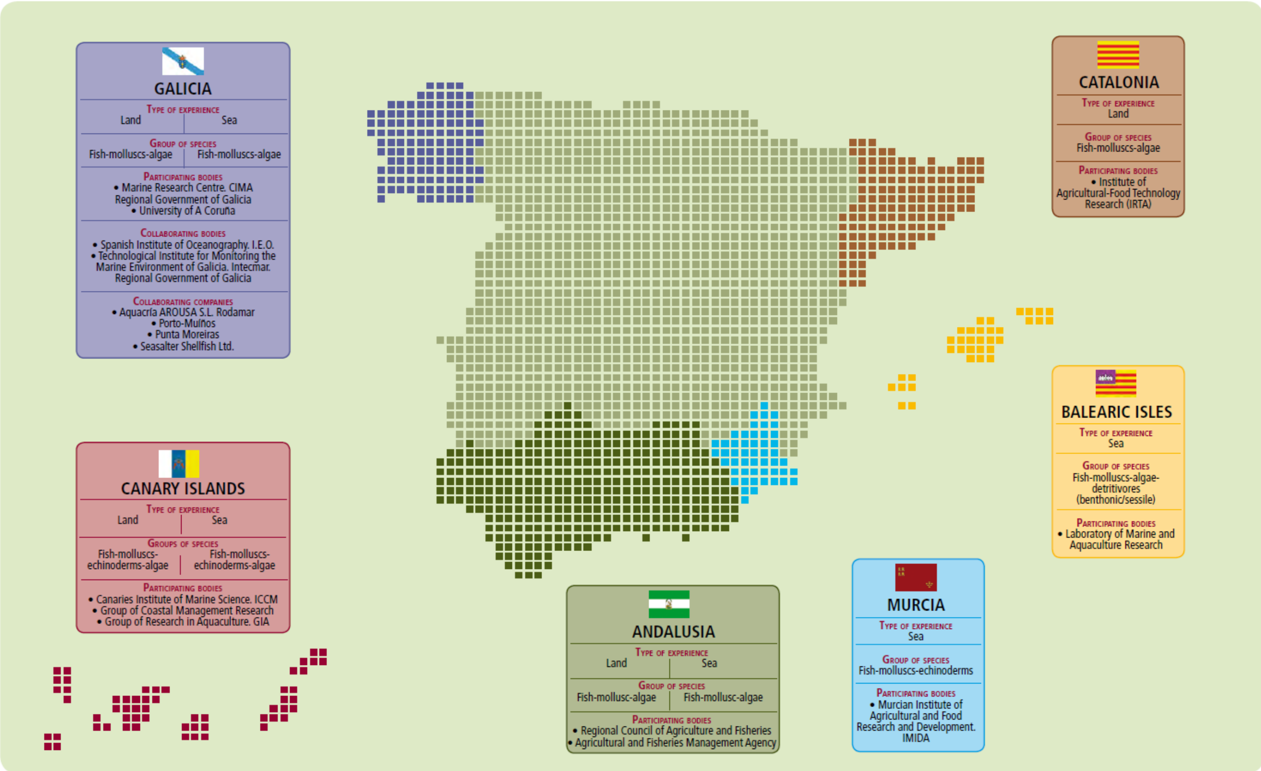

Fig 8. IMTA systems implemented in 6 different regions in Spain (JACUMAR funded projects, Guerrero and Cremades, 2012)

In France, the EPURVAL2 project (2017-2021) (https://www.europe-en-france.gouv.fr/fr/projets/epurval-2-mise-en-place-de-sites-pilotes-pour-lepuration-et-la-valorisation-des-effluents-de) tests different IMTA systems including the integration of seabass, seabream and holothurian (*Holothuria tubulosa*) in fish cages in Corsica and in land-based systems.

3.3. Escapes

In Prevent-Escape, a pan-European project funded by the EU carried out between 2009-2012, recommendations and guidelines for aquaculture technologies and operational strategies were put forward to reduce escape events. Fish escaping from sea-cage aquaculture is a potential risk for natural biodiversity that may cause undesirable genetic effects in native populations through interbreeding, and ecological effects through predation, competition and the transfer of diseases to wild fish. Moreover, escape events bring a significant cost to the sector, estimated at almost 50 million euros, as well as a traceability problem for the aquaculture product.

Prevent-escape provided recommendations about technical standards for sea-cage aquaculture equipment. Different techniques and indicators were developed in order to differentiate escaped and wild fish including external appearance, morphometry, fatty acid profiles and trace elements in scales.

More recently, a Spanish project co-financed by the European Fisheries Fund and the Spanish Biodiversity Foundation, called ESCA-FEP, offered guidelines for prevention of fish escapes (Izquierdo-Gomez *et al.,* 2014 a) and defined recapture plans to mitigate their impact and reduce the economic loss of aquaculture companies (Izquierdo-Gomez *et al.,* 2014b).

Currently, the project on Global change resilience in aquaculture (GLORIA), also funded by Spanish institutions and the European Maritime and Fisheries Fund, is providing new knowledge about climate change effects in escape events from coastal aquaculture as well as methods to improve the traceability of escaped fish entering distribution chains, in order to increase the food safety of consumers.

4. Recommendation synthesis

1. Improve MSP

Marine Spatial planning tools have been developed for research purposes and few tools are used by decision-maker to facilitate licencing procedures.

- Efforts have been made during AquaSpace and TAPAS projects to transfer tools and apply them in different case studies. In Mediterranean countries, MSP tools are still needed and could facilitate aquaculture development by reducing potential conflicts with other sectors (see WP7)
- Stakeholders should have access to open data platforms (ex COPERNICUs, EMODNET, EATIP). MSP tools should integrate key data relevant for aquaculture.

2. Facilitate site selection and licensing and monitoring processes

- Harmonization of licensing and monitoring processes
- Adapt monitoring according to farm scale and ecosystems (considering the ecological carrying capacity).
- Define the pertinent level of legal obligation.
- Use of environmental impact (and indicators) as standard in participative approach in order to better apprehend ecological issues in new aquaculture projects
- Selection of pertinent/core indicators at each relevant scale: recent projects have selected keys indicators through iterative and participatory process. Those indicators should be used (see Indam, PerformFISH)
- Modelling tool should be used to predict potential impact and adapt the EMP requirement.

3. Reduce the impact of fish feed and fish waste

- At global scale: improve environmental profile of feed: improve feed composition, reduce use of fishery resources
- At farm scale: improve FCR and feeding strategy (see MedAID recommendations)
- Precision fish farming should be developed to monitor, control and reduce MFF impacts.
- Recirculating aquaculture system
- IMTA should be developed in considering Mediterranean specificity (review not included in this report).

4. Prevent escapes

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6. Annex I. Source FAO 2010 “Synthesis of relevant good practice in environmental and aquatic heath at farm level & waterbody level”

FARM SCALE	FAO 2010
Optimizing feeds and feeding strategy	• feeding process should optimize feed conversion rates (FCRs) to increase profits and decrease nutrients and organic matter losses
Diseases and responsible use of veterinary drugs and chemicals.	• Biosecurity frameworks to prevent and control diseases and potential health risks to the culture species or to the environment. • Veterinary drugs and chemicals used should comply with national regulations and international guidelines (e.g. the World Organisation for Animal Health (OIE, 2009).
Prevention and control of escapees from the farm and safe movement of living aquatic organisms.	• ensure secure containment and physical safety nets at all times, during the normal activities of changing nets, water flushing to avoid escapees. • Large farm should have emergency systems to notice, control or mitigate massive escapes. • Movement of live aquatic animals should comply with all relevant health management measures (FAO, 2007) and procedures such as quarantine (Arthur, Bondad-Reantaso and Subasinghe, 2008) to avoid health-related risks to farmed individuals and to wild populations and the environment in general
Effluent management and excess nutrient reutilization.	• Local recycling and integration • On-farm or higher level infrastructure for waste water and sediment treatment, coupled with recycling of nutrient-rich residues at whatever scale is cost effective • More efficient use of input resources (e.g. higher quality feed and better feed management practices resulting in decreased FCR’s • Limits to entry/inputs based on estimated environmental capacity • Increased environmental capacity through development/enhancement of natural treatment systems or “green infrastructure”; and/or • Site rotation and fallowing (e.g. cage culture) to reduce local benthic impacts by allowing time for recovery

WATERBODY SCALE	
Strategic environmental assessment (SEA)	• To mainstream environmental and social considerations into programmes, plans and policies, • To mitigate negative impacts and maximize potential positive synergies at the sector watershed/waterbody scale and/or sector scale
Defining limits to change	• Definition of **ecological threshold** (the point at which environmental change threatens sustained delivery of ecosystem services). In practice, extremely difficult, especially with respect to change in biodiversity. The definition of "acceptable" will depend on local social and economic conditions and perspectives. • There may be very different perspectives as to what constitutes a suitable "acceptable limit" or an "adequate level of precaution. • In some case, defining limits to change is relatively straightforward. For example a certain concentration of nutrients in water may trigger undesirable or toxic algal blooms. This point may be termed a threshold characterized by significant differences in terms of services provision.
Maintaining an "agreed" biodiversity	• Biodiversity is often associated with ecological resilience. a reduction in biodiversity may reduce available pathways for natural processes and by implication, ecosystem resilience. A precautionary approach would seek to conserve as much biodiversity as possible. If local losses are accepted (e.g. in fish cages), then recovery in the vicinity must be ensured. In setting limits to change, it is essential that some resilience is retained in terms of service provision. This necessitates two things (i) acceptable limits should include a safety margin; and (ii) factors that strengthen system resilience such as biodiversity and livelihood diversity should be promoted as much as possible.
Staying within carrying capacity	• Understanding and measuring environmental capacity allows for the determination of the scale of activity that can be accommodated without threat to an environmental standard. Environmental capacity measures the resilience of the natural environment in the face of impact from human activities and must be measured against some established standard of environmental quality. In setting limits to change, it is essential that some resilience is retained in terms of service provision
Environmental carrying capacity	Environmental carrying capacity in the context of aquaculture refers to a specific area or waterbody, such as a bay, estuary, lake or river and usually concerns: • The rate at which nutrients can be added without triggering eutrophication • The rates of organic flux to the benthos without major disruption to natural benthic processes; or • the rate of dissolved oxygen depletion that can be accommodated without causing mortality of the indigenous biota (GESAMP, 1996) Aquaculture development should always be within the carrying capacity of the ecosystem. An ecosystem approach would examine more carefully the desirability of different nutrient levels in different parts of an agro-ecosystem from the perspectives of the various users and in terms of the stability of the system as a whole. Thus, there needs to be flexible and participatory approach to setting water quality standards.

Acceptable water quality standards	The water used for aquaculture should be suitable for the production of food that is safe for human consumption. Farms should not be sited where there is a risk of the water in which animals are reared being contaminated by chemical and biological hazards. If wastewater is used, World Health Organization (WHO) guidelines for the use of wastewater in aquaculture should be followed (WHO, 2006). Farms should maintain water quality within the relevant national water quality standards. The standards used by government usually relate, very loosely, to nutrient levels that may cause algal blooms and deoxygenation or compromise drinking water quality. These issues, however, need to be examined in relation to a waterbody or system and the needs and aspirations of the people who depend on it.
Encouraging culture-based fisheries and stock enhancement when appropriate	Stocking of fish in enclosed waterbodies and areas amenable to fencing, especially artificial lakes and reservoirs, may results in yields significantly greater than those from wild fisheries. Such aquaculture-fisheries integration offers a great potential for poverty alleviation and food security with minimal inputs (only the seed) and minimal or no environmental impacts, since there is neither containment nor external feeding.
GLOBAL SCALE	
Wild fish stocks and provision of sustainable fish feed	Aquaculture must reduce its reliance on global fisheries for fishmeal and fish oil if it is to supply a substantial proportion of fish for human consumption in a sustainable way. Impressive gains have been achieved in reducing FCRs for some carnivorous fish and in substituting non-fish ingredients with formulated feeds. Serious challenges remain in terms of lowering the aggregate level of fishmeal and fish oil inputs in feeds and alleviating pressure on reduction fisheries over time. Global efforts must be made to find alternative, more sustainable feed ingredients for carnivorous fish and for all fed-aquaculture species in general. The culture of omnivorous and herbivorous species should be enhanced, as well as the culture of filter-feeder and extractive species.
Trade	The aquaculture sector has emerged to increase fish supplies and to meet the demands of the market and must do so through fair trade, considering all EAA guiding principles. Adequate certification systems can facilitate and enhance aquaculture production with an ecosystem perspective, taking into consideration all the above.

7. Annex II. TAPAS toolbox

TAPAS toolbox content

The TAPAS toolbox was developed for industry and decision-making authorities to provide advice and information to improve the planning and licensing of aquaculture. Within the toolbox there is information on modelling tools, guidance tools and documents, and case studies that describe how the tools can be used and give examples of their application. The toolbox also outlines key stages of the licensing process that were identified following a review of existing practice and evaluation of bottlenecks. The licensing process covers the following stages:

Location: The suitability of a location for aquaculture affects all aspects of production, so site selection is one of the most important decisions for an aquaculture company. However, selecting a site can be a difficult task as the suitability of a location will vary for different species and depends on biological requirements, environmental conditions, regulations, and social and economic factors. It is important to include all relevant aspects as many of the negative issues associated with aquaculture have been a result of poor planning and inappropriate siting.

Licences. In most countries, a number of licenses or permits are required before an aquaculture system can be established in a specific location. The number and type of licenses will vary depending on the species, system and area. The Licensing process described here refers to the planning process and the general steps required to obtain planning permission and a permit to establish an aquaculture farm. The names and terminology may be different depending on the jurisdiction but content is relevant throughout Europe and can be adapted and applied to specific cases. It is important to remember that other permits or licences may also be required once a farm has been established.

Pre-application is an important stage which can highlight potential issues at an early stage and may influence the decision whether or not to proceed to full application. Data and modelling can be performed to assess site suitability and potential environmental impact to determine if the investment is worthwhile. Regardless of site suitability, in many areas public opinion is a major barrier to development. Therefore, prospective applicants can also use the pre-application stage to assess community acceptance. This may be a formal process with community meetings or it could be more informal

Application. This stage involves preparing and submitting the application to the relevant authorities. Regulators have a role in providing guidance for applicants preparing their submission and also ensuring the application system is user-friendly. Aquaculture producers should ensure their submission fulfils all criteria outlined by regulators and all required information is included in the application.

The Environmental Impact Assessment (EIA) is a process by which environmental and production information is gathered and assessed for the environmental impacts of a development (both positive and negative). Under EU regulations, national authorities decide if an aquaculture development(s) requires an EIA. This decision is achieved through a “screening procedure” using thresholds of aquaculture activity and potential impacts to assess projects on an individual basis. The thresholds vary between countries and types of aquaculture. Once it has been decided that an EIA is required, the developer may request the competent licensing and governance authority to identify the content of the EIA, the areas to be addressed and information required from the developer. This is known as scoping. The information identified by the scoping statement is then presented as a final report, known as an Environmental Statement (ES) which then goes out for consultation with statutory consultees and stakeholders

THE CONSULTATION PROCESS. The completed Environmental Statement, produced at the end of the EIA process, will go out to statutory and non-statutory consultees and the general public. The licensing authority will consider the views of these stakeholders when making a decision on a license application. Prior discussion and consultation with stakeholders, and where possible, addressing their concerns, can pre-empt challenges arising at this stage. Consultations are conducted over a fixed time period, which varies by country.

Decision. At this stage, a decision is made on whether a licence is approved or not. This is primarily the responsibility of statutory decision makers, usually the regulatory authority, as they must evaluate the application and determine if it fulfils the required criteria and addresses any potential concerns. Producers are unlikely to have major involvement in this stage, unless the decision makers request extra information. Decision makers will also consider responses from the public consultation as part of the process

Monitoring. Once a farm has the necessary licences and has been established, there are a number of ongoing procedures that ensure the farm is operating in compliance with the terms of the licence and regulatory standards. These procedures will help minimize environmental impact and ensure farming conditions are appropriate for good health and the welfare of the farmed species.