Discussion of Spatial Planning for Aquaculture

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Abstract

This text is unit 12 in a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture' made by the AquasSpace project. It provides a backwards look at, and a critical overview of, the course and a discussion of the way forward for spatial planning of Aquaculture

Contents

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1 Study guide

This text was written during the H2020 Aquaspace project (2015-2018, contract no. 633476) for a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture'. The course consists of a number of units; this unit is the final unit and provides a look back over the ideas introduced in the course and a discussion of the way forward for the spatial planning of aquaculture. It draws on the outcomes of the research carried out in the AquaSpace project.

The unit comprises:

- the document that you are now reading, which includes self-assessment questions, suggestions for further reading, and the exercise of drafting a short research proposal.

The learning outcome is:

- to be able to give, and critically evaluate, an account of the 'state of the art' in relation to the aspects of spatial planning for aquaculture that have been presented in this course;
- to identify some topics relating to aquacultural expansion that need further research or tool development

Because much of this unit derives from work carried out during the AquaSpace project, we start with a summary of the project (section 2). Next (section 3) is a reminder of the theoretical framework for application of the Ecosystem Approach to Aquaculture, introduced in unit 2, and then an overview (section 4) of the variety of aquaculture, needed because routes to expansion are likely to be different for different types of cultivation.

After this we summarise and discuss AquaSpace findings: stakeholder opinions about constraints on aquaculture (section 5), an overview of the tools developed and tested during the project (section 6), a brief discussion of the factors currently restricting expansion (section 8), and our conclusions (section 9) about the way forward for research and for aquacultural expansion itself. Because we see social issues as crucial in planning, they get a section (7) to themselves. Citations such as D2.1 refer to AquaSpace deliverables, available from the AquaSpace website.

2 AquaSpace

The AquaSpace project had the goal of providing increased space for aquaculture to allow increased production of cultivated organisms in the sea and fresh-water. The context was the need to find new sources of food (especially, protein),[1] whilst ensuring economic, environmental, and social sustainability through adoption of the Ecosystem Approach to Aquaculture (EAA).

The project identified the main constraints that seemed to be impeding the development of a variety of types of aquaculture. Tools that could help overcome these constraints were identified and eval-

[1] The need for new sources of food emerges from considering the expanding human population of the world, people's increasing standard of living, and the widely recognized state of the world's capture fisheries as operating at or above maximum sustainable yield.

uated. Some tools were tested in real case studies, and customized and improved during the project, and six new tools were created to respond to some of the requirements identified for further development and better management of aquaculture. Most of the analysed tools were related to spatial planning of aquaculture.

The application of the EAA and the utility of relevant tools was assessed in 15 case studies at 17 sites in Europe and in North America, China, Australia and New Zealand. The case studies embraced a range of spatial scales, a variety of types of aquaculture at different trophic levels with different environmental interactions, and a medley of space-related development constraints as defined by local stakeholders.

The theoretical and technical knowledge gained during the project was used to assemble on-line materials forming the AquaSpace Toolbox and the educational materials of which this unit is a part, available at www.aquaspace-h2020.eu.

3 Theory

AquaSpace approached its tasks with a problem-solving mandate, which this course has attempted to embed in a theoretical framework. Because interactions between human societies and their environment can be constructed in various ways, this framework is not the only possible one. It does, however, emerge from the principles of the *Ecosystem Approach to Aquaculture* (the EAA, table 1) and the appreciation that human actions in the biophysical world are steered by societal processes that can be categorized as deliberative, market-based, or hierarchical. Thus the concepts in figure 1, introduced in unit 2, which allow the constraints on expansion of aquaculture to be seen as relating to needs for technical development and for economic, environmental and social licences.[2]

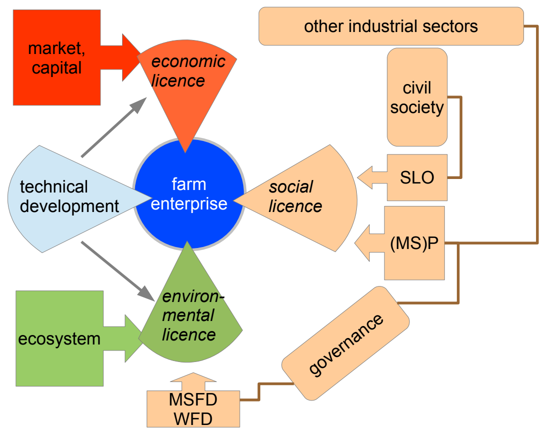

Figure 1: Three *licences* required for successful operation of an aquacultural enterprise. (MS)P: (Marine Spatial) Planning; SLO: Social Licence to Operate; MSFD: Marine Strategy Framework Directive (2008/56/EC); and WFD: Water Framework Directive (2000/60/EC).

The relationships between steering, licences, EAA principles and the various categories of indicators used by the integrating tools discussed in section 6, are complex. The *licences* of figure 1 can correspond to

[2] Implicit in the thinking behind this unit is the philosophical position known as *Critical Theory* (Moon and Blackman, 2014; Bohman, 2016), involving the use of practically-oriented research in a theoretical framework to move towards a desired outcome, in this case the goal defined by the EAA principles, whilst critically reflecting on the goal and the framework.

Table 1: The three principles of the Ecosystem Approach to Aquaculture (Aguilar-Manjarrez et al., 2017).

Aquaculture should . . .	
(i)	be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience
(ii)	improve human well-being with equity for all relevant stakeholders (e.g. access rights and fair share of income)
(iii)	be developed in the context of other sectors, policies and goals, as appropriate

the formal permissions needed to operate a farm, but are best though of as switches that need to be 'on' for a farm to function.

The *owner*[3] of the *economic licence* switch is the owner of investment capital, who provides the licence by deciding to invest that capital in a farm or other component of the aquacultural industry.

The owner of the *environmental licence* switch is the regulator who can approve or disapprove plans to keep farm effects on natural ecosystems within limits set by ecologists on behalf of society under laws resulting from EU directives or similar principles.

The owner of the *social licence* switch is in most cases the planner, who, to an extent decided by their society, takes account of EAA principles (ii) and (iii) and whether *Social Licence to Operate* (SLO) exists; they may be required by law to withhold development permission if an environmental licence does not exist; and there must, of course, be space available to allocate for the farming activity.

In practice, there may be more than one owner of a switch, resulting in the need for operators to gain multiple permissions from multiple public organisations. And finally, as will be seen in discussing tools, the information to determine whether a switch is to be set on or off, may be economic, environmental or social in nature irrespective of the type of the licence.

[3] *Owner* is used in the technical sense taken from the Soft System Methods of Checkland (1999), to refer to those who can start or stop something.

4 Variety of aquaculture

There is a variety of types of aquaculture, i.e. of the species cultivated, the equipment used to contain and grow them, the intensity and scale of production and the environments used. This variety was introduced in unit 1 and exemplified in the Case Studies (unit 11). It has consequences for economic, environmental and social licences for the expansion of each kind of aquaculture.

Although the following is not a complete list, we distinguish:

- high intensity of production, potentially high environmental impact, profitable, *farming of fin-fish in floating net-pens*, requiring imported feed; including cold-water salmonids featured in Canada and Scotland case studies, and warm-water perciforms in Mediterranean case study;

- cultivation of *filter feeding bivalve molluscs*, such as mussels, taking food from water flows; lower production intensity, lower impact, and lower profit per unit area, requiring larger areas for viable enterprises, but may contribute valuable ecosystem services; bivalve farming featured in France, Italy, Northern Ireland, New Zealand, Portugal, Spain, and USA case studies; *farming of seaweeds*, which take nutrients from water flows, belongs in this category although it remains experimental in Europe;

- *Recirculating Aquaculture Systems* (RAS), which recycle up to 90% of the water they use. They provide controlled and biosecure conditions, but are capital and energy intensive. They are currently increasingly used for rearing young of cultivated organisms;

- *ponds*, traditional low-intensity fish cultivation using natural resources produced within the pond; may enhance local ecosystem services; exemplified by carp farming in the Hungary case study;

- *Integrated Multi-Tropic Aquaculture* (IMTA), involves the waste products from one food production process being converted into valuable products by other farmed organisms, a process that decreases waste and increases the efficiency of the food production system. It is thus best seen primarily as a way of increasing output from existing farmed areas, secondarily as reducing nutrient and organic loads. The main example in AquaSpace was in China.

See appendix B for more details, including estimates of production intensity.

5 Opinions about constraints on expansion

O'Hagan et al. (2017, D2.1) reviewed strategic aquaculture planning policies, strategies and targeted actions that have been put forward to allow the sector to expand in the EU, and polled regulators, industry representatives and scientists for their views on these. They found that there was a general weakness in implementation of the policies. Although most EU Member States have strategic plans for aquaculture, few have committed to increasing the amount of space allocated to aquaculture, or to simplifying licensing procedures, in any definitive way.

Further evidence of constraints came from analysis by Galparsoro et al. (2018, D5.1) of stakeholder opinions in AquaSpace case studies. The most frequently cited issues related to planning, regulation and licensing and to conflicts with other users (Table 2). Almost universally across the case studies, farmers and other practitioners pointed to continued difficulties in licensing procedures, which are complex and inflexible, and contribute significantly as an impediment for expansion; with Portugal's 42 licences required for a shellfish site being a notable example.

However, stakeholders consulted or engaged during AquaSpace were predominantly from the industry, government or research sectors (figure 2). Perhaps because the purpose of the consultations were to better understand constraints on the expansion of aquaculture, there was under-representation of stakeholders who might oppose expansion either on social li-

Table 2: Constraints on aquacultural expansion: frequency of reports from the 17 sites of the 15 AquaSpace case studies. Top 3 issues shown for each of 4 dimensions of analysis. From Galparsoro et al. (2018, D5.1). The last two dimensions relate to *social licence*.

ENVIRONMENTAL	
Environmental impact	5
Ecological carrying capacity	5
Environmental conditions	5
ECONOMIC & MARKET	
Production cost	8
Market competitiveness	4
Reliability of production systems	3
POLICY & MANAGEMENT	
Administrative procedures/ licensing	17
Planning & regulation	15
Different roles of management authorities	2
OTHER SECTORS	
Conflicts with other users	17
Social licence	2
Stakeholder engagement	2

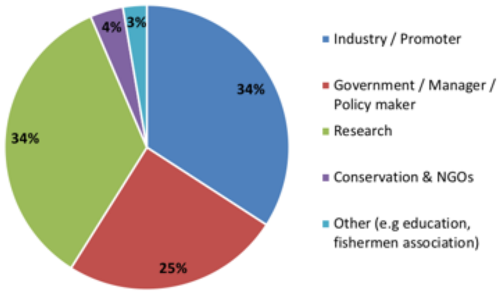

Figure 2: Categorisation of stakeholders attending AquaSpace workshops, from Galparsoro et al. (2018).

cence grounds or because of sectoral conflicts. This is something that should be addressed in future research, and there are well-established methods for exploring issues when stakeholders are too conflicted to meet together.

The top 3 constraints listed under 'Economic & Market' in table 2 might be interpreted as challenges that might be overcome, at least in part, by technical development. Study of the programmes for industry-oriented research meetings, such as those held by Aquaculture Europe in 2016 and 2017, suggest that industry-related research has been focusing on improvements to fish strains and fish feeds. Although these economic & market issues were cited in only one in two AquaSpace case studies, this may have been because the industry stakeholders considered them to be under their own control, whereas they did wish to draw attention to external constraints such as the difficulties in getting development permits.

6 Tools

As defined in unit 2, a *tool* is *a mechanical or informational structure used purposively by actors to bring about a change in the social or physical worlds.* This includes a wide variety of things, but mostly in the present case combinations of computer programs and data sets. Particular tools were discussed in units 5 to 10 and all the tools investigated by AquaSpace were summarised in unit 11 and described in the AquaSpace ToolBox.

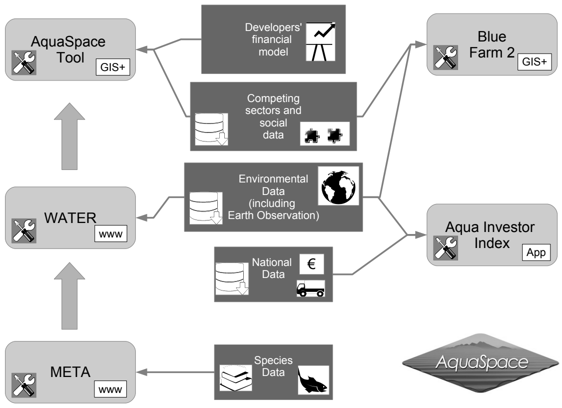

Figure 3: Relationships amongst AquaSpace Integrating Tools

6.1 . . . for integration

A number of *integrating tools* were developed during AquaSpace to help planners and developers to bring together the large amounts of information required for decision-making in (marine) spatial planning. Figure 3 shows the data requirements of these tools, and their links with each other. The most complex tools (*the AquaSpace Tool* (AST), Gimpel et al., 2018, and *BlueFarm2* (BF2), Brigolin et al., 2017) assemble spatially-varying information about environment, society (including policy) and economy, which can be used by planners and developers. Some of this information AST draws from the *WATER* tool that maps environmental suitability for different species of farmed animal. The *Aqua Investor Index* (AII) assembles information on a country-by-country basis.

Unit 6 provided an introduction to the tools and the types of data they use. Data needs depend on tool, and includes information about:

- environmental conditions, in order to find parts of the sea that provide suitable conditions for the species to be cultivate;
- use of this part of the sea by other sectors, including capture fisheries, shipping, energy generation, tourism and nature conservation, in order to determine potential conflicts and synergies;
- factors relating to costs of operating an aquaculture enterprise, such as distance to a port or the need for sturdier equipment in waters more exposed to strong winds and large waves;
- factors that might influence social licence, such as the visibility of the zone and its activity from land or routes taken by tourist craft, and the number of people who might be affected;
- jurisdictions: who are the competent authorities for licensing activities, and what rules do they apply?

In the next two subsections we consider the utility of these tools, and others described in the AquaSpace ToolBox, for economic licence and environmental licence. Social licence and related matters are dealt with in section 7.

6.2 . . . for economic licence

The existence of an *economic licence* means that an enterprise is making, or is expecting to make, a profit. The factors that determine this are not only market-related, but can include environmental suitability for the cultivation of a particular species and social factors such as availability of educated workers or existing claims on desirable space by other sectors.

The AST allows developers to choose amongst potential sites or scenarios on the basis of spatially-determined production costs, such as distance from a shore-base and harbour, and it takes information from WATER concerning the suitability of coastal regions for the cultivation of the intended species.

Countries differ in features such as transport and market infrastructure, and the ease or difficulty in licensing. The AII quantifies how these features affect the attractiveness of a country for investment in aquaculture, which contributes to economic licence. Although aimed at entrepreneurs, the tool also provides advice to governments, because these are matters that could be remedied by national policies.

As we have already remarked, the economics of fin-fish and shell-fish cultivation differ. Fin-fish farming is profitable and has benefitted from much capital investment with increases in labour productivity. Shell-fish farming appears to have been less profitable in most of our case studies, needing subsidy in Portugal and special marketing techniques in Italy. China and New Zealand are exceptions.

According to classical economic theory, if all externalities were properly costed, the market should ensure the most efficient use of the *Ecosystem Services* exploited by aquaculture. In practice it is not the case that externalities are adequately taken into account. For example, in many countries the use of environmental capacity to assimilate nutrients or organic waste, which is a public good, is available free of charge to the fish farm that first appropriates it. Conversely, cultivation of filter-feeding bivalves or seaweeds can expand this capacity (in IMTA) or more generally improve water quality in estuaries. The US case study makes the case for paying shellfish farmers for the ecosystem services, such as nutrient recycling, that they provide. Thus methods for valuing Ecosystem Services (ES) can be seen as economic tools, and ES layers could be built into integrating GIS, as exemplified by the way in which potential for IMTA is built into the AST.

The effect of disease on farmed animals, and the need to prevent infection of wild populations, are costs to the farmer, as well as giving rise to concern about the environmental effects of disease treatments. Several EcoHydroDynamic Models (EHDM), devised to simulate the dispersal of the sea-lice parasites of farmed salmonids, were used and improved during AquaSpace case studies in Norway and Scotland, with the aim of improving the identification of disease management zones and thus improving the cost-efficiency of disease treatments as well as satisfying regulators. The AST includes a generalised disease risk indicator.

6.3 . . . for environmental licence

The main (spatially-varying) environmental constraints on aquaculture are:

- those which restrict the area in which conditions are suitable for cost-effective cultivation of particular organisms; such areas are mapped by the WATER tool;
- those which determine the carrying capacity or waste assimilative capacity of a particular water body for a total amount of a particular form of aquaculture;[4]
- those which prevent development because of proximity to *Marine Protected Areas* (MPA) that might be harmed by aquaculture; the AST and the local applications of the AkvaVis tool have been found to be useful in case studies in identifying such spatial conflicts.

Finally, as was particularly the focus in the Hungarian and US case studies, and has also been discussed in relation to economics, some forms of aquaculture can enhance ecosystem services. Fish ponds in Hungary provided habitats for birds, and oyster farming in US estuaries could improve water quality. Useful tools in these cases were methods for identifying and valuing ecosystem services, and EHDM to quantify effects of increasing the production of shellfish.

[4] This is a topic addressed by AquaSpace's sibling project, TAPAS (H2020 no. 678396) and studied during the earlier ECASA project.

7 Social issues

Social licence is presented in figure 1 as the most complex of the three licences, involving both a formal public planning process and informal public consent. The latter is called here *Social Licence to Operate* (SLO). The two components can interact, as was investigated in the Scotland case study, and the planning process may require evidence of environmental licensing, or consider the economic benefits of a development. A second pair of topics concerns stakeholder engagement in planning processes, and how scientists can engage in these processes: topics that relate to the balance between hierarchical and deliberative steering of the use of marine ecosystem services that was introduced in unit 2.

7.1 Social Licence to Operate

Although fish ponds and some forms of shellfish cultivation are long-established forms of aquaculture, farming of fish in net-pens is a new industry. Its exponential growth since about 1970 has generated a perception of an alien presence in what are seen as pristine seascapes, and it is unsurprising that popular opposition has increased. AquaSpace findings in the Scotland case study show that very often it is this opposition to fish-farming that takes the initiative, leaving industry to respond defensively. Social Licence to Operate (SLO) is more than good public relations: it requires mutually beneficial interactions between communities and the industry, as first described for mining (Gunningham et al., 2004).

There exist methods for obtaining SLO (Prno, 2013), including the stakeholder engagement that was a feature of most AquaSpace case studies. We discuss this below. Sociological research in AquaSpace was mainly concerned with elucidating opinions about fish farming. In the Scotland case study this was by means of analysis of public comments on planning proposals, and studies of public perceptions of virtual (digitally-generated) farms. This research lead to the hypothesis that acceptance or rejection of visible aquacultural development relates to community narratives about the use of coasts; narratives, once established, lead to selection of evidence (e.g. relating to environmental impact) either for or against development, with consequent polarization of communities. It is on this basis that we conclude that fin-fish farming needs to take the initiative in growing SLO around positive narratives of industry development and its social and economic benefit to coastal communities.

Social objections to fish-farm development were also noted in the Canada and Norway case studies. Lack of SLO can overlap with sectoral conflicts, as exemplified in Greece (Mediterranean case study) between tourism and fish-farming or between capture fisheries and mussel farming in the Spain case study. Our impression is that the aquaculture industry is beginning to accept that 'Corporate Social responsibility' and local engagement can aid SLO, while governments consider spatial planning to be the solution for sectoral conflicts.

7.2 Planning

Planning is the formal part of the process by which society considers use of space. As explained in unit 3, it involves policy formation and zoning as well as consenting to particular developments at particular sites.

Although there are historic examples of the allocation of marine space, the law and practice of planning has mostly developed in relation to what the EU *Maritime Spatial Planning Framework Directive* (2014/89/EU, the MSPFD) calls *Town & Country Planning* (T&CP). As reported by AquaSpace partners Galparsoro et al. (2018), Maritime Spatial Planning as mandated by the MSPFD is only beginning to be implemented in most EU member states, and in any case often does not apply to aquaculture as this is subject to T&CP. Ehler (2014) characterises the objectives of MSP as "usually specified by a political process", but the development of planning policies is typically seen as a technical process, and the public tends to become involved only in relation to individual developments, getting frustrated when what might be reasonable objections are ignored because of policy decisions that have already been made.

Furthermore, in most case studies, developers experienced the planning process as unnecessarily slow and complex. This may have been because of the way the process has evolved to require a variety of permits from a variety of organisations. For example, the first salmonid farms in Scotland needed only a sea-bed lease from a UK organization called the Crown Estate, created in the 18th Century to manage royal property. Now there is additionally a requirement for a planning permit (issued by local government subject to consultation with the Scottish nature conservation authority to avoid harm to Marine Protected Areas), a Marine Licence issued by the Scottish Government, and a 'Controlled Activities Regulation' licence to prevent pollution, issued by the Scottish environmental protection agency after consulting with the marine science department of the Scottish government concerning assimilative capacity (Gatward et al., 2017). Even so, this is simple compared with the requirement in Portugal for 42 licences for a shellfish farm.

These complexities have arisen out of societal demands to (i) bring aquacultural development under public control, and (ii) prevent harm to the natural environment and societally-valued habitats, organisms and ecosystem services. Despite many national aquacultural strategies aiming at simplification, it is not clear how this might be achieved without diminishing the ability of communities to influence development or without decreasing environmental protection.

Finally, it appears that planning is often constrained by history. What is already in place, not only holds on to space, it can also inhibit new developments adjacent to that space. For example, in the case of Greece within the Mediterranean case study, it seems to have been easier for fish-farming to develop in municipalities without tourist hotels. More subtle is the persistence of institutions (rules, regulations, customs) originating in or adapted to earlier conditions. Recently developed forms of aquaculture may thus receive less favourable public treatment than traditional maritime sectors such as capture fisheries. Further studies of these legacy effects would be useful.

7.3 Stakeholder Engagement

Many implementations of the Ecosystem Approach and the EAA require some form of stakeholder engagement, although who counts as a stakeholder, and how much they can influence planning and licensing, is variable. In unit 2, a *stakeholder* was defined as "a person or organisation that has a legitimate claim to be heard in . . . an action situation". To be heard may mean only to have views sought or it may mean to engage fully in a deliberative process. The distinction between individual stakeholders and representatives of organisational stakeholders is also important. Powerful governmental and non-governmental organisations, viewed as key stakeholders in policy-formation processes, typically participate in these processes through mandated representatives briefed for *strategic action* rather than *communicative action*.[5]

AquaSpace engaged with stakeholders, both on a European scale and in workshops organised by case studies. There were three aims: to better understand constraints on the expansion of aquaculture, to communicate with tool users in indus-

[5] *Communicative action* was defined in unit 2 as "social action oriented to reaching understanding amongst actors" and was seen by Habermas (1984) as an ideal deliberative process in which validity claims are presented and discussed and from which could emerge positive-sum outcomes, those that most participants would find reasonable. Habermas contrasts this with *strategic action*, in which participants seek to achieve predetermined outcomes that may be mutually exclusive.

try and government, and to encourage deliberative processes. However, as already discussed, there was under-representation in AquaSpace case studies of stakeholders who might oppose expansion either on social licence grounds or because of sectoral conflicts. Thus our stakeholder engagement only partly addressed the deliberative aspects of spatial planning, and there is a need for research in how better to bring more sectors of the community into this process.

7.4 Action research

'Research' was a well-represented stakeholder group in the case studies (figure 2), and so we need to discuss the roles that a researcher might play in relation to the *Issues*, the topics of concern in the case study.

According to the prevailing model of research, an actor who is a scientist has a privileged role in the gathering and interpretation of knowledge about the Issue. He or she is like a doctor, approached by patients who feel unwell and wish to be diagnosed and cured by an expert who will draw on knowledge that the patient cannot understand. In some cases the doctor subsequently reports the diagnosis and the outcome of treatment in a technical paper that might be intended to advance the medic's career as well as to disseminate knowledge, and in any case in which the patient is described as the passive object of study.

This is *Mode 1 research*, which, according to Nowotny et al. (2003), is "characterized by the hegemony of theoretical or, at any rate, experimental science; by an internally-driven taxonomy of disciplines; and by the autonomy of scientists and their host institutions, the universities". Its work requires scientists to make objective observations of their subject matter, which might be sited in the natural environment, in the economy, or in societies. In contrast, a new paradigm of knowledge production ('Mode 2') seems more appropriate for the engagement of scientists with stakeholders. Mode 2 is "socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities". It is close to, although not the same as, Action Research, which "is a disciplined process of inquiry conducted by and for those taking the action" (Sagor, 2000) with the aim of bringing about change in a specific context. It involves planning, observation, evaluation and critical reflection (Koshy et al., 2011).

In mode 2 science, and in action research, the process of research may be of as much benefit as the research findings. This appears to have been the case in at least some AquaSpace case studies, in which the process by which project scientists generated knowledge was at the same time a process by which the knowledge was shared with wider society and came to influence policy relating to aquacultural development. Evidence for this can be seen in the interviews with public officials in the AquaSpace results videos (D6.5) dealing with Hungary, Italy and Scotland.

8 What restricts expansion?

As evidenced in unit 1, and despite EU policies, aquaculture in the EU28 has not expanded during the last decade. Amongst the reasons could be:

- an absolute lack of suitable space
- an absolute lack of assimilative or provisioning capacity
- insufficient market demand for farmed aquatic organisms
- a lack of capital for investment
- unfavourable economic and infrastructural conditions
- failure of planning processes to allocate suitable space and assimilative/carrying capacity because of weakness of aquaculture's voice or lack of adequate planning tools
- public hostility
- technical limitations in the industry
- a lack of scientific knowledge about environmental effects of aquaculture or of conditions suitable for cultivation

This list may not be complete. For some of the explanations, AquaSpace has evidence only in the form of stakeholder opinion. For example, the most-reported economic constraint was that of 'production cost' (figure 4), whereas lack of capital was never mentioned. 'High production costs' presumably means costs that are high in relation to the market price fetched by the farmed fish or shellfish. To understand the cost issue further would require operating budgets from examples of different aquaculture types, but AquaSpace did not investigate these.

Table 3: The area available for cultivation of the listed species in European waters, according to that predicted by the WATER tool as 'moderate' or better on the basis of the tool's OPTIMAL settings and the following selection variables: for *species* - temperature; for *water quality* - chlorophyll, and dissolved oxygen; for *operations* - significant wave height, current speed and water depth. The EHDB model cited for mussel production is that of Tett et al. (2012), which adds a Dynamic Energy Balance (DEB) model (Grant and Bacher, 1998) to a fjord model (Tett et al., 2011).

Species	Mussel: *Mytilus galloprovincialis*	Salmon: *Salmo salar*
Area available from WATER, km^2	1435	443
Assumed yield, tonnes wet weight ha^{-1}	3 (from EHDB model for *M. edulis*)	345 (from Norwegian case study)
Potential annual production (tonnes) if all area used	400 thousand	15.3 million
2013 annual production (tonnes)	377 thousand (EU28)	1.44 million (Europe)

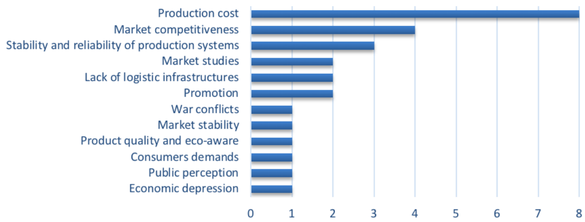

Figure 4: Frequency of reported issues with an economic and market dimension: number of study sites out of maximum 17, from Galparsoro et al. (2018, D5.1).

Results from the WATER tool can be used to estimate potential European production of salmon and mussels if all space identified as suitable by the tool could be occupied (Table 3). At first sight the table implies that a large increase in production is possible in the case of salmon, but not for mussels. The mussel yield has been estimated on the basis of exploiting all primary production in a moderately productive region; higher phytoplankton production (as a result of nutrient fertilization, seen in the northern Adriatic and in the Bay of Seine in the Italy and France case studies), might increase the yield and thus the calculated mussel production.

Conversely, the estimated salmon production takes no account of limitation by the availability or cost of fish-derived feed, or by an upper limit to waste assimilative capacity. Assuming a buffer zone around farms of ten times the farm area, reduces the potential annual production to 1.5 million tonnes per year. As remarked in unit 11 in case of the Norway case study, although salmonid-farming only occupies a small proportion of coastal sea area, requirements for minimum separations between farms make it difficult to identify additional space in nearshore waters, and it is not politically acceptable to reduce the demands regarding sustainability.

9 The way forward

9.1 EAA and sustainability

EAA principle (i) requires aquaculture to be developed by using ecosystem services in a sustainable way. Whereas modern knowledge of marine ecosystems and modern methods of regulating environmental impact are in most cases adequate to protect the marine environment from significant degradation by aquaculture,[6] there is a major obstacle to the sustainable expansion of the farming of carnivorous fish such as salmonids. This is the global limitation of supplies of fish protein and fish oil that originally made up most feed. Vegetable products are now being used to replace about two-thirds of the protein (Ytrestøyl et al., 2015), but there remains a problem with sourcing the omega-3 PUFA[7] that are needed by salmonids and, it is claimed, provide some of the health benefits of eating these fish. Furthermore, use of plant materials requires productive land to be used to

[6] See Taranger et al. (2015) and Tett et al. (2018) concerning the regulation of environmental impact of salmonid-farming in, respectively, Norway and Scotland. Regulation must of course be effectively applied, and other stakeholders must believe that it is being applied.

[7] Plants do not normally syntheize these PUFA (poly-unsaturated fatty acids), but some crops, including oilseed rape, have been genetically engineered to do so (Ruiz-Lopez et al., 2014).

support marine industry and thus does not help in feeding our planet's growing population, even if farmed fish are more efficient than cattle, pigs or chicken at converting vegetable foodstuffs into animal protein (Torrissen et al., 2011).

The obvious alternative is to expand farming of low-trophic level species, especially filter-feeding bivalve molluscs, which harness marine primary production that would otherwise be unavailable. Shellfish farming provides lower economic returns but potentially employs more people than fin-fish farming; as it can help recycle anthropogenic nutrients and improve water clarity, societal payment for its ecosystem services could improve its profitability. However, the production intensity of bivalve farms is much less than that of finfish farms, and significantly increasing the production of mussels, oysters, etc will require large areas of sea. This is also true for seaweed farming.

9.2 Expand Offshore

As already argued, there may be little more space available to aquaculture within 1 nm of the shore, or within the depth constraints currently set in the WATER tool. This is because of environmental limitations, conflicts with other sectors, and social objection. Also making inshore aquacultural development difficult is the complexity of regulation and permissions needed. Although MSP is in principle integrated over sectors (and thus public bodies) it rarely applies to the inshore, where Town & Country Planning dominates, and many organisations can be involved in regulation. Partly explaining the above is the recency of development of most forms of aquaculture, which may underlie both social objections and the weak voice of the industry in planning.[8]

Clearly, more work is needed with the WATER tool and other models, but the simple calculation in the previous section hints that the high targets currently set for an increase in salmon production by the Scottish and Norwegian governments might not be achievable without new technology, either that decreasing environmental impact intensity inshore (and so allowing more production at existing sites) or that enabling cultivation in more exposed offshore conditions. The issues explored in the Italy case study (Brigolin et al., 2017), for example, also suggest that expanding offshore is the best way to increase output of mussels.

Expansion of fish-farming into offshore areas (beyond the remit of town and country planning) will require investment in new technologies; multi-sector MSP could provide a low-risk planning environment for this investment.

9.3 What kind of MSP?

MSP has been seen as a solution to many of the difficulties and constraints for the expansion of aquaculture, as well as being a tool for the implementation of the EAA. However, its broad definition, as "a public process of analyzing and allocating the spatial and temporal distribution of human activities" (Ehler, 2014) is open to a variety of interpretations. Here we briefly consider two extreme cases and the actual situation.

[8] China is an exception, but here the policy is to decrease production while increasing quality.

Algorithmic

An algorithm is an ordered set of rules for solving a problem. We ask the reader to imagine that the AquaSpace Tool (Gimpel et al., 2018) (or equivalent other GIS) has been further developed so that it can compute the optimum scenario for sustainably using and fairly distributing the ecosystem services of a coastal sea, in particular by identifying zones within which specified sectoral developments are permitted whilst activities by other sectors are prohibited.

As presently designed, the AST allows scenarios to be compared by means of standardized values of multiple indicators. Optimisation requires a set of rules for aggregating indicators, perhaps by converting to monetary values so as to allow a comparative cost-benefit analysis of alternative scenarios. The use of such CBA is already common in environmental decision making (Martino et al., accepted). An alternative involves a multi-dimensional indicator state space, with rules defining the locations in this state-space that society considers optimal.[9] The public aspect of MSP would in all these cases be the process that led to the definition of the optimisation rules, which would be carried out at the collective-choice level of governance (and the policy-formation stage of MSP) in order that the AST could be used at the operational level for zoning and aquacultural site allocation.

[9] Tett et al. (2013) describe and discuss the use of a state-space defined by biotic indicators in the context of assessing marine ecosystem health.

Participatory

Whereas an algorithmic implementation of MSP treats operational planning as a technical process, a participatory implementation would include deliberation in operational processes. For this case we ask the reader to image a somewhat different development of the AST, one in which maps and evaluated scenarios are displayed on a touch table[10] to groups of stakeholders, who can interact with each other as well as the GIS to arrive at a mutually agreed outcome. Such deliberation might involve fish-farmers and capture fishermen meeting in a village hall on a small cold and windy northern island, to discuss a siting a new mussel farm, or farmers and hotel owners getting together in the cool back room of a bar near the proposed site of new net-pen farm in sunny Mediterranean waters. Ostrom (2005) compares such a 'bottom-up' approach to the regulation of Public Goods with the 'top-down' regulatory approach often preferred by governments. She points out that the latter tends to suppress the former, and that 'top-down' regulation needs to be well-resourced if it is to succeed.

The kind we have

Actually-existing MSP, as we have observed it during AquaSpace, can involve elements of both the algorithmic and participatory approaches, but, often it is a complex mess that neither satisfies stakeholders nor encourages aquaculture development within

[10] *A touch table* is a large, touch-sensitive, computer screen deployed horizontally like a table, and running GIS software.

the EU28.[11] As already discussed, the complexity arises in part from multiple overlapping jurisdictions as well as from the differences between policy-making and the approval of development at a particular site. To achieve optimization, MSP needs to integrate over all waters and sectors, whereas in most cases 'formal MSP' (that in the EU28 resulting from transposition of the MSPFD) applies only to offshore waters, with those close to the coast, where most aquaculture is currently sited, subject to Town and Country Planning in which aquaculture has a weak voice and in which existing land uses (and the objections of local residents or hoteliers) tend to dominate.

9.4 Invest in software tools

AquaSpace has created some new tools, and improved others, that can support strategic planning of aquaculture (AkvaVis, AST, BF2, WATER), help investors identify sites (AII, AST) or manage disease (Lakselus and WestLice). The complexity of the integrating tools, in particular, indicates the variety of information that needs to be taken into account for planning purposes.

Spatial tools need large quantities of spatial data, which have been obtained on a European scale from EU data bases such as COPERNICUS, EMODNET, and EUROSTAT. Development of dynamic web services would enable automatic updating of the tools. However, use of such tools for national planning purposes requires higher resolution than currently available from EU data bases and adaption to reflect national planning policies.

AquaSpace has demonstrated how these tools can be useful. However, to become fully operationalised, they will need substantial further public and industry investment in their development.

9.5 Engage the public

Understanding and changing societal attitudes to the several types of aquaculture is crucial for aquacultural expansion. As already mentioned, an overarching hypothesis is that acceptance or rejection of visible aquacultural development relates to community narratives about the use of coasts; narratives, once established, lead to selection of evidence (e.g. relating to environmental impact) either for or against development, with consequent polarization of communities

It is possible that offshore development will be less opposed by coastal communities because less visible from them. Instead, however, opposition might be taken up by non-governmental organisations, for example arguing against the consequences of offshore farming for sea-birds. Such contests might be seen as sectoral conflicts, to be resolved through better MSP. Nevertheless, if maritime societies are adequately to consider the sustainable use of their marine resources, there is a need for better public education in these matters as well as more engagement in deliberation.

9.6 Invest in research

It is observable that, when the fish-farming industry has identified a technical con-

[11] As a topic for further research, it would be interesting to compare regulatory and environmental constraints on expansion of fin-fish farming in Norway and Turkey with those in Scotland and Greece.

straint either for internal (production and marketing) reasons or external (regulatory) reasons, it is likely to fund research or development itself. Publicly-funded research therefore has a different role, which is to benefit society more widely, by providing 'Public Goods' (Ostrom, 2005) such as a knowledge base on which technical advances can be made, or tool developments of collective benefit. AquaSpace case studies included three examples of the latter. Two of these were the sea-lice dispersion models to improve delineation of disease management zones and to provide real-time forecasting of lice infection risks, as described in the Norway and Scotland case studies. In New Zealand, mussel farmers collectively funded the development and maintenance of a web-tool to forecast yield.

In addition there is a need for holistic, publicly-funded research into risks and opportunities offered by aquacultural expansion for sustainable ecosystems and the societies that use them. It will be useful here to re-introduce the idea of an *action situation*, which lies at the heart of the scheme for analysis of access to ecosystem services devised by Ostrom and colleagues (Ostrom, 2005, 2007; McGinnis and Ostrom, 2014). It was defined in unit 2 as "a focused social activity in which actors interact communicatively concerning an Issue", to which we add now, 'in a particular biophysical, social and economic context', and identify the *Issue* as something to do with aquaculture and in particular relating to a licence switch. Figure 5 is a modification of a key diagram from Ostrom (2009) to provide an analysis framework for future research in relation to the governance and planning issues that have been raised in this unit and in the course as a whole.

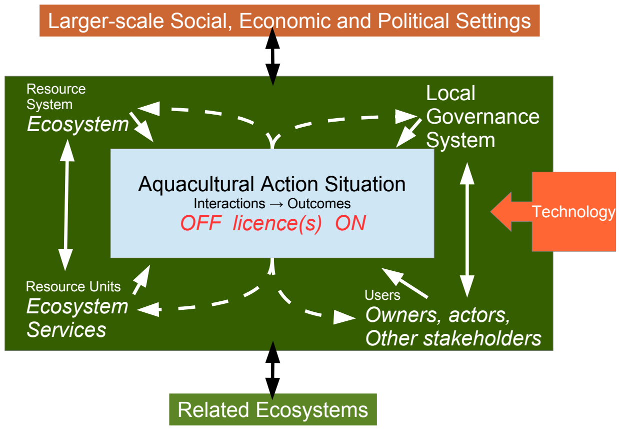

Figure 5: Ostrom's *Action Situation* diagram (Ostrom, 2007, fig. 1) modified to describe the licence-related interactions that have been considered in this unit. The bounded social-ecological system implied by this diagram should be viewed as dynamic, evolving over time as a result of internal processes and the effects from outside of environmental pressures and economic and social drivers.

This unit has presented social issues as being key constraints on aquacultural expansion. Perhaps we should see this as a sectoral example of a generic problem that, according to Ostrom (2005), many pre-modern societies have solved on the local scale, but which increasingly faces modern societies on both the local and larger scales. How can citizens more fully participate in devising as well as implementing policies for the sustainable use of ecosystem services?

10 Further Reading

The FAO cultured aquatic species fact sheets provide information on many cultivated species.[12]

To read further about the integrating, spatial planning, tools developed during AquaSpace, see Brigolin et al. (2017) and Gimpel et al. (2018).

Concerning limitations on aquaculture expansion, and possible remedies, see AquaSpace reports D2.1(O'Hagan et al., 2017) and D5.1 (Galparsoro et al., 2018). They are available on the Library/Main reports page of the AquaSpace website.

Short AquaSpace results videos that include descriptions of stakeholder engagement in Hungary, Italy and Scotland, can be accessed by way of the Library/Videos page of the AquaSpace website.

11 Exercise

- Write a short research proposal (1 page A4, or maximum 500 words) for the advancement of knowledge or the improvement of tools in relation to a single issue relevant to the expansion of aquaculture. Specify:
  - the issue to be addressed
  - the aim of the proposal
  - the methods to be used

Two examples are provided in Appendix A. One of these is based on the original proposal for the AquaSpace project, while the other is a study (small-scale in comparison) of knowledge about the EAA and the benefits of applying it.

[12] www.fao.org/fishery/culturedspecies/search/en

12 Self Assessment Questions

The SAQs that follow test your achievement of the learning outcome for this unit, which include an understanding of the theory, methods and issues introduced in other units of the course.. No answers are given.

1. Describe the 'state of the art' in deciding where to position an AZA (Allocated Zone for Aquaculture) in the case of fin-fish.
2. Contrast the zoning issues in your answer to the previous question, with those applicable to fish-farm site consenting.
3. Give an example of an actual or hypothetical aquacultural development that respects the principles of the EAA.
4. Distinguish between net-pen farming of fin-fish and long-line cultivation of mussels in terms of environmental impact, farm economics, and social attitudes.
5. Make the case for societal subsidy of certain forms of aquaculture in return for provision of ecosystem services.
6. Explain what restricts aquacultural expansion within 1 n.m. of the shore.
7. What kinds of research into aquacultural issues should be publicly-funded and which should be left to industry?

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Appendix

A Example research proposals

Two examples are provided. The first is large-scale and adapted from the original proposal for the AquaSpace project.

Issue to be addressed

Allocation of aquaculture space has constraints set by legislation, carrying capacity issues of production, ecology, economy, and society, as well as conflicts with other users. Aquaculture grows more readily in areas with spatial plans because many of these fundamental issues of site selection have already been addressed during the planning process, so reducing demands when preparing new applications. However, this only works well if an Ecosystem Approach has been adopted during the planning process: one which involves a thorough evaluation of the spatial interactions in the area and engages all the relevant stakeholders in a sensitive and iterative manner to ensure that the interests of other users have been fairly considered and public anxieties assuaged in an appropriate manner.

Aim of the proposal

The AquaSpace project has the goal of providing increased space for aquaculture to allow increased production.

Methods to be used

We will achieve this by by identifying the key constraints experienced by aquaculture development in a wide range of contexts and aquaculture types, taking into account all relevant factors and advised by a Reference User Group. We will then map these constraints against a wide variety of tools/methods that have already been developed in national and EU projects for spatial planning purposes. In the freshwater sector only, we will also consider ecosystem services provided by aquaculture that are relevant to integrated catchment planning and management. At 16 case study sites having a variety of 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, we will assess appropriate tools using a common process so as to facilitate synthesis and comparison. Findings will be presented on an interactive web-based platform with tailored entry points for specific user types (e.g. planners, farmers, public) to enable them to navigate to the tools most appropriate to their application. The knowledge and information gained during this process will be developed into an on-line module at Masters Level which will also be developed into a short CPD course aimed at aquaculture planning professionals. The public will be engaged by an innovative school video competition and a vehicle to ensure project legacy will be established.

The second is, in comparison to the above, small-scale; for this reason it might not lead to definitive conclusions about the EAA, but should provide insights into understanding and application of the EAA.

Issue to be addressed

The three principles of the Ecosystem Approach to Aquaculture (Aguilar-Manjarrez et al., 2017) are intended to provide an environmentally sustainable and socially equitable basis for the expansion of aquaculture. However, it is unclear how far they are incorporated into local regulation of different types of aquaculture, if regulators are adequately aware of them, and how much they influence outcomes for ecosystem health.

Aim of the proposal

The aim of the proposal is understand regulatory knowledge, use, and impact of the EAA principles, in Scotland.

Methods to be used

Marine Spatial Planning in Scotland is being implemented through Regional Marine Planning Partnerships. We will use a comparative approaching, studying documents on aquaculture policies and interviewing RMMP members in two existing partnerships for evidence of knowledge and use of the EAA principles. The two partnerships are in socially and environmentally contrasting parts of Scotland, but both embrace salmonid and bivalve cultivation. In addition we will examine recent reports from Scotland's environmental protection and biodiversity protection organisations concerning the ecosystem health of marine waters (using WFD and MSFD criteria), to see if differences in health can be related to differences in application of the EAA.

B Types of aquaculture

This appendix expands the summaries in section 4.

High intensity farming

Net-pen farming of Atlantic salmon (and some rainbow trout) takes place mainly in cool northern well-oxygenated salt waters, with young fish reared in freshwater hatcheries. Net-pen farming of sea-bass and sea-bream takes place mainly in the warmer waters of the Mediterranean, with young fish reared in salt-water hatcheries.

Such farming is a highly intense activity in terms of biomass and waste production per hectare, requires substantial capital investment, employs comparatively few staff on each farm because of automation, and is typically profitable for farm owners so long as diseases can be avoided.

In all cases of net-pen farming the main environmental concerns are of (i) the input of sinking organic matter on sea-bed biota, especially on sea-grass meadows in the Mediterranean (Holmer et al., 2008) and on soft-sediment zoobenthos beneath salmonid farms; and (ii) the risk of eutrophication resulting from nutrient releases REF. In the case of salmonids, sea-lice parasites are an additional concern; they can infect wild salmon, and the chemicals used to treat them can be harmful to other aquatic life REF. The use of zoning to reduce sea-lice cross-infection was studied during the AquaSpace Norwegian and Scottish case studies.

Sustainability of feed is a major issue (Ytrestøyl et al., 2015) as world supplies of fish-meal and fish-oil are at their limits, and replacement by vegetable protein and oil requires use of land.

Some relevant numbers relating to intensity were provided by Bostock et al. (2010). According to them, the mean production density of cage-grown sea-bass and sea-bream is 1125 t ha^{-1}, and that for cage culture of salmonids as 1750 t ha^{-1}. However, these figures seem likely to be based only on the sea-surface area of the cages, rather than the sea-bed footprint of the group of cages making up a farm. AquaSpace's Norwegian case study reported average production density for salmon farming as 345 tonnes per hectare.

Taking the AquaSpace figure and applying a standard model for feed conversion (Black, 2001) and assuming that salmon feed is 30% marine fish from trophic level 3 and 70% derived from soy, suggests that providing feed for a hectare of salmon consumes the primary production of about 7 thousand hectares of sea and about 100 hectares of land.[13]

Extensive farming

The cultivation of *marine shellfish* studied in AquaSpace included: sea-bed ranching of mussels in Carlingford lough, clams in the Adriatic, and oysters in New England; cultivation of oysters in sea-bed structures in Normandy and China with spat obtained from hatcheries; and farming of mussels on posts, tables or attached to long-lines (in Adriatic, Algarve, Basque Country and Normandy studies) with either natural or hatchery seeding.

The production intensity of shellfish is at least an order of magnitude less than that for finfish, and hence shellfish farming requires more area than finfish farming per unit of output; however, it can contribute ecosystem services, especially removal of POM and nutrient-stimulated phytoplankton; and in feeding on phytoplankton and organic detritus it is exploiting a food source not otherwise usable by humans; finally, the risk of harmful algae to the cultivated shellfish, and to their human consumers, is growing in importance.

Data from the case study in Sanggou Bay, China, suggests oyster yield of 32 tonnes (wet weight) per hectare, with 3.3 t ha^{-1} for scallops. A DEB model for loch Creran, in Argyll, Scotland suggests 3.1 t ha^{-1} based on consumption of all available phytoplankton production in the farmed area (Tett, unpublished). Bostock et al. (2010) report 76 t ha^{-1} of mussels, but it is clear from their values for water use that this production relies on the supply of phytoplankton/POM from a much wider area. Thus, despite the range of values given here, both the demand and the yield intensities of shellfish farming is at least one, and often two, orders of magnitude less than that of cage-farming of finfish, and this impacts on profitability.

The only example of the cultivation of *marine invertebrates* other than bivalve molluscs was that of sea-cucumber farming

[13] The marine fish that are the source of fish protein and fish oil are typically forage fish such as anchovetta, which feed on zooplankton that has fed on phytoplankton, the latter with a typical annual primary production of 100 g C m^{-2} yr^{-1}. Trophic transfer efficiency (e.g. phytoplankton to zooplankton, is usually taken as 10%. Typical production of soy protein taken as 3.4 t ha^{-1} yr^{-1}, from Langemeier, M. and E. Lunik (2015). International Benchmarks for Soybean Production, farmdoc daily (5):225.

noted in the China case study. The cultivation of *seaweeds* also featured in the China case study, but is only in the early stages of development in Europe. Because seaweeds are mostly water, the production of significant amounts of biomass will require very large areas, with consequences for environmental and visual impacts that are yet to be explored.

Ponds

Fin-fish in freshwaters: pond-farming of trout and carp takes place in many European countries; carp being reared on pond production of invertebrates, while trout require manufactured feed; in the Hungarian case study, carp farming was a comparatively low-intensity, low-technology activity that may enhance local ecosystem services. It is reported that Hungarian pond farming currently provides lower income per hectare than grain farming; providing payment for ecosystem service enhancement might improve fish-farm budgets and thus encourage expansion.

RAS

Recirculating Aquaculture Systems (RAS) recycle up to 90% of the water they use, by removing nutrients and organic waste. They provide controlled and biosecure conditions, but are capital and energy intensive (see unit 1, appendix A). They are currently increasingly used for rearing young of cultivated organisms, but were not studied in AquaSpace.

IMTA

IMTA, Integrated Multi-Trophic Aquaculture, involves the waste products from one food production process being converted into valuable products by other farmed organisms, a process that decreases waste and increases the efficiency of the food production system (Hughes and Black, 2016). It is thus best seen primarily as a way of increasing output from existing farmed areas, secondarily as reducing nutrient and organic loads. This could occur on three spatial scales:

- *river basin scale* exemplified by the Adriatic and Normandy case studies, where shellfish benefit from (mainly agricultural) nutrients discharged by the Po and Seine rivers;
- *Water Body scale IMTA* exemplified by the AquaSpace case study in Sangguo Bay, combining cultivation of waste-producing caged fish with shellfish, invertebrate and seaweed culture over 130 km^2 in China the benefits outweigh the costs of additional complexity, but this is not the case in Europe where the market value of the extractive species is perceived as small compared with that of fin-fish (Hughes and Black, 2016);
- *farm-scale polyculture* it is impractical and unnecessary to combine filter-feeding bivalves and seaweed with net-pen cultivation within the limited area of a farm; however, worms or echinoderms might be reared beneath fish cages, and some use might be made of nutrient-stripping algae in RAS. These possibilities were not studied during AquaSpace