# Introduction to AquaSpace integrating tools

Vanessa Stelzenmüller, Antje Gimpel (Thünen Institute)
Paul Tett (SAMS)

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## Abstract

*This text is part of the introduction to a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture' made by the AquasSpace project. It introduces the principles behind tools for Marine Spatial Planning and site selection for aquaculture. Four tools are described. The META tool assembles data on growth conditions for cultivated species. The other three are spatial tools: WATER identifies locations (in Europe) where these species can best be grown; the Aqua Investor Index guides selection of a country for investment; and the AquaSpace Tool - considered at length - evaluates sites and scenarios.*

## Contents



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# 1 Unit 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 provides an introduction to the principles underpinning the tools developed by AquaSpace partners to optimise the use of marine space against multiple (economic, environmental and social) criteria.

Four tools are described here: the cultivated species data-base *META*, and three spatial tools: *WATER* for identifying locations within Europe where particular species can best be cultivated; the *Aqua Investor Index* that helps investors to identify the best European country in which to invest in aquaculture, and the *AquaSpace Tool* for evaluating sites and scenarios. It is the last of these that is considered in most detail.

The unit comprises a text (the document you are now reading), a set of slides, required further reading, and some exercises. The text provides an introduction to the slides, which can be used as the basis for a class-room lecture about the AquaSpace Tool.

The first set of learning outcomes for this unit relate to understanding the main theoretical principles used by the tools, After studying the materials, you should be able to

- explain the need for a variety of indicators to support marine spatial planning;
- describe a selection of indicators used in the spatial tools, explain the way the indicators are calculated and where the necessary data can be obtained;
- explain and critically discuss the way in which indicator values are integrated in the spatial tools

The second learning outcome requires access to ArcGIS software and familiarity with the use of this GIS (Geographic Information System). In this case, you should be able to

- demonstrate an application of the AquaSpace tool, for example by reproducing the AquaSpace 'German North Sea' Case Study

Although unit 5 in this module introduces the principles behind GIS, the module is not intended as a vehicle for teaching or learning about GIS technology and use.[1]

# 2 Introduction

Picture a map, made up of pixels (figure 1). Take one pixel. A developer might ask, can I put a mussel farm there? A planner might answer, no, the space is already occupied by a wind turbine. Or, yes, subject to certain restrictions relating to environmental disturbance. Imagine that this question has been asked for all pixels, so that the developer now has a map of where they might

[1] Those who are already familiar with GIS technology will recognize that the description given in this text is simplified. Important discrepancies are footnoted and listed in appendix A. The purpose of the simplification is to enable our account to focus on the principles by which the uses of space can be optimised rather than the specific way the principles are applied using a particular GIS software.

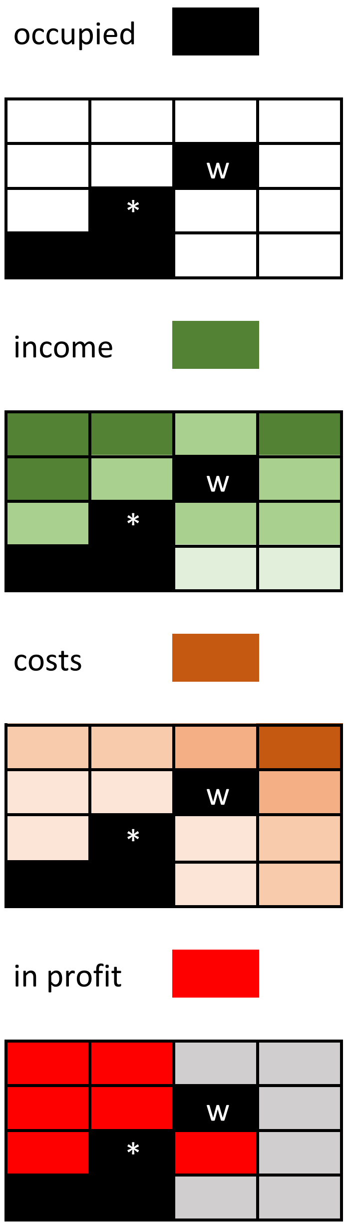


Figure 1: Simple spatial planning map: 4× 4 pixels. 'Occupied' pixels are those on land or already assigned for use. Operating port shown by star, and wind farm by 'w'. Income proportional to growth rate of mussels and thus on amount of phytoplankton. Costs depend on distance from port. Only red pixels return a profit.

place their proposed farm. What they now need to decide is where they will actually place it. A simple answer from the economic perspective is, place it where it will make the greatest profit.

A business has costs from labour and consumables and from paying interest on loans used to buy equipment. It derives income from selling its product. Let's assume that there is fixed cost for farm equipment and mussel spat delivered to a port. Mussels grow faster in waters with more phytoplankton, thus generating more income; however, maintenance and harvesting costs increase with distance from port. In principle, the best place to site the farm will be where profit is greatest, i.e. where the excess of income over costs is greatest.

Figure 1 shows one of the pixels already assigned to a wind farm (i.e. a group of turbines harnessing wind energy). It might be possible to combine wind and mussel farming, but for the present the two uses will be seen as mutually exclusive. Suppose that a planner is required to decide between permitting a wind farm and permitting a mussel farm at a particular site. A simple way to make this choice would be to compare the potential profit for each use.

In this example, profit or profitability, expressed in euros or dollars, pounds or krone, is being used as a single indicator of the best places to site various activities in the sea, where 'best' is to be understood in terms of optimum social benefit as well as the interests of the aquacultural industry. However, in many cases it will be necessary to take account of a wider range of factors that will or should influence a decision to site a farm in a given location, or designate a zone for aquaculture. Sometimes all these factors can be quantified in money units, but when that it is not possible or desirable, an alternative is to use tools that can provide multi-variable assessments. One of these is the AquaSpace Tool. We call it an **integrative tool** because it assembles information relating to the environmental and social effects of aquaculture, as well as to the economics of the industry.

## 3 Layers

The maps of figure 1 could be realised as a base-layer chart showing coastline, water depths, etc, and three transparent overlays or data layers. Given a numerical computer and appropriate software, the layers can be gridded, as in the figure, so that each cell (or pixel) in each layer can be assigned a numerical value in an array in computer memory. In order to reference these numbers, a co-ordinate system is needed: for example using $x = 1 \ldots 4$ to refer to the horizontal direction, numbering columns from left to right in the matrices in figure 1), $y = 1 \ldots 4$ to refer to the vertical direction, numbering rows from bottom to top, and $z = 1 \ldots 4$ to refer to map layers.

Thus, income$[x = 4, y = 4, z = 2]$ refers to the number in the top-right-hand corner of the second grid, and the following 'pseudocode' specifies the calculation of the profit layer:

```
with x values from 1 to 4,
 with y values from 1 to 4,
  compute profit[x,y,4] =
    income[x,y,2] + costs[x,y,3]
 (continue with next y)
(continue with next x)
```

One more step is needed for this software to become a Geographic Information System (GIS). In such systems, the grid is georeferenced, which is to say linked to latitude and longitude on the surface of planet Earth. Thus, a reference to the *resolution* of the grid is to be interpreted as the dimensions of the grid mesh when projected onto physical space, i.e. the real-world size of each grid element or pixel.[2]

Users of a real GIS need to define layers, populate them with data, and decide on rules for combining values. The AquaSpace Tool is the result of decisions about layers and combinatorial rules. It also provides a European-scale data base that can be drawn on to populate many of the information layers used by the Tool. As will be seen, it is much more complex in the data it uses and its combinatorial rules than the simple example just considered.

## 4 Indicators

The English-language definition of *indicator* is 'a thing that indicates the state or level of something'. Unit 2 defined indicator as 'a variable that quantifies some aspect of a complicated system, such as an ecosystem' and considered indicators within the frame of environmental monitoring and adaptive management of aquacultural enterprises. In the present context, 'indicator' is used with the meaning of 'something to

[2] *Resolution* and *scale* are different. At a *scale* of 1:10,000, 1 cm on a map corresponds to 100 m on the ground. *Resolution* refers to the real-world spacing of data, which might for example have been obtained at 1 km intervals, with interpolation between values for maps displayed at larger scales.

be taken into account in making an investment or planning decision', and, therefore, something that might be allocated a GIS layer to show how it varies with space.

Many of the indicators described in the following sections are constructed or compiled by processing data sets, such as those obtained by Remote Sensing of the coastal ocean or by mapping the sea-bed or the distribution of the human population. These underlying data distributions may also be assigned layers in a GIS.

# 5 AquaSpace Tool

During the AquaSpace project, stakeholders identified the need for a spatial planning tool that could integrate over many indicators of *risk* and *opportunity*.[3] The AquaSpace Tool was developed to provide such a tool (Gimpel et al., 2018).

## 5.1 Overview

The Tool comprises a set of computer program and data files for use with ArcGIS software. They can be obtained by way of the link at the Thünen Institute AquaSpace Tool page, and installed as instructed in the Tool handbook (Gimpel et al., 2017).

[3] The phrase *costs and benefits* is sometimes used instead of *risk and opportunity*. The latter terms could be seen as the 'future tense' of the former. Considered solely in terms of business economics, the opportunity offered by a development is that it will, eventually, return a profit, the risk is that it will make a loss. In addition, planners will want to consider opportunities to benefit society at large, for example through increased employment, and the likely costs of risks to the environment through disturbance or pollution.

ArcGIS is a commercial Geographical Information System (GIS) and the use of the Tool within this system requires familiarity with this software. However, we do not assume such knowledge, or the availability of an ArcGIS licence. Our aim, here, is to introduce and explain the main principles that underpin the Tool and which need to be understood for any evaluation of competing claims on the use of maritime space or to make the best decision about where to site a farm.

Suppose that an entrepreneur wishes to develop a farm for sea-bass in the coastal waters of a northern European country. A preliminary analysis identifies 15 possible sites (figure 2. Thus there are 15 possible development scenarios, one for each site. The main output from the Tool is the 'wheel diagram', figure 4, which allows the comparison of the 15 scenarios using 27 indicators of risk and opportunity.

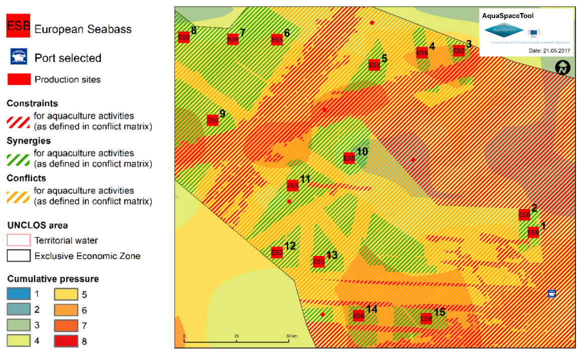


Figure 2: AquaSpace Tool: example map. This shows 15 sites for sea-bass farms within German territorial waters of the North Sea.

The indicators are grouped into 4 categories:

**Inter-sectorial:** dealing with potential for spatial conflicts or synergies, and the need for minimum distances between activities;[4].

**Environmental:** dealing with the suitability of the local environment for the farmed species and the environment's local sensitivities to farming of this species;

**Economic:** dealing with the likely economic performance of the proposed farm, and its benefits for the wider economy;

**Socio-cultural:** dealing with the variables that affect *social licence*.

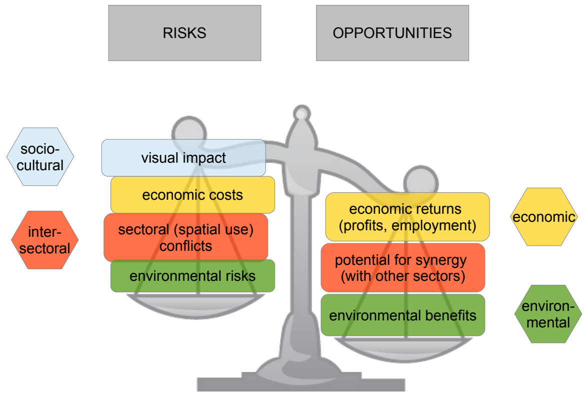


Figure 3: Balance for weighing Risks and Opportunities, using the indicator categories of the AquaSpace Tool. Imagine this balance placed in each pixel in figure 1 or at each potential site in figure 2.

Whereas a developer might be mainly concerned with the economic indicators, a planner, acting on behalf of society, will try to make an over-all evaluation of the risk-opportunity balance (figure 3) for each pixel in which a farm site is proposed. In the following sections we describe only one or two indicators from each category; for full details, consult the Tool handbook (Gimpel et al., 2017),

## 5.2 Inter-sectorial

EAA principle (iii) states that "[a]quaculture should be developed in the context of other sectors, polices and goals ..." (Aguilar-Manjarrez et al., 2017). Thus, two of the 'inter-sectorial' indicators in the AquaSpace Tool consider the potential of a proposed farm site for conflicts and synergies with other industrial sectors.

In addition, there are two special cases. One relates to synergies within the aquacultural sector through the co-cultivation of different kinds of organisms, i.e. to Integrated Multi-Trophic Aquaculture (IMTA). The other relates to the risk of disease spreading between sites with similar organisms, i.e. to conflicts within the sector.

The conflict indicator provides the example from this category. Each of the potentially conflicting sectors in table 1 requires GIS layers showing zones or sites assigned to them. For example, farms are incompatible with shipping lanes (so conflict with 'Marine Traffic' is assigned a high value), but may be able to co-exist with cables and pipelines already installed on the sea-bed.

According to the simplified GIS account used here, the value of the conflict indicator

[4] According to the simplified account of GIS used here, a minimum distance could be ensured by a rule that allocated no more than one activity to each pixel. See appendix A for an account of how it is done in the AquaSpace Tool

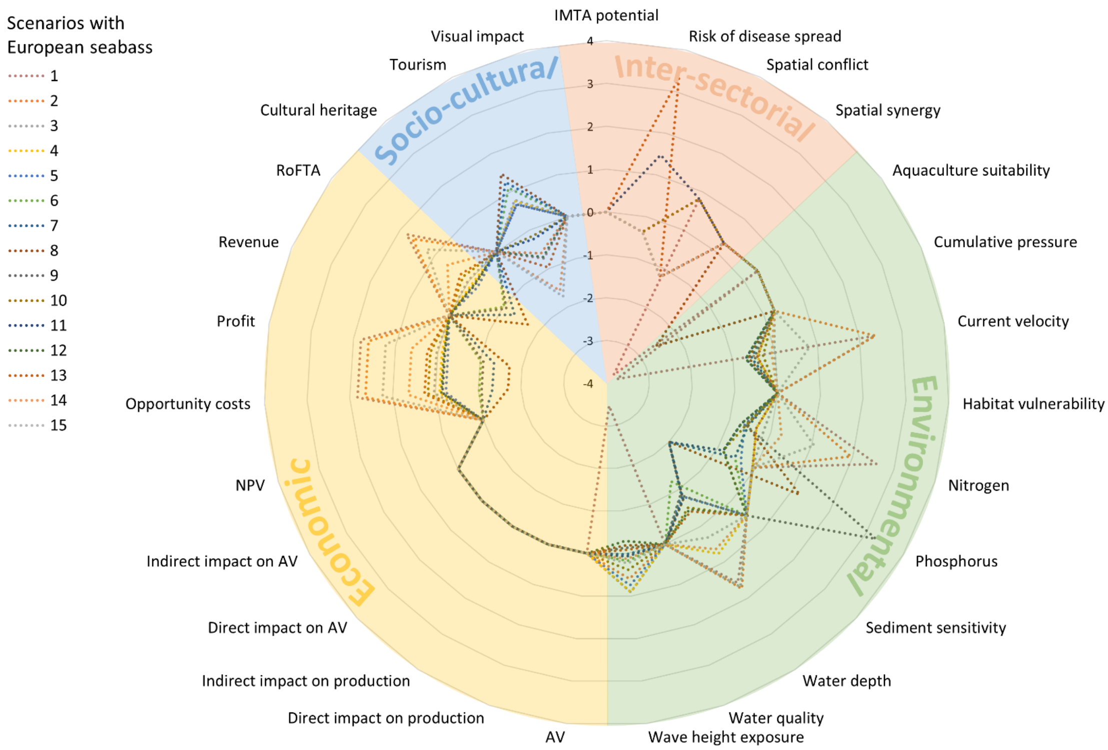


Figure 4: An example of a 'wheel diagram' output from the AquaSpace Tool for use in comparing scenarios using values of the 27 indicators named around the periphery of the wheel. Each indicator value has been normalised with a z-transformation.

Table 1: AquaSpace Tool: other sectors and their potential conflicts with aquaculture. 0 = no conflict; 5 = mutually exclusive. From Gimpel et al. (2013). *Tourism is treated by the tool as a socio-cultural indicator rather than potentially conflicting sector.*

| | |
|---|---|
| (Capture) Fisheries | 5 |
| Ocean Energy (offshore wind) | 2 |
| Platforms (Oil, gas) | 4 |
| Cables | 0 |
| Pipelines | 0 |
| Sediment extraction | 5 |
| Marine traffic | 5 |
| Waste Disposal | 5 |
| Marine Protected Areas (MPA) | 4 |
| *Tourism ('Economic')* | *(3)* |

is the sum of the values in table 1 for each sector present at the proposed farm site - i.e. falling in the same GIS pixel.[5]

## 5.3 Environmental

EAA principle (i) states that "[a]quaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience" (Aguilar-Manjarrez et al., 2017). Therefore the Tool takes account of environmental sensitivity to the activities of the farm at the site in question. As an example, the *habitat vulnerability* indicator assigns values to sea-bed habitats classified according to EUNIS (the European Nature Information System) of the European Environment Agency. Table 2 gives a few examples.

[5] In fact the AquaSpaceTool detects conflicts on the basis of a 'footprint' drawn around each proposed site and the overlap of this footprint with locations specified for the competing activities.

Table 2: Vulnerability of some EUNIS-coded habitats to aquacultural activity. 1 = least vulnerable, 3 = highly vulnerable.

| Habitat | code | vuln |
|---|---|---|
| High energy infralittoral rock | A3.1 | 1 |
| Circalittoral sandy mud | A5.35 | 2 |
| Seagrass beds | A5.33 | 3 |
| Maerl beds | A5.51 | 3 |

For example, *maerl* is a slow-growing calcareous red seaweed forming the basis of sea-bed communities that are often legally protected under national transpositions of the EU Habitats Directive. Proposing to site a farm in a pixel corresponding to a sea-bed where maerl has been identified, would score high and be identified as undesirable.

In addition, each type of cultivated organism grows best under a particular range of environmental conditions. The AquaSpace gets values of environmental suitability for the cultivation of the selected organism from the WATER database described in section 6.

## 5.4 Economic

The 10 indicators in the 'Economic' category of figure 4 are of two kinds. *Direct* indicators quantifies potential benefits to developers; *impact* indicators explore potential effects ton society. Of course, developers may wish to assess impacts as part of a case for a development permit.

A simple profit indicator was discussed in sections 2 and 3. The formula for the *profit* indicator used in the Tool is

```
profit = (production * market price)
  - operating costs, wages, etc
```

where `operating costs` includes fuel for boats travelling to the farm site and so depends on distance from the harbour used as a base for operations. The user of the tool is asked to supply relevant information that depends on type of cultivated organism, technology, and local economic conditions.

Operating a new farm adds to regional and national GDP both through the output of the farm (and the wages it pays its employees) and by stimulating demand in other economic sectors, such as those manufacturing farm equipment or engaged in processing the products of aquaculture. The Tool uses a procedure standard in economics, the Leontief Input-Output Model, to calculate these effects; it requires data specific to the economy of the country. The results are used for the four *impact* indicators. Because these indicators are computed from national statistics, their values as displayed in figure 4 do not differ amongst scenarios/sites. However, the Tool also outputs economic reports that might, for example, be used to assess the societal value of different types of aquaculture, or to compare use of sites for farming wind or fish.

Relevant here is EAA principle (ii): "[a]quaculture should improve human well-being with equity for all relevant stakeholders (e.g. access rights and fair share of income)".

## 5.5 Socio-cultural

EAA principle (ii) is also relevant here. *Ecosystem services* theory (discussed in unit 2) describes a number of intangible or cultural benefits that people receive from marine ecosystems. Quantifying these is a difficult task (Kenter et al., 2015, 2016), and the AquaSpace Tool considers only the visibility of potential sites as its socio-cultural indicators. Roughly speaking, the indicator is the inverse of the distance between the site and locations on land, or on sea-routes used by tourists, from which the site might be visible. Visibility is assumed to detract from the value of a site. Visibility theory is further discussed in unit 9.

## 5.6 Data

The AquaSpace Tool's indicators use many kinds of data. Some of these data are specific to local conditions, or to the methods and management of the proposed farm, and must be entered by the Tool user. Other data have been compiled as part of the AquaSpace project and are provided in a data-base accompanying the tool. Because the data-base covers the whole of Europe, its spatial resolution is moderate, and Tool users may wish to acquire higher- resolution data for a region of interest.

Table 3 gives some example data sources for the Tool. For complete details, consult the AquaSpace Tool handbook (Gimpel et al., 2017).

As should be apparent, MSP requires much information about the spatial distribution of environmental characteristics and human activities. Much of the work involved in creating the AquaSpace tool was concerned with the identification and assembly of data-sets, and these provide part of the value of the tool. In some cases, data will need updating – for example as water temperatures (used to assess *Aquaculture suitability*) change due to global warming – and this may require new data-sets to be downloaded from their sources. It is possible that such updating can become semi-automatic, as tools communicate directly with data providers through *web services*.[6]

Table 3: Example sources of data for the AquaSpace Tool.

| | |
|---|---|
| *Spatial conflict* e.g. with Ocean Energy | European Marine Observation and Data Network: EMODNET: 'Search data' under theme 'Wind Farms' |
| EUNIS habitat maps for *Habitat vulnerability* | EMODNET seabed habitats |
| *Water Depth* | EMODNET-bathymetry-Digital Terrain Model |
| Population distribution for *Visual impact* | Statistical Office of the European Union: EUROSTAT - GEOSTAT |

## 5.7 Integration

The AquaSpace Tool was designed for integration, which is to say the bringing together of information, quantified in a variety of indicators, to support judgements about siting a new farm. The 'wheel diagram' of figure 4 is designed to provide this support by allowing comparisons to be made between scenarios or sites. However, one more data-manipulation step is needed before values of the variety of indicators can be shown together.

The problem lies in the range of values within and between indicators. For example, the *revenue* and *profit* indicators in the 'Economic' category of the AquaSpace Tool could return values in the millions of euros, whereas the *IMTA potential* from the 'Intersectorial' category can have values of either 1 or 0. The Tool therefore uses a *z-transformation* to allow the user to focus on

[6] A *web service* is a service offered by an electronic device to another electronic device, communicating with each other via the World Wide Web and using an interface definition language in which the first device specifies the data it requests and the second device describes the data structure that it returns. (Wikipedia)

differences between sites/scenarios.

Let $C_i$ refer to the value of a particular indicator at site $i$ and $\overline{C} = \frac{1}{n}\sum C_i$ to the average over all $n$ sites. The transformation is

$$z_i = \frac{C_i - \overline{C}}{\sigma_C} \quad (1)$$

where $\sigma_C$ is the standard deviation of the values of the indicator over all sites/scenarios considered.

The comparisons in figure 4 allow the 'best' site to be identified, all sites being considered for the same purpose of growing sea-bass. The tool can also allow comparison of the risks and the opportunities from cultivating different types of organisms, which is why the comparison dimension is also called *scenarios*.

# 6 WATER and META

The two web-based tools META and WATER contribute information to the AquaSpace (GIS add-in) Tool that has just been described, and to the Investor Index (app) that is described in section 7.

META abbreviates 'Maritime and Environmental Thresholds for Aquaculture' and can be accessed at the Longline Environment META website It assembles data on the environmental requirements of a variety of cultivated aquatic organisms. This includes information on temperature, salinity, dissolved oxygen, ammonia and current speed, amongst other variables.[7] A few examples of temperature data are listed in Table 4.

Table 4: META database: some temperature data. 'Thr[eshold]' gives minimum and maximum tolerable temperatures, 'Opt[imum]' gives best range for growth, °C.

| Organism | Thr | Opt |
|---|---|---|
| Salmon (*Salmo salar*) | 2 – 24 | 10 – 16 |
| Sea-bass (*Dicentrarchus labrax*) | 2 – 32 | 19 – 25 |
| Mussel | | |
| (*Mytilus edulis*) | 2 – 27 | 8 – 18 |
| (*M. galloprovinicalis*) | 5 – 30 | 14 – 20 |

WATER abbreviates 'Where can Aquaculture Thrive in EuRope' and is available at the Longline Environment WATER website. As described by Boogert et al. (2017), it brings together information on spatially varying environmental parameters from a variety of sources (exemplified in Table 5), and uses these data in combination with the species characteristics provided by META to make maps such as that in Figure 5. These then provide the *Aquaculture suitability* layer for the species in the AquaSpace tool.

WATER divides the European EEZ into 1 km$^2$ pixels and assesses the value of each environmental parameter within each pixel in relation to the requirements of a selected species. The assessment used a scale from 1 (unsuitable) to 5 (highly suitable). The variables were selected to represent biologic tolerance of the species and operational constraints of the culture practice.

For example, a pixel which has 5 or fewer months in the year outside the 14 to 20 °C

[7] More information about the META database is given by Boogert et al. (2017), who refers to it as the 'WATER species database' because it is used by the WATER tool.

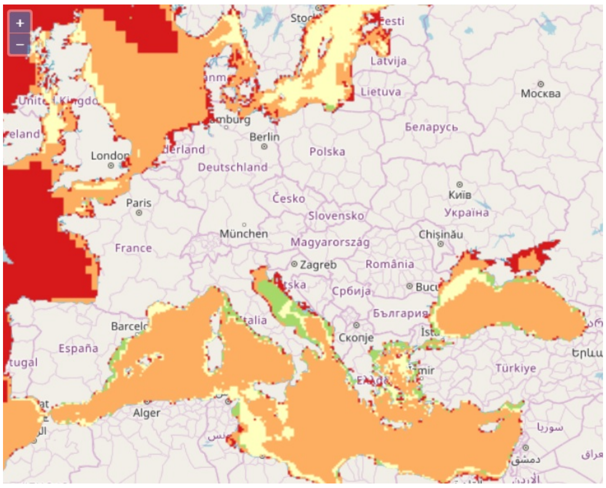


Figure 5: Screen grab from WATER website, mapping the distribution of conditions for the Mediterranean mussel, *Mytilus galloprovincialis*, Pixels with good conditions are coloured green, moderate conditions yellow.

Table 5: Example sources of data for the WATER Tool.

| | |
|---|---|
| *Water temperature* | (EU) Marine Environment Monitoring Service, using remote sensing: COPERNICUS: 'Services Portfolio' – 'Access to Products', 'Parameters' – Temperature |
| *Water Depth* | General Bathymetric Chart of the Oceans GEBCO |

range that is optimal for growth of *Mytilus gallprovincialis* would score 1 for cultivation of this mussel, whereas if there are 11 or more months within the optimum interval for temperature, a value of 5 would be scored. The scores for all relevant variables are then brought together and the minimum score used for the map (and for the *Aquaculture suitability* indicator in the AquaSpace Tool). Thus the green areas in figure 5 represent pixels where no variable scored less than 4. In the case of mussels, the relevant variables are water temperature, chlorophyll, dissolved oxygen, wave height, current speed and water depth.

# 7 Aqua Investor Index

A fourth tool developed during AquaSpace was the Investor Index, which allows the comparison of (European) countries as potential hosts for investment in aquaculture. It uses 20 indicators to produce the results shown in figure 6. The indicators are arranged in five categories (table 6), with details and data sources given in the tool handbook (Ferreira et al., 2017).

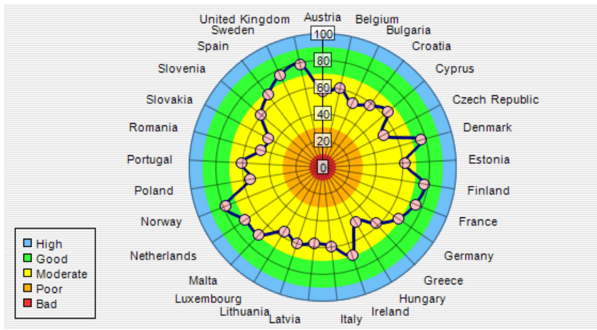


Figure 6: Investor Index Output

Table 6: **Categories** and Indicators used in the Aquaculture Investor Index

| | |
|---|---|
| **Market** | Price (for aquacultural products), Consumption (fish), Economy (GDP/capita etc), Infrastructure (transport) |
| **Production** | Hatchery & nursery (for eggs, young fish or spat), Coastline (site suitability), Digital capacity (internet), Insurance (availability) |
| **Regulation** | Institutional (quality), Business-friendly, Licensing (time required for aquculture), Fiscal (tax etc burden) |
| **Environment** | Depth (of sea in EEZ), Temperature (marine 'climate'), Current speed (areas in classes), Dissolved Oxygen (areas in classes) |
| **Social** | Legal (reliability and acceptance of rule of law), Sectoral (aquaculture as proportion of 'fish economy'), Education and Training (at tertiary level), Corruption (public power used for private gain) |

Indicators are complex constructions from data. To take an example, the *Temperature* indicator is constructed from sea-surface temperature data taken obtained by Remote Sensing. The data have been used to construct a climatology for each cluntry, a typical annual cycle of temperature averaged over all that country's seas. Three cultivated species (sea-bass, sea-bream and salmon) are evaluated (for each country) by computing the number of months in the year for which the climatological water temperature is within the optimum range for each species (taken from META). Finally, the species with the greatest number of suitable months is chosen, and this month number converted to a value between 0 and 5.

Each indicator returns a value between 0 and 5, as in the temperature indicator example. Thus the maximum possible score is 20 ior each indicator category, and the Investor Index values can range between 0 and 100. The wheel diagram shown in Figure 6) allows two kinds of judgement.

- An investor can compare scores amongst countries to decide where to fund aquaculture;
- Public authorities in low-scoring countries can identify what needs to be done to attract investment.

For both purposes it may be useful necessary to drill down into the Index. As an example, Table 7 compares category scores for Belgium and Croatia, which score similarly overall, but differ in their details.

The authors of the Investor Index decided to give equal weight to all the indicators. However, some users of the results may disagree with this, thinking (for example) that

Table 7: Investor Index: a comparison of category scores for two countries, BE (Belgium) and HR (Croatia). Values from Ferreira et al. (2017).

| Category | BE | HR |
|---|---|---|
| Market | 15.3 | 9.7 |
| Production | 10.7 | 12.8 |
| Regulatory | 11 | 12 |
| Environmental | 12 | 17 |
| Social | 11.5 | 6.7 |
| Investor Index | 61 | 58 |

the 'Market' category of indicators is more important than the 'Social' category. The tool allows such users to explore the effects of changing the category weightings between 0.5 and 1.5 relative to other categories.

# 8 Discussion

This text has mentioned four tools developed during the AquaSpace project:

**the META tool** provides data on environmental thresholds for cultivation of aquatic animals and algae: available at Longline Environment META website

**the WATER tool** shows where these organisms will grow best in European waters; available at Longline Environment WATER website

**the Aquaculture Investor Index** brings together aquaculture-related information on markets, production capacity, regulation, natural environment, and societal organisation in each European country; it is an app available from Google Play: see also Longline Environment Investor Index page

**the AquaSpace tool** includes files of geo-referenced data for many spatially-varying environmental and social variables across Europe, and can be obtained by way of the link at the Thünen Institute AquaSpace Tool page

All four tools synthesise many data, and the three spatial tools use these data for integrated assessments. Each integrates in a different way. The Investor Index adds values from the 20 indicators, each of which can range from 0 to 5. WATER selects, in each pixel, the minimum score from the set of relevant scored variables. The Aquaspace Tool $z$-transforms each indicator value for comparability, but does not aggregate them.

How to integrate over a variety of indicators is a well-known problem in assessment of ecosystem state (Borja et al., 2014), and there is no agreed solution. When they try to put a monetary value on ecosystem services, environmental economists in effect propose conversion to euros or dollars as an integrating method. This was the simple method set out in section 2, and it it remains in use in environmental cost-benefit analysis, as for example when public authorities decided whether to proceed with a coastal realignment scheme (da Silva et al., 2014). However, it is thought to be inadequate to deal with complex situations involving many criteria (Turner et al., 2015).

Nevertheless, the use of a conceptual balance in Figure 3 points to the need for a single integrating variable so that each indicator carries appropriate weight in the final decision about which site or scenario to select. The concept of *utility* (Appendix B) might be helpful here. Utility is the capacity of something to satisfy human well-being needs. A planner could aim to identify the scenario or site that has the greatest utility for society, because it provides the greatest possible increase in well-being amongst people affected by the choice. However, while this seems a satisfactory theoretical solution to the integrating problem, the practical issue is that of finding conversions from indicator values to utility.

Supposing that were possible, it seems a logical development for tools such as the AquaSpace Tool be evolved into an Artificial Intelligence to make planning decisions by maximising utility. Expert judgement and human agency would be embedded in the tool's programming in respect of the choice of indicators and the indicator-utility conversion, but subsequent decisions would be made purely algorithmically. Such an approach to MSP might be attractive to public authorities, because removing the human element not only decreases costs but also removes the vagaries and delays of human decision making,

But is this the way to go? The alternative is to keep the tools we have described here as decision support systems, augmenting rather than replacing human *agency*, and able to make use of social deliberative processes such as those introduced in unit 10. In either case it is likely that the tools will evolve with further research and changes in data availability and computing technology.

# 9 Exercises and Reading

Read the paper by Gimpel et al. (2018) that describes the AquaSpace Tool. After this, two options are suggested:

1. if ArcGIS is available, read the AquaSpace Tool handbook (Gimpel et al., 2017), install the Tool databases and software, and carry out the exercises proposed at the end of the slides that form part of this unit;

2. otherwise, read the Investor Index handbook (Ferreira et al., 2017), especially tables 1 – 6 to understand the nature and relevance of the indicators used to compare countries.

# 10 Self Assessment Questions

The SAQs that follow test your achievement of the learning outcomes and help you think actively about the points raised in this lecture. No answers are given. The (parenthetical) numbers refer to sections and the letters to appendices.

1. In the simple maps of figure 1, which factors determine whether placing a farm in a particular pixel leads to a profit or a loss? (2, 3)

2. What are the risks associated with proposals for a new aquacultural enterprise? Identify as many as you can relevant to each of the three EAA principles. (5.1)

3. The Interaction matrix of figure 8 is to be applied pixel-wise to data in GIS

layers A, B and C. Which maritime sectors could be indicated by the headings B or C?[8] What is the A-A interaction and why is it shown as negative? (5.2)

4. What environmental characteristics are taken into account by the *aquacultural suitability* indicator in the AquaSpace Tool and the **Environment** category in the Investor Index? (5.3, 7, 9)

5. How can remote sensing aid marine spatial planning? (6)

6. Why do indicator values in the AquaSpace Tool need to be $z$-transformed? (5.7) What alternative transformations or conversions might be appropriate for an integrating tool? (6, 7, B)

7. Belgium and Croatia are very different countries. Why do they have similar Investor Index scores? (7, 9)

8. What, in your opinion, are the strength and weaknesses of the AquasSpace Tool and the Investor Index? (8)

Table 8: Interaction matrix: A is aquaculture, B and C are other maritime sectors; $-$ is a potential conflict, and 0 no conflict.

| | A | B | C |
|---|---|---|---|
| A | $-$ | | |
| B | 0 | $-$ | |
| C | $-$ | 0 | 0 |

[8] Here's a possible answer: B is seabed pipelines and C is marine traffic.

# Appendices

## A Real GIS versus the pixel approach

This appendix lists the main points in which ArcGIS and the AquaSpace Tool technologies differ from the simplified, pixel-based account, given in the main text. In order to understand the differences, contrast two ways in which a map might be printed:

- as in an ink-jet or laser printer, by setting down a grid of elements (pixels), each specified by a colour and brightness in a 2D array of values: this is *raster* or *bitmap* graphics; increasing depth of the sea-bed could in this case be shown by increasing shading, or by a gradient of colour;

- drawn by a pen moved between coordinates on the plotting surface: this is *vector* graphics; in this case, seabed depth might be shown by contours linking points of equal depth, each contour being stored as a list of $x - y$ coordinates.

A GIS uses both sorts of data. For example, a map of chlorophyll concentrations derived from remote sensing might be provided as a 2D array of values, whereas a marine protected area (MPA) might be specified as a 'shape file' for a line closed on itself at its ends and enclosing the area.

In the simple model used in the body of this text, a GIS layer for a particular type of MPA would be a 2-D array with the cell values either 0 (no MPA) or 1 (MPA present);

interactions with aquaculture would be reported when a pixel in a layer for potential farms and a pixel in an MPA layer both contained 1. In fact, the AquaSpace tool considers a potential farm site as a point (with specified co-ordinates) surrounded by a circular region of effect; interaction with a MPA would be computed if the region of farm effect overlapped the contour-defined MPA region.

Where the conflicting activity is, like the farm, also centered on a point with known co-ordinates, the Tool evaluates the relevant indicator on the basis of the distance between the two, as Figure 7 illustrates for waste disposal.

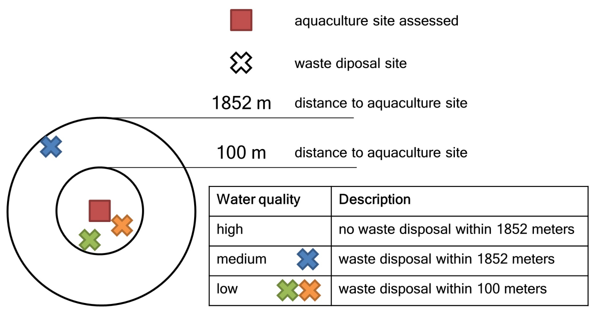


Figure 7: AquaSpace Tool: determination of water quality at farm site, using information in the GIS layer 'waste disposal'. The calculated water quality depends on the distance of the waste disposal site (e.g. discharge of urban waste water) from the farm. From Gimpel et al. (2017).

Finally, users of maps and GIS should keep always in mind that a map is a conceptual representation, therefore a simplification, of some aspects of the world. It is not the territory it represents. Even in the case of the highly simplified representation in figure 1, it was easy to write that a 'pixel was already occupied', when the intended reference was to the physical space occupied by e.g. a wind farm. This can lead to faulty outcomes. For example, it might be possible to operate wind farms and fish farms alongside each other, even if the planning rules for the pixel map allow only one activity per pixel.

# B Integrating tools for utility maximisation

Unit 2 introduced the Ecosystem Approach to Aquaculture and the ideas that aquaculture is an activity taking place within social-ecological systems thatcan be analysed by ecological, economic, and sociological methods. This appendix takes an economic perspective, by which we mean an approach concerned with the efficient utilisation of the biophysical resources of the natural environment and of the resources of people, equipment, infrastructure and finance available within society.

*Utility* is an abstract economic concept; it is what, according to a utilitarian ethic, results in the satisfaction of human well-being needs. Thus the aim should be to maximise the utility that can be obtained from a given set of resources. This aim does not mean neglecting effects of human activity on the natural environment, because these effects can impact directly on peoples' well-being and can have indirect consequences if they damage ecosystem services.

For example, a fish-farm sited within a few miles of the coast will have generate positive utility because it provides employment and profit to some people (generating income that those people can use to satisfy some of their well-being needs) and negative utility because some (other) peoples' well-being will be decreased by the sight of industrial structures in the sea.

According to classical economics, rational individuals seek to maximise utility by exchanging goods of which they have a surplus for those which they lack. Money makes this more efficient by serving as a medium of exchange. If it were possible to convert all the indicator values in the AquasSpace Tool into money values, either positive for an opportunity or negative for a risk, then the optimum spatial plan would be one that maximised the overall money value of a site or scenario.[9] In this case, the optimum plan could be found algorithmically, i.e. by a suitable computer program, perhaps a further development of the Tool.

There are two objections to this: first, it might not be possible to agree either the relationship between a farm development and change in stakeholder's well-being or the monetary value of the well-being changes; second, it might not be considered desirable to use a monetary valuation (Sandel, 2012). In that case there is a need for human agency and judgement in the interpretation of multi-indicator data, and the Tool has the function of helping, but not replacing, human agency. The $z$-transformation used by the Tool does not result in a 'common currency' for all indicators, but does simplify the task of comparing their values.

[9] Implicit in this scheme is the need for monetary transfers to compensate those whose well-being has been reduced; in the language of environmental economics, this is referred to as taking account of the *externalities* created by the fish-farm development.

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