PORTODIMARE

D.1.8.1 PORTODIMARE Module for mapping Allocated Zone to Aquaculture (AZA) in the Adriatic-Ionian Region

10 2019

Author: Project partner 2, CORILA	CNR Consiglio Nazionale delle Ricerche; ISMAR Istituto di Scienze Marine

Table of Contents

1. Introduction

The AZA (Allocated Zones for Aquaculture - FAO, 2012) module implemented a spatially explicit Multi-Criteria methodology, namely SMCE (Spatial Multi-Criteria Evaluation) for identifying Allocated Zones for Aquaculture (AZAs), *i.e.* marine areas where the development of aquaculture is prior to other uses. According to FAO, this is a key step in the implementation of the Ecosystem Approach to Aquaculture. SMCE is a well-established methodology in the aquaculture site selection (see e.g. Pérez et al., 2005; Longdill et al., 2008; Radiarta et al., 2008; Brigolin et al., 2015; Dapueto et al., 2015; Brigolin et al., 2017).

Basic SMCE theory is to investigate different possibilities in the light of multiple criteria and conflicting objectives generating a rankings of alternatives choice (Voogd, 1983). The foundation of SMCE is the Analytic Hierarchical Process (AHP) developed by Saaty (1980), which is used to develop a set of relative weights for each criterion considered. SMCE allows dealing with complex spatial decision problems combining different criteria once they are grouped, standardized, and weighted. This approach takes into account the spatial constraints to the development of aquaculture activities and a set of criteria, concerning for example to the potential biomass production, the environmental impact and the socio-economic sustainability. This methodology can be usefully employed in a co-constructive AZA identification process, as stakeholders can be involved in the selection of the importance to be assigned to these criteria.

For the AZA identification can be used spatial and temporal continuous data and, in this context, earth observation represents an important and free source of information, which can be used in site selection of shellfish and finfish farms. A wide range of satellite-based products and services can effectively support the planning and management of aquaculture practices. In particular, Sea Surface Temperature (SST) and Chlorophyll-a can be used for mapping potential biomass yield: these maps can be combined with other selection criteria and constraints by means of multicriteria methodologies, in order to obtain suitability maps. In order to develop the AZA module, we used the data produced within the Copernicus Marine Environment Monitoring Service (CMEMS; http://marine.copernicus.eu/) EU initiative.

Assumption is that the module can ideally run on the whole Adriatic-Ionian Sea domain. However, within the PORTODIMARE geoportal specific sub-areas were selected for the case study driven and customized user experience. Indeed, the module has been developed and tested in a selected number of case studies, which are representative of the most important aquaculture typologies and farmed species: mussel (*Mytilus galloprovincialis*), Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*). The Italian area, from the Friuli Venezia Giulia region up to the Apulian region, was selected to test the module for mussels, while for seabass and seabream were selected two areas, the Slovenian area and the Ionian Greek area (Figure 1).

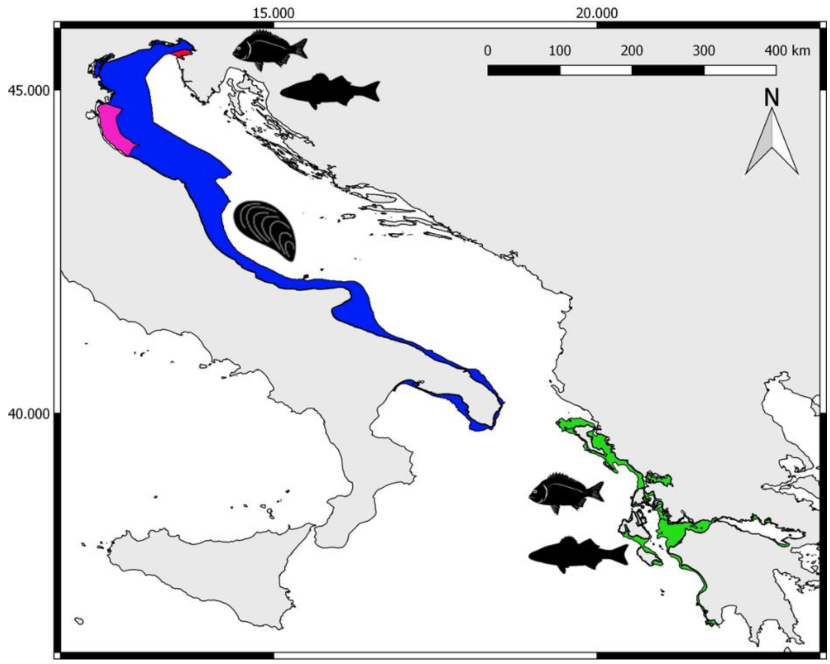

Figure 1. Study areas and selected species

The SMCE applied for the AZA module was carried out following the framework developed in Brigolin et al. (2017; Figure 2) throughout three steps: i) criteria normalization; ii) weight assignment to each criterion; iii) suitability index calculation (see Radiarta et al., 2008).

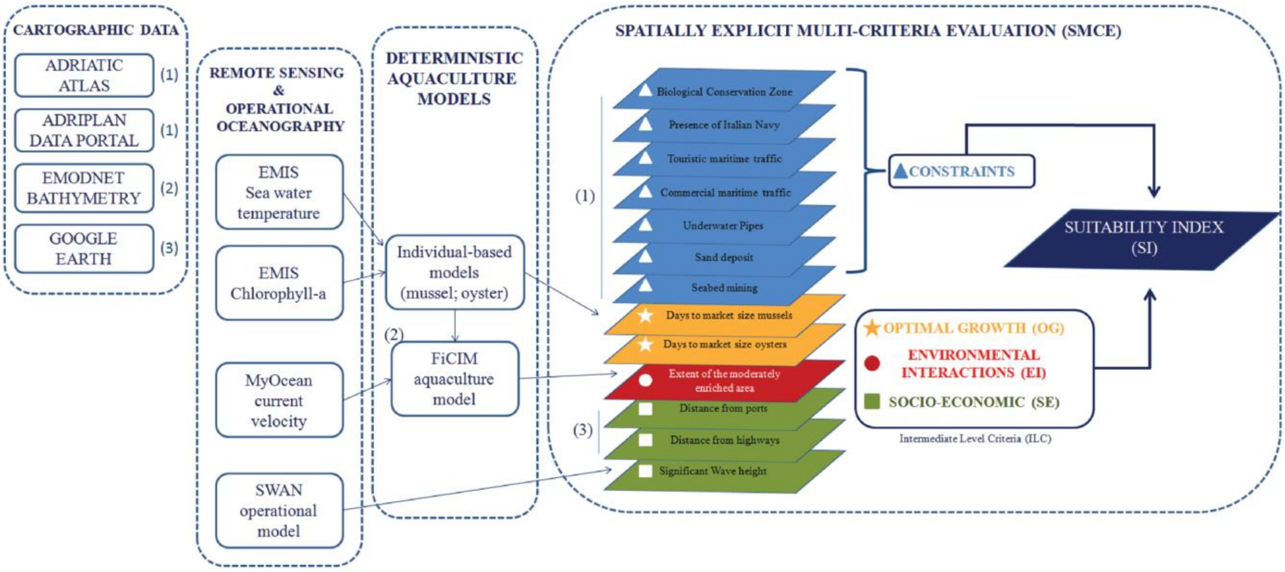

Figure 2. SMCE framework (*source Brigolin et al., 2017*)

The Suitability Index (SI) was calculated by applying the weighted linear combination using the following equation:

$$SI = \sum w_i x_i$$

where

w_i = weight of the assigned to factor *i*

x_i = criterion score of factor *i*

SI values ranged from 0 to 1, where values close to 1 indicate the highest suitability. In this application we used three criteria: (i) optimal growth, (ii) significant wave height and (iii) distance to harbour.

2. Criteria estimation

In the following paragraphs are briefly reported the methods to estimate each criterion. Analyses were performed using free open software R 3.5.1, R packages RAC - R package for AquaCulture (Baldan et al., 2018), raster, ncdf4 and maptools (R Core Team, 2018), and QGIS 2.18.24 Las Palmas (Quantum GIS Development Team, 2018).

2.1. Optimal growth

Optimal growth criterion was estimated applying individual-based mathematical models (*i.e.* Scope for Growth) for the selected species. Mussel, seabass and seabream growth performance were estimated using three species-specific models. The equations implemented and the parameters used are described in detail in Brigolin et al. 2009 (mussel), Brigolin et al. 2010 (seabream), Brigolin et al. 2014 (seabass and seabream). These models allow one to explicitly take into account the influence of water temperature and food availability on individual growth and metabolism. In this respect, environmental forcing required in input are chlorophyll-a concentration and sea water temperature. These data were obtained from Earth Observation enabling us to map the optimal growth criterion expressed in "time required to reach the commercial size" for the species considered. In particular, SST and Chlorophyll-a datasets at 1 km^2 spatial resolution for the years 2017 and 2018 were selected.

The optimal growth indicator (*i.e.* "time required to reach the commercial size") was estimated for two market size both for shellfish and finfish. In details, we selected as criterion for the mussel 5 cm and 7 cm of length (Figure 3), and 350 g and 500 g of total weight of seabream (Figure 4) and seabass (Figure 5).

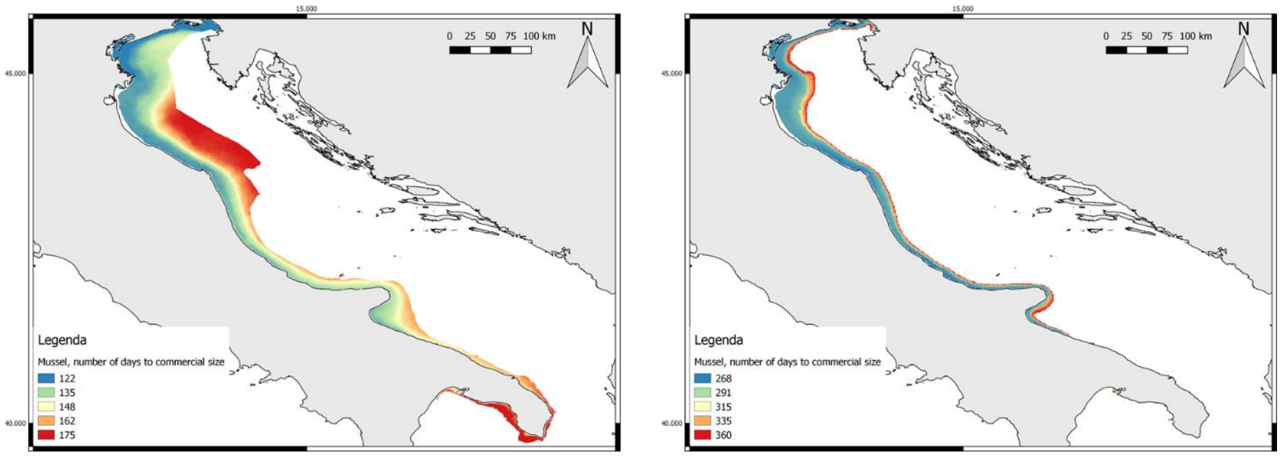

Figure 3. Mussel, number of days required to reach the commercial size of 5 cm (left) and 7 cm (right).

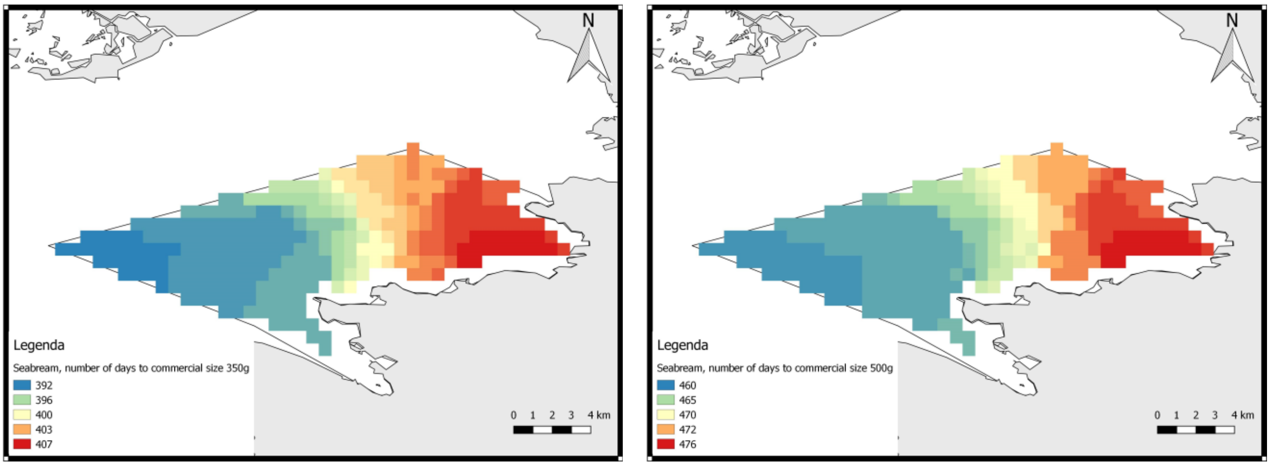

Figure 4. Seabream, number of days required to reach the commercial size of 350 g (left) and 500 g (right).

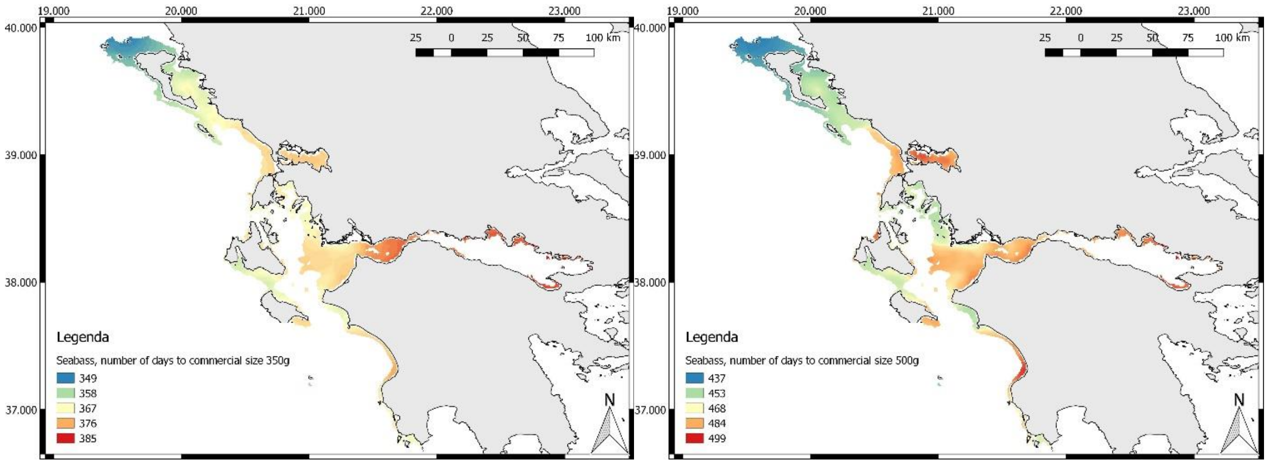

Figure 5. Seabass, number of days required to reach the commercial size of 350 g (left) and 500 g (right).

2.2. Significant Wave Height

The Significant Wave Height (SWH) criterion, providing a measure of the roughness of the sea at each specific site, was estimated on the basis of the 90th percentile of the sea surface SWH, estimated for each centre grid, starting from the satellite data downloaded from the CMEMS website. We used the Mediterranean Sea hourly dataset at a spatial resolution of *ca.* 4 km^2 for the period comprised between 2017 and 2018, produced within the CMEMS project applying a coupled hydrodynamic-wave model implemented in the Mediterranean Sea and based on the WAM Cycle 4.5.4 wave model.

We estimated the SWH criterion for the Italian (Figure 6), Slovenian (Figure 7) and Ionian Greek (Figure 8) areas.

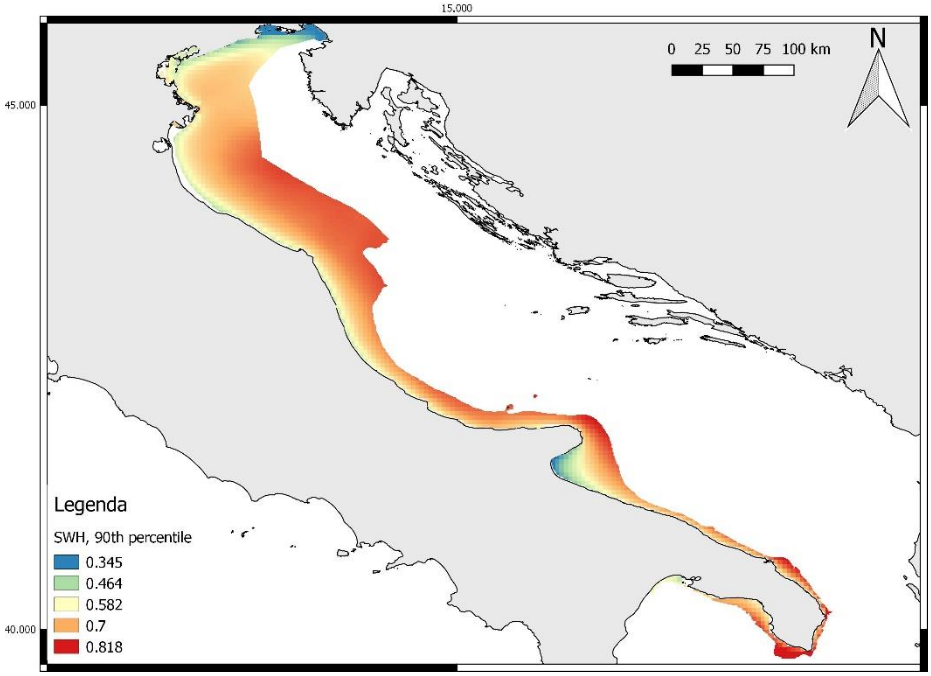

Figure 6. Italy - Significant Wave Height, 90th percentile.

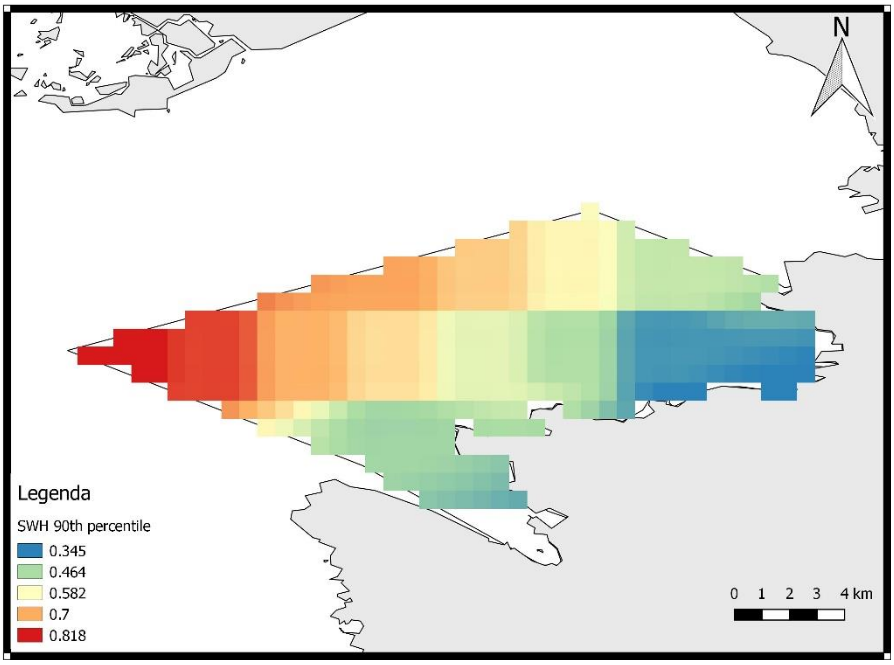

Figure 7. Slovenia - Significant Wave Height, 90th percentile.

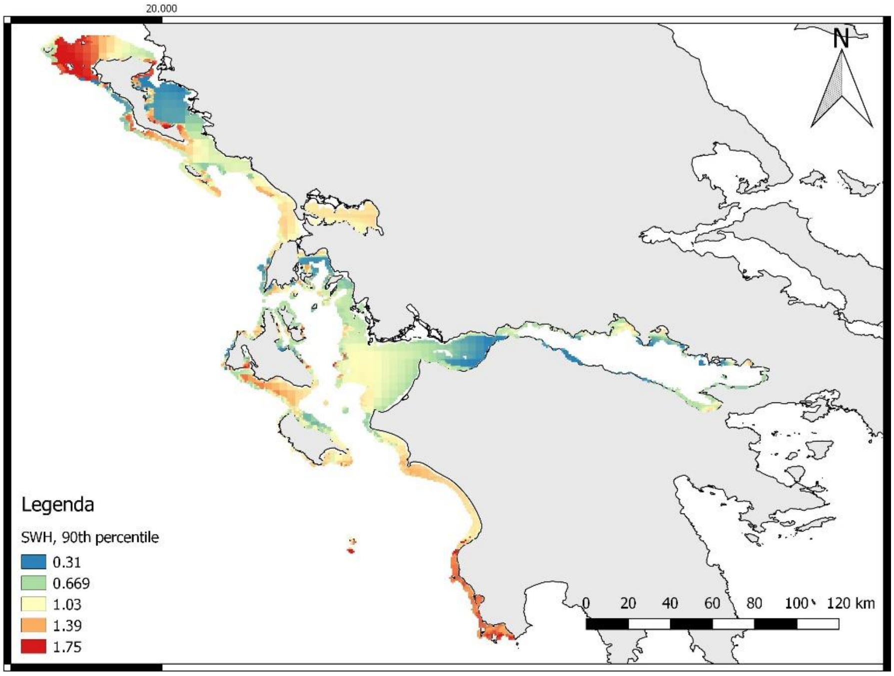

Figure 8. Greece - Significant Wave Height, 90th percentile.

2.3. Distance to Harbour

The three areas used for the AZA module development were divided in grid depending on the spatial resolution of the SST dataset. Subsequently, the distance to harbour criterion was estimated by measuring the distance, in km, from each centre of the grid to the nearest harbour, through the Nearest Neighbour Analysis in QGIS (version Las Palmas, 2.18.24). This criterion was estimated for the Italian (Figure 9), Slovenian (Figure 10) and Ionian Greek (Figure 11) areas.

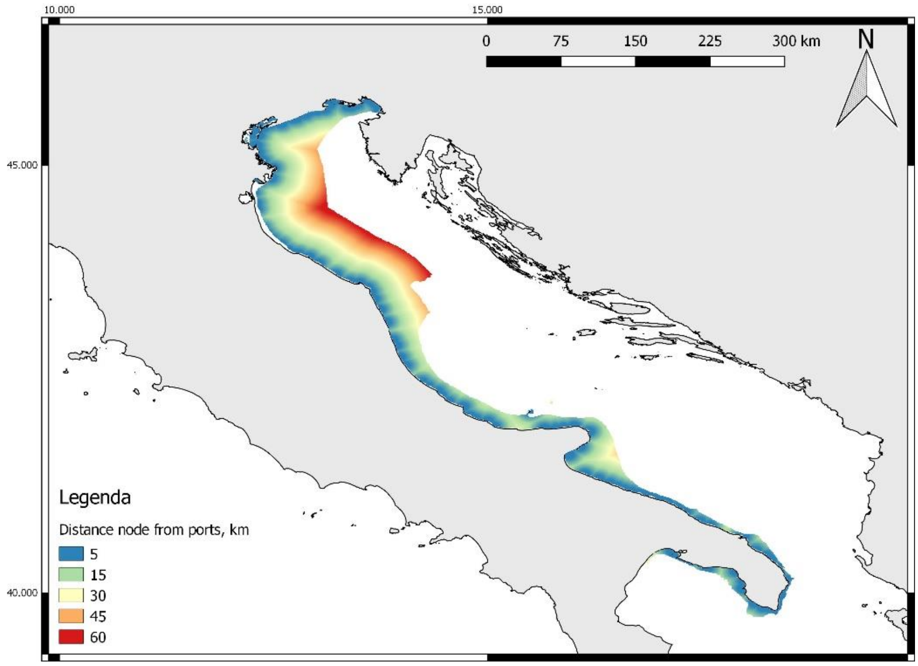

Figure 9. Italy - distance to the nearest harbour, km.

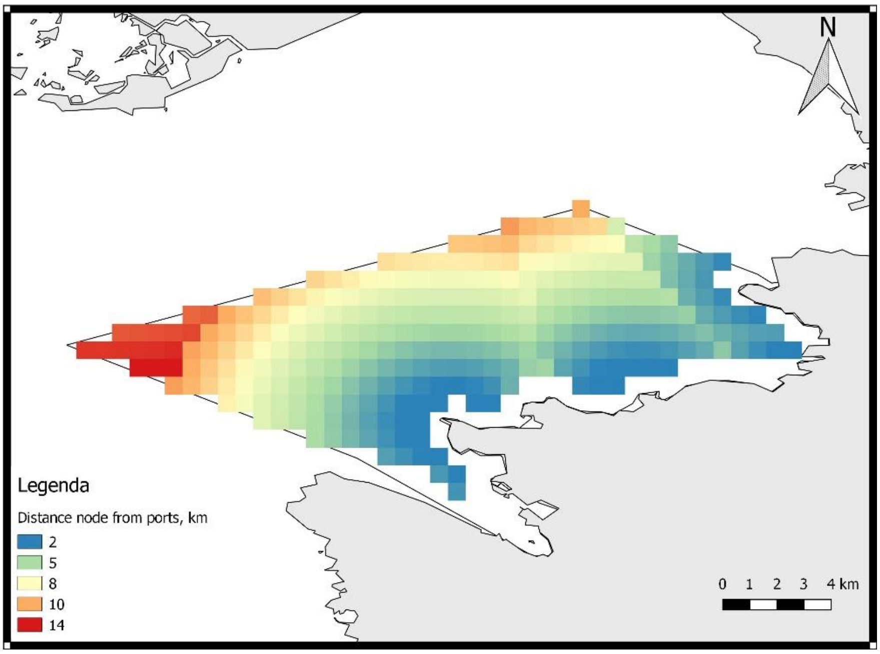

Figure 10. Slovenia - distance to the nearest harbour, km.

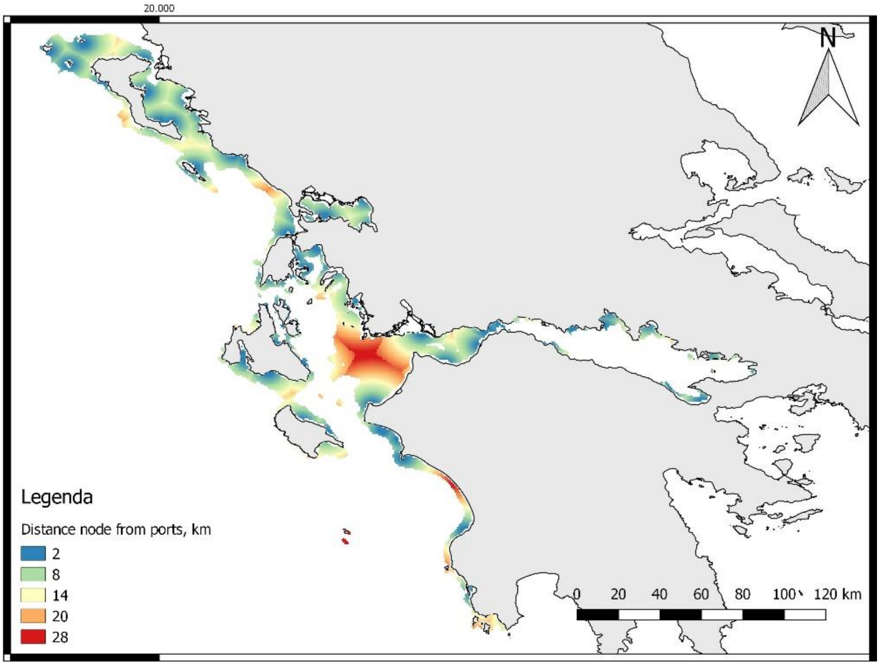

Figure 11. Greece - distance to the nearest harbour, km.

2.4. Additional criteria

The AZA module developed, besides the criteria presented in the previous sections, considered additional criteria for two of the test areas. For the Emilia Romagna test area, the environmental impact of a potential shellfish farm was estimated. The mapping of this criterion required the estimation of the organic enrichment of surface sediment because of the presence of a shellfish farm. In order to achieve this goal, the transport and deposition on the seabed of the organic matter released by shellfish was simulated using the integrated model Fish Cage Integrated Model (FiCIM), described by Brigolin et al. (2014). Details about the deposition model used were reported in Brigolin et al. (2017).

For the Ionian Greek area, through the collaboration with another PORTODIMARE project partner, the Hellenic Centre for Marine Research, the SMCE criteria were implemented with the fishing effort criterion. Details about the estimation of this criterion are reported in the Deliverable 1.11.3.

3. Constraints

All the constraints were collected for the ADRION area, in order to identify unavailable areas, and successively superimposed to the suitability maps for shellfish and finfish aquaculture, by using a Boolean classification scheme (suitable areas 1, unsuitable areas 0) (Falconer et al., 2013). Under a precautionary approach, around the constraints a security distance buffer of 500 meters was considered (see Holmer et al., 2008). Indeed, the potential environmental impact of the farming activity was considered only for the Emilia Romagna test area.

4. AZA module

The AZA module was developed as easy-to use and flexible, the users can modify the criteria used in the SMCE analysis and the weights. All the criteria to run the AZA module were uploaded, together with the weights and the constraints, in the PORTODIMARE geoportal and are available for the users.
The criteria already available within the PORTODIMARE geoportal could be integrated with new ones (e.g. Harmful Algal Bloom, fish pathogens, nutrient input and risk of hypoxia, environmental impacts, etc.). Hence, the users have the possibility to replace some available layer with new ones: the system will confirm whether the layer is usable or will give an error message as far as possible indicative.
In a summary interface, the users receive an indication of the weights applied by default for each criterion, with the possibility of modifying the weights assigned. The users can run the tool and subsequently is informed about the output availability. The output visualization can be modified by changing the suitability index clustering. After examining the output, the user can save it in her/his personal area and share it with other portal users.
The **input data** of the AZA module are:

1. Optimal growth models' outputs (normalised data, raster, 1 km^2 spatial resolution):
    - Mussels– days to market size 5 cm
    - Mussels– days to market size 7 cm;
    - Seabass– days to market size 350g;

- Seabass– days to market size 500g;
- Seabream– days to market size 350g;
- Seabream– days to market size 500g.

2. Economic factors (normalised data, raster, 1 km^2 spatial resolution):
   - Distance to harbour;
   - Significant wave height.
3. Weights assigned by default but modifiable by the users.
4. Environment interactions:
   - Buffer zones (polygon shapefile) around constraints;
   - For the Emilia Romagna test area, the environment interaction is considered within the SMCE process.
5. Constraints: Polygon shapefile of constraints are superimposed in the final suitability maps by using a Boolean classification scheme (suitable areas 1, unsuitable areas 0). The layers include: Aquaculture farms, Marine Protected Areas, biological conservation zone, military areas, Touristic maritime traffic, cable and pipelines, offshore sand deposit, seabed mining, oil and gas extraction, *Posidonia oceanica* meadows (maybe other, depending on availability).

The **output layers** of the AZA module are:

- ✓ 1 raster map of the suitability index of the areas potentially available for the selected aquaculture activity (mussel, seabass or seabream). The suitability index will be mapped and clustered in 5 classes, in details: 0.00 – 0.25 (html: #d7191c), 0.25 – 0.35 (html: #fdae61), 0.35 – 0.50 (html: #ffffc0), 0.50 – 0.75 (html: #a6d96a), 0.75 – 1.00 (html: #1a9641);
- ✓ 1 raster map of the suitability index of the areas potentially available of the whole area, without the super-imposed constraints and the buffer of the sensitive areas, available for the selected aquaculture activity (mussel, seabass or seabream). The suitability index will be mapped and clustered in 5 classes, modifiable by the user, in details: 0.00 – 0.25 (html: #d7191c), 0.25 – 0.35 (html: #fdae61), 0.35 – 0.50 (html: #ffffc0), 0.50 – 0.75 (html: #a6d96a), 0.75 – 1.00 (html: #1a9641);

- ✓ Raster maps of the input criteria;
- ✓ Aquaculture suitability files in ascii format.

The users of the AZA module can be different, such as:

● public authorities, involved in maritime spatial planning and in licensing of aquafarms;

● current operators, seeking to expand/diversify their activity;

● investors interested in a preliminary assessment of areas eligible for the allocation of investment in aquafarming.

As stated previously, assumption is that the module can ideally run on the whole Adriatic-Ionian Sea domain. However, within the portal specific sub-areas were selected for the case study driven and customized user experience.

4.1. Strength and limitation

The identification of suitable areas for the expansion of aquaculture presents both purely technical-scientific aspects, linked to the current scientific knowledge, and problems connected to the decision-making aspects and the planning process. The set of indicators used within the AZA module could be expanded in different ways. This must be done, however, taking into account the availability of data and the reliability of the models needed to derive the indicators.

A rather novel aspect of AZA module is represented by the inclusion within the SMCE framework of individual-based mathematical models, and for the Emilia Romagna test area, of more complex integrated biogeochemical models of the farm. The AZA module provides useful resources for processing data obtained from remote sensing and producing maps relative to each specific criterion. This goes in the direction of overcoming limitations imposed by scarcity of data for SMCE applications. With respect to the specific area, the Adriatic-Ionian basin, should be remarked the importance of taking into account the results of the AZA module within the MSP implementation, also considering the early stage of its application in the ADRION countries.

As remarked by Radiarta et al. (2008), weighting is one of the primary challenges when a multicriteria evaluation is applied, indeed different maps of aquaculture suitability can be obtained by varying the criteria weights. In the AZA module the weights were already imposed in order to give an indication of their importance, but these can be easily modified by the users directly in the PORTODIMARE geoportal. Indeed, to date do not exist a univocal and objective procedure to determine the importance of each criterion, being an element that to some extent is subjective. Consistently with the spirit of the EU Directive on Maritime Spatial Planning, the definition of weights should be the results of a participatory process involving different stakeholders.

A main strength of AZA module depends on the use of SST and Chlorophyll-a satellite data as inputs for mechanistic models simulating eco-physiology and growth of mussel, seabass and seabream, while recent studies considered directly the environmental variables, such as the water temperature values, in relation to the thermal tolerance of the selected species (e.g.: Weiss et al., 2018; Gentry et al., 2017; Longdill et al., 2008; Radiarta et al., 2008). The advantage of using a mechanistic model is related to the possibility of obtaining the integrated assessment of the temperature effects on fish physiology and growth over time.

One of the main weakness of AZA module are related with static criteria layers, hence the suitability based on these criteria will not change dynamically. At the same time, considering the flexibility of the tool, the users can modify the input data of the analysis with more updated layers. Moreover, the AZA module does not consider the carrying capacity of the system, because its estimation involves a long-term effort in developing and validating biogeochemical, ecological and growth models. Modelling the carrying capacity will require to consider the whole socio-ecological system and being site-specific cannot be integrated in the AZA module.

Once identified suitable areas, through the AZA module developed within the PORTODIMARE project, the next step should consist in a more downscaled approach which could allow to deeply examine the complex mosaic of local factors interacting with aquaculture installations.

5. References

Baldan, D., Porporato, E.M.D., Pastres, R., and Brigolin, D. (2018). An R package for simulating growth and organic wastage in aquaculture farms in response to environmental conditions and husbandry practices. PLoS One 13(5), e0195732. doi: 10.1371/journal.pone.0195732.

Brigolin, D., Meccia, V.L., Venier, C., Tomassetti, P., Porrello, S., and Pastres, R. (2014). Modelling biogeochemical fluxes across a Mediterranean fish cage farm. Aquac. Environ. Interact. 5, 71-88. doi: 10.3354/aei00093

Brigolin, D., Pastres, R., Tomassetti, P., and Porrello, S. (2010). Modelling the biomass yield and the impact of seabream mariculture in the Adriatic and Tyrrhenian Seas (Italy). Aquac. Int. 18(2), 149-163. doi: 10.1007/s10499-008-9232-4

Brigolin, D., Porporato, E.M.D., Prioli, G., and Pastres, R. (2017). Making space for shellfish farming along the Adriatic coast. ICES J. Mar. Sci. 74, 1540-1551. doi: 10.1093/icesjms/fsx018

Dapueto, G., Massa, F., Costa, S., Cimoli, L., Olivari, E., Chiantore, M., ... & Povero, P. (2015). A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy. Ocean & Coastal Management, 116, 64-77.

Falconer, L., Hunter, D. C., Scott, P. C., Telfer, T. C., and Ross, L. G. (2013). Using physical environmental parameters and cage engineering design within GIS-based site suitability models for marine aquaculture. Aquac. Environ. Interact. 4(3), 223-237. doi: 10.3354/aei00084

FAO. (2012) Report of the thirty-sixth session of the General Fisheries Commission for the Mediterranean, 14–19 May 2012, Marrakech, Morocco. GFCM Report No. 36. Rome, 71 pp. http://www.fao.org/3/a-i3086e.pdf.

Gentry, R. R., Froehlich, H. E., Grimm, D., Kareiva, P., Parke, M., Rust, M., et al. (2017). Mapping the global potential for marine aquaculture. Nat. Ecol. Evol. 1(9), 1317. doi: 10.1038/s41559-017-0257-9

Holmer, M., Argyrou, M., Dalsgaard, T., Danovaro, R., Diaz-Almela, E., Duarte, C.M., et al. (2008). Effects of fish farm waste on Posidonia oceanica meadows:

synthesis and provision of monitoring and management tools. Mar. Pollut. Bull. 56, 1618e1629. doi: 10.1016/j.marpolbul.2008.05.020

Longdill, P. C., Healy, T. R., and Black, K. P. (2008). An integrated GIS approach for sustainable aquaculture management area site selection. Ocean Coastal Manage. 51(8-9), 612-624. doi: 10.1016/j.ocecoaman.2008.06.010

R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Radiarta, I. N., Saitoh, S. I., and Miyazono, A. (2008). GIS-based multi-criteria evaluation models for identifying suitable sites for Japanese scallop (Mizuhopecten yessoensis) aquaculture in Funka Bay, southwestern Hokkaido, Japan. Aquaculture 284, 127–135. doi: 10.1016/j.aquaculture.2008.07.048

Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation. McGraw Hill, New York/RWS Publications, Pittsburgh, 287 pp.

Weiss, C. V., Ondiviela, B., Guanche, R., Castellanos, O. F., and Juanes, J. A. (2018). A global integrated analysis of open sea fish farming opportunities. Aquaculture 497, 234-245. doi: 10.1016/j.aquaculture.2018.07.054