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1 Cover Letter

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Dear Editor,

I submit you the attached MS on **A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy** by Massa F., Costa S., Cimoli L., Olivari E., Chiantore M., Federici B., Povero P. and myself.

The paper regards the development of a Spatial Multi-criteria Evaluation (SMCE) able to identify suitable areas for siting offshore medium size fish farms in Ligurian Sea in an easy, quick, efficient and effective way. It follows an integrated approach and can be potentially adapted and applied to any coastal system. As far as we are aware, never in Italy this approach was adopted.

The spatial planning of the coastal zone has become a key point for the management of those areas in which both environmental and human variables come into play. Mariculture is a relatively new activity that stresses in those areas and interacts with other activities. Therefore, it is important to designate to this suitable sites that on one side do not affect the quality of the breading fish and on the other one do not conflict with the surrounding environment.

I hope it could be of interest for Ocean & Coastal Management.

All my best,
Giulia Dapueto

Genoa, 26nd May 2015

***2 Title Page with all author info**
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A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy

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Highlights

- Our SMCE identifies suitable site for offshore marine fish farm at regional scale
- This is the first developed procedure applies in Italy (Ligurian Sea)
- 65 suitable areas are identified, 40% of them with high values, especially in Tigullio Gulf
- Suitable areas are well discriminated and classified on a suitability scale
- It is an easy, quick, efficient and effective procedure that can be potentially adapted and applied to any coastal system

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ABSTRACT

Mariculture is a relatively new activity that is expanding globally and interacts with other coastal uses. Therefore, it is necessary to allocate suitable sites from environmental, economic and social points of view, involving different stakeholders in the decision-making process. In particular, in the Ligurian Sea (Italy), for its environmental characteristics and tradition, fish farming should be further boosted and an accurate marine spatial planning should be done. This paper presents a spatial multi-criteria evaluation (SMCE) addressed to identify suitable areas for siting offshore medium size fish farms in the Ligurian Sea at the regional scale. The SMCE procedure follows an integrated approach that can be potentially adapted and applied to any coastal system. The site selection is based on the definition of criteria that assess their suitability and on conditions related to the entire study area. Suitability values are ranked on a scale from 1 (suitable) to 10 (optimal). More than 9000 ha were identified and almost 40% of this area gets high suitability values, from 7 to 9, pointing out the untapped potential for Ligurian marine coastal zone. Results demonstrate that our SMCE, and in particular its procedure, allows identifying the most suitable areas in an easy and quick way and solving effectively the complex spatial problem of suitable site selection for fish farming.

Key words:
Spatial multi-criteria evaluation
GIS
Marine spatial planning
Fish farming
Suitable site selection
Allocated zone for aquaculture

1. Introduction

Mariculture has undergone a rapid expansion around the world in order to cope with growing protein demand of increasing world population. Its development leads to an increase of environmental concerns and questions about possible ecological impacts and growing risk of competition between fish farmers and multiple users of coastal space and marine resources (Pérez et al., 2005).

Specifically, aquaculture in the Mediterranean region has grown significantly in recent years. In 2006 in Italy, 126 farms of marine species were recorded, 54 of which were operating using floating cages. In 2008 (the most recent data available) marine fish Italian production from mariculture has reached almost 29 thousand tons, 9600 tons sea bream, 9800 sea bass, 3500 mullet and the remaining shi drum, white sea bream and bluefin tuna. Shellfish production accounted for 165 thousand tons, 115 mussels and 50 clams (ISMEA, 2009).

At present Ligurian (North-western Mediterranean) mariculture accounts for 8.3% of the national mussel (*Mytilus galloprovincialis*) and clam (*Tapes decussatus*) production and 4% of the national production of sea beam (*Sparus aurata*) and sea brass (*Dicentrarchus labrax*) (Cattaneo-Vietti et al., 2010).

Fishery is one of the traditional activities in the Liguria region economy, mainly based on small artisanal communities and represents an important economic sector for the high value of its commercial product (anchovies, transparent gobies, shrimps, lobsters, hakes, red mullets and curled octopus). However, traditional fishery suffers from a general ageing and from the competition with other activities and is showing decrease, following the worldwide steady decline in fisheries production as a consequence of excessive fishing effort (FAO, 2012, 2013). Consequently and oppositely, mariculture has been developing in Liguria.

At present, the Ligurian Sea has all the necessary conditions for encouraging further development of this production. In this context, it is necessary to take into account that natural and socio-economic complexities are interweaving: the Ligurian coast is, at the same time, a strategic crossroad of port and commercial traffic, a biodiversity hotspot, an international touristic attraction and the residence of almost all the regional population (http://www.ambienteinliguria.it).

If from one side the installation of mariculture farms implies economic and social advantages (e.g. supply of important sources of healthy and nutritious seafood, support of the rising demand for fishery products while fostering economic growth), on the other has several economic, social and environmental implications (Engle, 2009; GESAMP, 2001; Holmer, 2010). First of all, mariculture can affect different components of the marine environment, but also breeding species can be affected by the surrounding environmental conditions. The economic and social impacts of mariculture (e.g. interaction with navigation, conflicting interaction with other economic activities, visual impact) are complex and interconnected. Furthermore, mariculture policy-making process and planning involves stakeholders with different objectives and mandates. These interactions are stronger and more complex at increasing urbanization of the area, rising stakeholder competition and significantly affecting the consultative process (Sevaly, 2000).

A proper design of Allocated Zones for Aquaculture (AZAs) is necessary in order to develop a sustainable mariculture. In fact it has to provide a healthy product that satisfies the market demand but without bringing environmental degradation and negative interaction with other activities and that is

economically advantageous. In recent years the European Community issued directives and communications (2000/60/EC, 2008/56/EC, 2014/89/EU, COM(2011) 417 final, COM(2002) 511 final, COM(2009) 162 final) to develop appropriate strategies and action programmes. In particular, the research and innovation programme Horizon 2020 aims at preservation of marine aquatic resources and their biodiversity within the Blue Growth strategy. In order to harmonise and unify the management of maritime space, a directive establishing a framework for maritime spatial planning has recently been adopted (2014/89/EU).

Italy, coherently with FAO guidelines (FAO, 1995, 2005a, 2005b) and EU legislation and strategies, issued the Legislative Decrees no. 154/2004 and 152/2006 (art. 111). However, at present, national technical rules that define requirements for the regulation of these activities have not been issued yet. The Italian agency for new technologies, energy and sustainable economic development (ENEA) has published guidelines for the granting of concessions at sea, with particular reference to fish farming. The lack of national criteria to build marine farms stimulated few Italian administrative regions to draw up guidelines, referring to EU and national normative instrument. Specifically, Liguria Region issued Regional Low no. 21/2006 and Decree of the Municipal Council no. 1415/2007.

Site selection is a key factor in any mariculture operation, guaranteeing both the activity success and the product quality as well as solving land or water use conflicts. Following a participatory and ecosystem approach, based on environmental, economic and social factors, it is possible to select the most suitable sites for aquaculture that minimize environmental stress, maximise potential for species growth, and minimize production costs and avoid, or at least minimize, potential conflicts with other users (GESAMP, 1991, 1996; Pérez et al., 2005). It requires knowledge and communication of socioeconomic and environmental processes, understanding the relationships between multiple human pressures and the status of ecosystems (Parravicini et al., 2012; Stelzenmüller et al., 2013). Site selection is a complex spatial decision problem that has a large number of alternatives (different initial choices implicate the definition of different solutions) and that involves decision makers carrying different stakes and preferences. So this choice is not easily and univocally identifiable (Malczewski, 1997).

During the last decades, the evolution of multi-use planning of ocean space and resources has become a crucial step in achieving an ecosystem-based sea use management (Douvere, 2008; Tammi & Kalliola, 2014). The combination of GIS software and multi-criteria evaluation (MCE) techniques in a spatial multi-criteria evaluation (SMCE) is a potential tool that can help users in solving complex spatial decision problems. As amply documented by several authors (Carver, 1991; Kamruzzaman & Baker, 2013; Krois & Schulte, 2014; Voogd, 1983) GIS and MCE may be jointly used to solve conflictual problems (Malczewski, 2000): GIS provides a suitable framework for the application of spatial analysis methods and MCE techniques provide the means to manage multi-criteria situations taking into account the expert knowledge of the decision-maker (Carver, 1991).

SMCEs are increasingly being used in various sectors (Bagdanavičiūtė et al., 2015; Baiocchi et al., 2014; Ceballos-Silva & Lopez-Blanco, 2003; Dragan et al., 2003; Li et al., 2013; Store & Kangas, 2001; Van der Merwe et al., 2013; Zucca et al., 2008) providing an approach for improving spatial decision-making processes and their quality, in which conflictual position of different stakeholders comes into play (Charabi & Gastli, 2011; Carver, 1991; Hossain et al., 2009; Kamruzzaman & Baker, 2013; Krois &

Schulte, 2014). In particular regarding aquaculture, SMCE provides an efficient and effective analytical and predictive tool for planning its development and testing the consequence of possible alternative decisions (Aguilar-Manjarrez & Ross, 1995; Hossain et al., 2009; Liu et al., 2014; Longdill et al., 2008; Nayak et al., 2014; Pérez et al., 2005; Radiarta et al., 2008; Silva et al., 2011). However, as far as we are aware, never in Italy this approach was adopted.

In this study, a SMCE has been developed with the support of free and open source GIS software. In particular a procedure that incorporates a variety of information has been realised to identify suitable sites for offshore medium size marine fish farm in the Ligurian Sea, Italy (regional scale). Especially sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax)* are considered: these naturally live and are already farmed in this area; moreover there is a great demand on the market.

2. Materials and methods

2.1. Study area

Liguria is an Italian region, located in the northernmost sector of the Western Mediterranean Sea (Fig. 1). Liguria is a long, narrow strip of land and sea characterised by 345 km of rocky and sandy coast (Ferretti, 2003), with a very narrow continental platform, rapidly exceeding 2000 m depth. As a consequence, the coastline is strictly affected by the deep sea, causing the requirement of a more efficient management.

The Ligurian marine coastal zone is exposed, with no shelter from Libeccio (south-west) and Scirocco (south-east) winds, mostly affecting, respectively, the west and the east coast. In general Scirocco is the more frequent wind, while Libeccio is the dominant one that causes the most important and powerful storms. In terms of hydrodynamics the entire Ligurian coast is affected by large and well-defined cyclonic circulation active all over the year (Astraldi et al., 1995; Manca Zeichen et al., 2008), although in the coastal area meteorological forcing and the coastal shape may temporarily support an anticyclonic circulation (Misic & Fabiano, 2006). The Ligurian Sea is an oligotrophic system due to its scarce chlorophyll-*a* content and a general P-limitation. However, it displays a complex and well-developed food web, suggesting that the efficiency of production and regeneration of organic material in the food web is remarkable and losses minimal (Misic & Fabiano, 2006).

This well-defined circulation helps to maintain, within the Ligurian marine coastal zone, the mean surface temperature lower than the adjacent basins, in particular the Tyrrhenian Sea (Astraldi et al., 1995). The temperature follows the seasonal patterns of temperate zones: about 12-13 ℃ in winter and 24-25 ℃ in summer, with a significant increase in the average monthly temperature of the coastal waters in the last decade (Cattaneo-Vietti et al., 2015). From literature salinity ranges between 36.7 and 38.1 (Misic & Fabiano, 2006; Misic et al., 2011), although surface minimum values are affected by the land runoff. Water transparency (as measured by Secchi disk) ranges from 10 to 25 m in the marine coastal zone (Della Croce et al., 1994), even though short local phenomena of high turbidity are mainly related to river runoff leading to increased turbidity and supply of nutrients due to the rains.

The Ligurian coastal ecosystem is heterogeneous and well-structured. The coastal marine environment, thanks to morphological and biological features and to its higher primary production than the average of

the western Mediterranean (Cattaneo-Vietti et al., 2010), hosts an important biodiversity, both in species and habitats, with key-roles in ecosystem processes. This justifies the high number and the importance of Sites of Community Importance (SCIs) and Marine Protected Areas (MPAs), which have been established. In particular, there are 26 marine SCIs, characterized by the presence of the seagrasses *Posidonia oceanica* and *Cymodocea nodosa*, coral reefs and other valuable ecosystems, 3 coastal MPAs and a protection area established at the regional level.

Marine and coastal communities have always been affected by human presence, with consequent structural changes especially due to the intense urban and industrial coastal development and to the management of activities (e.g. fishing) non-compatible with the objectives of protection and conservation. This was additionally exacerbated, in the last decades, by climate changes (Bianchi et al., 2010).

According to the Italian national institute of statistics (ISTAT), Liguria Region, in the 2000s, is one of the most densely populated coasts and the region with the highest coastal urbanisation, because of the presence of important urban and port activities and of several polluted discharges (Cattaneo-Vietti et al., 2010; Ruggieri et al., 2011). Along its coast there are three important commercial ports, in terms of size and operations, in La Spezia, Genoa and Savona-Vado, followed by Imperia's one, and 36 marinas. The strong tourist and seaside vocation of the area make the population density increase during the summer ad trigger the small fishing ports to develop facilities for recreational boats making yachting one of the principal recreational activities (Salmona & Verardi, 2001).

2.2. SMCE for site selection of a marine fish farm

To achieve the aim of this work, identifying the best sites for offshore marine fish farming in the Ligurian Sea, a SMCE model has been developed. Its procedure considers only factors and conditions relative to the whole study area and no strongly site-specific ones, as environmental impacts (OSPAR, 2009) and hydrological conditions. This kind of approach doesn't include dynamic models for the determination of the temporal variability of local environmental drivers too (Silva et al., 2011). Once identified suitable areas according to general considerations (regional scale), local analyses should be performed to deeply examine specific factors (local scale).

The SMCE procedure (Fig. 2) has been developed and divided into four steps: 1) Factors and related conditions that can affect the suitability of a fish farming site are identified and consequently data and information are collected; 2) Data and information are elaborated with GIS software in order to combine factors obtaining criterion and constraints maps; 3) These maps are combined into a single one to produce, as a result, the suitability map, integrating experts' judgement (stakeholders) used to attribute a relative importance to each criterion. Areas identified with this procedure have to be compared with the dimensions of a typical farm; 4) Finally, a verification of the procedure is performed, by comparing identified suitable areas with existing farms.

In this procedure two fundamental MCE methods used for land-use suitability analysis in GIS are employed: Boolean overlay (simply overlay) and weighted linear combination (WLC) (weighted overlay) (Eastman, 1999; Jiang & Eastman, 2000; Malczewski & Rinner, 2005; Malczewski, 2006; O'Sullivan & Unwin, 2003). In particular, Boolean overlay is used to obtain constraints and criterion maps: factors are combined by logical operators such as intersection (AND) and union (OR). Then, criterion maps are

standardized to a common numeric range, weighted and combined by WLC, masking by Boolean constraints map, into an overall layer to produce the final result. The result is a continuous mapping of suitability.

The present procedure has been carried out using two main GIS software: Geographic Resource Analysis Support System (GRASS) 7.1.0 to import data into a GRASS geodatabase (Location/Mapset) and define the Python script of the procedure in order to chain operations (i.e. GRASS modules) into one process (i.e. model) and update data in an easy way; and Quantum GIS (QGIS) 2.6.0 to compose, edit and export all the cartographic maps. These free and open source software allow a simpler and more effective development process than that associated with proprietary software (Zambelli et al., 2010), and they are widely supported and constantly improved by the scientific and non-scientific community.

A complete overview of the procedure is presented in Fig. 3. Especially, it shows the list of factors that define criteria and constraints for identifying suitable areas (different colours), where GIS software are used, and the points of the process in which the methodologies (MCE, expert judgment, verification) are applied.

The SMCE procedure has been applied to the Ligurian marine coastal area, picking out related data and information as described in details in the following paragraphs.

2.2.1. Step 1: Identification of factors and data collections

In order to select suitable sites for offshore fish farming, first of all, those factors that characterise the farm were identified (Table 1), taking into account cage farming of sea bass and sea bream. Choice of factors and of proper conditions was done by extensive examination of similar case studies, legislation in force, from European to local administrative scale, and expert judgement. The conditions for each factor have been chosen according to the specificities of the Ligurian area.

Management aspects are essential in farm planning. Marine farm should be located in areas with sea bottom features such as to allow the positioning, the anchoring and the routine and emergency maintenance operations of the farm. In particular, the steeper the slope the more complicated and expensive is the mooring system. Floating cages should be located above non-rocky seabed, where sea depth is not too high, to reduce costs and problems associated with mooring and to allow divers operations, but not too shallow, in order to allow proper water exchange to disperse the wastes, avoiding environmental consequences and risk of self-pollution to the farm. Seabed composition of Ligurian Sea is mostly sandy and pelitic (ICRAM, 2002), so no area results to be constrained for anchoring the cages.

Moreover, based on the experience of existing farms, cages are submerged when the wave height exceeds 2.5 m. An extended period of submersion, i.e. more than 100 days per year, would cause the farm to become economically disadvantageous: sea conditions and the submersion of the cage prevent the possibility to feed the farmed species, consequently causing a too large mortality event and a great economical loss (Co, AQUA s.r.l., pers. comm.). Significant wave heights data for the period 1979-2010 in the Ligurian Sea was provided by the WAVEWATCH III model using a resolution of 10 km in order to characterise the whole area. This model is validated using buoy data provided by the Italian Rete Ondametrica Nazionale (RON) (Mentaschi et al., 2013, 2015). The monthly-averaged significant wave heights in the above-mentioned period show maximum values in winter, with a peak in December and

January: the largest values are always less than 2 m and are observed offshore, while maximum values of 1 m characterize the coastal area. These values then gradually decay during spring and summer, with a minimum in July and August (less than 1 m offshore). In case of stormy events, maximum significant wave heights can be up to 9 m in December and March in the central area of the basin and go reducing towards the coast, but these events are usually short. Furthermore the punctual observed data from the offshore RON buoy of La Spezia in the period 1989-2001 is in agreement with the model. These data shows that waves higher than 2.5 m are recorded for no more than 400 cumulative hours per year (Franco et al., 2004), here over-estimated to 30 days. Therefore both modelled monthly wave heights and observed data from the RON buoy excludes the possibility of excessively extended periods of submersion of the cages. However, local variation of the wave field due to the interaction with the bottom should be investigated as part of a site-specific analysis.

Fish cage farming could produce negative effects on the surrounding environment, due to the waste release, such as fish faecal products and uneaten feed. Consequently areas with an elevated ecological value (MPAs, SCIs and other valuable biocoenosis, beaches, diving sites) must be excluded.

Furthermore, areas which could represent potential sources of pollution for the farm have to be avoided. The excessive nutrients loads from urban and industrial waste (sewage pipes, harbours) can cause eutrophic and dystrophic conditions and can expose farmed animals to pathogenic or toxic agents that may cause contaminations or die-offs. The areas of dispersion of the released materials should be avoided. Moreover, the risk that the environment will produce a cumulative effect due to different types of impacts that insist in the same area is present (Halpern et al., 2008).

In general, because of the conservative nature of the marine environment, the large water volume and exchange, and its oligotrophy, physical-chemical parameters are considered of little importance (Pérez et al., 2005), even if local increases of values can influence the marine environmental quality, important for the fish growth and health. Specifically, temperature and salinity values higher or lower than the optimal ones would lead to a slowdown in the growth and health of the fish; a good oxygenation is essential for the fish breathing; low values of dissolved oxygen and high nutrients could be related to eutrophic and dystrophic conditions; whereas an increase in turbidity can affect fish directly by injuring their breathing organs, reducing their growth rate or preventing their reproduction. Sea bream and sea bass are eurythermal and euryhaline species: both have a temperature condition optimum within 18-26 ℃ but tolerate higher (maximum of 32-34 ℃ for sea bream and 28 ℃ for sea bass) and lower temperatures (lethal limit around 4/5 ℃) and can live from marine to coastal lagoon and estuarine salinity conditions (FAO Cultured Aquatic Species Fact Sheet). Moreover they need dissolved oxygen concentration larger than 5 mg/l (FAO Cultured Aquatic Species Fact Sheet). All bred fishes eat only highly controlled food supplied by man and doesn't feed anything from sea, if not minimally. Consequently, marine chemical substances aren't ingested, bioaccumulated or biomagnificated and so they aren't a relevant problem.

Therefore, the Ligurian Sea, and in particular its marine coastal areas, shows values in accordance with fish growth ranges, indeed these species are naturally present in these waters. Turbidity and possible pathogens and pollutants are exceptions, whose concentration is strongly influenced by the river runoff.

For the development of a marine fish cage farm, inland facilities are needed and should be evaluated.

Only offshore areas close to ports that can support this type of activities should be considered. Ports presence should be evaluated on the basis of their commercial importance, dimension, reachability and onshore spaces and of the commercial and industrial structures in neighbouring areas for fish sale.
Finally, in the process of selection of suitable sites, areas characterised by special prohibitions or other conflicting activities must be excluded.
Cartographic data used for the preparation of the criterion and constraints maps are freely distributed, mainly downloaded from the Cartographic Portal of the Liguria Region (http://www.cartografia.regione.liguria.it/) in vector format, in according with data scale and cartographic resolution (Table 1). Exceptions are: the Ligurian bathymetry map provided by the Hydrographic Institute of the Italian Navy in vector format; the nautical maps provided by the Hydrographic Institute of the Italian Navy and the Pilot book of the Italian seas (VV.AA., 2010) in raster format; and the Ligurian marine sediment map provided by the Italian central institute for scientific research and technology (ICRAM, 2002) in raster format.

2.2.2. Step 2: Elaboration of criterion and constraints maps

For the purpose of this work the previously cited factors (except for those considered as local or homogenous and not restrictive in all study area) were divided into constraints and criteria (Environmental quality, Optimal conditions for fish growth and Socio-economic evaluation) for identifying suitable areas for fish farming. Constraints and each criterion are characterised by a certain number of factors, for a total of 16. Fig. 4 shows the hierarchical structure with the relation between criteria and constraints, weights assigned to them, factors and their conditions for the case of Liguria.
Since the variety of scales on which all criteria can be measured, their scores are transformed into comparable units. To each criterion map an integer standardised score was applied, from 0 (not suitable) to 10 (most suitable). Similar studies have used standardised scores of 1-4, 1-8, 1-16 (Aguilar-Manjarrez & Ross, 1995; Pérez et al., 2005; Salam & Ross, 2000), but they were considered not appropriate for the data used.

1st criterion "Environmental quality"

According to the Water Framework Directive 2000/60/EC, Italian legislation (Ministerial Decree 260/10) requires that the Administrative Regions define, at least every 3 years, the State of Environmental Quality of its marine costal water bodies, evaluating ecological and chemical status (Fig. 5). The environmental quality map edited by regional agency for Ligurian environmental protection (ARPAL) provides synthetic and validated information about the environmental quality of the 26 regional marine coastal water bodies. Since fishes eat only food supplied by man and so marine chemical substances aren't ingested if not minimally, only the ecological status was taken into consideration. Ecological status is evaluated by ARPAL combining biological quality elements (phytoplankton, macroalgae, the seagrass *Posidonia oceanica* and benthic macro invertebrates), physical-chemical parameters (dissolved oxygen, nutrient, transparency, temperature and salinity) and non-priority chemical pollutants (Attachment 8 of M.D. 260/10) with a standard methodology. The ecological status map (http://geoportale.regione.liguria.it//geoviewer/pages/apps/repertorio/repertorio.html?id=1670) was used

to define the environmental quality criterion of first order environmental parameters, avoiding *in situ* collection. The ecological status was associated with a level of quality, which corresponds to a standardised score for this criterion. Any status with a quality better than "bad" are considered acceptable, but with decreasing score as follows: "high" (10), "good" (8), "sufficient" (6), "poor" (3) and "bad" (0). The output of this criterion is shown in Fig. 6a.

2nd criterion "Optimal conditions for fish"

Due to physical-chemical characteristics of the Ligurian Sea, problems of lower suitability in the study area for the considered fish species arise only in proximity of river and stream mouths, where turbidity increases and pathogens or pollutants could be carried. In order to protect farms from this potential impact, a representative area of the plume of the principal rivers and streams was considered. Since flow rate data for streams is often unavailability, the plume extension is estimated considering the size of the upstream hydrographical basin, the size of the river/stream mouth and the presence of particular pollution situations. Rivers and streams were divided into 5 classes, each of which was associated with a different buffer (Table 2): 2 nm (nautical miles), 1 nm, ⅔ of nm, ½ nm and ⅖ of nm. Plume areas were scored as 1, while external areas were scored as 10 (Fig. 6b).

3rd criterion "Socio-economic evaluation"

Ports that can offer the necessary facilities and services for a fish farming activity have been selected and scored on basis of available background facilities: ports larger than 2 ha, and with structures available within 5 km, and closer than 12 km from highway as the crow flies (only exception is the port of Portovenere in which the real distance is considered). Starting from the position of each selected port, an offshore area of maximum distance in which the farm may be located has been identified, so that the time and the cost for accessing it are not excessive. Three distance ranges were considered (0-3 km, 3-5 km and 5-7 km), with decreasing scores.

Combining the above information and scores, a socio-economical classification of marine areas was obtained (Fig. 6c), with standardised scores from 1 (less suitable) to 10 (most suitable). A score of 0 was associated to areas not suitable from the socio-economical point of view.

Constraints map

Constraints are all factors and conditions that make an area unsuitable for siting the farm in the study area. So their mapping allows screening out the not suitable alternatives. This step helps to avoid conflicts in decision-making: the sites where there are prohibitions, which are not available or not completely suitable for offshore fish farming implementation are excluded.

First of all, constraints include areas that haven't suitable morphology, i.e. depths higher than 50 m and lower than 10 m and slope steeper than 15°. Whereas , in this area seabed composition is not a limiting factor cause of its homogenous grain size..

Data exploration has shown that there are not extended period of cage submersion due to wave height larger than 2.5 m, so wave height is not a considered as a constraint for the positioning of cages in Ligurian Sea.

To avoid the mutual impact between the farm and the surrounding environment and/or other human activities, MPAs, marine SCIs, beaches and areas with high cultural and ecological heritage, where usually there are diving activities have to preserved. Sewage pipes and the main ports are to be avoided. These areas and a surrounding buffer area (summarised in Fig. 4) should be excluded from the analysis. The precautionary respected area around MPAs, SCIs and beaches was 500 m wide. For sewage pipes a buffer as a function of their depth must be avoided. In fact, the horizontal distribution of waste particles released from farms and sewage pipes was calculated using the dispersion formula suggested by Gowen et al. (1989), where it is directly proportional to the depth under cage and the current speed and indirectly to the settling velocity of release material. The mean of the maximum speed of currents observed during the period 1985-1996 by the Department of Earth, Environment and Life Sciences in the Ligurian Sea (0.4 m/s) was used, according to Capello et al. (2014); the water depth of in correspondence of farms was approximated to 45 m and the pipe depths were considered; the settling velocity of the lighter material released was approximated to fish faeces velocity (0.04 m/s) (Chen et al., 1999; Doglioli et al., 2004; Pérez et al, 2002). Instead a buffer of 1 nm from the main ports has to be respected, also to avoid interference with navigation.

Finally, areas characterised by prohibitions for traffic, anchoring, mooring or particular activities, such as fishing according to the Italian coast guard regulations (VV.AA., 2000; Hydrographic Institute of the Italian Navy) are forbidden. In particular, areas inside and immediately outside the ports, even the smaller ones, where entry and exit manoeuvres are regularly carried out, have to be excluded.

All areas that result unsuitable for at least one criterion were included in the constraints map (Fig. 6d). It was obtained by Boolean union and used as an inverse mask in the final elaboration for obtaining the suitability map, in order to limit raster computation effort.

2.2.3. Step 3: Suitability map

After setting constraints map as mask, criterion maps are joined with experts' judgment, that represents the weights assigned to each criterion, through a weighted linear combination (WLC), obtaining as final output the suitable areas. In fact, the maps of criteria identify all suitable areas and the experts' judgements allow classifying these areas on a scale from suitable to optimal (scale of suitability).

WLC is one of the most used decision methods in GIS (Dragan et al., 2003; Eastman, 1999; Graymore et al., 2009; Pérez et al., 2005; Simão et al., 2009 Wang et al., 2010), because it is easy to implement using map algebra operations and geospatial overlay. Moreover, linear combination is an intuitive and powerful method to create realistic scenarios easy-to-understand for decision-makers (Malczewski, 2000). Even though WLC methods can be implemented both with vector and raster format, in this work was applied on raster maps because easier to implement and better supported by used GIS software. Hence, criterion and constraints maps were created in vector format and then converted in raster format, using a spatial resolution of 50 m in accordance with the dimension of the typical farm; the final suitability map has been calculated at the same resolution.

Each criterion and constraints raster map (Fig. 7) is composed by *i* pixels. Each pixel is associated with the value x_{ij}, which represents standardised score of *i*-th pixel with respect to *j*-th criterion. Formally, decision rule of WLC evaluates each alternative through the following function:

$$A_i = \sum_j w_j x_{ij}$$

where A_i alternatives represents the suitability of the *i*-th pixel in the final map, w_j is the normalised weight of *j*-th criterion so that $\sum w_j = 1$, and x_{ij} the standardised score (Malczewski, 2000).

Criterion weights were obtained by interviewing (by means of questionnaires) several experts holding different stakes (fish farmers, researchers, senior civil servants, and collaborators of MPAs). They were asked to evaluate the relative importance of the three criteria using their experiences within their disciplines to make judgements. The evaluation process was undertaken by applying the point allocation rating method using a predetermined scale (from 0 to 100) so that the more points a criterion receives the greater its relative importance and the total of all criterion weights must sum to 100. Results from each expert were converted into normalized weights, subsequently averaged to reduce experts' subjectivity and raise the level of accuracy of the judgments. The normalized averaged weights for the environmental quality, optimal conditions for fish and socio-economic evaluation obtained in the present research are 0.176, 0.164 and 0.660, respectively (Fig. 4). These values are associated to the corresponding criterion map.

From all areas obtained following this procedure, those which could not accommodate a typical farm were removed. According to literature (ISPESL, 2002; Olivares, 2003) and other existing national and international farms and farmers' organisations, a typical structure of an offshore marine fish cage farm for medium production is considered as follows. Its structure includes 10 cages arranged in two rows (Fig. 8). Each cage occupies 0.1 hectare (20 m x 20 m), including minimum distance among two cages. The total area occupied by a typical farm is 4 hectares (160 m x 250 m), including a surface area of 1 hectare and a surrounding area for the anchoring. Consequently, areas with an extension smaller than 4 hectares and narrower than 160 m (the shorter side of the typical farm) were excluded from the suitability map.

Suitability values were reclassified in an integer scale from 1 (suitable area) to 10 (optimal area).

2.2.4. Step 4: Verification

Model verification is an essential part, both for controlling data quality and testing the outcomes of the procedure (Nath et al., 2000). The verification is carried out by comparing the suitable sites identified and the positions of the existing fish farms.

Ligurian fish mariculture is presently licensed in three offshore floating marine fish farms: two in the municipalities of Alassio and Lavagna that produce high quality sea beam and sea bass, and one in Portovenere municipality, considered although not presently operating because the concession is still granted by the Liguria Region.

Spatial multi-criteria analysis is subjected to uncertainty due to many different sources that can lead to a variation of the final result. In order to study the robustness of the suitability map a sensitivity analysis (Rahman, 2012) was conducting varying, according to Malczewski (2000) and Chen et al. (2010), criterion weighs of ±10% and ±20%, in order to understand the influence of the weights on spatial pattern of the suitable sites.

3. Results

The suitability map is shown in Fig. 9 and a summary of the results are presented in Table 3. A total of 65 areas were identified and classified as suitable for positioning an offshore fish farm in the Ligurian Sea, for a total extension of about 9,030 hectares. They represent 17.0% of the marine coastal zone with a suitable morphology in terms of slope and depth (between 10 and 50 m depth and slope less than 15°: about 53 thousand hectares). All identified areas in the Ligurian Sea record suitability values from 2 to 9. About a third of the areas identified (28.5%) shows a value of 4, equal to a medium suitability. About 61.9% of areas are almost equally distributed between the values 6, 7 e 8 (medium-high suitability). The 2.0% of areas has a value of 2, the 6.2% of 5 and only 1.4% is very suitable (value 9). While no area has obtained a suitability values of 1, 3 and, especially 10, the maximum value.

In the Imperia province 19 areas are found (Fig. 9b). The higher number of areas is located in Savona province, with 29 areas (Fig. 9c, d). In the Genoa province there are 4 areas in front of Cogoleto and Arenzano (Fig. 9d), 2 areas in front of Recco and Camogli and 8 areas in the Tigullio Gulf (Fig. 9e). Finally, there are 3 areas in front of La Spezia and Portovenere (Fig. 9f), whose total extension is larger than 4700 hectares. The two areas with the higher suitable value (9) are in front of the municipalities of Savona and Arenzano (Genoa), respectively with an extension of 7.7 ha and 115.4 ha. The verification phase of the procedure has shown that all existing fish farms are actually located in suitable areas (Fig. 10).

The sensitivity analysis showed that the criterion “Socio-economic evaluation” is the one that has the greatest influence on the suitability map, as expected by weights assigned by the experts’ judgement (four times greater than the weights of the other two). Overall, a positive or negative variation of this criterion leads to a shift of the areas to higher suitability levels. In particular, more than 50% of areas show values of 6 and 7.

4. Discussion

Mariculture is a relatively new activity that is expanding globally and specifically in the Ligurian Sea, but it interacts with other activities of the coastal zone. Therefore, it is necessary to designate to this activity suitable sites from environmental, economic and social points of view.

The Ligurian marine coastal zone is a complex system, in which there are many environmental resources and diversified uses of marine coastal zone. The problem of spatial planning (suitable site selection) for any activity in the coastal zone requires the consideration of several seemingly incompatible data and information (Longdill et al., 2008). Moreover, in the start-up of a new productive activity many stakeholders come into play and they have to be involved in the decision-making process in a transparent way.

Given the increase of fish demand and the favourable conditions for a further development of fish farming in the Ligurian Sea, a SMCE able to identify suitable areas for siting an offshore fish farm for medium production in this area has been developed, following an integrated approach. It is based on GIS technologies and MCE techniques and provides all the possible alternatives useful to the decision

path for the management of the coastal zone. The use of GIS in mariculture to select suitable sites is amply documented, and there are also several studies that used SMCE to identify AZAs (Hossain et al., 2009; Longdill et al., 2008; Nayak et al., 2014; Pérez et al., 2005; Radiarta et al., 2008; Silva et al., 2011).

The SMCE allowed discriminating unsuitable areas from suitable ones at the regional scale, based on the defined typical farm, the study area and the considered factors. Other factors should be taken into account (e.g. currents and wind, visual impacts, chemical analyses, possible conflicts with local fisheries or temporary activities, local marine traffic), but the availability of data at finer scale for the whole study area is often not possible or expensive. For this reason these local factors should be considered only after the selection of the suitable SMCE areas to choose the ultimate best sites at local scale.

This SMCE identified 65 suitable areas for installing an offshore fish farm in the Ligurian Sea (Fig. 9 and Table 3), many of which adjacent and grouped in areas of larger extension. These areas are well distributed along the Ligurian coast, with some exceptions. On the whole, the Tigullio Gulf is the best zone both for area extension (larger than 2450 hectares) and suitability values (mean value of 7), although the best sites are allocated in front of Savona and Arenzano (Genoa). With some exceptions, the marine zones in front of the western Riviera from Noli to Celle Ligure and the Genoa Gulf from Genoa to Recco result unsuitable due to the presence of several human activities and two important ports. Also the eastern Riviera from Sestri Levante to La Spezia is unsuitable for the presence of areas of high environmental relevance and the lack of ports.

To verify the obtained results, the positions of the existing fish farms have been overlapped on the final map. The existing offshore fish farms are in front of the town of Alassio, Lavagna and Portovenere and all of them occur in suitable areas (Fig. 10). Alassio farm (Fig. 10a) is in a suitable borderline area because of the presence of a very near sewage pipe and of a site of community importance; however it shows a good ecological status, probably thanks to a clockwise current circulation (Capello et al., 2014) or other local conditions that minimize the anthropogenic inputs. Lavagna (Fig. 10b) and Portovenere (Fig. 10c) farms fit completely in identified suitable areas.

Once identified suitable areas according to general considerations, as said before, local analyses should be conducted to deeply examine specific factors. Locally wave height could have a greater relevance in the positioning of the cages because of the interaction with the sea bottom: higher resolution data can be collected only in the identified areas, in order to reduce costs and sampling time. Marine currents should be analysed at a higher scale than the entire basin in order to improve the pollutants dispersion and the hydrodynamism of the water column. The visual impact of the farm should be evaluated, for example considering the number of houses along the coastline, the presence of valuable areas or the elevation above sea level of coastal areas. It is also necessary to consider conflicts with local fishery, adding the associated areas to constraint ones, but data is difficult to find at the basin level. Moreover, the routes of recreational boating should be analysed to improve forbidden areas.

This presented SMCE can be further improved, both in criteria analysis, considered factors, and in the GIS software procedure that produces the map of classified suitable areas. Especially, the socio-economic evaluation could be further analysed: a network analysis might be done by GIS software in order to take into account the minimum time for reaching the port, considering the street distance and

the type of street instead of the linear distance; only inland facilities that can be loaded and unloaded point and in which products can be brought for sale should be selected (e.g. inland port areas, markets and supermarkets).

5. Conclusions

This paper shows as the developed SMCE, and in particular its procedure, allows identifying suitable areas to install new offshore fish farms in an easy and quick way solving effectively this complex spatial problem. Moreover it supplies a suitability value for each area based on experts' judgement.

This SMCE allows a first identification of suitable areas based on different factors and criteria at the regional level. At a later stage, a detailed analysis at local scale is necessary to choose ultimate best sites. Despite this, the SMCE can be further refined, both in criteria analysis and considered factors, and in the procedure for the GIS software that outputs the map of classified suitable areas.

A possible future development is to create, starting from the Python script, a decision tool for stakeholders. A desktop GIS tool can be developed, but a web service to a wide audience with limited GIS functionality is preferable. In fact the geodatabase could also be accessed via web services and formats such as the OpenGIS Consortium Web Map Service (WMS), Web Feature Service (WFS) and Keyhole Markup Language (KML). This tool will allow changing factors and conditions and potentially applying this SMCE to any coastal system, not only in Liguria.

Furthermore, this SMCE can be used to have information on future spatial planning. Appropriately modifying its procedure, including factors and criteria related to other activities, it may be used to assess the suitable areas for the installation of farms for the production of energy or other fish activities (e.g. offshore wind farms, shellfish farms and onshore mariculture farms).

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A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy

Giulia Dapueto, Francesco Massa, Sara Costa, Laura Cimoli, Enrico Olivari, Mariachiara Chiantore, Bianca Federici, Paolo Povero

Figure legends

Figure 1. The study area: Liguria, Italy. Map obtained using QGIS 2.6.0 with the reference system WGS84 / UTM32N.

Figure 2. SMCE procedure conceptual diagram and relative steps.

Figure 3. Detailed flowchart of SMCE procedure. The layers that define constraints and criterion maps are differntly coloured.

Figure 4. Procedure schema for suitable site selection for fish farming in Liguria. In particular relations between result, criteria (with related normalised weights), factors and their conditions (with description).

Figure 5. Diagram for the definition of the State of Environmental Quality of water bodies according to Italian Ministerial Decree 260/10.

Figure 6. Criteria maps generated for siting offshore fish farms in Liguria: a) Environmental quality; b) Optimal conditions for fishes; c) Social economic evaluation. And d) map of Constraints. The reference system used for these elaborations is WGS84 / UTM32N.

Figure 7. Example of the weighted linear combination method of criteria raster maps (redrawn from Pérez et al., 2005): the suitability map is obtained linearly combining raster criterion maps made up of pixel, each of which is associated with a standardised score, and weighted according to expert's judgement.

Figure 8. Structure of the typical offshore marine fish-cage farm for medium production (seen from above).

Figure 9. Suitability map for siting offshore mariculture farms in Liguria: areas classified from suitable to optimal. The reference system used for these elaborations is WGS84 / UTM32N.

Figure 10. Comparison map between the areas identified with SMCE and the existing farms in front of: a) Alassio; b) Lavagna; and c) Portovenere. The reference system used for these elaborations is WGS84 / UTM32N.

Figures

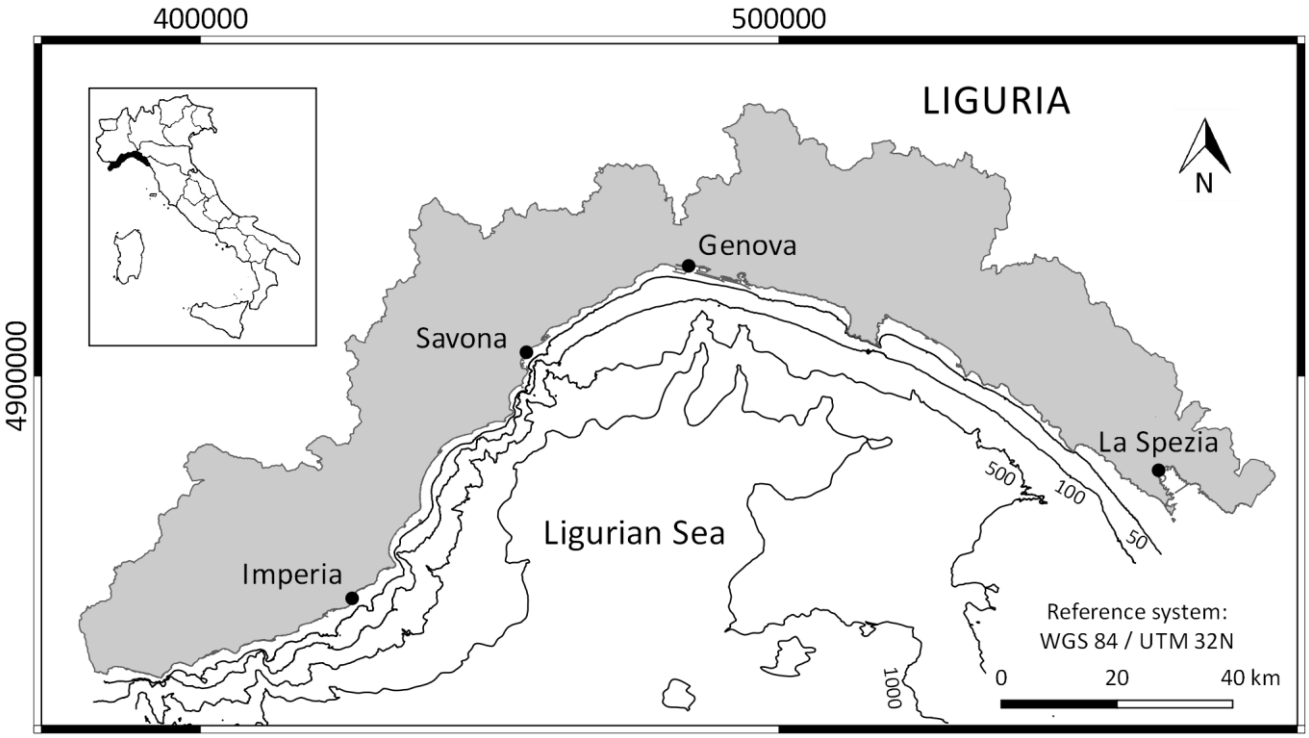

Figure 1

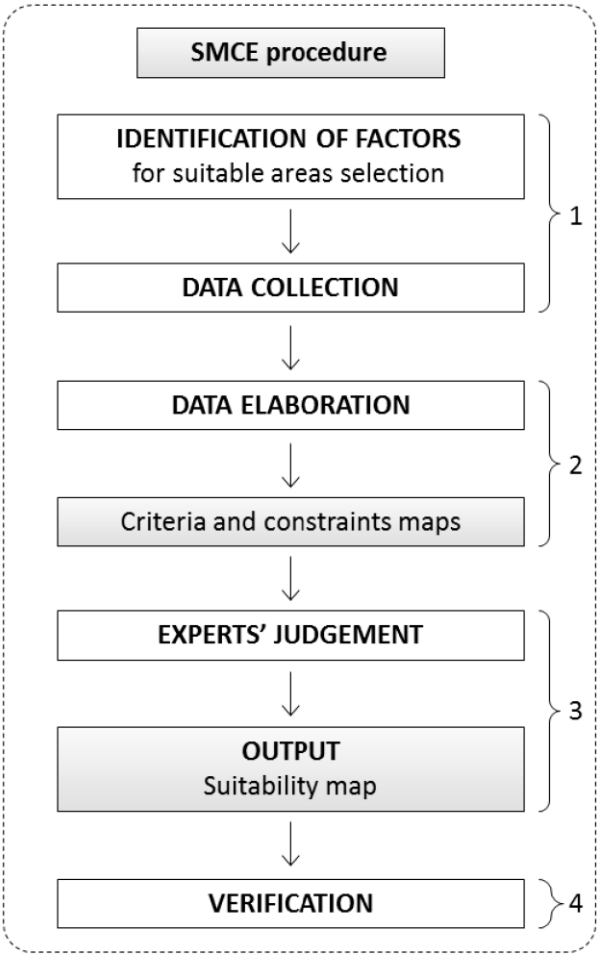

Figure 2

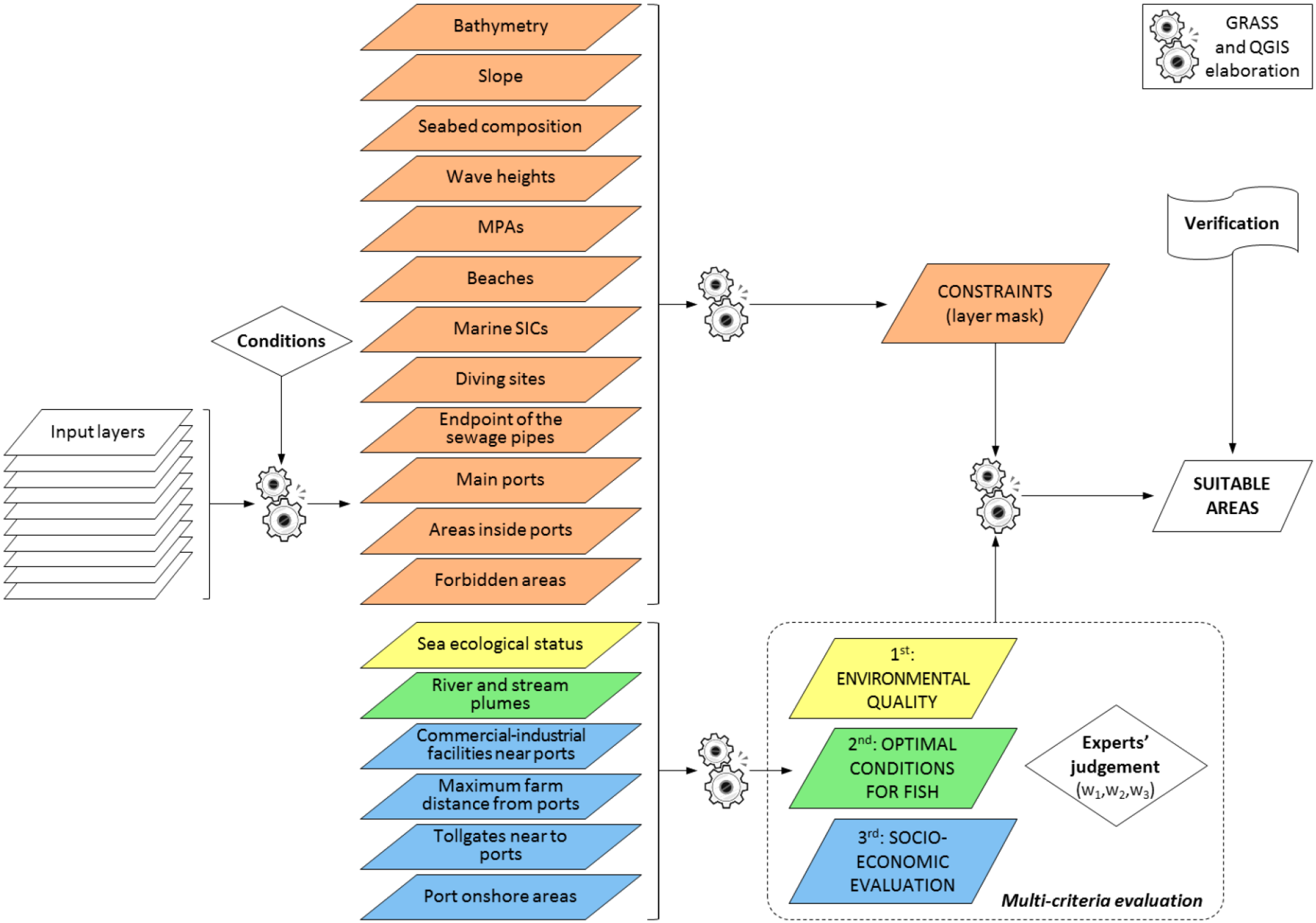
GRASS and QGIS elaboration
Bathymetry
Slope
Seabed composition
Wave heights
MPAs
Beaches
Marine SICs
Diving sites
Endpoint of the sewage pipes
Main ports
Areas inside ports
Forbidden areas
Verification
CONSTRAINTS (layer mask)
Conditions
Input layers
SUITABLE AREAS
Sea ecological status
River and stream plumes
Commercial-industrial facilities near ports
Maximum farm distance from ports
Tollgates near to ports
Port onshore areas
1st: ENVIRONMENTAL QUALITY
2nd: OPTIMAL CONDITIONS FOR FISH
3rd: SOCIO-ECONOMIC EVALUATION
Experts' judgement (w1,w2,w3)
Multi-criteria evaluation

Figure 3

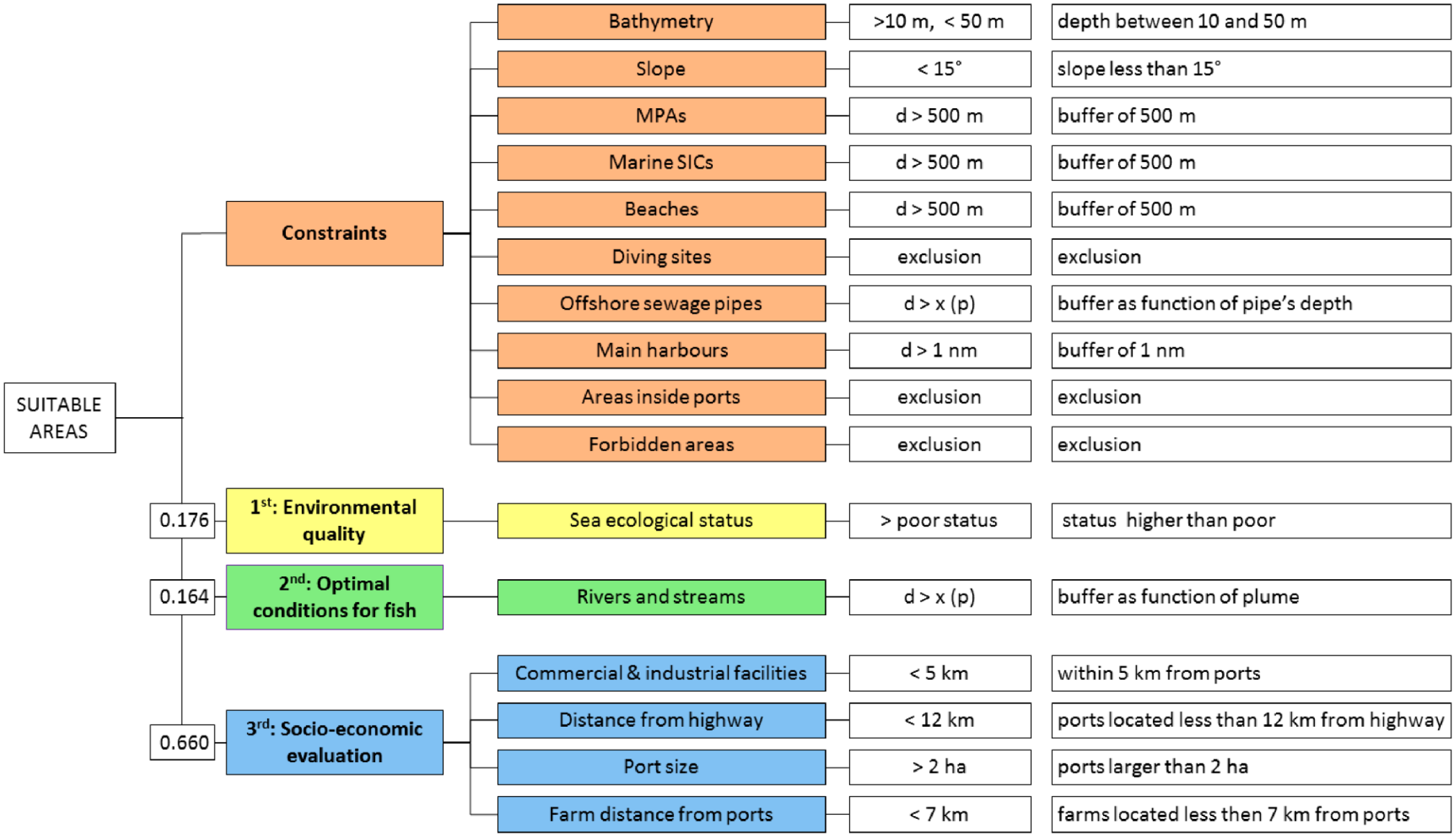
SUITABLE AREAS
Constraints
Bathymetry
>10 m, < 50 m
depth between 10 and 50 m
Slope
< 15°
slope less than 15°
MPAs
d > 500 m
buffer of 500 m
Marine SICs
d > 500 m
buffer of 500 m
Beaches
d > 500 m
buffer of 500 m
Diving sites
exclusion
exclusion
Offshore sewage pipes
d > x (p)
buffer as function of pipe's depth
Main harbours
d > 1 nm
buffer of 1 nm
Areas inside ports
exclusion
exclusion
Forbidden areas
exclusion
exclusion
0.176
1st: Environmental quality
Sea ecological status
> poor status
status higher than poor
0.164
2nd: Optimal conditions for fish
Rivers and streams
d > x (p)
buffer as function of plume
0.660
3rd: Socio-economic evaluation
Commercial & industrial facilities
< 5 km
within 5 km from ports
Distance from highway
< 12 km
ports located less than 12 km from highway
Port size
> 2 ha
ports larger than 2 ha
Farm distance from ports
< 7 km
farms located less then 7 km from ports

Figure 4

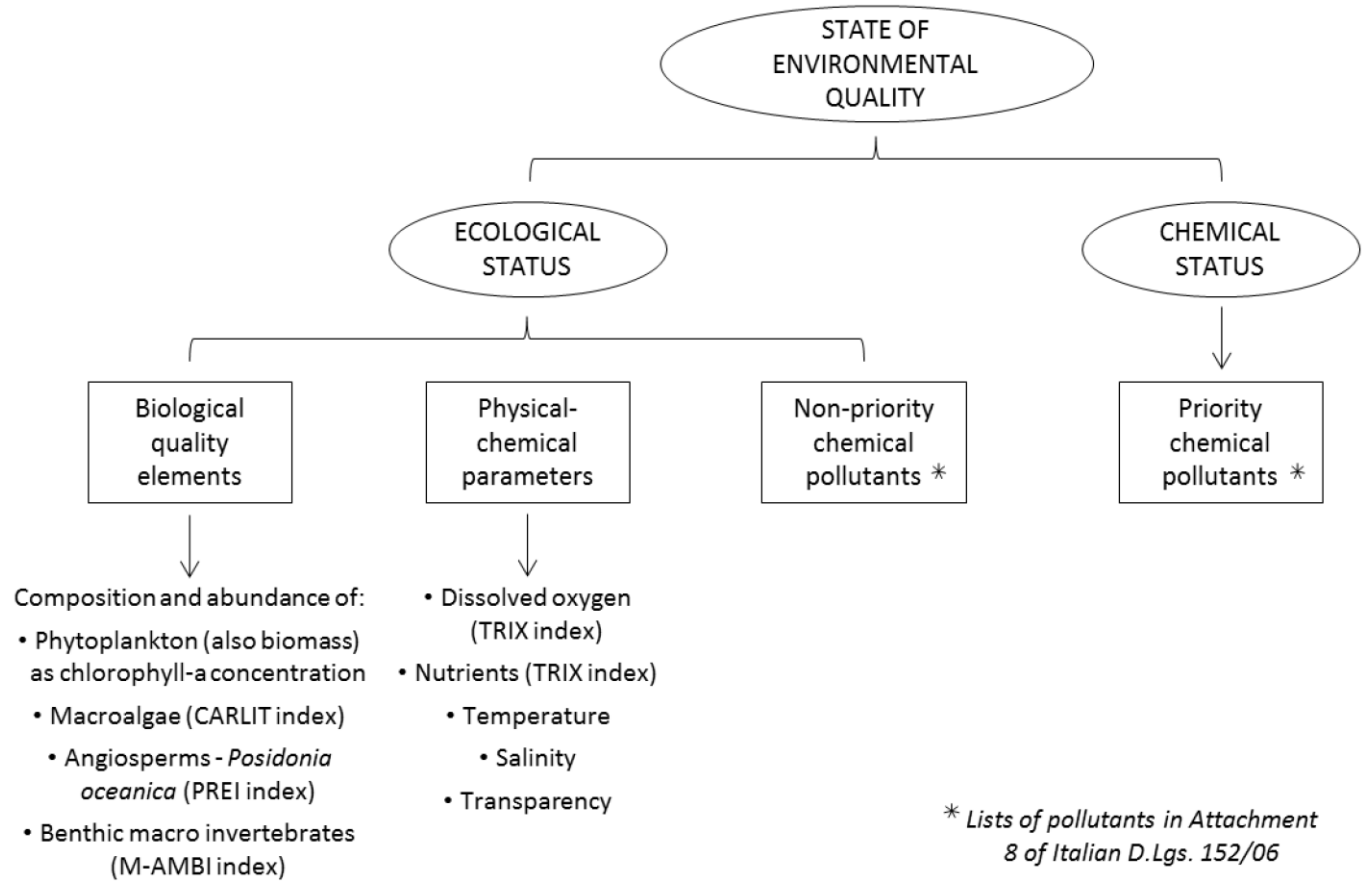

Figure 5

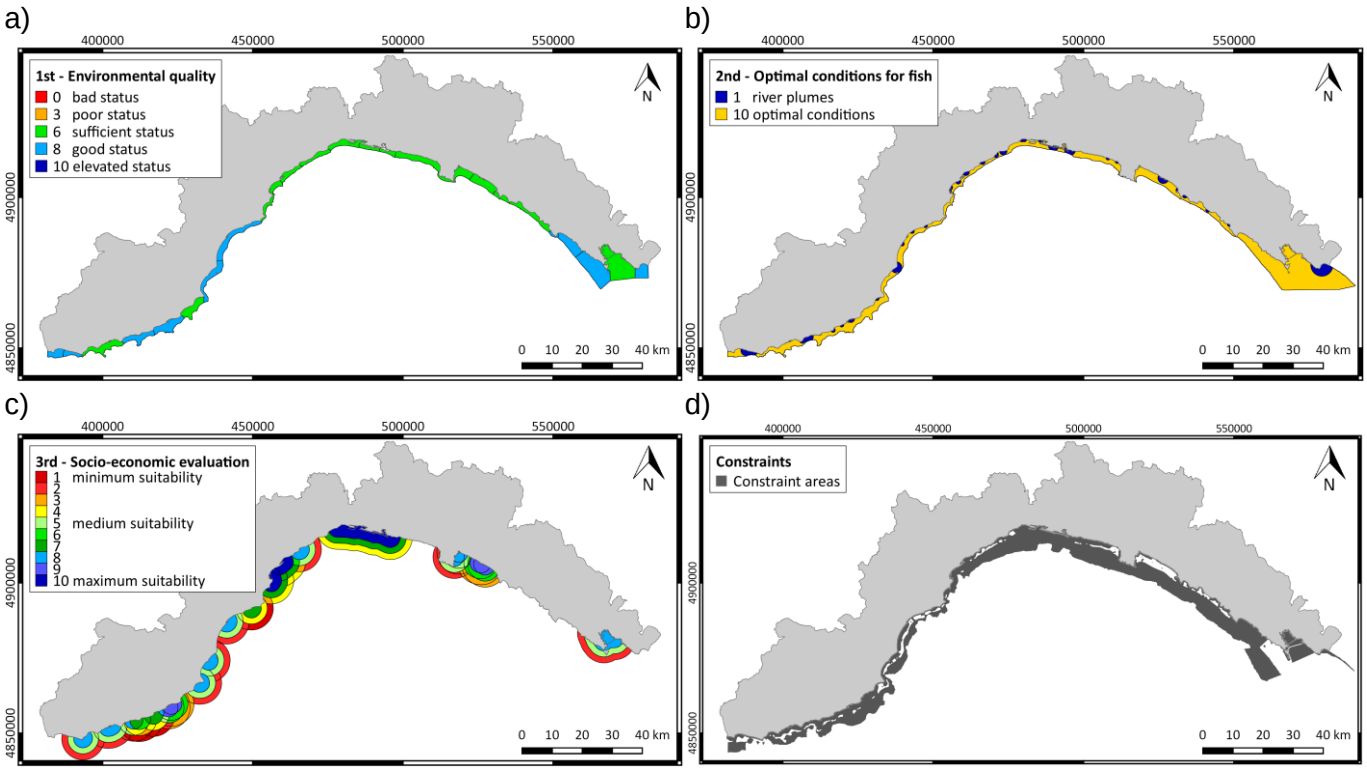

Figure 6

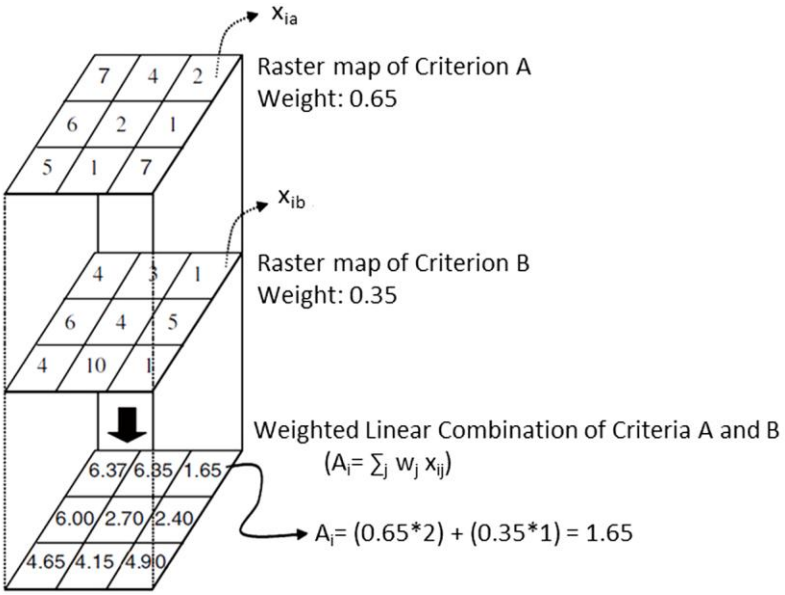

Figure 7

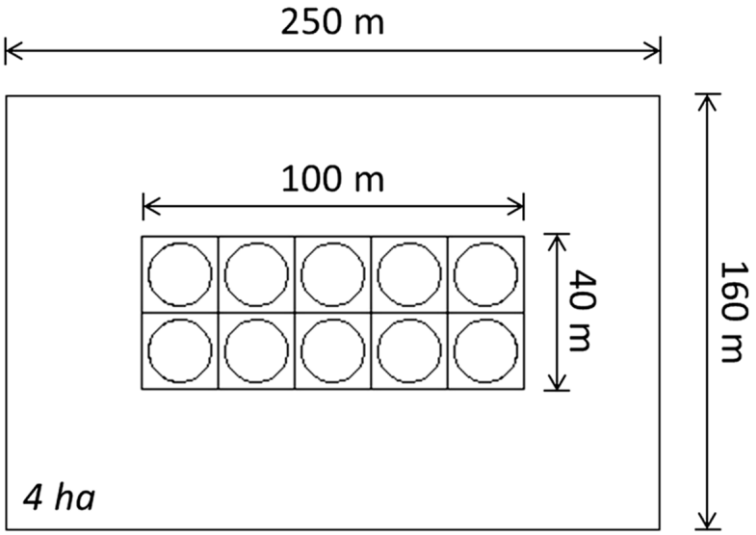

Figure 8

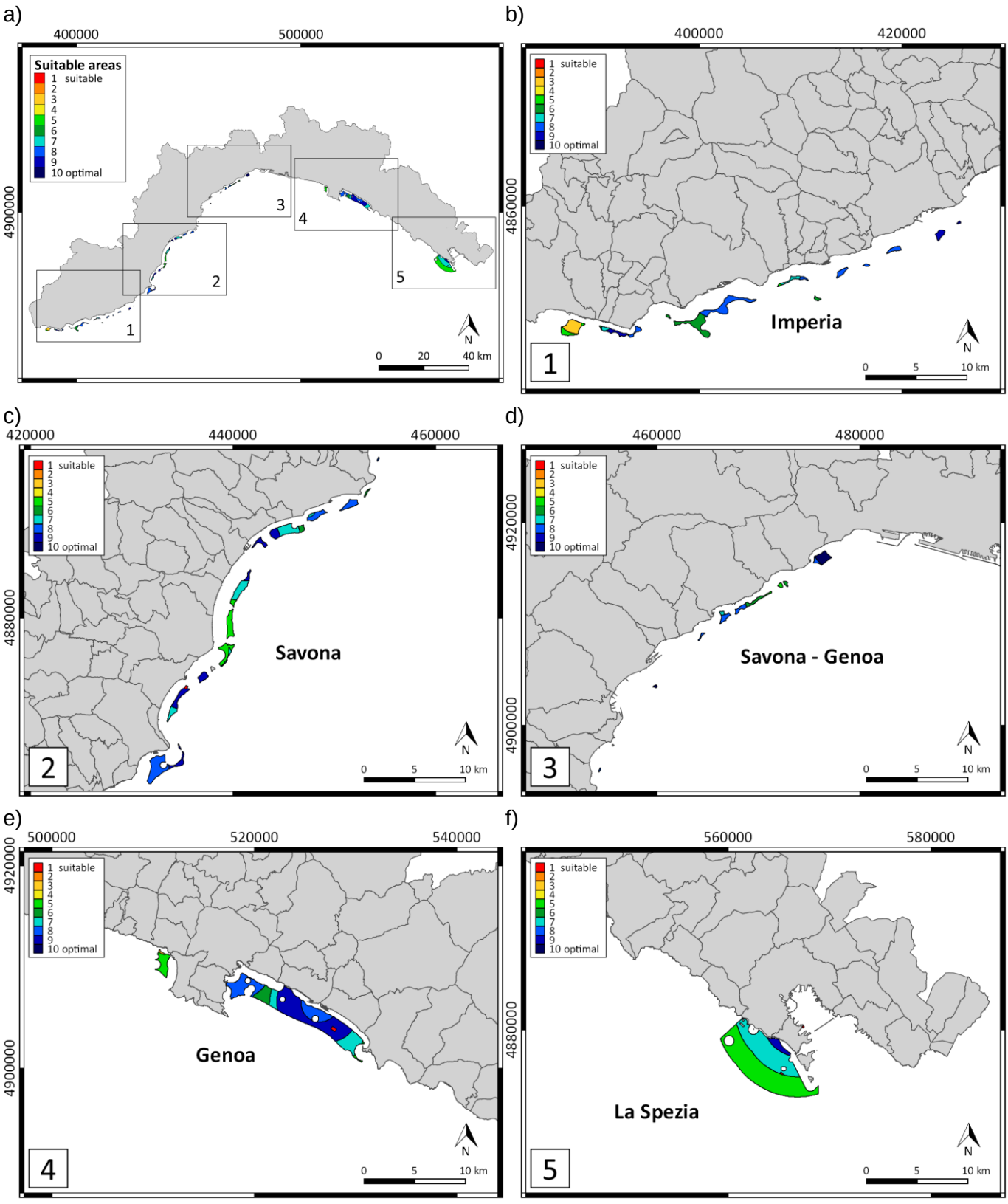
a)
400000
500000
4900000
Suitable areas
1 suitable
2
3
4
5
6
7
8
9
10 optimal
1
2
3
4
5
N
0 20 40 km
b)
400000
420000
4860000
1 suitable
10 optimal
Imperia
1
N
0 5 10 km
c)
420000
440000
460000
4880000
Savona
2
d)
460000
480000
4920000
4900000
Savona - Genoa
3
e)
500000
520000
540000
4920000
4900000
Genoa
4
f)
560000
580000
4880000
La Spezia
5

Figure 9

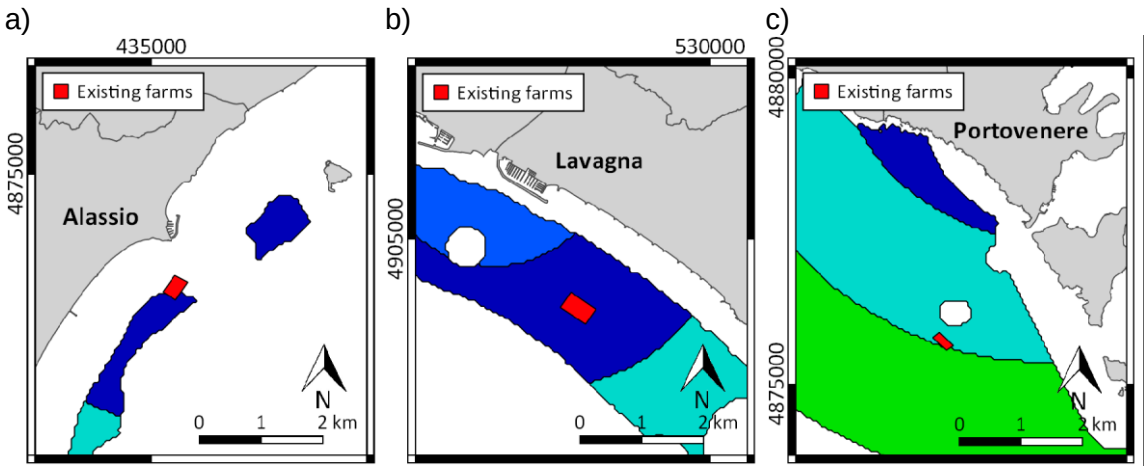
a)
435000
4875000
Existing farms
Alassio
N
0 1 2 km
b)
530000
4905000
Existing farms
Lavagna
N
0 1 2km
c)
4880000
4875000
Existing farms
Portovenere
N
0 1 2 km

Figure 10

A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy

Giulia Dapueto, Francesco Massa, Sara Costa, Laura Cimoli, Enrico Olivari, Mariachiara Chiantore, Bianca Federici, Paolo Povero

Table legends

Table 1. Factors for fish farming site selection in Liguria, sources of data used for the analysis and data format (• vector, ◘ raster and ❖ table list).

Table 2. Classes of rivers and streams to which is associated an offshore distance (in nautical miles, nm) representative of the plume (with their municipalities).

Table 3. Summary of suitable sites (from raster map) grouped for suitability value, expressed in terms of number of suitable areas and extension in hectares and in percentage respect to suitable areas.

Tables

Factor	For …	Data source and format
Bathymetry	farm positioning, anchoring and routine/emergency operations; preventing farm waste dispersion	• Bathymetry of Liguria from 2500 m to 5 m depth - scale 1:20000 • Coastline - scale 1:5000 - edition 2012
Slope	farm positioning and anchoring	• Bathymetry of Liguria from 2500 m to 5 m depth - scale 1:20000
Type of seabed	farm positioning and anchoring	• Marine sediments of Liguria - scale 1:50000 - edition 2002
Wave height	farm positioning, anchoring and accessibility	◻ Wave heights for the period 1979-2010 in the Ligurian Sea (WAVEWATCH III model) ❖ Wave heights from La Spezia buoy of Italian National Wave Recording Network
Marine protected areas	protection from potential farm pollutions	• Marine Protected Areas - scale 1:30000 - edition 2007
Marine sites of community importance	protection from potential farm pollutions	• Land and Marine S.C.I. - DGR 705/2012 and DGR 613/2012 - scale 1:10000
Beaches	protection from potential farm pollutions	• Land use - scale 1:10000 - edition 2012
Diving sites	protection from potential farm pollutions	❖ Diving sites coordinates from Ligurian MPAs (personal communications)
Sewage pipes	farm protection from potential pollutions	• Coastal purification - scale 1:10000 - edition 2008
Main harbours	farm protection from potential pollutions	• Areas of expertise Port Authorities - scale 1:5000 - edition 2010 • Land use - scale 1:10000 - edition 2012
Coastal marine environmental quality	guaranteeing fish growth and health	• Classification of the State of Surface Water Bodies (ARPA) 3-year period from 2009 to 2011, DGR 1615/2012 - scale 1:10000 - edition 2011
River and stream plumes	evaluating physical-chemical parameters for fish growth	• Watershed - scale 1:25000 - edition 2001 • Classification of the State of Surface Water Bodies (ARPA) 3-year period from 2009 to 2011 - DGR 1615/2012 - scale 1:10000 - edition 2011
Commercial and industrial facilities near the port	fish processing, transport and sale	• Land use - scale 1:10000 - edition 2012
Port distance from highway (tollbooths)	selecting storage areas for the fry to breed and the fish to sell	• Roads viability, Priority Layers CTR - scale 1:10000 - edition 2003
Port size	selecting ports able to support aquaculture activities	• Land use - scale 1:10000 - edition 2012 • Coastline - scale 1:5000 - edition 2012
Areas whit prohibitions	identifying areas in which aquaculture is not allowed	◻ Nautical map no. 1, 2 and 3 from the Hydrographic Institute of the Italian Navy - scale 1:100000 - edition 2010 ◻ Nautical map from the Pilot book of the Italian seas - scale 1:100000 - edition 2010

Table 1

Class	Buffer distance	Rivers and streams (Municipality)
1	2 nm	Magra (Ameglia)
2	1 nm	Roja (Ventimiglia) Argentina (Arma di Taggia) Centa (Albenga) Polcevera (Genova) Bisagno (Genova) Entella (Chivari/Lavagna)
3	⅔ nm	Nervia (Ventimiglia) Impero (Imperia) Sansobbia (Albissola Marina) Lerone (Cogoleto)
4	½ nm	Vallecrosia (Vallecrosia) Armea (Sanremo) Letimbro (Savona) Teiro (Varazze) Arrestra (Varazze/Cogoleto) Cerusa (Genova) Leira (Genova) Varenna (Genova) Chiaravagna (Genova) Petronio (Sestri Levante)
5	⅖ nm	S. Lorenzo (San Lorenzo al Mare) Prino (Imperia) Merula (Andora) Varatello (Borghetto Santo Spirito) Maremola (Pietra Ligure) Aquila (Finale Ligure) Segno (Vado Ligure) Quiliano (Savona) Sori (Sori) Recco (Recco) Gromolo (Sesti Levante) Castagnola (Deiva marina) Ghiararo (Levanto)

Table 2

Suitability value	No. of areas	Surface (ha)	Surface (%)
1	0	0	0
2	2	183.38	2.0
3	0	0	0
4	11	2572.30	28.5
5	9	561.38	6.2
6	12	2140.32	23.7
7	16	1690.97	18.7
8	12	1760.03	19.5
9	2	123.06	1.4
10	0	0	0
Total	***65***	***9031,44***	***100,00***

Table 3

***Detailed Response to Reviewers**

We would like to thank you very much for your reply and consideration of the Manuscript: **A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy**.

We submit the revised manuscript version which was amended, considering all comments by the referees. We would like also to thank the Reviewers for the useful comments that certainly have helped to improve the quality and the presentation itself. We believe the paper has been improved.

We accepted all the suggestions, except for a few that are later explained and elaborated on.

Changes have been applied to both the manuscript and other files:

- Title Page with all author info: Dapueto_et_al_Submission_Title_Reviewd.docx
- Manuscript (without Title Page): Dapueto_et_al_Submission_Manuscript_Reviewd.docx
- Table: Dapueto_et_al_Submission_Tables_Reviewd.docx
- Figure: Dapueto_et_al_Submission_Figures_Reviewd.docx
- Highlights: Dapueto_et_al_Submission_Highlights_Reviewd.docx
- Cover letter: Dapueto_et_al_Submission_Cover_letter_Reviewd.docx

We also provide as supplementary material a KML file with the final map of suitable areas for fish farming along Ligurian coasts, obtaining from the conversion of the raster map into a vector one: "Suitable areas map KML" (Suitable_areas_fish_farming_Liguria.kml).

First of all, taking into account the comments of Reviewer n. 3, we improved the grammar of the text.

We made a change in the authors' affiliations. For the author Laura Cimoli there is a double affiliation since she recently moved to the University of Oxford; however, this study has been developed entirely while she was at the University of Genoa.

NB: Each reference (page and line) into the comments is referred to the pages/lines number of the new manuscript with the accepted revisions.

For Table and Figures both old and new numerations are specified. In particular, the order of the figures was modified and changes to the figures were made mainly according to the suggestions of the Reviewer n. 3 (in the relative file only the corrections of the legend are indicated).

Considering the comments of the **Reviewer n. 1**, corrections and improvements were made and summarised as follows (before reviewer's question and after our answer).

1. *How the authors did account for "sustainability" of the study area in their approach is not clear from the text.*

We have better explained what "sustainability" means in our work and in particular we explained what the development of a sustainable mariculture is about (***page 2, lines 38-40; page 3 line 1; page 3, lines 16-17***): a development that provides a healthy product that satisfies the market demand but without bringing environmental degradation and negative interaction with other activities and that is economically advantageous.

2. *The authors should clarify the target species in their manuscript.*

   At the end of the Introduction (***page 4, lines 8-10***) we have clarified what the considered species for the study and the motivations are.

3. *Some environmental or ecological parameters are oversimplified in their methodology. I would like to see real data related to the first order parameters for cage aquaculture such as turbidity, temperature, salinity etc.*

   This comment is a valuable indication. We made additions in different parts of the text in order to better justify our choices.

   - First of all in the paragraph "2.1 Study area" (***page 4, lines 20-38***) we extended the physical and chemical description of the Ligurian Sea in order to better characterise it from the point of view of the first order parameters for a marine fish cage farm .
   - Secondly, in "2.2.1 Step 1: Identification of factors and data collections" (***page 7, lines 16-36***) we detailed the description of the physic-chemical parameters that affect the fish growth (temperature, salinity, dissolved oxygen, turbidity and nutrient): we explained how these parameters affect fishes and inserted ranges tolerated by the farmed species.
   - These improvements allow us to say that the Ligurian Sea shows values in accordance with fish growth ranges. Exceptions are turbidity and possible pathogens and pollutants, whose concentration is strongly influenced by the river runoff (***page 7, lines 37-39***). Therefore in the second criterion (optimal conditions for fish) we consider only river and stream plumes as the only potential sources of lower suitability.

   Moreover, we expanded and elaborated the description of the criterion relating to the environmental quality, in particular the State of Environmental Quality, who defines it (the Italian Ministerial Decree 260/10 according to the Water Framework Directive 2000/60/EC), how it is evaluated, what it is made of and the data source (***page 8, lines 29-40; page 9, lines 1-3***). To better understand the definition of the State of Environmental Quality, we added the diagram for Italy: ***Figure 5***.

4. *There should be also data on significant wave height at least monthly averages for the region.*

   Regarding to the significant wave height, in the first step of the procedure (Identification of factors and data collections: ***page 6, lines 32-40; page 7, lines 1-11***) firstly, we expanded the description

of its effect on offshore fish cage farming. We specified the source of data and, as requested by the reviewer, we used the monthly average wave height (WAVEWATCH III model) instead of an annual average inclusive of all variations. We also added wave height observed data from the Ligurian buoy of the Italian Rete Ondametrica Nazionale as confirmation that 100 days per year with waves higher than 2.5 m in height are not reached.

5. *It is not clear from the text how the authors collected marine environmental data or chemical biological data (Table 1) and what type of parameters are available, who collected those parameters and which standards were used during the measurements.*
   As reported in previous answers, we specified the data source of physic-chemical parameters (***page 7, lines 21-36***), the environmental quality (***page 8, lines 29-40; page 9, lines 1-3***) and wave height (***page 6, lines 32-40; page 7, lines 1-11***). Moreover, Table 1 and Table 2 were combined into a single one (***Table 1***) better explaining what each factor is for, data sources and format.

6. *What type of data model they used for the GIS project and what they think about the updating procedure of the built geodatabase.*
   In the paragraph where the SMCE for site selection of a marine fish farm is described (***page 6, lines 4-8***), we clarified the data model used for the GIS project and the updating process of the data used for the creation of the result map.

7. *The authors should also explain the weighting procedure of the data. How they decided about the mean weights in Table 4.*
   We detailed both the process of evaluation by experts and the process of criteria weighting (***page 11, lines 4-14***). In addition to this, we eliminated the related Table 4 and its data was included in the text instead.

We didn't understand exactly what the **Reviewer n. 2** means with "diagrams on the Ligurian Sea using the software". In the paper we present different type of diagrams: a block diagram representative of the procedure steps; the flowchart of the procedure; the procedure schema for Liguria with the relation between result, criteria and factors; the criterion and constraints maps; a diagram representative of the WLC procedure; and in particular the output map of the procedure obtained with GIS software and the comparison with existing farms (***Figures 9 and 10***). The procedure was applied only to one case of study; consequently the output map with suitable classified areas is only one. If the reviewer is interesting in something else specifically, could he make us a more precise request? We are pleased to answer.

Taking **Reviewer n. 3**'s advices we made the following changes.

We answered about the use of the software in the description of the SMCE in material and methods (***page 6, lines 4-10***) and in the Conclusions (***page 14, lines 14-19***). It is important to note that we didn't build the software, but we developed the Python script of the procedure with GRASS commands in order to chain operations into one process and update data in an easy way. This is a possible basis for a future development of an automated procedure for a desktop GIS tool or a web service to a wide audience with limited GIS functionality. We think to do this but it cannot be developed in a short time. In accordance with this, we eliminated the term "tool" associated to our SMCE. Moreover, we attached, as supplementary material, the KML file relative to the final map to provide an interactive way to explore and query the results.

With the term "transferability" we meant to imply the possibility of adapting and applying the procedure (changing factors and conditions) to other coastal areas, not only in Liguria. Hence in the Abstract and in the Highlights the term has been replaced with "potentially adapted".

In the description of the study area we added the nutrient conditions of the see (***page 4, lines 23-29***). Moreover we broadened the influence of nutrients on fish growth and how and why they were considered in the procedure (***page 7, lines 16-19 and 24-28; page 8, lines 35-39***).

The biological information to determine locations for healthy offshore fish farming are explained in the third point of the Reviewer n. 1 (***page 4, lines 20-38; page 7, lines 24-33***).

In regard to the figures, the following changes were made.

- In the ***Figure 2*** the numbers relative to the procedure steps (***page 5, lines 28-35***) were added to the figure near boxes in order to make its reading more clear.
- The legend of the old Figure 4 (***Figure 8***): was improved.
- In the old Figures 6, 8 and 9 (***Figures 6, 9 and 10***) a legend near each map was improved or added to help the reading of the figures. Especially in regards to the description of scores of the criterion maps and of the final suitability map.
- We improved both the ***Figure 7*** and its legend, clarifying the application of the weighted linear combination to the case of fish farming.
- Furthermore some other legends were improved and small changes to texts inside the Figure 3 and in the old Figure 5 (***Figure 4***) were made.

Suitable areas map KML

Click here to download KML File (for GoogleMaps): Suitable_areas_fish_farming_Liguria.kml