Ocean & Coastal Management 116 (2015) 64–77

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

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

Giulia Dapueto [a, *], Francesco Massa [a], Sara Costa [a], Laura Cimoli [a, b], Enrico Olivari [a], Mariachiara Chiantore [a], Bianca Federici [c], Paolo Povero [a]

[a] Dipartimento di Scienze della Terra, dell'Ambiente e della Vita (DISTAV), Università degli Studi di Genova, Corso Europa 26, 16132 Genoa, Italy
[b] Department of Physics, University of Oxford, Parks Road, OX1 3PU, Oxford, United Kingdom
[c] Dipartimento di Ingegneria Civile, Chimica e Ambientale (DICCA), Università degli Studi di Genova, Via Montallegro 1, 16145 Genoa, Italy

ARTICLE INFO

Article history:
Received 26 January 2015
Received in revised form
26 May 2015
Accepted 29 June 2015
Available online xxx

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

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.

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,

* Corresponding author.
E-mail address: giulia.dapueto@edu.unige.it (G. Dapueto).

http://dx.doi.org/10.1016/j.ocecoaman.2015.06.030
0964-5691/

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 and 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 and Baker, 2013; Krois and 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 and Lopez-Blanco, 2003; Dragan et al., 2003; Li et al., 2013; Store and 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 and Gastli, 2011; Carver, 1991; Hossain et al., 2009; Kamruzzaman and Baker, 2013; Krois and 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 and 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 et al., 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 and 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 and Fabiano,