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Space allocation for coastal aquaculture in North Africa: Data constraints, industry requirements and conservation issues

Daniele Brigolin [a, *], Hichem Lourguioui [b, c, d], Mohamed Amine Taji [e], Chiara Venier [a], Antoine Mangin [e], Roberto Pastres [a]

[a] Dipartimento di Scienze Ambientali, Informatica e Statistica, Università Ca' Foscari di Venezia, Calle larga S. Marta 2137, 30123 Venezia, Italy
[b] Laboratoire des Ecosystèmes Marins et Littoraux, Ecole Nationale Supérieure des Sciences de la mer et de l'Aménagement du littoral, ENSSMAL, campus universitaire Dely Ibrahim, BP 19, Bois des cars, Alger, Algeria
[c] Facultés des Sciences Biologiques, Université des Sciences et de la Technologie Houari-Boumédiène, B.P. 32 El-Alia, Bab-Ezzouar 16111, Alger, Algeria
[d] Commissariat National du Littoral (CNL), Avenue Mohamed Fellah 30, Kouba, Alger, Algeria
[e] ACRI-EC, rue Mustapha El Maâni 209, 20100 Casablanca, Morocco

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A B S T R A C T

This paper presents a methodology for the selection of coastal sites for finfish cage farming, based on both satellite remotely sensed data and mathematical models. Such methodology can be applied, at screening level, also in areas where field data are lacking, and consists in two steps. In the first one, candidate areas are ranked according to criteria which take into account the risk of cage breaking due to wave actions and fish welfare requirements. This step involves the post-processing of satellite data and results of operational oceanographic models by means a multi-criteria methodology implemented in a GIS environment. In the second step, an integrated aquaculture impact assessment model is applied to the most suitable areas in order to obtain a preliminary assessment of the potential interaction of a newly established cage with benthic habitats. The methodology was applied to an Algerian coastal area near the town of Bejaia where the central government is planning to develop aquaculture activities. Results show that the procedure allows to perform a site selection, which combines the quality of a site from the aquaculture use perspective with the conservation of endangered benthic habitats (*Posidonia oceanica* meadows) under the spatial restrictions imposed by existing activities. This result goes in the direction of defining site selection methodologies complying with the principles of the ecosystem approach to aquaculture and providing a science-based support in the framework of the implementation of the UNEP/MAP ecological approach.

1. Introduction

Marine finfish cage farming is an economically relevant activity exerting pressures on coastal systems (Hargrave, 2005) and requiring a science-based management in order to be carried out in a sustainable way (Soto et al., 2008). At the Mediterranean level this industry grew from 77×10^6 USD to 689×10^6 USD during the nineties. In the last decade the positive trend decreased, and in recent years the sector has been stagnating (FAO, fishtatJ). Nevertheless, the European Union has included aquaculture among the activities of key relevance for the blue-growth strategy (COM, 2012/494) and the European Aquaculture Technology and Innovation Platform explicitly mentioned the importance of developing technologies and best practices for selection of aquaculture sites (EATIP, 2012) within its action plan for the development of Mediterranean coastal aquaculture. The strategic importance of the site-selection issue for the sustainable development of aquaculture is also recognized by non EU Mediterranean countries (GFCM, 2010).

Issues related to space allocation can be roughly categorized in two classes (see e.g. Radiarta et al., 2008): 1) suitability of a site, in terms of carrying and assimilative capacity, with respect to aquaculture typology, and 2) conflicts with other uses of a coastal area. Within the broader context of Marine Spatial Planning (MSP) (Douvere and Ehler, 2009) the evaluation of the collective pressures and the balancing of competing activities are also required. In such a context, the trade-off between the achievement of a blue-growth

* Corresponding author.
E-mail address: brigo@unive.it (D. Brigolin).

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objectives and the maintenance of a good ecosystem status is mandatory according to both the Marine Strategy Framework Directive 2008/56/EC (MSFD; European Community, 2008) and the UNEP-MAP EcAp "Ecosystem Approach" (UNEP/MAP/PAP, 2008), which is going to be implemented by Mediterranean countries.

The use of indicators and models (Ferreira et al., 2010) can support decision makers in the allocation of new zones for aquaculture, thus enhancing its social acceptability. However, the lack of adequate sets of input data often represents a key limitation to the use of site selection models, particularly in those Mediterranean countries where systematic monitoring programs of water quality and hydrography are still to be implemented. To this regard, Satellite Remote Sensing (SRS) data could represent, at least at a screening level, a low-cost alternative for supporting the application of site selection model. The use SRS data in aquaculture applications has received much attention in recent years, and a number of works has been published on the subject (Kapetsky and Anguilar-Manjarrez, 2007; Aguilar-Manjarrez et al., 2010; Saitoh et al., 2011; Stuart et al., 2011).

In this paper we present a screening methodology for allocation of zones for finfish aquaculture and subsequent site selection, which is based on the integration of satellite data, oceanographic models, and site selection ones. This was developed within the concept of Allocated Zones for Aquaculture (AZA), which was adopted by the Mediterranean Fisheries Commission as a management tool for sustainable aquaculture planning (GFCM, 2012/36/2012/1). The methodology was applied to a Southern Mediterranean coastal area in Algeria where cage aquaculture is not developed as yet but is recognized as a promising venture. The main objectives of the paper are:

1) to show how satellite data and a wave model can be used for selecting suitable areas for cage culture for European seabass *Dicentrarchus labrax* L., 1758 (herein seabass) and Gilthead seabream *Sparus aurata* L., 1758 (herein seabream) cage farming;
2) to provide a preliminary assessment of potential environmental interactions of this activity with sensitive habitats, such as *Posidonia oceanica* meadows, by means of a an integrated site selection model.

2. Materials and methods

The procedure here proposed takes into consideration use conflicts as constraints and both a set of requirements concerning the profitability of farms and their environmental impacts. As displayed in Fig. 1, it consists in three steps:

a) candidate Allocated Zones for Aquaculture (AZA) areas were determined by taking into account the conflicts with other uses which are not compatible with cage culture, such as tourism and navigation, as well as the presence of sensitive habitats (in this case *P. oceanica* meadows);
b) AZA were then identified on the basis of the effects of environmental drivers having an impact on fish welfare and cage resistance: three layers were considered, see Fig. 1, concerning the spatial distributions of significant wave height, wave induced currents, and light diffusion coefficient k_d. In these two steps (a, b) a Boolean classification scheme (suitable areas 1, unsuitable areas 0) was adopted (Falconer et al., 2013);
c) eligible sites within AZA were then further screened for a preliminary characterization of the Allowable Zone of Effect (AZE) (GFCM, 2012), using the integrated aquaculture impact assessment model FiCIM (Brigolin et al., 2014) for calculating indicators of pressure on the benthic system and assessing the potential biomass yield.

2.1. AZA identification

According to Kapetsky and Aguilar-Manjarrez (2007) coastal aquaculture was operationally defined to be located within 3 km from the coast. In accordance with Radiarta et al. (2008) and Longdill et al. (2008) interactions with other uses were defined as constraints. The following uses were considered:

1) priority areas for coastal tourism;
2) priority areas for navigation.

Furthermore, the presence of sensitive habitats, and in particular of *P. oceanica*. meadows, was taken into account.

As represented in Fig. 1 the analysis considered two classes of environmental drivers potentially affecting quality and quantity of the production and the risk for the invested capital (cage; stocked fish), namely waves and water quality. Two indicators concerning wave impacts were considered: i) the 90th percentile (P_{90}) of the significant wave height (H_s) distribution (H_s is the average height of the one-third highest values in a continuous series which is very commonly used for marine structure design as being a direct indicator of the waves energy); ii) the mean value of wave-induced current speed U_b, which represents the amplitude of the fluctuating current due to wave.

The first parameter is a proxy of cage exposure to net deformation (Lader et al., 2007). H_s has a direct relationship with the risk of rupture of a cage, which, beside causing economic losses, threatens the wild population genetic pool (Dempster et al., 2013). In the current analysis, those areas at which the P_{90} H_s value was not exceeding 3 m were selected as suitable for cage deployment. This threshold was set based on the previous work by Pérez et al. (2003) (assuming that Corelsa (R) cage model will be utilized). The same 3 m threshold was also reported by Kapetsky and Anguilar-Manjarrez (2007) when characterizing coastal versus off-shore aquaculture environments. The second parameter represents an important component of the overall current velocity in coastal areas. According to Ferreira et al. (2012) the current speed affects the FCR (Feed Conversion Rate – weight of feed provided to weight of fish harvested), which decreases monotonically as the velocity increases thus decreasing profitability of the activity and increasing its environmental impacts. Ferreira et al. (2012) also remarked that low currents negatively affect the compositional and organoleptic quality of seabass and seabream fillet. The spatial distributions of the 90th percentile of both H_s and U_b were estimated using the SWAN model (Booij et al., 1999). SWAN is a wave propagation model, based on the spectral action balance equation, capable to simulate the advective propagation, refraction, and diffraction of wind-waves and swells close to the shore. SWAN accounts for wind, dissipation and nonlinear wave interaction. Water quality for aquaculture was related to the level of transparency, evaluated by considering the diffusive attenuation coefficient K_d at 490 nm (herein k_d), which was included in the analysis in order to account for the effect of high turbidity levels on the physiology of farmed fish (e.g. Gray et al., 2014).

In the third step, the integrated model FiCIM (Fish Cage Integrated Model), described by Brigolin et al. (2014), was applied in order to obtain a preliminary assessment of fish farm environmental interactions with the seabed and an estimation of biomass yield. The model provides a detailed representation of seabass and seabream growth and population dynamics inside the rearing cages, based on a bioenergetic individual model. FiCIM also allows one to simulate the