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Spatial analysis for site selection in marine aquaculture: An ecosystem approach applied to Baía Sul, Santa Catarina, Brazil

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ABSTRACT

The aim of this research was to propose and evaluate a methodological approach to integration and spatial data analysis in order to generate information towards a participatory site selection for bivalve marine aquaculture in the Baía Sul, Florianópolis, Santa Catarina, Brazil. For this purpose, the Baía Sul was investigated considering an ecosystem approach for aquaculture leading to an assessment of its potential for marine aquaculture. The planning of the aquaculture parks was made through a participatory process to incorporate both environmental carrying capacity and social carrying capacity. Experts and modellers developed a GIS model to assess the potential for marine aquaculture in Baía Sul. Continuous (unclassified) maps were used to provide spatial information about the variation of the potential for marine aquaculture in the Baía Sul. The maps were used to plan 53 aquaculture parks over the Baía Sul. The site selection of the parks was made in six public hearings attended by 403 stakeholders from 38 institutions representing different sectors with diverse interests in coastal zone. The results showed that although the Baía Sul is suitable for the growth of bivalve molluscs, some hydrodynamic characteristics and the influence of urbanization constitute a sanitary risk for the activity. Experts, modellers and stakeholders had a different perception about the importance of criteria in the aquaculture parks site selection. While the experts and modellers considered the environmental criteria as the most important aspect to locate the aquaculture parks, the stakeholders took into account mainly the logistics. The final result of the aquaculture parks location, approved by the Brazilian Ministry of Fisheries and Aquaculture (MPA), adopted the site selection by the stakeholders, providing aquaculture parks in areas with sanitary risk for the bivalve cultivation. The main advantage of the adopted assessment strategy was to identify the divergence between experts, modellers and the stakeholders and the distance that still exist between scientist and decision makers in Brazil.

Statement of relevance: This is the first article about a participatory GIS for aquaculture in Brazil. The method was developed to be according to Ecological Approach to Aquaculture. The results highlight the importance of the participatory GIS in suitability study and site selection because the decision making process is different over the view of researchers, technicians and other social stakeholders.

1. Introduction

Due to the rapid growth of aquaculture worldwide (FAO, 2014), the Food and Agriculture Organization of the United Nations (FAO) adopted the concept "Ecosystem Approach to Aquaculture" (EAA) in order to minimize environmental impacts and social and economic conflicts (Soto et al., 2008), through integrated coastal zone management (ICZM) policies (McCreary et al., 2001; Treby and Clark, 2004). The application of EAA includes four strategic carrying capacity analysis (Ross et al., 2013). The physical carrying capacity, based on the suitability of production, considers environmental factors and the relationship to the farming system. The production carrying capacity, used to estimate the maximum production concerns the stocking density at which harvest are maximized. The ecological carrying capacity defines the amount of production that can be supported by the environment, taking into account all ecological processes and activities in a given area (e.g. a bay or an estuary). The social carrying capacity represents the stakeholders decision making process of aquaculture planning, considering all those tree carrying capacity levels, the social needs and conflicts for the use of coastal zone. For an EAA, the public participation in decision-making processes is necessary (Aguilar-Manjarrez et al., 2010) and depends on the communication and

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integration between science and management (Byron et al., 2011).

The need to generate territorial information for EAA reinforces the importance of using spatial analysis combined with multi-criteria analysis techniques (Kapetsky and Aguilar-Manjarrez, 2007; Aguilar-Manjarrez et al., 2010; Meaden and Aguilar-Manjarrez, 2013; Ross et al., 2013). Geographic Information Systems (GIS) have been used since the 1990's for mapping, modelling and assessing the potential to select areas for marine aquaculture (Ross et al., 1993; Parker et al., 1998; Silva et al., 1999; Scott and Vianna, 2001; Pérez et al., 2003; Pérez et al., 2005; Beltrame and Bonetti, 2007; Radiarta et al., 2008; Silva et al., 2011, Micael et al., 2015).

Maps resulting from GIS modelling are commonly used for the selection of sites for marine aquaculture while considering environmental, socio-economic and logistic criteria (Buitrago et al., 2005; Radiarta et al., 2008; Silva et al., 2011; Liu et al., 2013; Micael et al., 2015). Those maps are generated by modelling, in which the classes of descriptors (variables of interest), the layers of factors (transformed descriptors) and the layers of constraints are weighed and integrated through multi-criteria analysis (Aguilar-Manjarrez and Ross, 1995). The results are discrete suitability maps used to evaluate and discuss the spatial distribution of areas with different levels of suitability for production.

The discretization of those maps in classes of suitability generates well-defined boundaries between classes. Discrete classification is not the best representation of suitability maps for a participatory decision-making process, considering the continuous nature of the natural factors (Couclelis, 1992; Couclelis, 1996; Couclelis, 2003), mainly in the aquatic environment. The discretization of maps in classes of suitability represents the interpretation of experts and modellers, with fewer or no participation of stakeholders. About this lack of communication between experts, modellers and stakeholders, Byron et al. (2011) proposes a framework to incorporate both environmental carrying capacity and social carrying capacity.

This paper presents a methodological approach based on multi-criteria analysis (MCA), GIS and ICZM. MCA and GIS were used to build an environmental carrying capacity model for bivalve marine aquaculture in the Baía Sul, Florianópolis, Santa Catarina State, Brazil. The strategy was to try to overcome some site selection modelling limitations identified in most adopted frameworks: 1) The representation of potential areas for aquaculture with well-defined boundaries; 2) the modelling of spatial factors based exclusively on reclassification procedures; and 3) the lack in the analysis of the different perceptions of criteria importance among stakeholders involved in the participatory process.

This methodological approach aimed to assist the participatory process of delimitation of areas intended for aquaculture parks. According to Brazilian law (Brasil, 2003) aquaculture parks are delimited areas in the aquatic environment comprising a set of individual aquaculture areas. The aquaculture parks should be planned by the Brazilian Ministry of Fisheries and Aquaculture (MPA) through a participatory process. After the approval of the aquaculture parks, the aquaculture areas can be bid to the individuals interested.

The overall objective of this research is to propose and analyse the result of a methodological approach to plan the aquaculture parks in Brazil. For this, four specific objectives were defined: (i) to characterize the potential of the selected study area based on continuous maps of environmental, social, economic and logistical descriptors; (II) to evaluate the potential of the study area for marine aquaculture based on environmental, socioeconomic and logistic criteria; (III) to apply a participatory process to select sites to allocate aquaculture parks with participation of experts and stakeholders; and (IV) to analyse how the stakeholders used the continuous maps of criteria and the map of potential for bivalve aquaculture in the process of selecting the location of the aquaculture parks.

Furthermore, the authors expect that the methodological approach to be proposed in this study could cause an impact beyond the Brazilian management needs and interests since it can be easily reproduced on other coasts dealing with aquaculture development. This replication could give a broader interest on the adoption of the proposed scheme and stimulate the reanalysis of historic marine data on GIS-based site selection projects.

2. Study area

The study was conducted in the state of Santa Catarina, southern coast of Brazil. The bivalve production of Santa Catarina state in 2014 was 21,553 t, mussels (17.853 t), oysters (3.670 t) and scallops (30 t) (Santos and Costa, 2014). The study area is the southern part of Florianópolis bay system, locally known as Baía Sul (central coordinate of the system: 27°42′S; 48°35′W) (Fig. 1). The Baía Sul has an area of 180.7 ha, 128.4 km perimeter. Baía Sul is a semi-enclosed water body, oriented towards the north-south direction and with an indented coast, forming several small coves and short beaches. The Baía Sul is subjected to a strong urban pressure due to the conurbation process of the municipalities of Florianópolis, São José and Palhoça and there are conflicts over the use and occupation of the coastal zone (SPG, 2010a). These municipalities account for 70% of the production of mussels and 94% of the production of oyster in the state of Santa Catarina (Santos and Costa, 2014).

3. Materials and methods

The method adopted consists of four stages (Fig. 2): the first is descriptive, the second, analytical, the third involves the participatory decision-making process for aquaculture parks allocation, and the last stage is to evaluate how the stakeholders interpreted the results of the potential evaluation for allocate the aquaculture parks. The first three stages are present in various works related to site selection (Meaden, 1987; Ross et al., 1993; Parker et al., 1998; Scott and Vianna, 2001; Pérez et al., 2005; Buitrago et al., 2005; Beltrame and Bonetti, 2007; Kapetsky and Aguilar-Manjarrez, 2007; Silva et al., 2011; Micael et al., 2015), although their sequence may vary from author to author. In a different approach, in this article continuous raster maps and standardization equations were used rather than classification and weighting. Furthermore, the fourth stage was introduced to analyse how the stakeholders used the information generated by the experts and modellers in order to allocate aquaculture parks (Byron et al., 2011).

3.1. Selection of variables, descriptors, data sources and organization of GIS database

Twenty-five variables were considered representative of the local suitability for the development of bivalve marine aquaculture. Their selection was obtained in a workshop comprising 18 experts in marine aquaculture, coastal management, biology, geography and oceanography, representing eight institutions, following a practice suggested in some site selection publications (Meaden, 1987; Scott and Vianna, 2001; Buitrago et al., 2005; Byron et al., 2011) and by FAO for EAA (Ross et al., 2013). This group of experts, coordinated by the authors of this article (modellers), was composed by researchers, aquaculture technicians of Brazilian Ministry of Fisheries and Aquaculture (MPA), technicians of Brazilian Coastal Zone Management Plan (GERCO) and bivalve producers. They were responsible for the determination of criteria, spatialization of descriptors, determination of factors, definition of standardization equations and for the AHP application.

Table 1 summarizes how the variables were organized and processed. It shows the variable names, acronyms and the range of values in their respective units. It also contains the sources of data, the methods of generation of spatial layers and the abbreviations of descriptors. For factors, it shows the standardization equations for the scale 0–1, the acronyms and the criteria they belong to (environmental, socio-economic or logistic). Finally, it shows the constraints representing the legal criteria.