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Spatial planning for forthcoming shrimp farming in southern coast of Brazil: a tool to coastal management

Guilherme Caldieraro Viana[1]*; Luiz Henrique Sousa Salgado[2]; Felipe Schwahofer Landuci[2,3]

[1] Universidade Federal do Rio de Janeiro, Programa de Pós-Graduação em Biotecnologia Vegetal e Bioprocessos – Rio de Janeiro (RJ), Brazil.

[2] Fundação Instituto de Pesca do Rio de Janeiro, Diretoria de Pesquisa e Produção – Rio de Janeiro (RJ), Brazil.

[3] Universidade Federal do Rio de Janeiro, Instituto de Biologia, Departamento de Biologia Marinha– Rio de Janeiro (RJ), Brazil

*Corresponding author: caldieraro.biomar@gmail.com

ABSTRACT

Geographic information systems, the integration technique of multi-criteria assessment, together with the analysis hierarchy process, are recognized in decision support to describe and predict locations for implementation of different projects. In Brazil, shrimp farming has been consolidated for more than 30 years in the Northeast and North regions and is emerging in the Southeast. The purposes of this study were to analyze, classify and quantify through spatial planning for the establishment of shrimp farming in the North Fluminense region of the state of Rio de Janeiro, Brazil. The composition of the final model was structured into hierarchical categories with two models, factors, and constraints. The model of factors was subdivided into five sub-models: water abstraction, environmental, transport, public, and economic infrastructure. In turn, restrictions were composed of urbanized areas, environmental reserves. The best areas were identified as those that were flat, close to rivers, related to the environmental sub-model criteria (21%); followed by the sub-models of public, economic, and water abstraction infrastructure (20%), and transport with the lowest weight attributed (17%). The analyses indicated a great potential for the implementation of shrimp farming in the region, estimated in a total area of 628,088 ha, classified as adequate or very adequate (> 0.6).

Keywords: Geographic information systems; Analysis hierarchy process; Aquaculture; Carciniculture.

Análise das áreas adequadas para emergente carcinicultura na costa sudeste do Brasil: uma ferramenta para o planejamento costeiro

RESUMO

Sistemas de informações geográficas, a técnica de integração de avaliação multicritério, juntamente com o processo de análise hierárquica, são reconhecidos no apoio à decisão para descrever, explicar e prever locais para implementação de diferentes empreendimentos. No Brasil, a atividade da carcinicultura está consolidada há mais de 30 anos nas regiões Nordeste e Norte e desponta na Região Sudeste. As propostas deste estudo foram analisar, classificar e quantificar por meio do planejamento espacial as melhores áreas para o estabelecimento da carcinicultura na região norte fluminense do estado do Rio de Janeiro. A composição do modelo final foi estruturada em categorias hierárquicas com dois modelos, fatores e restritivos. O modelo de fatores foi subdividido em cinco submodelos: captação da água, ambiental, transporte, infraestrutura pública e econômico. Já as restrições foram compostas das áreas urbanizadas, reservas ambientais. As melhores áreas foram identificadas como aquelas planas, próximas de rios, relacionadas aos critérios do submodelo ambiental (21%); seguidas pelos submodelos de infraestrutura pública, econômica e captação da água (20%); e de transporte com o menor peso atribuído (17%). As análises indicaram grande potencial para a implementação da carcinicultura na região, estimada em uma área total de 628.088 ha, classificada entre adequada ou muito adequada (> 0,6).

Palavras-chave: Sistema de informação geográfica; Processo de análise hierárquica; Aquicultura; Carcinicultura.

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INTRODUCTION

In 2020, global aquaculture production reached a record 122.6 million tones, being responsible for 49.2% of global aquatic animals production. Among the total, 7,73 million tones were of Crustaceans, being the Pacific white leg shrimp (*Litopenaeus vannamei*) the most cultivated, representing 51.7% of the total global production (FAO, 2022). Asia is the main continent in farmed shrimp production, especially in China (39.2%), Indonesia (14%), Vietnam (12.1%), Thailand (7.4%), and India (6.5%), accounting for 85.1% of global production in 2020; and Central and South America, contributing to 14.5% of world production, being Equator (47.4%), Mexico (18.7%) and Brazil (10%) the main producer's countries (FAO, 2020).

Aquaculture plays an important role in the growth of many developing countries, due to its social and inclusive aspect, with an estimated 20 million people employed in the sector (35% of total employment is engaged in the primary sector), increasing up to 61.7% of total production in upper-middle-income countries (2.76 billion of global population), from 19.8% in 1990. In the same period, the share of aquaculture in lower-middle-income increased from 14.7 to 46.2% percent (FAO, 2022).

In Brazil, shrimp farming began in the early 1970s at Northeast Region and spread throughout the country. In the last years, it has been adopted a socially and economically viable production model, respecting the environment and adopting appropriate technologies for sustainable production, developing in harmony with the protection of marine, estuarine or aquaculture ecosystems (Ribeiro et al., 2014). The activity has been important economically and socially in rural areas, generating business and producing food of high nutritional value, both coastal and inland, including using salinized areas of estuaries and the semi-arid region of Northeast Brazil. The very expressive sales are still focused on the domestic market, contributing to revenue of around BRL 3 billion in 2020 and generating 112,500 direct and indirect jobs (Fonseca and Mendonça, 2021).

Shrimp farming is a well-organized sector with about 3,000 producers, mainly in small farms systems (75%), followed by medium (20%), and large ones representing only 5% (Rocha, 2019), and it is mostly based on intensively fed monoculture (IFM) of Pacific white leg shrimp farmed in large ponds (Valenti et al., 2021). Due to the economic importance and considered the most organized shrimp farming industry, the Northeast region can be seen as an example of institutional arrangement and technological trajectory in Brazil; first with the introduction and adaptation of external technologies, followed by intensification research in the public and private sector, leading to relevant innovations in the cultivation system along the entire regional production chain, and the activity consolidation (Tahim et al., 2019).

The state of Rio de Janeiro is the second most important state in the country in terms of number of inhabitants, population density and gross domestic product (GDP), contributing in 2018 with R$ 758 billion to the country's economy (IBGE, 2021). Its territory is the third smallest state in the country, much of it mountainous, where the plains and bays are under intense pressure from human use, or are affected under some kind of legal jurisdiction. Its extensive coastline, 645.9 km, is equivalent to 7.5% of the country's coastline, and it has been developing and consolidating aquaculture as a relevant economic activity. In this scenario, shrimp farming in the North Region emerges (Landuci, 2021). In the last years, an increase of 27% in production was registered (IBGE, 2022).

Before starting the production of marine shrimp, a prior planning of such economic activities is needed, to adapt the implementation to the social and environmental characteristics of the region, providing the legal, policy and technical frameworks required to sustain growth and innovation, as proposed by Food and Agriculture Organization of the United Nations (FAO) commitment to a Blue Transformation. This Blue Transformation aims to enhance the role of aquatic food systems in feeding the world's population and ensures fisheries and aquaculture grow sustainably, considering environmentally friendly policies and practices, and technological innovations (FAO, 2022).

Site selection requires geographically related data and information from multiple viable alternatives, but these alternatives are often conflicting and involve incompatible evaluation criteria. Therefore, it is important to consider short and long term, which may overestimate or underestimate the readiness for implementation in a particular location (Landuci et al., 2020).

Multiple factors are related to aquaculture planning, and remote sensing (RS), geographic information systems (GIS), and the multicriteria assessment (MCA) integration technique are recognized as a support system for assessment in decision making, especially if associated with the analysis hierarchy process (AHP). The AHP has been used as a powerful tool to describe, explain, and predict suitable sites, considering criteria of interest, and reducing subjectivity in decision making by creating a series of filters (Calle Yunis et al., 2020).

With this, the elaboration of a database for the spatial planning in the establishment and development of the shrimp farming activity, through models built in a GIS, is a powerful tool in the planning and identification of appropriate sites. In this study, we aimed to identify regions for potential implementation and expansion of shrimp farming in the north region of Rio de Janeiro state, integrated with current regulations in force, in a context of a sustainable and inclusive development.

MATERIALS AND METHODS

Study area

The north region of Rio de Janeiro state comprises 22% of the total area of the state. It has 849,515 inhabitants, according to the 2010 Demographic Census carried out by the Brazilian Institute of Geography and Statistics (IBGE), comprising nine municipalities: Campos dos Goytacazes, Carapebus, Cardoso Moreira, Conceição de Macabu, Macaé, Quissamã, São João da Barra, São Francisco do Itabapoana, and São Fidélis (Fig. 1).

Traditionally, the region had its economy based on the sugarcane agro-industry. However, in recent decades the development of the oil industry has assumed an important role in the local economy, being the main factor of GDP growth throughout the state indicated by Foundation State Center for Statistics Research and Server Training of Rio de Janeiro (Ceperj, 2017). This recent change in the main activities in the region led, especially the municipalities of Campos dos Goytacazes and Macaé, to stand out as important centers for the establishment of chemical, mechanical, food and service industries, as well as an increase in population migration to the region.

The coastal zone north of Rio de Janeiro state, on the southern flank of the Paraíba do Sul River mouth, is formed by an extensive delta-shaped coastal plain of transgressive sandy strands, evidence of the maritime fluctuations of the Holocene era (Folharini and Furtado, 2014).

In the last five years, shrimp farming in lining ponds near has started to grow around Barra do Furado and Canal das Flechas, an artificial channel that serves as the main way into the sea of the Feia Lagoon, the regulating body of water of a vast hydrographic region, consisting of dozens of lagoons interconnected with great economic and social importance, and integrated ecosystems. In general terms, each farm produces three crops per year, bypassing a revenue of BRL ten million of value (Landuci, 2021).

Model development

The model was framed in hierarchical structures subdivided into two groups of models (factors and constraint), with the factors being divided into five sub-models (water abstraction, environmental, transport, public infrastructure, and economic), containing 16 criteria in total, and a sub-model of additional

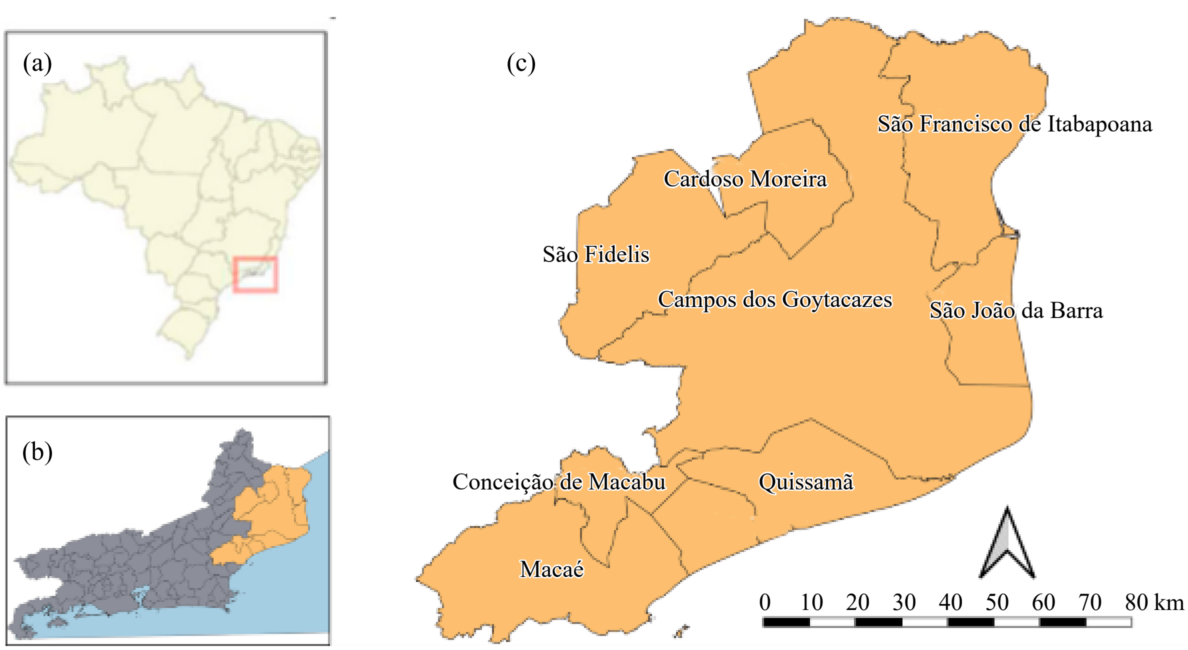

Figure 1. (a) Location of the state of Rio de Janeiro, (b) the Norte Fluminense region of the state, and (c) the delimitation of the nine counties that make up the Norte Fluminense region.

restriction. The models were built based on the MCA, being carried out in four stages:

- The identification of criteria that can be evaluated;
- The composition of the established criteria layers and the normalization of the criteria value through Fuzzy reclassification;
- The attribution of weight to each criterion. Therefore, an electronic questionnaire was prepared (Google-forms®) and distributed to different public and private agents, associated with the activity, to assign the scores for each criterion;
- The overlapping of the layers referring to each criterion in a process of weighted linear combination (WLC) of the suitability modeling for the farm's implementation (Fig. 2).

Identifying the criteria is a fundamental step in the process of selecting places where shrimp farming will be implemented. Thus, relevant criteria were identified based in the literature review and experts' opinion, taking into account information on environmental, socioeconomic, production quality, marketing, monitoring practices, in addition to licensing and regulation processes (Freitas et al., 2011; Ribeiro et al., 2014; Calle Yunis et al., 2020; Dhar et al., 2020; Dorber et al., 2020; Jayanthi et al., 2020; Morshed et al., 2020; Fonseca and Mendonça, 2021; Jayanthi et al., 2022).

Data are sometimes not structured in an ideal way, or have subjective and personal aspects. In this way, we use the method of AHP developed by Saaty (1977), commonly used to develop a set of relative weights for each parameter. At this stage, decision-makers draw attention to the weight of criteria according to the opinions of experts regarding the importance of each of the parameters, when making pairwise comparisons at each hierarchical level, with the employee being able to expand relative weights, called preferences, to differentiate criteria importance.

The process of logic normalization and Fuzzy modeling (Lootsma and Schuijt, 1997) was used to combine and transform the layers into normalized units, allowing to classify levels of adequacy and identify the ideal attributes of the criteria, based on a comprehensive review of the literature and the available expert knowledge. The WLC is used to incorporate maps after normalization (fuzzy) and determine the weight of each criterion defined from the AHP. The WLC is a widely used multi-criteria evaluation, due to the ability to weight and incorporate several parameters to produce a concise analysis, combining several

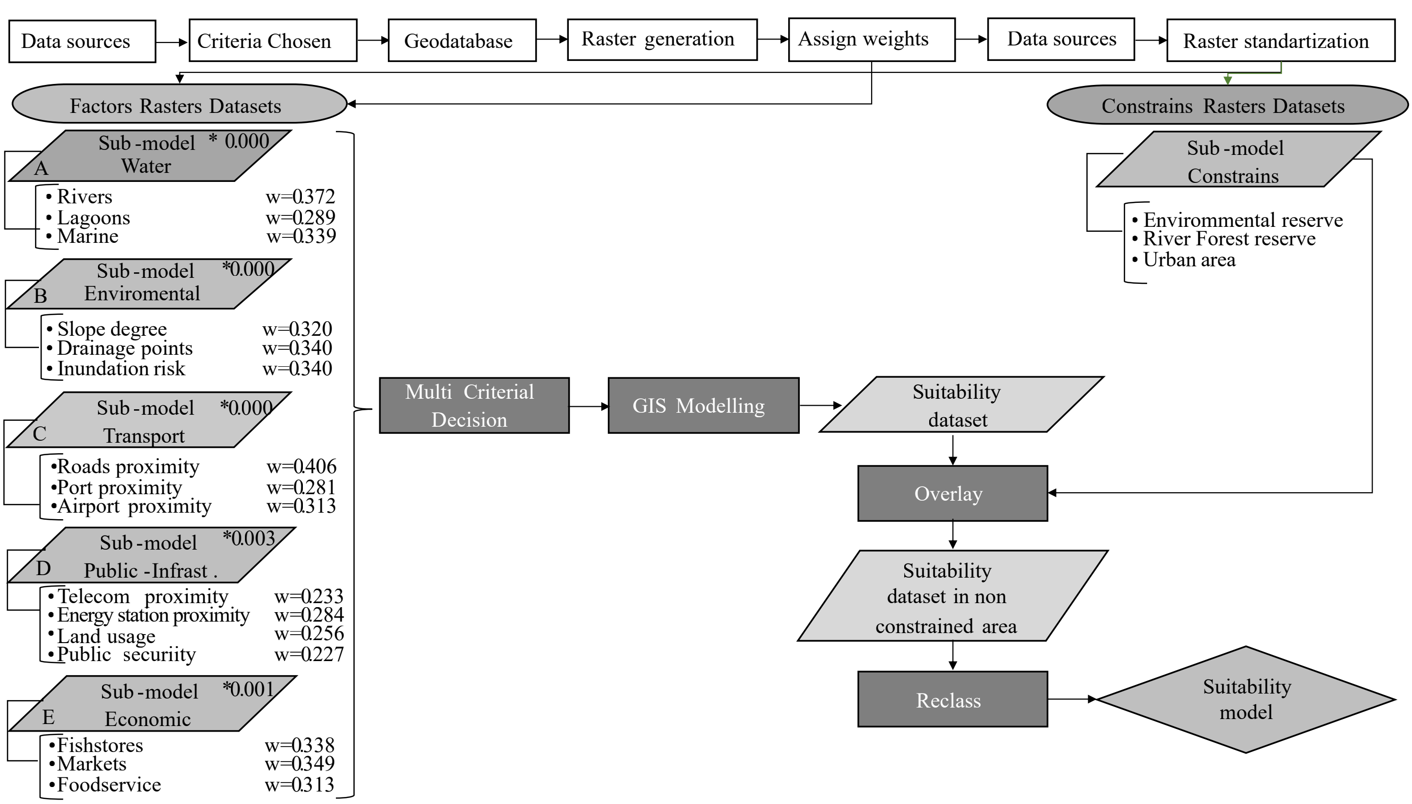

Figure 2. Flowchart of the conceptual geographic information systems (GIS) model in decision support for the establishment of shrimp farming in the North Fluminense region.

raster entries, referring to different factors, related to the distinctive or relative weights (Drobne and Lisec, 2009).

Data preparation, processing, and development of submodels and final model were performed using IDRISI SELVA Qgis® 3.24.1 software (QGIS Development Team, QGIS Geographic Information System, Open-Source Geospatial Foundation Project). All models and components were converted to the UTM-23S and UTM-24S georeferencing system, with 30-m resolution before analysis. For specific local features and identification of elements of interest, they were tagged from high resolution images using the HCMGIS plug-in.

Later the constraints and sub-model were overlaid and subsequently reclassified into five suitability classes (< 0.2; 0.2–0.4; 0.4–0.6; 0.6–0.8; > 0.8) using Landuci et al.'s (2020) base in an equally distributed, considering the range 0–1 as from least suitable to most suitable, and categories area (hectares) calculated for the nine counties.

Besides data had not been used on modeling due the lack of consistent information, other local characteristics have been observed, such as water quality index, a measure obtained from five years (2014-2019) monitoring program made by State Institute of the Environment (INEA); and land usage cover data from IBGE, to help evaluate the area potential for shrimp farm establishment.

Criteria identification and layers elaboration

The layers were made from geographic and legislative data, as specified a priori (Kapetsky and Aguilar-Manjarrez, 2007; Stelzenmüller et al., 2017). For each criterion, a layer was created to represent its distribution (Fig. 3), based on data obtained directly from competent institutions, and holders of the most reliable public information at the national level (National Water and Basic Sanitation Agency–ANA, Geological Survey of Brazil–SGB, IBGE, National Department of Transport Infrastructure–DNIT and Brazilian Institute for the Environment and Renewable Natural Resources–IBAMA-Ministry of the Environment–MMA); or feature scanning from high resolution images (DIGIT), as described in Table 1.

The distance layers of determined factors were generated using the Euclidean distance calculation through digitized points in high resolution images in QGIS. This classification method is a supervised classification procedure that uses the sum of the square root of the difference between x and y ($\sqrt{((x1 - x2)^2 + (y1 - y2)^2)}$, in their respective dimensions to associate a pixel with a certain class of distance in relation to another, and it applies better to standardized data that does not have any kind of treatment of scale adaptation. From the distance maps, related to criteria of factors, such as: water capture, environmental, transport and public infrastructure, and economics, were used to identify points of greatest suitability for the establishment of the enterprise.

It is important to find a suitable interpolation method that optimizes the estimation of unknown local values. In the case of descriptive factors such as those whose values fluctuate within the spatial variation, the inverse distance interpolation method (IDW) was applied, using different georeferenced vector points with known values (XYZ). The IDW method assigns weighted weights to sample points, so that the influence of one point on other decreases with the distance from the new point to be estimated (Chang, 2006).

We included all the restrictions found in the current legislation including coastal zoning (INEA, 2015a; 2015b) to generate the constraints layer. Restrictions to shrimp aquaculture activity included the shapefile data of IBAMA-MMA Atlantic Forest Reserve area with a 30 m resolution; River Forest Reserve buffer zone of 30 m from water bodies banks, defined in Law no. 12,651/12 from Novo Código Florestal Brasileiro (Brasil, 2012) for rural properties with two to four fiscal modules and above; and digitalization feature in high resolution image of the constructed areas with 30-m resolution (Table 1). Finally, we used Boolean algebra to obtain a single constraints map layer (Fig. 3).

RESULTS

In general, respondents (n = 29) declared themselves as: producers (3%), researchers (62%), decision makers (22%), and service providers (13%). The participation of researchers, managers, and decision makers during the evaluation of the criteria contributed to avoid conflicts in the development of the model, and uncertainties in the results. All the proposed sub-models presented a low consistency index (CR) < 0.1 (Fig. 2), suggesting that the weights of the pairwise comparison criteria were consistent.

The water sub-model (Fig. 4), which evaluates criteria for availability and location of water resources, the most important criteria were considered, rivers and canals (0.372), followed by coast (0.333), and lakes and ponds (0.289). In the composition of the environmental sub-model (Fig. 4), the criteria drainage (0.340) and risk of flooding (0.340) were equally important, presenting antagonistic results in most of the region; and the

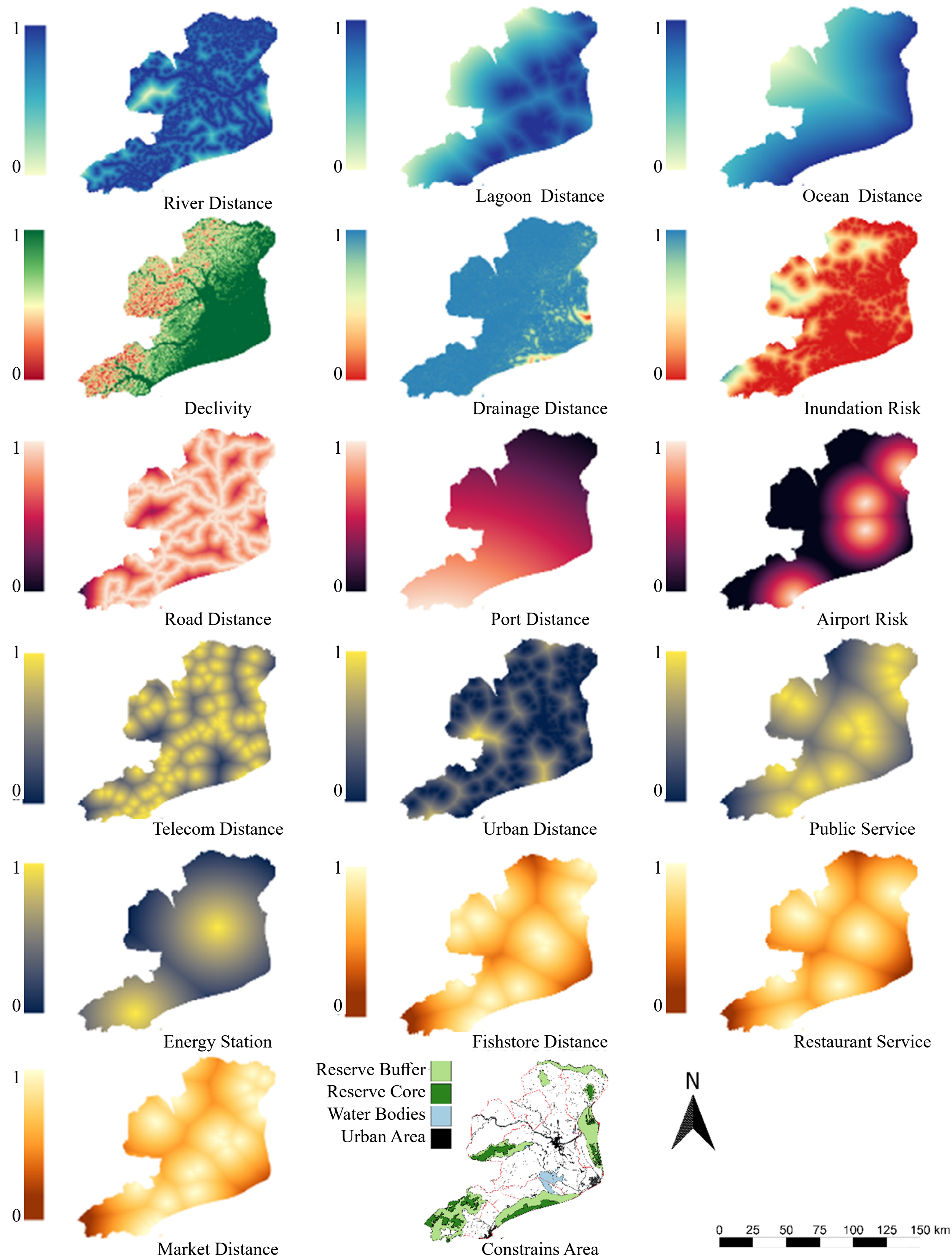

Figure 3. Fuzzy scale spatial distribution of the different layers used on water, environmental, transport, public infrastructure, economic sub-model, and constraints area.

Table 1. Sub-models criteria and constraints, data range, raster operation, fuzzy reclass, control points, and data source applied on the weighted linear combination.

Sub-Model	Data range	Raster operation	Fuzzy reclass	Weight	Control points	Data source
Water				0.200		
Rivers	0-11 km	Euclidian distance	Linear decreasing	0.372	0-max	ANA
Lagoon	0-45 km	Euclidian distance	Linear decreasing	0.289	0-max	ANA
Marine	0-83 km	Euclidian distance	Linear decreasing	0.333	0-max	ANA
Enviromental				0.214		
Slope degree	0-70°	Reclassification	Linear decreasing	0.320	0-max	SGB
Inundation risk	0-18 km	Euclidian distance	Linear increasing	0.340	0-max	IBGE
Drainage points	0-6 km	Euclidian distance	Linear decreasing	0.340	0-max	IBGE
Transport				0.177		
Road proximity	0-20 km	Euclidian distance	Linear decreasing	0.406	0-max	DNIT
Airport proximity	0-33 km	Euclidian distance	Linear decreasing	0.313	0-max	IBGE
Seaport proximity	60-216 km	Euclidian distance	Linear decreasing	0.281	0-max	IBGE
Public infrastructure				0.207		
Energy station	0,3-64 km	Euclidian distance	Linear decreasing	0.284	0-max	IBGE
Telecom proximity	0-20 km	Euclidian distance	Linear decreasing	0.233	0-max	IBGE
Public security	0-47 km	Euclidian distance	Linear decreasing	0.227	0-max	DIGIT
Urban area	0-20 km	Euclidian distance	Linear increasing	0.256	0-max	IBGE
Economic				0.202		
Markets	0-48 km	Euclidian distance	Linear decreasing	0.338	0-max	DIGIT
Fishstore	0-48 km	Euclidian distance	Linear decreasing	0.349	0-max	DIGIT
Foodservice	0-48 km	Euclidian distance	Linear decreasing	0.313	0-max	DIGIT
Constraints						
Mata Atlântica Reserve	0	Vector to raster	Boolean	Constrains	-	IBAMA
Urban area	0	Vector to raster	Boolean	Constrains	-	IBGE
River Forest Reserve	30 m	buffer	Boolean	Constrains	-	ANA

ANA: National Water and Basic Sanitation Agency; SGB: Geological Survey of Brazil; IBGE: Brazilian Institute of Geography and Statistics; DNIT: National Department of Transport Infrastructure; DIGIT: feature scanning from high resolution images; IBAMA: Brazilian Institute for the Environment and Renewable Natural Resources.

slope criterion (0.320) having a slightly lower weight assigned to them.

About the transport sub-model (Fig. 4), the criteria with the highest weight were road highway access (0.406), followed by airports (0.313) and ports (0.281) distance, evaluated, therefore, as less important. The public infrastructure sub-model (Fig. 4) had a very similar distribution of importance between criteria, in which the distance from urbanized areas was the main counterpoint to the proximity of the other criteria, in the same way as the economic (Fig. 4) sub-model, with also little variation observed in the weights assigned to the layers drawn from the distances from restaurants, fish stores and markets.

In the final suitability model, the environmental sub-model presented the highest contribution (0.214), followed by public infrastructure (0.217), economic (0.202), water (0.200), and finally the transport sub-model (0.177). After model values reclassification and constraints areas identification, the suitability class map has been generated (Fig. 5).

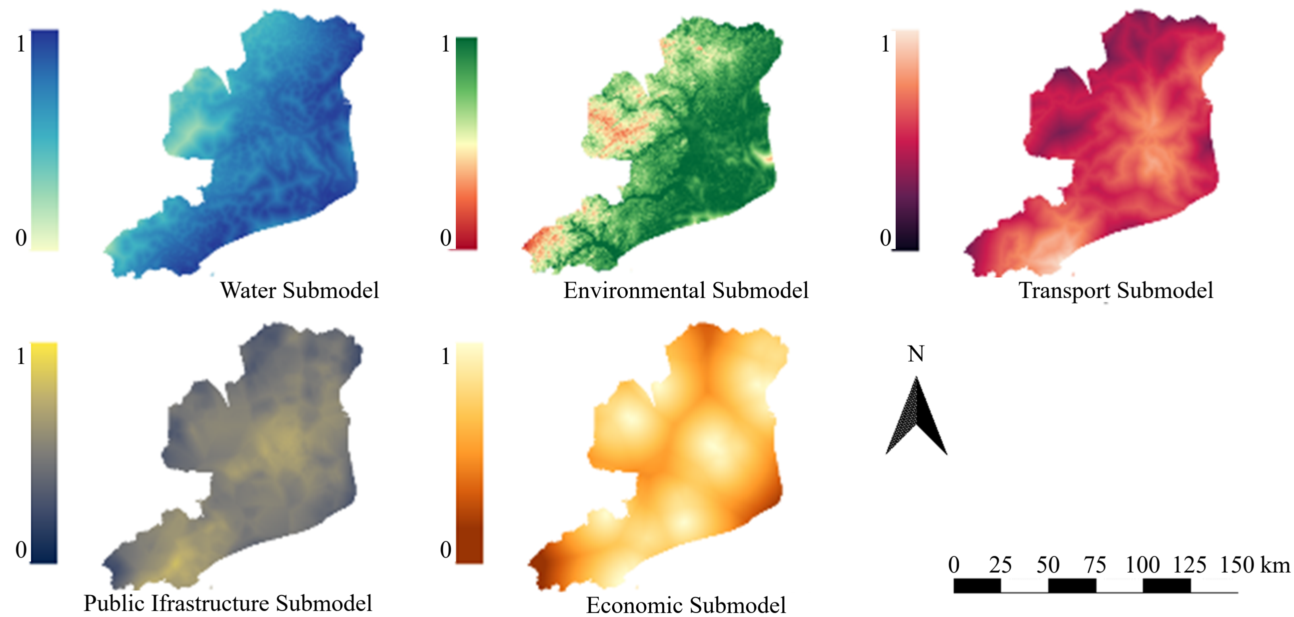

Figure 4. Fuzzy scale spatial distribution of water access, environmental, transport, public infrastructure and economic sub-models (fuzzy class).

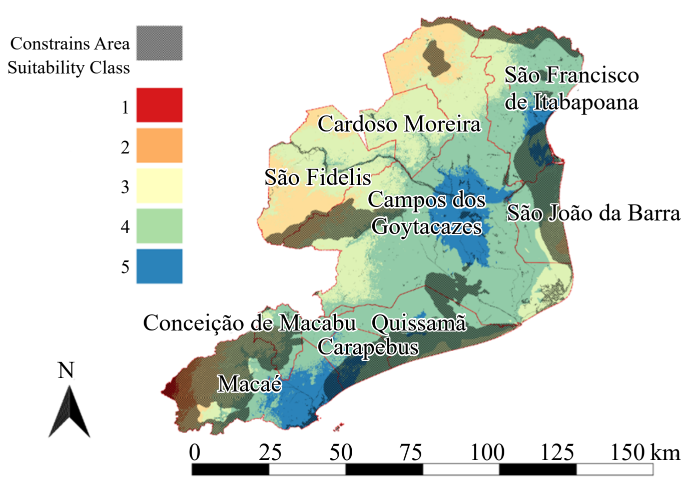

Figure 5. County limits and identification, constraints areas and suitability class final map for Norte Fluminense Region.

The region presented a total of 413,901 ha as the most suitable (> 0.8), followed by a total of 214,187 ha classified between 0.6–0.8; 67,022 ha of moderated suitable (0.4–0.6); and only 13 ha (0.2–0.4) and 2,074 ha classified as less suitable, highlighting the great potential of Campos dos Goytacazes, with 201,265 ha most suitable (> 0.8) and 95,737 ha suitable (0.6–0.8); as well as a total constraints area of 1,319,154 ha (Table 2).

In addition to the final suitability model, for later comparison, the water quality index (WQI) of the rivers monitored in the region was also formulated, which presented an average rating between 55 and 69, as well as the allocation of land use in the region (Fig. 6), which presented a total area of 1,670,534 ha classified as Anthropogenic Agropastoral Area, legally suitable for the establishment of shrimp farming.

DISCUSSION

Although aquaculture has increased significantly in Brazil, it is still not a solid and sustainable activity, since many steps of the production chain are fragile, including extension services, credit policies, environmental licensing, legislation, processing, distribution, and commercialization (Landuci, 2021).

Several parameters must be initially checked in the implementation area, and periodically monitored in the farms, in order to maintain high productivity, as well as a correct adaptation of the conditions imposed by Law no. 413/2009 from Environment National Consultive Council (Brasil, 2009), for the correct implementation and legal maintenance of shrimp farming. In addition, the product must also meet the requirements of the Quality and Food Safety Management System (SGQSA). And so, the information obtained from remote sensing data at different levels of geoprocessing, which describe the physical, biological,

Table 2. Table of the suitability categories, 1 (< 0.2), 2 (0.2–0.4), 3 (0.4–0.6), 4 (0.6–0.8) and 5 (> 0.8), and the constraints area in acres (ha) of the Norte Fluminense region counties.

County	Suitability class					
	1 (ha)	2 (ha)	3 (ha)	4 (ha)	5 (ha)	Constraints (ha)
Campos dos Goytacases	0	0	28,919	95,737	210,265	619,083
Carapebus	0	0	0	0	14,342	36,412
Cardoso Moreira	0	0	463	41,354	9,298	42,478
Quissamã	0	0	0	68	33,178	130,920
São Francisco de Itabapoama	0	0	0	15,563	58,795	116,750
São Fidélis	0	8	36,617	54,756	4,394	110,020
São João da Barra	0	0	0	2,226	17,013	51,320
Conceição de Macabu	0	0	0	1,026	19,746	61,254
Macaé	2074	13	1,023	3,457	46,870	150,917
Norte Fluminense region total	2,074	21	67,022	214,187	413,901	1,319,154

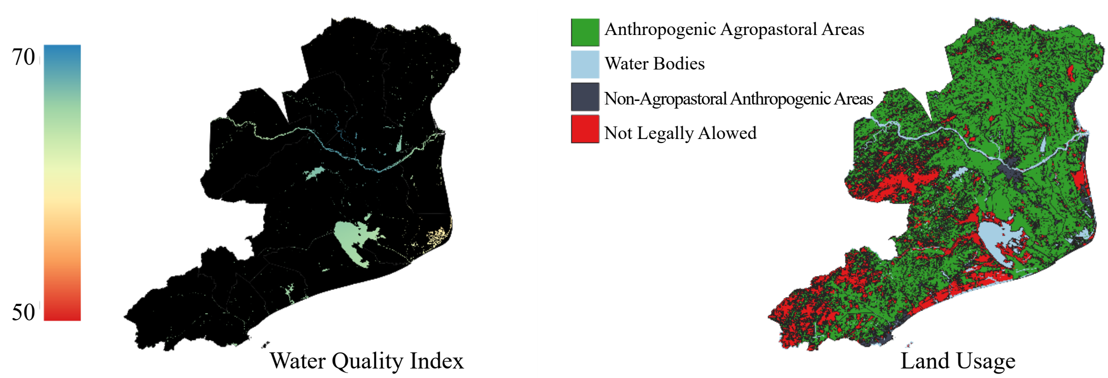

Figure 6. (A) Water quality index and (B) land use attribution maps, used associated with modeling results to corroborate with the area shrimp farm viability.

geographic, hydrochemical, socioeconomic and infrastructural aspects, are extremely useful, in a way to guarantee an increase in productivity, as well as the preservation of areas sensitive to possible environmental impacts (Jayanthi et al., 2022).

Among the considered characteristics, we can highlight the access of water, which can be carried out from different sources: rivers and canals, reservoirs, wells, lakes, ponds, sea, or from the public network. The present study showed greater weight for rivers and canals as a water abstraction source, followed by sea, lakes, and ponds, demonstrating a great interest in inland production from waters with different degrees of salinity. Since the mainly cultivated specie *L. vannamei* have euryhaline physiology with great osmoregulation capabilities, tolerating salinities from 0 to 50 ppt (Chong-Robles et al., 2014) and as a tropical specie, it lives in temperature ranges of 15–28 °C, being tolerant to 34–37 °C (Liao and Chien, 2011).

In Brazil, most production comes from farms in estuarine regions in the Northeast, in semi-intensive systems. In the recent years, there has been an intensification towards the production in inland areas, minimization of environmental impacts, and in small production units with biofloc technology with several inland farms with low salinity waters, obtaining a survival rate of 60–80% (Valenti et al., 2021), and increased rapidly from 4,000 tones in 1997 to 90,000 tones in 2003, decreasing after that. The decrease in shrimp production observed since 2003 has been due to different factors, including seasonal floods and viral diseases, mainly myonecrosis virus and white spot syndrome virus described by Brazilian Shrimp Farmers Association (Fonseca and Mendonça, 2021), because of that duration of rearing cycles has been significantly reduced to mitigate mortality.

In intensively fed monoculture (IFM) and biofloc technology (BFT) systems, the conversion rate ranges from 1 to 1.8 with 30 to 35% crude protein feeds provided, normally stocked at more than 100 juveniles/m^2, and using aerators/blowers and high energy input, demanding a stable energy source. Organic farm uses no feed, and the growth of shrimp with rearing cycles of three or four months, with 10–20 shrimp postlarvae (PL) stocked per m^2, and productivity is around 2–6 t/ha/year. Higher productivity can be achieved when multiphase systems are applied, fed with high-quality extruded diets, and probiotics are used to improve water quality and enhance their immune status (Valenti et al., 2021).

It is not recommended that the water source to supply the ponds be carried out in places subject to high thermal variation, as well as from areas with stagnant water or with any suspicion of chemical or biological contamination. The evaluation of the physical-chemical and biological parameters is essential for the good practice of shrimp farming, reducing costs in the implementation and maintenance of the culture, allowing an increase in productivity and reduction of financial risks, in addition to helping to predict possible environmental impacts at the time of project implementation (Senar, 2017).

The information presented in the water sub-model in association with the identification of the WQI of the monitored rivers in the region can contribute for decision makers about water quality aspects. These data, together with the characteristics analysis obtained from the environmental sub-model, points local conducive characteristics to shrimp farming implementation, since flood-free areas with suitable water and soil characteristics, should be the proper option for commercial shrimp culture, being susceptible to flooded regions considered unfit (Jayanthi et al., 2020).

The environmental sub-model also showed little influence of slope degree, with 817,512 hectares showing less than 15° of slope, which corresponds to 91% of the total area, not being a high excluding criterion in the area, as previously described for a suitable shrimp farm establishment at Brazil Southern region (Freitas et al., 2011).

Most of the study area is classified in land usage as Anthropogenic Agropastoral Areas, which is important in the assessment of the initial evaluation for the establishment of shrimp farming, and contributed to the identification of a wide area conducive to the zoning process in the region, since the construction of shrimp ponds can be responsible for the transformation of primary land and therewith in a change of land use (Calle Yunis et al., 2020; Dorber et al., 2020).

To further improvement of the model, future local analyses of soil texture, granulometry, pH and organic matter; meteorological characteristics, such as precipitation and evaporation rates; and water bodies characteristics such as river carrying capacity, will allow the identification of the most favorable locations for the implementation of cultivation even more accurately (Senar, 2017; Valenti et al., 2018; Jayanthi et al., 2022).

In addition, the evaluation of regional logistic and economy, represented in the transport, public infrastructure and economic sub-models, is fundamental for the success of the enterprise, directly interfering in the acquisition of inputs and young forms, and to the product distribution and trade, which is mainly done at Northeast region of Brazil, where shrimp farm is well established. By there, the sector is well-organized with about 3,000 producers, most of than in small farms (75%), followed by medium (20%), and large (5%), with most of production done at farms in estuarine regions in Rio Grande do Norte and Ceará, where semi-intensive systems are commonly used (Rocha, 2019; Valenti et al., 2021).

Public infrastructure showed close weight attribution for all four criteria, demonstrating a slightly greater concern with structural implementation infrastructure, than on security maintains, since energy cost and access can be a driven factor depending on shrimp farm type, especially in closed systems with high aeration (Dhar et al., 2020). Similar results were observed for the economic sub-model, where fish stores had a slightly higher score, followed by markets and foodservice, showing a low selectivity to the final product destiny, and transport sub-model pointed to a high interest in the local market, dependent mostly of the road access, having the highest scores.

Brazil, once the world leader in the productivity of farmed marine shrimp (6,083 kg/ha/2003), with most production processed and exported, nowadays is not considered a potential producer and exporter despite the viable logistical and operational structure, mainly due the unstable exchange rate of the Brazilian currency to the US dollar, that makes the export of shrimp a risk venue. However, since the 2010s, the domestic market became the major outlet for farmed shrimp, contributing to sustain and expansion of shrimp trade and revenue (Valenti et al., 2021), which may be related with score attribution to transport, public infrastructure, and economic sub-models.

Five sub-models were identified and mapped to determine the spatial suitability for shrimp farms implementation. The weight of sub-models is in accordance with previous results, when no large differences were observed between energy, environmental, economic and equity surveys proposed in sustainability perspectives of shrimp farms in Bangladesh by Dhar et al. (2020). In contrast, results observed by Calle Yunis et al. (2020) demonstrate highest weight attribution for economic sub-criteria (distance to roads, distance to markets, distance to inputs), representing 44.57%, followed by the environmental sub-criteria (land cover/land use, land slope, clay content of soil, pH of soil, distance to rivers) with 43.31%, and the social sub-criteria (distance to populations and protected areas), with 12.12%. These results bring up the importance of AHP methodology, which depending on local characteristics and interpretation of weight attribution by the collaborators may change from place to place, and influence site selection.

Site evaluations based on multiple criteria analyses can minimize ecological impacts, reduce the land use conflicts, and maximize the evaluation of productive lands for shrimp farming. However, the structure of the model and the way in which the data are combined can directly influence the results, and there is a danger that important criteria will be lost under the influence of others. In the present study, the variation in the amplitude of weight assignment, between 0.406 for the road and 0.281 for ports distance category in the transport Sub-model, and 0.227 for the public security and 0.284 energy station proximity in the public infrastructure sub-model, which demonstrate a coherent assignment of weight ($CI < 0.1$) in the AHP.

The study area presented a total of 413,901 ha classified with values above 0.8, considered as very adequate, which Campos dos Goytacazes county presented the highest number of areas classified as high suitable areas (> 0.8), followed by São Francisco de Itabapoana. The study demonstrates the potential benefits in locating productive lands for shrimp aquaculture and provides a way to identify potential areas in the Norte Fluminense region of Rio de Janeiro state for its establishment and expansion.

Despite the evaluated criteria showing positive results for the enterprise establishment, the increased integration and attribution of new criteria in future modeling, in addition to site-specific local data analysis, will increase the ability to identify areas to implement even more conducive areas with greater reliability.

CONCLUSIONS

Our approach confirms the usefulness of GIS to identify potential locations for implementation and expansion of shrimp farm aquaculture in Norte Fluminense region of Rio de Janeiro state, on which demonstrated large suitable areas, as the ones inserted in Campos do Goytacazes, São Francisco de Itabapoana and Macaé counties, with suitable condition for this enterprise.

Creation of specific plans for the activity development, considering environmental and economic sustainability, should be encouraged, and the suitability maps elaborated could be an effective tool to contribute enable the policymakers and stakeholders to make better land-use planning, on shrimp farm licensing at identified zones, and also on the emergence of a new trajectory in the sector, driven by a partnership between research and education institutions and producers.

And so, GIS technique applied to identify potential locations for shrimp farm aquaculture should be encouraged in other parts of state and country regions, to help on the survey for new suitable areas in Brazil, in a way to improve aquaculture production with a reliable environmental concern and care.

CONFLICT OF INTERESTS

Nothing to declare.

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