Journal of Integrated Coastal Zone Management / Revista de Gestão Costeira Integrada 19(2):61-69 (2019)
http://www.aprh.pt/rgci/pdf/rgci-n118_Freitas.pdf | DOI:10.5894/n118

GESTÃO COSTEIRA INTEGRADA
Journal of Integrated Coastal Zone Management

Coastal planning and land use of marine shrimp farming in southern Brazil

Planejamento costeiro e uso do solo para o cultivo de camarão marinho no sul do Brasil

Rodrigo Randow de Freitas[1], Paulo Roberto Armanini Tagliani[2], Wilson Wasielesky Jr.[3], Luís Henrique da Silva Poersch[4]

[1] *Universidade Federal do Espírito Santo (UFES), Centro Universitário Norte do Espírito Santo (Ceunes). Email: rodrigo.r.freitas@ufes.br*
[2] *Laboratório de Gerenciamento Costeiro, Instituto de Oceanografia, Universidade Federal do Rio Grande (FURG), Postal Code 96201-900, Brazil. Email: paulotagliani@furg.br*
[3] *Universidade Federal do Rio Grande (FURG), Instituto de Oceanografia, Estação Marinha de Aquacultura, Postal Code 96201-900, Brazil. Email: manow@mikrus.com.br*
[4] *Universidade Federal do Rio Grande (FURG), Instituto de Oceanografia, Estação Marinha de Aquacultura, Postal Code 96201-900, Brazil. Email: lpoersch@mikrus.com.br*

ABSTRACT: The study area lies in the lower estuary of Lagoa dos Patos in the city of Rio Grande (Lat/Long: 32°02'16.39"S/52°06'28.41"W), Rio Grande do Sul state, Brazil, comprising a total area of approximately 280,000 hectares (ha). To select areas suitable for marine shrimp farming, data processing and digital modeling were conducted with the Idrisi Andes Edition® GIS software using freely available images. Additionally, the most commonly used criteria, socioeconomic factors, infrastructure and logistics, soil, climate, topography, and water availability, were used. To improve upon the obtained results from a classification based exclusively on the distinction between restricted and suitable areas for aquaculture, a suitability score for each criterion analyzed was created, and distances from suitable sites were measured. According to the suitability rating (prioritized from 1 to 4), 2,100 ha (24.01% of the area) were considered suitable with excellent conditions; 3,100 ha (34.80%) were considered good; 3,600 ha (40.37%) were marginally suitable; and, finally, a small fraction of 70 ha (0.82%), was considered acceptable but not recommended. This study has demonstrated the potential of GIS to support the selection of areas suitable for marine shrimp farming.

Keywords: Shrimp culture; Patos Lagoon; Remote Sensing; Litopenaeus vannamei.

** Submission: 31 MAY 2017; Peer review: 6 OCT 2018; Revised: 29 JUN 2019; Accepted: 15 JUL 2019; Available on-line: 30 JUL 2019*

RESUMO:A área de estudo situa-se no estuário da Lagoa dos Patos, na cidade do Rio Grande (Lat / Long: 32°02'16.39"S / 52°06'28.41"W), no Rio Grande do Sul, Brasil, compreendendo área total de aproximadamente 280.000 hectares (ha). Para selecionar as áreas adequadas para o cultivo de camarão marinho, processamento de dados e modelagem digital, foram realizadas com o software Idrisi Andes Edition®, usando imagens gratuitas e disponíveis. Além disso, os critérios utilizados foram socioeconômicos, infraestrutura e logística, solo, clima, topografia e disponibilidade de água. Visando uma melhorara nos resultados, a partir de uma classificação baseada exclusivamente na distinção entre áreas restritas e adequadas para aquicultura, foi criado um índice de adequação para cada critério analisado, sendo medidas as distâncias desses locais. De acordo com a classificação de adequação (priorizada de 1 a 4), aproximadamente 2.100 ha (24,01% da área) foram considerados adequados com excelentes condições; 3.100 ha (34,80%) foram considerados bons; aproximadamente 3.600 ha (40,37%) foram adequados; e, por último, uma pequena fração, aproximadamente 70 ha (0,82%), foi considerada aceitável, mas não recomendada. Assim, este estudo demonstrou o potencial do SIG no apoio a seleção de áreas adequadas para a aquicultura de camarão marinho localmente.

Palavras-chave: cultivo do camarão; Lagoa de Patos; Sensoriamento remoto; Litopenaeus vannamei.

INTRODUCTION

Considering the increase in global fishing efforts, the decline in some fish stocks (Beamish *et al.* 2006; Caillouet Jr. *et al.* 2008; Travers *et al.* 2010) and the increase in global population, aquaculture has been rapidly developing worldwide in recent years. Given these scenarios, methods for selecting suitable sites for a variety of aquaculture activities are necessary (Mcleod *et al.* 2002; Karthik *et al.* 2005; Pérez *et al.* 2005; Hossain *et al.* 2007; Longdill *et al.* 2008).

In Brazil, the uncontrolled growth of aquaculture farming has caused some conflicts. Such as Marine shrimp farming that has expanded since the introduction of the exotic shrimp Litopenaeus vannamei in protected areas in the 1990s.

Specifically, in the state of Rio Grande do Sul, marine shrimp farming has expanded since the introduction of L. vannamei. However, the potential for productive growth is also associated with a real increase in the threat of environmental and socioeconomic impacts that can directly affect the sustainability of crops (FAO 2016; Perez *et al.* 2002; Giap and Yakupitiyage 2005; Karthik *et al.* 2005; Klumb-Oliveira and Souto 2015; Testa *et al.* 2015; Bruhn *et al.* 2016).

Therefore, the development of aquaculture activities initially requires space planning to adjust the location of farmed species to the environmental and socioeconomic characteristics of the region. In this context, the information obtained from remote sensing at different levels and data generated by the application of geoprocessing tolls, along with land use and biological, geographical, hydro-chemical and socioeconomic data, are useful for achieving the goal of assuring an increase in productivity and preservation of the areas that are sensitive to environmental changes (Kapetsky *et al.* 1988; Pérez *et al.* 2003; Giap and Yakupitiyage 2005; Freitas and Tagliani 2007; Ballester-Moltó *et al.* 2015).

According to Poersch *et al.* (2006), due to the environmental characteristics and lower costs of implementation, the estuary of Patos Lagoon has been the preferred area for the implementation of these projects, resulting in the first marine shrimp farm in the municipality of São José do Norte.

Thus, planning is essential for environmentally sustainable land use practices. The most important benefit of planning is identifying possible conflicts related to coastal resource use (land and water) and preventing possible environmental and social impacts (Corbin and Young 1997; Rajitha *et al.* 2007; Barbieri *et al.* 2014; Gatune *et al.* 2017).

MATERIAL AND METHODS

The study area is located in the lower estuary of Patos lagoon and adjacent coastal plain, in the city of Rio Grande (Lat/Long: 32°02'16.39"S/52°06'28.41"W), Rio Grande do Sul, Brazil, comprising a total area of approximately 280,000 hectares.

The local economy is primarily based on fishing, trading, agricultural crops and cattle ranching (rice and livestock), and port and oil activities. Lowlands, marginal wetlands, coastal dunes and beaches, grasslands or subshrubs with or without interspersed agricultural areas characterize the physiography, with little overall variation in slope (0 to 0.9 m). The average annual precipitation in the city is 1,400 mm and the average annual temperature is between 16 and 20°C (Cargnin *et al.* 2013; Dillenburga *et al.* 2017). Also, characteristic is the existence of large areas of intensive planting of pines (Pinus elliottii), used for wood production and resin extraction (Tagliani and Vicens 2003).

To select suitable areas for marine shrimp farming in

Rio Grande, information data processing and digital modeling were conducted with the GIS software Idrisi Andes Edition® and CartaLinx®, using images freely available on the National Institute for Space Research (INPE) website (http://www.dgi.inpe.br/CDSR/). The image used was Landsat 7 ETMXS.

The resample module in the GIS was used to obtain a georeferenced image, and the digitization and separation into layers of all features of interest in the study area were conducted. The polygons of each layer were scanned using the georeferenced image as the basis; then, each layer was converted from vector to raster format, creating the final database (Freitas *et al.* 2009; Maia and Castro 2014). Thematic maps (scale 1:350.000) separated into individual layers were processed in the Idrisi Andes GIS and were integrated into a characterization/identification model that was constructed for this study (Figure 1).

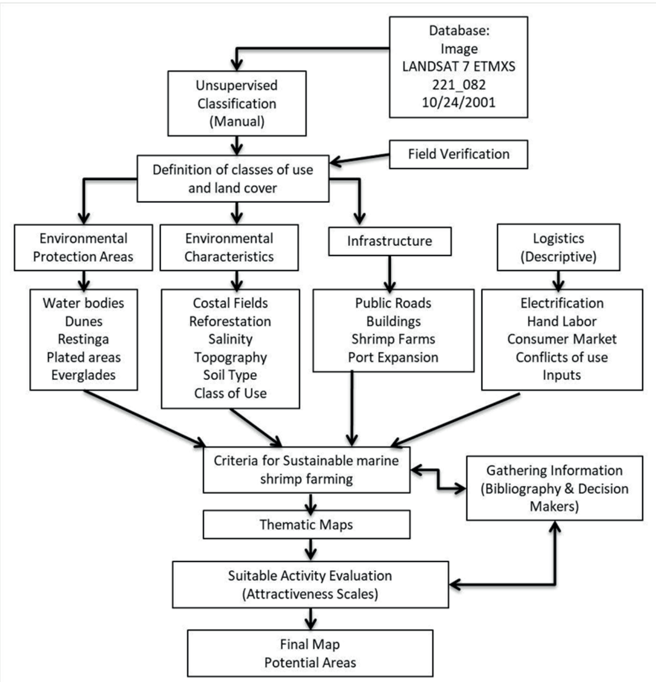

Figure 1. Methodology analysis for marine shrimp farming in the study area - Flowchart (adapted from Rajitha, Mukherjee and Chandran (2007).

Figura 1. Análise metodológica para o cultivo de camarões marinhos na área de estudo - Fluxograma (adaptado de Rajitha, Mukherjee and Chandran (2007).

The most commonly used criteria are those involving socioeconomic factors, infrastructure and logistics, soil, climate, topography, and water availability (Salam *et al.* 2003; Giap and Yakupitiyag 2005; Beltrame *et al.* 2006; Hossain *et al.* 2007; Radiarta *et al.* 2008; Egler and Gusmão 2014). In this study, restrictive criteria (protected areas, conservation areas, etc.) were used first to create exclusion (unfit) areas.

After their determination, the restrictive criteria were spatially described using specific GIS routines (function buffers), creating buffer zones. This was possible through the overlapping of areas with legal restrictions (an overlay module) and the creation of a single image, where a value of "1" represents an area without restriction and a value of "0" is an area with restrictions. For areas without restriction, any area smaller than 1 hectare was excluded as its use in farming was considered uneconomical (Freitas *et al.* 2009).

For example, buffer zones were used by Torres and Andrade (2010) in a study aimed at identifying installation areas for marine fish farming enterprises. These buffer zones were areas of protection, where the installation of aquaculture enterprises was prohibited to avoid conflicts with other activities.

For the land use capacity criterion, the present study used the system adapted by Lepsch *et al.* (1983), specifically, the rating classes (I to VIII), which indicate the degree of limitation on agricultural land use. In class I there is no degree of limitation and, in Class VIII, there is land with higher degrees of restriction.

Thus, to improve the results obtained with a classification scheme based only on the distinction between restricted and suitable areas for shrimp farming, suitability scores were assigned to each criterion examined, and the distances from suitable areas were calculated (Kapetsky *et al.* 1988; Salam *et al.* 2005; Freitas *et al.* 2009). This second analysis was performed by superposing suitable areas on digital thematic maps to determine the distances from water sources and public roads. After the analysis of the results obtained in the laboratory, an on-site verification was conducted in the study region in March 2010.

The other criteria examined for shrimp farming development were considered to be merely descriptive, such as the distance from consumer markets, local available manpower, pollution, temperature, and electricity, among others (Frankic 1998; Freitas *et al.* 2009).

RESULTS AND DISCUSSION

The results of this study show the appropriate areas and those considered unsuitable for the cultivation of marine shrimp in Rio Grande, confirming the potential for aquaculture activity in the city. This information will only serve to support the planning of aquaculture activities, as most of the studies focused on identifying areas for aquaculture development using only simple maps, whose information for decision making among investors, funding agencies and public authorities is inconclusive (Aguilar-Manjarrez and Ross 1995).

Therefore, with the growing importance of rationally exploiting natural resources, thus minimizing any usability issues of coastal resources, we attempted to group the uses and current coverage of the county's land into different classes, including coastal fields, wetlands (plated), marshes, dunes, salt marsh forests, reforestation areas, roads, building areas and water bodies.

The selected image was divided by classification into 11 layers with all the features of interest in the study area (Figure 2). Different criteria for selecting suitable areas for shrimp farming have been used, varying from place to place and from culture to culture. This classification scheme allowed us to first identify those areas with potential for shrimp farming and also the legally restricted or environmentally unsuitable sites.

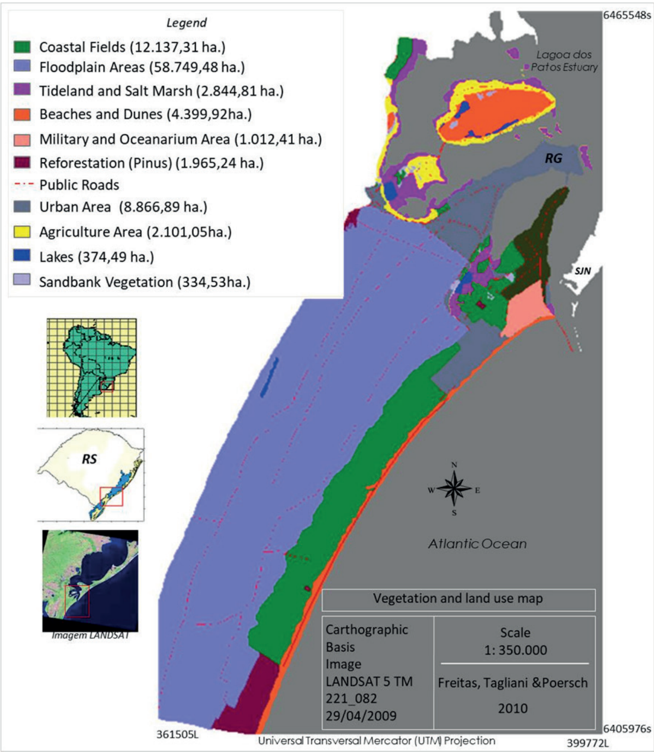

Figure 2. Vegetation and land use map of the Rio Grande municipal district.

Figura 2. Mapa de vegetação e uso da terra do município de Rio Grande.

First, a constraining criterion was used to create legally restricted areas. The criterion based on legally restricted areas was applied, as the State Foundation of Environmental Protection (FEPAM) currently requires this criterion for the implementation of new aquaculture ventures (Freitas *et al.* 2009). After the constraining criterion was defined, specific GIS routines (buffer modules) were performed to create buffer zones.

Coastal fields, considered ideal for marine shrimp farming (Peixoto *et al.* 2005), were the primary target of this study, comprising approximately 12,000 hectares. A preliminary classification was conducted to facilitate an additional categorization of image classes of land use or occupation, and thus focus on realistic suitable areas, as suggested by Rajitha *et al.* (2007) (Figure 3).

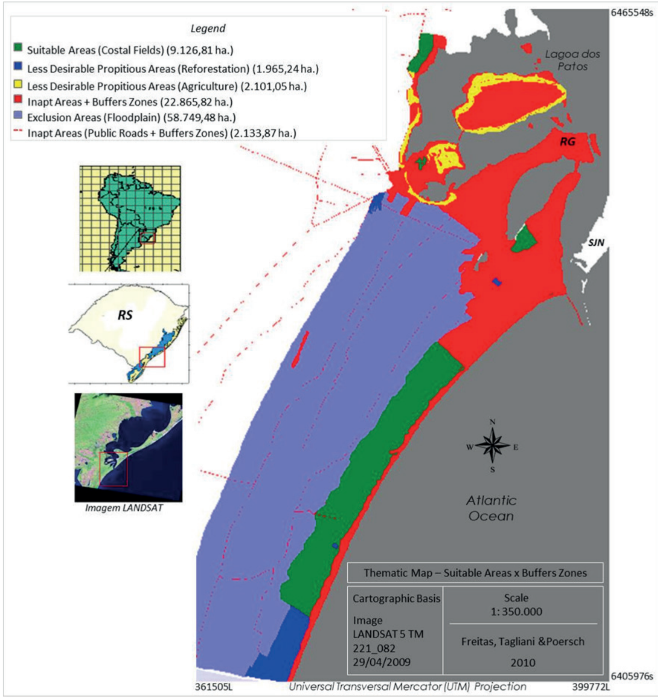

Figure 3. Thematic map of legal and environmental exclusion zones (buffers).

Figura 3. Mapa temático das zonas de exclusão legal e ambiental (buffers).

Other important features considered were wetlands or areas subject to seasonal flooding, including those areas with sea grass and wetlands surrounding lagoons, comprising approximately 60,000 hectares; coastal beaches and dunes, representing approximately 4,000 hectares; and high-density populations and harbors, with approximately 9,000 hectares, among others.

Areas characterized as reforestation (Pinus sp.) and agricultural fields were classified as suitable, but were considered less desirable for shrimp farming. This decision was based on the presence of the existing activities that were considered a major source of income in the region, thus avoiding possible land use conflicts. These, however, still represent important areas that may be used in future for marine shrimp farming.

As a result of the application of another criterion (suitable areas vs. distance from water sources), 2,000 acres were considered excellent for the implementation of shrimp farming (21.24% of the total suitable areas). Around 3,000 hectares were considered good (33.03%) and 2,700 hectares were considered marginally suitable (29.89%). Areas considered unsuitable constituted more than 1,400 acres (15.84%) (Figure 4).

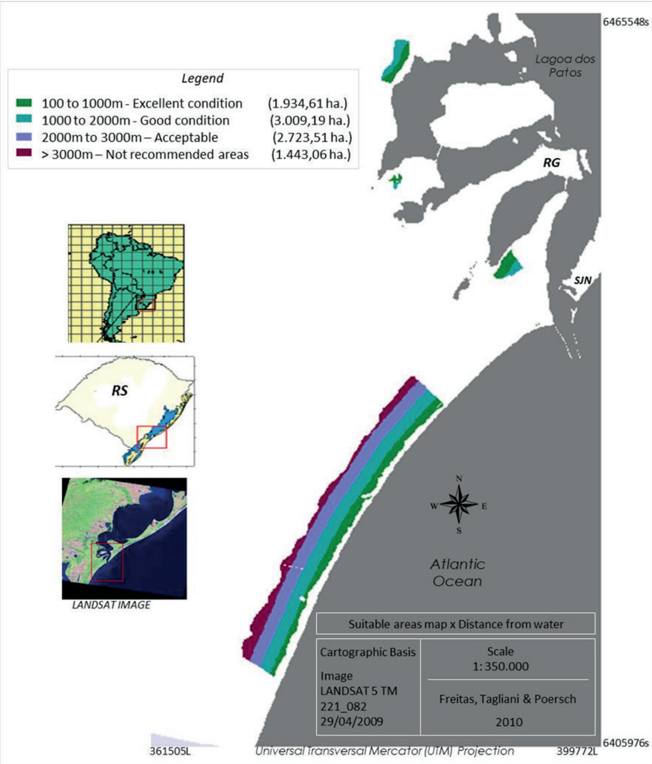

Figure 4. Water distance suitability scores from Lagoa dos Patos and the Atlantic Ocean.

Figura 4. Escores de adequação da distância da água da Lagoa dos Patos e do Oceano Atlântico.

The criterion based on the distance from water sources for the construction of ponds using overlapping layers was applied due to the high construction costs and water needs associated with aquaculture. These requirements can make the implementation and development of shrimp farms unfeasible (Lee and Wickins 1997) (Figure 4). As reported by several authors, water availability is the most important environmental criterion when selecting suitable areas for aquaculture (Pérez *et al.* 2003; Salam *et al.* 2003; McIntosh *et al.* 2004; Freitas *et al.* 2009; Rêgo *et al.* 2016).

Another criterion used to identify suitable areas was the distance from public roads. Based on this criterion, 780 hectares were considered excellent for implementing aquaculture (8.54% of the total suitable areas). Around 930 hectares were considered good (10.25%) and 2,800 hectares were acceptable (31.13%). Finally, areas not recommended constituted more than 4,500 hectares (50.09%) (Figure 5A).

Because of the importance of the distance from public roads criterion, the total suitable area was found to not be as large as expected; therefore, beaches were considered another pathway for the flow of production and delivery of inputs (Figure 5B). These areas were reconsidered because of the unrestricted daily flow of cars throughout the year (Rosa and Cordazzo 2007). Thus, considering all public roads and beaches, there was a considerable reduction in areas not recommended from 50.09% to 10.93%.

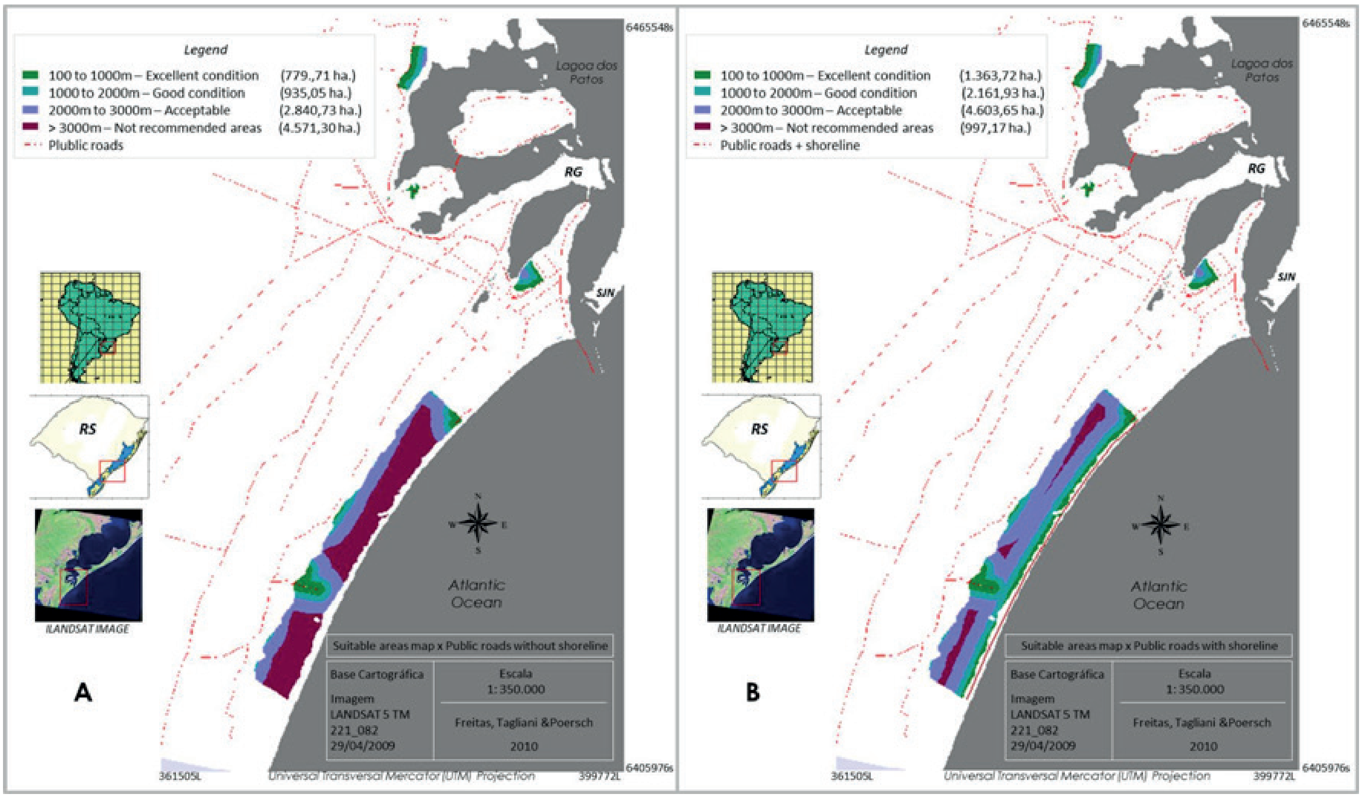

Figure 5. Thematic maps of suitability scores for: A, distance from public roads without a shoreline; B, distance from public roads with a shoreline.

Figura 5. Mapas temáticos dos escores de aptidão para: A, distância das vias públicas sem litoral; B, distância das vias públicas com o litoral.

Regarding the criterion of land use capacity, only areas with a soil class higher than V were included. These soil types have features that are not ideal for agriculture or require considerable investment, thus avoiding potential land use conflicts in the region. Therefore, for the classification of soil, Sombroek (1969) used a system developed by the USA Soil Conservation Service; this system is universally known and adapts well to the region (United States Department of Agriculture 1975). The soil and the temperature of the region are very similar to many regions in the USA. This system was originally created for the detailed mapping of cultivated areas and, especially, to prevent large-scale erosion.

The extreme importance of erosion dangers, including the slope of the land, was sometimes neglected, often only considering the possibility of improving pastures. Sombroek (1969) proposed an adjustment to soil class V, which, according to the USA Soil Conservation Service System (United States Department of Agriculture 1975), only refers to land that is flat or nearly flat, and excludes other limitations including the danger of erosion. The modified system is essential for establishing a plan for crops. The classification is a basic criterion for cropland, pastures or forestry productivity.

Thus, based on the thematic map, approximately 9,000 hectares were considered most recommended (Figure 6A). For the entire area considered suitable for shrimp farming, all classes were higher than the desired land use capacity.

Regarding the soil type, only areas with soil characteristics compatible with shrimp farming (sandy, clay or clay-sandy) were included, whereas areas with high organic content were excluded (Figure 6B). All the soil types found in suitable areas, as described by Sombroek (1969) ((HPd2 and HPd4 – traces of coastal beach, sandy texture, relief plain, grassland and zones of high energy (waves)) (AQd2 – coastal dunes, extensive sand deposits, flat relief, grassland, current and extensive cultivation of Pinus sp.) (HGPe2 – lowlands of streams, medium/clayey, relief plain, aquatic vegetation with

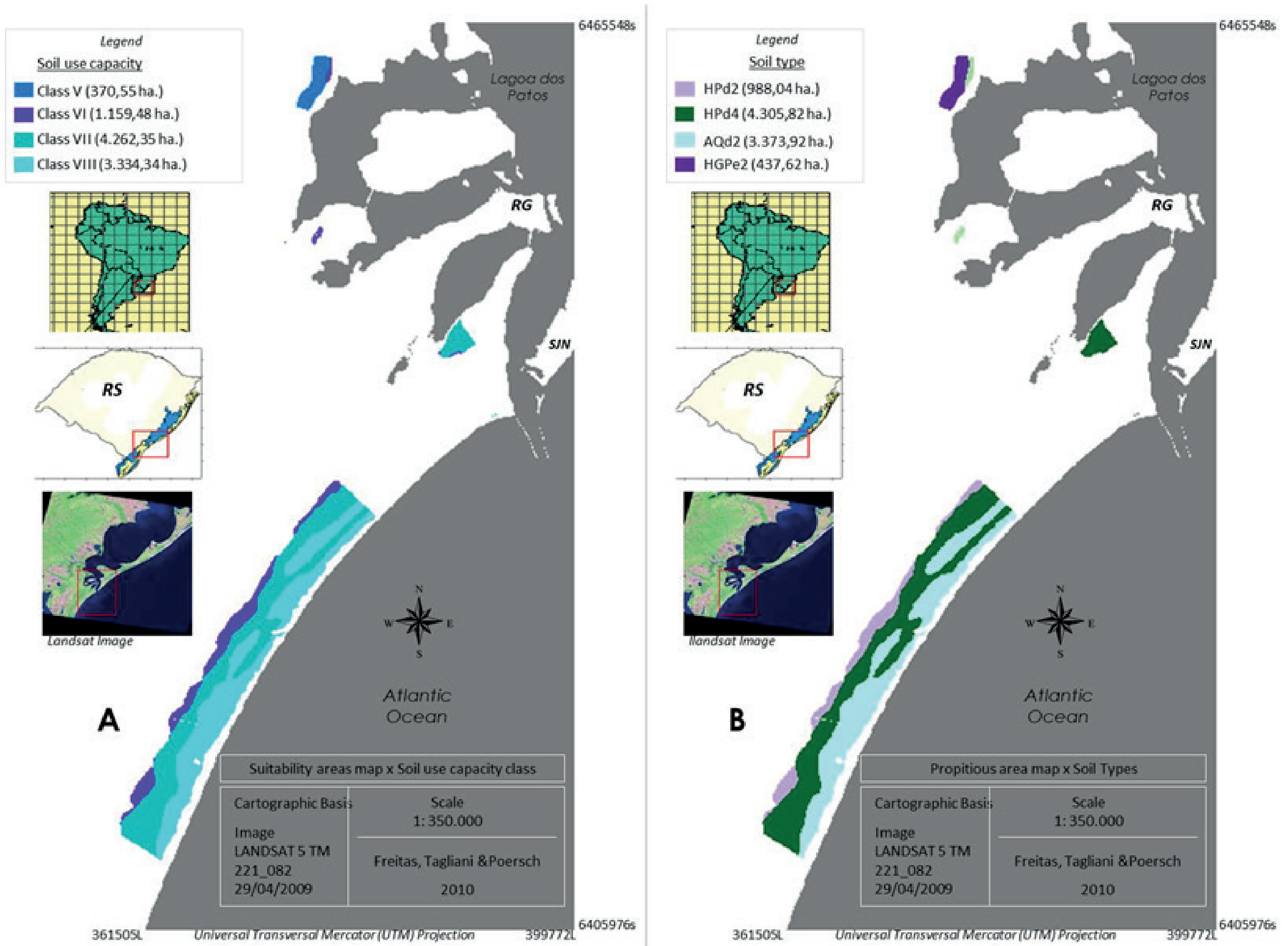

Figure 6. Thematic maps of suitability scores for: A, soil use capacity class; B, soil type.

Figura 6. Mapas temáticos dos escores de aptidão para: A, classe de capacidade de uso do solo; B, tipo de solo.

alluvial soil)), exhibited characteristics compatible with shrimp farming.

Corroborating this analysis, areas with high organic content primarily consisted of areas characterized by marsh vegetation, wetlands and nearby water bodies. These areas had previously been considered buffers and were, therefore, considered non-suitable areas (Figure 3).

The construction of various thematic maps combining the criteria of elevation (<1 meter), temperature (shrimp do not grow well in winter), soil types, and class of use revealed that these variables did not significantly (locally) affect the suitability of areas. Therefore, they were included only as descriptive and supportive criteria.

Based on all thematic maps for each specific criterion, we created a scale of suitability for shrimp farming. This avoided the inclusion of restricted areas (Boolean images) that would only fit between suitable and restricted areas (equal to 1 or 0) (Figure 7).

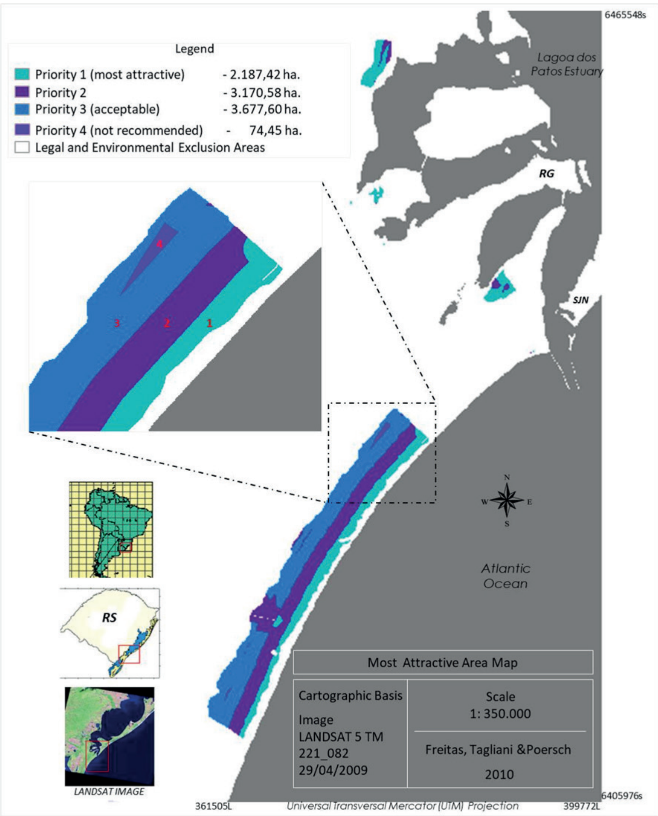

Figure 7. Map of the potential of implantation of the marine shrimp farm in the study area.

Figura 7. Mapa do potencial de implantação de fazenda de camarões marinhos na área de estudo.

Finally, according to the scale of suitability (priority between 1 and 4), approximately 2,100 ha (24.01%) were considered to be suitable, possessing the most attractive features or excellent conditions; approximately 3,100 ha (34.80%) were good; approximately 3,600 ha (40.37%) were marginally recommended; and, finally, a small fraction, approximately 70 ha (0.82%), was considered acceptable but not recommended, as these areas are distant from public roads and water sources (Figure 7).

FINAL CONSIDERATIONS

The analysis of geomorphologic characteristics, water availability, accessibility to markets and supplies, available labor, power lines, and technical support in the study area indicated mostly favorable conditions for shrimp farming. Even the areas considered to have low potential, with different investment needs, can achieve important levels of production.

From the definition/classification of the local physiography, various buffer zones were mapped to comply with the current laws and environmental practices. As a result, 9.41% of the total area of the city was considered suitable (9,126.81 ha) for shrimp farming.

This small fraction, compared to the total area of the municipality, is attributed to the presence of unsuitable areas and their buffers (23.59%), areas considered suitable but not a priority for immediate investment (existing agricultural and forestry activities) (4.20%), and excluded areas (60.60%). Although the latter consists of coastal fields, they were not considered potential aquaculture sites because field verification identified them as flooded areas, areas subject to flooding, or distant from water catchment sources (Lagoa dos Patos and the Atlantic Ocean).

Thus, the study demonstrated the potential of GIS to assist in the selection of suitable areas for marine shrimp farming. All the criteria used in the present study, such as soil type, class usability, distance to water sources and public roads, were sufficient to identify potential areas for local activity, and even at the state level.

ACKNOWLEDGMENTS

This study was financed by the Brazilian Federal Government, Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq. Wasielesky and Poersch received a productivity research fellowship from CNPq.

LITERATURE CITED

Aguilar-Manjarrez, J.; Ross, L.G. (1995) - Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico. Aquaculture International, 3(2), 103-115. DOI: 10.1007/BF00117877

Ballester-Moltó, M.; Sanchez-Jerez, P.; García-García, B.; Aguado-Giménez, F. (2015) - Husbandry and environmental conditions explain temporal variability of wild fish assemblages aggregated around a Mediterranean fish farm. Aquaculture Environment Interactions, 7: 193-203. DOI: 10.3354/aei00148

Barbieri, E; Marquez, H.L.A.; Campolim, M.B.; Salvarani, P.I. (2014) - Avaliação dos Impactos ambientais e socioeconômicos da aquicultura na região estuarina-lagunar de Cananéia, São Paulo, Brasil. Revista de Gestão Costeira Integrada, 14(3):385-398. DOI: 10.5894/rgci486

Beamish, R.J.; McFarlane, G.A.; Benson, A. (2006) - Longevity overfishing. Progress in Oceanography, 68(2), 289-302. DOI: 10.1016/j.pocean.2006.02.005

Beltrame, E.; Bonetti, C.; Bonetti, J. (2006) - Pre-selection of areas for shrimp culture in a subtropical Brazilian lagoon based on multicriteria hydrological evaluation. Journal of Coastal Research (ISSN 0749-0208), Special Issue No. 39. Proceedings of the 8th International Coastal Symposium (ICS 2004), Vol. III (Winter 2006), pp. 1838-1842. Available on-line at: http://www.jstor.org/stable/25743079

Bruhn, A.; Tørring, D.B.; Thomsen, M.; Canal-Vergés, P.; Nielsen. M.M.; Rasmussen, M.B.; Eybye, K. L.; Larsen, M.M.; Balsby, J.S.; Petersen, J.K. (2016) - Impact of environmental conditions on biomass yield, quality, and bio-mitigation capacity of Saccharina latissima. Aquaculture Environment Interactions, 8: 619–636. DOI: 10.3354/aei00200

Caillouet, C.W.; Hart, R.A.; Nance, J.M. (2008) - Growth overfishing in the brown shrimp fishery of Texas, Louisiana, and adjoining Gulf of Mexico EEZ. Fisheries Research, 92(2), 289-302. DOI:10.1016/j.fishres.2008.01.009

Cargnin, A.P.; Bertê, A.M.A.; Lemos, B.O.; Oliveira, S.B. (2013) - Quinze anos de transformações na economia e sociedade gaúchas contados pelas páginas do atlas socioeconômico do rs. Boletim Geográfico do Rio Grande do Sul (ISSN: 2446-7251), 24:29-62, Porto Alegre, Brasil. Available on-line at: http://revistas.fee.tche.br/index.php/boletim-geografico-rs/article/view/3195

Corbin, J.S.; Young, L.G. (1997) - Planning, regulation, and administration of sustainable aquaculture. In: John E. Bardach (Editor), Sustainable Aquaculture, pp.201-233, Wiley, New York (USA). ISBN: 978-0-471-14829-6. Available on-line at http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471148296.html

Dillenburga, S.R.; Barboza, E.G.; Rosa, M.L.C.C.; Caron, F.; Sawakuchi, A.O. (2017). The complex prograded Cassino barrier in southern Brazil: Geological and morphological evolution and records of climatic, oceanographic and sea- level changes in the last 7–6 ka. Marine Geology 390, 106–119. DOI: 10.1016/j.margeo.2017.06.007

Egler, C.A.G.; Gusmão, P.P. (2014) - Gestão costeira e adaptação às mudanças climáticas: o caso da Região Metropolitana do Rio de Janeiro, Brasil. Revista de Gestão Costeira Integrada, 14(1):65-80. DOI: 10.5894/rgci370

Food and Agriculture Organization of the United Nations - FAO. (2016) - The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. (ISBN 978-92-5-109185-2), 200pp., Rome, Italy. Available on-line at: http://www.fao.org/fishery/sofia/en

Frankic, A. (1998) - A framework for planning sustainable development in coastal regions: an island pilot project in Croatia. PhD Dissertation, 124pp., Virginia Institute of Marine Science, College of William & Mary, Williamsburg, VA. Available on-line at: http://www.vims.edu/library/theses/Frankic98.pdf

Freitas, D.M.; Tagliani, P.R.A. (2007) - Spatial planning of shrimp farming in the Patos Lagoon Estuary (Southern Brazil): an integrated coastal management approach. Journal of Coastal Research, 136-140. DOI: 10.2112/1551-5036-47.sp1.136

Gatune, C.; Vanreusel, A.; Troch, M. (2017) - Sunlight and sediment improve the environment of a litter biofilm-based shrimp culture system. Aquaculture Environment Interactions, 9: 73-85. DOI: 10.3354/aei00209

Giap, D.H.; Yi, Y.; Yakupitiyage, A. (2005) - GIS for land evaluation for shrimp farming in Haiphong of Vietnam. Ocean & Coastal Management, 48(1):51-63. DOI: 10.1016/j.ocecoaman.2004.11.003

Hossain, M.S.; Chowdhury, S.R.; Das, N.G.; Rahaman, M.M. (2007) - Multi-criteria evaluation approach to GIS-based land-suitability classification for tilapia farming in Bangladesh. Aquaculture International, 15(6):425-443. DOI: 10.1007/s10499-007-9109-y

Kapetsky, J.M.; Hill, J.M.; Worthy, L.D. (1988) - A geographical information system for catfish farming development. Aquaculture, 68(4):311-320. DOI: 10.1016/0044-8486(88)90245-1

Karthik, M.; Suri, J., Saharan, N.; Biradar, R.S. (2005) - Brackish water aquaculture site selection in Palghar Taluk, Thane district of Maharashtra, India, using the techniques of remote sensing and geographical information system. Aquacultural Engineering, 32(2):285-302. DOI: 10.1016/j.aquaeng.2004.05.009

Klumb-Oliveira, L.A.; Souto, R.D. (2015) - Integrated coastal management in Brazil: analysis of the National Coastal Management Plan and selected tools based on international standards. Gestão Costeira Integrada, 15(3):311-323. DOI: 10.5894/rgci531

Lee, D.O.C.; Wickins, J. (1997) - Cultivo de crustáceos. 449p., Acribia, São Paulo. ISBN 10: 842000796X.

Lepsch, I.F.; Bellinazzi, J.R.; Bertolini, D.; Espíndola, C.R. (1983) - Manual para levantamento utilitário do meio físico e classificação de terras no sistema de capacidade de uso. 170p., Sociedade Brasileira de Ciência do Solo, Brasil. ISBN: 978-85-86504-12-9.

Longdill, P.C.; Healy, T.R.; Black, K.P. (2008) - An integrated GIS approach for sustainable aquaculture management area site selection. Ocean & Coastal Management, 51(8):612-624. DOI: 1016/j.ocecoaman.2008.06.010

Maia, M.A.M.; Castro, J.W.A. (2015) - Methodological proposal for characterization of marine geodiversity in the South Atlantic: Vitória-Trindade Ridge and adjacent areas, southeast of Brazil. Gestão Costeira Integrada, 15(3):293-309. DOI: 10.5894/rgci519

McIntosh, D.; Baldwin, T.K.; Fitzsimmons, K. (2004) - Aquaculture development potential in Arizona: A GIS-based approach. World Aquaculture Magazine 34(4): 32–35. Available on-line at: https://www.was.org/magazine/ArticleContent.aspx?Id=147

McLeod, I.; Pantus, F.; Preston, N. (2002) - The use of a geographical information system for land-based aquaculture planning. Aquaculture research, 33(4):241-250. DOI: 10.1046/j.1355-557x.2001.00667.x

Peixoto, S.; Wasielesky, W.; Cavalli, R.O.; Santos, M.H.S.; Poersch, L. (2005) - Diretrizes para o desenvolvimento responsável da carcinicultura na região do estuário da Lagoa dos Patos, Rio Grande do Sul, Brasil. Gerenciamento Costeiro Integrado (ISSN 1677-4841), 4(6):1-4, Brazil. Available on-line at: http://www.aprh.pt/rgci/issues.html

Perez, O.M.; Telfer, T.C.; Ross, L.G. (2003) - Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Tenerife (Canary Islands). Coastal Management, 31(4):355-366. DOI: 10.1080/08920750390232992

Perez, O.M.; Telfer, T.C.; Ross, L.G. (2005) - Geographical information systems-based models for offshore floating marine fish cage aquaculture site selection in Tenerife, Canary Islands. Aquaculture Research, 36(10):946-961. DOI: 10.1111/j.1365-2109.2005.01282.x

Poersch, L.; Cavalli, R.O.; Wasielesky Júnior, W.; Castello, J.P.; Peixoto, S.R.M. (2006) - Perspectivas para o desenvolvimento dos cultivos de camarões marinhos no estuário da Lagoa dos Patos, RS. Ciência Rural, 36(4): 1337-1343. DOI: 10.1590/S0103-84782006000400051

Radiarta, I.N.; Saitoh, S.I.; Miyazono, A. (2008) - GIS-based multi-criteria evaluation models for identifying suitable sites for Japanese scallop (Mizuhopecten yessoensis) aquaculture in Funka Bay, southwestern Hokkaido, Japan. Aquaculture, 284(1):127-135. DOI: 10.1016/j.aquaculture.2008.07.048

Rajitha, K.; Mukherjee, C.K.; Chandran, R.V. (2007) - Applications of remote sensing and GIS for sustainable management of shrimp culture in India. Aquacultural Engineering, 36(1):1-17. DOI: 10.1016/j.aquaeng.2006.05.003

Rêgo, I.S.; Aguiar, L.F.M.C.; Soares, M.O. (2016) - Environmental zoning and coastal zone conservation: the case of a protected area in Northeastern Brazil. Revista de Gestão Costeira Integrada, 16(1):35-43. DOI: 10.5894/rgci603

Rosa, L.S.D.; Cordazzo, C.V. (2007) - Perturbações antrópicas na vegetação das dunas da Praia do Cassino (RS). Cadernos de Ecologia Aquática (ISSN 1980-0223), 2(2):1-12. Rio Grande, Brazil. Available on-line at: http://www.cadernos.ecologia.furg.br/images/artigos/16_Rosa&Cordazzo.pdf

Salam, M.A.; Khatun, N.A.; Ali, M.M. (2005) - Carp farming potential in Barhatta Upazilla, Bangladesh: a GIS methodological perspective. Aquaculture, 245(1-4):75-87. DOI: 10.1016/j.aquaculture.2004.10.030

Salam, M.A.; Ross, L.G.; Beveridge, C.M. (2003) - A comparison of development opportunities for crab and shrimp aquaculture in southwestern Bangladesh, using GIS modelling. Aquaculture, 220(1-4):477-494. DOI: 10.1016/S0044-8486(02)00619-1

Sombroek, W.G.; Averbeck, H.; Durán, A. (1969) - Soil Studies in the Merim Lagoon Basin Uruguay/S, Brazil. (report, maps and cross sections). CLM/PNUD/FAO Report, Treinta y Tres, Uruguay. Available on-line at: http://ref.data.fao.org/map?entryId=dd2f9f00-88fd-11da-a88f-000d939bc5d8

Souto, M. V. S. E., and Amaro, V. E. (2005) - Aplicação das técnicas de geoprocessamento para o mapeamento da vulnerabilidade natural para a região da Ponta do Tubarão, litoral setentrional do Estado do Rio Grande do Norte, Município de Macau. In: Simpósio Brasileiro de Sensoriamento Remoto, pp.2773-2778, 12. (SBSR), Goiânia, São José dos Campos: INPE. ISBN 85-17-00018-8. Available on-line at: http://marte.sid.inpe.br/col/ltid.inpe.br/sbsr/2004/11.19.18.35/doc/2773.pdf

Tagliani, C.R.A.; Vicens, R.S. (2003) - Mapeamento da vegetação e uso do solo nos entornos do estuário da Laguna dos Patos, RS, utilizando técnicas de processamento digital de imagem do SIG SPRING. In: Anais eletrônicos, XI Simpósio Brasileiro de Sensoriamento Remoto, pp.1461-1468, Belo Horizonte, Brasil. ISBN: 85-17-00017-X. Available on-line at: http://urlib.net/ltid.inpe.br/sbsr/2002/11.06.16.55

Testa, J.M.; Brady, D.; Cornwell, J.C.; Owens, M.S.; Sandford, L.P.; Newell, C.R.; Suttles, S.E.; Newell, R.I.E. (2015) - Modeling the impact of floating oyster (Crassostrea virginica) aquaculture on sediment−water nutrient and oxygen fluxes. Aquaculture Environment Interactions, 7(3):205–222. DOI: 10.3354/aei00151

Torres, C.; Andrade, C. (2010) - Processo de decisão de Análise Espacial na selecção de áreas óptimas para a Aquacultura Marinha: O exemplo da Ilha da Madeira. Gestão Costeira Integrada, 10(3):321-330. DOI: 10.5894/rgci180

Travers, M.; Watermeyer, K.; Shannon, L.J.; Shin, Y.J. (2010) - Changes in food web structure under scenarios of overfishing in the southern Benguela: comparison of the Ecosim and OSMOSE modelling approaches. Journal of Marine Systems, 79(1-2):101-111. DOI: 10.1016/j.jmarsys.2009.07.005

United States Department of Agriculture (1975) - Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys, pp.869, Second Edition Agriculture Handbook Number 436, Natural Resources Conservation Service, Washington, DC., USA. Available on-line at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051232.pdf