Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v45i1.64103

GEOSCIENCES

Geotechnologies applied to geographic information system (GIS) of Fish farming in Rondônia state, Western Amazon

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ABSTRACT. This research demonstrated a Geographic Information System (GIS) of licensed fish farms in Rondônia state, Brazil. Based on structuring of the GIS, spatial analyzes of location and distribution of fish farms were carried out in relation to highway network; to drainage; to microregions of Rondônia and the verification of the density. Methodological procedure consisted of modeling the Database (DB), whose information was obtained from Secretaria do Estado de Rondônia para Desenvolvimento Ambiental (SEDAM/RO), which holds the references of licensed fish farms processed in SPRING and ARCGIS 9 Arcmap 9.3 software. For spatial statistics, the Kernel density estimator was applied. The main result is the fact that GIS made it quick and easy to search for data and information about the fish farms studied. The highest density was 4937.64 fish farms per unit area in Ji-Paraná microregion, which is located in the Central region of Rondônia state. In thematic mapping, the fish farms showed some spatial dependencies, as follows: I – They depend on main access, highway BR 364. II – The cluster of fish farms is arranged where there is greater availability of water, that is, they depend on water courses. Therefore, positioning and distribution of fish farms take place in the three main microregions, Ji-Paraná 40.30% of licensed fish farms, followed by microregions of Cacoal 16.02% and Ariquemes 15.87 %.

keywords: Database; Information systems; Kernel density estimator; Spatial Analysis.

Received on june 22, 2022
Accepted on april 04, 2023

Introduction

Over the years, the Rondônia state, known by ranchers as the "Natural State of Livestock" (Cargnelutti et al., 2014), has shown great potential for the aquaculture sector and, in this way, fish farming has shown significant growth from perspectives agribusiness and family farming, standing out as a promising cluster in the North region of Brazil.

The selection of an area for aquaculture purposes is subject to diverse and interdependent factors, such as the hydrological potential; the edaphoclimatic requirements, the cultivation system to adopted; the species to cultivated; legal, social and cultural aspects and infrastructure conditions, among others (Hurtado et al., 2018). The Western Amazon region, due to its natural characteristics, is favorable to practice of aquaculture in most of its terrestrial and aquatic environments (Brabo et al., 2015). In this overview, Rondônia state has potential and vocation for the full development of aquaculture and the main municipalities that offer favorable conditions for activity are Porto Velho, Cacoal, Ariquemes, Ouro Preto do Oeste, Ji-Paraná, Rolim de Moura and Pimenta Bueno (Anjos et al., 2015). These areas were recommended due to fact that they are close to federal and state highways and favor the structuring of the Geographic Information System (GIS), concentrating information in a digital platform and enabling an analysis of the spatialization of fish farming in Rondônia state.

The use of GIS emerges as an economically viable alternative to generate information related to fish farming. Given this overview, information systems, when used in a well-directed way, bring improvements in the services provided and offered, improvement in decision making, due to faster and more accurate information (Silva et al., 2013; Leite, Barros, & Silva, 2019), contributing to fill existing gaps in the literature on aquaculture, at different geopolitical levels. In this sense, the present research was pioneering in the State of Rondônia, because, besides allowing the geospatialization of aquaculture activity through the production of thematic maps, the identification of different densities of fish farms per area and the main elements motivating these regional differences, it was the first that also allowed the understanding of the expansion process of the activity in the state territory over time.

Natural conditions conducive to development of aquaculture and the vocation of rural producers for the activity triggered and directed a significant expansion of fish farming activity in Rondônia state (Sousa, Assis, Cozer, & Oliveira, 2019). It is a fact that the production chain of fish farming is complex, mainly with regard to organization of the production chain, the market, industrialization and logistics, and in these areas the activity showes a deficit, leading Rondônia state to consolidate itself as a producer of fish raw material (Sabaini, Casagrande, & Barros, 2015; Meante & Dória, 2017).

Seeking to provide agile and reliable alternatives for aquaculture environmental management, providing subsidies for zoning of public spaces for implementation of aquaculture parks and enabling a better targeting of investments in this economic activity, GIS is a tool that can be adjusted to different fields, such as supervision, teaching, research and extension and scientific development (Silva et al., 2013; Martin, Tommaselli, & Garcia, 2019). Therefore, SIG strengthens the action plan of the management and inspection institutions, providing quick and concise information. In addition, it improves the decision-making process by managers (Silva, Yáñez, Martín-Díaz, & DelValls, 2012). In this way, the structuring of GIS will contribute to the identification of the location, spatial patterns, distribution and density of fish farms in Rondônia state.

Given the assumptions, the aimed of this study was to carry out the structuring of GIS, concentrating information on fish farms in a digital environment and to carry out an analysis of the spatialization of fish farming in Rondônia state, Brazil.

Material and methods

Study area

The studied area is in Rondônia state (Figure 1), located in the North region of Brazil, bordered by Mato Grosso, to east; Amazonas, to north; Acre to west and Republic of Bolivia to west and south. Rondônia has a territorial extension of 237,590,543 km², consists 52 municipalities, has an estimated population of 1.8 million inhabitants (Instituto Brasileiro de Geografia e Estatística [IBGE], 2020). According to CPTEC/INPE (2019), the climate of Rondônia state is classified in the Köppen system, as predominantly Am - Tropical Rainy Climate (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). About 66% of territory's surface is between 100 and 300m altitude, 30% between 300 and 800m and 4% below 100m (SEDAM, 2019).

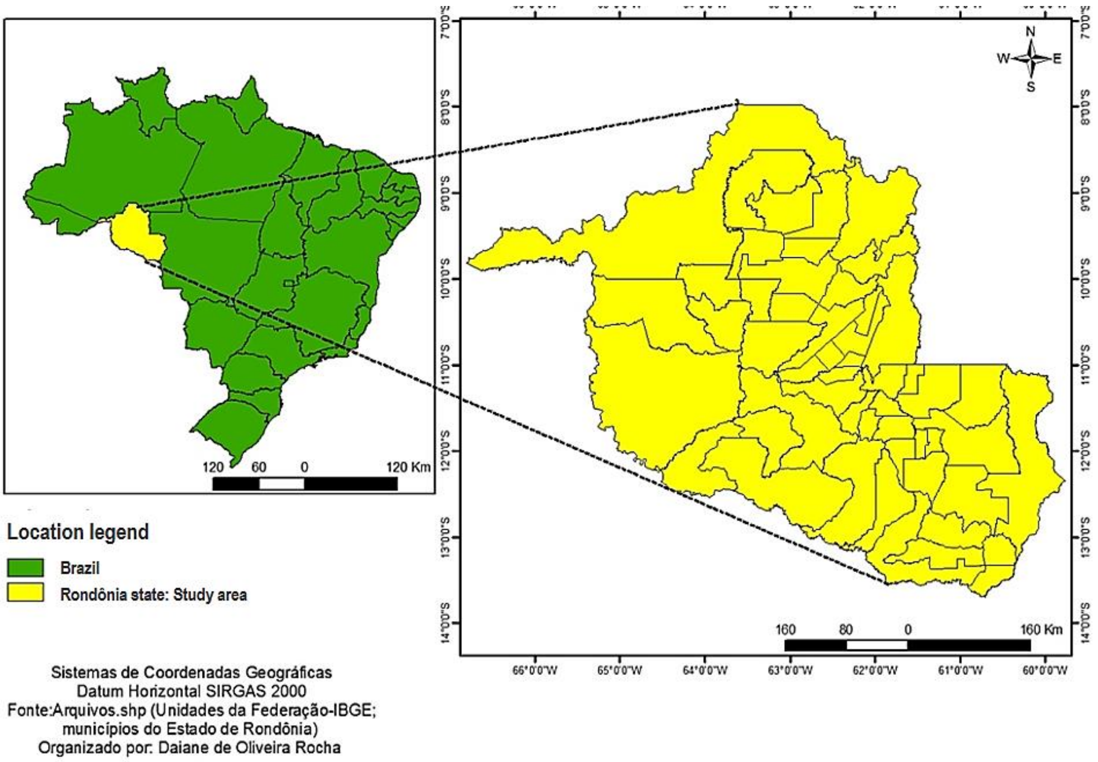

Figure 1. Geographical location of Rondônia state, Western Amazon, Brazil.

In the Brazilian fish farming overview, the state of Rondônia is the third largest producer of farmed fish and the largest producer of native fish, with a production of 57.2 thousand tons in 2022 (PEIXE BR, 2023). The main species cultivated in the excavated tanks in Rondônia is tambaqui (*Colossoma macropomum* Cuvier, 1818). However, the cultivation of other species also stands out, for example matrinxã (*Brycon amazonicus* Spix & Agassiz, 1829), pirapitinga (*Piaractus brachypomus* Cuvier, 1818), ambatinga (female, *Colossoma macropomum* X *Piaractus brachypomus*, male), surubim (*Pseudoplatystoma corruscans* Agassiz, 1829), pintado da Amazônia (female, *Pseudoplatystoma sp*. X *Leiarius marmoratus*, male), pirarucu (*Arapaima gigas* Schinz, 1822) and others (Silva et al., 2022).

The main entry route for inputs (feed, fertilizers, rural lime, etc.) and for the outflow of aquaculture production is highway BR 364, which crosses Rondônia state from border with Mato Grosso to border with Acre. The main waterway is Madeira River, the largest tributary of the Amazon River, essential for entry and exit of products in Rondônia state. It is used for flow of the Manaus Free Trade Zone and for supply of the Amazonian capital, fundamental in economic development of Rondônia state.

Data collect

Informations was provided by Secretaria do Estado de Rondônia do Desenvolvimento Ambiental (SEDAM/RO), specifically in Fisheries Resources Division, which holds data corresponding to environmental licensing processes of all municipalities. The information obtained in the current study refers to the years 1994 to 2013. The image diagnosis was performed using the distribution factors of licensed fish farms by municipality and by year. In addition, it was possible to verify which species were cultivated, the flooded area of the ponds, as well as, through the GIS diagnosis, it was possible to obtain an estimate of production and geographic estimates of each fish farm. The data obtained were stored and organized in Epi info™ software, version 3.5.3 - 2011 (OS: MS-Windows, Programming language C Sharp).

GIS deployment

For data analysis and processing, two ARCGIS software, version 9, Arcmap 9.3, student version and the SPRING Software, available free of charge on the website of Instituto Nacional de Pesquisas Espaciais (INPE), were used. The methodology adopted for structuring the GIS was divided into three important phases: I. Modeling the Real World; II. Database Creation; III. Operation, as adopted by Antonucci, Aguiar, Aguiar and Andrade (2018), in the structuring of a GIS of vegetable crops in Ji-paraná municipality, RO, Brazil.

In this way, the data obtained from SEDAM/RO were spatialized in GIS and through spatial analysis tools, such as a Kernel estimator, the integration with the geographic data base of Rondônia state was carried out, using Sirgas 2000 as Horizontal Datum.

Data modeling and variable definitions

The Conceptual Modeling of DB and the definitions of the attributes table variables were conditioned by needs of SEDAM/RO. In this phase, the targets characterized in object view were distinguished: fish farms, flooded area, hydrography, highways network and municipal boundary; Conventional classes, year of implementation, address, cultivated species, production estimate and those responsible for the project. According to Antonucci, Aguiar, Aguiar and Andrade (2018) each field in the table has attributes that are, in SPRING, classified into four types: Integer, Real, Date and Text.

These DB elements limit and restrict possible errors. Each variable has its purpose within the DB, as specified below: I. YEAR: refers to the year in which the environmental licensing process for fish farming activity started on a given property; II. NAME: refers to the owner responsible for the property, it is described in the DB by the physical name or by corporate name for a legal entity, which is responsible for resolving the legal issues imposed on it; III. ADDRESS: mentions the location of the property (sector, rural line, gleba); IV. MUNICIPALITY: refers to the municipality to which the property under licensing belongs; V. SPECIES: refers to species that was described in the project, in which it is determined in the licensing, which will be cultivated on the property; VI. GEOGRAPHIC COORDINATES: are the coordinates of the licensed properties that are collected by SEDAM/RO, when the property surveys are carried out. In GIS, Geographic coordinates is represented as “COORD GEOG”; VII. X and Y: as the coordinates collected by SEDAM/RO were in latitude and longitude, the program used to process the data did not accept this format, so it was necessary to transform all coordinates that were in latitude and longitude to UTM; VIII. FLOODED AREA: Refers to measurement of the area destined for fish farming on each property, that is, size in hectares (ha) occupied by fish farming. It serves as a basis for estimating production, which on average are considered productivity between 6 to 10 tons of fish per hectare/harvest. In the GIS, the Flooded Area is represented by "FLOODED AREA"; IX. PRODUCTION ESTIMATE IN TONS/YEAR: refers to estimate that is made taking into account the production capacity of the flooded area, according to adopted cultivation system (extensive, semi-intensive or intensive systems). In the GIS, the Production estimate in Tons per year is represented by "PRODUCTION".

Thematic maps elaboration

After the data were in DB, thematic maps (infographics) were structured, using Graphic Semiology rules. This standard can be understood as a set of guidelines that guide the elaboration of thematic maps with the use of symbols that characterize the information Adanali (2022). Furthermore, considerations of the existing relationships between the data of same information make up conceptual basis of graphic semiology. Thus, information must be interpreted through a visual variable (color, shape, value and size). These visual variables can be used in points, lines or areas (zones) (Karami, Rangzan, & Saberi, 2013). Thus, the modes of implementation of Graphic Semiology can be designated as: punctual, linear or zonal. Thus, in this study, fish farms were represented by points, rivers, limits and highways will be represented by lines, and densities and any information occupying an area will be represented by zones.

Results and discussion

Until December 2013, the Rondônia state had 3,290 fish farms officially registered with SEDAM/RO. The first environmental license for fish farming took place in year 1994, in the Pimenta Bueno municipality, located in the Zona da Mata region, followed by Vilhena municipality, located in the Southern Cone region, in yer 1995. Therefore, it can say that the Fish farming in Rondônia state was irradiated from the interior, registering slight increases in the number of expeditions of environmental licenses in the first years and only from the year 2000 onwards there was a significant increase in such emissions. The increase in number of licensed fish farms until 2012 was growing, with 1336 licensing processes. However, in 2013 it showed a decrease of 43% compared to the previous year, registering 569 environmental licensing processes for fish farming.

After processing the data from 3,290 fish farms, only 2,578 fish farms were selected in DB, due to the lack of geographic coordinates, a primordial factor in the analysis and/or being incorrectly collected, to which, when added in the software used, they were located outside the study area. The 712 fish farms that were not included in DB can added later, because the DB has flexibility in handling, as already mentioned, it can changed, increased and edited in an agile and safe way, simply by collecting it again coordinates and insert them into the DB.

According to definition Clarke (1986), Geographic Information Systems (GIS) are computer-aided systems for the capture, storage, retrieval, analysis and display of spatial data. In this context, the GIS resulting from this study responded with excellence to the proposed objectives, enabling the manipulation and transformation of the extensive database into information, according to the interpretations aligned with the objectives of this study, notably, the visualization of spatial data related to fish farming.

Regarding the positioning and spatial distribution of enterprises in the study area in relation to highways network, some specific characteristics are observed in the spatial accommodation of fish farms. The first is that most fish farms are located close to BR 364, characterizing a spatial dependence. The second is the large number of fish farms that are too close together composing a spatial cluster, demonstrating the regions where this activity was most developed during the 90s and 2000s (Figure 2)

The highways BR 364, together with the access highways, provide accessibility in flow of the product, ease of access and contribute to cost-effectiveness and production logistics. Other factors that may contribute to this behavior are the characteristics of the product. Fish is one of the most perishable foods and, therefore, needs adequate care from the time it is caught fresh until it reaches the consumer or the processing industry. Its conservation depends on a demanding cold chain. The time interval determines the intensity with which the enzymatic and/or oxidative alterations occur, affecting the cost-benefit of production. Poor side highways, associated with unfavorable transport conditions, can cause product losses and high losses.

The study by Antonucci, Aguiar, Aguiar and Andrade (2018), carried out with vegetable farms in Ji-Paraná municipality, also demonstrated the dependence of this type of deficit on highways network, showing the importance of developing the sector. In this way, when cultivated in places of difficult access, there is a negative influence on the spatial distribution and economy of fish farms.

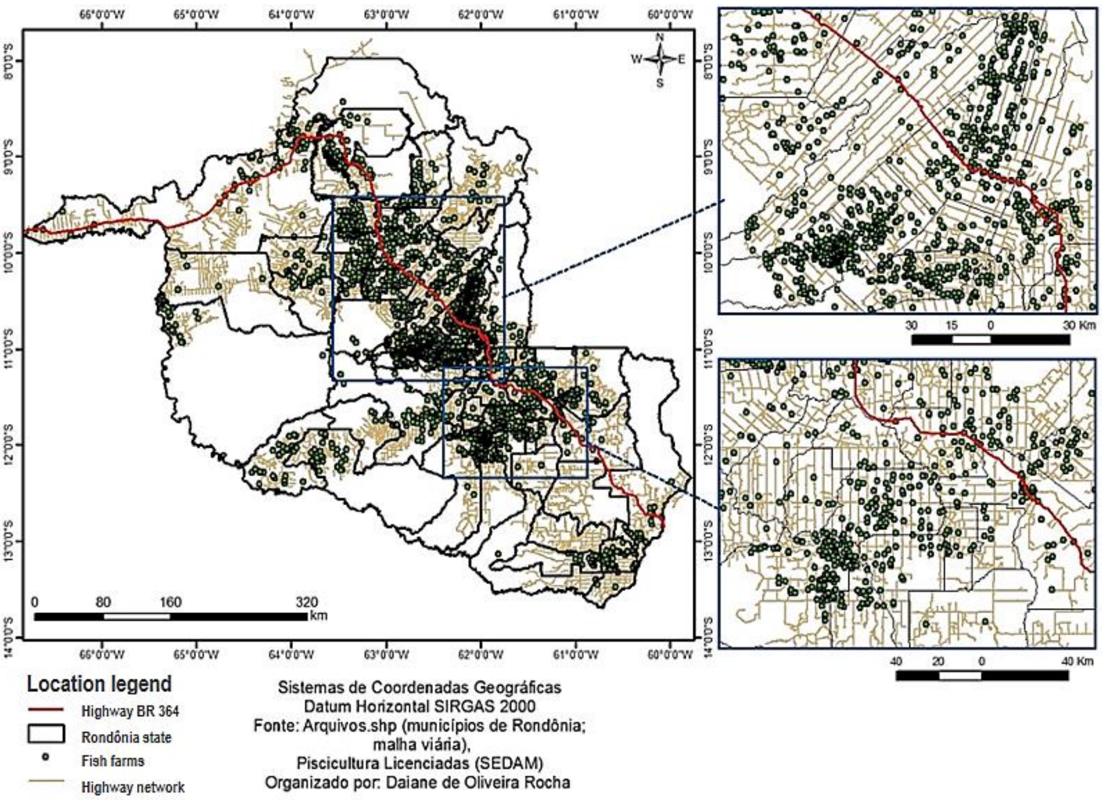

Figure 2. Positioning and spatial distribution of fish farms in Rondônia state, in relation to highways network.

Rondônia state is privileged in terms of availability of water resources, in addition to having a favorable climate and areas suitable for implementation of fish production activities. Thus, the diagnosis of the spatial distribution and the positioning of fish farms in analogy to drainage was also analyzed (Figure 3). As observed in the spatial analysis, it can say that the choice of location for implementation of fish farming coincides with the use of idle areas on the properties, which have great productive potential for aquaculture.

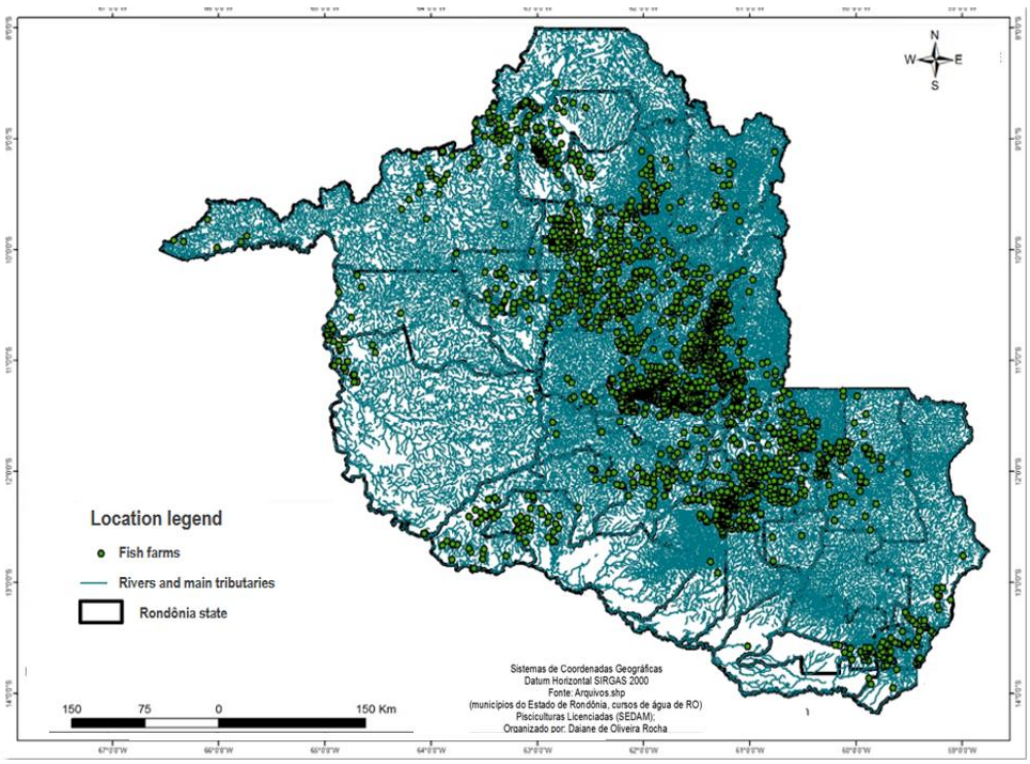

Figure 3. Drainage and fish farms in the study area, Rondônia state, Western Amazon.

Figure 4 demonstrates positioning and spatial distribution of fish farms in the study area in relation to the microregions of Rondônia state. It can be seen, in descending order, that the Ji-Paraná was the most representative with 40.30% of licensed properties, followed by Cacoal 16.02%; Ariquemes 15.87% and so on, Porto Velho 12.37%; West Dawn 4.58%; Vilhena 4.54%; Guajará-Mirim 3.72% and Colorado do Oeste muncipality 2.60% (Figure 4).

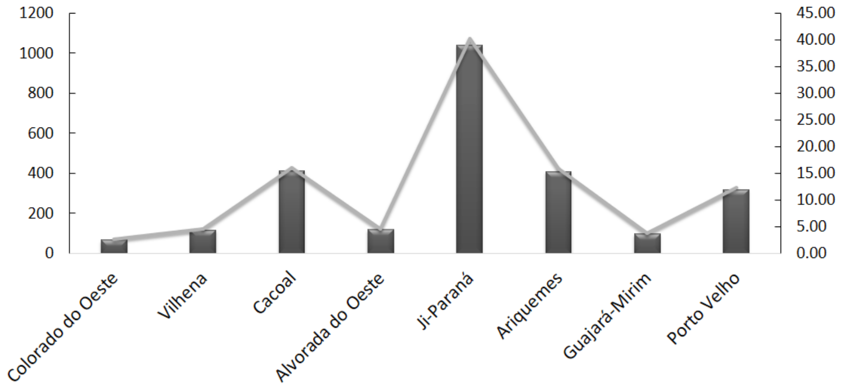

Figure 4. Numbers of licensing by municipalities of Rondônia state, between years 1994 and 2013.

It could seen that the formation of cluster of fish farms in the region is where there is greater availability of water resources, compared to other areas of the study where there is no great incidence of this activity. It was observed, as highlighted on the map, the spatial dependence on water courses, which serve as a source of supply for fish farming.

As mentioned in course of the study, the municipalities that have the greatest potential for activity in Rondônia state are: Porto Velho, Cacoal, Ariquemes, Ouro Preto do Oeste, Ji-Paraná, Rolim de Moura and Pimenta Bueno municipalities, due to their proximity to federal highways and Rondônia state, and waterways (Pereira, 2020). Making an analogy between the distribution of fish farms by microregions (Figure 5), with the distribution of fish farms in relation to drainage, a component discussed in previous item, it can seen that in regions where the large cluster of fish farms occur, there is enormous availability of water resources, in addition to being close to BR 364, thus facilitating the growth of sector in Ariquemes, Cacoal, Ji-paraná, Porto Velho and Pimenta Bueno municipalities, which are located close to highway BR 364 (Pereira, 2020).

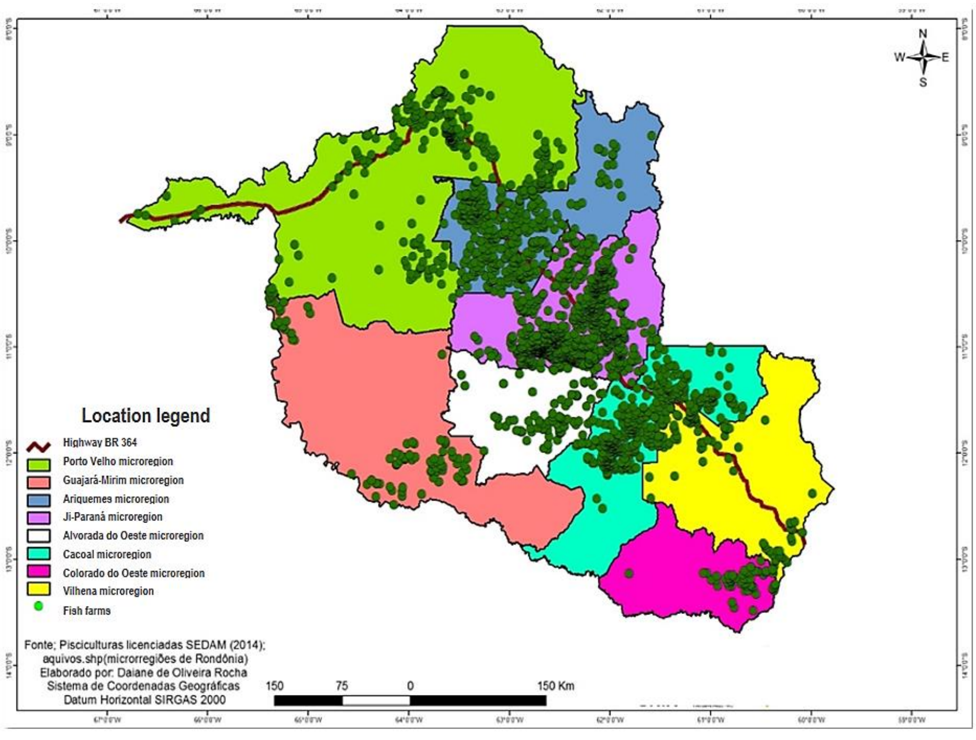

Figure 5. Positioning and spatial distribution of Fish farms in Rondônia state in relation to Porto Velho, Guajará-Mirim, Ariquemes, Ji-Paraná, West Dawn, Cacoal, Colorado do Oeste and Vilhena microregions.

According to licenses issued, it was possible, by logical deduction, to say that the development of fish farming in Rondônia state is divided into two phases: the first phase corresponds to the interstice between the years 1994 to 2004, with the attenuated development of the activity (Figure 6).

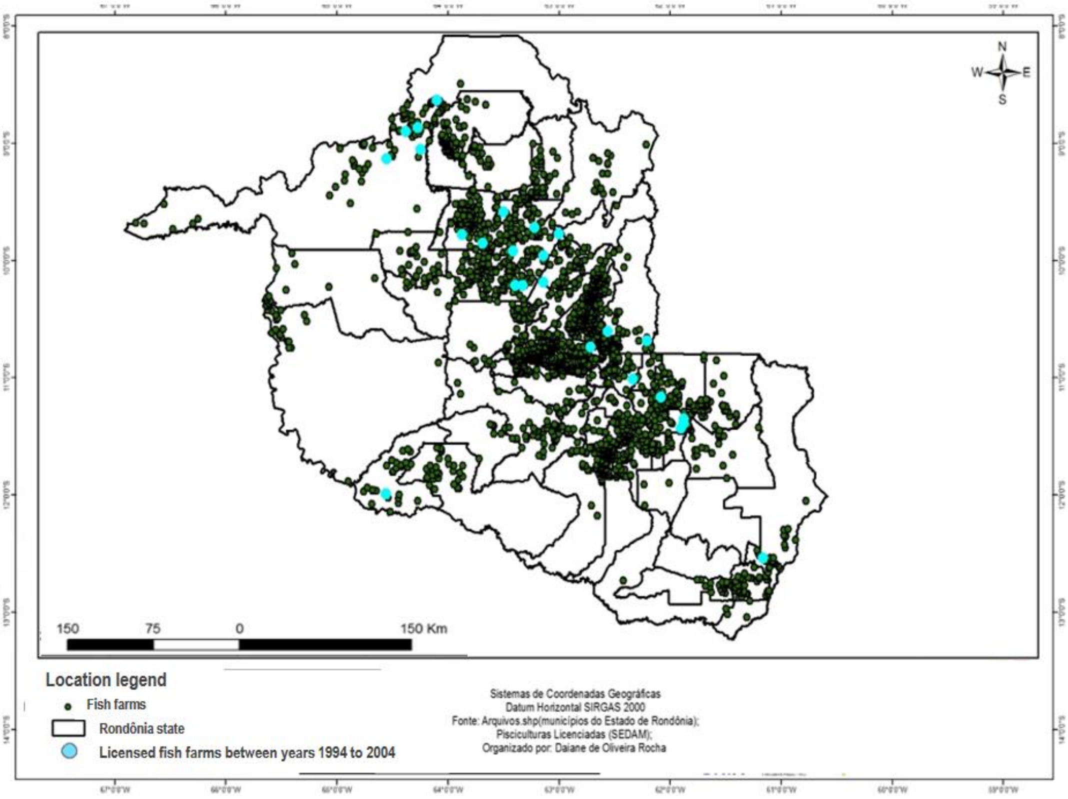

Figure 6. First phase of fish farming development in Rondônia state.

Concerning factors that we can cite as crucial in the initiative of regularizing the properties that carry out the fish farming activity, were the laws related to development of the activity, Law no. 1038 of January 22, 2002 already established guidelines for the protection of fishing and incentives for aquaculture in Rondônia state, invoking the Licenses and Registrations, where the thirteenth article of the third chapter states that individuals or legal entities that carry out activities related to the capture, collection, production, transport, conservation, commercialization, processing, industrialization of fish or who carry out the activity of fishing, including ornamental species, in any of its modalities, "are required to register with the competent state environmental agency", these measures certainly contributed.

The second phase comprises a marked development of the activity from the year 2005 to 2012, with growth slopes of about 50% per year, featuring a vertiginous growth of the activity between the years 2007 to 2012, with the exception of the year 2013 there was a 42% decrease compared to the previous year, with 569 licenses, this drop can be attributed to decrease in properties that were previously irregular (Figure 7).

Inspections and measures were increasingly frequent, collaborating in monitoring and control of the fish farming sector. The creation of Law no. 1,861, of January 10, 2008, which provides for, defines and disciplines fish farming in Rondônia state, making provision in Chapter V, which deals with Licenses, Registrations and Authorizations and its ninth article that individuals or legal entities will only be able to carry out aquaculture activity for commercial purposes with the Licensing to granted by SEDAM/RO, collaborated in growth of the number of licenses.

The Conselho Nacional de Meio Ambiente (CONAMA) also addresses the issue of licensing, as described in Resolution No. 413, of June 26, this resolution 2009 - ICMBio, this resolution exists on the environmental licensing of the aquaculture, and makes other arrangements. And also, planning and control of aquaculture activities based on environmentally correct production with all care taken to protect forest remnants and water quality, including in existing enterprises.

It should noted that creation of Law no. 2,555, of September 15, 2011, contributed significantly to growth in the number of licenses in year 2012, as it established tax exemption for fish farming in areas of up to 5.0

hectares and any licensing in anthropized or consolidated areas, certainly providing a unique opportunity for the regularization of formerly clandestine activities. Analyzing the fish farms licensed year 2011 onwards, 83% have a flooded area of up to 5 (five) hectares of water depth, proving the contribution of Law no. illegally.

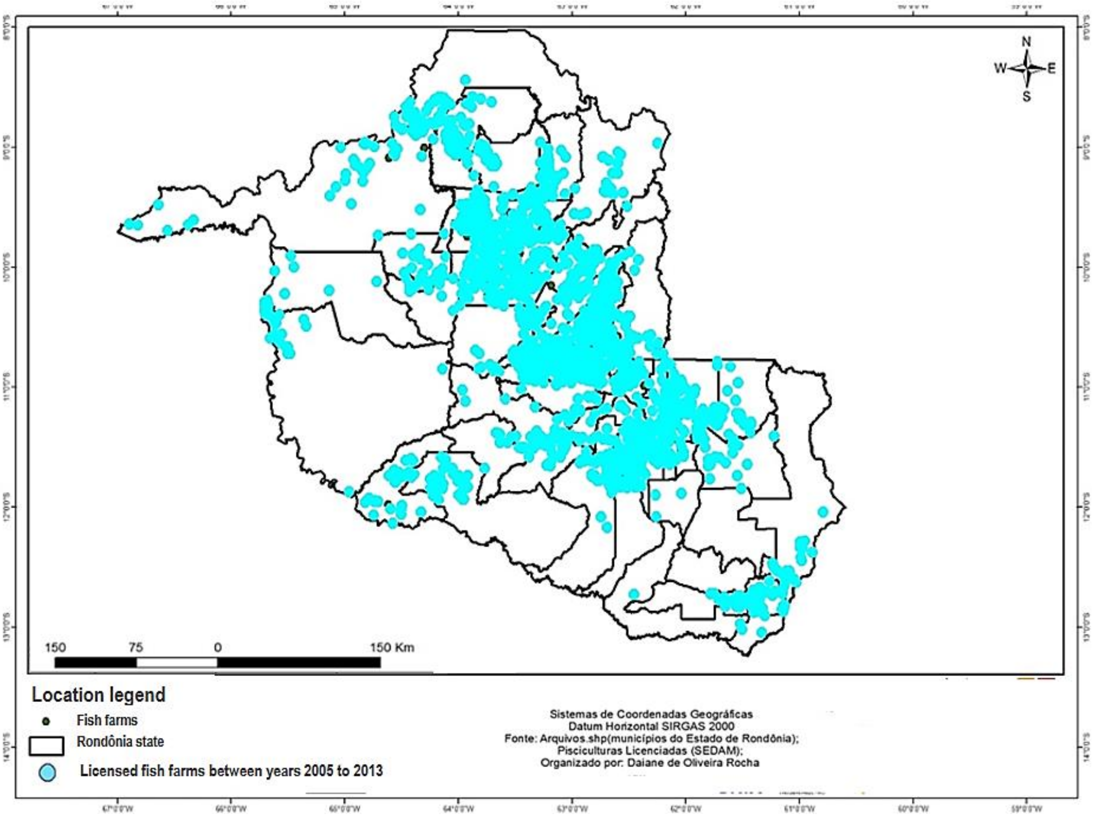

Figure 7. Second phase of fish farming development in Rondônia state.

Some factors that contribute to growth of fish farming can linked to development of the commercial sector, which in turn, was due to expansion of public policies that facilitated access to existing government programs, such as the "Mais Pesca e Aquicultura", powered by Ministério da Pesca e Aquicultura instinct, the "Programa Água Produtiva" created in year 2011 by Rondônia state government through Secretaria de Estado do Desenvolvimento (SEDES/RO) and carried out in collaboration with the Associação de Assistência Técnica e Extensão Rural do Estado de Rondônia (EMATER/RO) through its more than 60 units distributed throughout the Rondônia state under the intervention of Secretaria de Estado da Agricultura, Pecuária e Regularização Fundiária (SEAGRI/RO), the program also has a partnership with Secretaria de Estado do Desenvolvimento Ambiental (SEDAM/RO).

The Project "Mais Pesca e Aquicultura" was launched in year 2011 in which municipalities receive machinery to build excavated tanks for farming fish on rural properties, actions that serve as a stimulus for the activity as an important source of income and job creation, contributing to the incorporation of areas for fish farming, benefiting rural producers with hours/machine at effectively low costs when compared to current standards.

A spatial analysis of the density of fish farms in the study area was performed (Figure 8). For this, the Kernel estimator was applied and revealed the density spectrum of the spatial distribution of fish farms and composed a surface whose value is proportional to intensity of fish farms per unit of area. The map revealed that the fish farms are located in different areas, but they are well adjoined and accommodate close to highway BR 364, as previously reported. It was also observed that the highest density of fish farming was 4937.64 fish farms per unit of area and that they are concentrated in the Central region of the Rondônia state, in Ji-Paraná microrregion, characterizing it as having the highest number of licensed fish farms in Rondônia state, which certainly competes as the one with the greatest supply of fish.

According to Mendonça et al. (2020), when applying geoprocessing tools for the environmental diagnosis of microbasins, integrated with field observations, as carried out in this study, it was possible to gather numerous information regarding the advance of use and occupation developed in these areas, historically characterizing the anthropization process and the different types of impacts generated. Field observation made it possible to identify the impact generated by industrial effluents in microbasins, in addition to the lack of urban infrastructure in Ji-Paraná microregion, which is extremely harmful to water resources. The *in loco* observation of this information, together with the spatial and temporal analyses, allowed the elaboration of a complete diagnosis regarding the environmental situation of the Igarapé microbasin. This study allowed us to identify that the micro basin is largely anthropized and with a high environmental degradation process. Thus, the implementation of instruments that improve the management of the resource is extremely necessary, and the framework of this stream is recommended.

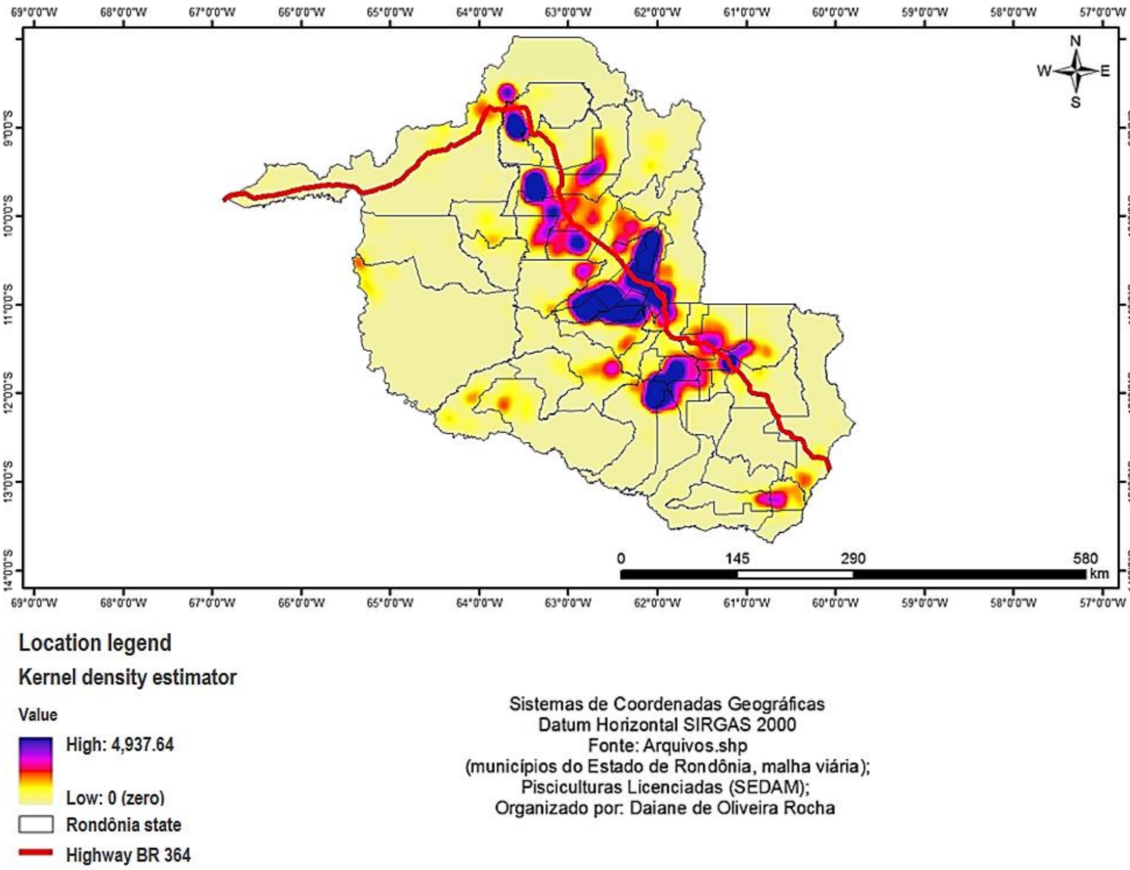

Figure 8. Kernel density estimator map for Rondônia state.

Conclusion

The establishment of a GIS for fish farming in Rondônia state facilitated data organization and insight generation for the aquaculture sector. This GIS enabled effective information management, revealing spatial distribution and density of fish farms. The resultant database supported diverse spatial analyses, offering valuable insights into the sector. The GIS serves as a rich, expandable resource for additional analyses beyond this study, aiding governmental and private decision-making processes.

Acknowledgements

To the Secretaria do Estado de Rondônia para Desenvolvimento Ambiental (SEDAM/RO), especially to the Physical Environment Coordination, Fisheries Resources Division, for the reception and provision of the collected data. We also thanks CNPq/FAPERO for granting a postdoctoral scholarship to Jerônimo Vieira Dantas Filho [167879/2022-7].

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