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GEOGRAPHIC-ECONOMIC COMPLEXITY OF THE MESOFUNCTIONAL FISH FARMING PRODUCTION CLUSTER IN THE LOWER-MIDDLE SÃO FRANCISCO RIVER (PE/BA/AL)

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Abstract

This article aims to analyze the productive clustering of tilapia in the Lower-Middle São Francisco River (PE/BA/AL), based on the category of analysis of geographic-economic complexity (DIAS, 2024), grounded mainly in the critical social theory and political economy of territory of Milton Santos. The methodology combines bibliographic review, secondary data and field work. The results indicate that it is a mesofunctional agglomeration, with intermediate geographic-economic complexity, marked by the activity of community associations of fish farmers. Such associations innovate in productive organization and income generation, even in the face of technical, environmental and social limitations. Meatpacking plants and medium-sized companies also form part of the spatial production circuit, although to a lesser extent. The agglomeration reveals a particular territorial dynamic, in which community experiences coexist with structural challenges, evidencing a complexity in consolidation in the context of Brazilian and Northeastern tilapia farming.

Keywords: Tilapia farming; Horizontalities; Spatial Production Circuits.

Resumo / Resumen

COMPLEXIDADE GEOGRÁFICO-ECONÔMICA DA AGLOMERAÇÃO PRODUTIVA MESOFUNCIONAL DE PISCICULTURA NO SUBMÉDIO DO SÃO FRANCISCO (PE/BA/AL)

Este artigo tem como objetivo analisar a aglomeração produtiva de tilápias no Submédio do rio São Francisco (PE/BA/AL), a partir da categoria de análise complexidade geográfico-econômica (DIAS, 2024), embasada principalmente pela teoria social crítica e economia política do território de Milton Santos. A metodologia combina revisão bibliográfica, dados secundários e trabalho de campo. Os resultados indicam que se trata de uma aglomeração mesofuncional, com complexidade geográfico-econômica intermediária, marcada pela atuação de associações comunitárias de piscicultores. Tais associações inovam na organização produtiva e na geração de renda, mesmo diante de limitações técnicas, ambientais e sociais. Frigoríficos e empresas de médio porte também integram o circuito espacial produtivo, embora com menor abrangência. A aglomeração revela uma dinâmica territorial particular, em que experiências comunitárias convivem com desafios estruturais, evidenciando uma complexidade em consolidação no contexto da tilapicultura brasileira e nordestina.

Palavras-chave: Tilapicultura; Horizontalidades; Circuitos Espaciais de Produção.

COMPLEJIDAD GEOGRÁFICO-ECONÓMICA DEL CLÚSTER DE PRODUCCIÓN DE ACUICULTURA MESOFUNCIONAL EN EL CURSO MEDIO-BAJO DEL RÍO SÃO FRANCISCO (PE/BA/AL)

Este artículo tiene como objetivo analizar la agrupación productiva de la tilapia en el Bajo-Medio Río São Francisco (PE/BA/AL), basándose en la categoría de análisis de la complejidad geográfico-económica (DIAS, 2024), fundamentada principalmente en la teoría social crítica y la economía política del territorio de Milton Santos. La metodología combina revisión bibliográfica, datos secundarios y trabajo de campo. Los resultados indican que se trata de una aglomeración mesofuncional, de complejidad geográfico-económica intermedia, marcada por la actividad de asociaciones comunitarias de piscicultores. Estas asociaciones innovan en la organización productiva y la generación de ingresos, incluso frente a limitaciones técnicas, ambientales y sociales. Las plantas frigoríficas y las medianas empresas también forman parte del circuito de producción espacial, aunque en menor medida. La aglomeración revela una dinámica territorial particular, en la que vivencias comunitarias coexisten con desafíos estructurales, evidenciando una complejidad en la consolidación en el contexto del cultivo de tilapia brasileño y nordestino.

Palabras-clave: Tilapicultura; Horizontalidades; Circuitos Espaciais de Produção.

INTRODUCTION

Tilapia farming is a specialized branch of fish farming and has established itself as one of the most significant aquaculture activities in Brazil, driven by its adaptability to diverse environmental conditions, easy management, and growing market demand. By articulating multiple territorial scales and involving different types of actors, tilapia farming takes on a leading role in the process of use and appropriation of Brazilian territory (SILVEIRA, 2008), structuring local socioeconomic dynamics in certain regions. This scenario demands an analytical approach capable of capturing the complexity of the forms of productive organization, the technical modalities, and the territorial interactions mobilized by the sector.

In this context, this paper aims to analyze the mesofunctional tilapia production cluster located in the Lower-Middle São Francisco River region, encompassing cities in the states of Pernambuco, Bahia, and Alagoas. The analysis is based on the theoretical-methodological analytical category of geographic-economic complexity, which allows us to understand the territorial arrangements resulting from the interaction between technical, informational and normative densities, as well as the articulation between the spatial circuits of production, their circles of cooperation and circuits of the urban economy, in the terms proposed by Santos (1988; 2006; 2008) and Dias (2024).

The Lower-Middle São Francisco region was chosen due to its significant tilapia production in net-pens, its organizational and institutional diversity, and for having community associations that stand out as horizontal structures (SANTOS, 2006), both for their production volume and for the social and technical innovations they lead. This is one of the main tilapia farming clusters in the country, whose mesofunctional setting is characterized by complex interactions between actors in the lower circuit and the marginal upper circuit of the urban economy. The mesofunctional productive cluster of the Lower-Middle São Francisco developed around the reservoirs of the Paulo Afonso (Moxotó) (BA/AL) and Luiz Gonzaga (Itaparica) (BA/PE) hydroelectric plants, as Figure 1 shows.

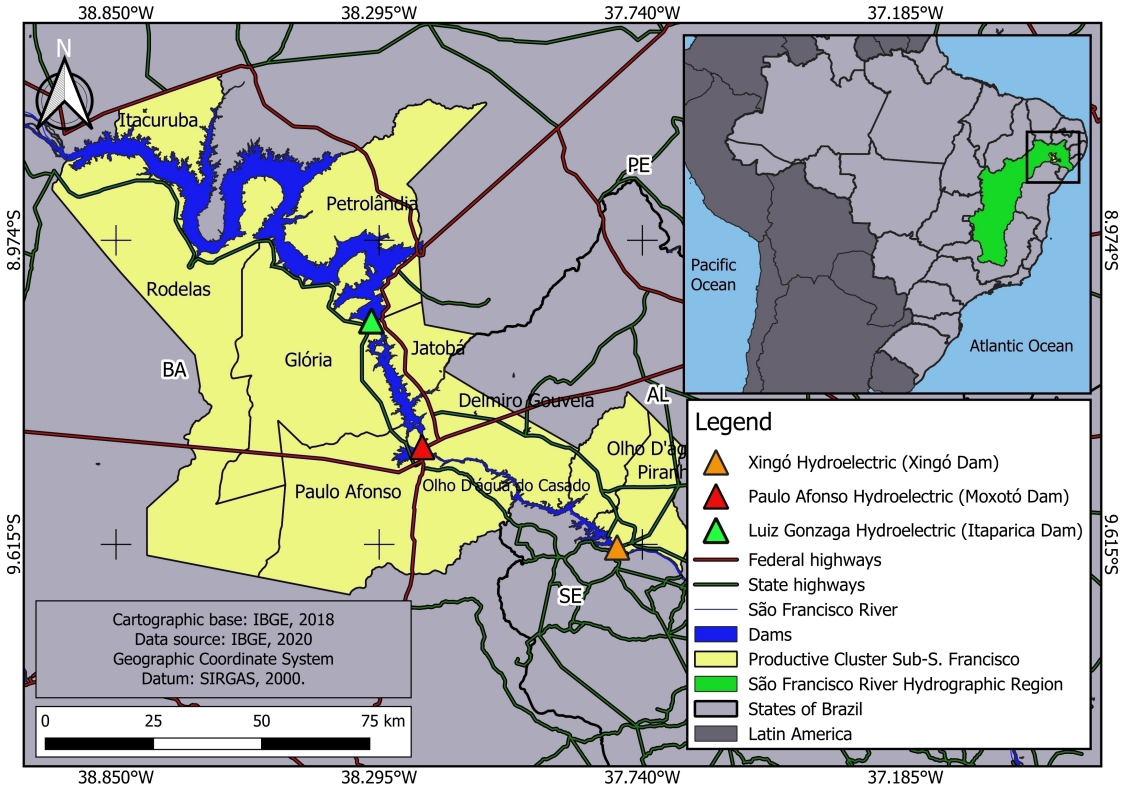

Figure 1 - Location map and road network of the productive agglomeration of the Lower-Middle São Francisco River (BA/AL/PE). Source: Prepared by the authors (2025).

The paper is structured in three main sections, in addition to this introduction and the final considerations. The first section presents the methodology used to classify tilapia production clusters based on their geographic and economic complexity. The second section discusses the characteristics of the mesofunctional agglomeration of the Lower-Middle São Francisco River, highlighting its territorial structure, productive dynamics, diversity of actors, and institutional articulations. Finally, the third section focuses on the horizontal structures that shape this agglomeration, paying special attention to community associations of fish farmers, their organizational strategies, challenges, and social contributions. This analysis aims to contribute to the geographical debate on land use, productive specialization, and regional development through a critical reading of Brazilian fish farming.

METHODOLOGY FOR CLASSIFYING PRODUCTIVE CLUSTERS BASED ON GEOGRAPHICAL-ECONOMIC COMPLEXITY

The analysis and classification of tilapia production clusters are based on the analytical category of geographic-economic complexity (DIAS, 2024). As a science focused on the study of space, Geography faces the epistemological challenge of understanding and explaining the complexity inherent in its object of study. Geographic space is, by definition, a complex system formed by the dynamic interaction between human actions and technical objects. In this context, complexity expresses both the processuality of reality and knowledge, as well as the spatial construction resulting from multiple interrelationships between phenomena (GOMES; VITTE, 2014).

According to Hartshorne (1978, p. 172), Geography needs to face this challenge: “Geography cannot abandon its goal, which is to understand, in the best possible way, the complex of phenomena that exist interrelated in situ.”

This theoretical-methodological proposal aims to assess geographic-economic complexity through the technical, informational, and normative densities present in the objects and actions of a given territorial area during a specific period, through the dynamism of flows, diversity, and relationships generated by the actors in the spatial circuit of production and cooperation circles, through horizontalities and verticalities, and through the types of proximities present in the analyzed area. Thus, the greater the diversity of actors involved in these circuits, the greater the complexity of the productive cluster. Conversely, less diversity indicates less complexity.

Productive clusters can be considered as horizontalities (SANTOS, 2006, p. 192), which are “extensions formed of points that aggregate without discontinuity, as in the traditional definition of region [...]”. However, these extensions are simultaneously traversed by centrifugal forces, which occur on various scales, concomitantly promoting processes of verticalization “[...] points in space that, separated from each other, ensure the overall functioning of society and the economy” (SANTOS, 2006, p. 192). In other words, these are relationships that link productive clusters to distant locations and to the global aquaculture system.

The way actors integrate into the circuits of the urban economy (SANTOS, 2008) contributes to understanding the division of labor and the interdependence among actors engaged in more or less modern activities. Knowledge networks (VALE, 2012) present in clusters are also considered, manifesting through organizational and technical information, norms, opportunities, and other immaterial flows inherent to the dynamics of tilapia farming (DIAS, 2024).

In the current period of globalization, the world is structured as a mosaic of increasingly specialized subspaces, generating material and immaterial flows with different densities and directions. These flows make up what are called spatial production circuits, which Santos (1988, p. 17) defines as “the various stages through which a product would pass, from the beginning of the production process until it reaches final consumption”. As for cooperation circles, “[...] they create hierarchies, specializations, flows. Their overlaps delineate the territorial division of labor. It is within it that the processes of geographical transfer of value take place” (MORAIS, 2017, p. 43). They bring together actors and actions — of an immaterial nature — that contribute to the intensification and constancy of fluidity between the stages of the spatial circuit of production (CASTILLO; FREDERICO, 2017).

Regarding the circuits of the urban economy, Santos (2008) defines the upper circuit as that composed of modern activities, intensive in capital and technology, with access to credit and complex services, aimed at higher-income consumers. The lower circuit, in turn, encompasses labor-intensive activities with low access to credit and technology, aimed at low-income consumers, including its own participants. According to Milton Santos, these circuits are interdependent and form complementary subsystems within the urban economy.

This theoretical and conceptual intertwining is necessary because stages of spatial production circuits and cooperation circles are increasingly taking place or unfolding within urban dynamics. This is due to the expansion of the technical-scientific-informational environment, especially after the 1970s, which broadened the concept of urban space beyond city limits, transforming dynamics that were previously typically rural (DIAS, 2024, p. 74).

This paper presents the methodology for comparing and classifying tilapia production clusters. Three main parameters are used: productive capacity (production volume/productivity); diversity of actors that make up the spatial circuit of production and the circles of cooperation; and belonging to a specific circuit of the urban economy, that is, to the upper, upper marginal, or lower circuit (SANTOS, 1988; 2008).

The geographic-economic complexity of each productive cluster is determined based on the intensity levels of these three variables—higher or lower. The levels are: low, medium, or high complexity. The classification is based on three types: low-level clusters, called Monofunctional Productive Clusters; medium-level clusters, called Mesofunctional Productive Clusters; and high-level clusters, called Multifunctional Productive Clusters. Figure 2 below simplifies this methodology and the resulting typologies.

Productivity		Diversity of actors C.E.P** C.C*		Belonging to the Circuits of the Urban Economy		Level of Geographic-Economic Complexity	Type of Productive Cluster
High	+	High	+	Upper/Lower	=	High	Multifunctional
High	+	High	+	Upper Margin/ Lower	=	Average	Mesofunctional
Average	+	High	+	Upper/Lower	=	Average	Mesofunctional
Baixa	+	High	+	Upper/Lower	=	Average	Mesofunctional
High	+	Low	+	Lower	=	Low	Monofunctional
Average	+	Low	+	Lower	=	Low	Monofunctional
Low	+	Low	+	Lower	=	Low	Monofunctional

Figure 2 – Methodology for identifying the typologies of productive clusters. Source: Dias (2024).

To measure the productive capacity variable, we relied on the average annual production per fish farm in the cluster in thousands of tons, provided by entities such as Embrapa Fisheries and Aquaculture (2023). When we talk about high productivity, we refer to productive clusters with averages above 100 tons per establishment, average productivity from 50 to 100 tons, and low productivity from 0 to 50 tons.

In the case of the variable "diversity of actors in the spatial circuit of production and cooperation circles," the Embrapa database, extracted from the Aquaculture SITE (Strategic Territorial Intelligence System), was also used. This database provides information on the number of actors, including: fish farms, associations, Embrapa units, processing plants, environmental agencies, feed mills, educational institutions, consulting firms, aquaculture equipment and health companies, and fattening producers. Therefore, by defining the clusters, it is possible to compare the degree of diversity among these actors.

In the case of the third variable, the qualitative approach is more effectively incorporated into the methodology. Through fieldwork combined with direct observation techniques, and semi-structured interviews, we verified how the aforementioned actors behave in relation to the circuits of the urban

economy—upper, upper-marginal, and lower. This qualitative and quantitative operationalization provides the conditions for the classification shown in Figure 2, enabling analyses of the geographic and economic complexity of a specific agglomeration and/or comparisons between them.

To briefly exemplify and compare, the productive cluster in Western Paraná, for example, has high productivity, a high diversity of actors, and a predominance of upper-circuit membership, and is classified as highly complex and multifunctional in typology. The one in Northern Paraná has average productivity, a high diversity of actors with a balanced distribution across the circuits of the urban economy; therefore, it is of medium complexity and mesofunctional. In contrast, the productive cluster around the Boa Esperança Reservoir in Piauí has high productivity, low diversity of actors, and a predominance in the lower circuit, suggesting low complexity or monofunctionality. This comparison and classification are based on data published in 2023 by Embrapa, referring to 2021 and operationalized by the methodology in 2024 (DIAS, 2024).

In this sense, the productive cluster analyzed in this paper was classified as mesofunctional, therefore possessing a medium level of geographic-economic complexity. This characterizes it as intermediate, between monofunctional and multifunctional clusters. This characterization stems from a relative balance between the factors that internally structure these productive clusters. In this type of cluster, the diversity of actors in the spatial circuits of production and in the circles of cooperation is moderate, with a relatively balanced distribution among the upper, upper-marginal, and lower circuits of the urban economy. Thus, their territorial dynamics tend towards a certain balance between horizontal and vertical processes (SANTOS, 2006; DIAS, 2024). They are generally composed of a considerable number of fattening producers and, even if in smaller numbers, by specific actors linked to other stages of the spatial production circuit and cooperation circles. Although the presence and moderate diversity of these actors vary from one mesofunctional cluster to another, there is a greater degree of dynamism compared to monofunctional clusters.

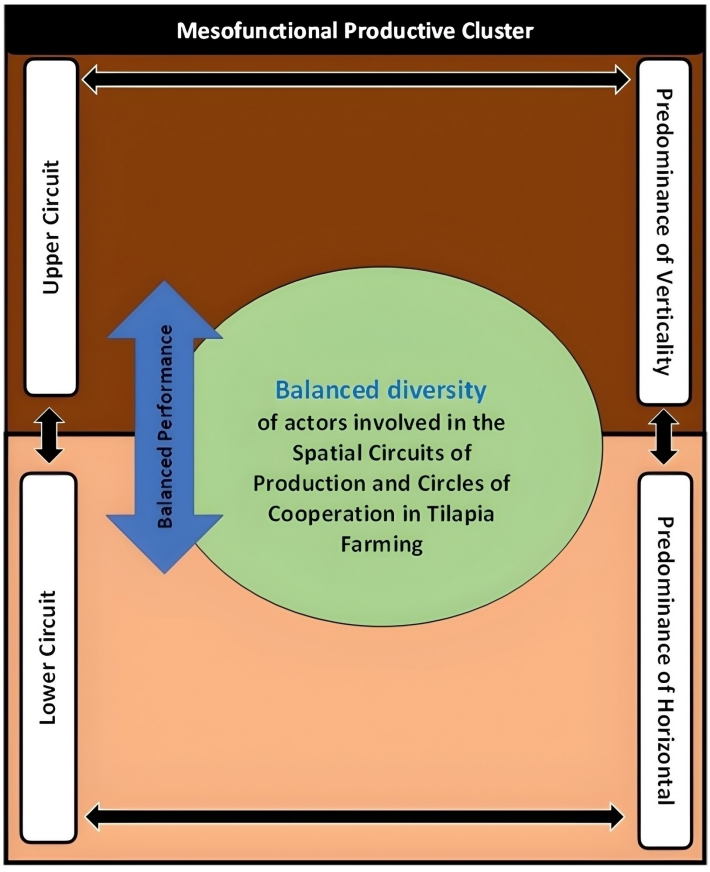

Figure 3 – Infographic of the level of diversity and performance of the actors involved in the configuration of Mesofunctional Productive Clusters. Source: Dias (2024).

As with monofunctional departments, geographical proximity is very relevant. But in this case, there are other proximities present, such as institutional and organizational ones (PECQUEUER AND ZIMMERMANN, 2005). These proximities ultimately increase the spread of knowledge networks, whether local, national, or global, which, in turn, creates an innovative environment capable of driving innovation in products and processes (VALE, 2012). Figure 3 shows a schematic illustration of the internal organization of this type of cluster.

This intermediate dynamism is also reflected in higher technical and informational densities in production than in monofunctional clusters. Similarly, the capacity for organization and political articulation is also intermediate, situated between the levels observed in multifunctional and monofunctional agglomerations, both in the context of Brazilian tilapia farming and in the global aquaculture system.

MESOFUNCTIONAL AGGLOMERATION OF THE LOWER-MIDDLE SÃO FRANCISCO RIVER (PE/BA/AL)

The productive cluster of the lower-middle São Francisco River is composed of nine cities in the states of Bahia, Pernambuco, and Alagoas, has a total population of 239,449 inhabitants, an average GDP per capita of R$18,966, and an average HDI of 0.624, according to data from the IBGE Demographic Census (2022). Despite these average values, the region reveals some heterogeneity among the cities. Glória (BA), Itacuruba (PE), Olho D'Água do Casado (AL), and Piranhas (AL) have HDI scores between 0.500 and 0.599, classified as low. In contrast, Petrolândia (PE) has an HDI higher than 0.700, considered high, highlighting internal inequalities. These disparities are also evident in GDP per capita, which ranges from R$9,000 to R$45,000 across towns and cities in the agglomeration.

The water from the Itaparica and Moxotó reservoirs began to be used for fish farming from the 1990s onwards, initially by medium- and large-scale producers from cities such as Maceió and Recife. These producers, already engaged in activities such as sugarcane farming, had capital and sought to diversify their investments by leveraging the region's water potential (DIAS, 2024).

However, it was from 2000 onwards that the activity grew significantly, driven mainly by small- and medium-sized local producers. Tilapia farming using the net-cage technique has proven to be a viable alternative amid the socioeconomic challenges of the semi-arid Northeast (BARROSO et al., 2018). According to the IBGE Agricultural Census (2017), this productive cluster has 160 establishments dedicated to tilapia production. But what makes this a mesofunctional cluster? Firstly, it is a cluster with outstanding productivity, ranking 3rd in the country in productivity, behind only the Western Paraná cluster (1st) and Ilha Solteira (2nd). In 2021, it totaled 30,600 tons of tilapia, with an average productivity of 191.5 tons per establishment (IBGE, 2017; PEIXE BR, 2022).

Another factor that gives the Sub-Middle São Francisco agglomeration a mesofunctional character is the high diversity of actors present in the stages of spatial production circuits and cooperation circles (CASTILLO; FREDERICO, 2017). Regarding the actors' belonging to the circuits of the urban economy, the more intense presence of actors linked to the upper marginal and lower circuits stands out. In 2019, 20 specific actors were directly involved in tilapia farming in the Sub-Middle São Francisco (IBGE, 2017). Next, in Figure 4, we can see the spatial distribution of these specific actors in the productive cluster. A higher concentration is observed in Paulo Afonso (BA) and Jatobá (PE).

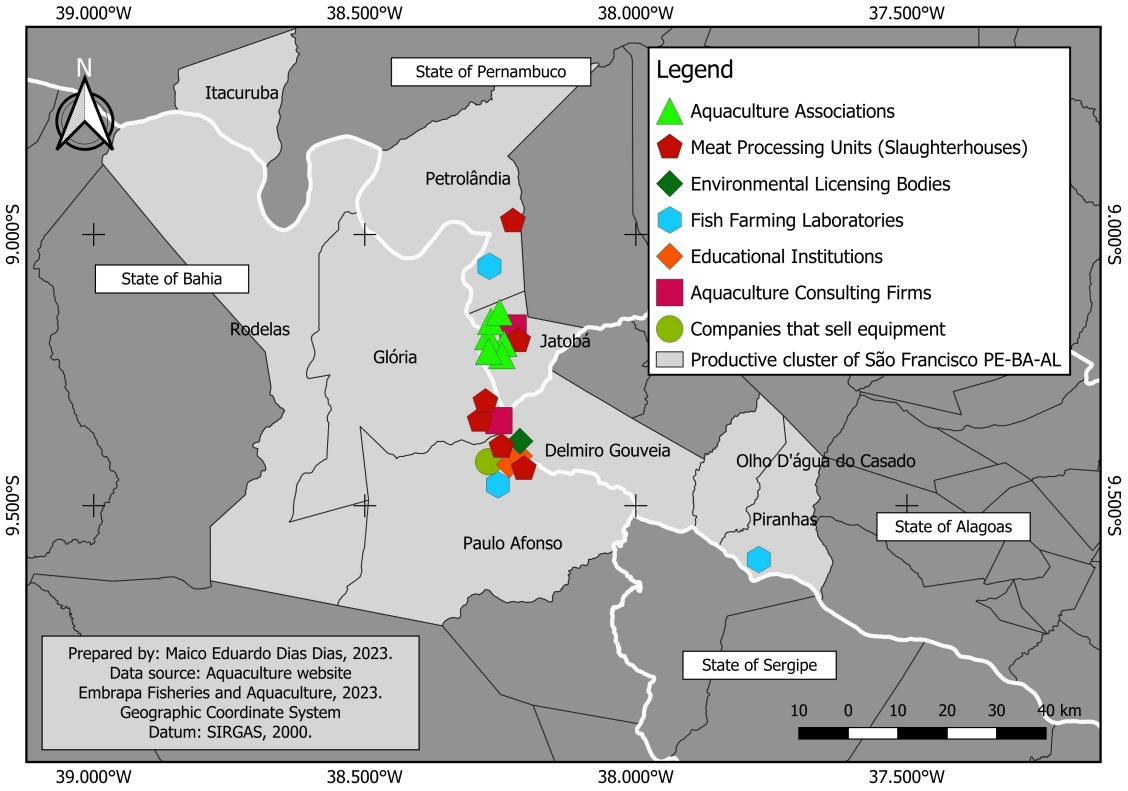

Figure 4 - Map of specific actors involved in the spatial circuit of production and cooperation, in 2019.
Source: Embrapa Fisheries and Aquaculture, 2023. Prepared by the authors (2025).

Figure 5 shows the arrangement of relationships and processes of these actors, distributed within a framework of predominance of horizontal and vertical connections, upper and lower circuits.

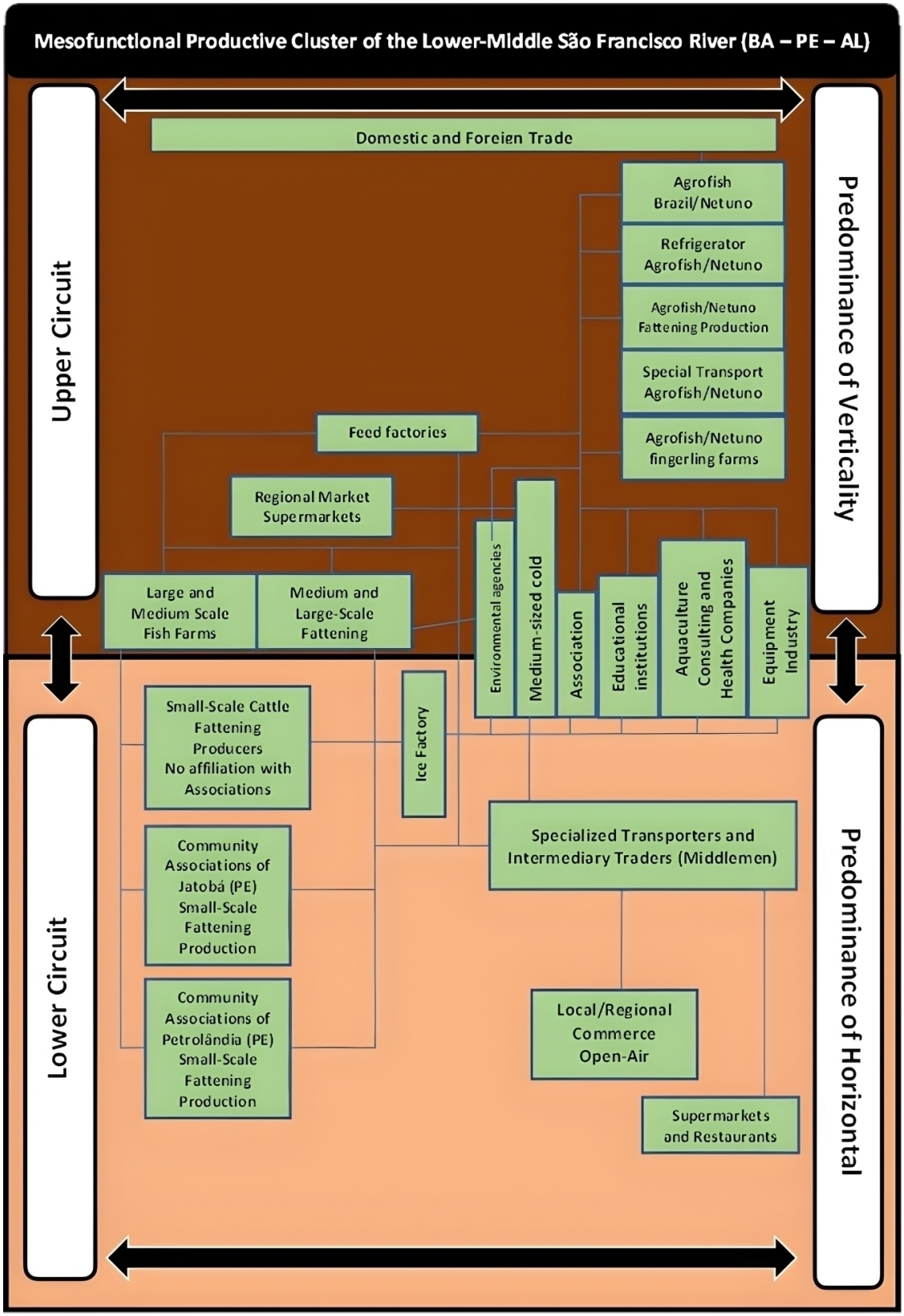

Figure 5 - Situation of the actors in the mesofunctional productive cluster of the Lower-Middle São Francisco River (BA/PE/AL). Source: Prepared by the authors (2025).

In particular, community-based fish farming associations predominate, representing 30% of the specific actors. As will be detailed later, their organization and mode of operation characterize them as small-scale producers. Aspects such as intensive labor use rather than capital, technical expertise in production, marketing strategies, and limited access to credit place them in the lower circuit of the urban economy (DIAS, 2024; SANTOS, 2008).

Regarding the other actors present in the Lower-Middle São Francisco agglomeration, we have the following distribution: fish farms account for 15% of the total, educational institutions 10%, consulting firms 10%, equipment companies 5%, environmental agencies 5% as well, and meat processing plants 25%.

The Lower-Middle São Francisco region has a considerable number of fish processing plants. However, these establishments focus on serving large producers, with whom they maintain closer relationships, since most of the fish they receive and process come from this group.

It is important to clarify that the classification of size, such as small, medium, or large producer, must be understood within the specific context of the agglomeration analyzed. In the Lower-Middle São Francisco region, the so-called large producers, or meat processing plants, are considered larger than other local actors. However, when compared to actors in multifunctional clusters, such as the agro-industries of Western Paraná, C. Vale, and Copacol, their size is relatively smaller. Regardless of the cluster to which they belong, the similarities between these actors are more related to the qualitative nature of their multi-scalar relationships with the fish farming production circuit at regional, national, and global levels. In general, large actors establish vertical relationships (SANTOS, 2006), generating and reproducing economic and territorial hierarchies.

Another aspect to highlight is the actors' relationship with the circuits of the urban economy, as observed through their participation in the construction of horizontalities (SANTOS, 2006, 2008). These horizontalities, in turn, configure productive agglomerations, even defining their expression as a territorial division. We consider that the situation of these actors (the meatpacking plants), the internal structure of these establishments, and their actions place them in the upper marginal circuit of the urban economy in the agglomeration under analysis.

As we can see, the mesofunctionality of this productive agglomeration expresses the dynamism of a large number of actors, involving both vertical and horizontal processes (SANTOS, 2006). However, we will focus on a particular horizontal aspect of the agglomeration, belonging to the lower circuit of the urban economy: community tilapia-farming associations.

HORIZONTALITIES: THE STRENGTH OF COMMUNITY TILAPIA FARMING ASSOCIATIONS

Considering that the Lower-Middle São Francisco River is located in the semi-arid Northeast of Brazil, an area with the greatest water deficit in the country, relating it to one of the largest productive fish farming clusters in Brazil seems, at first glance, to be somewhat paradoxical. However, the perennial nature of the São Francisco River, fed by rainfall in the upper and middle parts of the basin (Minas Gerais and part of Bahia), transforms this region into a true oasis in the Sertão. This context combined with the spread of technical, scientific, and informational resources, especially the construction of large hydroelectric dams has favored the use of reservoir water for fish farming.

The agglomeration's consolidation occurred through institutional actions. According to Tenório et al. (2021), intensive production in floating structures began in 1995, with experiments conducted by CHESF (Companhia Hidroelétrica do São Francisco) in the Delmiro Gouveia reservoir. Starting in 1997, the activity was boosted in the Xingó reservoir (municipality of Paulo Afonso/BA) through actions by the state and municipal governments, via Bahia Pesca S.A., expanding to the Moxotó (AL, BA, PE) and Itaparica (BA, PE) reservoirs. In 2019, regional tilapia farming production in the Sub-Middle reservoirs combined with the Lower São Francisco reached 50,065 tons/year.

Initially, these policies attracted large companies. One example is the project by the Municipality of Paulo Afonso and the Bahia state government in the late 1990s, which encouraged the arrival of the MPE group, associated with the North American company Arraina Inc., creating Advanced Aquaculture

Technology (AAT), specialized in tilapia farming in raceway systems (BALOGH, 2005). This system consists of a series of high-flow water tanks, allowing for 1 to 20 water changes per hour. The tanks are rectangular concrete tanks arranged in sequence at different levels, with a total volume of 34.64 m3. Water is drawn from the Moxotó reservoir to supply the raceways, using gravity and a vacuum pump to draw water to the raceways (BALOGH, 2005).

Another important case is the arrival of Netuno (now Agrofish/Netuno) in the 2000s. The company controls several stages of the spatial production circuit in Paulo Afonso/BA: fingerling farms, fattening net-pens, processing unit, fishmeal and fish oil factory, and its own transport (SANTOS, 2006; DIAS, 2024). Despite this, the basis of the productive dynamics lies in community associations, representatives of the lower circuit of the urban economy. As the map in Figure 6 shows, the largest production volumes in 2022 are concentrated in Jatobá and Petrolândia (PE), precisely where these associations are more present.

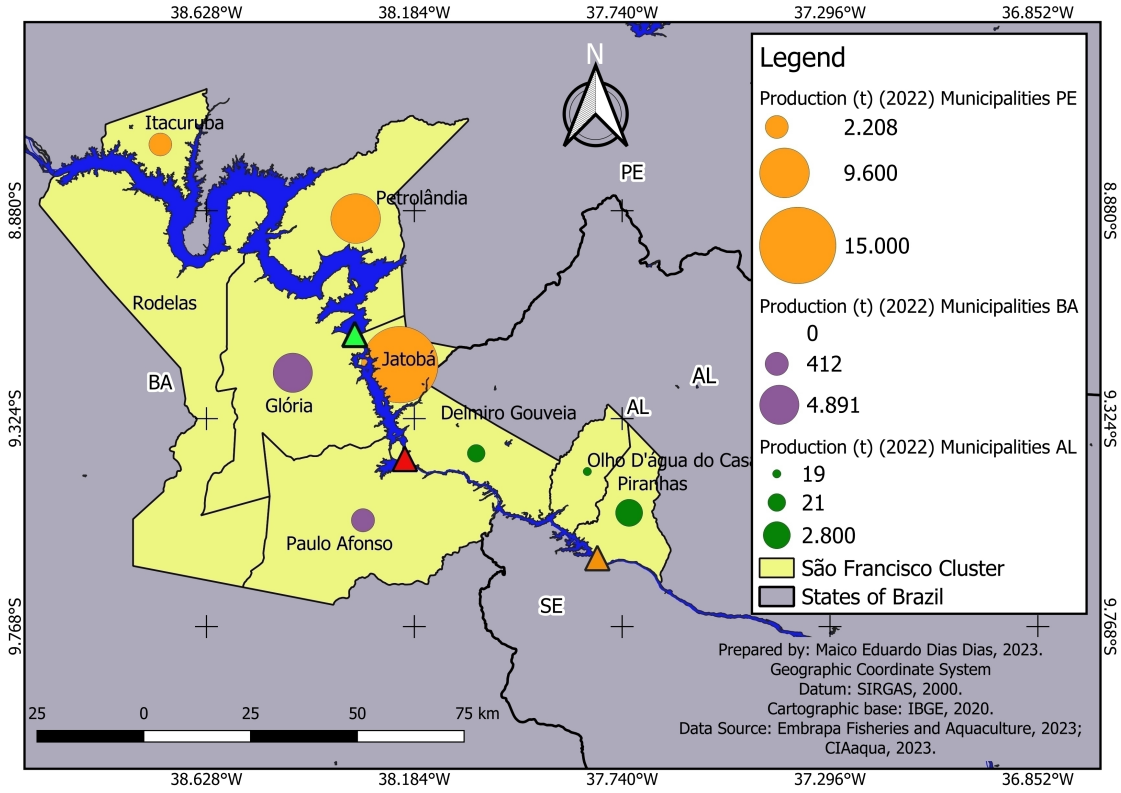

Figure 6 - Map of tilapia production (in tons) in the productive cluster of the Lower-Middle São Francisco (BA/AL/PE), 2022, by municipality. Source: Embrapa Fisheries and Aquaculture, 2023. Prepared by the authors (2025).

The community associations in the agglomeration were conceived and founded by Father Antônio Miglio, from the Diocese of Floresta (PE), with the support of Ivone Lisboa, an advisor hired by the Diocese. Both have led, from the beginning, the extension activities that gave rise to these organizations (DIAS, 2024). In 2002, faced with poverty and lack of opportunities in the Pernambuco hinterland, Father Antônio identified fish farming as an alternative for social emancipation. With resources from the Diocese itself, the first net-cage projects were implemented in Jatobá (PE), and later in Petrolândia and Itacuruba (DIAS, 2024).

The associations are organized according to their own methodologies and focus on the tilapia fattening phase in net cages. Each association is composed of 12 members, including the Diocese, which participates in the distribution of profits—called “surplus” by the members—at the end of each production cycle (approximately six months). Initially, this share covered the Diocese’s investments; currently, it is reinvested in creating new associations and maintainning technical services, such as that

of the responsible fisheries engineer. The organizational relationships between clusters are characterized by geographical proximity with a clear dissemination of buzz, local knowledge networks (VALE, 2012; PECQUEUER AND ZIMMERMANN, 2005).

Each project has 65 net cages with a capacity of 14 m³, with an average monthly production capacity of 15 tons of tilapia. Sales guarantee members a monthly income between two and four minimum wages. The organizational model involves men and women and has been adjusted over time in response to difficulties encountered, leading to more detailed internal regulations. Figure 7 below shows the net cages of the Boa Esperança Association of Fish Farmers of MARI.

Figure 7 - Fish farming cages of the Boa Esperança Association of Fish Farmers of MARI, São Francisco River, Jatobá/PE. Source: Fieldwork (2023).

Located in Jatobá/PE, it was created in 2006 and integrates the dynamics of community associations in the productive agglomeration of the Lower-Middle São Francisco River. In 2023, the structure had 35 net cages in use, out of a total of 65 authorized in its project. In this context, only six members were directly involved in the activities: four women and two men. The MARI association's production focus exclusively on tilapia farming, with an average stocking density of 2,000 fish per net cage, equating to approximately 150 fish per cubic meter. A unique aspect of this production is the feeding method, considered unusual in the context of Brazilian fish farming. Feeding is done manually, at 20-minute intervals, by workers from the association itself. This practice was conceived and continues to be guided by Father Antônio Miglio, who closely monitors the activities of the associations.

Much of the maintenance of the fish farming cages in these associations is carried out by the members themselves. Cage maintenance is primarily necessary for two reasons. The first is the presence of the golden mussel (Limnoperna fortunei), which attaches to nets and obstructs water flow, requiring periodic cleaning. The second is related to the intense proliferation of the water hyacinth (Eichhornia crassipes), which, in addition to hindering water circulation in the cages, can, on windy days, displace the equipment from its fixing points, causing structural damage and requiring repairs. These problems result in losses and require diverting the already limited workforce from fish management to maintenance tasks.

The problem of water hyacinth presence affects the entire productive cluster, and it is more intense in the Moxotó reservoir, especially along the banks in Jatobá/PE and Glória/BA (TENÓRIO et al., 2021). The infestation causes significant damage to the cluster, leading many fish farming units to suspend their activities or cease operations. Figure 8 illustrates the large concentration of water hyacinths on the banks of the São Francisco River in the access area to the MARI association's fish farm.

Figure 8 - Proliferation of water hyacinths (Eichornia crassipes), Boa Esperança Association of Fish Farmers of MARI, São Francisco River, Jatobá/PE. Source: Fieldwork (2023).

The challenges faced by community associations go beyond technical and environmental issues, such as the presence of water hyacinths and golden mussels. They include sociocultural obstacles, as the region is strongly marked by social inequality and ingrained patterns of sexism and misogyny. In this context, women who join these associations often face prejudice and discrimination, motivated solely by occupying spaces traditionally reserved for men.

Furthermore, there is resistance from segments of the local elite towards the emergence of these community initiatives. This is mainly because the associations began offering more decent work alternatives for women who were previously restricted to domestic services with precarious pay. As a consequence, there was a reduction in the supply of labor for this type of service, leading to an increase in daily wages paid to the workers who remained in this activity (DIAS, 2024).

This scenario highlights that community associations have been promoting significant transformations in Jatobá's socioeconomic dynamics, contributing to women's empowerment and the creation of concrete livelihood alternatives in a region historically marked by exclusion.

Despite the progress made by community associations, significant challenges remain, especially regarding infrastructure and work equipment. Members still use wooden boats propelled by oars, and the walkways connecting the fish farm cages are also constructed of wood. These elements, fundamental to daily operation, suffer accelerated wear and tear due to intensive use, constant exposure to strong winds, and the accumulation of water hyacinths. Like the cages themselves, these structures require frequent maintenance.

The structural precariousness is not limited to the instruments directly involved in production. The set of floating platforms that connects the walkways to the fish-farming tanks also includes a covered area used as a shelter. This space allows members to remain on site overnight, according to a prearranged work schedule. The nighttime presence serves a strategic function: ensuring continuous surveillance of the structure, preventing incidents, and minimizing losses.

All members of the Association share the responsibility for the production, and profits from fish sales are distributed equally. To ensure smooth collective operation, weekly planning meetings are held to discuss work techniques, improvement strategies, and daily demands, to enhance the performance of productive activities.

This collective organization has made relevant incremental innovations. One example is the adaptation of a barge equipped with a collector and ratchet to remove water hyacinths near the tanks. Another advance was the acquisition of four-wheeled carts to transport feed bags from the storage area to the boats on the riverbank, thereby facilitating internal logistics.

The exchange of knowledge and the collective effort to identify needs, difficulties, and solutions go beyond the limits of a single association. When new practices are developed and prove effective, they are shared and adopted by other associations, forming what can be understood as local buzz (VALE, 2012)—the informal diffusion of knowledge and innovation among nearby units.

In another association, called the New Alliance of Fish Farmers, it was possible to observe its spatial organization and the specific aspects of its operation. Created in 2007, the association remains active and shares several characteristics with other community organizations in Jatobá/PE, such as the basic project that foresees the installation of up to 65 net cages, of which 40 were in operation at the time of the fieldwork.

Among its unique features, it stands out as the first local association to admit women as members. Furthermore, practical solutions to improve management efficiency were identified, such as installing feed containers on walkways next to the tanks to facilitate feeding. A differentiated feeding frequency for the fish was also observed, carried out every 30 minutes. In the following image (Figure 9), we can see the production of another association, called Nova Aliança.

Figure 9 - Feeding done by the worker (associate), Nova Aliança Association, São Francisco River, Jatobá/PE. Source: Fieldwork (2023).

The success of the community associations proposed by Father Antônio Miglio, combined with the water resources of neighboring towns and cities, especially Petrolândia/PE, led to the associations being partially replicated upstream of the São Francisco River, in the Itaparica reservoir.

This diffusion, however, did not occur by merely reproducing the original model. Although the associations in Petrolândia/PE were influenced by the format developed in Jatobá/PE, they have distinct characteristics. In Petrolândia, the community organization process involved greater participation from actors within the agglomeration's cooperation circle than in the context of Jatobá.

Among the main agents working to strengthen these associations in Petrolândia, the Municipal Government stands out, developing initiatives aimed both at utilizing the waters of the São Francisco River for fish farming and at promoting local tourism activities. These actions have contributed to diversifying the municipal economy, strengthening integration among productive sectors, and promoting new opportunities for territorial development. The map in Figure 10 shows the main destinations for tilapia production from the associations of Jatobá/PE and Petrolândia/PE. These commercial flows have been limited to the states of the Northeast region precisely because whole fish are sold on ice.

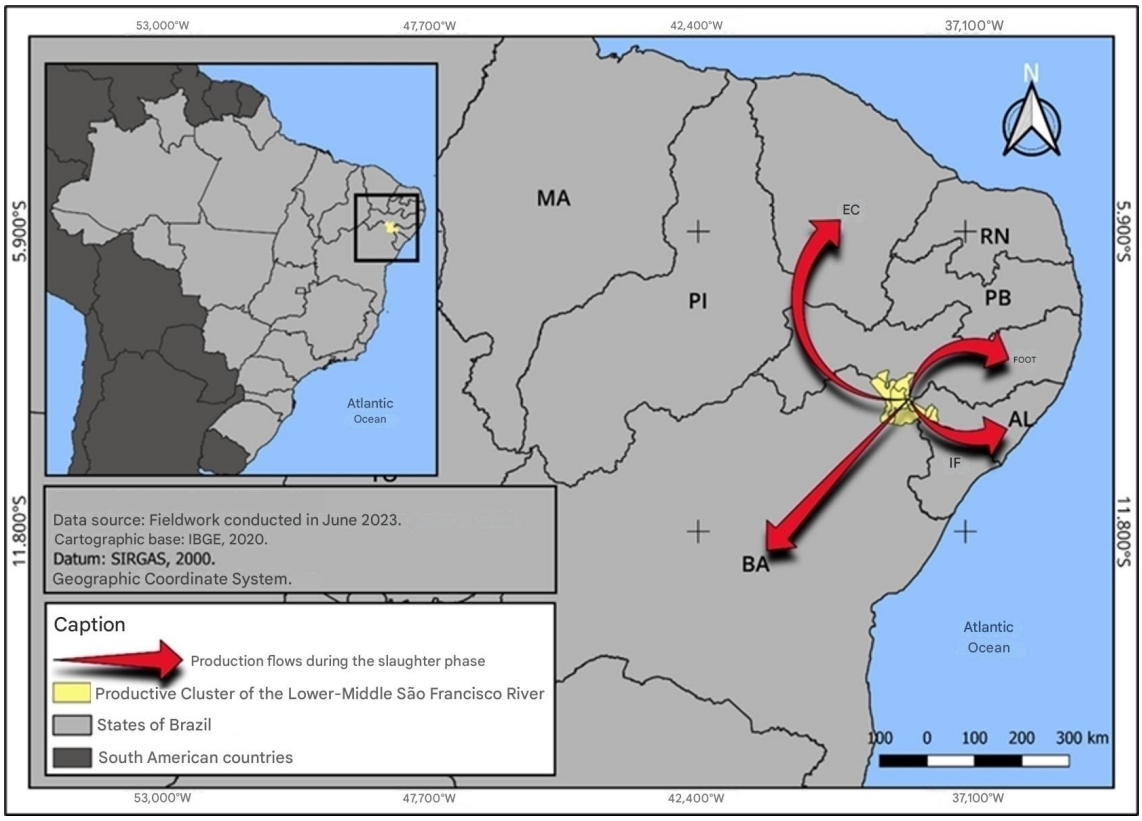

Figure 10 - Map of the main destinations for tilapia production at the slaughter stage from the associations of Jatobá/PE and Petrolândia-PE. Source: Organized by the authors (2025).

The absence of a cold storage facility near Petrolândia/PE is a significant gap in the processing of tilapia cultivated by local associations. This can be associated with mesofunctional conditions, a medium level of geographic-economic complexity reflected by the absence of agro-industries, and, consequently, lower technical and informational density (SANTOS, 2006). This deficiency contributes to the commercialization flows of production following trajectories similar to those observed in the associations of Jatobá/PE. In this context, the sale of whole fish predominates, mainly destined for open-air markets in towns and cities within the agglomeration or for cold storage facilities located at a distance.

CONCLUSION

The productive cluster of the Lower-Middle São Francisco River presents a medium level of geographic-economic complexity, indicating a mesofunctional setting. This is expressed in the moderate presence of actors across the different circuits of the urban economy, with emphasis on the lower and upper marginal circuits, and in the coexistence of processes of verticalization and horizontalization of production, with emphasis on the latter. The analysis revealed that, although there are meat processing plants and medium-sized companies with regional and national reach (predominantly in the upper marginal and upper circuits, articulating vertical connections), the base of the production is sustained by initiatives of community associations (predominantly in the lower circuit, representing horizontal connections), which use the technical modality of net-pens, mainly in Jatobá and Petrolândia/PE.

In this context, the agglomeration's intermediate geographic-economic complexity (mesofunctional) is characterized by the articulation of its densities. Regarding technical density, although the average productivity is high—191.5 tons per establishment in 2021—, placing the agglomeration among the three largest in the country, the lower circuit, represented by the associations, operates with precarious infrastructure (boats and wooden walkways) and intensive use of labor, with

adapted management methods such as manual feeding, reflecting a low technical density in part of the agglomeration. On the other hand, the upper circuit includes actors with greater capital and technical expertise, such as Agrofish/Netuno, which controls stages such as fry production, processing, and its own transportation. However, the absence of local processing plants is a technical deficiency that limits processing and the consequent value-addition to community-based production.

In addition to technical density, informational density is marked by the coexistence of codified/formal knowledge networks (Educational Institutions and Consulting Firms) and an intense diffusion of local knowledge networks and buzz among community associations. Simultaneously, there is the internal organization of the associations, which have their own methodologies and regulations for profit sharing, shared responsibility for production, and continuous monitoring of the structure. These endogenous norms demonstrate a high degree of organization and political articulation at the community level of this territorial use.

These community associations are a relevant socio-territorial governance innovation in the context of the semi-arid Northeast of Brazil. They demonstrate how local cooperation networks, based on geographical and institutional proximity, can positively affect income generation, social inclusion, and the economic empowerment of traditionally marginalized populations, particularly for female leadership. However, the challenges faced by these organizations, such as inadequate infrastructure, limited access to credit, environmental problems (the proliferation of water hyacinths and golden mussels), and social and gender inequalities, indicate structural limitations that prevent progress towards greater productive complexity. The absence of local processing plants, for example, restricts processing and value addition.

Therefore, the study on fish farming in the Lower-Middle São Francisco River contributes to the geographical debate on land use, productive specialization, and regional development. Firstly, by analyzing geographical-economic complexity, the category is operationalized to classify and understand such territorial arrangements. Secondly, the work maps horizontal connections, highlighting that geographical proximity and the organizational forms of the lower circuit are crucial for spreading innovations and generating solidarity, offering a critical reading of the appropriation of territory. Finally, it analyzes the dynamics of regional development in the semi-arid region, the productive specialization of fish farming, and how the coexistence of high productivity with social and structural challenges in the Northeast reveals the contradictions of regional development. Therefore, the productive cluster of the Lower-Middle São Francisco River is considered an emblematic example of the contradictions and potential of land use for tilapia farming in Brazil. This study reinforces the importance of public policies and territorial strategies that value local arrangements, promote greater institutional articulation, and expand the technical and economic conditions for the consolidation of complex, and above all, more inclusive, production systems.

DATA AVAILABILITY

Not applicable.

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