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Abstract: This study investigates the distribution and diversity of activities related to bioeconomy in the Brazilian Amazon, leveraging concepts from spatial analysis such as rural-urban integration, agglomeration economies, and local-global knowledge. Methodologically, formal job data at the municipal level is analyzed, employing the Standardized Location Quotient (SLQ) alongside additional analyses. The findings reveal a network centered around Manaus-AM and other state capitals, where bio-industries (agroindustry and biotechnologies) are concentrated over time. These agglomerations are surrounded by regional economies specializing in groups of bioeconomy, such as farming, nature, or livestock production. However, the “spatial bioeconomy” in the Amazon highlights a limitation in the utilization of landscapes for multiple activities, signaling a challenge in enhancing biodiversity in the long term. Despite this, institutions within the Brazilian Amazon possess the capacity to implement projects of bioeconomy with positive impacts on local communities. In conclusion, this approach emerges as a crucial conduit for expanding spatial interactions while simultaneously addressing environmental and social concerns within regions abundant in bioresources.

Keywords: Spatial analysis. Bioeconomy. Brazilian Amazon.

Resumo: Este estudo investiga a distribuição e diversidade das atividades relacionadas à bioeconomia na Amazônia brasileira, adotando conceitos de análise espacial, como integração rural-urbana, economias de aglomeração e conhecimento local-global. A metodologia utilizou de dados formais de emprego em nível municipal, aplicando-os no Quociente de Localização Padronizado (SLQ) e em análises adicionais. Os resultados revelam uma rede centrada em Manaus-AM e outras capitais estaduais, onde as bioindústrias (agroindústria e biotecnologias) concentraram-se ao longo do tempo. Essas aglomerações estão cercadas por economias regionais especializadas em agrupamentos da bioeconomia, como agricultura, natureza ou pecuária. No entanto, a “bioeconomia espacial” amazônica sugere uma limitação na diversificação de atividades em um mesmo local, sinalizando um desafio em melhorar os níveis de biodiversidade no longo prazo. Apesar disso, instituições dentro da Amazônia brasileira possuem a capacidade de executar projetos da bioeconomia com impactos positivos nas comunidades locais. Em conclusão, esse conceito emerge como um meio crucial para expandir as interações espaciais, ao mesmo tempo em que aborda questões ambientais e sociais em regiões abundantes de recursos biológicos.

Palavras-chave: Análise espacial. Bioeconomia. Amazônia brasileira.

Resumen: Este estudio investiga la distribución y diversidad de actividades relacionadas con la bioeconomía en la Amazonía brasileña, utilizando conceptos de análisis espacial como integración

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rural-urbana, economías de aglomeración y conocimiento local-global. La metodología utilizó datos de empleo formal a nivel municipal, aplicándolos al Cociente de Ubicación Estandarizado (SLQ) y análisis adicionales. Los resultados revelan una red centrada en Manaus-AM y otras capitales de estado, donde las bioindustrias (agroindustria y biotecnología) se han concentrado a lo largo del tiempo. Estas aglomeraciones están rodeadas de economías regionales especializadas en clusters de bioeconomía, como la agricultura, la naturaleza o la ganadería. Sin embargo, la “bioeconomía espacial” amazónica sugiere una limitación en la diversificación de actividades en el mismo lugar, lo que señala un desafío para mejorar los niveles de biodiversidad a largo plazo. A pesar de esto, las instituciones dentro de la Amazonía brasileña tienen la capacidad de ejecutar proyectos de bioeconomía con impactos positivos en las comunidades locales. En conclusión, este concepto surge como un medio crucial para ampliar las interacciones espaciales y al mismo tiempo abordar cuestiones ambientales y sociales en regiones abundantes en recursos biológicos.

Palabras clave: Análisis espacial. Bioeconomía. Amazonía brasileña.

INTRODUCTION

The bioeconomy intertwines agriculture with industries, utilizing resources from biodiversity, including biomass and bio-waste, to enhance the sustainability of regional economies (Torres, 2022). This integration relies on the capacity of geographical spaces to absorb knowledge for application into technological innovations (Birch, 2009). Within these environments, often characterized as “ecological modern spaces,” rural areas relinquish autonomy in the management of natural resources, while urban centers provide the necessary infrastructure for bio-clusters (Horling; Marsden, 2011). This interplay between rural and urban areas is a fundamental aspect of the knowledge-space dynamic, shaping the core principals of “spatial bioeconomy.”

The utilization of the bioeconomy as a mechanism to integrate rural landscapes and urban centers (Hodge; Bruskas; Giurca, 2017) holds promise for bringing socio-economic benefits to regions, including job, particularly in sparsely populated peripheries abundant in valuable natural resources (Lehtonen; Okkonen, 2013), such as the Amazon rainforest in Brazil. This tropical land is recognized as one of the most socio-biodiverse biomes globally, abounding with native plants possessing market value, previously referred to as “outback drugs” (Prado Júnior, 2012). However, the formation of linkage effects in the Brazilian Amazonian regions is hindered by insufficient human and financial capital (Oliveira; Piffer, 2017).

Assuming the bioeconomy as a bridge to rural-urban integration, while also contributing to spatial concentration through the lens of “knowledge-space,” this study aims to examine the emergence of bio-based activities in the Brazilian Amazon throughout the 21st century. Within these considerations, it delineates three primary goals: i) identifying whether the bio-sectors are agglomerated or dispersed in this space; ii) determining whether these activities are categorized as part of a bioeconomy within a plantation (monoculture, global chains) or a sociobiodiverse economy (pluriculture, local markets); and iii) assessing whether the Amazonian regional economies are transitioning towards eco-friendly models.

The motivation behind this research stems from the ongoing debate among scholars regarding the genuine role of the bioeconomy in promoting sustainability. In response to this discourse, this study seeks to contribute by delving into the practical applications and implications of the bioeconomy, particularly within the challenging ecosystem of the Brazilian Amazon (Bergamo *et al.*, 2022), from a spatial perspective. Additionally, the research aims to provide insights into the mechanisms that can facilitate the integration of rural and urban cores in peripheries abundant in valuable natural resources. This investigation is crucial for comprehending the real-world dynamics of capital flows into regions, a key factor in promoting sustainable economic development (Oliveira; Rodrigues, 2020).

The remaining sections of this manuscript are organized as follows. The next part outlines the general concept of the bioeconomy and its applicability in Brazil, followed by a description of the research methods and materials devised for this study. Subsequently, the results derived from the applied methodology are presented. A comprehensive examination of the bioeconomy, informed by a literature review and key assumptions, is detailed in the subsequent section. Finally, the last segment offers conclusive insights drawn from the study.

2 – CHALLENGES IN BIOECONOMY

Bioeconomy, firstly represented by biofuel and biomass, have emerged as an alternative framework for reducing greenhouse gas (GHG) emissions and enhancing sustainability (McCormick; Kautto, 2013). However, initial high expectations have dwindled over time, relegating these bio-based activities to the status of another traditional economic sector (Kleinschmit *et al.*, 2017; Kotiaho, 2017; Wesseler; Von Braun, 2017). This skepticism is evident even in bioethanol, an industry with a high level of knowledge-space (Staffas; Gustavsson; McCormick, 2013), which is currently developing technologies to utilize sugarcane in the production of bio-based bulk materials (Scheiterle *et al.*, 2018).

Numerous nations utilized the early principles of the bioeconomy as a policy agenda for regional sustainable development (Goven; Pavone, 2014; Staffas; Gustavsson; McCormick, 2013). For instance, the United States of America dedicated its efforts to securing the transition of the fuel supply from fossil to bio-based fuel. Simultaneously, the European Union's Bioeconomy the pillars of substantial investments in research, development, and the innovative utilization of biomass (Aguilar; Twardowski; Wohlgemuth, 2019).

Nonetheless, the model of biomass-biofuel reliant on monoculture has not only contributed to the exacerbation of poverty and environmental devastation (Queiroz-Stein *et al.*, 2023) but also poses uncertainties and controversies surrounding the concept of bioeconomy as a reference toward a greener economy (Pfau *et al.*, 2014). In response, a new approach has emerged to analyze bio-based activities in regional economies (Zilberman *et al.*, 2013; Muizniece; Zihare; Blumberga, 2019), focusing in the multifunctionality and biodiversity of landscapes (Grossauer; Stoeglehner, 2023). The adoption of criteria for distinguishing between different types of "bioeconomies" provides another example of the practical application of this concept (Bugge; Hansen; Klitkou, 2016).

Furthermore, the integration of additional sustainability principles into the bioeconomy, such as circular economy practices and the promotion of industries operating within ecological limits, gained significant traction only in the late 2010s (Aguilar; Twardowski; Wohlgemuth, 2019; Ronzon *et al.*, 2020). During this period, new institutions emerged, fostering successful synergistic clusters between businesses and public authorities, particularly in countries endowed with abundant bioresources and robust innovative systems, such as the Nordic economies (Refsgaard *et al.*, 2021).

2.1 – BIOECONOMY IN THE BRAZILIAN AMAZON

In the late 1960s, the federal government supported cattle-ranching, mining, and lumber operations within precarious lands in an effort to assert control over the wild territory of the Amazon (Mello, 2006; Oliveira; Araújo, 2013; Oliveira; Piffer, 2017). However, this political agenda in the last quarter of the 20th century faced criticism from both foreign authorities and local environmentalists. In response to these challenges, institutional arrangements emerged in Brazil aimed at addressing the protection of indigenous peoples, peasants, and traditional communities (Queiroz-Stein *et al.*, 2023). These groups were engaged in a struggle against the expansion of monoculture farming, deforestation, and other predatory economic activities in the Brazilian Amazon.

In the 21st century, new concerns related to climate change and greenhouse gas emissions are compelling governments to promote the adoption of sustainable

production models in the Amazon region (Macedo; Araújo, 2019). One of these approaches advocates for the rescue of indigenous knowledge while seeking to improve extractive activities in rainforests by adding value (Barbosa *et al.*, 2021; Nascimento *et al.*, 2023). The Amazon Biotechnology Center, established within the Industrial Cluster of Manaus, the state capital of Amazonas, is already driving innovation through this local-knowledge (Silva; Oliveira, 2021; Duarte; Oliveira; D'Andrea, 2023; Evangelista; Cunha; Ferreira, 2023).

On the other hand, states neighboring Amazonas lack technological assets capable of attracting bio-industries. This issue is evident in Pará, where the concept of social bioeconomy is still in the initial stages of development (Santos, 2023). Recognizing this issue, the federal government has recently undertaken political and institutional reforms. These include the creation of the National Secretary of Bioeconomy under the Ministry of Environment and Climate Change, aiming to coordinate policies for the sustainable use of natural resources guided by traditional knowledge. Additionally, the goal of establishing the social bioeconomy has been integrated into the Director Plan of Embrapa (Brazilian Agricultural Research Corporation) with the aim of achieving it within the next 10 years.

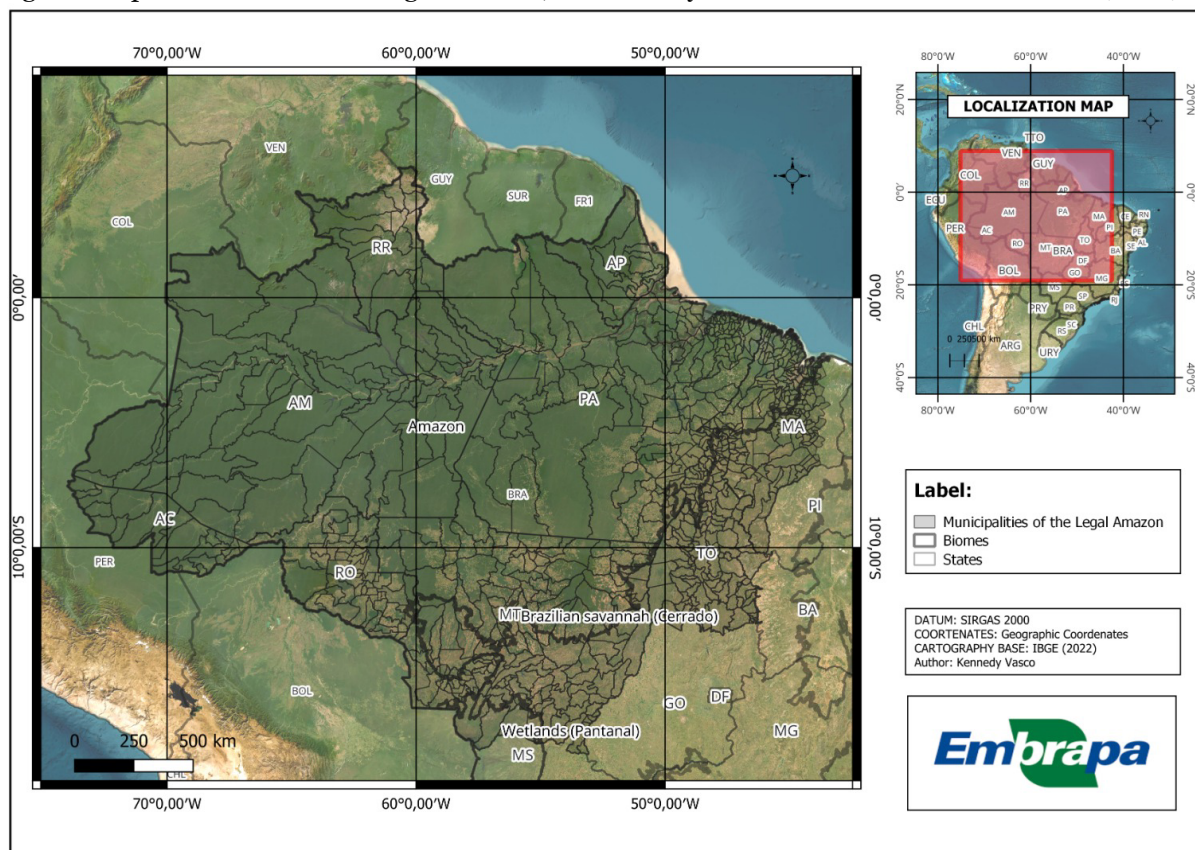
The recent political support, projects, and investments employing the term “social bioeconomy” in Brazil entail numerous problems (Ollinaho; Kroger, 2023). The turbulence lies in the coexistence of two distinct “bioeconomies” within the country. One relies on a plantation economy led by biofuel industries, resulting in significant environmental impacts (Horling; Marsden, 2011). The other is based on the domestication and genetic improvement of native plants, a crucial “old” agricultural practice aimed at achieving scale, market access, and profits, which could elevate operational costs for peasants (Homma, 2022).

In response to these challenges, it is necessary to employ appropriate approaches to bioeconomy in the Amazon. The diverse nature of Amazonian territories, encompassing varied knowledge and utilization of biological resources, must be considered in project planning (Costa *et al.*, 2022). Furthermore, cities play a pivotal role in mediating and transforming relationships between society and nature (Lopes *et al.*, 2023). Protecting and ensuring the rights of indigenous territories and traditional communities, fostering a forest-based economy, promoting agrobioeconomy, and advancing sociobioeconomy are other key topics addressed in studies on bioeconomy in the Amazon.

3 – METODOLOGY

The research area comprises the Legal Amazon, a geographical delineation established by the Brazilian government in the mid-20th century, according to Article 2º of Federal Law nº 1.806/1953 (Brasil, 1953). This region includes nine states: Acre (AC), Amapá (AP), Amazonas (AM), Maranhão (MA), Mato Grosso (MT), Pará (PA), Rondônia (RO), Roraima (RR), and Tocantins (TO). It incorporates large metropolitan areas, such as Manaus-AM and Belém-PA, which alone account for nearly 9% of Brazilian GDP. Additionally, it extends beyond the Amazon biome to encompass the Brazilian savannah (Cerrado) and the world's largest tropical wetland, the Pantanal, as depicted in Figure 1.

Figure 1 - Spatial localization of Legal Amazon, in this study referred as the Brazilian Amazon (2022)



Source: IBGE (2022). Elaborated in Laboratory of Geoprocessing in the Fisheries and Aquaculture unit of Embrapa.

As there are 773 municipalities in the Legal Amazon, this geographic scale is easily integrated with the Annual List of Social Information (RAIS, in Portuguese abbreviation), which belongs to the Ministry of Labour and Employment. This official statistical source compiles information on formal jobs in Brazil, offering free access and frequent updates. Its utilization provides a practical method for monitoring bioeconomy sub-sectors through performance indicators at different points in time and across locations (Ronzon *et al.*, 2020).

The RAIS database follows the National Classification of Economic Activities (CNAE, in Portuguese abbreviation), version 2.3, elaborated by the Brazilian Geographic and Statistical Institution (IBGE, in Portuguese abbreviation). This categorization system allows the sorting of activities into subsectors of the bioeconomy (Zilberman *et al.*, 2013). The priority is to detect the rise, expansion, and supposed integration of urban-rural economies in the Brazilian Amazon. Considering this issue, the activities were categorized into five groups (Table 1):

Table 1. Groups of bioeconomy activities selected from RAIS/CNAE/IBGE (2011/2021)

Group	CNAE 2.3	Activity
Farming	0133-4/01	Acai cultivation
	0133-4/06	Guarana cultivation
	0135-1/00	Cocoa cultivation
	0139-3/06	Rubber tree cultivation
	0210-1/05	Cultivation of timber species, except eucalyptus, [...]
Nature	0220-9/01	Wood extraction in native forests
	0220-9/02	Charcoal production in native forests
	0220-9/03	Collecting Brazil nuts in native forests
	0220-9/04	Latex collection in native forests
	0220-9/05	Palm heart collection in native forests
	0220-9/99	Collection of non-timber products [...]
	0220-9/06	Conservation of native forests
	0312-4/01	Freshwater fish fishing
	0312-4/02	Fishing for crustaceans and molluscs in freshwater
	0312-4/03	Collection of other freshwater aquatic product
	0312-4/04	Activities to support freshwater fishing
Livestock	0159-8/01	Beekeeping
	0322-1/01	Freshwater fish farming
	0322-1/02	Freshwater shrimp farming
	0322-1/03	Farming oysters and mussels in fresh water
	0322-1/04	Breeding ornamental fish in freshwater
	0322-1/05	Raniculture
	0322-1/06	Alligator farming
	0322-1/07	Activities to support freshwater aquaculture
	0322-1/99	Freshwater aquaculture crops and semi-crops [...]
Agroind.	1020-1/01	Preparing of fish, crustaceans and molluscs freshers
	1020-1/02	Manufacture of canned fish, crustaceans and molluscs
	1031-7/00	Manufacture of fruit preserves
	1032-5/01	Manufacture of canned palm hearts
	1033-3/01	Manufacture of concentrated fruit, vegetable and [...]
	1033-3/02	Manufacture of fruit, vegetable and vegetable juices, [...]
	1093-7/01	Manufacture of cocoa and chocolate products
	1093-7/02	Manufacture of candied fruits, candies and other sweets
	1111-9/02	Manufacture of other spirits and distilled beverages
	1122-4/01	Soft drink manufacturing
	1122-4/02	Manufacture of mate tea and other ready-to-drink teas
	1122-4/03	Manufacture of soft drinks, syrups and [...]
	1122-4/04	Manufacturing of isotonic drinks
	1122-4/99	Manufacture of other non-alcoholic beverages not [...]
Biotech.	1931-4/00	Manufacture of biofuels
	2013-4/01	Manufacture of fertilizers and organo-mineral fertilizers
	2062-2/00	Manufacturing of cleaning and polishing products
	2063-1/00	Manufacture of cosmetics, perfumery and personal [...]
	2110-6/00	Manufacturing of pharmaceutical products
	2121-1/03	Manufacture of herbal medicines for human use
	3839-4/01	Composting plants

Source: Brasil (2024). Organized by authors. Note: Agroind. means Agroindustry, Biotech. means Biotechnology.

Ideally, the Brazilian Amazon should encompass a diverse array of bioactivities across its territory. Prolonged spatial concentration within any single group signifies a potential sustainability deficit, particularly concerning Farming, Nature, or Livestock (Table 1). Furthermore, it is advisable to advocate for the diversification of activities among these groups, serving as a mechanism to enrich spatial knowledge and protect local biodiversity (Lopes *et al.*, 2023). Following these principles,

industries such as tire and furniture manufacturing, despite utilizing inputs from the rainforest, were excluded from this sample. In contrast, the inclusion of biofuels in this analysis stems from their substantial representation within the Brazilian economy.

The contribution of bioeconomy groups within the Amazonian economy relies on the Location Quotient (LQ), a well-established regional indicator used to assess the degree of local industry specialization (Pominova; Gabe; Crawley, 2022) for various purposes. However, LQ may yield undesirable results, such as overestimated clusters. To address this limitation, it is customary to introduce a more stringent cut-off, $LQ > 1.25$ or higher, as opposed to the conventional $LQ > 1$, to delimit the agglomeration of an industry in a region. However, this arbitrary criterion lacks robust reliability (Tian, 2013). A suggestion is to adopt the Standardized Location Quotient (SLQ), which is the z-statistic of the original LQ, as follows:

$$SLQ_{ij} = \frac{LQ_{ij} - \underline{LQ_i}}{std(LQ_i)} \quad (1)$$

Where $\underline{LQ_i}$ and $std(LQ_i)$ are the mean and standard deviation of the LQ of industry I in region j ,

The cut-off level for confirming the existence of agglomeration in a region is established by the critical value of the standard normal distribution at the 5% significance level, denoted as 1.96 for a two-tailed test or 1.64 for a one-tailed test (O'Donoghue; Gleave, 2004). This approach has a variation based on the Fundamental Theorem of Statistics (Tian, 2013). Moreover, further advanced approaches in the literature based on LQ, such as Spatial Input–Output Location Quotient (SI–LQ), which considers the co-location of industries across adjacent regions (Tian; Gottlieb; Goetz, 2019), are available in the literature, as well as suggestions addressed by complementing LQ with other metrics, such as the Gini coefficient (Pominova; Gabe; Crawley, 2022).

Having defined the study area, database, and the regional indicator, the methodology proceeds through the following steps:

1. Compiling statistics of jobs from the RAIS database for the subsectors of bioeconomy activities in the municipalities of the Legal Amazon.
2. Harmonizing the compiled data to align with the specified bioeconomy groups, as detailed in Table 1.
3. Estimating the participation of bio-based activities in each municipality of the Brazilian Amazon using the regional indicator SLQ.
4. Generating maps to facilitate the identification of spatial interactions, such as concentration or dispersion of bioeconomy groups.
5. Performing complementary analyses to highlight the multiple use of landscapes
6. Discussing the results considering the literature review.

The study incorporates data from 2021, the most recent available information in RAIS, and the year 2011, providing an analysis spanning 10 years. The SLQ calculations were executed using R Studio, REAT package (version 3.0.3), designed to aggregate models and analytical methods specific to regional and urban economics, as well as economic geography. Finally, this research was conducted at the

Geoprocessing Laboratory of Embrapa, within the Fisheries and Aquaculture Unit, located in Palmas-TO. It has received financial support from two key projects: “Carbon Footprint and Impacts of Aquaculture Expansion in the Amazon” (Calling Amazônia+10/CONFAP) and “Aquaculture as a Sustainable Alternative in Cattle Farming Areas in the Legal Amazon” (Calling Profix – FAPT/CNPq, under the coordination of Dr. Balbino Antônio Evangelista from the Fisheries and Aquaculture Unit of Embrapa).

4 – RESULTS AND DISCUSSIONS

The analysis of the Standardized Location Quotient (SLQ) for the years 2011 and 2021 unveils significant specialization in bioeconomy activities across various municipalities within the Brazilian Amazon (Table 2). While sectors such as Biotechnology, Agroindustry, and Nature consistently maintain their concentration levels, there is observable dispersion in the Farming and Livestock sectors throughout the region over the study period. This spreading trend, albeit positive, underscores the relatively modest participation of bioeconomy industries in the overall Amazonian economy.

Table 2. Description of SQL results and complementary analysis

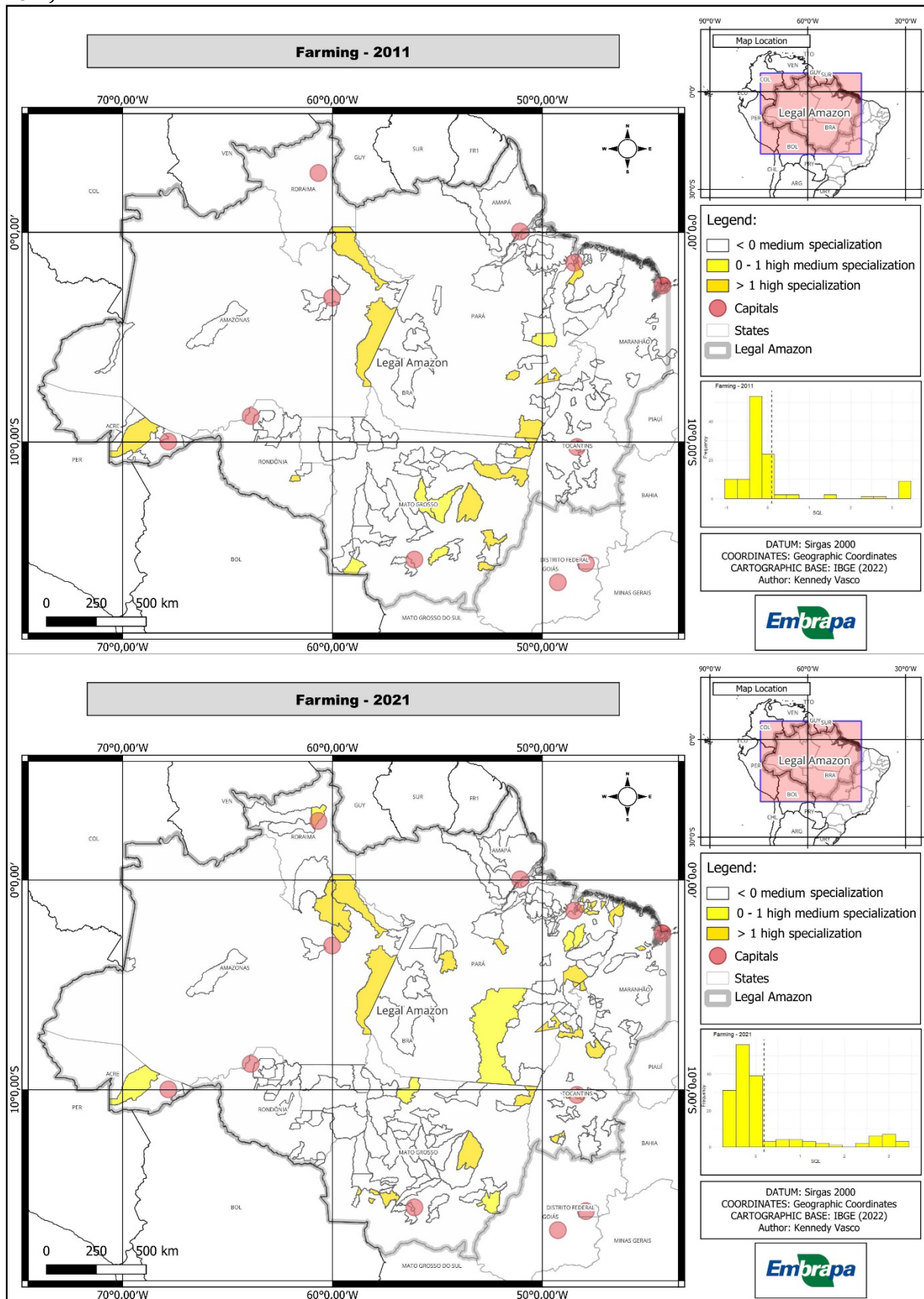
	2011					2021				
	Min.	Max.	Mean	Gini	Spec.	Min.	Max.	Mean	Gini	Spec.
Farming	-0.96	3.39	0.09	0.98	19	-0.65	3.21	0.19	0.97	37
Nature	-2.23	1.98	0.25	0.94	51	-1.56	2.27	0.00	0.95	51
Livestock	-0.69	3.38	0.27	0.97	23	-0.57	2.75	0.30	0.93	52
Agroind.	-6.98	1.98	-1.55	0.97	26	-6.66	1.96	-2.40	0.97	28
Biotech.	-2.61	3.81	-0.29	0.98	20	-2.26	4.04	-0.61	0.98	22

Source: Research results. Organized by authors. Note: The Gini Index refers to number of jobs; “Spec.” means the quantity of municipalities specialized (SQL > 0.01) in each group of bioeconomy, Agroind. means Agroindustry, Biotech. means Biotechnology.

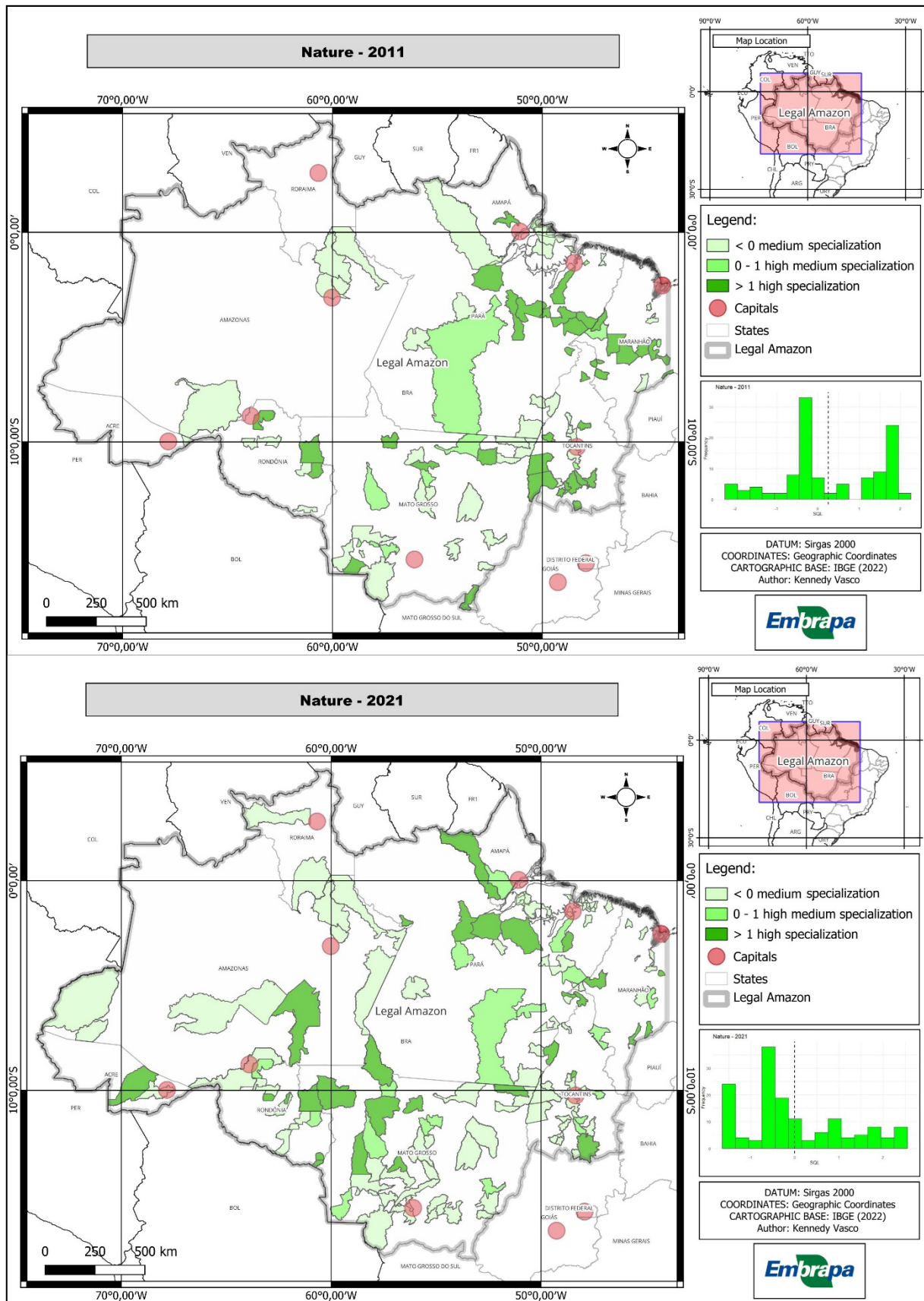
The Nature group appears to have experienced stagnation in the number of municipalities specializing in such activities over time. Conversely, Livestock witnessed significant expansion across the Amazon territory, increasing from 23 to 52 municipalities, a 56% rise. Dispersion is also noticeable in Farming (a 49% rise), whereas it was relatively stable in Agroindustry and Biotechnology.

In terms of spatial analysis, observations are supported by the maps depicted in Figure 2. The first group examined consists of municipalities specializing in Farming. They demonstrate an expanding trend across the territory, particularly concentrated around state capitals such as Boa Vista-RR, Belém-PA, and Palmas-TO. Additionally, significant agglomeration is observed in areas with multiple regional urban centers, notably extending from Manaus-AM to Santarém-PA, the northern region of Mato Grosso, the southeastern region of Pará, and the southern region of Tocantins. Within these geographical delineations, the Lower Amazon River basin emerges as a focal point for the potential development of new sustainable agricultural systems.

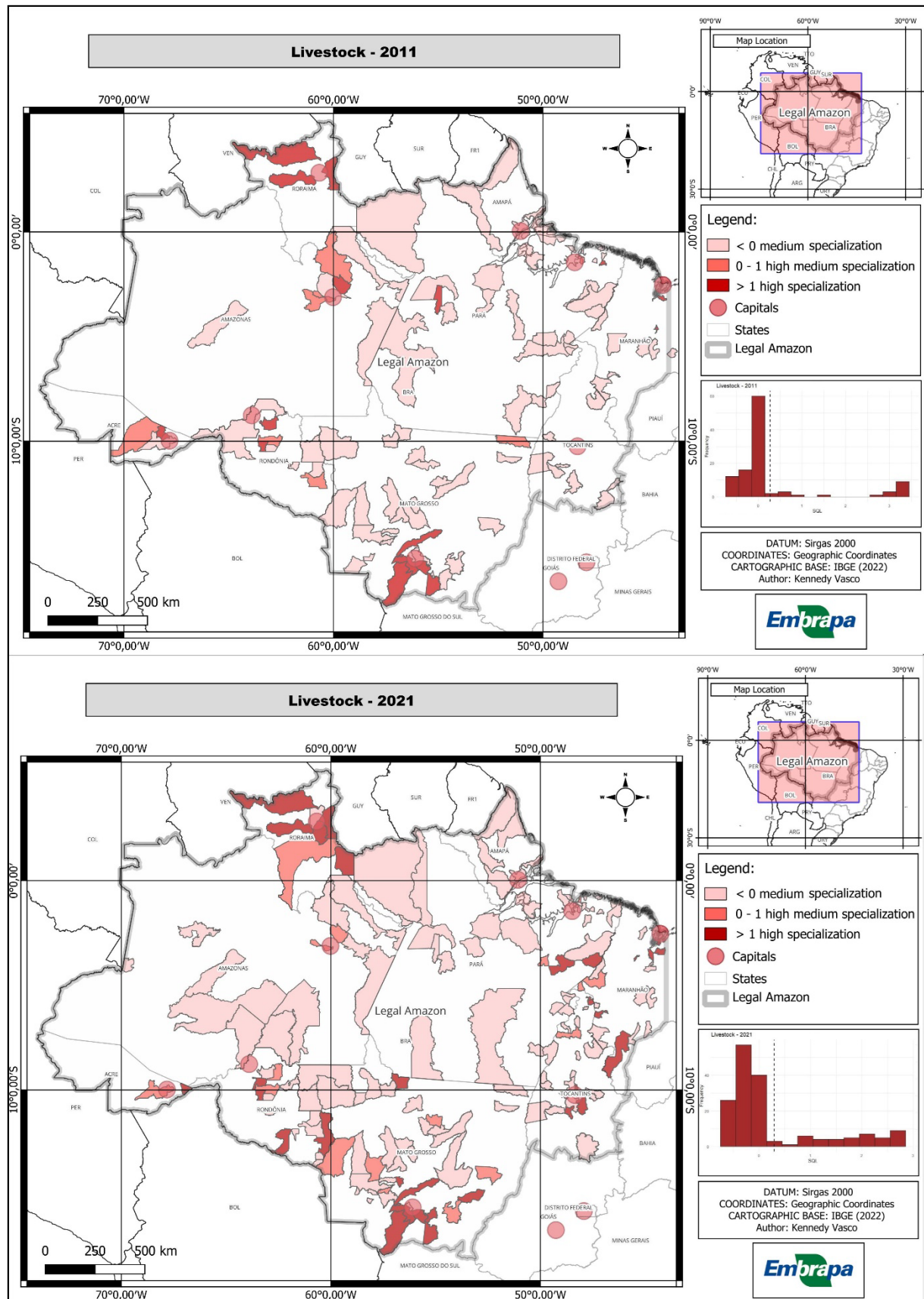
Figure 2 - Level of specialization in the bioeconomy groups according to SQL -Brazilian Amazon (2011-2021)



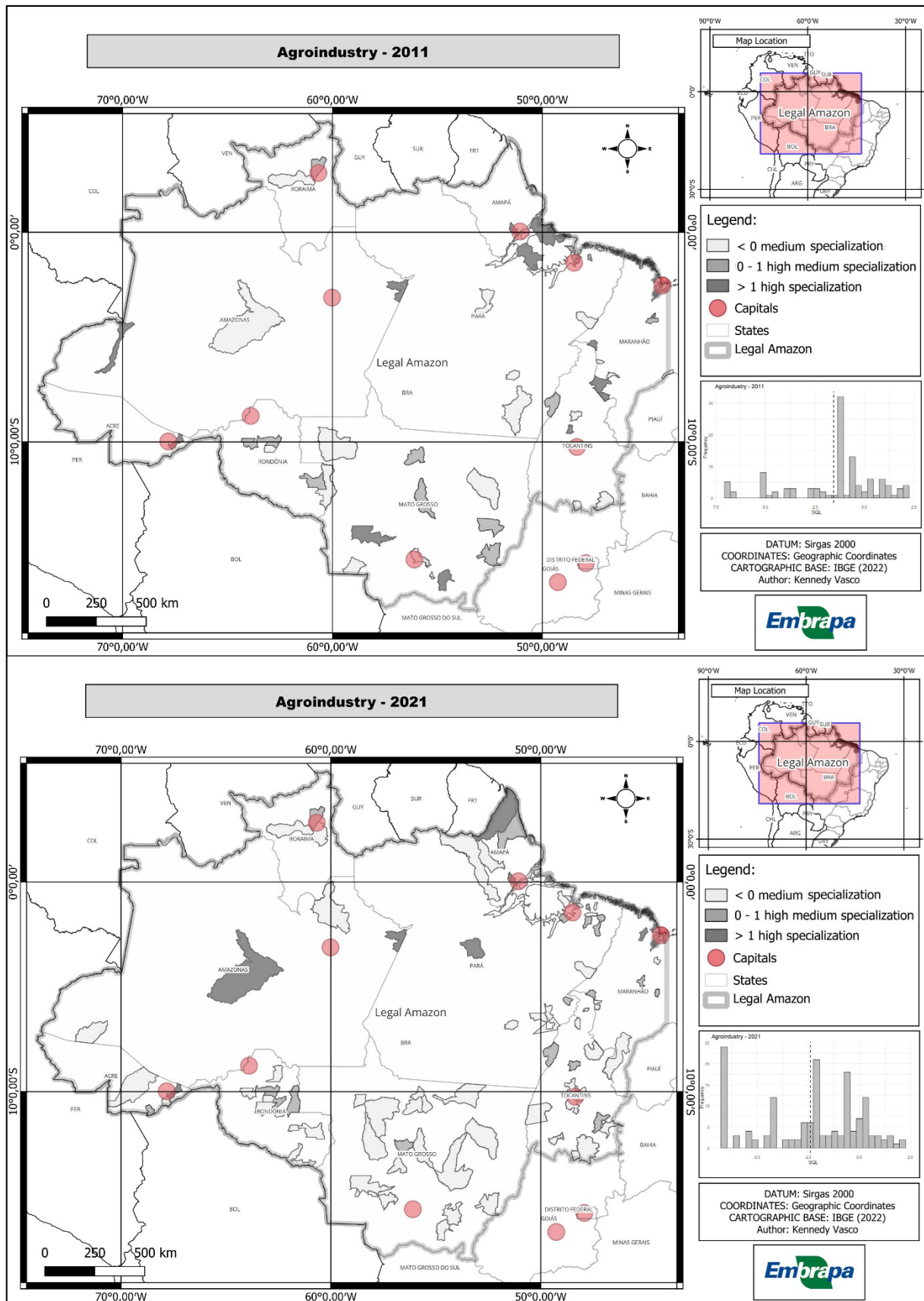
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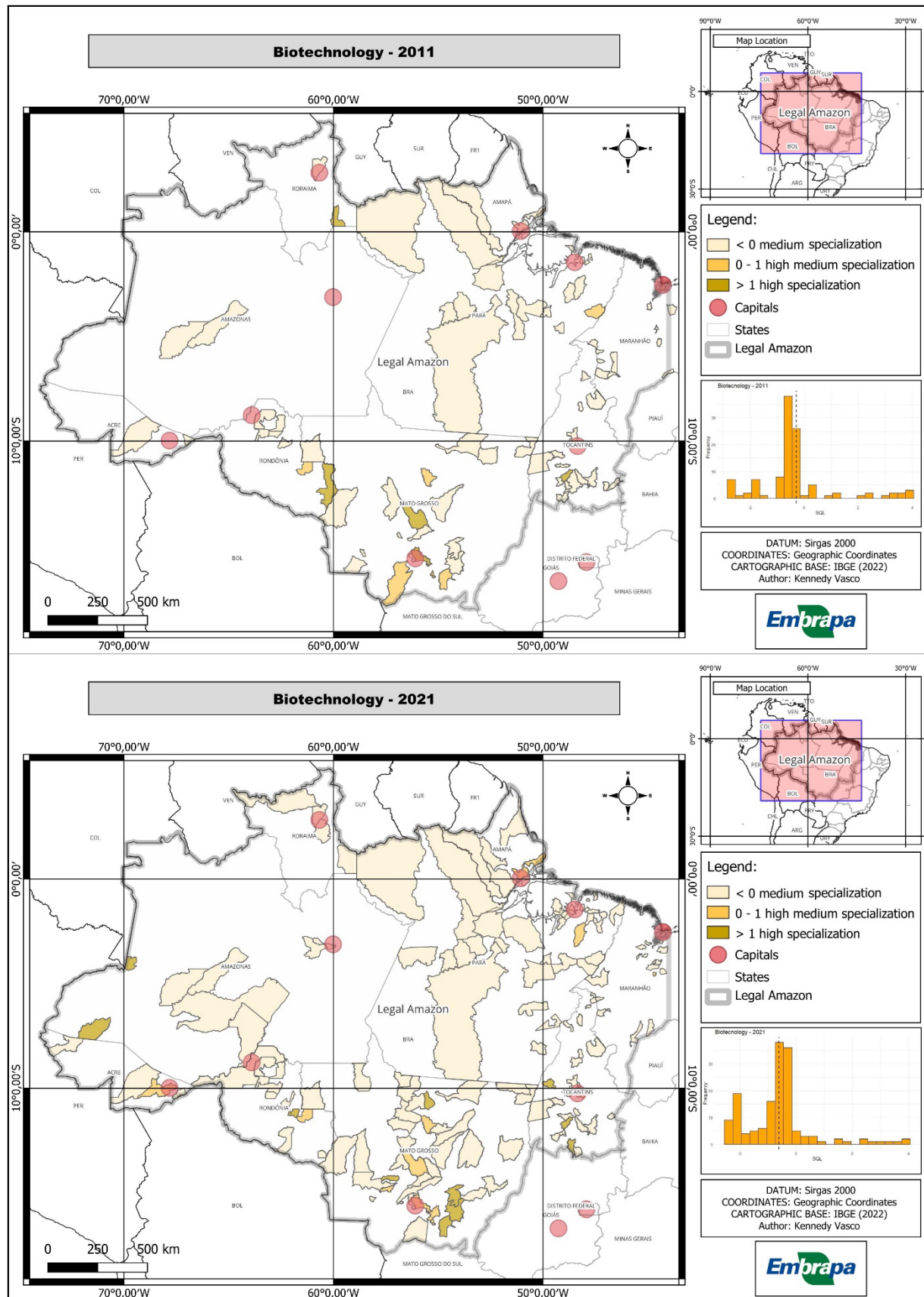
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Source: Research results. Organized by authors. Note: Scale of legend as “Below 0” (medium specialization); “0-1” (high medium specialization); “Above 1” (high specialization).

In 2011, robust rural-urban interactions were observed in the Nature through SLQ analysis, particularly in the central and eastern regions of Pará, the central region of Maranhão, and the southwestern region of Tocantins. However, as municipalities transitioned to other sectors by 2021, such as Farming or Livestock, or abandoned these activities, this network gradually weakened. An illustrative example of this shift is observed in Formoso do Araguaia-TO, situated in the vicinity of Bananal Island, previously engaged in vegetal charcoal production but now absent from bioeconomy activities. This discontinuity underscores concerns regarding the ability of these activities to foster sustainability and preserve biodiversity.

The Livestock sector has facilitated robust spatial interactions among municipalities, particularly evident around the capital city of Roraima, Boa Vista-RR, and Mato Grosso, Cuiabá-MT, where freshwater fish farming has been a driving force behind the expansion of the bioeconomy in the Brazilian Amazon. Conversely, despite the significant contributions of these urban centers, the surrounding areas of Manaus-AM have experienced a decrease in specialization over time. Nevertheless, municipalities in the vicinity of Palmas-TO, the capital of Tocantins, and the Jamarý Valley in the central-north region of Rondônia, close to Porto Velho-RO, have compensated for this decline.

The Agroindustrial sector, which involves the value addition of rural products in urban areas, exhibits constrained spatial interactions. In this context, Macapá-AP, the capital of Amapá, emerges as a focal point for fostering relationships with municipalities in Marajó Island, state of Pará, known for palm heart processing. However, by 2021, this network had dissipated, replaced by other municipalities in Amapá, such as Oiapoque-AP and Calçoene-AP, specializing in fishery products. Another noteworthy region is the states of Roraima and Rondônia, where fish farming is increasingly undertaken by their agroindustries.

Biotechnology exhibits a pattern similar to Agroindustrial, with the states of Tocantins and Mato Grosso concentrating spatial linkages facilitated by Porto Nacional-TO and Paraíso-TO, located near Palmas-TO, both specialized in biofuels. Additionally, Cuiabá-MT and Rondonópolis-MT reveal high levels of employment in cleaning and polishing products. By 2021, the biofuel industries in Tocantins experienced a decrease in their contribution to the state's economy, despite an increase in the number of formal contracts in Porto Nacional-TO. This observation suggests an ongoing process of spatial agglomeration, which could potentially lead to the creation of a cluster in this municipality.

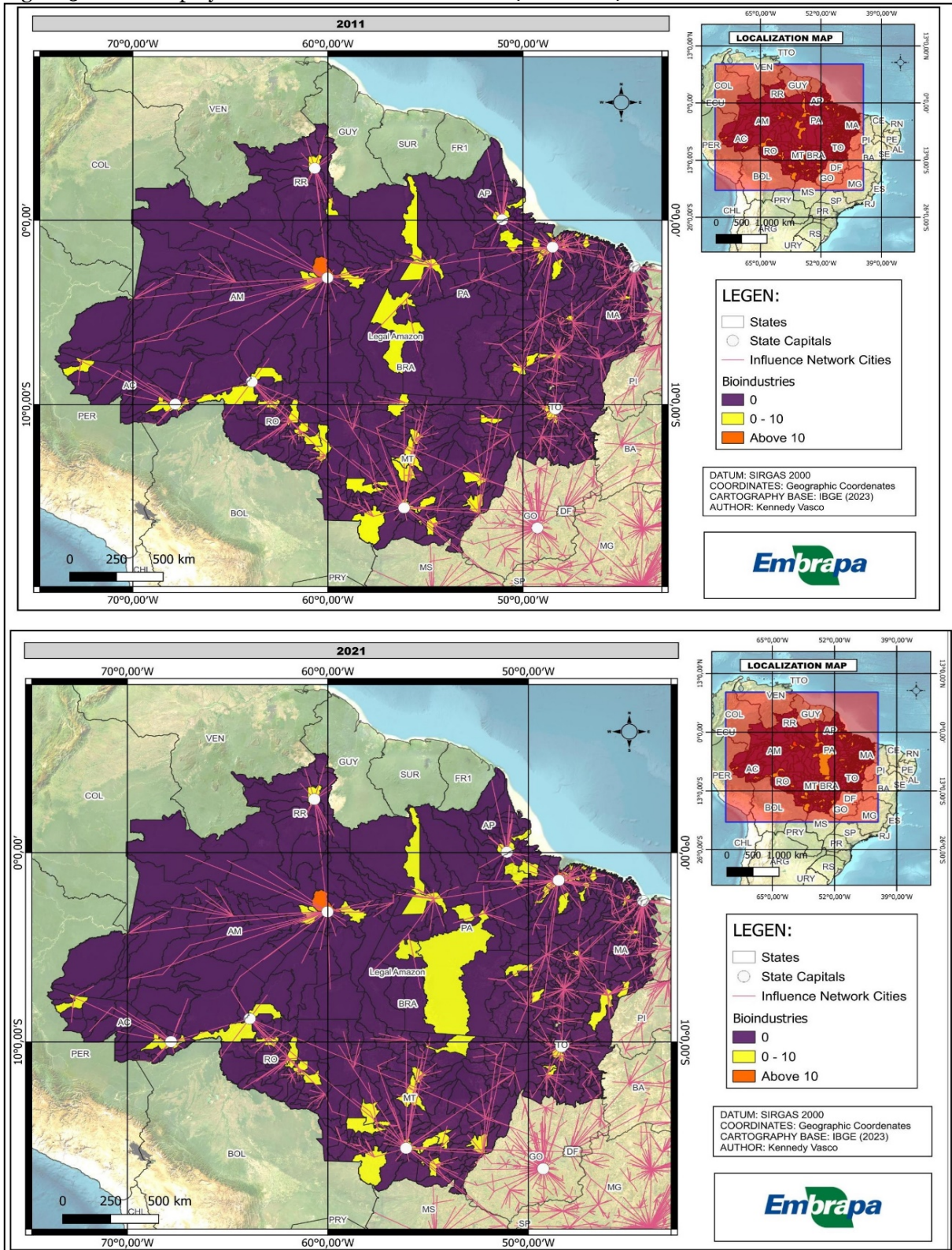
3.1 – THE MULTIPLE USE OF LANDSCAPES

In terms of multifunctional land use, Porto Esperidião-MT, situated between wetlands and rainforests, exhibited notable specialization in both Farming and Agriculture in 2011. In 2021, while Porto Esperidião-MT was historically known for its rubber industry, Ariquemes-RO integrated fish farming with food industries. Another example is Araisos-MA, which also engaged in fish cultivation, but its agroindustry primarily focused on fruit production.

The RAIS database underscores the significant rise of açaí cultivation as a prominent crop in the Amazonian region, experiencing a remarkable 13% increase in employment between 2011 and 2021. Particularly noteworthy, Tomé-Açu-PA, Castanhal-PA, and São Francisco do Pará-PA were engaged in both cocoa and açaí cultivation with formal contracts by 2021, demonstrating a high level of land use diversification. On the other hand, local economies often fail to exploit land for multiple productions related to natural resource exploration.

Regarding bio-industries (Agroindustry and Biotechnology), manufacturing facilities are primarily concentrated in the state capitals of the Brazilian Amazon (Figure 3).

Figure 3 - Total employment in Amazon bio-industries (2011-2021)



Source: Research results and IBGE (2018). Organized by authors. Note: values of employment in Z.

These urban centers are characterized by a high level of employment in productions such as soda drinks and biofuels. In 2011, half of all employees in the bioeconomy manufacturing sector were based in these urban centers. However, by 2021, this percentage had decreased to almost 40%. While these findings may initially suggest a process of spatial dispersion, Figure 3 reveals that these activities remain highly concentrated, particularly in the vicinity of the state capitals.

Despite the purported deconcentration of bio-industries in the Amazon, their spatial interactions have remained consistent over the years. Manaus-AM, renowned for its Industrial Cluster, serves as the primary manufacturing hub in the region. It is complemented by Belém-PA, Cuiabá-MT, and Macapá-AP. Additionally, regional urban centers such as Balsas-MA, Porto Nacional-TO, Rondonópolis-MT and Santarém-PA play vital roles in facilitating these connections across the region. Moreover, economies specialized in bio-based activities, such as the Lower Amazon River and the Juary Valley of Rondônia in Livestock, are strategically positioned near state capitals or regional urban cores.

CONCLUSION

The findings from the study on the “spatial bioeconomy” in the Brazilian Amazon unveil a diverse landscape of bio-based trade networks. This heterogeneous framework can be attributed to several factors. Firstly, the prevalence of monocultures aimed at instable global markets (Oliveira; Rodrigues, 2020), noticeable in agribusiness regions like Mato Grosso and Tocantins, situated in the “deforestation arc,” where biofuel industries have thrived. Additionally, limitations inherent in regions distant from major urban centers hinder their ability to add value to rural productions. Furthermore, the presence of biological industrial clusters, driven by local knowledge, in key cities such as Manaus-AM, also influences this territorial variation.

As a consequence, the prospects for bioeconomy initiatives grounded in sustainable practices across the entire Legal Amazon remain uncertain. Few examples exist of localities redirecting their economies towards eco-friendly models, indicating a relatively limited utilization and preservation of available socio-biodiversity. This deficiency in multifunctionality within landscapes may perpetuate the paradoxical model of the “bio-monoculture to global chains,” drawing criticism for its contribution to environmental degradation, social issues, and weakening capital flows into regions.

Despite the challenges, açaí cultivation (Farming group) and fish farming (Livestock group) are expanding across this biome. These bio-based economies not only generate local employment opportunities but also serve as potential catalysts for the development of sustainable land use practices. Moreover, institutions such as the National Secretary of Bioeconomy in Brasília-DF, the Amazon Biotechnology Center located within the Industrial Cluster of Manaus, and the research units of Embrapa across the Legal Amazon states possess the expertise to spearhead notable and innovative sustainable projects in this region. In a nutshell, they play a crucial role in reinforcing rural-urban integration in populated peripheries abundant in valuable natural resources by sharing local knowledge.

Future studies in Amazonian bioeconomy might prioritize assessing the sustainability of each bio-based activity or region. This evaluation encompasses various parameters not analyzed in this study, such as circular economy practices, collaboration between regions and central governments, adherence to environmental limits, adaptation to social and climate changes, ensuring food security, and fostering

green innovation. By conducting comprehensive assessments based on these criteria, researchers can optimize the utilization of bioresources in a manner that respects both the environment and local communities, facilitating their integration as inputs for emerging bio-industries in nearby areas.

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