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SPATIAL DISTRIBUTION OF *NELTUMA JULIFLORA* (SW.) RAF. IN THE RIO GRANDE DO NORTE STATE - BRAZIL, BY VISUAL INTERPRETATION OF SATELLITE IMAGES

Distribuição espacial de Neltuma juliflora (Sw.) Raf. no Rio Grande do Norte - Brasil, por interpretação visual de imagens de satélite

Distribución espacial de Neltuma juliflora (Sw.) Raf. en el estado de Rio Grande do Norte - Brasil, mediante interpretación visual de imágenes de satélite

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ABSTRACT

The expansion of mesquite (Neltuma juliflora) in the Brazilian semiarid region is of concern due to its invasive nature and its impact on the Caatinga. This study mapped its distribution in Rio Grande do Norte using satellite images analyzed in the GIS environment, with QGis and Bing Maps data. The methodology involved seven steps, including manual vectorization and field verification. The results showed that the species is concentrated near water bodies, especially in the Apodi-Mossoró and Piranhas-Açu rivers. The Central Potiguar mesoregion presented the largest occupied area (22,012.80 ha), followed by the West (13,072.67 ha) and Agreste Potiguar (4,866.07 ha), while the East Potiguar registered inexpressive values. The study highlights the importance of continuous monitoring and public policies for the management of mesquite, seeking to balance its forage uses with the preservation of native vegetation. Remote sensing proved to be effective in identifying and mapping the species, contributing to environmental control strategies.

Key words: Mesquite; Caatinga vegetation; GIS; Invasive species.

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RESUMO

A expansão da algaroba (Neltuma juliflora) no semiárido brasileiro preocupa por seu caráter invasor e impacto na Caatinga. Este estudo mapeou sua distribuição no Rio Grande do Norte por meio de imagens de satélite analisadas em ambiente SIG, utilizando o QGIS e dados do Bing Maps. A metodologia envolveu sete etapas, incluindo vetorização manual e verificação em campo. Os resultados mostraram que a espécie se concentra próxima a corpos d'água, especialmente nos rios Apodi-Mossoró e Piranhas-Açu. A mesorregião Central Potiguar apresentou a maior área ocupada (22.012,80 ha), seguida pelo Oeste (13.072,67 ha) e Agreste Potiguar (4.866,07 ha), enquanto o Leste Potiguar registrou valores inexpressivos. O estudo destaca a importância do monitoramento contínuo e de políticas públicas para o manejo da algaroba, buscando equilibrar seus usos forrageiros com a preservação da vegetação nativa. O sensoriamento remoto mostrou-se eficaz para identificar e mapear a espécie, contribuindo com estratégias de controle Ambiental.

Palavras-chave: Algaroba; Caatinga; SIG; Espécie invasora.

RESUMEN

La expansión del algarrobo (*Neltuma juliflora*) en el semiárido brasileño genera preocupación por su carácter invasivo y el impacto en la vegetación nativa de la Caatinga. Este estudio mapeó su distribución en Río Grande del Norte mediante imágenes satelitales y herramientas SIG (QGIS con Bing Maps). La metodología incluyó siete etapas, como la vectorización manual y la verificación en campo. Los resultados mostraron que el algarrobo se concentra cerca de cuerpos de agua, especialmente en los ríos Apodi-Mossoró y Piranhas-Açu. La mesorregión Central Potiguar presentó la mayor área (22.012,80 ha), seguida por el Oeste (13.072,67 ha) y Agreste Potiguar (4.866,07 ha), mientras que el Leste Potiguar presentó datos de escasa magnitud. El estudio destaca la necesidad de monitoreo continuo y políticas públicas para manejar el algarrobo, equilibrando sus beneficios forrajeros con la preservación de la vegetación nativa. El uso de sensores remotos fue eficaz para identificar y mapear la especie, apoyando estrategias de control ambiental.

Palabras clave: Algarrobo; Caatinga; SIG; Especie invasora.

1 INTRODUCTION

Mesquite (*Neltuma juliflora* (Sw.) DC.; = *Prosopis juliflora*), according to a taxonomic review proposed by Hughes et al. (2022), was introduced in the Brazilian northeastern semiarid in the 1940s as a regional development strategy, starting with only four trees planted in Pernambuco in 1942 (Cunha; Gomes, 2012). The introduction of the species was a successful government policy to establish xerophiles in the dry northeastern region, with its fruits used in animal feed and its wood for cuttings, firewood, and charcoal (Santos; Diodato, 2017). The species spread rapidly through the "shallows" of Rio Grande do Norte, Paraíba, Pernambuco, Bahia, and Piauí due to its adaptation to Brazilian semiarid environmental conditions (Santos et al., 2019). Its introduction in Rio Grande do Norte occurred through experiments at the São Miguel Farm, municipality of Angicos, with the

enthusiasm of technicians and researchers, facilitating the distribution of pods and seedlings to rural properties (Santos; Diodato, 2017).

The invasion of *N. juliflora* (Mesquite) in the Brazilian semiarid has caused ecological and socio-environmental impacts. Studies show that *N. juliflora* affects the diversity and, consequently, the structure of invaded communities, forming dense population massifs that compete with native species and compromise the floristic composition, diversity, and structure of native communities (Pegado et al., 2006a; Andrade et al., 2009). Farmers in Pernambuco perceived the species as both a resource for animal feed and a cause of negative impacts, including herd mortality and irreversible environmental changes, highlighting the need for sustainable management strategies (Oliveira et al., 2024). The introduction and spread of *N. juliflora* are also shaped by political and scientific debates, reflecting its dual role as an agricultural innovation and an ecological threat, with its management interconnected with local socioeconomic networks (Cunha; Gomes, 2012). These findings underscore the complexity of addressing biological invasions in the Caatinga.

Orbital images are now considered essential for obtaining products through remote sensing in the face of the dissemination of N. juliflora and for monitoring its occupation over large areas and, in some cases, in areas of difficult access (Silva; Cruz, 2018). Visual interpretation stands out among the remote sensing techniques. It allows the identification of homogeneous regions in the study area by analyzing patterns and similarities among features and adjacent objects, facilitating the understanding and analysis of the spatial distribution of phenomena (EOS Data Analytics, 2025; Novo, 2021; Lillesand et al., 2015).

Mapping the spatial distribution of N. juliflora supports public policy guidelines for its management and control, thereby avoiding its dispersion into native vegetation with characteristics of biological invasion. Therefore, this work aimed to map the spatial distribution of mesquite in Rio Grande do Norte by visual interpretation of satellite images in a Geographic Information System (GIS) environment.

2 METHODOLOGY

The geographic area for the survey and analysis of *N. juliflora* distribution was the state of Rio Grande do Norte. The work script involved seven stages, namely: preparation and analysis of cartographic material and data from the Associação de Plantas do Nordeste (APNE, 2016); preparation of the interpretation key of the satellite image elements; visual interpretation of images from 2023; digital mapping in the GIS environment by manual

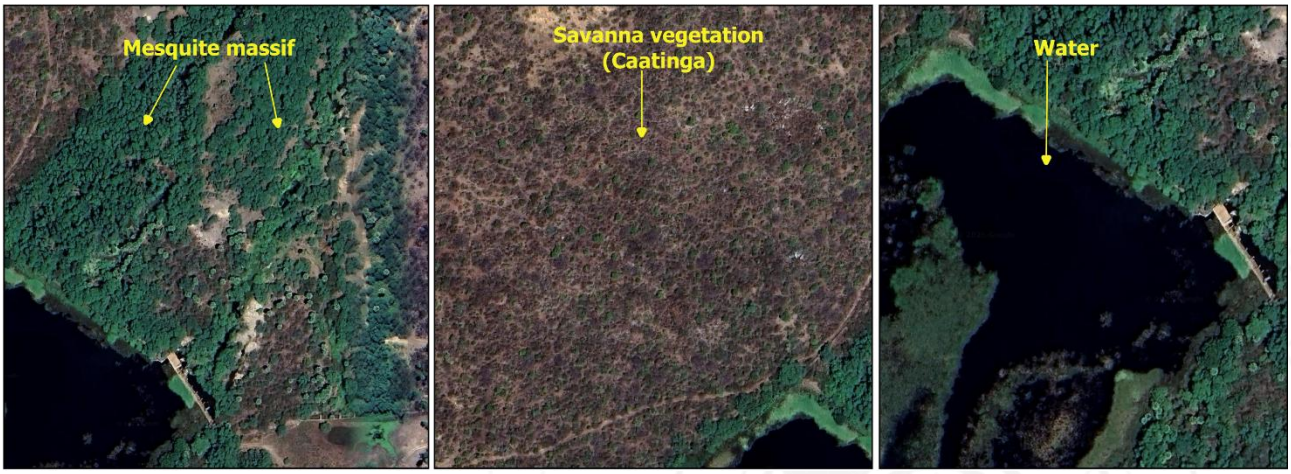
vectorization on screen; verification of identified objects - field reconnaissance, to confirm the veracity of what was observed in the satellite images; preparation of maps of the mesquite coverage, year 2023, by mesoregion of Rio Grande do Norte; results analysis.

For the visual interpretation of the elements, satellite images of mesquite were used, in the free Geographic Information Systems Program QGIS version 3.16.7 - “Hannover” with image interpretation as the methodology (QGis Development Team, 2021).

According to Jensen (2009), image interpretation elements include location, hue and color, size, shape, texture, pattern, shadow, height and depth, volume, slope, aspect, site, situation, and association. For this work, the following interpretation elements were adopted: tonality/color (ease of discriminating color), texture (impression of roughness), and location (proximity to water bodies).

The classes considered and the pattern in the satellite images were: Mesquite: light green color; less rough texture; distribution following the water bodies; generally, with densification forming massifs; Caatinga vegetation: brownish green color; rougher texture; irregular distribution; sparse density; Water bodies: black color with greenish tones; smooth texture; irregular, linear, rectilinear, or curvilinear shape for rivers (Figure 01). An interpretation key was developed to support the visual analysis and vectorization of polygons in a GIS environment.

Figure 01 – Spectral distinction between areas of Mesquite, Caatinga vegetation, and the body of water used in the elaboration of the interpretation key of satellite images. The area corresponds to the Seridó region, municipality of Caicó.



Source: Netgis (2015).

The visual analysis of images from the dry season was conducted to elaborate on the interpretation key for the elements present in the satellite images and to obtain a more precise outline of the areas occupied by mesquite. During this season, *N. juliflora* maintains foliage, resulting in greater spectral contrast compared to native deciduous vegetation. This characteristic facilitates their identification in orbital images due to their distinctive spectral signatures, as well as their texture, tonality, and spatial distribution patterns, which are usually associated with areas near bodies of water.

The visual interpretation of the classes was performed using high-resolution 50 cm images, processed by Digital Globe and made available by Bing through the QuickMap web service in the QGIS program (Netgis, 2015). The mapping scale was ultra-detailed (1:1,500).

The basis of Bing Maps, developed by Microsoft, for terrestrial areas is formed from intermediate-resolution images (Landsat and Spot), high-resolution satellite images, and orthophotos (Sztutman, 2014).

Due to the hydrochory of *N. juliflora*, characterized by its ability to establish and disseminate in areas adjacent to water bodies, it was possible to leverage the specific hydrographic network of each region studied to assist in the visual interpretation and vectorization of the mesquite. The hydrographic network was obtained in shapefile (.shp) format from data provided by the National Water Agency (ANA, 2013).

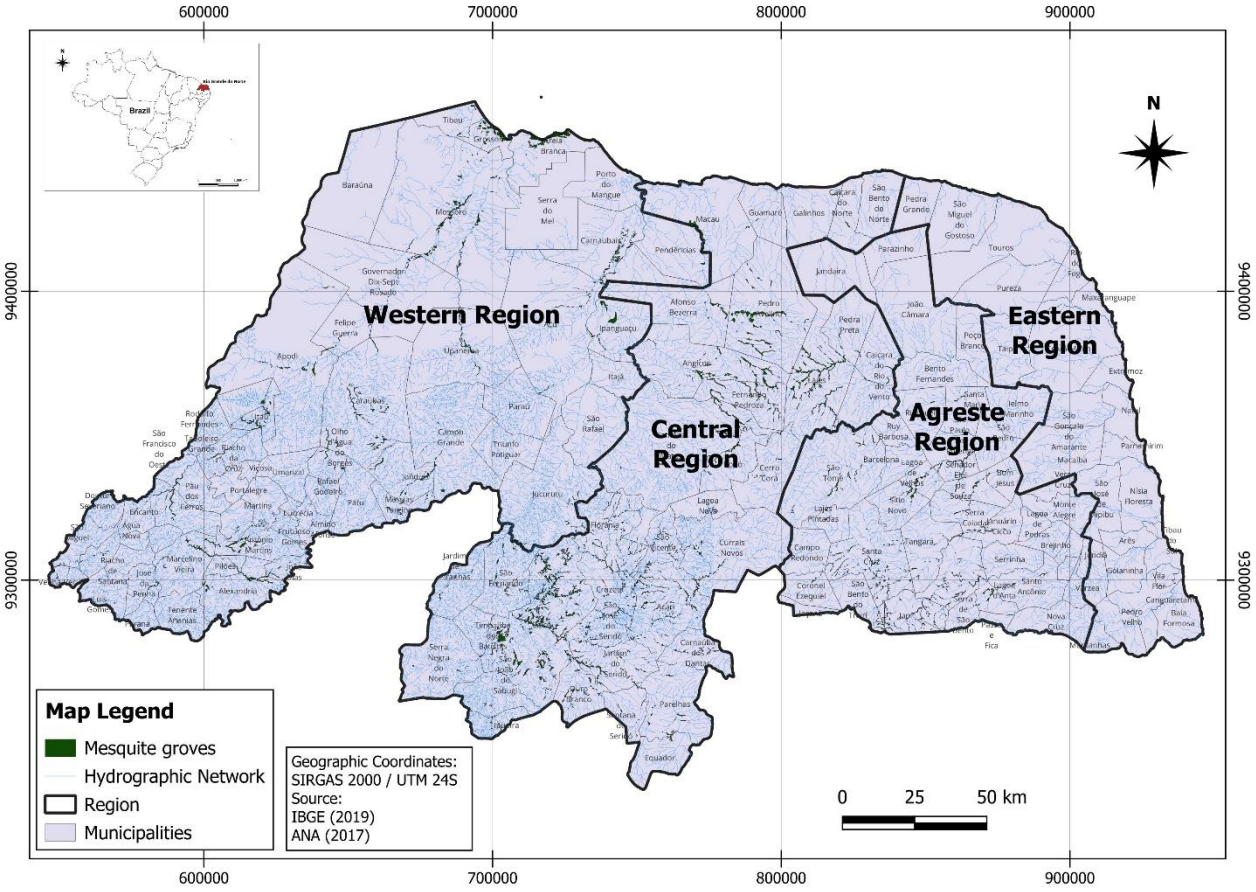
Verification of the elements interpreted in the images against reality is essential, making field recognition highly valuable for accurate identification. For this purpose, visits were made to 31 municipalities contemplating each Potiguar mesoregion: Acari, Alto do Rodrigues, Angicos, Apodi, Areia Branca, Bom Jesus, Caicó, Caraúbas, Cruzeta, Felipe Guerra, Fernando Pedroza, Florânia, Itajá, Janduís, Jucurutu, Lages, Mossoró, Natal, Nova Cruz, Olho D'agua dos Borges, Pau dos Ferros, Pendências, Santa Cruz, Santana do Matos, Santo Antônio, São Fernando, São Francisco do Oeste, São Paulo do Potengi, Senador Elói de Souza, Serra Caiada, Serra Negra, Severiano Melo, Tangará, and Timbaúba dos Batistas.

The last stage included the elaboration of mesquite maps by mesoregion and the spatial and statistical analysis of the results, including the calculation of area, frequency, and the interpretation of tabulated data in Microsoft Excel® (Microsoft Excel, 2011).

3 RESULTS AND DISCUSSION

The distribution of mesquite in the state of Rio Grande do Norte is irregular, with regions where the occurrence of *N. juliflora* is greater in surface area. The East Potiguar mesoregion showed no significant occurrence, with only isolated trees recorded (Figure 02).

Figure 02 – Distribution of the occurrence of *N. juliflora* massifs in the year 2023 in the state of Rio Grande do Norte, Brazil



Source: IBGE, 2019; ANA, 2017. Prepared by the authors (2024).

In addition, the spatial analysis shows that mesquite occupation is preferentially along watercourses, reinforcing the species' affinity for humid environments. This pattern, also reported by Terto (2023), indicates that greater water availability is a determining factor for the establishment and expansion of *N. juliflora*. In this sense, understanding the relationship between the species and the hydrographic network is essential for defining management strategies, especially in areas where invasion can compromise the regeneration of native vegetation and the dynamics of riparian ecosystems.

The data on the occurrence of mesquite in the state of Rio Grande do Norte in 2023 include the total area occupied across different Potiguar mesoregions (West, Central, and Agreste), the frequency of massifs, and the sizes of the largest and smallest massifs in each region. These indicators provide an overview of the distribution and concentration of mesquite in the state (Table 01).

Table 01 – Selected indicators of the occurrence of mesquite for the year 2023 in the state of Rio Grande do Norte, Brazil

Indicator	Potiguar Mesoregion			Total
	West	Central	Agreste	
Total area (ha)	13,072.67	22,012.80	4,866.07	39,951.54
Freq. Massifs	867	1,827	774	3,468
Largest massif (ha)	476.48	461.96	101.62	-
Smallest massif (ha)	0.08	0.01	0.06	-

Source: Prepared by the authors (2024).

The picture presented for Rio Grande do Norte, with an extension of almost 40,000 hectares of mesquite in 2023, mirrors a large-scale bioinvasion process observed throughout northeastern Brazil, in which the exotic species have shown adaptation and dispersal abilities that exceeded all initial forecasts and management strategies.

The claim that mesquite's growth occurs naturally in the absence of management plans is accurate; however, science explains its aggressiveness. The success of *N. juliflora* in the Caatinga is associated with a series of ecological characteristics, including its dispersal via endozoochory (dispersion of seeds through animal feces, especially cattle), which breaks seed dormancy when seeds are processed by the digestive systems of herbivores (Andrade et al., 2010). In addition, the species actively alters the environment to harm competitors through allelopathic effects, in which chemical compounds released by its leaves and roots inhibit germination and development of native Caatinga species (Guedes et al., 2012). This contributes to the creation of monospecific areas and a decrease in biodiversity. As a phreatophytic plant, it has an aggressive root system that reaches the water table, posing a risk to water resources in the semiarid area (Pegado et al., 2006b).

However, the dynamics of this invasion are even more complex. Terto (2023) indicates that the same exploitation that reduces areas highlights the deep and ambiguous relationship of the local community with the species in municipalities such as Ipanguaçu and Currais Novos. *N. juliflora* represents both an environmental challenge and an economic

opportunity for several rural communities, constituting an authentic socioeconomic paradox. During droughts, its pods become a vital source of food for herds, while its wood, with high calorific value, boosts the informal economy as firewood and charcoal (Souza et al., 2011). The relationship between livestock and *N. juliflora* generates a harmful cycle: herds are the primary disseminators of the invasive plant, but they also depend on it to survive during droughts. Thus, the economic activity that sustains rural families becomes primarily responsible for environmental degradation.

This complexity shows that managing *N. juliflora* cannot be simplified to eradicate or foster. The strategy most supported in the recent literature is that of integrated and adaptive management, which suggests a strategic zoning: total eradication areas in places of high priority for conservation, management areas for sustainable exploitation in regions already dominated by the species and with high economic dependence, and containment areas to slow the advance on native vegetation (Koech et al., 2011; Shackleton et al., 2014; Eschen et al., 2025). In this context, the drastic retraction observed in some Potiguares municipalities, such as the 81.45% in Ipanguaçu (Terto, 2023), should not be interpreted as a success in control, but rather as an alert of resource overexploitation, which can lead to future local energy and forage crises, showing that even intense exploration, without a management plan, does not represent a sustainable solution for invasion control.

In Rio Grande do Norte, *N. juliflora* occurs predominantly in small massifs (up to 200 ha) and is strongly connected to the hydrographic network, resulting in riparian fragmentation, especially in the Central and Western mesoregions (Table 02). Such a pattern is consistent with the hydrochory described for the genus *Neltuma* (formerly *Prosopis*) in arid and semiarid regions of other continents, reinforcing that watercourses function as a priority vector for the advancement of the species and the formation of new invasive cores (Mbaabu et al., 2019; Gebrehiwot; Steger, 2024). In different contexts, the authors observed that proximity to water bodies accelerated the expansion of *N. juliflora*, resulting in high population density and modifications in the structure of native vegetation. In addition, permanent or intermittent rivers favor the colonization of riparian fragments and the formation of continuous massifs, amplifying local ecological and water impacts and evidencing the importance of hydrological patterns in the invasive dynamics of the species.

In contrast, affected areas in East Africa and the Middle East also exhibit small linear patches along rivers and roads, whereas continuous massifs often arise in flat regions prone to homogeneous cultivation or the absence of ecological barriers (Eschen et al., 2021).

Table 02 – Frequency and area of mesquite massifs, in the year 2023, broken down by range of occurrence, in the mesoregions of the state of Rio Grande do Norte, Brazil

Range of occurrence by number	Potiguar Mesoregion					
	West		Central		Agreste	
	Freq.	Total area (ha)	Freq.	Total area (ha)	Freq.	Total area (ha)
0 to 100	849	990.73	1,795	16,386.05	773	4,764.45
101 to 200	13	1,626.56	24	3,350.79	1	101.62
201 to 300	3	660.22	6	1,464.30	0	0.00
301 to 400	0	0.00	1	349.70	0	0.00
401 to 500	2	885.16	1	461.96	0	0.00

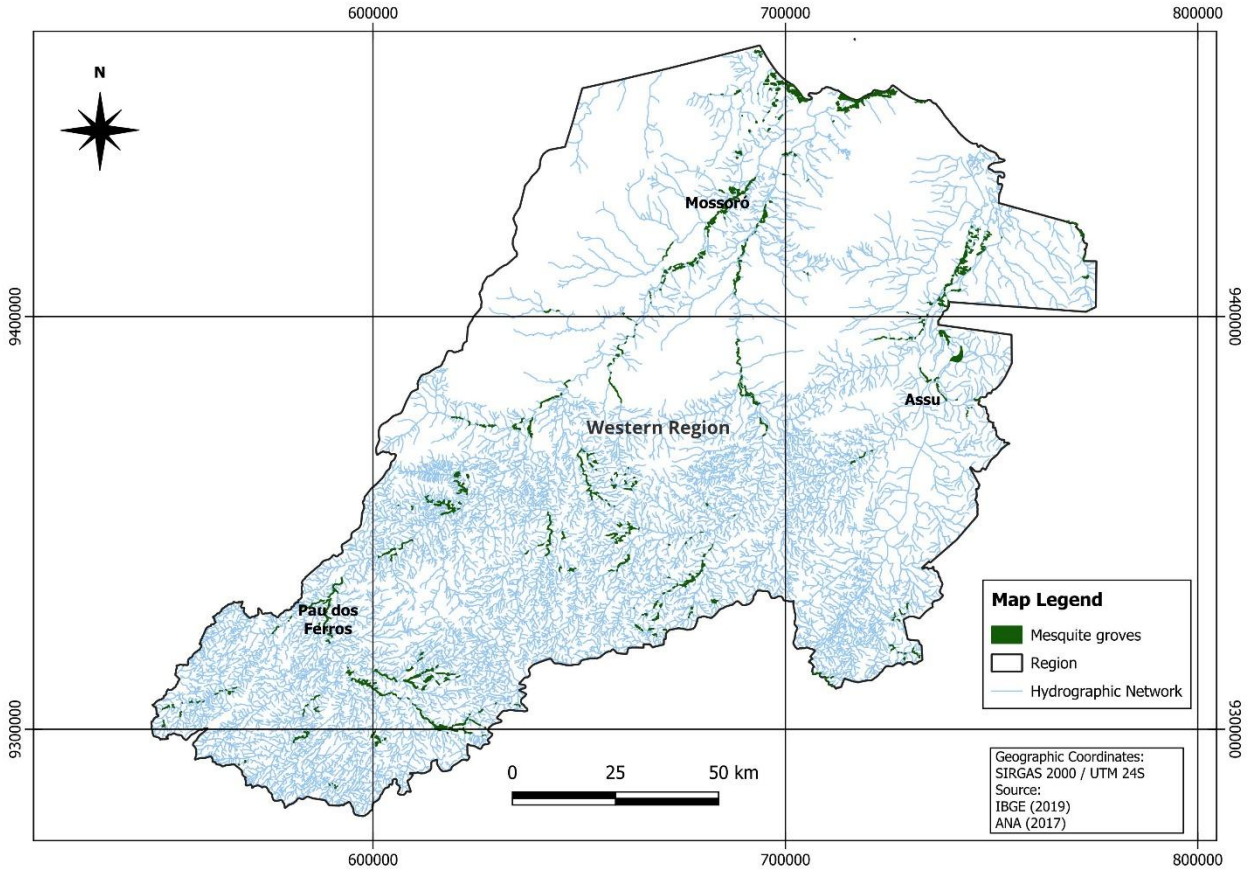
Source: Prepared by the authors (2024).

In the municipalities where coverage was reduced (such as Currais Novos, São Vicente, Tenente Laurentino Cruz, among others) due to the exploitation of firewood, the local pattern is similar to that observed in studies conducted in Africa. In these areas, the reduction in coverage can be immediate due to intensive cutting for energy use. However, in the absence of techniques that prevent regrowth of strains, the species usually reconstitutes itself and even expands along open borders (Eschen et al., 2023). Management experiments that include complete removal, stump treatment, and post-extraction restoration are more efficient in achieving lasting reductions (Kamiri et al., 2024).

Thus, the Potiguar results align with a global context in which the exploitation of firewood plays an ambiguous role. Although it can justify local falls, it does not represent a sustainable control strategy when used in isolation. In this sense, Eschen et al. (2021) and Koech et al. (2022) reinforce that, beyond mere extraction, the programs' success lies in the alignment between socioeconomic benefits and ecological recovery practices, demonstrating that isolated strategies do not guarantee lasting results. It is therefore advisable that these lessons be adopted in the management of *N. juliflora* in Rio Grande do Norte, prioritizing riparian fragmentation for monitoring and associating woody exploitation with effective regrowth control and recovery strategies for native Caatinga.

In the West Potiguar mesoregion, mesquite is predominantly distributed in the Mossoró area, where the species occurs along the Apodi-Mossoró and Carmo Rivers, and extends through their more distant tributaries. In the Assu region, the *N. juliflora* massifs follow the course of the Piranhas-Açu river, with a marked presence from the Engenheiro Armando Ribeiro Gonçalves dam, an area known as the Açu Valley (Figure 03).

Figure 03 – Distribution of the occurrence of *N. juliflora* massifs in the year 2023, in the West Potiguar mesoregion, Rio Grande do Norte, Brazil



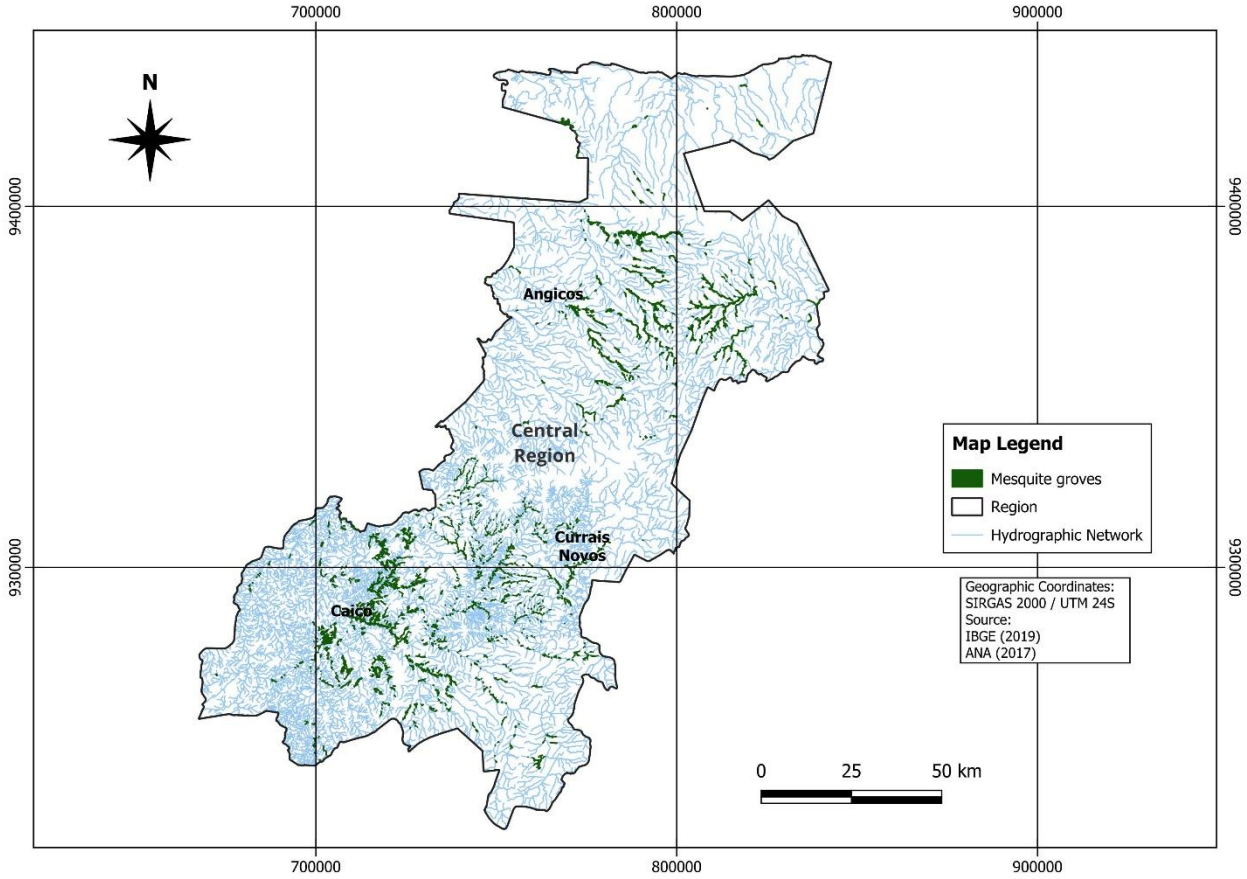
Source: IBGE, 2019; ANA, 2017. Prepared by the authors (2024).

Figure 03 shows the distribution of *N. juliflora* in the West Potiguar mesoregion, highlighting a clear and significant correlation between the species' presence and the hydrographic network. Two primary invasion cores are clearly visible. The first, located to the North, focuses on the municipality of Mossoró, where the mesquite creates linear corridors that follow the path of the Apodi-Mossoró and Carmo rivers. The second core, located to the east of the mesoregion, is in the Assu region, following the Piranhas-Açu River Valley, mainly downstream of the Armando Ribeiro Gonçalves dam.

This visual pattern reinforces the hypothesis of hydrochory (dispersion by water) as one of the vectors of the species' dissemination. In addition, the concentration in the Açu Valley, an area of irrigated agriculture and fertile alluvial soils, suggests that the combination of high water availability and soils modified by human activity creates an ideal environment for the rapid proliferation of *N. juliflora*.

Two well-defined areas of *N. juliflora* occurrence were observed in the Central Potiguar mesoregion: the Angicos and Caicó regions in the Seridó Potiguar (Figure 04).

Figure 04 – Distribution of the occurrence of *N. juliflora* massifs in the year 2023, in the Central Potiguar mesoregion, Rio Grande do Norte, Brazil



Source: IBGE, 2019; ANA, 2017. Prepared by the authors (2024).

The Central Potiguar mesoregion is the most impacted in the state in terms of total area. The map shows two distinct and relevant infestation foci. The first, located to the North, has the municipality of Angicos as its center and extends along the region's watersheds. The importance of this core is historical, as it corresponds to the area where the species was introduced experimentally in the 1940s. The persistence and density of the massifs in this region show the ability of *N. juliflora* over several decades. The second focus, located further South and with greater extension, predominates in the Seridó Potiguar region, with a significant concentration in the municipality of Caicó and adjacent areas, extending to Currais Novos. The dense presence along the Seridó rivers and their tributaries in this region

indicates a successful and expanding secondary invasion process, establishing this mesoregion as the core of the species' occurrence in the state.

The municipalities of Angicos, Fernando Pedroza, Lajes, and Pedro Avelino stood out for having the highest concentration of mesquite in the region, with Angicos as the primary point of introduction of the species in the state. According to Santos and Diodato (2017), the enthusiasm of technicians and researchers facilitated the distribution of pods and seedlings in rural properties and municipalities in the state, also counting on government incentives for production, distribution, and planting of the species. In addition, the species remains in its region of origin after more than 80 years, demonstrating its ability to adapt and persist in the local environment (Figure 05).

Figure 05 – Partial view of mesquite in the municipality of Angicos, State of Rio Grande do Norte, Brazil

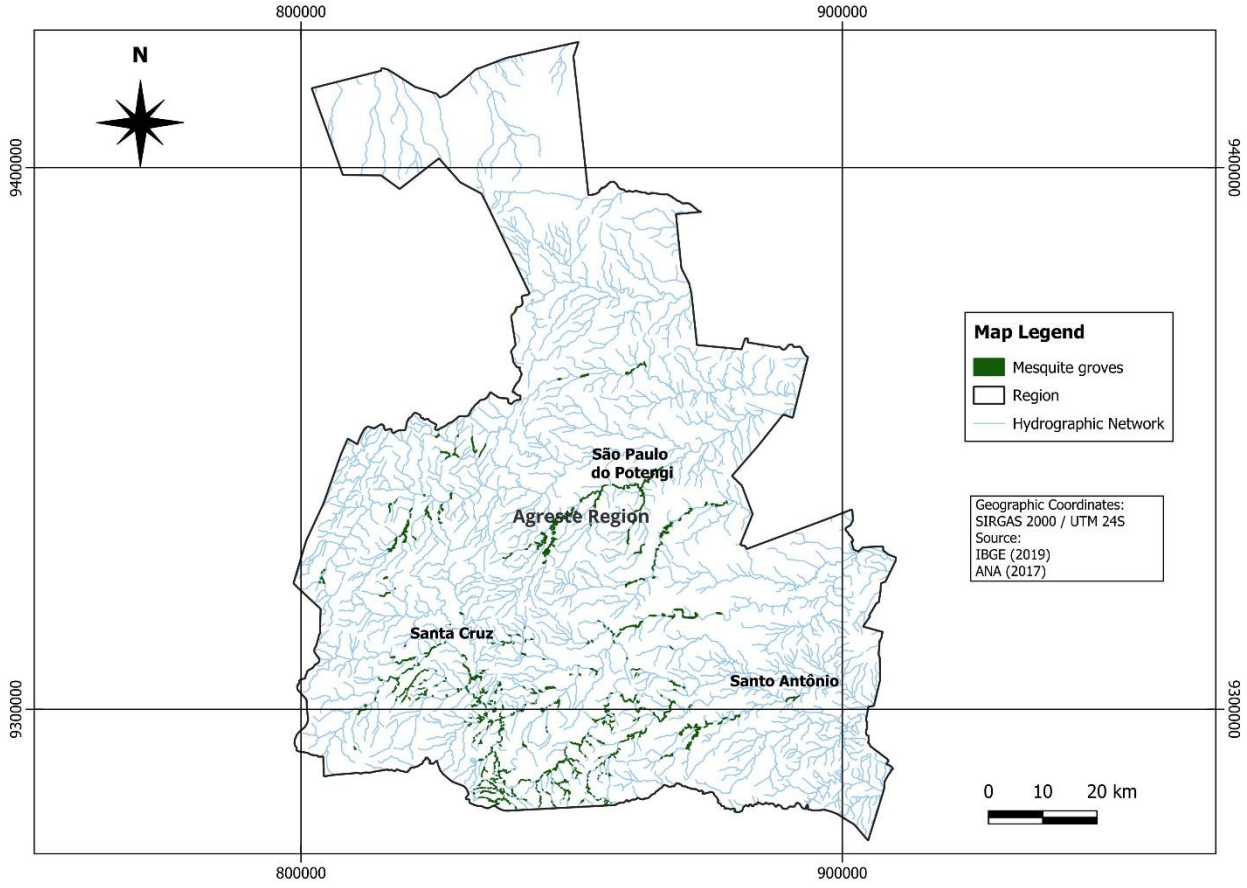
Source: Authors (2022).

In the Agreste Potiguar mesoregion, the presence of N. juliflora is relatively limited, concentrated mainly in the southern portion of the region (Figure 06). In this area, the species is relevant in the municipalities of Santa Cruz, Japi, São José do Campestre, and Monte das Gameleiras, located near the border with Paraíba.

This limited distribution suggests that the invasion front has not yet reached this area with the same intensity, or that the edaphoclimatic and land use conditions of the Agreste region may be less conducive to its large-scale expansion. The concentration at the southern border, along the waterways coming from Paraíba, where the species probably also occurs due to its dispersion pattern associated with these systems, indicates the need to consider the dynamics of invasion on an interstate scale rather than restricting the

analysis to Rio Grande do Norte. This transboundary dispersal pattern shows that invasive species control cannot be limited to administrative borders, requiring a regional strategy. This transboundary dispersal pattern shows that invasive species control cannot be restricted to administrative borders, requiring a regional strategy.

Figure 06 – Distribution of the occurrence of *N. juliflora* massifs in the year 2023, in the Agreste Potiguar mesoregion, Rio Grande do Norte, Brazil



Source: IBGE, 2019; ANA, 2017. Prepared by the authors (2024).

In addition, the lower overall density may be related to several limiting factors. From an environmental perspective, the Agreste mesoregion represents a transition area between the semiarid climate of the Sertão and the humid Zona da Mata (Ab'Sáber, 2012), exhibiting precipitation patterns and soil types that may be less conducive to maximizing *N. juliflora*'s invasive potential in relation to the conditions observed in the state's countryside. In addition, land-use and occupation systems, with possibly more diverse agriculture and less dependence on extensive livestock, which characterizes other areas, may offer fewer opportunities for endozoochoric dispersal and for the establishment of new foci. Thus, the

presence of *N. juliflora* in the Agreste Potiguar not only indicates an early stage of invasion but also highlights the region as a crucial point for monitoring dispersal vectors and applying containment measures to prevent the species from reaching the same magnitude of infestation observed in other mesoregions.

4 CONCLUSIONS

The primary implication of the results is that the expansion and fragmentation of *N. juliflora* in Rio Grande do Norte require integrated management strategies that allow the exploitation of the species to be used as an instrument of ecological control and restoration. The identified spatial patterns indicate that the species' presence is strongly linked to riparian regions, underscoring the importance of ongoing monitoring in these corridors. On the other hand, decreases in certain municipalities suggest that economic exploitation (mainly for firewood) may reduce local coverage, provided that techniques are employed to avoid regrowth.

The use of satellite images is confirmed as an essential tool for monitoring the spatial dynamics of the invasion of *N. juliflora*, as it allows the periodic updating of the maps, the detection of the expansion or retraction of the massifs, and, when necessary, the evaluation of future management measures through the continuous monitoring of the riparian corridors.

Thus, the mapping capability provided by remote sensing supports the planning of management strategies, including the identification of priority areas for control and the delimitation of regions where logging as firewood can be integrated into controlled suppression strategies.

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