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Study of green spaces of Private Natural Heritage Reserves and their surroundings in the city of Manaus, Amazon

Estudo de espaços verdes de Reservas Particulares do Patrimônio Natural e seu entorno na cidade de Manaus, Amazônia

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Abstract
The reduction of green areas in the city of Manaus has led to the increasing isolation of Private Natural Heritage Reserves (RPPNs), potentially impacting the biodiversity of these Conservation Units. We assessed the green areas of the RPPNs and their surroundings in 2019 and 2022. We quantified the green areas of the RPPNs, and classified maps were created for analysis. Seven RPPNs were included in the study, requiring the acquisition of the polygon for each area in shapefile format (.ssp) and processed in QGIS software. A buffer of 1000 and 2000 meters from a centroid was applied to obtain a wide analyzable area. The images obtained from Planet Labs for the years 2019 and 2022, making a mosaic to join the bands and generate a single image. The classification applied included supervised and unsupervised methods, using SAGA GIS software. The map created revealed significant reductions in green areas around the RPPNs. The use of supervised classification using the maximum likelihood method made it possible to distinguish and verify the changes in green areas in the RPPNs and their surroundings. Significant reductions in the green areas around the RPPNs in the urban area of Manaus stand out, made possible by analysis and classification using the maximum likelihood method.

Keywords: RPPN, Image classification, Urban expansion.

Resumo
A redução das áreas verdes na cidade de Manaus tem levado ao isolamento cada vez maior das Reservas Particulares de Patrimônio Natural (RPPNs), impactando potencialmente a biodiversidade dessas Unidades de Conservação. Avaliamos as áreas verdes das RPPNs e seu entorno nos anos de 2019 e 2022. Quantificamos as áreas verdes das RPPNs e mapas classificados foram criados para análise. Sete RPPNs foram incluídas no estudo, requerendo a aquisição do polígono para cada área em formato shapefile (.ssp) e processadas no software QGIS. Um buffer de 1000 e 2000 metros de um centroide foi aplicada para obter uma ampla área analisável. As imagens obtidas do Planet Labs para os anos 2019 e 2022, realizando um mosaico para unir as faixas e gerar uma única imagem. A classificação aplicada inclui os métodos supervisionados e não supervisionados, utilizando o software SAGA GIS. O mapa criado revelou significativas reduções nas áreas verdes nos entornos das RPPNs. O uso da classificação supervisionada pelo método de máxima verossimilhança permitiu a distinção e verificar as mudanças das áreas verdes nas RPPNs e seus entornos. Destacam-se significativas reduções nas áreas verdes em volta das RPPNs em área urbana em Manaus, possibilitada por meio da análise e classificação pelo método de máxima verossimilhança.

Palavras-chave: RPPN, classificação de imagens, expansão urbana.

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1. Introduction

Instituted in 1990 by federal decree 98914/1990 and amended by the decree 1922/1996 (Brasil, 1996) Private Reserves of Natural Heritage (RPPNs), are private areas transformed into conservation areas by their landowners (Nascibem et al., 2023). RPPNs were officially recognized as Sustainable Use Conservation Units from the year 2000, through the enactment of Law 9.985, which established the National System of Conservation Units (SNUC, in Portuguese) (Brasil, 2000). Subsequently, the federal government consolidated and regulated this category with the publication of Decree 5.746 in 2006.

This legislative evolution reinforced the essential role of RPPNs in environmental preservation, providing a solid legal framework for their sustainable management and significantly contributing to biodiversity protection across the national territory (IBAMA, 2004). In national context, the RPPNs are not equally distributed across the Brazilians biomes, when compared with others unites conservation areas. Just 15 in Pantanal (1%), 23 in the Pampa (3%), 56 in the Amazon (8%), 86 in the Caatinga (11%), 193 in the Cerrado (24%), and 623 in the Atlantic Forest (53%) (Nascibem et al., 2023)

RPPNs are classified as Integral Protection by National Law of Conservation Law of Units (Brasil, 2000), which means that their use is more restricted when considering sustainable units' conservation areas. Once established by public authorities, the RPPN will have a perpetual and inalienable nature. Therefore, if there is a sale, donation, or partition of the land, future owners must commit to its management and objectives.

Thus, for compensate landowners to do not explore RPPN's resources, there are mechanisms as economic and tax benefits, that incentives its conservation recognized as a type of payment for ecosystem services (PES) (Calvet-Mir et al., 2015; Grima et al., 2016; Salzman et al., 2018). However, the PES is little known and explored as a government strategy to promote the creation of RPPNs in Brazil (Silva et al., 2016).

According to the SNUC, the main objectives of Conservation Units (CUs) are the maintenance and valorization of biological diversity, the protection of threatened species and water and soil resources, the preservation and restoration of ecosystems, the promotion of sustainable development, the protection of natural landscapes and regional historical-cultural heritage, and the promotion of opportunities for research and ecological recreation (Mendo et al., 2006).

Activities such as research, tourism, and recreation in RPPNs are allowed, provided they do not result in environmentally harmful alterations. Therefore, it is crucial for the legal custodians of these areas to conduct rigorous monitoring, ensuring the preservation of the environment and compliance with established guidelines (Souza et al., 2012).

RPPNs are important instruments for biodiversity preservation, allowing landowners to contribute voluntarily to environmental conservation. When designated as RPPNs, landowners commit to maintaining the integrity of local ecosystems, playing a crucial role in protecting threatened species and promoting sustainable practices.

Worldwide Private Land Conservation Areas (PLCA) has demonstrated the importance and efficaciousness in maintaining natural land cover and biodiversity. For instance, in South Africa Shumba et al. (2020) point out that they are meeting the deficit left by the state-owned protected areas in reaching global conservation goals. Between 1990 and 2013, PLCAs lost significantly less natural cover (3%) and biodiversity intactness (2%) than unprotected areas (6% and 4% respectively). In Germany, in line

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with Target 3 of the Kunming-Montreal Global Biodiversity Framework, the European Union (EU) aims to protect 30% of its land and sea by 2030 (known as 30x30) (Kopsieker & Disselhoff, 2023). As shown by studies in Brazil, RPPNs promote the conservation of the forest fragmentation, protection of threatened species, development the scientific studies, as well as the environmental conscience by ecotourism (Allendorf et al., 2022; Lima & Franco, 2014)

In Manaus, both in the urban and rural environments, it is possible to find various green spaces that play a fundamental role in environmental preservation. The city, located in the heart of the Amazon Rainforest, houses a variety of Conservation Units (CU), which was divided between those of integral protection and sustainable use. Among these, the Private Natural Heritage Reserve (RPPN, in Portuguese) stands out.

The Municipal Government of Manaus has the legal prerogative to recognize private areas as RPPNs according to Law 886 of 10/14/2005 (Manaus, 2005). In the city of Manaus, there are seven existing RPPNs, protecting an area equivalent to 240.89 hectares: the Honda Reserve, Buritis Reserve, Norikatsu Miyamoto Reserve, Águas do Gigante Reserve, Bons Amigos Reserve, Sócrates Bonfim Reserve, and Nazaré das Lajes (Semmas, 2024).

Within the urban perimeter of Manaus, RPPNs face various threats that manifest both in their surroundings and within their boundaries. Among these concerns, notable challenges include land invasions and illegal appropriation, illicit practices, deforestation, hunting of wildlife, and contamination of water sources. These activities pose significant challenges to the integrity of these conservation areas, requiring a comprehensive and coordinated approach for their mitigation and prevention (Silveira et al., 2022).

To better understand the challenges that may arise in CUs, various measures can be taken to strengthen the protection of these areas. Among these strategies, initiatives involving remote sensing and Geographic Information Systems (GIS) stand out. The use of these technologies enables a more precise and comprehensive analysis of the environment, allowing for the efficient identification of changes and threats.

Deforestation taxes in the Amazon Legal measured by the National Institute for Space Research has demonstrated the loss forest cover have been increased significantly in 2017 from 7.100 km^2 to 12.700 km^2 in 2022 (INPE, 2024), contributing for the fragmentation of the biome (Montibeller et al., 2020). The Amazon state occupies the third largest in deforestation with 16.760,69 km^2 (13,04%) of total in 2023.

Regular monitoring through high-quality satellite imagery is a valuable tool for assessing the state of CUs over time. These images provide a comprehensive and detailed view, facilitating the detection of significant changes, such as deforestation, variations in vegetation cover, and other activities that may compromise the integrity of the protected area.

Moreover, the pivotal role of investigations and inspections conducted by relevant authorities extends to both the confines of CUs and their surroundings. These actions not only identify potential infractions such as invasions and illegal activities but also contribute to deterring and holding offenders accountable, strengthening the effectiveness of conservation policies.

Among the incentives for the creation of RPPNs, priority access to government funding sources stands out, along with the possibility of receiving financial support from non-governmental organizations (NGOs) and the assurance of greater legal protection for the land (de Vasconcellos Pegas & Castley, 2016). This facilitates the study and recommendations in accordance with the purpose of the RPPN.

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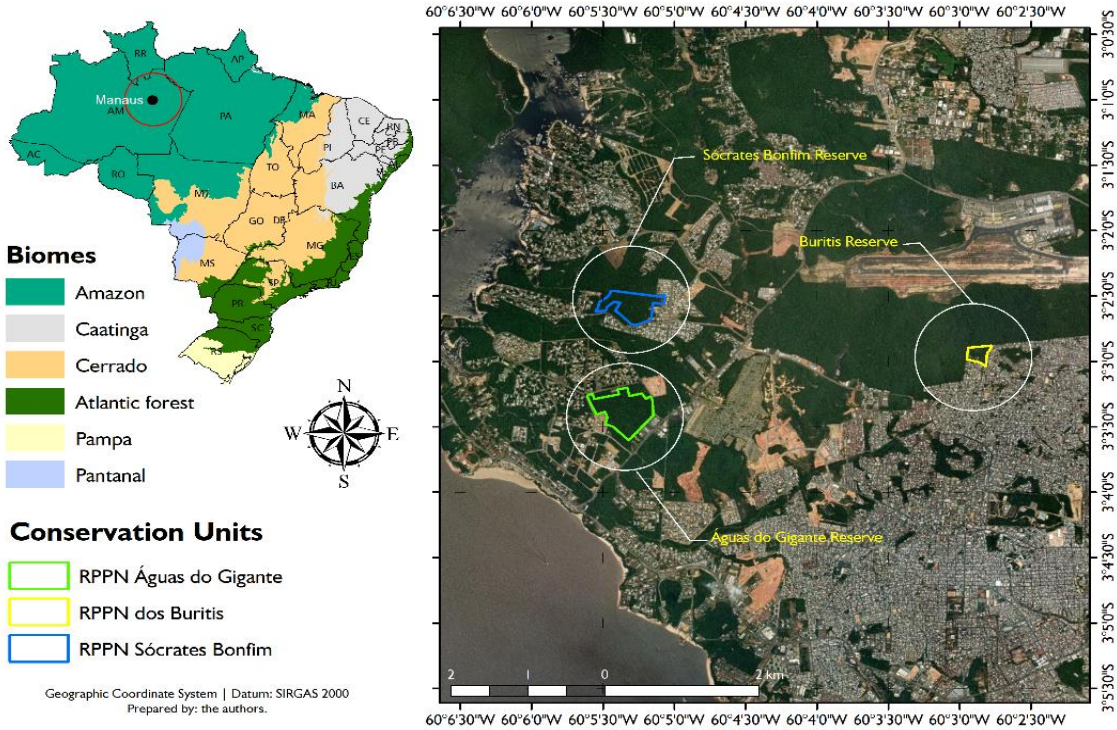
In this way, through remote sensing tools, we aimed to assess the green areas of RPPNs and their surroundings between 2019 and 2022. Additionally, efforts were made to classify these areas by creating maps that highlighted regions covered by vegetation and other characteristic elements of RPPNs.

2. Materials and Methods

2.1 Study site

The RPPNs are distributed in both urban and rural areas under municipal management in the city of Manaus. This city, located in the Northern region of Brazil, is the capital of the state of Amazonas, the largest state in the country. Its geographical coordinates are approximately 03º06'07" S latitude and 60º01'30" W longitude, at an altitude of approximately 92.9 meters (IBGE, 2024) . In the urban zone, the RPPNs are situated in the West and Center-West Zones (Figure 1) and the East Zone.

Figure 1. Distribution of the RPPNs in the West and Center-West Zones.



Source: Own elaboration with data from the Chico Mendes Institute for Biodiversity Conservation - ICMBio.

In the rural zone of the city of Manaus, the RPPN occupies positions along the State Highway AM-010 and the Federal Highway BR-174. Through the respective decrees outlined in Table 1, the motivations underlying the creation of these UCs were delineated. The primary purpose of the Honda Reserve and Buritis Reserve is the protection and preservation of natural resources, as well as the conservation of biodiversity within their areas. On the other hand, the Águas do Gigante Reserve, Sócrates Bonfim Reserve, and Nazaré das Lages Reserve aim at the integral protection and preservation of the natural ecosystem. Additionally, they seek to provide refuge for local

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fauna and flora, as well as protect the springs and areas of permanent preservation within their internal territories.

The Norikatsu Miyamoto and Bons Amigos Reserves have the primary objective of ensuring the integral protection of natural ecosystems and preserving the genetic resources of flora and fauna, with special attention to the pied tamarin, *Saguinus bicolor*. These areas aim to provide a conducive environment for scientific research, as well as for the development of educational activities and environmental interpretation. Furthermore, they seek to promote nature-based recreation practices and eco-tourism.

Table 1. Municipal Managed RPPNs in the city of Manaus.

Name of RPPN	Area (ha)	Establishment	Owner	Address	Reference
Honda Reserve	16.40	Decree 8.501, June 5 2006	Moto Honda da Amazônia Ltda	Bairro Colônia Japonesa	Manaus (2006)
Buritis Reserve	5.50	Decree 9.243, September 3 2007	Francisco de Paula Empresa T. Loureiro	Bairro Redenção	Manaus (2007)
Águas do Gigante Reserve	35.10	Decree 9.645, June 27 2008	Broker: Sr. Augusto Loreiro	Condomínio Alpha Ville – Estrada do Turismo	Manaus (2008a)
Norikatsu Miyamoto Reserve	76.90	Decree 9.503, March 6 2008	Norikatsu Miyamoto	AM010 Highway, km 33	Manaus (2008b)
Bons Amigos Reserve	31.97	Decree 9.854, December 26 2008	Sr. Marcos	BR 174, km 15	Manaus (2008c)
Sócrates Bonfim Reserve	23.00	Decree 0152, June 8 2009	Selma Bonfim e Arnaldo	Condomínio Praia dos Passarinhos – Estrada do Turismo.	Manaus (2009)
Nazaré das Lajes Reserve	52.60	Ibama Ordinance nº049/95 Decree 9.844, December 22 2008	Brazil SGI	Avenida Desembargador Anísio Jobim, km 11 – Colônia Antônio Aleixo	Manaus (2008d)

Source: Own elaboration with data from Manaus (2006, 2007, 2008a, 2008b, 2008c, 2008d and 2009)

In the creation of the maps, the images were acquired through the Planet interface. In this process, seven strips of images were selected, covering the areas of RPPNs: five

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from 2019 and two from 2022. The adopted criterion was always to prioritize cleaner images with fewer clouds and elements that could impact the accuracy of green space quantification.

To conduct the analysis of the seven image strips, it was essential to obtain the polygons of each region, achieved through the information contained in the decrees and provided by SEMA-AM. These polygons were processed in shapefile format (.shp) using the QGIS software.

When dealing with relatively compact areas, it was crucial to create a buffer of 1000 meters from a central point, expanding the analysis area. An exception was made for the Norikatsu Miyamoto RPPN, which required a 2000-meter buffer due to its size. In this case, the standard methodology was maintained. This approach allowed for a comprehensive visualization of the distribution of RPPNs within the perimeter of the city of Manaus.

After delineating the areas of interest, images from Planet Labs for the years 2019 and 2022 were acquired and presented in the form of strips. While some of these strips completely covered the areas of interest, in others, it was necessary to carry out a mosaic process to merge strips and create a single image. This procedure was executed meticulously, always maintaining projection conformity to ensure compatibility between the images.

To optimize image processing, the areas of interest were carefully delineated using the layer clipping technique, considering the buffer polygon. A clipping tool was employed, applying detailed specifications to ensure precise delineation.

A classification is a procedure that involves extracting information from images to identify patterns and homogeneous areas, used to map specific regions of the Earth's surface related to the topics of interest. This approach involved quantifying areas of forest, non-forest vegetation, urban or anthropized areas, and hydrography, considering the number of pixels associated with each class. Although the technique of visual interpretation is widely used, there is a growing preference for the use of computational classification due to its speed and ease in obtaining results (Crósta, 1992).

Classification is divided into two approaches: supervised and unsupervised, depending on the algorithm to be used. In both cases, the process involves two essential steps: the training phase and the classification phase (Moreira, 2011).The software used to conduct the classification was SAGAGIS, which offers various tools for this purpose. In the scope of this study, the technique of Maximum Likelihood Classification (Maxver) was chosen.

The Gaussian Maximum Likelihood Classifier (Maxver) is based on the use of spectral and spatial information of each pixel, approaching them statistically. This method infers the probability of an unknown pixel belonging to a specific class based on the identified and provided samples during the collection and training phase. Maxver operates as a parametric algorithm, associating classes by considering individual points of the image. It assumes that these classes follow a normal distribution, based on predefined parameters and a representative sample of acquired pixels (Leite & Rosa, 2012; Silva et al., 2011).

To perform the classification, it was necessary to mark the data on the image, creating various polygons indicating the different classes. These marked areas were referred to as training areas, serving as samples for the classifiers. Subsequently, the images were interpreted on the computer screen, where a part of the study area was selected to understand the physical and anthropic characteristics. This pilot area was

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chosen as a comparison standard (ground truth) for the subsequent supervised classification of urban targets.

For more precise identification of areas, Google Earth and Google Maps were particularly effective tools, providing greater accuracy in the specific delineation of each class.

Finally, the decision function for the Maximum Likelihood classifier was employed. In other words, this set of algorithms uses the mean and covariance of the samples to assign an identified class to an unknown pixel. Based on these parameters, the statistical probability of a pixel belonging to a particular class is calculated. After analyzing this probability for each class, the pixel is assigned to the class with the highest probability or, in some cases, no class is assigned (Ribeiro, 2003).
The decision function for the Maximum Likelihood classifier is given by:

$$G_i(x) = \frac{-1}{2} ln \left| \sum_i \right| - \frac{1}{2} (X - \mu_i)^T \sum_i^{-1} (X - \mu_i)$$

Where:
μi is the mean vector
Σi is the matrix of covariance

3. Results

The most significant reductions in green areas, recorded between 2019 and 2022, were observed in the vicinity of the Sócrates Bonfim Private RPPN, decreasing from 73.16% to 64.41%, and in the Águas do Gigante RPPN, decreasing from 64.85% to 59.35%, as shown in Table 1.

In the context of anthropized areas, an increase was noted between 2019 and 2022 in the RPPNs, with the Sócrates Bonfim RPPN increasing from 26.84% to 35.59%, the Águas do Gigante RPPN from 35.15% to 40.64%, and the Honda RPPN from 57.80% to 66.06%, as detailed in Table 1. This variable encompasses constructions, residences, roads, streets, football fields, sandy areas, exposed soils, and civil structures, among others.

In the Nazaré das Lages RPPN, a less pronounced decrease in green areas in its surroundings deserves attention, with a smaller percentage reduction from 66.07% to 66.83%, as indicated in Table 1. In the scope of this study, green areas were understood as both primary and secondary vegetation.

Regarding the analysis of hydrography, the Nazaré das Lages, Honda, and Bons Amigos RPPNs were recorded and examined. Surprisingly, in the Honda RPPN, a significant difference was observed during the study period, decreasing from 8.43% to 1.69%. It can be inferred that, during image processing, the classifier erroneously identified the pixel value of anthropized areas as part of the hydrographic area in 2019. In circumstances like this, it is possible that pixel values were very close, obscuring the actual classification. Another hypothesis for the variation in hydrography percentages may be associated with the seasonal cycle, highlighting periods of dry and wet seasons, as presented in Table 2.

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Table 2. Percentage quantification of green areas in RPPNs and their surroundings during the period of 2019 and 2022

	Green Area (%)		**Anthropized (%)**		**Hydrography (%)**	
	2019	2022	2019	2022	2019	2022
Nazaré das Lages RPPN	66.07	66.54	15.06	13.90	18.87	19.56
Buritis RPPN	56.45	58.34	43.55	41.66	-	-
Sócrates Bonfim RPPN	73.16	64.41	26.84	35.59	-	-
Águas do Gigante RPPN	64.85	59.35	35.15	40.65	-	-
Honda RPPN	33.77	32.25	57.80	66.06	8.43	1.69
Bons Amigos RPPN	77.11	74.98	21.02	22.97	1.87	2.05
Norikatsu Miyamoto RPPN	77.45	75.83	22.55	24.17	-	-

Source: Own elaboration with data from images obtained from Planet Labs for the years 2019 and 2022.

In the overall context, the green areas within the scope of the RPPNs showed no significant changes between 2019 and 2022. However, more pronounced changes were observed in their surrounding areas. In the Águas do Gigante RPPN, a considerable increase in anthropized area was evident, attributed to continuous urban growth in its vicinity. Within the RPPN, there was an increase in the construction of houses and buildings within the condominium where it is located (Figure 2).

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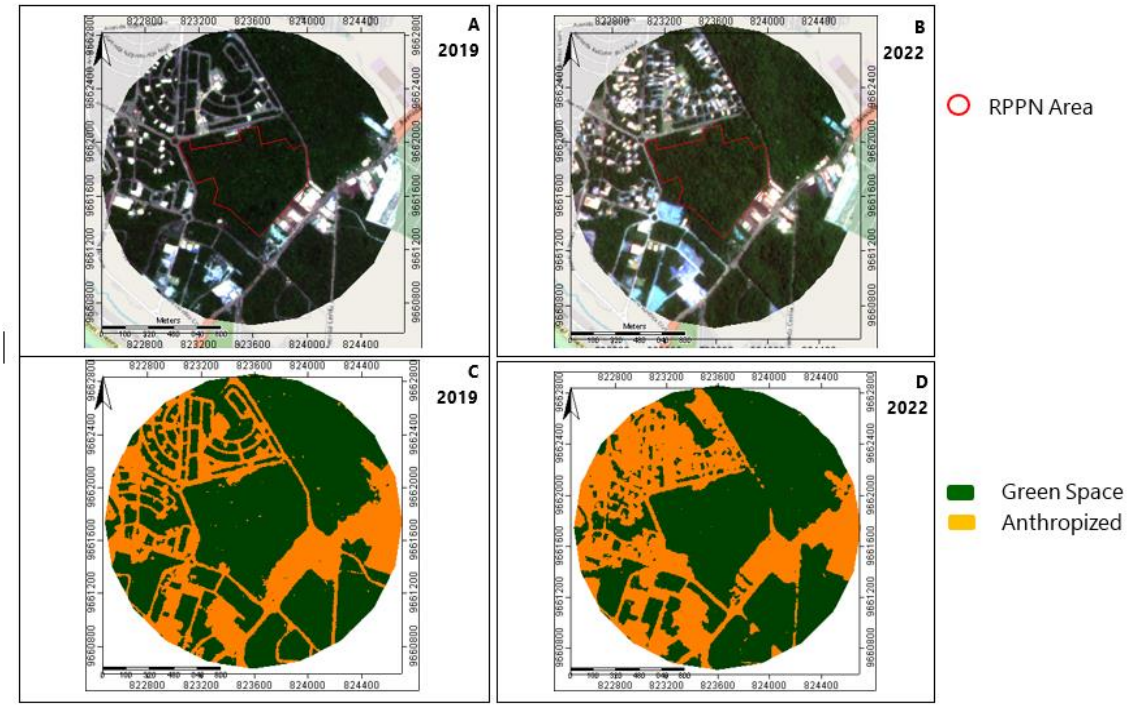
Figure 2. Águas do Gigante RPPN – Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

In the Bons Amigos Private Natural Heritage Reserve (RPPN), the preservation of green areas was sustained from 2019 to 2022. Located in a rural region near the BR-174 road, the RPPN stands out as a biodiversity oasis. In 2022, the image analysis revealed a notable interference from clouds; however, a discreet advance of human occupation in the vicinity was detected, as evidenced in Figure 3.

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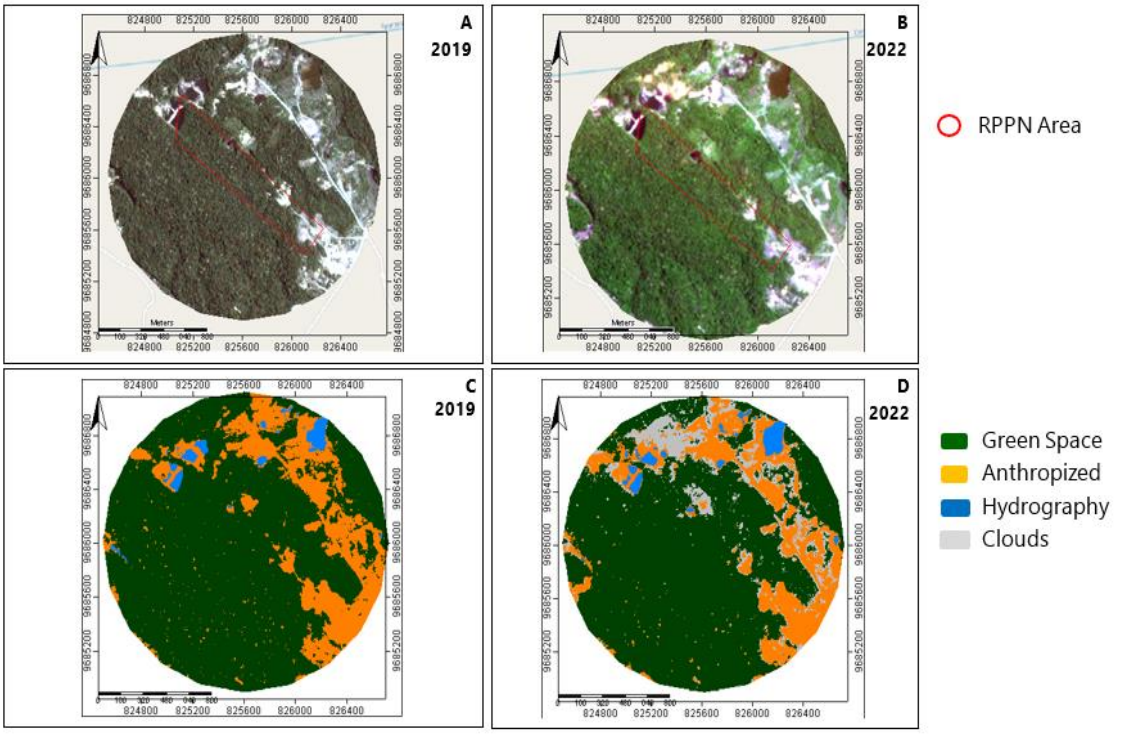
Figure 3. Bons Amigos RPPN – Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

In the Private Natural Heritage Reserve (RPPN) dos Buritis, located in the Redenção neighborhood, a significant increase in green area was recorded during the year 2022. In this perspective, it can be inferred that in 2019, the image of the surroundings of the RPPN was more evident, revealing a greater exposure of the soil, a condition not replicated in the visual representation of 2022, as illustrated in Figure 4.

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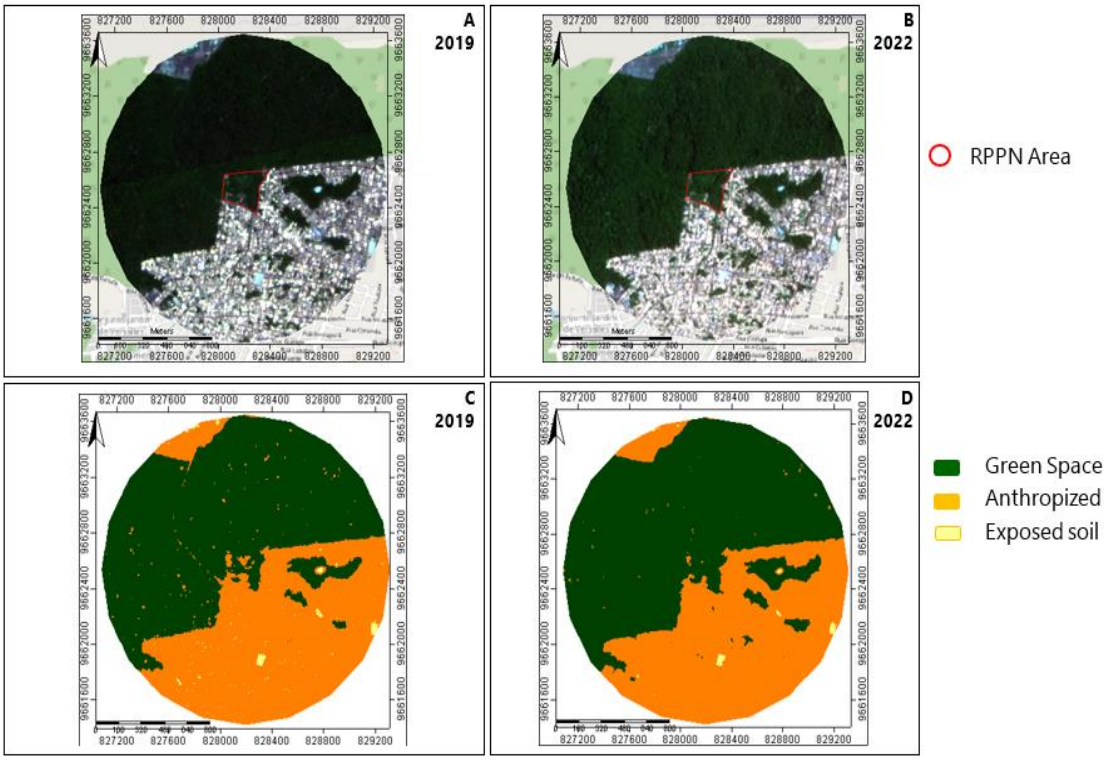
Figure 4. Dos Buritis RPPN – Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

The visual representation of the Honda RPPN showed inaccuracies in 2019, as the classifier erroneously identified segments of the anthropized area as part of the hydrography. This inconsistency can be largely attributed to the proximity of pixel values from the stream with those of some parts of the anthropized area. Additionally, it is plausible to consider that the dry period of the Amazonian summer contributed to the reduced flow of some streams, which may have influenced the misclassification. This scenario is clearly illustrated in Figure 5.

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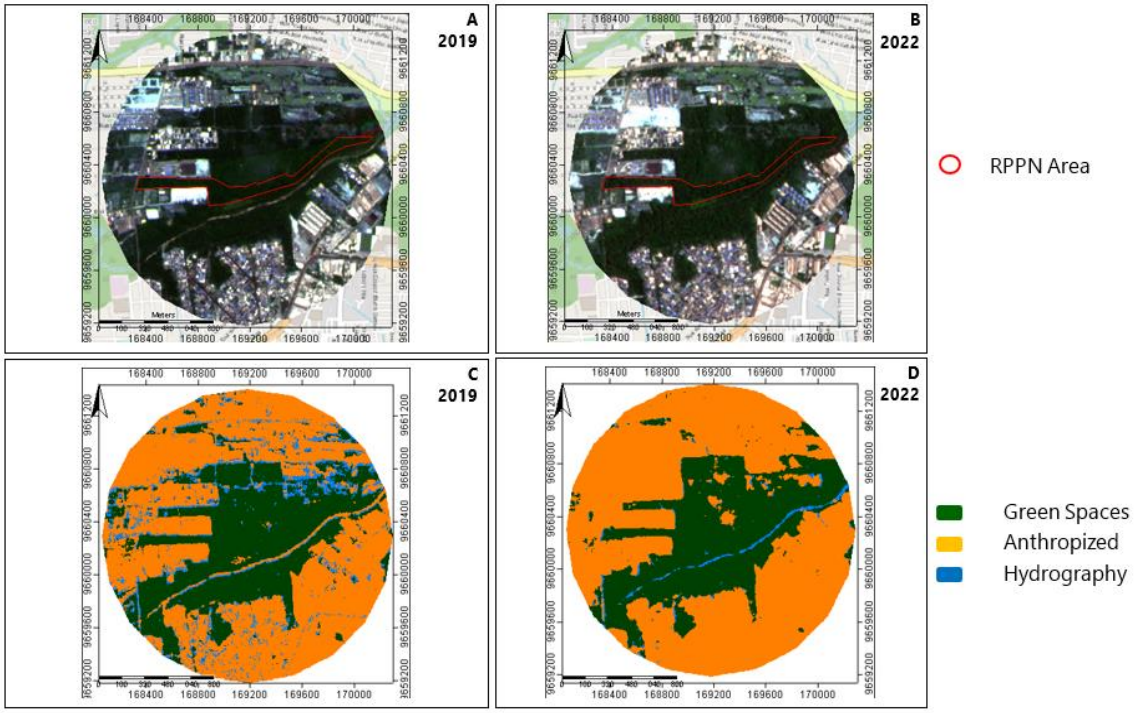
Figure 5. Honda RPPN – Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

The Nazaré das Lages RPPN showed a minimal decrease in green areas within its boundaries between 2019 and 2022. Located in the rural zone and near the Rio Negro, the RPPN reveals, through image analysis, a variable hydrology subject to direct influences from the flood and ebb periods, characteristic fluctuations of the region. There is also a notable increase in secondary vegetation around the reserve, indicating the reduction of primary forest and the emergence of secondary vegetation with lower diversity, as illustrated in Figure 6.

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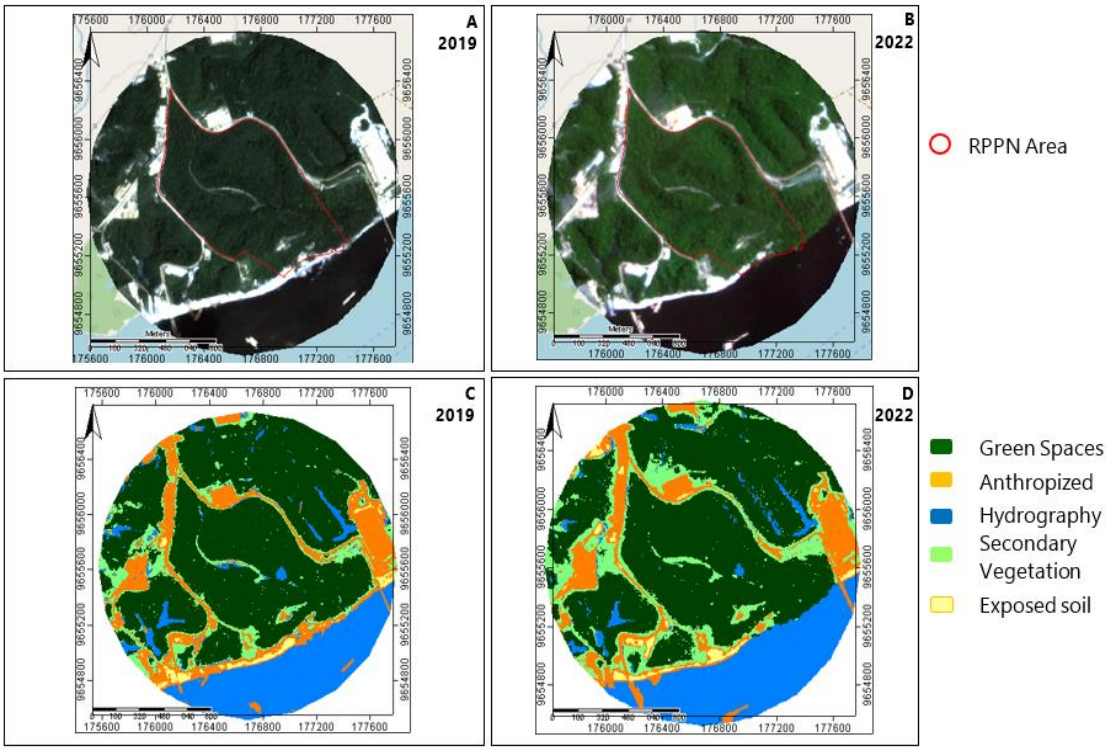
Figure 6. Nazaré das Lages RPPN– Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

The Norikatsu Miyamoto RPPN, located in the rural zone, showed a subtle increase in anthropic activities, consequently leading to a discreet reduction in green areas in its surroundings. This phenomenon is possibly correlated with the growth of settlements and land invasions, as illustrated in Figure 7.

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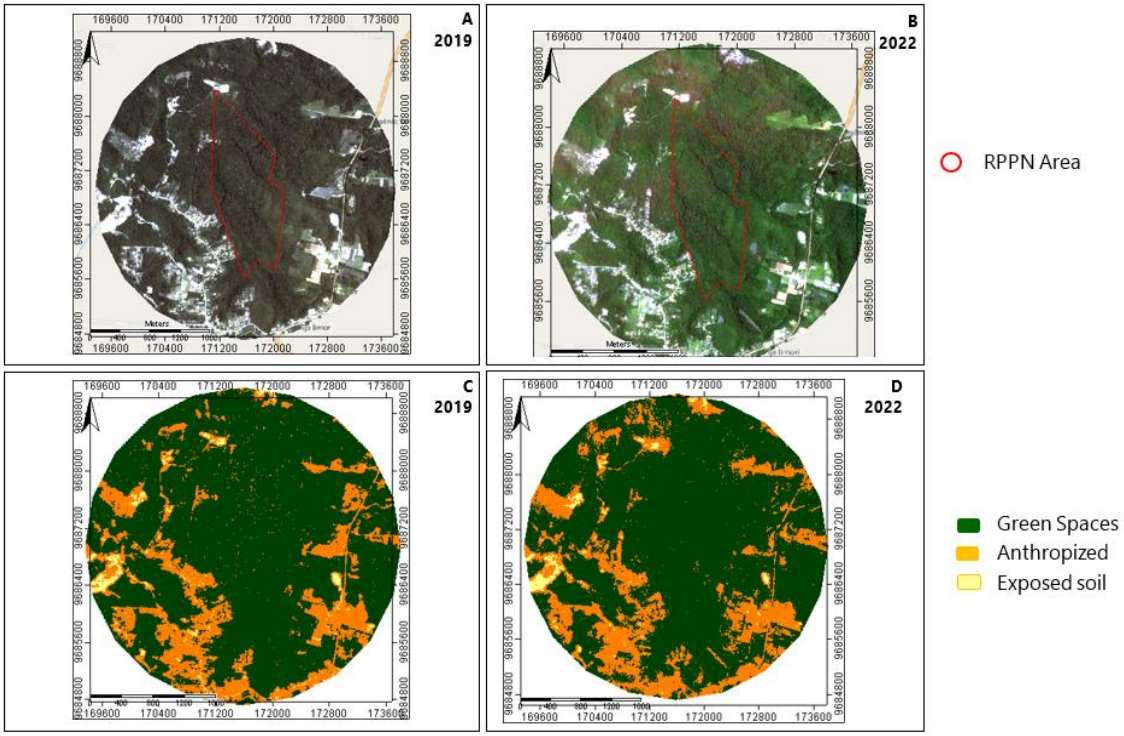
Figure 7. Norikatsu RPPN – Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

Despite the visual interferences caused by clouds and shadows in the images, the increase in urban development around the Sócrates Bonfim Private Natural Heritage Reserve (RPPN) became evident during the study period. This observation is justified by the presence of anthropized areas and exposed soils, indicating a notable human pressure on the green areas of the reserve and, consequently, on its entire biodiversity, as illustrated in Figure 8.

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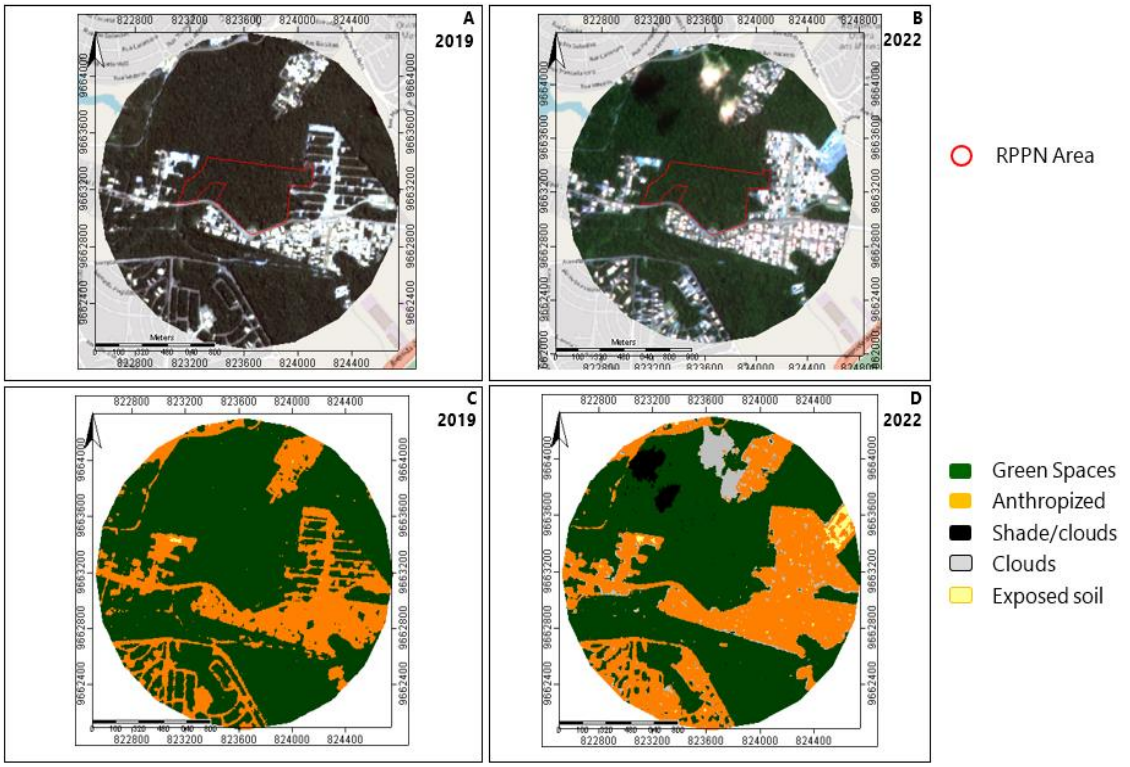
Figure 8. Sócrates Bonfim RPPN – Unclassified Maps A and B; Classified Maps C and D.



Source: Own elaboration with image data obtained from Planet Labs for the years 2019 and 2022.

4. Discussion

The Sócrates Bonfim and Águas do Gigante RPPNs are located within condominiums in the upscale area of the city. These areas have experienced significant changes in their green spaces, especially in the surrounding areas, due to the expansion of construction and increased buildings in the vicinity. This phenomenon has resulted in the reduction of green areas and an increase in anthropized areas.

The expansion of the urban area of Manaus is the result of the significant demographic growth within the city in recent decades. Similar to other major Brazilian cities, the lack of systematic urban planning and effective control over urban development has led to serious environmental problems. The significant population concentration in the East and North zones, for example, has contributed to the intensification of issues related to disorderly land use, degradation of vegetation cover, water body pollution, and deficiencies in basic sanitation (Nogueira et al., 2007).

In 2019, the city had a population of 2,182,763 inhabitants, while in 2021, Manaus experienced population growth, reaching an estimated 2,255,903 people (IBGE, 2024). Due to the environmental changes linked to this expansion of the urban area of Manaus, there is a continuous and progressive deforestation process observed in both its urban core and peripheral areas.

The RPPNs located within the urban perimeter of Manaus can be considered as forest fragments. These fragments face direct impacts, especially from edge effects, where native species of fauna and flora become progressively isolated, subject to the

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pressure of human influence, wind effects, the presence of invasive species, and urban lighting, among other factors.

A crucial aspect to highlight is the reduction of green areas, putting wildlife at an increasing risk of extinction due to the scarcity of food, shelter, and their progressive isolation. This study pointed out that the Honda RPPN, Buritis RPPN, Águas do Gigante RPPN, and Sócrates Bonfim RPPN recorded the highest percentages of reduction in green areas in their surroundings, making them more isolated and vulnerable.

Habitat destruction, resulting from deforestation processes, stands as one of the main threats to biodiversity (Sodhi & Ehrlich, 2010). This concern is particularly emphasized due to the decrease in green areas available for wildlife and the increasing isolation of populations occupying these impacted areas.

Some issues are intrinsically linked to the process of fragmentation, with the edge effect of the area being particularly noteworthy. In general, smaller areas will have a reduced capacity to sustain populations of various species of fauna and flora, potentially leading to the local extinction of these populations, influenced by random demographic and environmental events (Laurance & Vasconcelos, 2009).

The edge effect, an intrinsic issue, results in the modification of environmental conditions in fragments, consequently affecting the persistence of populations (Murcia, 1995). More exposed edges become more susceptible to abiotic effects, such as increased temperature and wind action, resulting in a higher rate of tree fall and mortality (Lovejoy et al., 1986). Additionally, there is a change in microclimate due to external influences, such as temperature, which differs from the interior of the forest.

The RPPNs Bons Amigos, Norikatsu Miyamoto, and Nazaré das Lages are located in the rural zone of the city of Manaus. Their forests maintain a connection with other areas of primary forest; however, they face distinct pressures compared to the urban area. These pressures include land use for resorts, land subdivision, establishment of sites, and even invasions.

In a study conducted by Freitas (2011), the identified problems in the Nazaré das Lages RPPN were listed. These include anthropic actions resulting from urban expansion, the installation of companies in the Industrial District II (on Suframa's lands), the fragmentation of water bodies, and the clandestine entry of residents from surrounding occupations.

According to Freitas (2011) , one of the crucial challenges in the management and administration of RPPNs is the lack of financial support, directly impacting investments in infrastructure. Additionally, there is a gap in the implementation of effective environmental control, as the RPPNs themselves are directly responsible for monitoring their areas.

In this study, it was found that within the scope of the RPPNs, there were few changes in green areas. However, in the surroundings of these reserves, green areas were significantly reduced due to urban expansion, resulting in the increasing isolation and/or fragmentation of RPPNs.

Despite the challenges faced by owners to maintain the preservation of RPPNs, it is understood that the mere status of a reserve already contributes to the protection of their properties and their attributes (Freitas, 2011).

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5. Conclusions

RPPNs play a vital role in the conservation of biological diversity. However, this study has highlighted significant reductions in surrounding green areas, notably in the Honda RPPN, the Buritis RPPN, the Águas do Gigante RPPN, and the Sócrates Bonfim RPPN, making them increasingly isolated and/or fragmented. These reductions were essentially the result of urban expansion. Nevertheless, RPPNs in Manaus play a crucial role in protecting local biodiversity and preserving fauna and flora.

In the context of this study, the use of the maximum likelihood method in supervised classification to quantify green areas proved acceptable, allowing for the distinction and analysis of changes in RPPNs and their surroundings.

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