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Papers

Analysis of Anthropic Pressure on Urban Mangroves: Subsidies for Environmental Protection and Territorial Planning

Sidney Vincent de Paul Vikou [1]
Otacílio Lopes de Souza da Paz [2]
Daiane Maria Pilatti [3]
Eduardo Vedor de Paula [4]

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Abstract
The mangrove represents an ecosystem that marks the transition between terrestrial and marine environments and is considered as an important ecological indicator for the ecosystem services provided. However, even with its ecological importance, this ecosystem suffers human pressures and has been losing area and environmental quality. In Brazil, and particularly in Paranaguá, a number of anthropic uses have caused strong pressures on mangroves. Therefore, the main objective of this research is to assess the degree of anthropization of the urban mangroves in the city of Paranaguá (PR), through the use of very high spatial resolution images, obtained from Remotely Piloted Aircraft in order to support municipal policies for land-use planning. The methodological scope adopted involved the production of maps with the QGIS 3.10 software, from the photointerpretation of orthomosaics obtained through a field campaign. The anthropization classes adopted in the legend were: Household Garbage (i), Debris (construction material) (ii), Untreated domestic effluents (residential) (iii) and Shackle (iv). As results, it was identified 475 points of anthropic pressure on the 22 mangrove patches analyzed. The main class was household garbage, followed respectively by untreated domestic effluents (residential), debris (construction material) and, finally, shackles. The conclusions point out that the use of high-resolution orthomosaics proved to be an important and effective tool in analyzing the anthropization of urban mangroves, highlighting the areas with higher pressure and contributing to a continuous monitoring. The products of this research can help in the elaboration of land-use planning instruments for the municipality, emphasizing the need for the construction of a holistic view in favor of mangrove conservation.

[1] Universidade Federal do Paraná - UFPR, Curitiba, PR, Brazil. sidneypaul@ufpr.br
[2] Universidade Federal do Paraná - UFPR, Curitiba, PR, Brazil. otacilio.paz@gmail.com
[3] Universidade Federal do Paraná - UFPR, Curitiba, PR, Brazil. daianepilatti@ufpr.br
[4] Universidade Federal do Paraná - UFPR, Curitiba, PR, Brazil. edugeo@ufpr.br

INTRODUCTION

Mangroves are the only forests located at the confluence of land and sea in the tropical and subtropical regions of the planet and are subject to the influence of the tides. They are found in estuarine areas, bays, and inlets that provide the appropriate conditions for their establishment. They are composed of trees or shrubs that grow in sheltered areas with low wave energy (ALONGI, 2002; DUKE et al., 1998; LUGO, SNEDAKER, 1974; SCHAEFFER-NOVELLI et al., 1990).

Mangroves perform several ecological functions, among which, are shoreline protection; trapping sediments carried by rivers; flood control; nutrient concentration; renewal of coastal biomass; generation of tangible goods (CUNHA-LIGNON et al., 2011; PEREIRA FILHO; ALVES, 1999; SCHAEFFER-NOVELLI et al., 2005; SOUZA et al., 2018).

Additionally, mangroves have an important role in carbon sequestration. As presented by Spalding et al (2021), the ability of mangroves to convert carbon dioxide (CO2) into organic carbon shows higher rates than almost any other habitat on Earth. This "blue carbon" is stored in biomass and soils, which can remain for centuries. Global-scale mapping of carbon stocks in mangrove soils and biomass indicates a total of 21.9 gigatons of (CO_2) stored in the present extent of mangroves (SPALDING et al., 2021).

Globally, they are found in 123 countries with an estimated area of 152,000 km2 (GIRI et al., 2010). They occur in two global sub-regions which are the Indo-West Pacific region that extends from East Africa to Polynesia and the East Pacific Atlantic region that extends from the Americas to West and Central Africa (UNEP, 2014).

In Brazil, mangroves extend from the mouth of the Oiapoque River in Amapá (4º30' N) to the municipality of Laguna in Santa Catarina (28º30' S) (SCHAEFFER-NOVELLI et al., 1990; SCHAEFFER-NOVELLI et al., 2000).

According to ICMBio (2018), they cover about 1,225,444 ha in almost the entire Brazilian coastline, with the states with the largest extension being Maranhão (505,000 ha), Pará (approximately 390,000 ha) and Amapá (226,000 ha).

To ensure the protection of this ecosystem,Conservation Units (UCs) have been created of both Proteção Integral e Uso Sustentável (Full Protection and Sustainable Use) (ICMBio, 2018). Additionally, the mangrove enjoys legal protection backed by Federal Law No. 12,651/2012, in its article 4, which defines mangroves as an Áreas de Proteção Permanente (Area of Permanent Preservation – APP) (ALBUQUERQUE et al., 2015; BRASIL, 2012; ROSÁRIO; ABUCHAHLA, 2018).

Despite its ecological importance and functions, mangroves are still subject to human pressures. Globally, due to the wide range of human activities carried out in the watersheds where they are located, mangroves have been disappearing at an annual rate of 1 to 2.1%. Aquaculture, agriculture, logging, fishing industry, urban, industrial and tourist facilities and climate change among others, represent the main activities triggering this loss (ALONGI, 2002; GIRI et al., 2010; SOUZA et al., 2019; UNEP, 2014).

In Brazil, mangroves face several threats to their conservation (FERNANDES et al., 2018; FERREIRA; LACERDA, 2016; MAGRIS; BARRETO, 2010; OTTONI et al., 2021; PAULA et al., 2019). On the coast of Paraná, the factors generating significant negative effects on mangroves encompass deforestation for purposes of urban expansion, industrial activities, port activities, among others; timber exploitation; real estate speculation; potential risks from aquaculture; contamination by oil and its derivatives, fertilizers, pesticides or heavy metals; dredging and landfills for construction of access roads; among others (LANA, 2004).

In the specific case of the municipality of Paranaguá, a mix of anthropic use encompassing urbanization, industrial and port activities, flow of tourists, land pressure, municipal policies, and the arrival of an excluded rural population have constituted strong drivers of pressures on the mangroves of the southern portion of Paranaguá Bay. The mangrove in urban areas has become urbanizable space or -a provider of animal resources (CANEPARO, 2000; CANEPARO; BRANDALIZE, 2008; PAZ et al., 2021; SILVA et al., 2015).

The mangrove is the object of several international and national studies (ALONGI ,2002; BIGARELLA, 1946; DUKE et al., 1998; LUGO; SNEDAKER, 1974; SCHAEFFER-NOVELLI et al., 1990; SCHAEFFER- NOVELLI et al., 2000). Among these, the use of remote sensing in the study of mangroves has been shown prominence (BALOLOY et al., 2020; DAHDOUH-GUEBAS, 2002; DINIZ et al., 2019; GIRI et al., 2010; LASSALLE et al, 2023; MAGRIS; BARRETO, 2010; PAZ et al., 2021; REIS- NETO et al., 2019; SANTOS; BITENCOURT, 2016; THOMAS et al.,

2018; XIMENES et al., 2023; YANCHO et al., 2020).

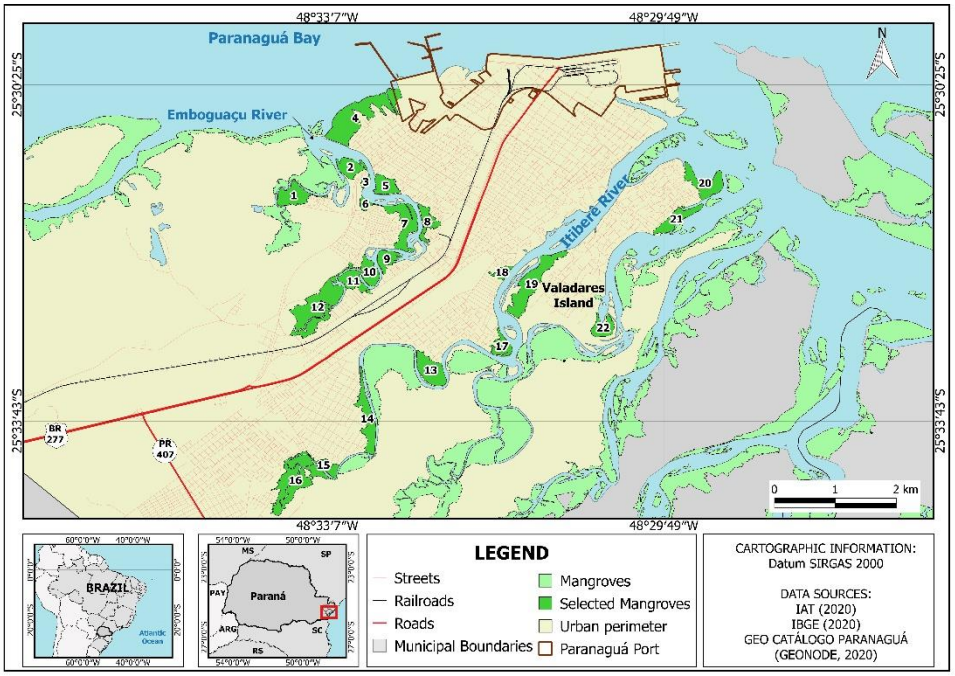
For Kuenzer et al. (2011), remote sensing is in widespread use when it comes to monitoring and mapping highly threatened mangroves. Typical mangrove habitats have difficult to access locations, so traditional field observation and survey methods are time-consuming and costly. To solve these problems, survey and monitoring tools available through remote sensing are needed. Thus, the present study aims to assess the degree of anthropization of urban mangroves in the city of Paranaguá (PR), using very high spatial resolution images, obtained from Remotely Piloted Aircraft in order to subsidize municipal policies for land planning.

MATERIALS AND METHODS

Study area characterization

The city of Paranaguá, as shown in Figure 1, is located in the metropolitan area of Curitiba, more specifically on the coast of Paraná. It covers a territorial area of 806.23 km² and a total population of 156,174 inhabitants, 96.38% representing the urban population (IBGE, 2021). urban population (IBGE, 2021). The municipality houses part of the Paranaguá Estuarine Complex (CEP) and is inserted in the domain of the Atlantic Forest biome, one of the world's biodiversity hotspots, and is also the largest continuous preserved area of this biome (MYERS et al., 2000).

Figure 1 - Map of the mangroves analyzed in the city of Paranaguá, Paraná coast, Brazil.



Source: IAT (2020); IBGE (2020); GEO CATÁLOGO PARANAGUÁ (2020). Elaborated by the authors (2022)

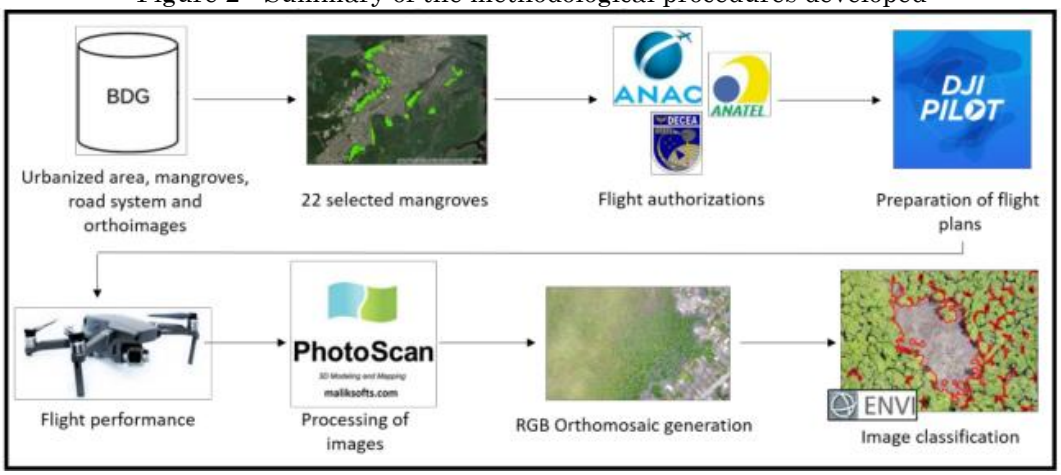
One of the characteristics of the urbanization of the city is the presence of many areas with irregular occupations, predominantly located in mangrove areas (PMSB, 2021). This conjuncture is since the urban network of Paranaguá has few alternatives to expand, leading to population concentration in precarious settlements characterized by high population density. The high demographic densities present in the city are not the result of a verticalization process of buildings, but of extensive and concentrated constructions in small dwellings (PDS, 2019).

The present study covered 22 mangroves patches whose selection criterion was the adjacency with the urban area of the municipality. They represent an area of 361.36 hectares and their location extends from the Emboguaçu River to Ilha dos Valadares, bordering the Itiberê River, which in turn stands out as an important factor when considering the history of the urban dynamics of the municipality.

Methodological procedures

The methodological path adopted in this study was developed based on the study by Paz et al. (2021), as presented in Figure 2.

Figure 2 - Summary of the methodological procedures developed



Source: Paz et al. (2021).

For the survey of anthropic pressure, we resorted to the use of orthomosaics generated from the imaging performed by Remotely Piloted Aircraft (RPA), popularly known as drone. The drone model used was the Mavic 2 Pro, and the flight plans were duly delimited before the fieldwork, using the DJI Pilot software. Two field campaigns were conducted (November 2019 and January 2020). The surveyed data were processed and, for each patch, an orthomosaic of spatial resolution of 0.1 m (10 cm) was generated.

Anthropization maps were produced with the aid of Quantum GIS 3.10 from the previously generated orthomosaics. For each of the 22 mangroves patches, a map was prepared at the screen scale corresponding to 1:500. From the photointerpretation of the ortomosaics four classes of anthropization were defined (chart 1): (i) accumulation of household waste, (ii) disposal of debris, (iii) discharge of untreated effluent from nearby residences and (iv) shackles (had discharge of untreated effluent, however, it was not possible to identify the source).

Chart 1 - Description of the mapped anthropization classes.

Class	Description	Orthomosaic	Oblique Photograph
Debris (construction material)	Accumulation of remains of civil construction residues, sludge, wood, stones, among others		
Untreated domestic effluents (residential)	Presence of PVC (polyvinyl chloride) pipes leading from the houses into the mangrove		
Household Garbage	It covers a wide category of waste, such as packaging, pet bottles, bags, and tires, among others		
Shackle	Discharge of untreated effluents in the open air		

Source: The authors (2022).

Each mangrove patch was assigned a numbering and additional information (perimeter, area, field date), as presented in Table 1.

In order to spatialize the occurrence of the anthropic pressure points surveyed, an analysis of the concentration of these points was performed. It was chosen to use the intensity estimator (Kernel) through the tool "heat map" available in QGIS. The Kernel function operates from the count of the set of points surveyed within a given area of influence, "weighting them by the distance of each to the location of interest". The main parameters that govern its use are the radius of influence and the estimation function (CÂMARA; CARVALHO, 2004, p. 5). For the present study, the radius used was 100 m and the Kernel function used was the Kartaric (configured as "default" of the software itself).

Table 1 - Nomenclature attributed to the mangrove forests.

Mangrove	Perimeter (m)	Area(ha)	Field Date
1	2.037,27	14,06	01/21/2020
2	755,37	10,95	01/21/2020
3	6.418,64	1,49	01/21/2020
4	1.791,77	46,39	01/21/2020
5	970,47	11,03	01/21/2020
6	4.146,35	2,01	11/20/2019
7	2.750,04	20,3	11/20/2019
8	1.821,20	10,21	01/21/2020
9	1.777,14	9,03	01/21/2020
10	2.326,51	10,84	11/20/2019
11	8.424,67	11,61	01/22/2020
12	1.999,28	33,64	01/22/2020
13	4.403,80	18,88	11/22/019
14	2.829,81	21,45	11/22/2019
15	9.011,47	6,05	11/22/2019
16	2.133,41	37,76	11/22/2019
17	1.219,88	8,04	11/22/2019
18	4.314,50	4,62	11/22/2019
19	2.839,35	38,59	11/21/2019
20	2.840,59	17,82	11/21/2019
21	2.073,13	13,32	11/21/2019
22	2.037,27	13,28	11/21/2019

Source: The authors (2022).

Additionally, in order to subsidize the municipal public management in mangrove protection actions, a survey of territorial planning instruments was carried out, namely: Plano Diretor de Desenvolvimento Integrado (Master Plan for Integrated Development); Plano Municipal de Saneamento Básico (Municipal Plan of Basic Sanitation); Municipal Plans of Basic (PMSB); Plano Municipal de Conservação e Recuperação da Mata Atlântica (Municipal Plan for Conservation and Recovery of the Atlantic Forest) and Programa Municipal de Regularização Fundiária (Municipal Land Regularization Program).

RESULTS AND DISCUSSION

Among the 22 mangroves patches analyzed, 21 presented some degree of anthropization within them or on their edges. The patch number 22 was considered a control, because it is in direct contact with the urban area, and no anthropic pressure points were identified within the analyzed classes. In total, 475 points were identified that portray some form of anthropic pressure on the mangroves analyzed.

As shown in Table 2, 45.26% of the points mapped, the class of household waste stood out (215 in total). In second place is the class of untreated domestic wastewater discharge, which presented a total of 177 points (37.26%), followed by the class rubble (construction material) that presented 74 points (15.58%) and, finally, the class shackles that presented 9 points (1.89%).

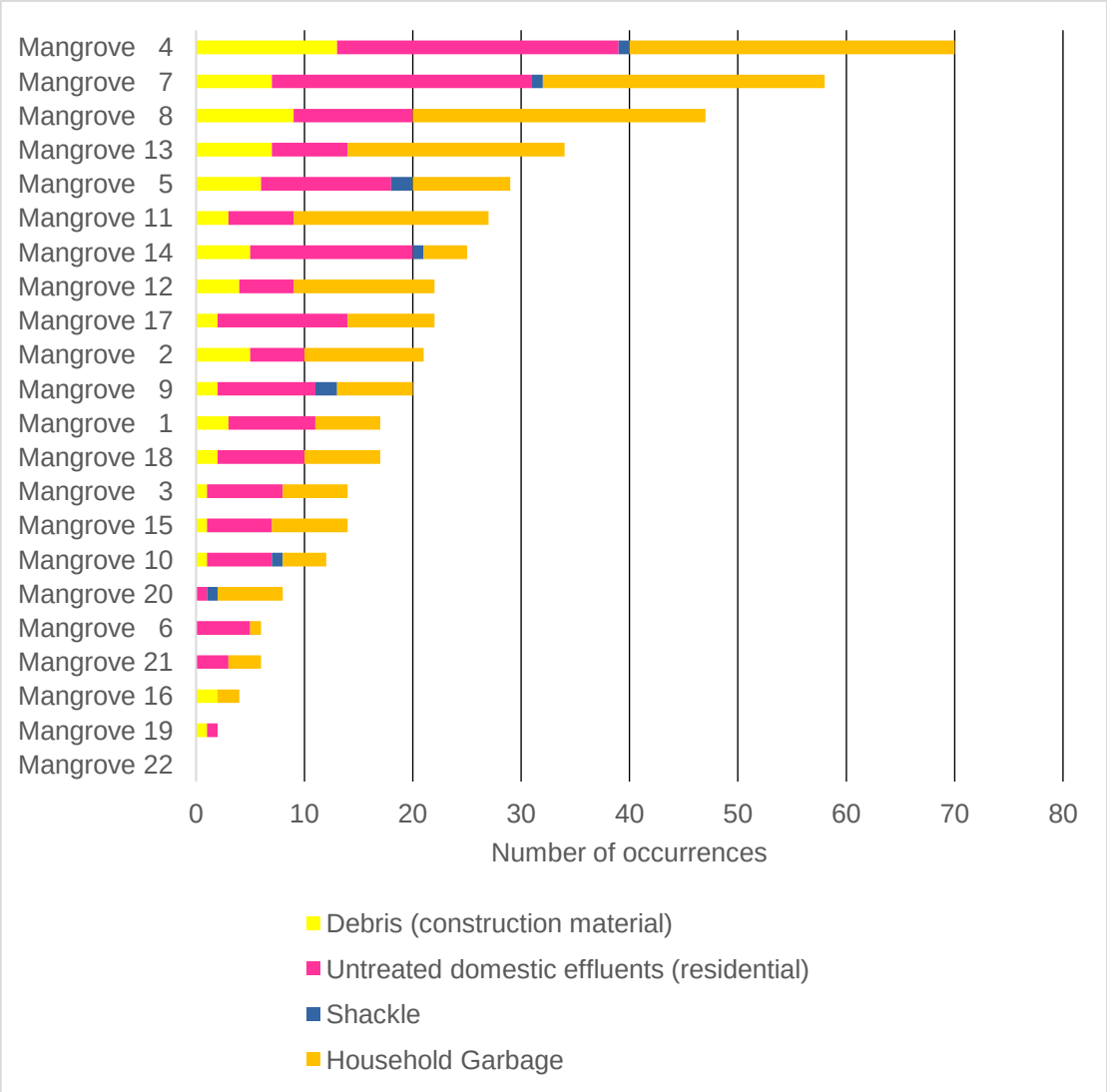
Table 2 - Number of anthropization points per mapped class.

Anthropization Class	Score	%
Debris (construction material)	215	45,26
Untreated domestic effluents (residential)	177	37,26
Household Garbage	74	15,58
Shackle	9	1,89
Total	475	100

Source: The authors (2022).

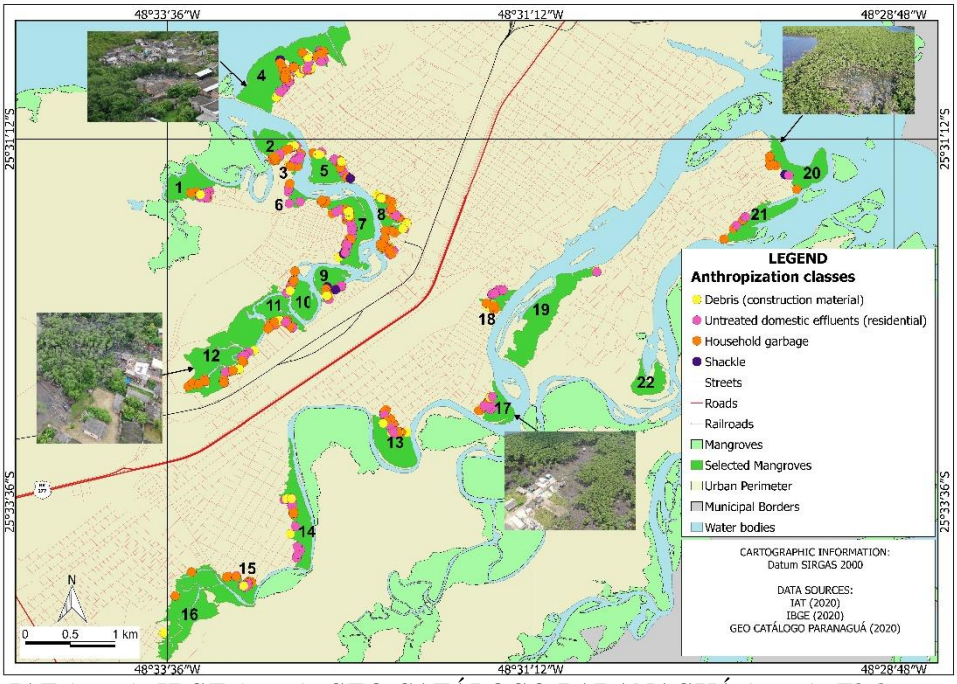
From figures 3 and 4, it can be observed that Mangrove 4 stands out in most anthropization classes, with the exception only of the mangrove class. Mangrove 8 presented the highest percentage of anthropic pressure points for the debris class (construction material). Mangrove Swamp 7 stood out in the untreated domestic effluent discharge class, while Mangroves 5 and 9, were in the shackle class. Finally, Mangroves 7 and 8 stood out in the domestic waste class. Mangrove 19 had the fewest points of anthropization, being only 2 points in total.

Figure 3 - Number of anthropization points mapped by class and mangrove.



Source: The authors (2022).

Figure 4 - Map of location of the points of occurrence of anthropic pressure.



Source: IAT (2020); IBGE (2020); GEO CATÁLOGO PARANAGUÁ (2020). Elaborated by the authors (2022).

As the mangrove patches present important variation in terms of area, the occurrence of anthropization points per hectare was also analyzed. In this sense, as shown in Table 3, Mangrove 3 presented the highest percentage of occurrences per hectare.

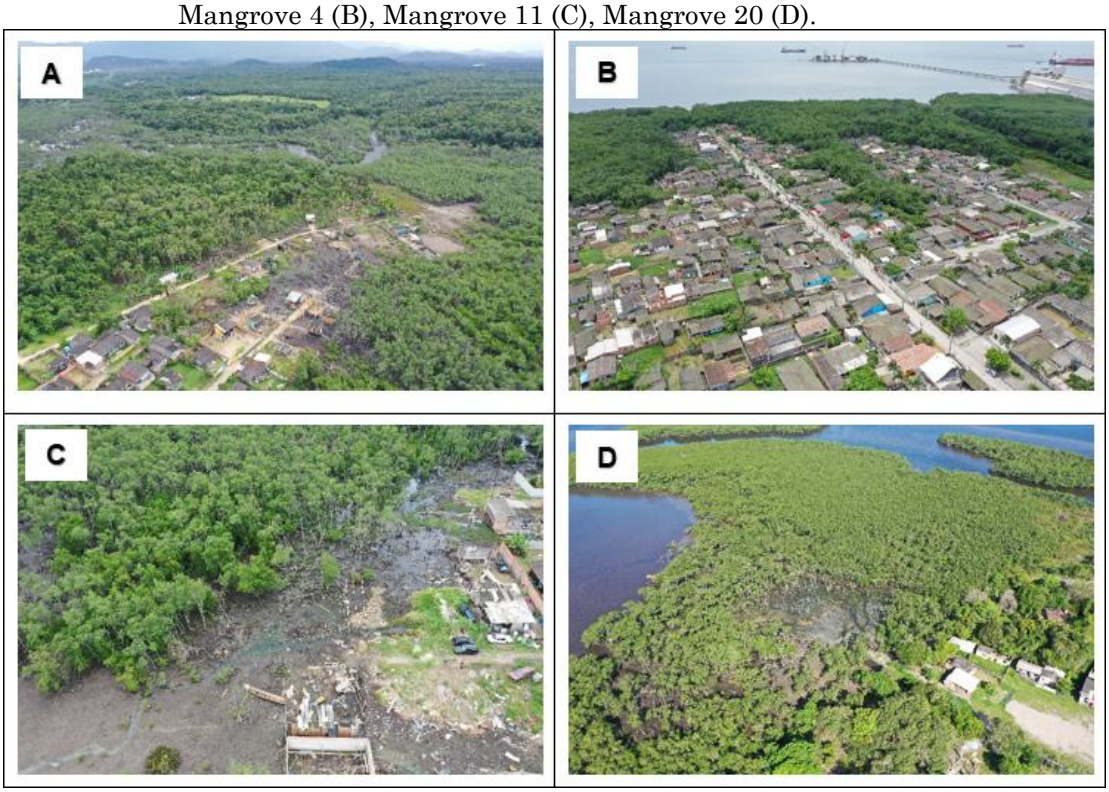
Table 3 - Relationship of the number of occurrences per hectare.

Mangrove	Perimeter (m)	Area (ha)	Total occurrences	Occurrences per hectare
3	6.418,64	1,49	14	9,40
8	1.821,20	10,21	47	4,60
18	4.314,50	4,62	17	3,68
6	4.146,35	2,01	6	2,99
7	2.750,04	20,3	58	2,86
17	1.219,88	8,04	22	2,74
5	970,47	11,03	29	2,63
11	8.424,67	11,61	27	2,33
15	9.011,47	6,05	14	2,31
9	1.777,14	9,03	20	2,21
2	755,37	10,95	21	1,92
13	4.403,80	18,88	34	1,80
4	1.791,77	46,39	70	1,51
1	2.037,27	14,06	17	1,21
14	2.829,81	21,45	25	1,17
10	2.326,51	10,84	12	1,11
12	1.999,28	33,64	22	0,65
21	2.073,13	13,32	6	0,45
20	2.840,59	17,82	8	0,45
16	2.133,41	37,76	4	0,11
19	2.839,35	38,59	2	0,05
22	2.037,27	13,28	0	0,00

Source: The authors (2022).

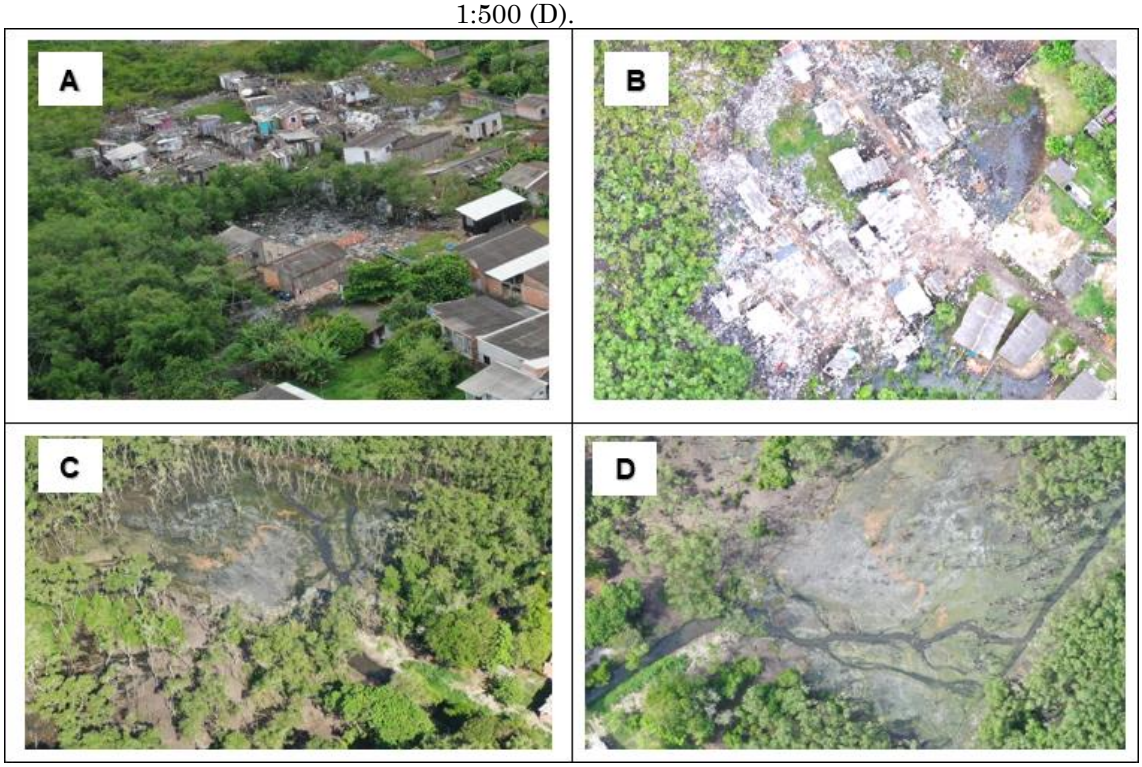
It is possible to observe (according to the photographs in Figures 5 and 6) a clear urban expansion, still precarious in infrastructure, that enters the Mangrove spots through a process of landfilling with solid waste deposit, with subsequent street and lot division – activities that occur almost always without legal authorization. There is also a lack of basic sanitation infrastructure.

Figure 5 - Set of oblique (panoramic) photographs of some patches of Mangrove. Mangrove 1 (A), Mangrove 4 (B), Mangrove 11 (C), Mangrove 20 (D).



Source: The authors (2022). Field survey.

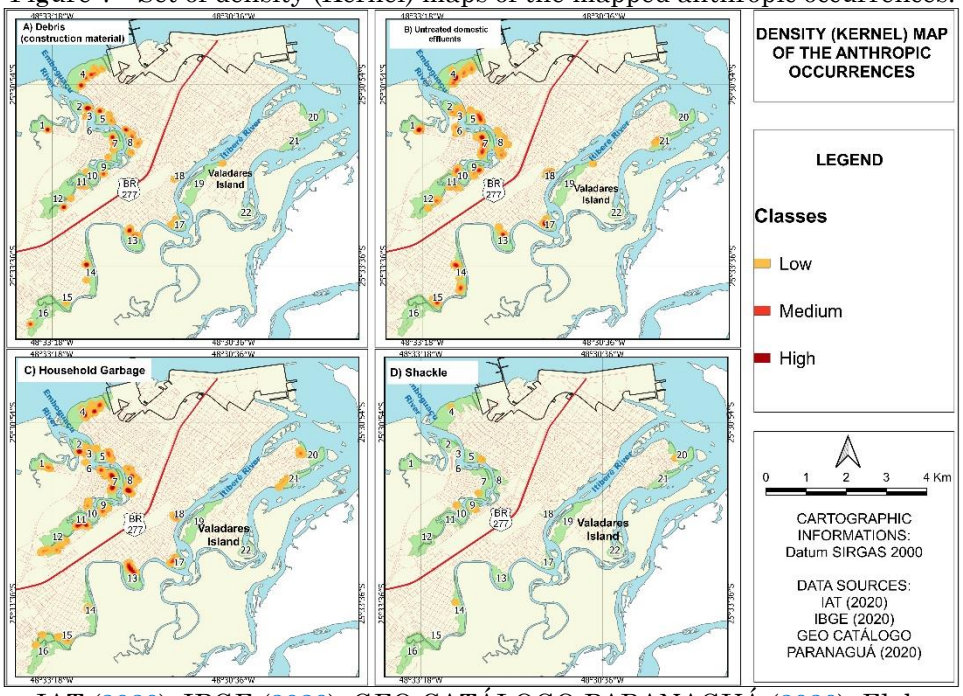
Figure 6 - Precarious occupation with solid waste within Mangrove 4, observed on oblique photograph (A) and on orthomosaic at canvas scale 1:500 (B). Untreated effluent discharge with shackle within Mangrove 20, observed on oblique photograph (C) and on orthomosaic at canvas scale 1:500 (D).



Source: The authors (2022). Field survey.

The results indicated by the spatial analysis of density (Kernel), considering a radius of 100 m (as shown in Figure 07) point to a concentration of anthropic pressure occurrences on the banks of the Emboguaçu River.

Figure 7 - Set of density (Kernel) maps of the mapped anthropic occurrences.



Source: IAT (2020); IBGE (2020); GEO CATÁLOGO PARANAGUÁ (2020). Elaborated by the authors (2022).

To understand the relationship between human pressure and the urban mangroves of Paranaguá, it is first necessary to understand the history of urban occupation, in other words, how the urban space of the city was organized. The spatial organization is the result of the relationships between the individuals who live there and the relationships they have with the environment in which they are established, thus being able to create changes in the patterns of land use and available natural resources.

The current situation of mangroves anthropization pointed out in the present study had already been previously alerted by Lana (2003). For the author, the protection of the mangroves was maintained because the coast of Paraná did not concentrate on the main urban centers and the agricultural and industrial activities, despite the pioneering nature of its colonization. However, with the reactivation of the Paranaguá port in the second half of the twentieth century, economic changes began to emerge, leading to pressures such as urban expansion, new subdivisions, construction of marinas and implementation of road and energy infrastructures. The subsequent emergence of conflicts was caused by the occupation and use of Mangrove areas by low-income populations in the urban perimeters of Paranaguá, Guaratuba and Antonina and, additionally, by the real estate valorization and construction of service infrastructures that directly or indirectly affect the adjacent mangroves (LANA, 2003).

When it comes to urban expansion, the 1950s brought economic changes that represented a crucial period marked by the transformation of Paranaguá into an important center of attraction of populations and thus completely changing its spatial dynamics. From the 1980s and 1990s, the urban expansion was guided by the BR-277 and PR-407, marked by the appearance of new subdivisions, resorts and the creation of the Embocuí Industrial District; a conjuncture that resulted in the intensification of irregular occupations in the mangroves of the urban area (CANEPARO, 2000; CANEPARO; BRANDALIZE, 2008).

In characterizing the urban expansion in the municipality, Silva et al. (2015) pointed out the existence of a horizontal and regularized growth in the areas established for the installation of new housing, but, on the other hand, an irregular occupation that occurs in areas of mangroves and riverbanks. The authors also point out the presence of several neighborhoods whose occupation took place in an irregular and disorderly way.

In a study by Tonetti et al. (2021), the authors delimited four categories of Landscape Units, within which the APP with residential use were located in mangrove areas. The anthropization characteristics found in the present study are similar to those presented by Tonetti et al. (2021) for being areas with rapid and disorderly urban occupation and characterized by the presence of poor urban infrastructure. The authors also point out that

these areas have a deficit regarding sanitary sewage, among others.

Reversing or improving the anthropization scenario presented in this study requires an important and coordinated action of the public authorities, in addition to the awareness of the population regarding the importance of protecting the mangroves. From this point of view, the city of Paranaguá went through a unique moment of environmental planning and land management, marked by the development of several instruments provided by law: Plano Diretor de Desenvolvimento Integrado (Integrated Development Master Plan,Federal Law No. 10.257/2001 ; Supplementary Law No. 294/2022); Plano Municipal de Saneamento Básico (Municipal Basic Sanitation Plan,Federal Law No. 11.445/2007 and Federal Law No. 14.026/2020); Plano Municipal de Conservação e Recuperação da Mata Atlântica (Municipal Plan for Conservation and Recovery of the Atlantic Forest,Federal Law No. 11.428/2006 and Decree No. 6.660/2008) and Programa Municipal de Regularização Fundiária (Municipal Land Regularization Program,Federal Law No. 13.465/2017).

Thus, it can be seen that the problem of mangrove anthropization is not necessarily linked to the lack of land use planning instruments. instruments for land use planning. Seeking integration among these various instruments and stimulating a dialogue in favor of mangrove protection could represent a promising way to ensure mangrove protection. It would be important to coordinate and centralize the results and proposals generated by these instruments in order to generate a holistic and no longer fragmented view of the problem of irregular urban occupation of the mangroves in Paranaguá.

Moreover, special attention should be given to the human pressure on the issue of sanitation, since it was identified the discharge of untreated effluents directly from homes or manholes into the mangroves. This brings up some considerations that concern the health and quality of life of the populations living in these areas. Thus, dealing with irregular urban occupation goes beyond a mere environmental protection issue to become a public health issue.

In this sense, the importance of integrating the aforementioned instruments to the set of laws on Mangrove protection (federal, state and municipal), should be accompanied by concrete actions of environmental education, fostering the inspection of these areas and/or the implementation of Conservation Units specific to the Mangrove, with duly stipulated buffer zones. Especially in the case of implantation of Conservation Units, according to the study developed by Lima et al. (2021), the authors pointed out that the Proteção Integral (Full Protection) Conservation Units play an important role in maintaining the conservation status of the Mangrove and in the stability of the microclimate.

CONCLUSIONS

The present study presents a differential and pioneering approach in terms of obtaining information about the anthropization of the Mangrove. In this sense, it was observed that the use of imaging, performed by Remotely Piloted Aircraft (RPA), was an excellent and important tool for obtaining data to assess the degree of anthropization of mangrove patches located in urban areas. The high level of detail of orthomosaics, due to the very high spatial resolution (0.1 meter in this study) allowed the photointerpretation and, consequently, the making of maps that show human actions within the mangrove patches, as well as on their edges. Thus, resorting to the use of PRA favors a continuous monitoring of the environmental quality of mangroves.

The observed anthropic pressure is characterized mainly by irregular occupation of the mangrove patches, through the removal of vegetation and subsequent landfill for household waste and debris disposal. The houses present precarious infrastructure, as well as a lack of basic sanitation that leads to pollution of the mangroves by different contaminants. The mangroves analyzed in this study presented a greater or lesser degree of anthropization among themselves, characterized by the history of land use that has occurred in recent decades and by their spatial distribution.

Finally, it is important to emphasize that the protection of the Mangrove ecosystem in the municipality also requires the joint and complementary action of the legislation in force, as well as of the territorial planning instruments. From this perspective, the products of this research offer subsidies for land use planning instruments, such as the Plano Municipal de Conservação e Recuperação da Mata Atlântica (Atlantic Forest Municipal Plan), the Plano Municipal de Saneamento Básico (Municipal Basic Sanitation Plan), and the Plano Diretor de Desenvolvimento Integrado (Municipal Master Plan), thus highlighting the need for the integration of these various

instruments in favor of the conservation of this ecosystem.

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AUTHORS CONTRIBUTION

Sidney Vincent de Paul Vikou conceived the study, developed the methodological proposal for the analysis of anthropization, participated in field campaigns, wrote the text of the article. He wrote the research project for funding acquisition. Otacílio Lopes de Souza da Paz designed the study, developed the methodology for the aerial survey as well as the collection, analyzed and processed data images. He contributed to the text and participated in the writing of the research project for the acquisition of funding. Daiane Maria Pilatti conceived the study, collected the data and contributed to the text. She wrote the research project for funding acquisition. She coordinated the project to which this paper is linked. Eduardo Vedor de Paula conceived the study and contributed to the text. He is responsible for acquiring financing. He acted in the coordination of the laboratory where this research was developed