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Scientific Paper

Environmental quality monitoring of restingas in the coast of southern Brazil using high resolution images: a tool for environmental management

Monitoramento da qualidade ambiental de restingas no litoral do sul do Brasil utilizando imagens de alta resolução: uma ferramenta para gestão ambiental

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ABSTRACT

The aim of this study was to evaluate the environmental quality of the Atlantic coast *restinga*, in south Brazil, using red, green and blue (RGB) drone images obtained in September of 2020 and 2021. The generated orthoimage was classified into different vegetation classes like herbaceous, shrubs and arboreal as well as other classes such as degraded and constructed areas. Classification was performed using the Random Forest algorithm, available from the Dzetsaka plugin for Quantum GIS. Of the total assessed area of *restinga* (289.17 ha), in 2020, 61.54% were conserved and 36.72% were degraded. In 2021 there was a decrease in conserved areas to 59.56%, and an increase in degraded areas to 38.85%. Regarding the sectors (1–8) evaluated in the two different years, sector 6 had the smallest preserved area of *restinga* (5.40 and 8.14 ha in 2020 and 2021, respectively), and sector 2 had the largest preservation area, with 44.07 ha in 2020 and 43.55 ha in 2021. Sectors 1,2,4, and 5 showed a reduction in conserved *restinga* areas (on average, 6.75%). An increase in conserved areas was observed in sectors 6 and 7 (on average, 20.4%) and in sector 8 (2%). These results show the potential of using images obtained by drone, in multi-temporal analyses of fragile areas such as *restingas*, helping with protection and conservation measures for these ecosystems.

Keywords: aerial monitoring; unmanned aerial vehicles; hotspots; conserving coastal vegetation.

RESUMO

O objetivo deste estudo foi avaliar a qualidade ambiental da restinga da costa atlântica, no sul do Brasil, utilizando imagens de *drones* nos espectros de vermelho, verde e azul (RGB) obtidas em setembro de 2020 e 2021. A ortoimagem gerada foi classificada em diferentes classes de vegetação como a herbácea, a arbustiva e a arbórea, além de outras feições como áreas degradadas e construídas. A classificação foi realizada utilizando o algoritmo Random Forest, disponível no *plugin* Dzetsaka para Quantum GIS. Do total de área da restinga avaliada (289,17 ha), em 2020, 61,54% encontrava-se conservada e 36,72% estava degradada. Em 2021 houve diminuição das áreas conservadas para 59,56% e aumento das áreas degradadas para 38,85%. Em relação aos setores avaliados nos dois anos, o setor 6 teve a menor área conservada de restinga (5,40 ha e 8,14 ha em 2020 e 2021, respetivamente), e o setor 2 teve a maior área de preservação, com 44,07 ha em 2020 e 43,55 ha em 2021. Os setores 1, 2, 4 e 5 apresentaram redução nas áreas de restinga conservadas (em média, 6,75%). Aumento nas áreas conservadas foi observado nos setores 6 e 7 (20,4%) e no setor 8 (2%). Esses resultados mostram o potencial do uso de imagens obtidas por *drones* em análises multitemporais de áreas frágeis como as restingas, auxiliando nas medidas de proteção e conservação desses ecossistemas.

Palavras-chave: monitoramento aéreo; veículos aéreos não tripulados; *hotspots*; conservação da vegetação costeira.

INTRODUCTION

The Brazilian biomes (Amazon, Caatinga, Cerrado, Pampa, Pantanal and Atlantic Forest) represent a significant portion of the world's total biodiversity, containing an endemically varied set of animal and plant life, which promotes great biodiversity richness (ALEIXO *et al.*, 2010; SILVA, 2014). One of those biomes is the Atlantic Forest, which covers the entire Brazilian coast, including the State of Paraná. The Brazilian Atlantic forest is considered a biodiversity hotspot because it presents 20 thousand plant species (an exceptionally high diversity), 40% of which are endemic (MYERS *et al.*, 2000; LAURANCE, 2009; SILVA, 2014).

Although the coastline of the state of Paraná is not very large, it shows large areas of preserved Atlantic forest along the coast, and different types of

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vegetation throughout the area of occurrence, such as mangroves and *restingas*, typical forms of vegetation of the Brazilian coast (ZAMITH; SCARANO, 2006; MARQUES; SILVA; LIEBSCH, 2015). However, the accelerated and unplanned anthropic occupation has caused serious social and environmental impacts — especially in fragile ecosystems and biomes which are closely related to the maintenance of biodiversity (PIERRI; ANGULO; SOUZA, 2006; ZAMITH; SCARANO, 2006; NASCIMENTO, 2011; SILVA *et al*., 2018).

The *restinga* is a set of physiognomically distinct plant communities under marine influence that are distributed in mosaics within areas of great ecological diversity (MARQUES; SILVA; LIEBSCH, 2015; CORREA; PRANDINI; SILVA, 2022). The vegetation consists of close-to-the-sea low-lying species that gradually increase in height as they move away from the high tide line, forming a transitional ecosystem to the Atlantic Forest (SCARANO, 2009; DALOTTO *et al*., 2018; INAGUE; ZWIENER; MARQUES, 2021). Due to the influence in arresting sea advance and promoting dune fixing, restinga vegetation areas are considered Permanent Preservation Areas (PPA), which means that these areas cannot be deforested or occupied within a minimum of 300 m measured from the high tide line (Brasil, 2012).

Due to lack of technology and government funding for proper inspection, *restinga* areas suffer from constant anthropic degradation due to real estate expansion, artificial landscaping, and population increase during summer seasons, which affects several of the region's endemic species and reduces ecological diversity (SILVA *et al*., 2018). Moreover, in many areas of the Brazilian coast, the native *restinga* has been replaced by irregular constructions or colonized almost exclusively by exotic plant species (SCARANO, 2009; KRAICZEI, 2015) — which can lead to the loss of fauna and flora biodiversity (SCARANO, 2009; DALOTTO *et al*., 2018). In this way, the diagnosis and monitoring of this PPA is essential to maintain the environmental quality of coastal areas and to avoid floods and sand advances over the city.

Within this context, unmanned aerial vehicles (UAVs; drones) are among the most innovative tools for diagnosing and monitoring environmental quality. These vehicles help to obtain high-resolution images for a generally cheaper price than short time traditional aerial surveys, enabling spatial and temporal analysis in several scientific studies (LI *et al*., 2020; NEUVILLE; BATES; JONARD, 2021; PRANDINI; CORREA; SILVA, 2021b).

Furthermore, drone overflight can enhance environmental diagnostics by collecting data on unhealthy and inaccessible in loco sites such as landfills, forests and slopes (ALMEIDA *et al*., 2019; ALMEIDA *et al*., 2020; SILVA *et al*., 2021; STODDART *et al*., 2022; WANG *et al*., 2022). Thus, it enables the estimation of recovery and/or degradation vegetation areas, and can be applied as a tool for evaluation, monitoring and management of these sites, among other applications (CORREA; PRANDINI; SILVA, 2022; ZHANG *et al*., 2022; SILVA; PRANDINI; CORREA, 2024).

Considering that the restinga is vitally important for maintaining biodiversity in the coastal region, and that it prevents the clogging of culverts on the roads of coastal cities and, consequently, flooding in the summer, and that monitoring its vegetation is difficult for municipal management to carry out due to the high costs and lack of trained personnel, and that drones can serve as low-cost environmental assessment tools, this study aimed to evaluate the dynamics of degradation and/or recovery of the *restingas* in Pontal do Paraná — a city in the coastline of southern Paraná (Brazil) — through drone overflight images taken during the months of September 2020 and compared with the ones from September 2021. The vegetation changes within this time interval were extracted using open-source software for data assessment.

MATERIAL AND METHODS

Acquisition and processing of images

The *restinga* area studied is located in the city of Pontal do Paraná, in the coastal region of the state of Paraná, southern Brazil. The municipality has an area of approximately 200 km^2, with an estimated population of 28,529 inhabitants (IBGE, 2022). The city's main characteristic is its seasonal population: during the summer, the high temperatures attract thousands of tourists. This work was more specifically carried out in Restinga Municipal Natural Park (RMNP) — comprising the extension of the restinga vegetation parallel to the coastline, spanning 32 beach bathing resorts. This territory was divided into eight sectors (Figure 1, Table 1), starting in Pontal do Sul (Sector 1) all the way to Monções resort (Sector 8). The division aimed to facilitate analysis of the images obtained by drone overflights and reduce the differences between study area sizes (Figure 1, Table 1). The mean length of the sectors was 2.72 ± 0.94 km (average ± standard deviation).

Acquisition and processing of images

In order to obtain the images, flight plans were made for each sector in optimal weather conditions such as clear skies, wind speed and temperature of around 9 km/h and 25°C, respectively, and at low tide, which had a predetermined route charted by Pix4Dcapture (v.4.13.1). With this configuration, the drone performed a fully autonomous flight, thus avoiding operator-caused handling errors. A total of 27 flight plans were necessary to cover the entire *restinga* area of the municipality. The settings used for each flight plan were: flight height of 60 m and platform speed of 7.7 m/s. The speed and flight height were established after field tests to achieve an optimal balance between flight time, image quality, and resolution.

The data were obtained in September of 2020 and 2021 through aerial photography using a red, green and blue (RGB) system camera attached to a DJI Phantom 3 Standard drone, which has the following technical specifications: speed up to 16 m/s, 12 MP image resolution, Field of View (FOV) lens of 94o 20 mm (35 mm format equivalent) f/2.8, achieving 4,000 x 3,000 pixel images, weight of 1.216 kg (including battery and propeller), focus accuracy of 0.5 vertically and 1.5 horizontally, and gimbal with 3 tilt axes. The drone's remote control operates on 5.725-5.825 GHz frequencies.

The flight plan images were processed by OpenDroneMap (ODM) to generate georeferenced orthomosaics for delimitation of the study area, and the Quantum Geographic Information System (QGIS) open-source software (v. 3.18) was used to geoprocess and analyze images using the EPSG:31982 - SIRGAS 2000/ UTM zone 22S coordinate reference system (CRS).

The analysis of the *restinga* was conducted in the area between the nearest street to the vegetation and the flora closest to the beach sand. The images were classified using a supervised classification, carried out with the Random Forest algorithm of the Dzetsaka plugin (KARASIAK, 2016).

Six classes of land use and cover were defined, and then, from these classes, samples were selected for classification of polygon attributes in the shape files: *restinga* vegetation (herbaceous, shrubby, arboreal trees); degraded sites

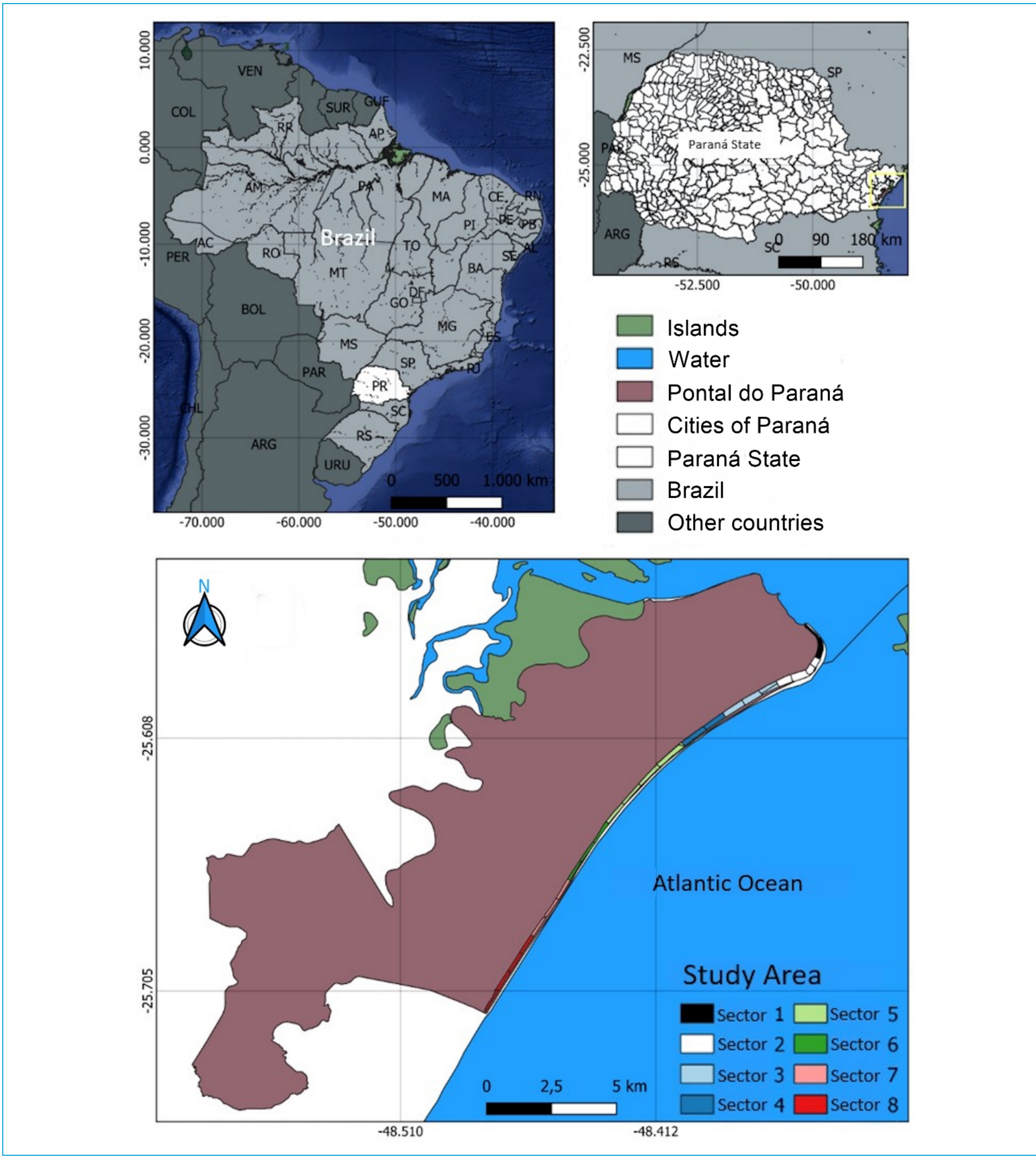

Figure 1 – Location of the study area at the Restinga Municipal Natural Park, Pontal do Paraná, Paraná State, Brazil. Coordinates in decimal geographic coordinates.

(clearings, exotic species, paths); sand (high tide region); construction (buildings and sidewalks); water sites (rivers and flooded areas); other attributes (solid waste, shadows, cars, bathers, boats). Figure 2 summarizes the characteristic features of the analyses applied.

To assess the conserved areas of vegetation, the herbaceous, shrubby and arboreal vegetation attributes were grouped together as preserved areas, whereas construction and degraded sites were grouped as degraded vegetation areas. We compiled the data obtained and assessed the areas related to each class to estimate the attributes of the *restinga* vegetation as well as the degree of degradation or conservation.

The data obtained through the supervised classification of orthomosaics, related to each class's areas, were evaluated using the R programming language

(v. 4.0.3) with the following packages: gsheet, dplyr, ggplot2, reshape2 and tidyverse. The data accuracy analysis was conducted using the Overall accuracy and the Kappa index of the Random Forest classifier available in QGIS.

RESULTS

A total length of 21.72 km of beaches in Pontal do Paraná were analyzed during September 2020 and September 2021, using drone overflights. The study showed that, in 2021, the total conserved area was 178.66 ha, whereas the total degraded area increased (116.52 ha) when compared to 2020 (106.18 ha), mainly due to irregular constructions. However, there was an increase of approximately 10.79 ha (3.73%) in the *restinga* vegetation within the RMNP since the previous year.

Sector 2 showed the greatest preserved area, with 44.07 ha (2020) and 43.55 ha (2021). A predominance of degraded area was observed in Sectors 6 (12.65 ha for 2020; 12.34 ha for 2021), 7 (11.89 and 8.28 ha, respectively), and 8 (19.71 and 19.14 ha).

In addition, many irregular constructions were identified in the *restinga* preservation area in Sector 6 (Figure 3). This area presented piled-up solid waste and weeding for landscaping purposes — an issue that stems from the irregular occupation of the Ipanema beach resort.

Table 1 – Sectors for drone flight plans according to bathing resort extension in the city of Pontal do Paraná, state of Paraná, southern coast Brazil.

Sector	Beaches	Extension (km)
1	Pontal do Sul – North	1.64
2	Pontal do Sul – South	1.96
3	Atami Sul; Atami	2.44
4	Guapê; Barrancos	2.00
5	Grajaú, Olho D'Água; Carmery; Shangri-lá	4.42
6	Ipanema; Leblon	2.82
7	Luciene; Praia Bela; Majoraine; Canoas; Santa Terezinha; Itapuã; Porto Fino; Guarapari	2.74
8	Monções; Praia de Leste; Mirassol; São Carlos; Patrick 2	3.70

Sector 1 (2021) had a decrease of 1.1143 ha in herbaceous vegetation, but also an increase of 0.8645 ha in shrub vegetation and 0.4250 ha in arboreal vegetation. However, flora degradation increased in 2021 due to an expansion of construction (0.5433 ha) and degraded areas (3.1332 ha).

In Sector 2, 1.6226 ha of herbaceous vegetation were suppressed, and 1.1522 ha of shrub vegetation were grown from 2020 to 2021. There was a reduction of 0.0509 ha in shrub vegetation in 2021 and an increase of 2.5867 ha in the total degraded area. On the other hand, Sector 3 only presented minor changes, with slight herbaceous (0.0253 ha) and shrub (0.0214 ha) growth. In addition, there was a decrease in arboreal vegetation (0.0809 ha), totaling an overall vegetation reduction of 0.0343 ha. Although an increase of 0.8086 ha was observed in buildings, the degraded area decreased by 1.3378 ha, resulting in a degraded area reduction of 0.5292 ha.

In 2021, Sector 4 presented a loss of herbaceous (2.8756 ha) and arboreal (3.0584 ha) vegetation, and an expansion in shrub vegetation (3.2947 ha). The sector's total degraded area expanded to 3.9715 ha in 2021. Meanwhile, Sector 5 had an increase in herbaceous vegetation (1.9598 ha) and a decrease in shrub (2.2247 ha) and arboreal (3.1322 ha) vegetation. The total degraded area in that sector increased by 5.1190 ha in September 2021.

In turn, in Sector 6 — the most degraded sector, with the largest irregular construction area —, herbaceous and shrub vegetation experienced growth of 1.2926 and 2.3909 ha, respectively, between the first and second years of the experiment. However, arboreal vegetation was reduced by 98.54% in 2021 from its initial area of 0.9561 ha in 2020, causing this type of vegetation to be almost extinguished in this sector (Figure 4). Figure 3 illustrates the orthophoto with the attributes assessed and the changes in the vegetation characteristics of the *restinga* from 2020 to 2021 in Sector 6.

In Sector 7, from 2020 to 2021, herbaceous and shrub vegetation increased by 1.8017 and 1.2609 ha, while arboreal vegetation decreased by 0.2972 ha. This sector obtained the greatest increase in *restinga* vegetation (3.6106 ha), totaling an increase of about 30% by 2021.

In Sector 8, the degraded *restinga* vegetation and construction areas exceeded the conserved vegetation in both 2020 (60%) and 2021 (56%) (Figure 4).

Figure 2 – Examples of attributes used to categorize the *restinga* vegetation: (A) *restinga* herbaceous vegetation; (B) shrubby vegetation; (C) arboreal vegetation; (D) site degradation with paths; (E) sand; (F) irregular building; (G) water sites; (H) others.

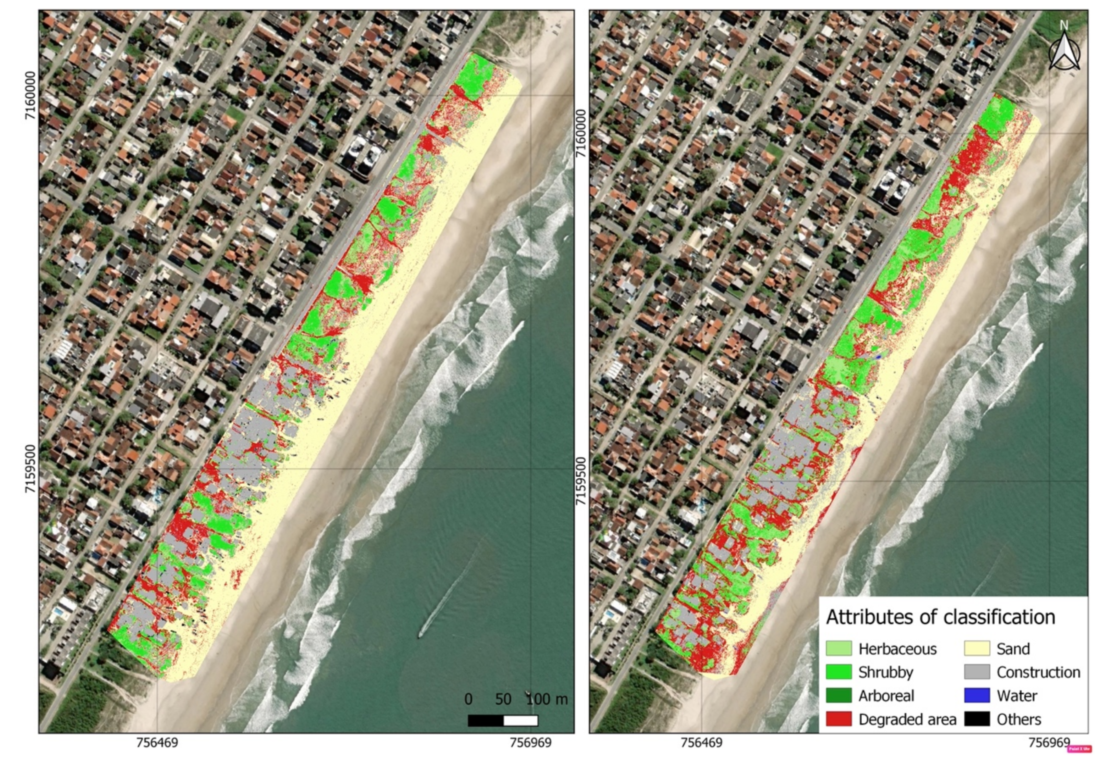

Figure 3 – Orthophoto's attribute analysis of Sector 6 in the city of Pontal do Paraná, Paraná State, Brazil, showing the types of vegetation characteristic of the *restinga* and the great irregular construction (gray) and (A) degraded areas (red) for 2020 and (B) the changes in the year 2021; coordinates in UTM.

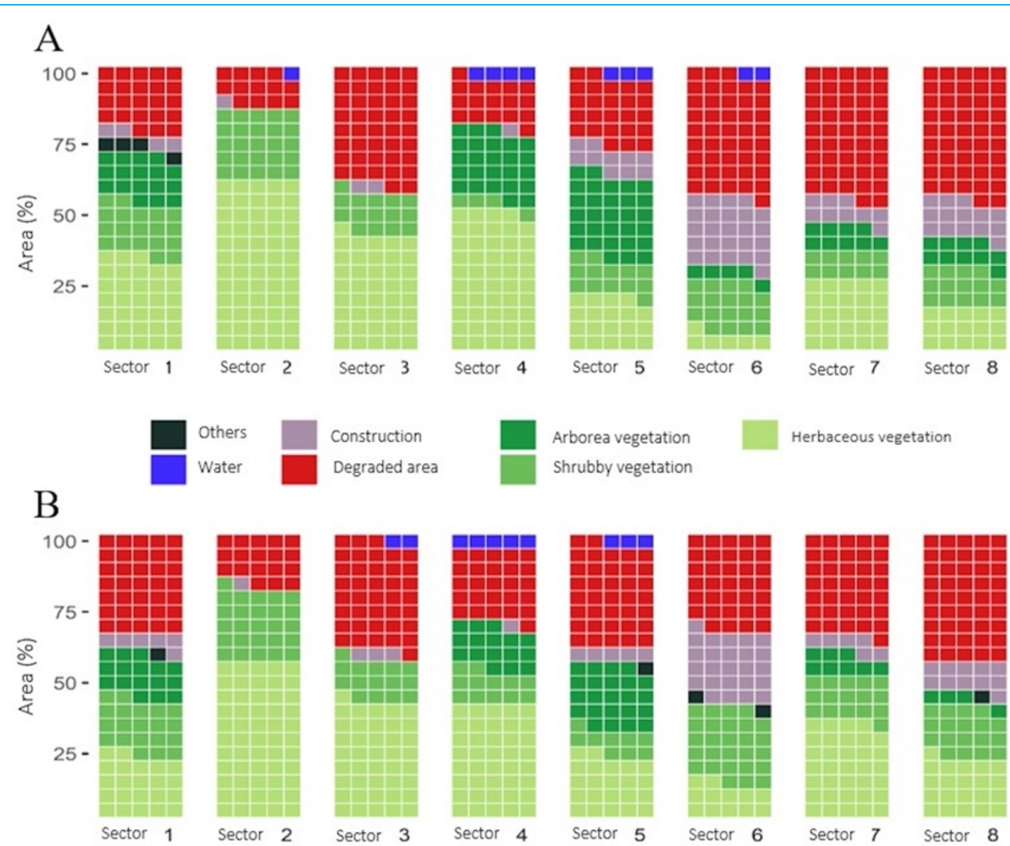

Figure 4 – Assessment of the supervised classification of attributes from the image analysis obtained from study areas divided by sectors in the city of Pontal do Paraná, Paraná State, Brazil, in September 2020 and 2021. Each square represents 1% of the used features. (A) year 2020; (B) year 2021. Accuracy index: Overall = 0.93 ± 0.018 (mean ± standard deviation); Kappa = 0.87 ± 0.016.

Despite that, in Sector 8 there was a vegetational expansion of 2.2185 ha for herbaceous and 1.2220 ha for shrub vegetation, with a decrease of 0.5675 ha in degraded areas within this sector (2021). However, a reduction of arboreal vegetation of 1.8205 ha was also observed.

DISCUSSION

This study indicates that the *restinga* vegetation suffers constant degradation, mainly due to vegetation clearing near the beach, exotic species cultivation for landscaping purposes, and irregular constructions, as evidenced by the high number of irregular buildings (from Sector 6) — an anthropic intervention that can lead this vegetation to extinction. The disorderly and irregular occupations observed on the edge of Pontal do Paraná's beaches, amplified according to the different degradation degrees of each resort, which hinder the environmental management of natural resources carried out by municipal authorities. Such irregular constructions could be verified in all sectors. In Sector 1 (2021), for example, *restinga* vegetation was found that did not exist the year before.

This shows that lack of enforcement is one of the obstacles to the preservation of the PPA. It also suggests that each resort will need an individualized environmental action plan that considers its specific attributes.

The irregular anthropic occupation near the beach also influences the width of *restinga* vegetation within the evaluated sectors. In Sectors 1 to 5, for example, the sandbank was wider than in other sectors, where occupation is closer to the high tide line. This vegetation suppression provokes a narrowing of the *restinga* strip, which may reduce endemic biodiversity (LAURANCE, 2009; MARQUES; SILVA; LIEBSCH, 2015).

As observed in this study, the *restinga* arboreal vegetation was the most impacted. This vegetation consists of close-to-the-sea low-lying species that gradually increase in height as they move away from the high tide line, forming a transitional ecosystem to the Atlantic Forest (SCARANO, 2009; DALOTTO *et al.*, 2018; INAGUE; ZWIENER; MARQUES, 2021). The decrease of this arboreal vegetation is explained by the fact that irregular constructions occupy the place where these vegetations usually occur, as evidenced in Sector 6, which presented the highest anthropic irregular buildings, that can lead this ecosystem to extinction.

Coastal erosion due to human activities is not restricted to Pontal do Paraná city. The State Government of Paraná published Decree nº 3.812/2020, granting municipalities permission to manage the *restinga* vegetation on Paraná State coast. Based on this decree, the cities of Matinhos and Guaratuba elaborated the suppression of this ecosystem, alleging that the presence of the vegetation favored robbery, rape and drug use. Such state intervention is an environmental crime, since the *restinga* vegetation is a PPA, and the suppression of such areas is prohibited by law (BRASIL, 2012; DIOPR, 2022).

Even so, an increase in *restinga* vegetation was observed — specifically in RMNP Sectors 6, 7 and 8. It is possible that the vegetation growth was an outcome of the coronavirus pandemic (COVID-19), considering that the city hall of Pontal do Paraná banned access to the beaches as a measure to prevent viral contagion (Decree nº 8.575/2020; Pontal do Paraná, 2020). In this way, lockdown measures may have allowed for vegetation recomposition in densely populated localities — such as those mentioned above.

However, we should highlight that, as this work has made it possible to verify which regions have sites most eroded by anthropic activities such as vegetation suppression and an increase in irregular constructions, it is able to support urban zoning that considers priority locations for environmental recovery, favoring the reestablishment of the *restinga's* biodiversity and preventing these anthropogenic actions from continuing to damage the ecosystem.

Besides that, this study detected the presence of solid waste dispersed in the *restinga*, which may stimulate the dissemination and transmission of diseases. For instance, it can promote the spread of dengue, transmitted by the *Aedes aegypti* mosquito — a very common virus in Paraná coast. It may also facilitate the proliferation of rodents and insects such as cockroaches, which poses a threat to public health. Irregular waste disposal may also endanger the other animals which make this ecosystem their home, such as burrowing owls, that can inadvertently ingest the waste (BETANIN; SILVA, 2016; SILVA; YAMANAKA; MONTEIRO, 2017; STRAPAÇÃO; MARTINS; SILVA, 2018; ORSI; MESTRE; RECHETELO, 2021).

In addition, invasive specimens were found near the *restinga*, which can cause damage to local biodiversity and make the environment more vulnerable to climate change, since specimens that are not natural to the ecosystems can provoke changes in the ecological properties of the soil, in nutrient cycling, in trophic chains, in the distribution structure of community populations and in the relationships between the several endemic specimens (FICK; HIJMANS, 2017; INAGUE; ZWIENER; MARQUES, 2021; SILVA; ZANDONA, 2022). Furthermore, climate change may alter the population dynamics of the *restinga* vegetation (INAGUE; ZWIENER; MARQUES, 2021), which should be evaluated in further work.

Although the methodology employed in the use of remote imaging for monitoring *restinga* vegetation in Brazil is quite recent, it has already proven to be an interesting tool for environmental management programs.

In the neighboring municipality of Matinhos, for example, Martini, Veiga and Centeno (2004) used satellite images to estimate the *restinga* area, and, by observing 3.92 ha, concluded that only 26.08% of the site presented vegetation — suggesting that the anthropogenic constructions in the area provoked flora degradation. On the other hand, in the same city, Puertas and Tonetti (2016) reported an increase in *restinga* vegetation after analyzing satellite images from 2001 to 2015.

In addition, Pinto-Coelho (2021) monitored the beaches on the coast of Vila Velha (a city of Espírito Santo State, Brazil) using drones, and his study showed just 3.18 ha (9.49%) of arboreal vegetation within a mapped *restinga* area of 33.52 ha. This suggests that the vegetation further from the tide line seems to suffer more degradation processes due to constructions.

A pilot environmental quality diagnosis study conducted in December 2020 at Pontal do Paraná city, employing a similar methodology to assess the *restinga* vegetation (PRANDINI; CORREA; SILVA, 2021b), reported results that corroborate the ones presented in September 2020 and 2021. Back then, the authors observed 289.08 ha of restinga vegetation, 184 ha (63.5%) of which were considered conserved and 105.45 ha (36.5%) were evaluated as degraded. This is in line with the results presented in the current study, in which the total conserved area in 2020 was found to be 61.54%, and the total degraded area was 36.72% — while in 2021 the total conserved area consisted of 59.56% and the total degraded area of 38.85%, suggesting that the methodology employed presented repeatability of results.

Furthermore, a work reported with orthophoto analysis of *restinga* vegetation in the municipality of Pontal do Paraná, using the Dzetsaka plugin in the QGIS software — the same that was used in this study — showed a high overall accuracy (90%) (PRANDINI; CORREA; SILVA, 2021a), corroborating the present study (93%), suggesting the data obtained is reliable.

In this way, our study indicates that drone images can be used to monitor the environmental quality of restinga, and its results allow identification of the seaside resorts which have suffered the most impact on their vegetation, possibly resulting in inspection and, if necessary, application of fines or penalties foreseen by criminal law — such as Federal Law nº 9605/1998 (Brasil, 1998). These data are also important for the elaboration of management plans for this conservation unit and for localizing regions with high degraded vegetation indexes. This begins with the environmental diagnosis of the area, evaluating the various economic and social activities developed within it, the occupations in its surroundings and their anthropogenic pressures, subsequently defining the appropriate uses for preservation and conservation (MMA, 2022; SILVA; ZANDONA, 2022). Since it was evidenced that some resorts are suffering greater impact than others, public authorities will be able to establish differentiated management plans for each of the studied sectors, thus improving the efficiency of the environmental management process.

However, even without an adequate management plan or technical study, on March 18, 2022, the City Hall of Pontal do Paraná published Municipal Decree nº 10.207, declaring the city's waterfront a permanent preservation area of public utility and social interest. The decree proposes the implementation of paved sidewalks, bicycle lanes, and access to the beach, and the installation of public facilities such as lighting, benches, garbage cans and gym equipment (Pontal do Paraná, 2022). This indicates the importance of continuous monitoring of the Pontal do Paraná *restinga*, due to its great ecological and social importance and the fact that it is constantly undergoing anthropic changes due to human proximity and public and diffuse interests.

The environmental programs need to make the population aware that this unique vegetation performs ecosystem services such as protection against sand erosion, sediment retention, and protection from sea-level rise. Besides, it is also an ecosystem rich in endemic flora and fauna species (INAGUE; ZWIENER; MARQUES, 2021; LUZ *et al.*, 2022).

Although the classification of *restinga* attributes may be subject to errors due to pixel overlapping or operator misinterpretation in the delimitation of polygons, as warned by Prandini, Correa and Silva (2021a), the results of our study suggest that this methodology, when applied alongside the use of drones to perform environmental monitoring, can be a tool of great applicability for assessing vegetation quality. It also provided rapid results at a low operational cost, using exclusively open-source software, which is indispensable for economically emergent countries like Brazil. This is because city halls have limited financial resources to monitor extensive biodiversity-rich areas such as *restingas*.

In view of this, we suggest continuing this project to evaluate the dynamic response of the *restinga* against anthropic impacts during the high (summer) and low (winter) seasons and assessing the influence of climate change on *restinga* vegetation. In addition, further studies are recommended to estimate the rates of vegetation recovery and/or degradation in order to support the public authorities in the decision-making process and in the environmental management of ecological resources.

CONCLUSION

The *restinga* vegetation in Pontal do Paraná is severely impacted by anthropic actions, with the arboreal vegetation being the most degraded, especially due to the irregular constructions on the beachfront. The assessment of high-resolution images obtained by drone overflights with exclusively open-source software analysis in the present study has proved to be a powerful tool for environmental analysis and mapping, indicating areas of lowest and highest vegetation degradation rates in order to support the priority areas for more accurate control and monitoring, aimed to guarantee optimized and low operational cost. It can be an important reference for environmental management in emerging countries like Brazil.

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AUTHORS' CONTRIBUTIONS

Silva, C.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Correa, A.D.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft. Prandini, M.K.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization.

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