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A drone diagnosis of the environmental quality of the restinga on the south coast of Brazil

Cesar Aparecido da Silva[1*], Matheus Kopp Prandini[1], Alan D'Oliveira Correa[1]

[1] Center for Marine Studies – Federal University of Paraná (Av. Beira-mar, s/n, P.O. Box: 61 – Pontal do Paraná, PR 83255-976 – Brazil).

* Corresponding author: silva@ufpr.br

Abstract

Drones have proven to be versatile tools for scientific studies aimed at assessing the environmental quality of various ecosystems. This study diagnosed the restinga vegetation in the coastal municipality of Pontal do Paraná, in the state of Paraná, Southern Brazil. This vegetation, which extends over 21.72 km of the coastline of the municipality, was grouped into eight sectors to optimize 27 drone flight plans. The images obtained were transformed into orthomosaics and classified into eight classes, following the random forest classifier: herbaceous, shrubby, arboreal, sand, degraded area, irregular construction, water, and other. We observed 289.11 ha of restinga, of which 183.66 ha (63.5%) corresponded to conserved areas and 105.45 ha (36.5%), to a total degraded area with irregular constructions, vegetation suppression, and introduction of exotic species. Sectors 1 and 5 showed the lowest (8.19 ha) and highest (21.00 ha) values of degraded areas, respectively. Sectors 6 and 8 were the most critical: their degraded areas exceeded the conserved areas of restinga by 4.15 and 3.95 ha, respectively. The main causes of the degradation n in this study refer to irregular occupation. Drone images are a valuable tool for environmental management and vegetation analysis of difficult-to-access sites.

Keywords: Restinga vegetation, Unmanned aerial vehicle, Environmental management, Aerial monitoring, Orthomosaics

INTRODUCTION

Field studies aimed at diagnosing and monitoring natural and anthropogenic environmental features face several obstacles, such as steep and difficult-to-access terrains, unhealthy regions, and high operational and logistical costs. These difficulties can be overcome with unmanned aerial vehicles (UAVs), commonly known as drones (Ogden, 2013; Neuville et al., 2021; Silva et al., 2021).

Versatility is one of the main advantages of drones. They can integrate high-quality imaging and global positioning systems (GPS) to obtain georeferenced images for several purposes (Prudkin and Breunig, 2019; Stoddart et al., 2022; Wang et al., 2022). Drone images can be processed to generate orthomosaics (or orthophotos), which consist of several combined georeferenced images. This geoprocessing, in turn, can be used to quantify the elements and characteristics of an area, such as its vegetation (Correa et al., 2022). Moreover, due to diagnosis or monitoring possibilities, the analyses obtained

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by geoprocessing orthophotos can assist the environmental management of areas such as the restinga (Silva et al., 2018; Correa et al., 2021).

Restingas, due to variable abiotic conditions and their location on sandy and saline soils, consist of various types of vegetation such as herbaceous, shrubby, and arboreal, and can be found all along the Brazilian coast (Lacerda et al., 1993; Marques et al., 2015). Since 1965, the restinga has been considered a Permanent Preservation Area (PPA) in Brazil by the former Código Florestal (Brazilian Forest Code) (Law No. 4.771/1965) and ratified by the current Brazilian code (Brasil, 2012). However, this ecosystem has been among the most affected by human colonization (Correa et al., 2021). The original restinga and dune vegetation covered approximately 70% of the Brazilian coast but in areas such as Baixada Santista, in the state of São Paulo, Southeastern Brazil, only 22% of the original restinga vegetation remains preserved (Guedes et al., 2006).

Moreover, the extreme characteristics and pressures from the coastal environment may render the impacts on the restinga irreversible (Guedes et al., 2006). High salinity, winds, elevated temperature, low nutrient content of the sandy soil, and exposure to solar irradiance are some environmental characteristics that make it harder for this vegetation to recover (Azevedo et al., 2014; Marques et al., 2015; Dalotto et al., 2018).

In coastal cities in the state of Paraná, Southern Brazil, several factors affect the restinga, and its degradation is considered an erosion factor of the beaches (Puertas and Tonetti, 2016). Stellfeld et al. (2020) conducted a spatiotemporal analysis of the coastline of the municipality of Matinhos. They concluded that the restoration and protection of restinga can naturally ensure that the coastline better adapt to a variable environment and prevent the increase of coastal erosion. Therefore, the protection of restinga is related to the promotion of healthier beach environments (Silva et al., 2018; Correa et al., 2021, 2022).

Kotler (2004) offered key proposals for managing this vegetation at the Restinga Municipal Natural Park (RMNP), in the coastal municipality of Pontal do Paraná, Paraná State, including zoning the region and developing preservation enforcement and monitoring programs. The author also highlights several factors that contribute to the degradation of restinga, such as irregular constructions, accumulation of solid waste, and inadequate access to the beach.

In this municipality, the restinga vegetation shows visible alterations, such as man-made pathways to the beach, introduction of exotic species for landscaping, cutting and trimming the vegetation, installation of showers for bathers, solid waste deposits (which can contaminate the soil and the water), constructions, and fishermen's and vendor's shacks, which are easily found all along the shore (Scarano, 2009; Fazion, 2013; Silva et al., 2017, 2018). These human interventions can drive endemic species to extinction (Correa et al., 2022).

Nevertheless, data related to the human impacts on restinga remain scarce, especially during the high season. Given this context, this study aims to make an environmental diagnosis of the restinga vegetation in Pontal do Paraná using a quadcopter drone to identify the most degraded areas and the main causes of this degradation. We hope the data will support the development of public policies to solve this chronic problem.

METHODS

Study Area

The study area is located at the Restinga Municipal Natural Park (RMNP) in the coastal municipality of Pontal do Paraná, Paraná State, Southern Brazil. This municipality has an area of 200 km^2 and an estimated population of 27,915 inhabitants (IBGE, 2022), which increases tenfold during the summer, when tourists visit the local beaches (Correa et al., 2022). The environmental diagnosis covered 21.72 km of restinga on the coastline of the municipality. In total, 32 beaches were evaluated, from Pontal do Sul to Monções (Figure 1).

Since Pontal do Paraná has no distinct territorial limits for each of its beaches, the coastline was divided into eight sectors. This division sought to optimize the analysis of the images and the data obtained by the drone flight plans. Due to its extension, Pontal do Sul was divided into two sectors (Pontal do Sul – North, sector 1 and Pontal do Sul – South, sector 2), thus reducing the differences between sector sizes. The remaining sectors encompass from two to eight beaches. The average length of the eight sectors totaled 2.72 ± 0.94 km (average ± standard deviation) (Table 1).

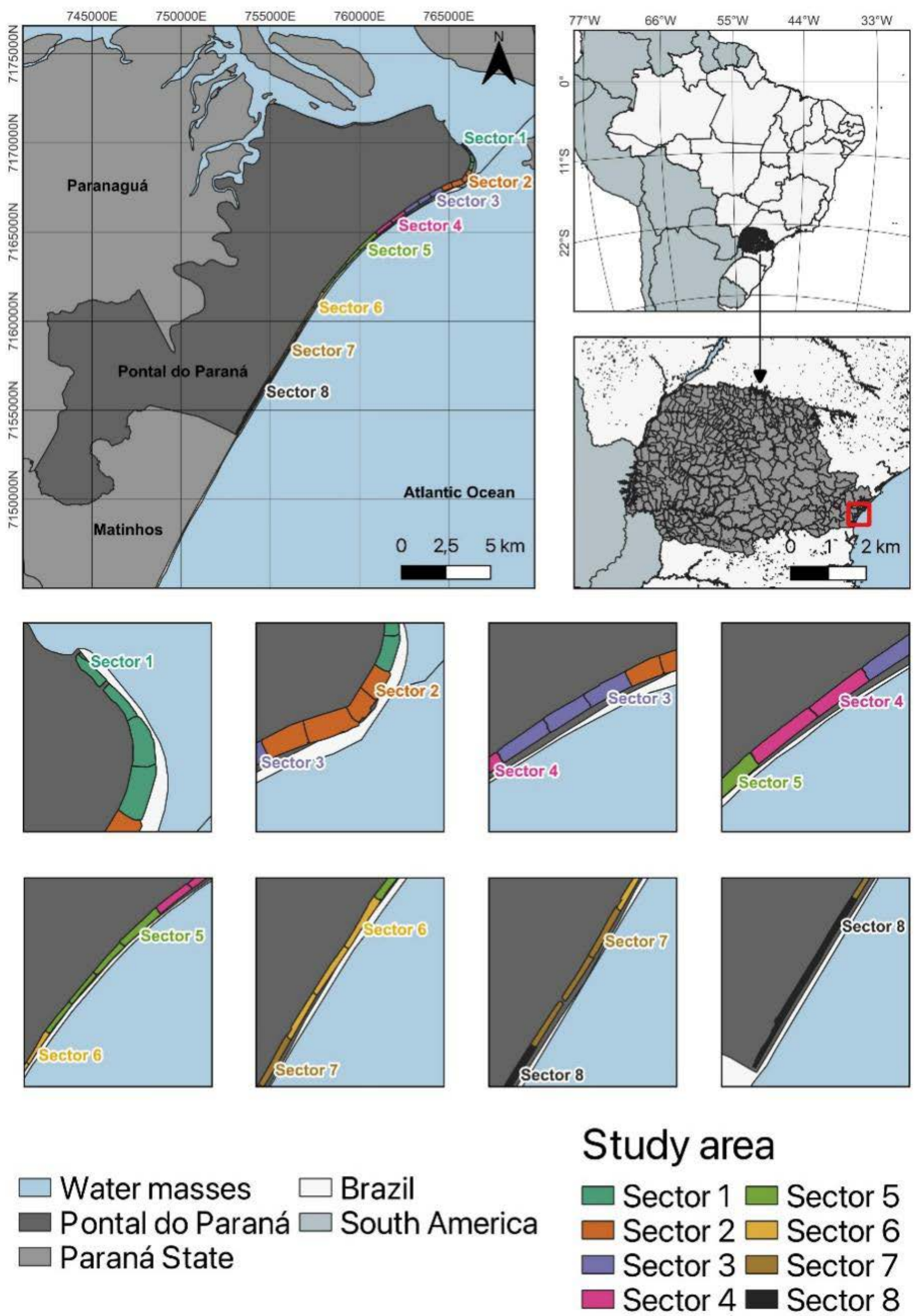

Figure 1. Location of the study area showing details of the sector division to optimize drone overflight at the Restinga Municipal Natural Park (RMNP). UTM projection (Zone 22S and Datum SIRGAS 2000).

Table 1. Division into eight sectors to optimize drone overflight according to the beaches in the municipality of Pontal do Paraná, Paraná State, south coast of 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
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	3.7

Image Acquisition and Processing

The drone overflight was carried out in accordance with the guidelines of the Brazilian National Civil Aviation Agency – license PP-995248508 ANAC for environmental studies.

To obtain the restinga vegetation images, flight plans were made for each sector, consisting of predetermined routes created with the Pix4Dcapture application so the drone could perform autonomous flight and handling errors could be avoided. An altitude of 60 m was adopted in the flight plan configurations, which yielded an estimated 2.60 cm px^{-1} ground sample distance (GSD). This altitude was determined by field tests that sought to optimize the relation between flight time and image quality and resolution. A total of 27 flight plans covered the entire extension of restinga. The images were captured in December 2020, the high summer season in Pontal. However, the high season that year was possibly affected by the COVID-19 (SARS-CoV-2) pandemic.

The drone (DJI Phantom 3 Standard) was configured thus: a maximum speed of 16 m s^{-1} with a 1/2.3" CMOS sensor and a 12 MP camera with a field of view (FOV) of 94 and 20 mm (equivalent to 35 mm) and an aperture of f/2.8; an image resolution of 4,000 x 3,000 pixels; a weight of 1.216 kg (battery and propellers included); a hover accuracy range of ± 0.5 (vertical) and ± 1.5 (horizontal); and a gimbal with 3 tilt axes. The drone control operates from 5.725 to 5.825 GHz.

The images captured during the flight plans were processed in the open-source software OpenDroneMap (ODM), which grouped them into a single image, creating an orthomosaic.

Geoprocessing and Classification

The orthomosaics were evaluated using QGIS (v. 3.18.3-Zürich). By default, the drone and the ODM project images and orthomosaics in the EPSG:32722 – WGS84/UTM were assessed according to the zone 22S coordinate system, respectively. Then, all orthomosaics were reprojected into the EPSG:31982 – SIRGAS 2000/ UTM zone 22S coordinate system since it is the official Brazilian datum and the most suitable for the region. The area of interest was then clipped by a shapefile layer to delimit it, removing spaces that failed to comprise the analyzed restinga area. The limit adopted in this study extended from the last street parallel to the vegetation toward the Atlantic Ocean relative to the beach area.

After the orthomosaics with shapefiles of each sector were produced, supervised image classification was performed with the Dzetsaka plugin (Karasiak, 2016). We used the random forest classifier algorithm described by Breiman (2001) to characterize the vegetation and soil. In total, eight classes were defined to quantify the supervised classification of the orthomosaics (Figure 2). The vegetative composition of the restinga was classified as herbaceous, shrubby, and arboreal. The "degraded area" class represents irregular vegetation suppression and pathways in the restinga vegetation, generally used by bathers to access the beach and occupied by illegal parking. Moreover, exotic species such as palm trees and grasses introduced by the local population were also considered degraded areas since they occupy the space of native species. The "sand" class was disregarded from the results for degraded areas and only aimed to determine the beginning of the vegetation. The "other" class was established for temporary features, such as shadows and fishermen's boats. The "water" class refers to water sources in the restinga, such as pools of water, small streams, and estuaries. "Irregular construction" refers to houses and other buildings in the restinga. Some classes were grouped to facilitate analyses: "total degraded area" comprises the "degraded area" and "irregular construction" classes, whereas "total restinga area" comprises the "herbaceous," "shrubby," and "arboreal" classes. To categorize the data, vector polygons were manually sampled on the orthomosaics according to the eight classes. Figure 3 details the categorization process.

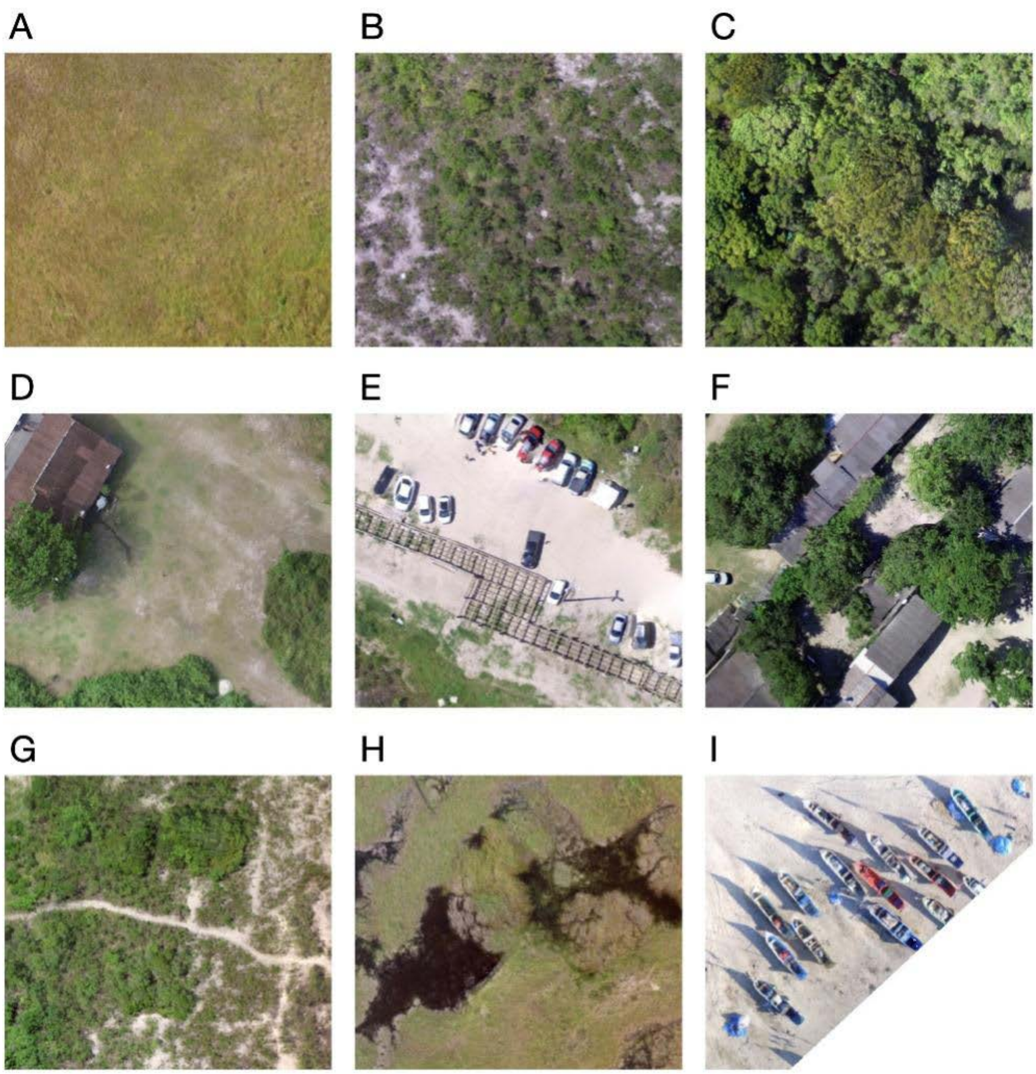

Figure 2. Example of classes used to categorize the restinga vegetation. A: Herbaceous vegetation; B: Shrubby vegetation; C: Arboreal vegetation; D: Irregular vegetation suppression; E: Illegal parking; F: Irregular construction; G: Pathways to the beach; H: Water; I: Other (fishermen's boats).

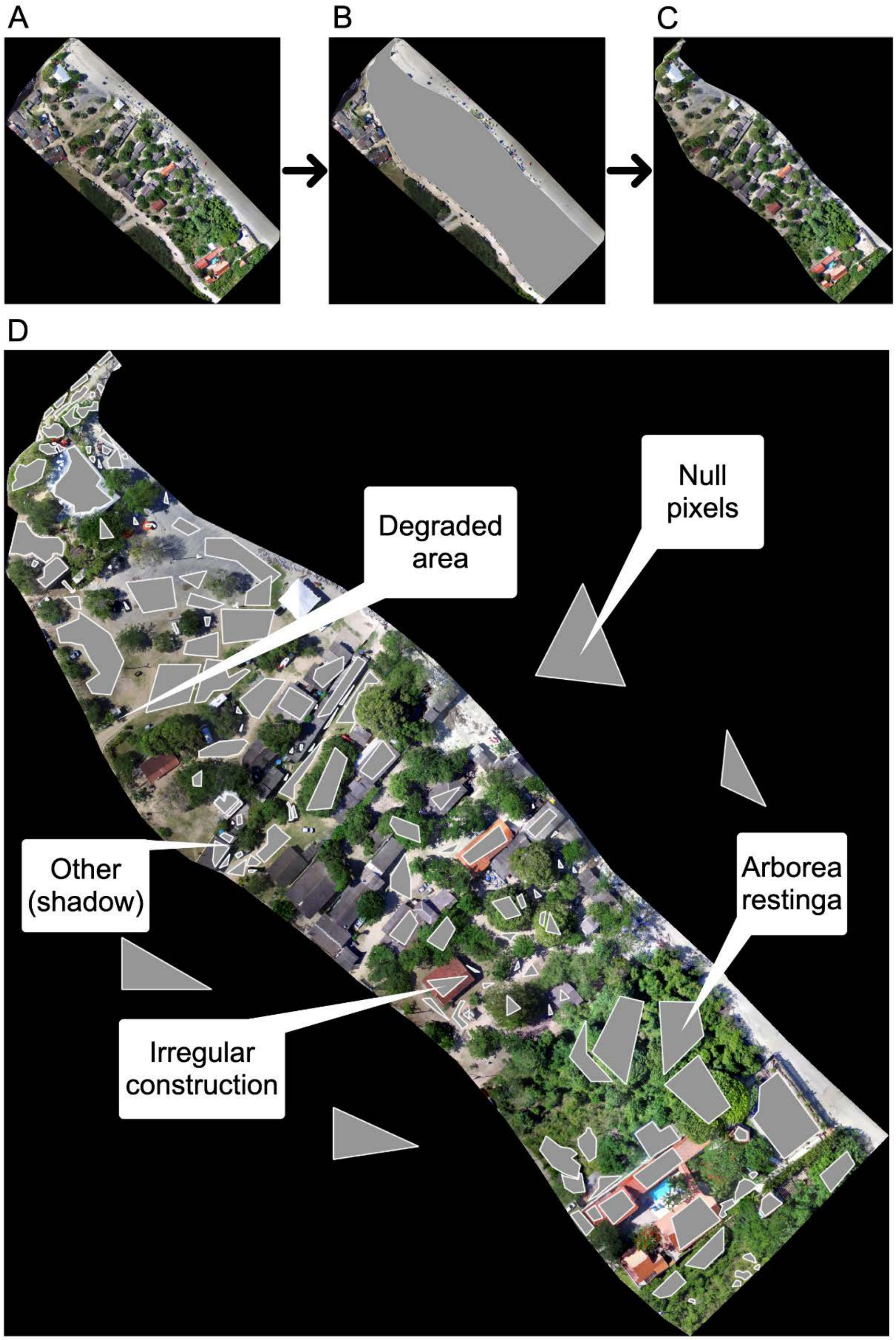

Figure 3. Summary of the election steps for the area of interest in each orthomosaic. A: Orthomosaic after processing and without clipping the area of interest; B: Area of interest manually defined with a shapefile layer; C: Orthomosaic with the area of interest clipped using the shapefile layer; D: Example of an extended orthomosaic for class selection using vector polygons to perform classification with the Dzetsaka plugin.

The obtained data were compiled and the areas related to each class were assessed to estimate the attributes of the restinga vegetation as well as the degree of degradation or conservation.

Data Analysis

Data of each class defined by the supervised classification were evaluated using R (v. 4.0.3) and the following plugins: ggplot2, dplyr, gsheet, tidyverse, and reshape2.

RESULTS

Pontal do Paraná has 289.11 ha of restinga, of which 183.66 ha (63.5%) correspond to conserved areas and 105.45 ha (36.5%) to its total degraded area. The area of herbaceous restinga in the municipality totaled 142.80 ha; decreasing from sector 2 to sector 6 and gradually increasing up to sector 8.

The total area of shrubby and arboreal restinga covered about 27.66 and 13.20 ha, respectively. All evaluated sectors showed degraded areas mainly resulting from the suppression of vegetation and irregular constructions. Sectors 1 and 5 had the lowest (8.19 ha) and highest (21.00 ha) values of degraded areas, respectively. Moreover, the degraded areas showed similarities in all sectors, except for those with the highest values: sectors 3 (16.97 ha), 5 (21.00 ha), and 8 (17.49 ha). The degraded areas in sectors 6 (12.70 ha) and 8 exceeded the conserved areas in these sectors by 4.15 and 3.95 ha, respectively.

This study normalized data as the percentage (%) of the total conserved and degraded areas of restinga and showed that sectors 6 and 8 have the highest percentages of degraded areas. Sector 6 (comprising the Marissol, Grajaú, Leblon, and Ipanema beaches) had 60% of degraded restinga areas, and Sector 8 (comprising Patrick 2, Itapuã, Miramar, São Carlos, Mirassol, Miami, Praia de Leste, Beltrami, Iracemã, and Monções beaches) showed 56% of degraded restinga areas. On the other hand, sector 2, which comprises Pontal do Sul – North Beach, showed the highest percentage of conserved areas of restinga in the municipality (81%).

Among the classes in the orthomosaic analysis, herbaceous vegetation predominated on the shore of Pontal do Paraná. Sector 1 showed the largest areas of arboreal (14%) and shrubby (17%) vegetation, whereas sector 2 had no arboreal vegetation at all. Only sectors 4 and 5 showed the "water" class. All sectors had irregular constructions, but sectors 6 and 8 showed the largest areas of irregular constructions (13 and 8%, respectively), whereas sector 3 showed only 1% (Figure 4).

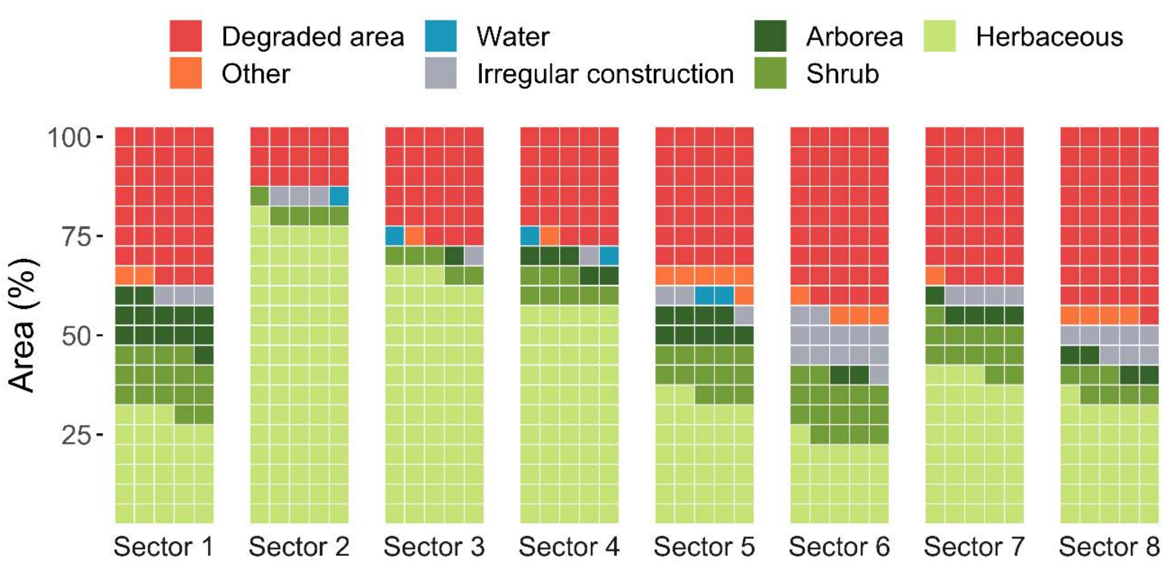

Figure 4. Total areas of the classes evaluated in the orthomosaic analysis of the eight sectors in the municipality of Pontal do Paraná, state of Paraná, Brazil, in December 2020. Results expressed in %. Each square represents 1% of the used classes.

Figure 5 is an orthophoto with the evaluated classes in sector 6, showing the conserved restinga vegetation, degraded area, and irregular constructions.

DISCUSSION

This study suggests the existence of chronic problems affecting the restinga vegetation in Pontal do Paraná: irregular occupations and unplanned tourist activities that degrade the environment as reported in other studies (Kotler, 2004; Fazion, 2013; Ribeiro et al., 2013; Silva et al., 2018). These problems also occur in other regions of the Brazilian coast, in which restinga is either at risk of extinction or already extinct (Falkenberg, 1999; Scherer et al., 2005; Guedes et al., 2006; Pierri et al., 2006; Zamith and Scarano, 2006; Puertas and Tonetti, 2016; Stellfeld et al., 2020).

Figure 5. Example of the evaluated classes in sector 6 showing the conserved and degraded areas of restinga and irregular constructions.

However, restinga is a dynamic vegetation, and this study only assessed the characteristics of its occupied areas in Pontal do Paraná. Kotler (2004), for example, mentions that restinga has highly volatile dynamics on a monthly or even daily scale, changing its landscape. Regarding its dynamism, Santos et al. (2021) observed that restinga vegetation affected by sea overflow recovered at a 1.8% increase rate over three years. On the other hand, the authors point out that the areas in which the vegetation suffered from human actions failed to recover with the same success.

Studies evaluating the restinga on the Brazilian coast have used different methodologies. For instance, in the estuarine-lagoon complex of Iguape, Ilha Comprida, and Cananéia, in the state of São Paulo, the identification of various restinga physiognomies was conducted with satellite images to differentiate between the following restinga formations: shrubby restinga, vegetation between sand ridges, short restinga forest, tall restinga forest, marshy field, wet restinga field, and swamp forest. The restinga areas identified in the municipalities totaled 28,612.45 ha in Cananéia, 15,531.30 ha in Ilha Comprida, and 98,471.82 ha in Iguape (Brizzotti et al., 2009).

In this study, the restinga vegetation had distinct characteristics in some sectors. Knowing the specific characteristics of each sector is crucial to manage the environment and plan recovery due to the differences in degradation degree and type. In sector 1, for example, irregular constructions were the main degradation type, especially in areas the ship channel near Ilha do Mel, whereas sector 8 showed a critical, systematic degradation of restinga. These data can guide specific environmental protection and recovery policies by local authorities. It is worth mentioning that the restinga vegetation has endemic flora and fauna species and serves as refuge and breeding environment for various animals, such as owls, seabirds, and turtles. Therefore, its degradation can impact both terrestrial and marine ecosystems (Silva et al., 2018). In addition to its intrinsic natural value, restinga is part of ecosystem processes such as sand and dune fixation, coastal protection (e.g., against sea overflow), and biodiversity maintenance, indispensable factors for the sustainable development of the Brazilian coast (Correa et al., 2021).

This study found that irregular constructions are one of the main degradation factors of the restinga. This corroborates Correa et al. (2022), who monitored the same restinga area in September 2020 using a similar drone methodology and found that the areas corresponding to Sectors 6 and 8 in this study had a high degree of irregular occupations and illegal pathways to the beach.

Correa et al. (2021) reported that irregular occupation takes place near the high tide line and suppresses the local vegetation. This study found that arboreal vegetation is sparse, corroborating those findings. In sector 2, for example, the arboreal restinga is virtually extinguished. Since restinga is a transition ecosystem to the Atlantic Forest (Dalotto et al., 2018; Inague et al., 2021), a decrease in its biodiversity may offer risks to many endemic species or even extinction (Laurance, 2009; Scarano, 2009).

On the other hand, herbaceous vegetation was the most prevalent in our study. It is the closest to the high tide line and some of its species can be considered as colonizing vegetation types (Oosting and Billings, 1942). The high prevalence of this vegetation may have occurred because this study took place during the COVID-19 pandemic, when Pontal do Paraná banned access to its beaches to prevent virus spread (Decree N. 8.575/2020; Pontal do Paraná, 2022). The lack of human interventions may have enabled the vegetation to recover in some sectors. Therefore, degradation data may have been underestimated, and further studies should be conducted after the pandemic to test this hypothesis.

Several environmental studies have been conducted using drones (Silva et al., 2018; Almeida et al., 2020; Neuville et al., 2021; Stoddart et al., 2022). Silva et al. (2021) assessed apparent solid waste in a landfill near restinga areas in Pontal do Paraná and concluded that drones enabled low-cost evaluations and analyses in unhealthy and dangerous areas, avoiding health-related risks to researchers.

Correa et al. (2022) monitored the restinga vegetation at the Pontal do Paraná RMNP using drones. They found that degradation remained relatively constant over one year. This suggests that degradation is a chronic problem in the municipality and that drones are important tools for public management as they can locate the most vulnerable and impacted sites, thus supporting governmental decision-making and the development of management and recovery plans.

A study conducted in the municipality of Vila Velha, Espírito Santo State, Southeastern Brazil, also analyzed the restinga using drones (Pinto-Coelho, 2021). It estimated that approximately only 9.50 ha of the local restinga was preserved. Results suggested that constructions on the seashore are one of the main environmental problems for the preservation of restinga (Pinto-Coelho, 2021), as in our study.

Environmental assessments conducted with drones may still have operational errors and overlapping pixel areas during the orthomosaic classification process. However, a drone study conducted at the RMNP by Prandini et al. (2021) using open-source software for image analysis such as those we used concluded that data accuracy exceeded 90%. Thus, drones are management tools that ensure reliable results and have low operational costs.

This study showed that drones can serve as operational tools to monitor the environmental quality of restinga in Pontal do Paraná. It also showed that the use of open-source software is a low-cost option to enable periodic assessments of the restinga, which, although a PPA, showed degraded areas with irregular occupations/ constructions and illegal vegetation suppression. Authorities should more effectively restrain illegal settlements and vegetation cutting and implement environmental education and awareness programs for the local community and tourists. Moreover, drones could locate the most degraded areas. These data can guide decision-making and environmental recovery plans, increasing the efficacy of management by the municipality.

CONCLUSION

Drone images showed the degraded and preserved areas of the restinga and found that the main degrading activities were irregular constructions and vegetation suppression, especially in sectors 6 and 8, which showed high degradation rates. Further studies are needed due to the importance of conserving this ecosystem.

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AUTHOR CONTRIBUTIONS

C.A.S.: Conceptualization; Methodology; Formal analysis; Investigation; Writing - Original draft; Writing – review & editing; Project administration; Supervision; Validation; Methodology;

M.K.P.: Formal analysis; Investigation; Writing – Original draft;

A.O.C: Conceptualization; Methodology; Formal analysis; Investigation.

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