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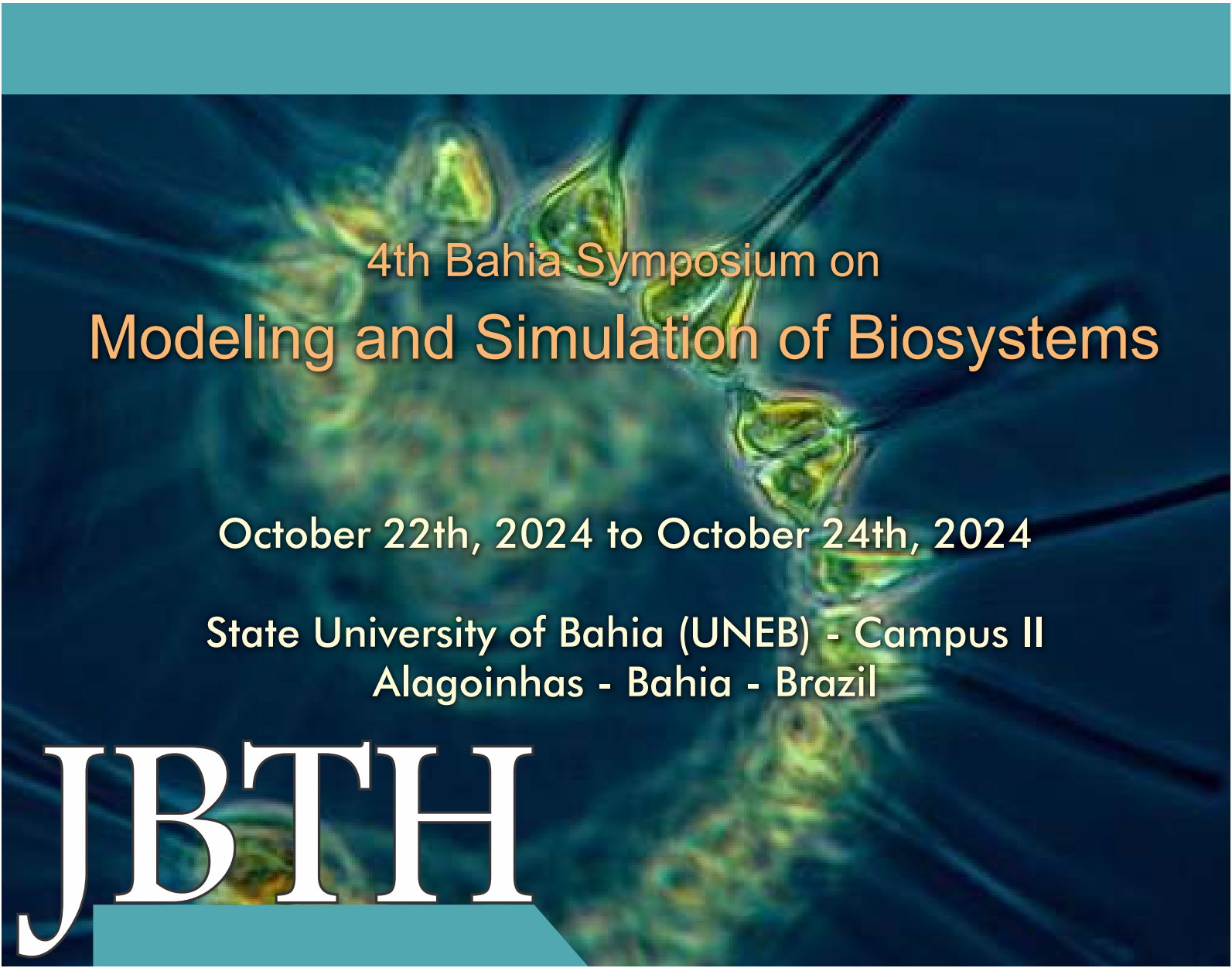

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Volume 7 • Supplement 1 **SUMMARY** *December 2024*

Original Articles

Systematic Review / Bibliometric Articles

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Quantification of Pigmented Regions in Detracted Images

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This study presents a method for analyzing and quantifying pigmented areas on dental surfaces after the application of caries detection products. The methodology integrates image enhancement, the creation of binary masks, and conversion to the HSV color space to isolate and accurately calculate the extent of pigmentation. A dataset consisting of 200 images of unpigmented teeth and 200 images of pigmented teeth was used, with strict criteria for selecting images that provided a clear frontal view, focusing on the upper and lower canine regions. The image processing steps included using LabelMe software for manual annotation and applying binary masks to segment the teeth from the background. Specific color filters identified pigmented regions. Histogram analysis in the HSV space validated the predominance of red shades corresponding to the pigmented areas, confirming the accuracy of the segmentation. The results demonstrate the effectiveness of the proposed method for calculating pigmented areas, providing an objective measure that can be used to assess the efficacy of products designed for bacterial plaque detection in dental applications.
Keywords: Computer Vision. Tooth Detection. Tooth Pigmentation.

The early detection of bacterial plaque is essential for ensuring oral health and preventing the progression of lesions that may compromise dental structures. Bacterial plaque is a biofilm that forms on the surface of teeth and is a primary factor in the development of cavities and periodontal diseases. Effective detection methods can assist oral health professionals in making more precise clinical decisions and implementing less invasive treatment strategies [1].

Historically, bacterial plaque identification has been performed through visual examinations, often aided by specific dyes that reveal the presence of plaque on dental surfaces. These dyes, such as red acid and iodine-povidone, bind to demineralized areas, highlighting lesions that may not be visible to the naked eye. However, these methods have limitations, including the subjectivity of result interpretation and the high cost of materials, which may hinder their large-scale use [1].

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Accuracy in detecting and monitoring bacterial plaque is crucial for early intervention and the continuous assessment of oral health. Failure to correctly identify plaque can lead to inadequate treatments, resulting in lesion progression and tooth loss. Thus, searching for more accessible, precise, and automated detection methods is very important for clinical dental practice [2].

Dental image segmentation is a critical step in quantifying bacterial plaque in imaging technologies and data processing. Segmentation involves extracting regions of interest, such as the pigmented tooth area, to ensure that subsequent area calculations are representative and reliable. Segmentation techniques range from simple threshold-based methods to advanced deep learning algorithms, such as convolutional neural networks [3].

However, dental image segmentation faces several challenges. Anatomical variability, such as differences in tooth morphology and surrounding structures, can complicate the application of standardized segmentation models. Additionally, the quality of captured images, especially in clinical environments with equipment of varying quality levels, can affect the accuracy of segmentation algorithms [3].

Panoramic radiographs, for example, are widely used in dentistry because they provide a comprehensive view of the dental arch. However,

segmenting individual teeth in these images is challenging due to the overlapping of structures and low resolution in some areas, which may compromise the precise identification of regions of interest [4].

Given these challenges, this study focuses on precisely quantifying the pigmented area in teeth after applying dyes. The proposal is to use advanced segmentation techniques to isolate the areas of interest and calculate the extent of pigmentation to improve the assessment of dye efficacy in bacterial plaque detection. This approach seeks to contribute to clinical practice and the development of automated tools that can be applied on a large scale, reducing costs and increasing the accessibility of detection methods [4].

Related Work

Tooth detection in medical images is a significant challenge due to teeth' morphological diversity and variations in image capture conditions. Several recent studies have explored innovative approaches to improving the accuracy and efficiency of this process, contributing to important advancements in the field.

Guo and colleagues [5] proposed an innovative method using Mask R-CNN with an attention mechanism for detecting abnormal teeth in dental X-ray images. This study stood out for improving detection accuracy and increasing diagnostic efficiency, achieving 79% accuracy. The application of Mask R-CNN proved effective in handling the complexity of the images, offering a promising solution for automatically detecting dental anomalies.

On the other hand, Sirinat and colleagues [6] explored tooth identification through a rotation-based correlation method. Although the approach showed potential, the lack of data on the effectiveness of the results suggests that further studies are needed to validate its application in different clinical contexts. This study emphasizes the importance of developing and testing new methods to ensure their robustness and applicability in practical scenarios.

Another relevant study is from Samiappan and colleagues [7], that applied Convolutional Neural Networks (CNNs) for tooth detection in radiographs of the lower and posterior regions of the mouth. This approach successfully segmented teeth and identified possible fractures, demonstrating the versatility of CNNs in different clinical contexts. The accuracy in fracture identification highlights the importance of CNNs in complex diagnoses, where precise segmentation is crucial for proper treatment.

Finally, Kong and colleagues [8] presented a two-stage approach with region-of-interest exclusion, achieving 0.76% accuracy in periodontitis classification. This study underscores the challenges faced in dentistry, particularly in detecting periodontal diseases, and the need for specialized approaches to improve diagnostic accuracy. The two-stage methodology offers a promising strategy for dealing with complex clinical cases where simple segmentation may not be sufficient for an accurate diagnosis.

Materials and Methods

Database

This study was conducted using two distinct datasets: a public database and a set of colored tooth images captured after the application of products for cavity identification. The public database includes 200 images of properly labeled non-pigmented teeth, while the pigmented database contains 200 images, of which 30 were classified in detail. The selected images provided a clear frontal view of the teeth, focusing on the region between the upper and lower canines, ensuring consistency for subsequent analyses.

Tooth Segmentation

Tooth segmentation was performed using the LabelMe software to manually label regions of interest in each image. LabelMe is a widely used image annotation tool developed by MIT in the computer vision community. This tool facilitates

the creation of annotated datasets for tasks such as object detection, image segmentation, and scene recognition, allowing for precise annotation of regions of interest.

To carry out the procedure, the image must first be opened in the software, where all points are marked, enclosing an area to form a polygon. Each image may contain one or more polygons. When saving, a JSON file is generated with specific coordinates for the marked regions (Figure 1).

Each object within the array of shapes will describe points, and a description will be provided during marking. Additionally, a reference will indicate which image these points were generated from.

After this step, a structure must be built to iterate through each vector of points, resulting in the complete segmentation of the regions of interest, as shown in Figure 2.

Definition and Calculation of Pigmented Regions

After segmentation, the color space was converted from BGR to HSV to isolate the pigmented regions. The hue (H) component was calculated as presented in Equations 1-3.

Figure 1. File generated after point marking.


```
{
  "version": "5.5.0",
  "shapes": [
    {
      "label": "E_In_C",
      "points": [
        [431.36, 98.98], [399.96, 174.56], [381.36, 273.40]
      ],
      "shape_type": "polygon"
    }
    ...
  ],
  "imagePath": "imgs/PHOTO-2024-05-29.jpg"
}
```


Figure 2. LabelMe segmentation result.

Equations 1-3.

$$H = \begin{cases} 0 & \text{if } \Delta = 0 \\ 60^\circ \times \left(\frac{G-B}{\Delta} \mod 6\right) & \text{if } C_{max} = R \\ 60^\circ \times \left(\frac{B-R}{\Delta} + 2\right) & \text{if } C_{max} = G \\ 60^\circ \times \left(\frac{R-G}{\Delta} + 4\right) & \text{if } C_{max} = B \end{cases} \quad (1)$$

Saturation was calculated as:

$$S = \begin{cases} 0 & \text{if } C_{max} = 0 \\ \frac{\Delta}{C_{max}} & \text{otherwise} \end{cases} \quad (2)$$

The value (V) was obtained as:

$$V = C_{max} \quad (3)$$

Masks in Images

The creation of masks is a widely used technique for segmenting or isolating specific parts of an image based on defined criteria, such as color, intensity, or textural characteristics. A mask is a binary image where pixels corresponding to a region of interest are set to white (value 255), while all other pixels are set to black (value 0). This technique allows subsequent operations to be applied only to the regions of interest, facilitating image processing and analysis.

In this study, we segmented the image based on color intervals corresponding to the regions of interest. Lower and upper thresholds for the color components in the selected color space defined these intervals. The binary mask checks whether each pixel in the original image falls within the defined color intervals. If a pixel is within the interval, it is set to white (255) in the mask; otherwise, it is set to black (0). It is also possible to combine different masks to create an interval filter for a matrix using a technique known as bitwise operation:

$$\text{Final Mask} = \text{Mask}_1 \,\&\, \text{Mask}_2 \,\&\, \ldots\ldots \,\&\, \text{Mask}_n \quad (4)$$

Results

We present the results obtained from the analysis of pigmented tooth images, focusing on calculating the pigmented area. The processing steps described in previously were applied to isolate and quantify the regions of interest, resulting in the calculation of the area affected by the pigment (Figures 3-5).

The analysis began with obtaining the original tooth image, where an enhancement technique was applied to improve the visibility of the pigmented areas. Additionally, many regions had light interference, which affected the results. The pre-processing ensured that the pigmented regions were highlighted, facilitating subsequent segmentation. After enhancement, segmentation was carried out using a binary mask that isolated the teeth from the rest of the image. This segmentation ensured that only the regions of interest—the teeth—were considered for pigment analysis, eliminating noise and background interference.

The pigmented regions were then identified using specific filters in the HSV color space, focusing on the hues associated with the red pigment. The generated mask allowed for precise isolation of the pigmented areas on the teeth. The area of the pigmented regions was calculated by counting the pixels within these areas. In the example presented, the total pigmented area was determined to be 118,570 pixels. This value represents the extent to which the dental surface is affected by applying the bacterial plaque identification product.

This image's characteristics were well-segmented, as there is a clear separation of the tooth regions and coloration. However, since we aimed for accurate prediction, we avoided false negatives. As a result, the color thresholds became more intense, leading to some issues with images with a gradient color. In this image, we notice that the left central incisor has a darker shade that gradually lightens, and the system did not identify this as a pigmented area.

Figure 3. Main results.

Figure 4. Main results.

Figure 5. Main results.

Since our analysis required fewer false positives, this was an acceptable error, considering that the dyes we aimed to compare mostly exhibited values within more intense intervals. As shown in the following Figures, the image contains regions with isolated dotted areas of pigment, yet the regions of interest were well-segmented, demonstrating the robustness of the method employed for identification.

References

1. Singhal DK, Acharya S, Thakur A S. Microbiological analysis after complete or partial removal of carious dentin using two different techniques in primary teeth: a randomized clinical trial. Dental Research Journal (Isfahan) 2016;13(1):30–37.
2. Marsh PD. Dental plaque as a biofilm and a microbial community–implications for health and disease. BMC Oral Health 2006;6(Suppl 1):14.
3. Dot G, Chaurasia A, Dubois G, Savoldelli C, Haghighat S et al. Dentalsegmentation: robust deep learning-based cbct image segmentation. medRxiv 2024;2024–03.
4. Sun Y, Feng J, Du H, Liu J, Pang B et al. Single tooth segmentation on panoramic x-rays using end-to-end deep neural networks. Open Journal of Stomatology 2024;14(6):316–326.
5. Guo Y, Guo J, Li Y, Zhang P, Zhao Y-D et al. Rapid detection of non-normal teeth on dental x-ray images using improved mask r-cnn with attention mechanism. International Journal of Computer Assisted Radiology and Surgery 2020;19(4):779–790.
6. Sirinart N, Paton W, Wareethip P, Charoenpong T. Teeth detection for panoramic dental X-ray image by rotated tooth template for telemedicine technology 2023;73–76. Available ate: https://www.scopus.com/inward/record.uri?eid=2-s2. 0-85149659116&doi=10.1109%2fICA-SYMP56348.2023.10044935&partnerID=40&md5=f248d3b4e1ff7592cb01c2144496435d.
7. Samiappan D, Jayaraj R, Nijanth Shankar K, Nithish Kumar N. Analysis of dental X-ray images for the diagnosis and classification of oral conditions. 2023:564–569. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2. 0-85153572797&doi=10.1109%2fICCMC56507.2023.10083914&partnerID=40&md5=5068cec077b498aeb21f5daa24b51124.
8. Kong Z, Ouyang H, Cao Y, Huang T, Ahn E et al. Automated periodontitis bone loss diagnosis in panoramic radiographs using a bespoke two-stage detector. Computers in Biology and Medicine 2023;152.

Seed Germination of Native Species of Atlantic Forest (Bahia, Brazil)

Rosângela da Silva Pinto[1*], Lisandra Roberta da Silva Pita[2], Maria Dolores Ribeiro Orge[1], Suelle Gonçalves Santiago[3], Elis Gean Rocha[4]

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The objective of this study was to evaluate the seed germination of native species of the Atlantic Forest biome. We evaluated sucupira *Bowdichia virgilioides* Kunth, jatobá *Hymenaea courbaril L.*, monkfish *Enterolobium contortisiliquum* (Vell.) Morong (Fabaceae), guava *Psidium guajava L.* (Myrtaceae) and jequitibá-rosa *Cariniana legalis* Kuntze (Lecythidaceae), through germination rate (GR), germination speed index (GSI), and mortality rate (MR), after pre-germination treatment stoovercome dormancy and subsequent production of seedlings to be used in Degraded Area Recovery Plans. Sets of 100 seeds were divided into four groups of 25 for the treatments, one physical by scarification (wall sandpaper number 120) and two chemicals by immersion in water at room temperature for 48 hours and acetic acid for 15 minutes. These treatments were compared with the control of untreated seeds, subsequently grown in washed sand at room temperature in the shade. The indexes GR, GSI, and MR were calculated and analyzed. In general, scarification was more efficient for *H. courbaril* (GR=48%) and *E. contortisiliquum* (GSI=0.75) but increased the MR of this in other species. Immersion in water favored new seeds of sucupira *B. virgilioides* (GR=52%, GSI=0.69), and immersion in acetic acid showed a varied and less effective performance overall. Scarification with sandpaper and immersion in water at room temperature for 48 hours were the most effective methods to increase the seedling production of the studied species.
Keywords: Overcoming Dormancy. Scarification. Water Immersion. Acetic Acid.

In native forests, viable seeds that do not germinate are typical, although the environmental conditions are favorable. These dormant seeds require exposure to some environmental factor that overcomes their dormancy to make them germinate. Numbness is a natural mechanism of resistance to environmental factors and can manifest itself in three ways: dormancy imposed by the integument, embryonic dormancy, and dormancy by the imbalance between germination-promoting and inhibiting substances [1].

Dormancy has important ecological significance as an adaptive trait that ensures the perpetuation and survival of species. Germination retardation keeps the species in the seed stage, the phase of the plant's cycle when its resistance to unfavorable conditions is most excellent. Late or prolonged dormancy can be induced in mature seeds of native tropical species to reduce the risk of adaptation and extend their permanence in the environment in response to unfavorable environmental conditions in the dry and rainy weather seasons [2].

Seeds of many native forest species have slow, irregular, or no germination, even under favorable environmental conditions or after proper harvest and storage [3]. This situation results from the impermeability of the integument associated with several botanical species, being more frequent in Fabaceae [4]. Numbness is a problem for cultivation due to irregular germination, affecting the seedling uniformity and seedling production time [5,6]. To overcome dormancy, it is necessary to use physical and/or chemical methods that favor germination.

The method includes scarification and the effect of temperature, while the chemical method can use water (distilled or running), hydrogen peroxide, acetic acid, hydrochloric acid, sulfuric acid, sodium hydroxide (caustic soda), acetone, and alcohol [7].

Restoring native ecosystems is crucial for environmental conservation and recovering degraded areas. There are still gaps in the scientific

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literature on germination in seedling production, so the objective of this work was to evaluate the germination of seeds of native species of the Mata biomeAtlantica through germination rate (GR), germination speed indices (GSI) and mortality rate (MR), after pre-germination treatments to overcome dormancy and subsequent production of seedlings to be used in Degraded Area Recovery Plans at Reunidas Gravatá farm and surrounding areas in Teodoro Sampaio, Bahia (Brazil).

The objective of this study was to evaluate the seed germination of five native species of the Atlantic forest biome through germination rate (GR), germination speed index (GSI), and mortality rate (MR), after pre-germination treatment stoovercome dormancy and subsequent production of seedlings to be used in Degraded Area Recovery Plans.

Materials and Methods

This germination study was carried out at the Reunidas Gravatá farm, Teodoro Sampaio municipality, Bahia (Brazil), from September 2023 to August 2024 (Figure 1).

The species chosen were sucupira *Bowdichia virgilioides* Kunth (Fabaceae), jatobá *Hymenaea courbaril L*. (Fabaceae), monkfish *Enterolobium contortisiliquum* (Vell.) Morong (Fabaceae), guava *Psidium guajava L*. (Myrtaceae) and pink jequitibá *Cariniana legalis* Kuntze (Lecythidaceae) (Figure 2).

The seeds were collected from matrices in municipalities in the center and north of the state of Bahia. In their processing, the peels and pulp were removed with scissors, hammers, and sieves. Then, they were stored in transparent polyethylene packages, sealed, and kept at room temperature for months in the seed house for further sowing.

Seeds of sucupira *B. virgilioides* were collected manually from the trees of UNEB Campus II in Alagoinhas in January/2023 for the first test in September/2023. For the second test, the seeds were collected manually from a tree from the Reunidas Gravatá farm in January/2024, with the help of pruning shears. The light, orange, and red seeds were used in the processing stage; the immature, broken, and greenish-brown seeds were discarded [8]. The seeds of jatobá *H. courbaril* were collected manually from a tree on the farm Morrinhos in Lajedinho in September/2023. For processing, a hammer was used to break the fruit, and a knife was used to break the fruit and extract the pulp. In May/2024, at the Reunidas Gravatá farm. Monkfish seeds *E. contortisiliquum* and guava *P. guajava* were collected manually from a single tree on the property with scissors pruning. In processing the seed, a sieve was used to remove the pulp. The seeds of the pink jequitibá *C. legalis* were collected manually with the help of a pruner of a single individual from the farm Santo Antônio in Teodoro Sampaio in October/2022, being transported in the pyxis itself and stored for about 15 months until its use in January/2024. The wings were removed at the moment of sowing during processing.

The seeds, chosen for their good visible appearance of size, standard coloration of each species, and integrity of the integument, were submitted to pre-germination treatments to overcome dormancy and, subsequently, cultivated in washed sand with a depth of 1 cm and a distance of 5 cm. Seeds were cultivated in the sowing protected by 100-micron diffuser film to reduce competition between seedlings. In monitoring, the seeds were watered twice daily (morning and afternoon) with a sprinkler system for 15 minutes.

Data on the germination time and general morphological aspects of the seedlings in three days/weeks for ninety days. Invasive seedlings were removed to avoid competition. The following were considered normal seedlings with complete essential structures and abnormal seedlings that did not show visible potential to continue their development even under favorable conditions [9,10].

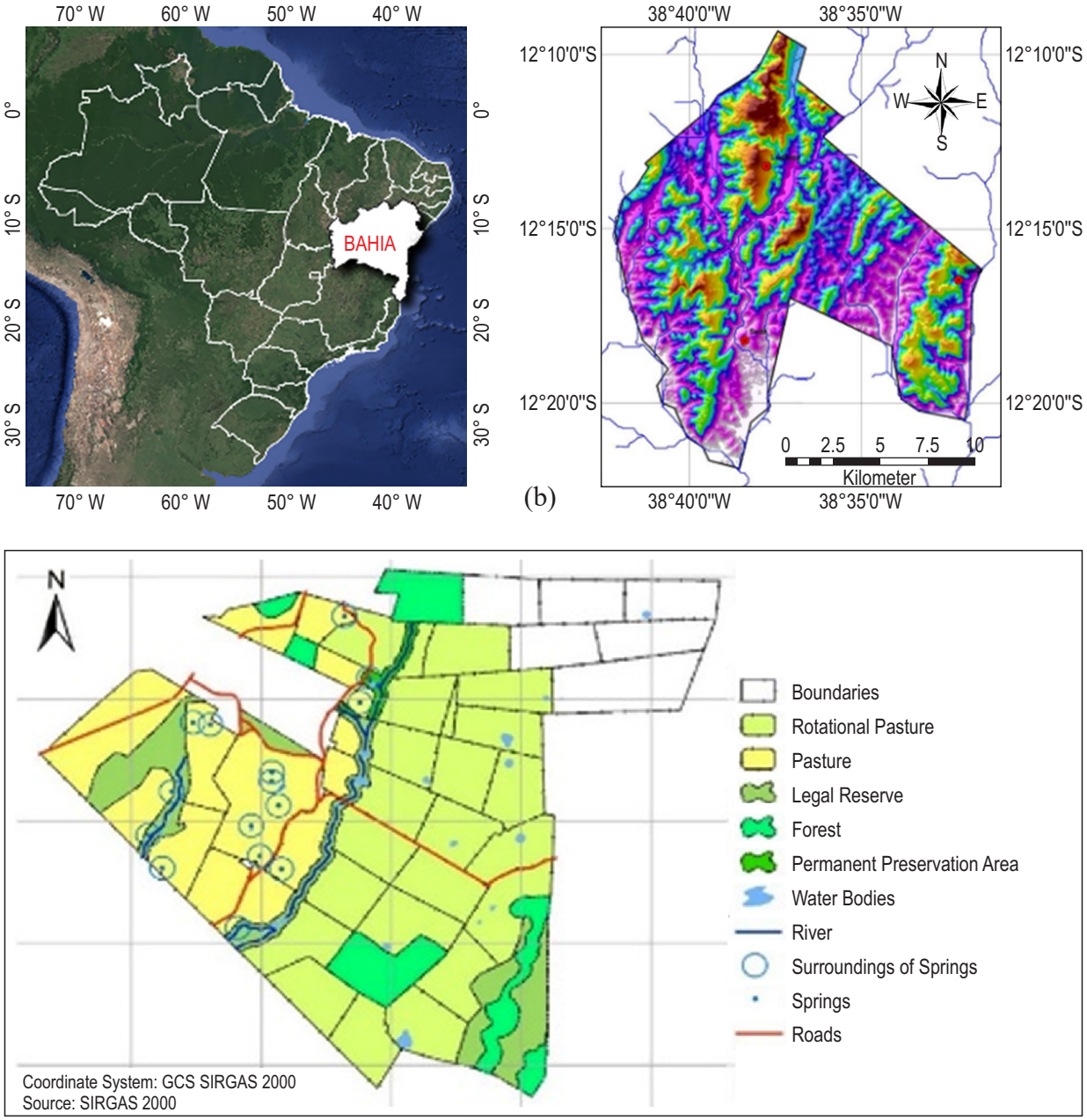
Six experiments were carried out with 100 seeds, two of which were *B. virgilioides* and four other species, *H. courbaril*, *E. contortisiliquum*, P. *guajava*, and *C. legalis*. The sets were divided into four groups of 25 to 3 treatments: one physical through scarification, with wall sandpaper (number 120) in the region opposite the embryonic axis; and

two chemical by immersion, in room temperature water for 48 hours and acetic acid for 15 minutes—the control of untreated seeds. Scarification was considered only the mechanical action of scraping the seed with sandpaper to cause superficial fissures with more or less pronounced scars in the seed coat. All the values of germinated or ungerminated seeds until the end of each experiment were used to calculate the germination rate (GR), germination speed index (GSI), and mortality rate (MR).

The equation obtained the germination rate (GR):

$$\%GR = (\sum ni \cdot N\text{-}1) \cdot 100$$

Figure 1. The state of Bahia (Brazil) (a), Teodoro Sampaio (b) and the study area at the Reunidas Gravatá farm (c).



Source: José Gabriel Ferreira dos Santos, 2023; Marcos de Oliveira Dias, 2017; ML Tavares Engenharia e Construções Ltda., 2010.

Figure 2. Fruits and seeds collected from 2023 to 2024.

1. sucupira *Bowdichia virgilioides* Kunth (Fabaceae); **2.** jatobá *Hymenaea courbaril L.* (Fabaceae); **3.** monkfish *Enterolobium contortisiliquum* (Vell.) Morong (Fabaceae); **4.** guava *Psidium guajava L.* (Myrtaceae); **5.** jequitibá-rosa *Cariniana legalis* Kuntze (Lecythidaceae).

where ∑ni is the total number of seeds germinated relative to the number of seeds arranged to germinate (N).

The germination speed index (GSI) was calculated pela equação [11]:

$$GSI = G\ 1/N1 + G2/N2 + ...\ Gn/Nn$$

where G1, G2, ... Gn is the number of germinated seeds; E1, E2, ... En is the number of normal seedlings in each observation; N1, N2, ... Nn is the number of days after sowing.

The mortality rate was calculated as a percentage, following the equation:

$$\%MR = (N\text{-}1)/N$$

N-1 is the number of individuals killed, and N is the number of individuals planted for each species and treatment.

All GR, GSI, and MR values of the 5 species were submitted to statistical analysis ($p<0.5$) by Statistica 7.0.

Results and Discussion

Comparing pre-germination treatments and native species, scarification allowed to achieve better GR results (48%) for jatobá *H. courbaril* and GSI (0.75) for monkfish *E. contortisiliquum* but increased the MR of this and the other Species. Immersion in water favored the GR (52%) of the new seeds of sucupira B. virgilioides in experiment 2. Immersion in acetic acid (15 min) performed poorly overall when compared to the other treatments (Table 1).

Considering each treatment and species separately, between the seeds of sucupira *B. virgilioides* used in both experiments, immersion in water for 48 hours favored GR (52%) and the GSI (0.69) probably by hydration controlled by the hardness of the resistant seed coat of new seeds in experiment 2, high impediment MR due to embryo drowning (Table 1).

In the jatoba seed *H. courbaril*, immersion in acetic acid (15 min) yielded a GR and GSI response of about 50% lower than scarification but 150% higher than hydration (48 h) and MR

Table 1. Germination rates of seeds submitted to treatments (1 physical, 2 chemicals, 1 control) to overcome dormancy. September/2023 to August/2024. Reunidas Gravatá farm, Teodoro Sampaio, Bahia (Brazil).

Species	Treatments											
	Scarification (wall sandpaper number 120			Immersion in water at room temperature (48h)			Immersion in acetic acid (15 min)			Control (not treated)		
	GR %	GI %	MR %	GR %	GSI	MR %	GR	GSI	MR %	GR %	GSI	MR %
B. virgilioides (E1)	36	0.60	64	12	0.11	88	8	0.07	92	12	0.08	88
B. virgilioides (E2)	32	0.24	68	52	0.69	48	28	0.18	72	16	0.13	84
H. courbaril	48	0.45	52	8	0.08	92	24	0.21	76	16	0.07	84
E. contortisiliquum	20	0.75	80	12	0.33	88	12	0.30	88	8	0.05	92
P. guajava	12	0.04	88	44	0.67	56	32	0.22	68	40	0.31	60
C. legalis	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0
Total	**148**	**2.08**	**352**	**128**	**1.88**	**372**	**104**	**0.98**	**396**	**92**	**0.64**	**408**
Average	**24.67**	**0.35**	**58.7**	**21.33**	**0.31**	**62**	**17.33**	**0.16**	**66**	**15.33**	**0.11**	**68**

(76%) lower than control and immersion in prolonged water, showing the need for further testing of treatments with the hydration period for this species. Water immersion (48 h) was contraindicated for overcoming integumentary dormancy of this species, and should the need to reduce immersion time be assessed, or associating immersion and temperature (Table 1).

Monkfish *E. contortisiliquum* seeds immersed in water (48 h) and acetic acid (15 min) also had low GR (12%) and high MR (88%), both similar to the control group. This showed inefficacy, probably due to not viable embryos due to drowning and intoxication, respectively. The beginning of germination of this species during immersion in water (48 h) was noted, but not the development of germinated seeds.

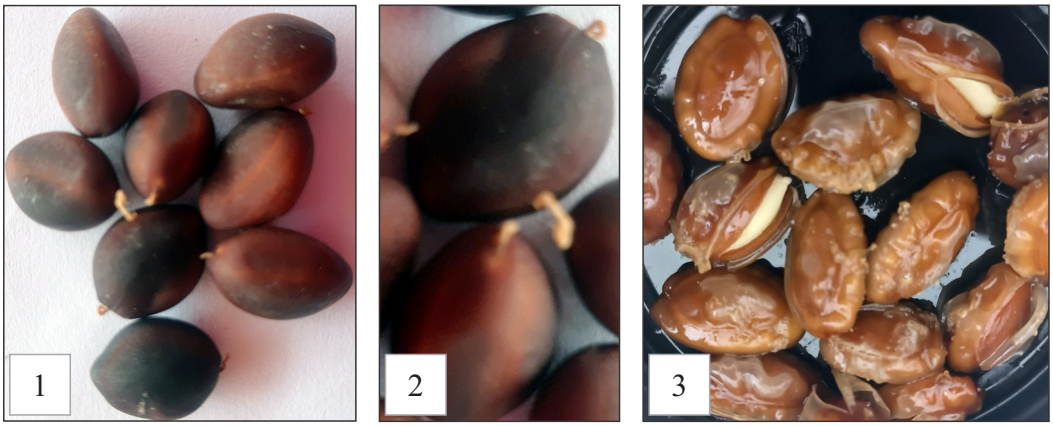
P. guajava seeds germinated after 48 hours of water immersion, achieving a germination rate (GR) of 44% and a germination speed index (GSI) 0.67. These results suggest the need to shorten the soaking period for a more efficient and simplified dormancy-breaking method. All seeds of *C. legalis* did not germinate until the end of the year. Experiment by the death of the embryo, although they are still stored in the capsular pixie with visible integrity (Table 1).

In the initial contact with water, the monkfish *E. contortisiliquum* seeds emit a structure that protrudes like a radicle, showing that perhaps the long period of immersion was detrimental (Figure 3). Other authors usually use 4, 8, and 12 hours, and the long period of 16 hours was considered a factor in increasing the mortality rate by [12].

The test of variance showed a difference ($F=9.80$; $df=71$; $p=7.361$ E-10) between the treatments used to overcome seed dormancy, with correlations between GR and GSI of the treatment with immersion in water (0.96; $p<0.05$), the MR between the treatments with water and acetic acid (0.93; $p<0.05$) (Figure 4).

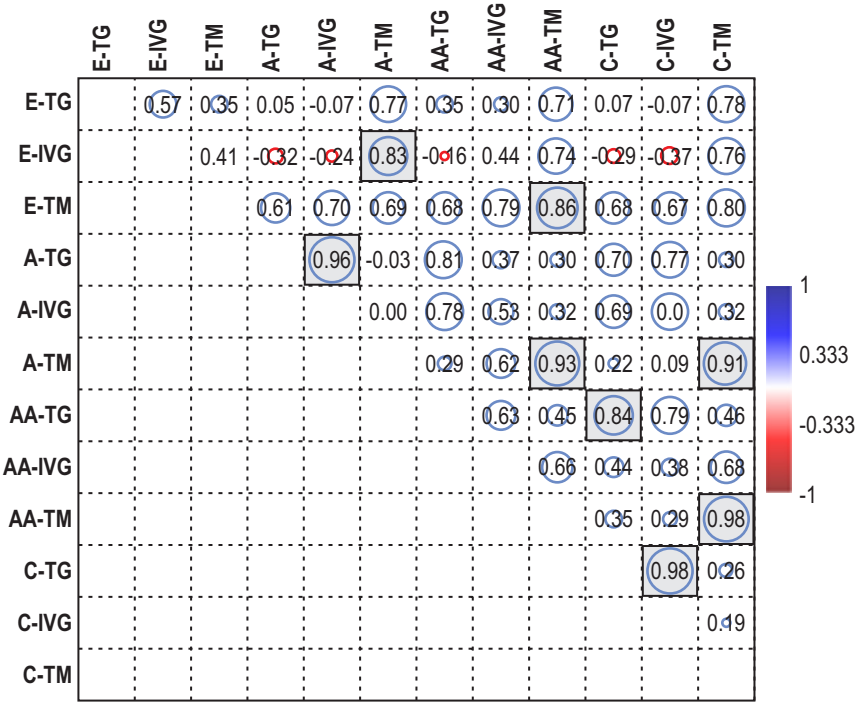
The jatobá *H. courbaril* had higher GR than the group between the sucupira *B. virgilioides* of experiment 1 and the monkfish *E. contortisiliquum*; all three species of the family Fabaceae had results close to GR and MR after scarification, despite the prominence of the monkfish *E. contortisiliquum* with greater GSI. The new seeds of sucupira *B.*

Figure 3. Seeds of monkfish *Enterolobium contortisiliquum* (Vell.) Morong in Reunidas Gravatá farm, Teodoro Sampaio, Bahia (Brazil), 2024.



1. Washed seed; 2. Sprouting structure in washing; 3. Germination in water immersion.

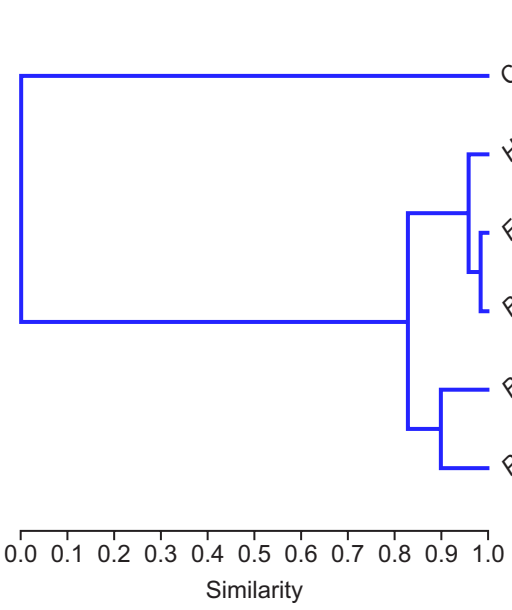
Figure 4. Correlation analysis ($p<0.05$) of germination and mortality rates of treated seeds. September/2023-August/2024. Reunidas Gravatá farm, Teodoro Sampaio, Bahia (Brazil).



virgilioides (Fabaceae) of experiment 2 and guava *P. guajava* (Myrtaceae) were close due to the average values of germination after immersion in water for 48 hours. The species *C. legalis* (Lecythidaceae) stood out from the other groups due to the total loss of 100 seeds treatment and control to overcome dormancy and germination (Figure 5).

When comparing the GR, GSI, and MR values between stored seeds of B. virgiliodes from experiment 1 and *C. legalis*, it is believed that native seeds lose their capacity when kept at room temperature in a dry environment for a prolonged period. On the other hand, in the native fragment, the humidity maintained in the leaf litter allows

Figure 5. Analysis of clusters by similarity between native species of the Atlantic Forest tested with pre-germination treatments to overcome seed dormancy, 2023-2024.



the seeds more time to overcome dormancy with regular germination throughout the phenological cycle in the natural environment.

The low values recorded for GR and GSI in the group controller, with untreated seeds, indicated the need for previous treatment to overcome numbness and increase inefficiency in the germination of the seeds of the selected native species, aiming at better results to reduce the MR.

This variation in results for the same species exposed to the same treatment was attributed to the storage time (8 months) of sucupira seed used in experiment 1 after the collection of the matrix tree, which may have acquired more excellent resistance due to integumentary hardening with maturation, being the more effective chiseling treatment for seeds stored as long as there is no contamination by fungi and consequent death of the embryo. On the other hand, the embryo of the new seed of sucupira used in experiment 2 was vulnerable to agents by chiseling after sowing, as the water had no effect in experiment 1, but reached the embryo of the new sucupira seed in experiment 2, causing it to germinate.

In both experiments with *B. virgilioides*, seeds were found that were still intact (hard) until the end and considered unviable (dead). This indicates that, despite the time of exposure to treatments to overcome dormancy, there were still those with integumentary resistance due to possible genetic variability.

Seeds that remain without absorbing water for a prolonged period and have an appearance that has not yet swollen after hydration are relatively common among species of the Fabaceae and Malvaceae families. This greater resistance, resulting from the impermeability of the seed coat to water, characterizes the seed's dormancy property [9,13].

Jatoba *H. courbaril* seeds present dormancy caused by the impermeability of the integument. Scarification proved highly effective, with a GR higher than that observed in the other treatments and control group, corroborating the studies [14-16]. Piña-Rodrigues and colleagues (2014) attributed the high MR of this species to the long period of immersion for 16 hours in cold water, considering that the standard used is 4, 8, and 12 hours [12]. It is recommended that seeds of this species be studied in detail regarding the period of immersion in water at room temperature to detect the optimal range of hydration without the embryo not viable by possible drowning, as may have been the case with immersion for 48 hours. Germination capacity indicates the total number of germinated seeds but does not consider the time it takes for seeds to reach the germination percentage [17]. The higher the germination speed, the more vigorous the seed [18].

Cruz-Silva and Rosa (2011) observed that scarification treatment with sandpaper was the most efficient for overcoming the dormancy and germination of monkfish *E. contortisiliquum* seeds [19]. Scarification also increased GSI and MR in seeds studied by Piña-Rodrigues and colleagues [12]. It can be inferred that rapid germination is characteristic of species pioneers with a rapid or opportune colonization strategy, taking advantage of favorable environmental conditions to develop

seedlings [17]. On the other hand, high mortality rates in the germination phase indicate a limited potential for natural recomposition by a late colonization species, which explains its threat of extinction [8].

Alves and colleagues (2015) obtained better germination of guava seeds *P. guajava* after immersion in cold water [20]. The softened appearance of the pink jequitibá *C. legalis* seeds at the end of the experiment may indicate the action of the decomposing microbiota (fungi and bacteria) that resulted in the inviability of the seeds of this species. Thin-skinned or little-skinned seeds may be more susceptible to colonization by fungi that decompose the embryo and prevent germination. Death of seeds can also be caused by the action of enzymes or toxins released by microorganisms in the germination phase orseedling growth [21]. Species from humid tropical regions have developed mechanisms to prevent water absorption, such as integument impermeability, to prevent germination soon after germination dispersal for seed survival in the environment [12].

Conclusion

The results demonstrate the efficacy of different pre-germination treatments in overcoming seed dormancy of native species of the Atlantic forest.

Scarifying with sandpaper and immersion in water at room temperature for 48 hours were the most effective methods, especially for the seeds of jatoba *H. courbaril*, monkfish *E. contortisiliquum*, the new sucupira *B. virgilioides* seeds from experiment 2, and of the guava *P. guajava*. These treatments provided higher germination rates and germination speed indexes, confirming their relevance for the production of seedlings of these species.

In general, the scarification was more efficient for jatobá *H. courbaril* (GR=48%) and monkfish *E. contortisiliquum* (GSI=0.75) but increased the MR of this species and the others. The water immersion favored the new seeds of sucupira *B. virgilioides* (GR=52%, GSI=0.69) to the detriment of the others, suggesting the need for experiments with a well-soaking period that refutes the hypothesis of embryo non-viability by drowning. Also, immersion in acetic acid (15 min) showed varied ineffectiveness, perhaps due to its toxic effect on the embryo, highlighting the need for future research to optimize its application or seek more effective alternatives.

The high mortality observed in some species, especially the pink jequitibá *C. legalis*, with MR=100%, suggests that factors such as storage time and fungi contamination can negatively influence seed viability.

Therefore, the application of appropriate pre-germination treatments is essential to maximize the germination efficiency of native seeds, contributing to programs for the recovery of degraded areas, especially in the Atlantic forest.

Further studies should explore combinations of treatments and the influence of environmental conditions on germination to further improve the production of seedlings for ecological restoration.

The experiment offered significant results on the germination characteristics of the native species studied from the Atlantic forest for some dormancy-overcoming treatments, giving suggestions for further studies that include new treatments with immersion time and use of temperature for better and more effective results in producing seedlings for use in a plan to restore degraded areas.

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References

1. Bewley JD, Black M. Sementes: fisiologia do desenvolvimento e germinação. 2a. ed. Nova York: Plenum, 1994:445.
2. Dantas JA da S, Rodrigues AC do C, Alves LB, Queires LCS., Orge MDR, Santos E et al. Evaluation of the seed

germination potential of two species, exotic and native, of Fabaceae as a colonization strategy in a degraded environment. Research, Society and Development 2021;10(8):9.
3. Ferreira CAR, Figliolia MB, Cruz RLP. Ecofisiologia da germinação de sementes de *Calophyllum brasiliensis* Camb. IF Sér. Reg., São Paulo 2007;31:173-178.
4. Carvalho NM, Nakagawa J. Sementes. Ciência, Tecnologia e Produção. Jaboticabal: FUNEP, 2000, 588.
5. Mendonça MS, Mendes AM. Análise morfológica de sementes, germinação e plântulas de jatobá Hymenaea intermedia Ducke var. adenotricha (Ducke) Lee & Lang. Acta Amazonica, Manaus Brasil 2004;34(1):9-14.
6. Melo M da GG de, Mendonça MS de, Nazário P, Mendes ÂM da S. Superação de dormência em sementes de três espécies de Parkia spp. Revista Brasileira de Sementes 2011;33(3):533-542.
7. Santarém ER, Áquila MEA. Influência de métodos de superação de dormência e do armazenamento na germinação de sementes de *Senna macranthera* (Colladon) Irwin e Barneby (Leguminosae). Revista Brasileira de Sementes 1995;17(2):205-209.
8. Soares JT. *Bowdichia virgilioides* Kunth: Morfobiometria, viabilidade e técnicas alternativas e sustentáveis para germinação e produção de mudas. Monografia (Engenheira Florestal), Universidade Federal do Espírito Santo. Gerânio Monteiro - ES, 2024, 46.
9. Brasil, Ministério da Agricultura, Pecuária e Abastecimento. Regras de Análise de Sementes (RAS). Secretaria de Defesa Agropecuária. Brasília, 1992:399.
10. Nogueira AC, Medeiros AC de S. Coleta de sementes florestais nativas. Circular Técnica 2007;144:11.
11. Maguire JD. Speed of germination aid in selection and evaluation for seeding emergence and vigor. Crop Science 1962;2(2):76-177.
12. Piña-Rodrigues FCM, Freire JM, Rolim SG, Jesus RM de, Grimaldi MC. Maturação e dormência de sementes florestais nativas para a restauração: 20 anos de experiência na reserva natural Vale, Linhares, Espírito Santo. Ciência & Ambiente 2014;49:131-152.
13. Silva LM de M, Aguiar IB de, Rodrigues T de JD. Seed germination of Bowdichia virgilioides Kunth, under water stress. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande 2001;5(1)1:115-118.
14. Almeida MJB, Ferraz IDK, Bassini F. Estudos sobre a permeabilidade do tegumento e a germinação de sementes de *Hymenaea courbaril L*. (Caesalpiniaceae), uma espécie de uso múltiplo. Revista da Universidade do Amazonas, Série Ciências Agrárias, 1999;8(1/2):63-71.
15. Tiago PV, Tiago AV, Carpejani AA, Silva BM da, Dardengo J de FE, Rossi A. Quebra de dormência e germinação de jatobá. I Seminário de Biodiversidade e Agroecossistemas Amazônicos, PPGBioAgro. Alta Floresta-MT, 23 e 24 de setembro de 2013.
16. Paixão MVS, Vieira KM, Ferreira EA, Mônico AF, Carvalho AJC de. Germinação e dormência em sementes de jatobá. Int. J. of Adv. Eng. Res. and Science (IJAERS) 2019;6(6).
17. Borghetti F, Ferreira AG. Interpretação de resultados de germinação. 209-222. In: Ferreira, AG, Borghetti F. (Eds) Germinação do básico ao aplicado. Porto Alegre: Artmed, 2004:323.
18. Nakagawa J. Testes de vigor baseados no desempenho das plântulas. In: Krzyzanowski FC, Vieira RD, França Neto JB. Vigor de sementes: conceitos e testes. Abrates (Londrina), 1999.
19. Cruz-Silva CTA, Rosa APM. Tratamentos para superação da dormência em sementes de orelha-de-negro (*Enterolobium contortisiliquum* (Vell.) Morong). Revista Varia Scientia Agrárias 2012;2(2):79-90.
20. Alves CZ, Silva JB da, Cândido AC da S. Metodologia para a condução do teste de germinação em sementes de goiaba. Revista Ciência Agronômica 2015;46(3):615-621.
21. Menten JOM. (Ed.) Patógenos em sementes: detecção, danos e controle químico. Piracicaba: ESALQ/FEALQ, 1995:320.

Morphometry of Seeds of the Species *Serjania comata* Radlk in a Remnant of Atlantic Forest, Alagoinhas, Bahia

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The Atlantic Forest is a biodiversity-rich area, but it is highly threatened due to the numerous human actions that have affected ecosystems since the colonial era. Considering that morphological studies of forest seeds will serve as subsidies for reforestation programs and research on seed technology and physiology in the conservation of native forests, the study on the morphometry of seeds of the species *Serjania comata* Radlk will contribute positively to knowledge despite the diversity of species present in the ecosystems, to characterize the morphometry of *S. comata* seeds in remnants of the Atlantic Forest, to represent biodiversity conservation strategies, serving as subsidies for the implementation of management projects for the recovery of degraded areas. The study area is a remnant of the Atlantic Forest in Alagoinhas-Ba, with collections from October 2023 to January 2024. After the seed processing process, they were characterized following descriptive parameters suggested by the literature. The species has fruits characterized as echizocarpic with three wing expansions and oblong-oval seeds, with a sharp end, rigid, shiny, brown integument and a visible hilum. The research analyzed morphometric data from 304 species of seeds, and it was possible to observe a slight variation in the variable's size and weight.
Keywords: Morphometry. Atlantic Forest. Seeds.

The Atlantic Forest is a region rich in biodiversity, but it is highly threatened due to the numerous human actions that have affected ecosystems since the colonial era. It was considered one of the world's hotspots due to its incredible biodiversity and the size of its degraded area, making it a priority for biodiversity preservation [1]. According to Cardoso (2016), "*The biome is responsible for regulating the flow of water sources, ensuring soil fertility, controlling climate balance, and protecting escarpments and mountain slopes*" [2].

In the Northeast of Brazil, the Atlantic Forest extends across eight Brazilian states, including Bahia, which has a high degree of diversity and endemism [3]. More than 46% of the remaining areas in the Northeast are located in Bahia [4]. However, these remnants are highly fragmented, making biodiversity conservation strategies extremely important.

Although studies on seed morphology are scarce, authors such as Barroso and colleagues (1999) [5] conducted a study on fruits and seeds with a descriptive book and an identification key for fruits, and Sena and Gariglio (2008) [6] are commonly cited for their guide, which provides instructions on the collection, processing, and storage of forest seeds. However, the Atlantic Forest on the Northern Coast of Bahia has few studies on the morphometry of its forest diaspores.

According to Araujo-Neto and colleagues (2002) [7], "*Morphological studies of seeds are important to facilitate research on soil seed banks, as well as to assist in identifying species in studies on the natural regeneration of degraded areas*". Since morphological studies of forest seeds will serve as subsidies for reforestation programs and research on technology and seed physiology in the conservation of native forests.

Defined by Judd and colleagues (2009) [8] as monophyletic, the Sapindaceae family is present mainly in tropical regions, with 141 genera and 1900 species [9]. Pereira (2014) [10] characterizes it as a family with important representatives in

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tropical vegetation, as the Atlantic Forest is one of its main centers of diversity and endemism. Maçaneiro (2016) [11], Meyer (2013) [12], Dullis and colleagues (2011) [13], and de Oliveira and colleagues (2013) [14] reaffirm that species of the family are commonly present in stages of natural regeneration of Atlantic Forest remnants.

The species *Serjania comata* Radlk is a climbing plant belonging to the Sapindaceae family, native to South America. It is a species found mainly in tropical and subtropical forests, including Brazil. The species is present in eight Brazilian states, including Bahia (Flora and Funga do Brasil, 2024) [15]. The species has a raceme inflorescence with white and yellow flowers; its fruits are schizocarps, with 3 winged samaroid mericarps, trispermic, and they have brown seeds with a visible hilum [16].

The study on the morphometry of seeds of the species *S. comata* will contribute positively to knowledge, despite the diversity of species present in ecosystems, for the restoration of degraded areas, as well as the preservation of endemic species, serving as a basis for management and forest restoration plans, since the species is important in the ecological dynamics of tropical forests, actively participating in seed dispersal and the structuring of the environment.

Therefore, the study's objective seeks to characterize the morphometry of *S. comata* seeds in remnants of the Atlantic Forest to represent biodiversity conservation strategies, serving as subsidies for implementing management projects to recover degraded areas and consequently highlighting the importance of knowledge about the biota.

Materials and Methods

Study Area

The study area is a remnant of the Atlantic Forest located in the municipality of Alagoinhas-Ba, belonging to Campus II of the State University of Bahia. It has approximately 50 ha under the coordinates 12°10'42" S; 38°24'43" W and an altitude of 150 meters. Its vegetation cover is characterized as a fragment of dense ombrophilous forest.

Collection

A total of 9 field trips were carried out on pre-established trails, starting in October 2023 and ending in January 2024. The fruits of the species found in the Atlantic Forest fragment were collected, preferably from a fertile branch of the plant, to collaborate in the identification process and integrate the reference collection, which was incorporated into the Herbarium of the State University of Bahia (HUNEB), Alagoinhas collection.

Collections were carried out during the period in which the seeds were at full physiological maturity since, according to Galvão and Medeiros (2002) [17], it is at this stage that they demonstrate more significant activity and germination percentage. Incorporating the previous methodology with that of Sena and Gariglio (2008) [6], aspects related to the fruits were observed to determine whether the seeds were viable for collection, such as change in color, dehiscence, size, shape, and texture or a combination of the aforementioned characteristics.

Based on Way's method (2003) [18], harvests were carried out directly from the fruits by shaking the branches, pruning, or collecting directly from the ground. Seeds that did not have visible damage due to the actions of pathogenic microorganisms were observed through their phytosanitary aspects. The samples were collected with pruning shears and stored in paper bags, on which field data (date, location, species habits) were recorded to be transported to the laboratory.

Herbalization and Identification

The collected material was herborized according to the usual botanical criteria [19], and taxonomic identification was performed by analyzing the material with consultation of a

specialized bibliography. The classification used for the family was according to Angiosperm Phylogeny Group version IV (APG IV) [20]. The nomenclature of the species was based on the Flora and Funga of Brazil [15].

Process

According to Sena and Gariglio (2008) [6], forest seed processing is the term used to describe all the stages that the seeds undergo after harvesting. These include peeling, threshing, pulping, cleaning, and drying.

Following the methods used by Sena and Gariglio (2008) [6], the seed extraction process was based on the type of fruit, using the best method to avoid damaging the seeds. As an indehiscent dry fruit, the seed was extracted using sharp instruments. This method was used with great caution to avoid damaging the seeds.

Drying is essential to reduce the water content of the seeds to low levels of metabolic activity, preventing degeneration and proliferation of fungi. The methods used by Draper (2004) and Galvão and Medeiros (2002) [17] were used to perform this procedure. This drying can be done using natural or artificial methods. The artificial method was used, which consisted of using an oven with a temperature adjusted to 50°C, and the heated air was forced through the seed mass to dry it [22]. After drying, the seeds were stored in adequately labeled glass jars with the collection information in a room with little light and air conditioning at a temperature not exceeding 17°C. When related to water vapor exchange with the environment, the type of packaging is classified as impermeable (airtight) and is recommended for seed storage.

Morphometric Characterization

Immediately after the seed processing process, morphometric characterization was performed, which included descriptive parameters suggested by González-Andrés (2001) [23], such as shape, color, and accessory structures. For the metric acquisition stage, observations were made using a stereoscope, where the length and width of each seed were also measured using the capture 2.3 program of the HD LITE 1080P camera, coupled to the stereoscope.

The portion between the basal and apical regions was considered as length, while the equatorial diameter of the fruit was considered as width. The number of seeds collected and the number per fruit was also determined. A WebLabor M254-Ai precision analytical balance was used to determine the weight of each seed. The mean, mode, median, standard deviation, and variance were calculated for each variable, according to Gomes (1987) [24] and Banzatto (1992) [25].

Results and Discussion

During the research, 9 collections were carried out over 4 months, in which 953 fruits of *Serjania comata* Radlk were produced. They were collected at 7 points on pre-established trails. Although cited by Coulleri (2014) [16] as having fruiting from June to August, the species under study presented fruiting during the collections from October to January.

Even with the high species incidence in the study area, not all specimens were in the fruiting period during the collection period. This demonstrates that the same species can vary its production cycle due to various factors, such as plant age, genetic variety, soil quality, water, and nutrient availability. According to Infosanbas (2020) [26], Alagoinhas has a territory composed of 14% Caatinga and 86% Atlantic Forest. The remaining area under study presents a transition area between both domains. Since the species is characteristic of tropical forests, being found in an area of high fragmentation and transition of ecosystems, the interpolation of fruiting of individuals is understandable.

The species *S. comata* exhibits schizocarpous fruits with three light brown winged expansions, trispermic. Among the 953 fruits collected, 41 did not have seeds, which may indicate some

imbalance or environmental change. The seeds are oblong-oval, with a sharp end, rigid, shiny, brown integument, and have a visible hilum (Figure 1).

The hilum is a morphologically distinct structure present on the surface of the seed. It is characterized by a scar of insertion or separation of the funiculus and a different coloration in relation to the rest of the integument. These characteristics are relevant for the identification of species and are widely used in morphological analyses [27].

In the metric measurements, the study presents 304 visibly healthy seeds, with slight variations, presenting lengths of 1.28 to 3.88 mm, width of 0.75 to 2.49 mm and weight of 03 to 21.5 mg (Figure 2). In Table 1, it is possible to visualize the variation existing in the size and weight of seeds, validating that the fruits that have wing expansions play an important role in the dispersal syndrome of the species since the wing-like structures that aid in the dispersal by the wind (anemochory) and the efficiency of this dispersal is directly related to the size, weight and shape of the seed, influencing its ability to be transported over greater distances [28].

Conclusion

Serjania comata Radlk presents a slight variation in its seed length and width, as well as in its weight, indicating a dimensional pattern appropriate for the species. The 304 seeds collected and analyzed indicate the species' great genetic variety, which is fundamental for its adaptation to different environmental conditions and selective pressures.

The variation and low production of fruits and seeds may be related to the edge effect and the

Figure 1. *S. comata* seed with visible hilum.

Figure 2. *S. comata* seed measurements.

Table 1. Length, width, and weight (mg) of seeds of *Serjania comata* Radlk.

Parameter	Length (mm)	Width (mm)	Weight (mg)
Mean	3.05	1.59	5.53
Mode	3.48	1.82	2,4
Median	3.42	1.63	3.6
Standard Deviation	0.60	0.35	4.79
Variance	0.36	0.12	22.83

impacts resulting from the fragmentation of the remnant under study since the area presents several anthropic interventions. These factors directly interfere with the ecological and reproductive dynamics of the species.

References

1. Myers N, Mittermeier RA, Mittermeier CG et al. Biodiversity hotspots for conservation priorities. Nature 2000;403:853-858.
2. Cardoso JT. A Mata Atlântica e sua conservação. Revista Encontros Teológicos 2016;31(3).
3. de Carvalho Sobrinho JG, de Queiroz LP. Composição florística de um fragmento de Mata Atlântica na serra da Jibóia, Santa Terezinha, Bahia, Brasil. Sitientibus Série Ciências Biológicas 2005;5(1):20-27.
4. Tabarelli M, Melo MDV, Lira OC. A Mata Atlântica do nordeste. Rio de Janeiro: MMA, 2006.
5. Barroso G et al. Frutos e sementes: morfologia aplicada à sistemática de dicotiledôneas. Viçosa: Universidade Federal de Viçosa, 1999.
6. Sena CM, Gariglio MA. Sementes florestais: colheita, beneficiamento e armazenamento. Natal: MMA. Secretaria de Biodiversidade e Florestas. Departamento de Florestas. Programa Nacional de Florestas. Unidade de Apoio do PNF no Nordeste, 2008. 28p.
7. Araújo-Neto JC et al. Caracterização morfológica de frutos e sementes e desenvolvimento pós-seminal de monjoleiro (*Acacia polyphylla* DC.). Revista Brasileira de Sementes 2002;24:203-211.
8. Judd WS et al. Plants systematics: a phylogenetic approach. 2nd Ed. Massachusetts: Sinauer Associates, 2002.
9. Acevedo-Rodríguez P et al. Sapindaceae In: Kubitzki K. (Ed) Flowering Plants. Eudicots: Sapindales, Cucurbitales, Myrtaceae. [The Families and Genera of Vascular Plants]. Springer, Berlin, p. 357–407, 2011.
10. Pereira LA. A família Sapindaceae na Floresta Atlântica do Nordeste Oriental. 2014. Dissertação de Mestrado. Universidade Federal de Pernambuco.
11. Maçaneiro JP et al. Regeneração de uma Floresta Ombróila Mista no Planalto Catarinense. Biotemas, Florianópolis 2016;29(4):31-42.
12. Meyer LG et al. Regeneração natural na Floresta Ombrófila Mista em Santa Catarina. In: Vibrans AC, Sevegnani L, Gasper AL, Lingner DV (eds.). Inventário Florístico Florestal de Santa Catarina, Vol. III, Floresta Ombrófila Mista. Blumenau. Edifurb, 2013.
13. Dullis M et al. Florística e Fitossociologia da Regeneração Natural em um Remanescente de Floresta Ombrófila Mista no Rio Grande do Sul. In: Congresso de Ciência e Tecnologia da UTFPR 2011, Paraná. Anais [...] Semantic Scholar, 2011.
14. de Oliveira LSB et al. Fitossociologia da regeneração natural de uma Floresta Ombrófila densa em Moreno, Pernambuco, Brasil. Revista Brasileira de Ciências Agrárias, Pernambuco 2013;8(1):119-124.
15. Serjania in Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro. Available at: <https://floradobrasil.jbrj.gov.br/FB32731>.
16. Coulleri JP. Taxonomía del género Serjania en Bolivia: un enfoque biosistemático. 2014.
17. Galvão APM, Medeiros AC de S. Restauração da Mata Atlântica em áreas de sua primitiva ocorrência natural. Embrapa Florestas-Livro científico (ALICE), 2002.
18. Way MJ. Collecting seed from non-domesticated plants for long-term conservation. 2003. In: Smith RD, Dickie JB, Linington SH, Pritchard HW, Probert RJ (eds.), Seed Conservation: turning science into practice. Royal Botanic Gardens, Kew, UK.
19. Fidalgo O, Bononi VL. Técnicas de coleta, preservação e herborização de material botânico. São Paulo: Instituto de Botânica, 1984.
20. Angiosperm Phylogeny Group (APG). A update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society, v. 161, 2009.
21. Draper D, Marques I, Graell AR, Costa F, Martins-Loução MA. Conservação de recursos genéticos o banco de sementes 'António Luís Belo Correia'. Jardim Botânico. Museu Nacional de História Natural. Lisboa-Portugal, 2004.
22. Garcia DC et al. A secagem de sementes. Ciência Rural 2004;34(2).
23. González-Andrés F. Caracterización morfológica. In González-Andrés F. & Pita Villamil, JM (Eds.). Conservación y Caracterización de Recursos Fitogenéticos.
24. Gomes FP. Curso de estatística experimental. Piracicaba: Nobel, 1987. 467p.
25. Banzatto DA, Kronka SN. Experimentação agrícola. 2.ed. Jaboticabal: FUNEP, 1992. 246p.
26. Infosanbas. Minas Gerais, 2020. Available at:https://infosanbas.org.br/municipio/alagoinhas-ba/#:~:text=Alagoinhas%20%C3%A9%20um%20munic%C3%ADpio%20da,Plano%20Municipal%20de%20Saneamento%20B%C3%A1sico.
27. Gonçalves EG, Lorenzi H. Morfologia vegetal. Nova Odessa: Instituto Plantarum 2011.
28. VENZKE, Tiago Schuch et al. Síndromes de dispersão de sementes em estágios sucessionais de mata ciliar, no extremo sul da Mata Atlântica, Arroio do Padre, RS, Brasil. Revista Árvore 2014;38:403-413.

Aspects of the Plankton Community from Sauípe Port Estuary, Bahia, Brazil

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The estuary forms at the meeting of the river and the sea. It houses a fundamental microbiological community of plankton, which plays a role in the trophic network and the decomposition of organic matter. The uncontrolled expansion of human occupation in areas near mangroves has led to degradation, with alterations in physical, chemical, and biological characteristics. The present study investigates the ecological aspects of planktonic communities in the estuary waters and the identification of species that indicate the water quality of the Port of Sauípe estuary, state of Bahia, Brazil. Estuary water samples were collected to identify plankton, with random releases of a conical plankton net with a screw cup and stored in plastic containers with Transeau solution. The water samples were filtered, and the material retained in the filter was analyzed. All samples were examined under an optical microscope to identify phytoplankton, zooplankton, parasites, and other microinvertebrate species. Cyanobacteria predominated in the phytoplankton, while Copepoda was the most common in the zooplankton. Among the parasites, *Ascaris lumbricoides* had been recorded six years earlier, but *Schistosoma haematobium* and *Entamoeba coli* are being recorded for the first time in the area. The plankton data indicate poor environmental quality in the estuary, with toxin-producing species and sanitary hazard parasites used for fishing, shellfish harvesting, recreation, and tourism in a reference place on the North Coast of Bahia, Brazil.
Keywords: Bioindicators. Phytoplankton. Zooplankton. Human Parasites.

Mangroves and estuaries are coastal aquatic ecosystems that serve as transition zones between land and sea, distributed in the intertropical zone of the planet. They provide a habitat for protection, feeding, mating, and reproduction for native or transient species [1]. The biodiversity in these ecosystems is characteristic and adapted to the saline stress, making them highly productive environments and a source of nutrients for the continental shelf. These ecosystems also have a significant socioeconomic impact on the people who live directly in these areas. In the interstitial water of the mangrove and estuary, microorganisms such as plankton and bacteria are found, playing diverse ecosystemic roles that support niches in the mangrove and coastal regions with their characteristic productivity [2].

Phytoplankton organisms are responsible for most oxygen released into the water and atmosphere, turning these ecosystems into natural nurseries for many animal species, mainly fish and crustaceans, which complete their life cycles in these environments [3].

The plankton community's diversity and species predominance depends on temperature, light, nutrients, competition, and predation factors. It is an important component in the dynamics of an aquatic environment and can influence various ecological processes in nutrient cycling [4]. Currents move diatoms and bacteria and disperse widely, while environmental conditions regulate survival [5].

Phytoplankton comprises euglenophytes and dinoflagellates, which perform photosynthetic activity in the euphotic zone. Zooplankton includes rotifers, microcrustaceans, cnidarians, flatworms, and protozoa. This group is further divided into holoplankton, which remains in the plankton throughout its entire life cycle in the water column, and meroplankton (temporary plankton), characterized by the eggs and larvae of invertebrates and vertebrates that disperse species and colonize new environments [6].

Among the phytoplankton organisms, there is a wide variation in forms and sizes. In terms of shape, they can be spherical, ellipsoid, short

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cylindrical, flattened, or elongated. In terms of size, they range from unicellular cyanobacteria to mucilaginous colonies. These factors determine their adaptation to aquatic environments. They can reproduce asexually and sexually, in the latter case increasing genetic variability and the species' chances of adapting to a transforming environment influenced by tides and anthropogenic actions [7].

Phytoplankton organisms are of great ecological importance as primary producers in the food web. Despite their short life cycle, they serve as bioindicators and provide insight into environmental conditions.

Analysis of phytoplankton fluctuations reflects environmental changes and makes it a suitable bioindicator due to its sensitivity to respond quickly to various environmental alterations and variations [8]. The composition and abundance of phytoplankton communities are good models for understanding the dynamics of continental aquatic ecosystems, as they are found in almost all coastal ecosystems, including species sensitive to pollution and tolerant to tidal variations.

Among the environmental factors that limit phytoplankton development are light, temperature, pH, and predation by zooplankton. Therefore, zooplankton is associated with the dynamics of coastal ecosystems and is an indicator of environmental quality due to its short life cycle, responding quickly to changes caused by anthropogenic actions. Zooplankton can be considered extremely important as the primary consumers in estuaries and oceans, transferring energy retained by microalgae to other trophic levels. They are organisms easily carried by currents due to their limited mobility, making them more susceptible to biological influences, which alters their distribution in the water column.

The zooplankton community has been used as a bioindicator to assess various environmental changes, such as pollution from pesticides and/or toxins from algae, acidification, and eutrophication, which affect water quality. This evaluation can be mainly made by studying their feeding behavior, as they consume bacteria, microalgae, protozoa, and organic matter, contributing to the clarification of effluent and playing a role in environmental bioremediation [9].

Thus, this study aimed to investigate the ecological aspects of the planktonic community in the waters of the Sauípe Port estuary and identify potential species as indicators of environmental quality for the estuary, which serves as a reference for the North Coast of Bahia, Brazil.

Materials and Methods

The study area was in the Sauípe Port estuary, located at the mouth of the Sauípe River, in the municipality of Entre Rios, on the North Coast of Bahia (Brazil) (12º24'S, 37º53'W) [10]. Two sampling points were selected in the estuary channel for plankton analysis: Point 1, in front of the beach huts, and Point 2, in front of the mangrove forest (Figure 1).

The local community uses the estuary and mangrove for fishing, shellfish gathering, leisure, and tourism. Beach huts are located on the left bank of the estuary. Sample collection was not conducted on the preserved right bank of the channel due to its difficulty in access without the aid of a canoe. Estuary water samples were collected during low tide in the morning (10:00), at the start of the incoming tide in the early afternoon (13:00), and during high tide in the mid-afternoon (15:00) in 2022. A conical plankton net with a 20 cm screwable cup was used for surface tows in the middle of the channel, following the methods by Magalhães (2011) [8]. Each 100 mL sample was stored in pre-labeled plastic bottles with approximately 20 mL of a Transeau solution (6 parts distilled water: 3 parts 95% ethyl alcohol: 1 part formaldehyde) for proper plankton preservation. At the Soil Laboratory of UNEB (DCET II, Alagoinhas), the collected material was filtered through filter paper and concentrated into appropriately labeled glass bottles. The samples were analyzed under an optical microscope (Bioval brand) for photographic documentation and specimen identification [5]. The data were used to calculate diversity, evenness,

Figure 1. Study area at the Porto of Sauípe estuary (up right and down), North Coast of Bahia state (Brazil) (up left).

Source: José Gabriel Ferreira dos Santos, 2023; authoral, 2023; Passeios & Viagens, 2017.

and richness indices through PAST version 4.17 [11], an open-source software, to estimate the ecological status of the plankton community in the estuary.

Results and Discussion

The plankton community of Sauípe Port was characterized by low diversity, a common feature in degraded tropical environments. At the same sampling points, several plankton representatives were identified in this study in 2022 and 12 in 2016. This comparison of results allowed us to infer the deterioration of environmental quality over the past six years.

In the phytoplankton community, the most representative group was Cyanobacteria, with the occurrence of *Pseudanabaena* sp. at both study points, dominating at point 2 (N=105). Additionally, *Demonostoc punense* comb. nov. (formerly *Nostoc punensis*) was found at Point 1 (N=1), and *Cylindrospermopsis raciborskii* was found at Point 2. These species are producers like microalgae, represented by *Fragilaria* sp.

(Stramenopila), *Euglena* sp. (Euglenophyta), *Ceratium* sp. (Dinoflagellata), and photosynthetic diatoms (Bacillariophyta), such as *Nitzschia acicularis* and *Thalassionema* sp. (Kingdom Protista) (Table 1, Figure 2).

Shellfish and fish can consume dominant populations of cyanobacteria and toxin-producing microalgae, affecting the local food web. Although cooking kills the microorganisms present in fish and shellfish, their toxins can cause severe food poisoning for humans.

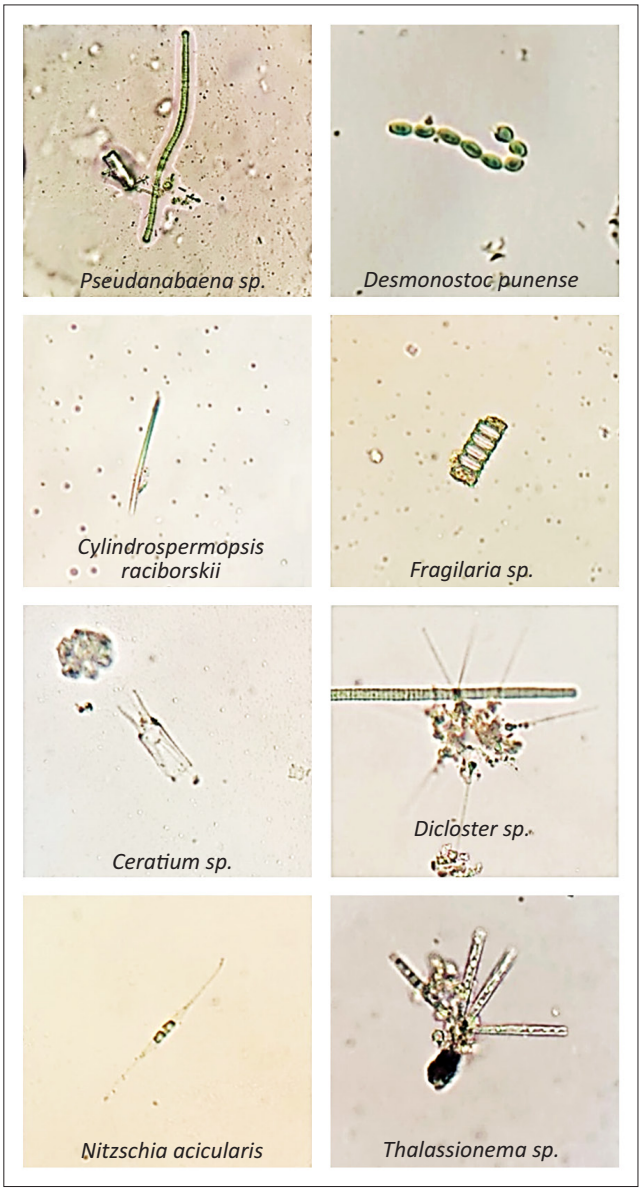
According to Kling and colleagues [12], the presence of Cyanobacteria in the phytoplankton community is not favorable, as some genera can be toxic to aquatic organisms and their consumers. Although they perform photosynthesis and often nitrogen fixation, cyanobacteria can pose a significant public health risk due to the occurrence of blooms of species potentially producing cyanotoxins.

Specimens of the genus Pseudanabaena (Pseudanabaenales, Synechococcophycideae) have elongated cells and are widely distributed in eutrophic aquatic environments, with their toxicity potential being poorly understood. Some species are producers of microcystins, which can

Table 1. Brief checklist of plankton collected in the Sauípe Port Estuary, Bahia, Brazil, 2023.

Species	Point 1	Point 2
Pseudanabaena sp.	2	105
Demonostoc punense	1	0
Cylindrospermopsis raciborskii	0	1
Fragilaria sp.	0	2
Euglena sp.	1	0
Ceratium sp.	1	0
Dicloster sp.	0	1
Nitzschia acicularis	1	0
Thalassionema sp.	0	1
Hyperia macrocephala	1	0
Copepoda (Harpacticoida)	2	0
Copepoda (Cyclopoida)	0	1
Euchlanis sp.	0	1
Ascaris lumbricoides	1	0
Schistosoma haematobium	1	0
Entamoeba coli	0	1

Figure 2. Individuals of the phytoplankton community from the Sauípe River estuary. Entre Rios, Bahia, Brazil, 2022.



be toxic to aquatic organisms and their consumers. The degree of intoxication depends on the amount ingested; no weight loss or lesions were observed in animals that received the extract via intraperitoneal injection, but weight loss and lesions in the kidneys, spleen, intestines, and liver were observed when administered orally [13].

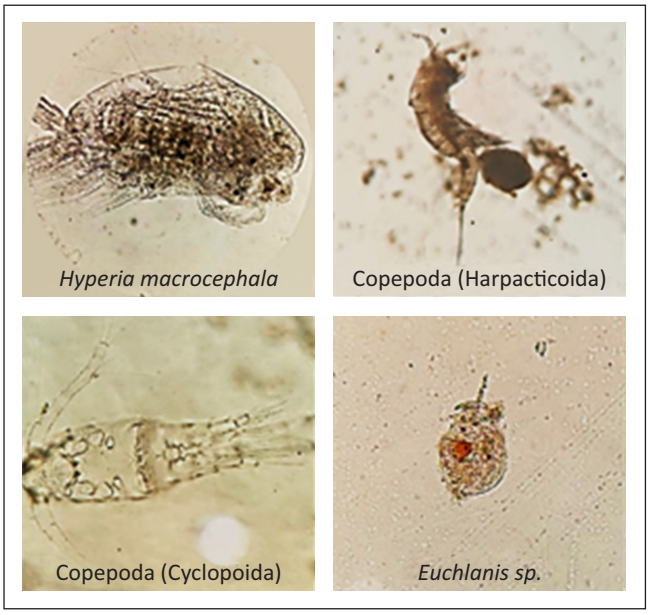
The abundance of benthic diatoms such as *Actinoptychus* sp. confirms the contribution of microphytobenthos present in the water column due to tidal currents that favor the suspension of sediments from shallow areas. The chain-like organization of the taxon *Thalassionema* sp. may indicate its adaptation to the coastal environment, as it favors continuity in the water column, minimizing sedimentation in regions with intense water mixing, especially related to river discharges [14]. There was higher zooplankton abundance during high tide, and copepods were the most representative individuals. In the zooplankton group, the following were recorded: human parasitic worms such as *Ascaris lumbricoides* (Nematoda) and *Schistosoma haematobium* (Platyhelminthes, Trematoda), the commensal amoeba *Entamoeba coli* (Amoebozoa), and microinvertebrates such as *Euchlanis* sp. (Rotifera), Hyperiamacrocephala, Harpacticoida, and Cyclopoida (Copepoda, Crustacea) from the Animalia kingdom (Figures 3 and 4).

The cosmopolitan parasitic species *Ascaris lumbricoides* and *Schistosoma haematobium* cannot be considered isolated cases in the area, as the likelihood of them being randomly collected with the tide movement is very low. These resistant enteric pathogens are considered parasitological indicators of organic pollution, either due to waste from bathers or sewage discharge from the stalls installed on the left bank of the estuary. *Ascaris lumbricoides* had already been recorded [4]; however, the record of *Schistosoma haematobium* is new and concerning due to sanitary risks. While the commensal amoeba *Entamoeba coli* is non-pathogenic and can inhabit the human colon, *Schistosoma haematobium* is a parasite of humans that causes hematobium schistosomiasis or bilharzia, which is associated with urinary schistosomiasis. It causes complications such as bacterial urinary tract infections, renal failure, and more severe cases such as urothelial cancer. The severity of the disease's sequelae depends on the worm and egg load and the duration of infection, as these eggs cause pathogenicity in the infected individual [15].

Zooplankton moves with the tides regularly twice a day, causing variations in salinity, temperature, and oxygen in the water column [16]. The density and species composition of zooplankton were studied by Srichandan and colleagues [17] in response to tidal fluctuations in an estuary in India. Abundance and diversity were higher during high tide, with records of taxa belonging to the groups. Migration of Copepoda, Cladocera, and larvae was also observed at night. Variation in abundance among species highlighted the need for collection along the tidal cycle and its relation to salinity. The Copepoda group contributes significantly to the total zooplankton biomass (Figure 3). In addition to being the primary

Figure 3. Parasitic and commensal species of zooplankton from the Sauípe River estuary. Entre Rios, Bahia, Brazil, 2022.

Figure 4. Predatory species of zooplankton from the Sauípe River estuary. Entre Rios, Bahia, Brazil, 2022.



food source for various fish species, they serve as a link between producers and consumers in the trophic web. Zooplankton organisms are sensitive to environmental changes and respond immediately to environmental quality. The appearance of Copepoda in different developmental stages may represent an adaptation of the group, as in early stages, organisms can occupy different niches compared to their adult phase [18].

In marine zooplankton, more groups are found among protozoa, microcrustaceans, and rotifers, primarily of the genus Brachionus. The latter is the most resistant to extreme conditions and indicates a negative effect on water quality, reflecting an increase in ammonia, soluble orthophosphate, nitrites, and nitrates [19].

Plankton analysis showed low diversity and richness, which is characteristic of degraded tropical environments. Dominance, diversity, equitability, and richness indices were considered. At point 2 near the mangrove, the cyanobacterium *Pseudanabaena* sp. (N=105) and toxin-producing microalgae dominated (Table 2).

The high dominance of these groups suggests an imbalance in the plankton community, likely reflecting an increase in pollution and environmental degradation over the last six years. The Shannon index, which measures diversity, shows that diversity is relatively low despite the abundance. This is indicated by the predominance of a few species and a smaller variety of taxa, which is common in eutrophic environments.

The Simpson index, which assesses the probability that two random samples will be of the same species, reinforces this observation, indicating a high probability of dominance by a few species over a more balanced diversity. Equitability, which reflects the uniformity in species distribution, confirms that low diversity is accompanied by an uneven distribution, where some species, such as cyanobacteria and microalgae, dominate others. This set of indicators reveals an aquatic environment suffering from ecological imbalance and degradation of environmental quality, evidenced by the dominance of potentially toxic species and the presence of parasites at alarming levels. This situation underscores the need for continuous monitoring and interventions to improve the region's environmental health. In the cluster analysis, *Pseudanabaena* sp. stood out

Table 2. Diversity and richness index of plankton from Sauípe Port estuary, Bahia, Brazil, 2023.

Index	Point 1	Point 2
Tax_S	9	8
Individuals	11	113
Dominance_D	0.0364	0.8630
Simpson_1-D	0.9636	0.1370
Shannon_H	2.5090	0.4216
Margalef	3.3360	1.4810
Equitability_1	1.1420	0.2028
Fisher-alpha	23.1500	1.9660
Chao-1	15.36	15.43
iChao-1	20.14	25.84
ACE	24.75	29.00

from the other species due to its abundance (N=105) at point 2 through the dissimilarity index (Euclidean distance), an effective tool for understanding general differences in the community. The samples are grouped based on the relative abundance data of species, indicating correlation patterns in the structure of the plankton community [19]. Based on the presence and absence of species, the correlation coefficient and the Jaccard evenness index allow for the grouping of similar samples, facilitating the understanding of which areas or conditions share similar biodiversity patterns (Figure 5).

The sampling points 1 and 2 did not differ (F=0.95 df=31, p=0.34) in their means in the variance analysis, raising a public health alert due to the presence of human parasites indicating environmental degradation in the Sauípe Port estuary caused by sewage, which contraindicates its use for tourism purposes.

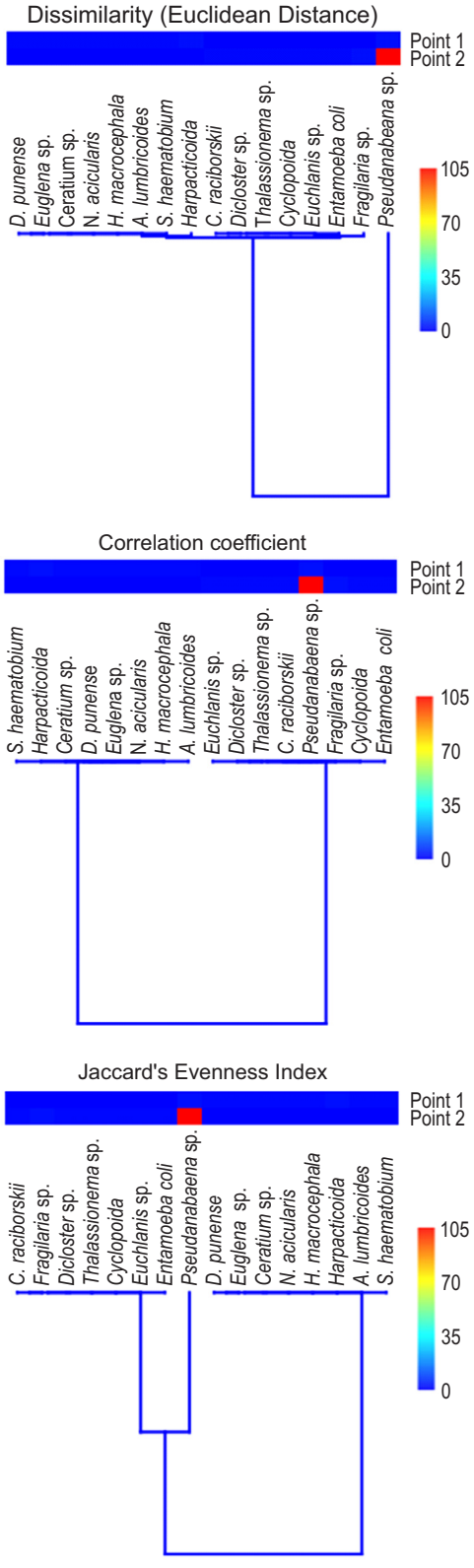
Conclusions

The evaluation of phytoplankton species biodiversity is not straightforward, despite many species being relatively well-known, due to the scarcity of taxonomic studies on this large group, which plays a significant role in aquatic ecosystems by interfering and serving as a bioremediation. The occurrence of potentially toxic Cyanobacteria species, such as *Pseudanabaena catenate*, highlights the need for proper site management to avoid harmful blooms in this community. These blooms could negatively affect aquatic organisms captured by the fishing community for human consumption. The release of cyanotoxins, which are risks to public health, requires continuous monitoring of water quality in the estuary.

There was a higher representation of microcrustaceans, particularly copepods, one of the most important zooplankton in the trophic chain.

The sampling points 1 and 2 did not differ ($p<0.05$). The presence of eggs from the parasite Ascaris lumbricoides and the worm Schistosoma haematobium, even in low occurrence, indicates contamination of the Sauípe Port estuary by sewage,

Figure 5. Cluster analysis of zooplankton species from the Sauípe River Estuary. Entre Rios, Bahia, Brazil, 2023.



raising a public health alert and contraindicating its use for tourism.

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References

1. Vannucci M. Os manguezais e nós: uma síntese de percepções. EDUSP, Universidade de São Paulo, 1999:27-53.
2. Dias ACF. Diversidade de Bactérias do Sedimento de Manguezal da Ilha do Cardoso Cananéia – São Paulo. Universidade de São Paulo/Instituto Butantan. Dissertação (Biotecnologia), 2008:59.
3. Barbosa WFA. Estrutura da comunidade fitoplanctônica do Estuário do Rio São Francisco (Alagoas/Sergipe, Brasil). Dissertação (Oceanografia), Universidade Federal de Pernambuco, Recife, 2011.
4. Santos ME, Silva MG, Orge MDR, Chagas RB. Análise preliminar da comunidade planctônica do Estuário do Rio Sauípe (Entre Rios, Bahia - Brasil). Anais do Congresso Nordestino de Biólogos - Congrebio 2016;6:443-451.
5. Brusca RC, Moore W, Shuster SM. Invertebrates. 3rd. ed. Sinauer Associates, Oxford, 2016:1104.
6. Yoneda NT. Plâncton. Centro de Estudos do Mar, Universidade Federal do Paraná, 1999.
7. Brasil J, Huszar VLM. O Papel dos traços funcionais na ecologia do fitoplâncton continental. Oecologia Australis 2011;15(4):799–834.
8. Magalhães ABS. Taxonomia, estrutura e dinâmica do fitoplâncton e do zooplâncton em um sistema piloto de tratamento de esgoto sanitário em lagoas de polimento. Tese (Botânica), Universidade Federal de Viçosa, Minas Gerais, 2011:204.
9. Rissik D et al. Plankton-related environmental and water quality issues. In: Plankton: A guide to their ecology and monitoring for water quality. Plankton 2009:39-72.
10. Passeios & Viagens. Um drone em Porto do Sauípe - Litoral Norte da Bahia. 2017. Youtube channel: @passeioseviagens
11. PAST Analyst v. 4.17 2024 Available at: https://www.nhm.uio.no/english/research/resources/past/
12. Kling HJ, Watson SB, McCullough GK, Stainton MP. Bloom development and phytoplankton succession in Lake Winnipeg: A comparison of historical records with recent data. Aquat. Gestão de Saúde de Ecossistemas 2014;14(2):219-224.
13. García AN. Estudo químico e de toxicidade subcrônica da cianobactéria Pseudanabaena galeata. Instituto de Botânica da Secretaria de Estado do Meio Ambiente. Dissertação (Biodiversidade Vegetal e Meio Ambiente), São Paulo, 2014:93.
14. Lourenço CB. O fitoplâncton na Zona Costeira Amazônica Brasileira: Biodiversidade, distribuição e estrutura no continuum estuário-oceano. Tese (Ciências), Universidade de São Paulo, Piracicaba, 2016:149.
15. Smith JH, Christie JD. The pathobiology of *Schistosoma haematobium* infection in humans. Human Pathology 2007;17(4):333-345.
16. Lee P-W, Hsiao S-H, Chou C, Tseng L-C, Hwang J-S. Zooplankton fluctuations in the surface waters of the estuary of a large subtropical urban river. Frontiers in Ecology and Evolution 2021;9:598274.
17. Srichandan S, Baliarsingh SK, Lotliker AA, Sahu BK, Roy R, Balakrishnan-Nair TM. Unravelling tidal effect on zooplankton community structure in a tropical estuary. Environmental Monitoring and Assessment 2021;193(362).
18. Cardoso LS, Ramos JD, Mello HOOM. Composição, densidade e abundância das populações de cladocera, copepoda e rotífera de áreas de proteção permanente do Rio Uberabinha. Uberlândia, MG, Revista em Extensão 2009;7(2).
19. Suetmasu GL. Aspectos generales y principios básicos de los sistemas de lagunas de estabilización. In: Seminario Internacional de Lagunas de Estabilización, Colombia, 1995:3-12.

Ecological Niche Model for *Palicourea jambosioides* (Schltdl.) C.M. Taylor in the State of Bahia, Brazil

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The Atlantic Forest is a complex of ecosystems of great importance, as it is home to a significant portion of Brazilian biodiversity. The Rubiaceae family is the fourth largest in number of species among the Angiosperms, presenting its most remarkable diversity in the phytogeographic domains of the Amazon and the Atlantic Forest. This study aimed to model the ecological niche of *Palicourea jambosioides* (Schltdl.) C.M. Taylor in the state of Bahia. Georeferenced occurrence data were obtained from the online databases SpeciesLink and GBIF, as well as consultations with physical herbaria and scientific articles, and were combined with climate information from WorldClim. The statistical validation of the models was performed considering AUC values ≥ 0.7 and TSS ≥ 0.4. The variables that most contributed to the modeling were BIO5 (26.1%), BIO15 (22.6%), BIO10 (15.8%), and BIO3 (15.0%). It was observed that *P. jambosioides* occurs mainly in areas of seasonal forest and restinga, with temperature and precipitation being the environmental variables with the most significant influence on its distribution. Thus, this study contributes to advancing knowledge about the distribution of the species and can offer subsidies for conservation actions in the state of Bahia.

Keywords: Biodiversity. Geographic Distribution. Atlantic Forest.

The Rubiaceae family was initially described by Jussieu in 1789 and has since been studied by researchers worldwide [1]. The species have high plasticity of habit and morphological characteristics. They are easily recognized by the interpetiolar stipules, rarely interpetiolar, opposite leaves, androecium isostemonous, and usually infectious ovary.

Rubiaceae is the fourth family of several species in the Angiosperms, after Orchidaceae, Asteraceae, and Leguminosae [2]. They occur in all regions of the world, but mainly in the tropics [3]. According to [4], the family has about 14,000 species, distributed in 600 genera, with great species richness in tropical regions.

The Atlantic Forest is the second-largest tropical rainforest on the American continent. It originally extended continuously along the Brazilian coast, penetrating as far east as Paraguay and northeastern Argentina in its southern portion [5]. The Atlantic Forest domain is home to many endemic plant species, many of which are threatened with extinction due to alarming rates of habitat loss [6,7].

A considerable factor is that many species have not yet been cataloged in these areas, resulting in the loss of much data, mainly related to geographic distribution. A strategy that can mitigate the effect of this space in the study of biodiversity is to estimate the actual or potential distribution of a species, characterize the environments with favorable environmental conditions, and identify where and how these places are distributed in space [8].

According to Flora and Funga do Brasil (2024) [9], the most incredible diversity of Rubiaceae occurs in the phytogeographic domains of the Amazon and Atlantic Forest. In the Brazilian territory, the family is present in all the domains represented, having 128 genera distributed in 1,416 species, 704 of which are considered endemic. In the northeast region, the family is cited among the most diverse and is represented by 424 species. Bahia is the second Brazilian state with the highest diversity of Rubiaceae, with about 375 species,

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second only to Amazonas, with about 532 species. Palicourea Aubl., has about 230 species [10]. According to Flora and Funga do Brasil (2024) [9], the genus has about 175 species and is distributed in the Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa, and Pantanal phytogeographic domains. The genus is characterized by presenting flowers with a tubular corolla, without odor, with intense colors and pollinated mainly by hummingbirds, and fleshy, blue to purple fruits, usually dispersed by birds [11]. The genus is closely related to Psychotria, differing from it by the gibbous corolla flowers [12].

Palicourea jambosioides (Schltdl.) C.M. Taylor is an endemic species of Brazil, occurring only in Bahia and Espírito Santo. According to Souza and colleagues [13], it is characterized by a shrubby habit up to 3 m high, persistent stipules bipartite at least at the apex, triangular, acute apex, glabrous; Opposite leaves, chartaceous, oblong, apex acute to acuminate, margin flat; Paniculate, subterminal, multi flower, white or lilac inflorescences; Monocline, heterostylous, sessile flowers; toothed calyx; lilac corolla, tubular, gibbous base, stamens inserted in the median portion of the tube; bifid stigma; Drupaceous fruit, purple to green, when immature, glabrous.

Modeling species' environmental requirements and mapping their distributions in space and time are important aspects of many biological analyses, especially in support of conservation and management interventions [14]. Thus, ecological niche models (ENMs) are empirical or mathematical approximations of a species' ecological niche [15]. They are a technique used to estimate actual or potential distribution ranges or sets of habitats favorable for a given species based on their observed presence and sometimes absence [16].

Understanding geographic distribution is crucial to supporting several research projects, especially ecology. This study sought to map the distribution of *Palicourea jambosioides* in Bahia using species distribution modeling and examine the climatic variables that influence the species' occurrence.

Materials and Methods

Bahia is the fifth largest state in Brazil, with 564,733,081 km² [17]. Due to its territorial extension and climatic and geographic variation, it is home to a great diversity of vegetation. Some of the main domains present are the Atlantic Forest, Caatinga, and Cerrado (Figure 1).

According to Giulietti and Pirani [17], "*formations of dense ombrophilous forests (Hiléia baiana), vegetation with marine influence (restinga, dunes), and vegetation with fluvial-marine influence (mangrove) are found in coastal areas; seasonal semideciduous forest in most of the areas bordering the dense ombrophilous forest and in the central plateau regions; savannas (cerrado), mainly west of the São Francisco River, but with disjunctions in the Chapada Diamantina and in the north of the state; seasonal deciduous forest and steppe savannas (caatingas) mainly in the interplanaltic depressions and western slope of the central mountain systems; and rupestrian fields, in areas above 900 m of the Chapada Diamantina*." Thus, they reflect rich and vast biodiversity, have endemic species, and offer environmental mechanisms.

The climate of Bahia is diversified due to the state's territorial extension and its different physiographic regions. In general, these climates can be considered mega thermal tropicals, with marked differences in rainfall [17]. The average annual rainfall varies from 363 mm in the northern and northeastern portions of the state to 2,000 mm recorded in the coastal plain of the municipality of Ilhéus [18].

The occurrence data of *Palicourea jambosioides* were obtained based on the research platforms SpeciesLink (www.specieslink.net) and Global Biodiversity Information Facility (GBIF - www.gbif.org), consultation of the published data and the visits to the physical collections of the Herbarium of the State University of Bahia (HUNEB), Herbarium Alexandre Leal Costa (ALCB), Herbarium of the State University of Feira de Santana (HUEFS). Data on the geographic distribution of the species were obtained based on the literature and the labels of the

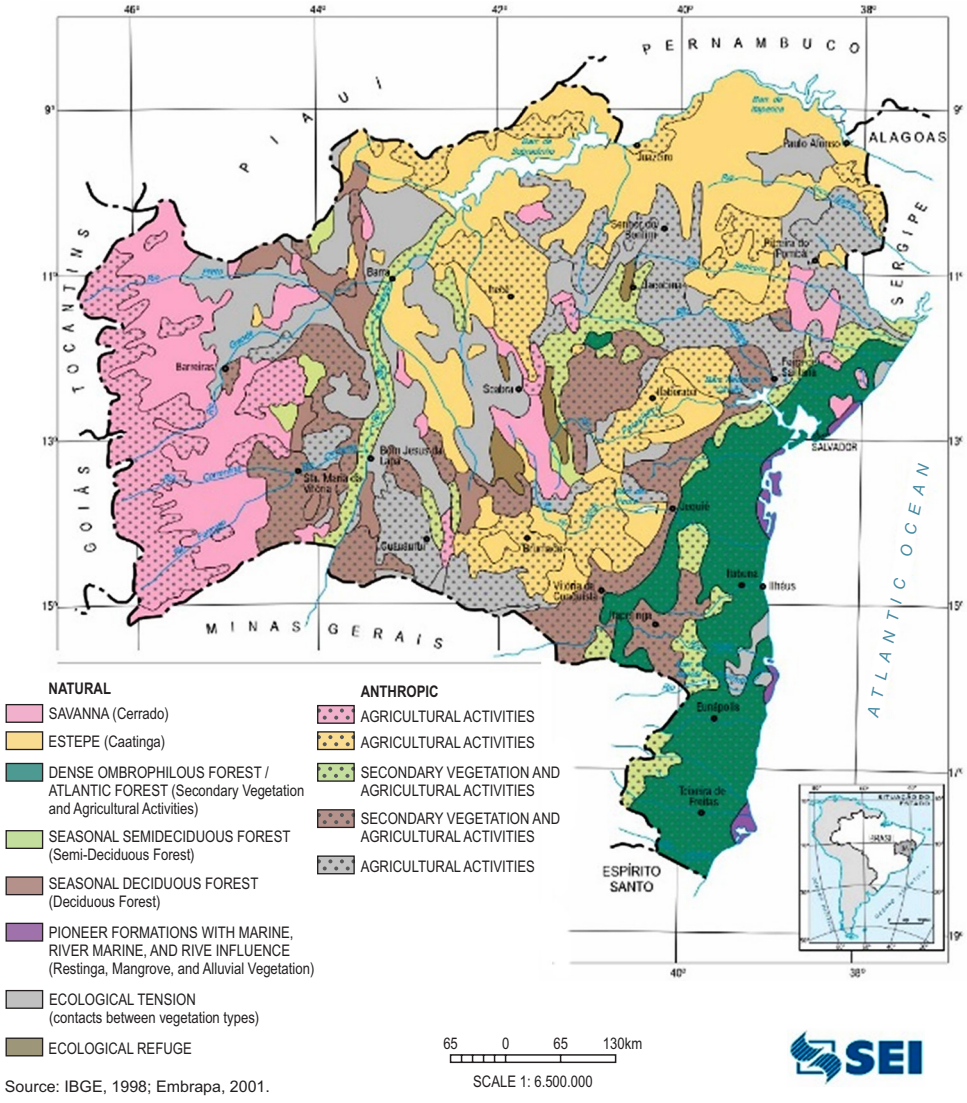
specimens analyzed. The spelling of the scientific name and authorship of the taxon was used [19].

Data on species occurrences were included in Excel spreadsheets, and specimens that were not identified by experts or had inaccurate geographic data were excluded from the analyses. Duplicates, wrong and/or missing coordinates, and occurrences without location data were removed. The tidyverse package [20] refined such data.

With the aid of the earth and tidyverse packages, the bioclimatic variables were obtained through the Worldclim (http://www.worldclim.org/) database in version 2.1 [21]. The 19 variables derived from monthly values of temperature and precipitation are presented in GeoTiff (.tif) format at the spatial resolution of the 2.5 arc-minute layers. The study area was delimited to Brazil and later to Bahia. The projections were combined through the methodology of ensembling [22].

The environmental variables selected through Pearson's correlation (with a cut-off value of 0.8) were BIO5 (Maximum temperature of the hottest month), BIO15 (Seasonality of precipitation), BIO10 (Average temperature of the hottest room), BIO3 (Isothermality), BIO4 (Seasonality of temperature), BIO9 (Temperature of the driest room), BIO8 (Average temperature of the wettest room), BIO13 (Precipitation in the wettest month),

Figure 1. Vegetation map of Bahia.



BIO 18 (Precipitation in the hottest room). To minimize the effects of multicollinearity in the models, the environmental variables were evaluated based on the calculation of the Variance Inflation Factor (VIF), thus resulting in the elimination of redundant variables, i.e., only the variables with the lowest degree of collinearity of the set were used. The generated models used the AUC and TSS metrics to be evaluated, whose AUC values ≥ 0.7 and TSS ≥ 0.4 [23]. All procedures were performed in R 4.4.1 [24] through the usdm package [25]. The model was trained for the states of Bahia and Espírito Santo using the Maxent 3.4.4 algorithm [26], with 10 replicates and a cross-validation method with 5 data partitions (k = 5). This algorithm is justified because it is notably useful for species in which the records of points of occurrence have a low number [27] and because it requires only points of presence [28].

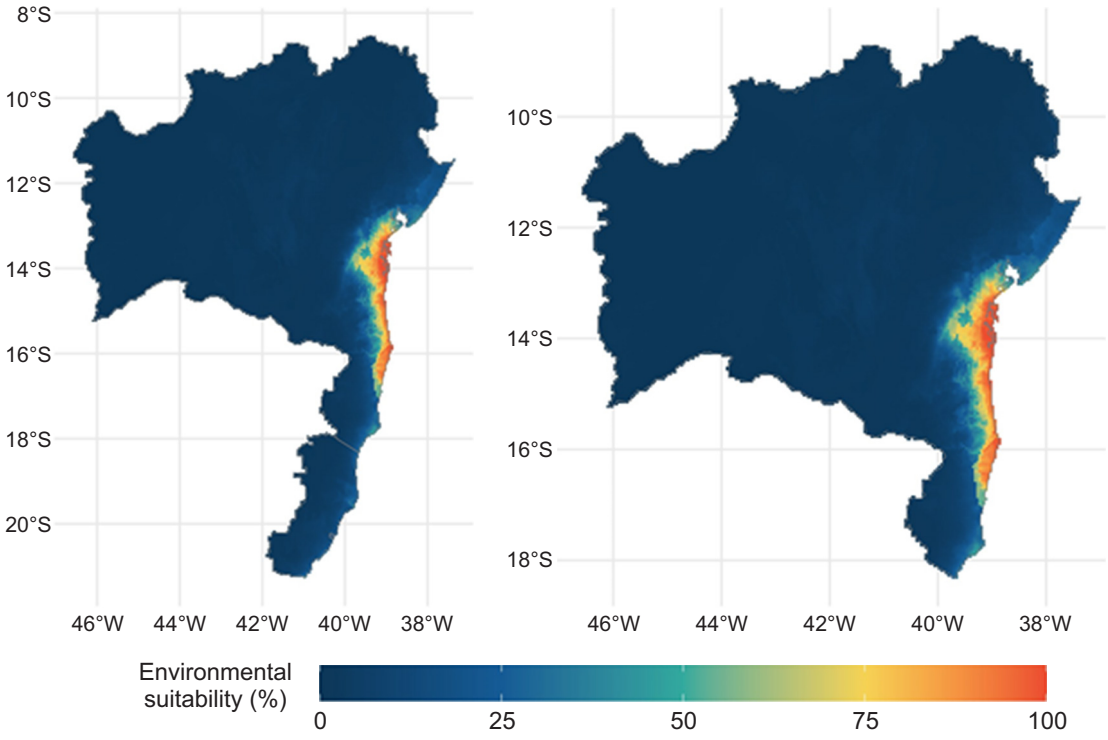
Results and Discussion

The model performed excellently with AUC = 0.93 and TSS ≥ 0.81 values for Bahia. According to the result on the projection map (Figure 2), the occurrence of the species should be concentrated in the coastal region of Bahia in the Atlantic Forest portion. The model suggests that this portion has areas where the occurrence tends to be 100 (%). of chance, that is, the species is found with certainty.

There are also occurrences in regions where the estimated presence is close to 0 (%), which means that the model does not entirely rule out the possibility of occurrences in regions further away from the coast, but they should be rare. In the central region of the distribution map, some occurrences stand out for their distance from their niche and are, therefore, a result generated by the insertion of data that record the occurrence in this remote region.

The values of the most significant variables with a relative contribution to the modeling based on the Pearson Correlation method were: BIO5- Maximum temperature of the hottest month (26.1%); BIO15- Seasonality of precipitation (22.6%); BIO10 -Average temperature of the hottest room (15.8%); BIO3- Isothermality (15%). It was possible to observe that the distribution of *P. jambosioides* in

Figure 2. Ensemble of projections for *Palicourea jambosioides* for the states of Espírito Santo and Bahia projected from the model for Brazilian territory.



Bahia occurs mainly in seasonal forest and resting areas, with temperature and precipitation being the environmental variables with the most significant influence on its distribution.

Climatic variables, especially those related to temperature and precipitation, are important because they directly influence plant development and are responsible for floristic changes along gradients [29,30]. According to reference [9], *Palicourea jambosioides* is distributed by domains of the Atlantic Forest. In a study carried out by [13, 31], the species was found in the Serras da Fumaça chain, previously known only from the coastal Atlantic Forest and resting areas. The Serra da Fumaça corresponds to one of the Jacobina Mountains, which is part of the northern portion of the Chapada Diamantina [17].

The Espinhaço Chain is a mountain formation extending north-south, from Bahia to Minas Gerais, under the phytogeographic influence of the Atlantic Forest, Cerrado, and Caatinga domains [32]. However, the dominant vegetation cover in the spinach chain is the rupestrian grassland [33]. Although these two biomes are separated by 250 km, which does not allow the survival of grassland species; Harley (1995) considers the existence of "intermediate" environments in which some occur [34].

According to Alves and colleagues [34], although the restingas occur at sea level and, on the other hand, the rupestrian fields are above 800 m, and the fields of altitude fields well above 1300 m, these altitude distinctions are not established as significant in the tropics. Thus, based on studies by Giulietti and Pirani 1988; Harley and Simmons 1986 Harley 1988, some species first occurred in Serra da Fumaça and are found along the Brazilian coast.

Palicourea jambosioides is a shrub native to Brazil [9]. It differs from the others through the leaves with inconspicuous secondary veins on both sides, the inflorescence with rachis, thick peduncles, and purple corolla [13]. Studies regarding the geographic distribution of *P. jambosioides* in Bahia are not found. Thus, biogeographic studies, including modeling tools, become extremely important, in addition to floristic and phenological surveys, as they can enrich the knowledge of the local flora and the distribution and conservation situation of the species.

Endemic species, such as *P. jambosioides*, have specific ecological roles that influence the structure and dynamics of plant and animal communities around them. Their presence can also affect vegetation composition and interaction with other species, including pollinators and herbivores. The conservation of *P. jambosioides* is important for the preservation of the biodiversity of the Atlantic Forest, as the biome is threatened by several factors, mainly by anthropogenic actions, thus putting the survival of many species at risk.

Conclusion

The ecological niche modeling allowed the visualization of the areas with the highest probability of occurrences of *P. jambosioides* in the states of Bahia and Espírito Santo, especially in the coastal region of the state of Bahia in the Atlantic Forest portion. The species is distributed mainly in seasonal forests and restingas, influenced by high temperatures and precipitation, whose conditions include humid environments and drier and seasonal ones. Ecological niche modeling is a valuable tool for expanding knowledge about the distribution of the species in the Atlantic Forest, and it can help new collections and intensify the increase in sampling effort in certain areas.

Acknowledgment

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Reference

1. Pessoa MCR. Diversidade e riqueza da família Rubiaceae Juss. no Cariri Paraibano. 2009. 83 p. Dissertação (mestrado) – Universidade Federal de Pernambuco.

CCB. Biologia Vegetal, Recife, 2009. Available at: https://repositorio.ufpe.br/bitstream/123456789/1008/1/arquivo7079_1.pdf.
2. Delprete PG, Jardim JG. Systematics, taxonomy and floristics of Brazilian Rubiaceae: an overview of current status and future challenges. Rodriguésia 2012;63(1):101-128.
3. Taylor CM, Campos MTVA, Zappi D. Flora da reserva Ducke, Amazonas, Brasil: Rubiaceae. Rodriguésia 2007;58(3):549-616.
4. Bramley G, Trias-Blasi A, Wilford R. Rubiaceae Juss. Manual de identificação de famílias de plantas temperadas de Kew. In: Kew Publishing Royal Botanic Gardens, Kew. 2023. Disponível em: https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:30032120-2/general-information#descriptions. Acesso em 01 set. 2024.
5. Tabarelli M, Pinto L, Silva JMC, Hirota MM, Bedê LC. Desafios e oportunidades para a conservação da biodiversidade na Mata Atlântica brasileira. Megadiversidade 2005;1(1):132-138.
6. Myers N, Mittermeier RA, Mittermeier CG, Fonseca GA, Kent J. Pontos críticos de biodiversidade para prioridades de conservação. Nature 2000;403(6772):853-858.
7. Tabarelli M, Aguiar AV, Ribeiro MC, Metzger JP, Peres CA. Prospects for biodiversity conservation in the Atlantic Forest: Lessons from aging human-modified landscapes. Biological Conservation 2010;143(10):2328-2340.
8. Pearson RG, Raxworthy CJ, Nakamura M, Townsend Peterson A. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 2007;34(1):102–117.
9. Flora e Funga do Brasil. Rubiaceae. In: Jardim Botânico do Rio de Janeiro. 2024. Available at: https://floradobrasil .jbrj.gov.br/FB210.
10. Tulli CF. Coléteres estipulares em Palicourea Aubl. (Rubiaceae): aspectos estruturais e funcionais. 2014. 99 p. Dissertação (mestrado). Universidade Estadual do Norte Fluminense Darcy Ribeiro - UENF, Campos dos Goytacazes, Rio de Janeiro, Brasil.2014. Available at: https://uenf.br/posgraduacao/biociencias-biotecnologia/wp-content/uploads/sites/12/2020/12/Versao-Final-Cristiane-Ferrante-Tullii.pdf#page=15.62.
11. Taylor CM. Conspectus of the genus Palicourea (Rubiaceae: Psychotrieae) with the description of some new species from Ecuador and Colombia. Annals of the Missouri Botanical Garden 1997;84(2):224–262.
12. Borges RL, Jardim JG, Roque N. Rubiaceae na serra geral de licínio de almeida, Bahia, Brasil. Rodriguésia 2017;68(2):581–621.
13. Sousa LA, Bautista HP, Jardim JG. Diversidade florística de Rubiaceae na Serra da Fumaça–complexo de Serras da Jacobina, Bahia, Brasil. Biota Neotropica 2013;13(3):289-314.
14. Sánchez-Mercado AY, Ferrer-Paris JR, Franklin J. Mapeamento de distribuições de espécies: inferência espacial e predição. Oryx 2010;44(4):615.
15. Barbosa MA, Sillero N, Martínez-Freiría F, Real R. Ecological niche models in Mediterranean herpetology: past, present and future. In: Zhang WJ (edi). Ecological Modelling. Hauppauge (NY). Nova Science 2012:173-204. Available at: https://www.researchgate.net/publication/256361075_Ecological_niche_models_in_Mediterranean_herpetology_past_present_and_future.
16. Soberón J, Nakamura M. . Niches, and distributional areas: concepts, methods, and assumptions. Proceedings of the National Academy of Sciences 2009;106(Supplement 2):19644-19650.
17. Giulietti M, Pirani JR. Patterns of geographic distribution of some plant species from the Espinhaço Range, Minas Gerais and Bahia. In Proceedings. Rio de Janeiro: Academia Brasileira de Ciências.1987. 18. do Meio Ambiente, B. M. Resumo executivo planos estaduais do programa Água doce 2010- 2019 Computer software manual]. 2010. Retrieved from https://antigo.mdr.gov.br/images/stories/ aguadoce/ArquivosPDF/resumo_executivo_PAD-1.pdf.
19. Garden, MB. Tropicos.org. Retrieved from https://tropicos.org, 2024.
20. Wickham R. Rstudio tidyverse: Easily Install and Load the "Tidyverse". 2023. Available at: https://cran.r-project.org/web/packages/tidyverse/index.html.
21. Fick SE, Hijmans RJ. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology, 2017;37(12):4302-4315.
22. Marmion M, Parviainen M, Luoto M et al. . Evaluation of consensus methods in predictive species distribution modeling. Diversity and Distributions 2009;15(1):59-69.
23. Allouche O, Tsoar A, Kadmon R. Avaliando a precisão de modelos de distribuição de espécies: prevalência, kappa e a estatística de habilidade verdadeira (TSS). Journal of Applied Ecology 2006;43(6):1223-1232.
24. R Core Team. R: A language and environment for statistical computing.Viena, Austria. R Foundation for Statistical Computing. Available at: https://www.r-project.org/.
25. Naimi B, Hamm NA, Groen TA et al. Where is positional uncertainty a problem for species distribution modelling?. Ecography 2014;37(2):191-203.
26. Phillips SJ, Dudík M, Schapire RE. Software Maxent para modelagem de nichos e distribuições de espécies (Versão 3.4.1). Available at: http://biodiversityinformatics.amnh.org/open_source/maxent/.
27. Van Proosdij AS, Sosef MS, Wierinja JJ, Raes N. Número mínimo necessário de registros de espécimes

para desenvolver modelos precisos de distribuição de espécies. Ecography 2016;39(6):542-552.
28. Wisz MS et al. Effects of sample size on the performance of species distribution models. Diversity and Distributions 2008;14(5):763-773.
29. Grubb PJ. Control of forest growth and distribution on wet tropical mountains: with special reference to mineral nutrition. Annu Rev Ecol Syst 1977;8:83-107. Rubiaceae. In: Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro. Available at: <https://floradobrasil.jbrj.gov.br/FB210>.
30. Pausas JG, Austin MP. Padrões de riqueza de espécies de plantas em relação a diferentes ambientes: uma avaliação. Journal of Vegetation Science 2001;12(2):153-166.
31. de Jesus V, Magalhães FH, Sousa LA et al. Composição florística da Serra da Fumaça, norte da Chapada Diamantina, Bahia, Brasil. Paubrasilia 2022;5:e101-e101. https://periodicos.ufsb.edu.br/index.php/paubrasilia/article/view/101.
32. Kamino LHY, Oliveira-Filho AT, Stehmann JR. Relações florísticas entre as fitofisionomias florestais da Cadeia do Espinhaço, Brasil. Megadiversidade 2008;4(1-2):39-49.
33. Giulietti AM, Pirani JR. Patterns of geographic distribution of some plant species from the Espinhaço Range, Minas Gerais and Bahia. In Proceedings. Rio de Janeiro: Academia Brasileira de Ciências 1987.
34. Alves RJV, Cardin L, Kropf MS. Angiosperm disjunction Campos rupestres-restingas: a re-evaluation. Acta Botanica Brasilica 2007;21(3):675-685.

Using the MLP Classifier Model with Markov Chains Observing the Bovespa Index

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The application of resources in the financial market in the form of investment is primarily linked to variable income, which has a higher risk, requiring a more thorough assessment to increase its assertiveness. Successful past experiences influence decisions and can lead to correct choices. Mathematical and statistical models should assist in decision-making to optimize their success. This work involves creating a web service connector to capture data from the BOVESPA index, randomly used to choose between three websites: Infomoney, Investnews, and Valor Invest. This work used an Artificial Neural Network (ANN) Classification model, the MLPClassifier, and compared this model alone and about itself with the insertion of the modeling with Markov Chains. The MLPClassifier model proved satisfactory, given that performance metrics measure its classifications, and the speed will depend on the number of hidden layers used. By including Markov Chains in the MLPClassifier model, it was possible to refine the classification process of the model, which already had a very high level of assertiveness.

Keywords: Stock Exchange. Markov Chain. MLPClassifier. Bovespa Index.
Abbreviations: Format. Microsoft Word Template. Style. Insert. Template.

The application of resources in the financial market in the form of investment is linked mainly to variable income, which involves greater risk, and a more detailed assessment is necessary to increase its assertiveness. Successful past experiences influence decisions and can lead to correct choices. Mathematical and statistical models should assist in decision-making to optimize success.

In this sense, Nascimento and colleagues [7] states that the mind avoids information overload, causing individuals to be induced into mental shortcuts, and a significant part of this process is executed unconsciously and automatically. In other words, such shortcuts guide us to escape from danger zones. However, using a mobile equipment management application, Mota [11] used technology to persuade users regarding energy consumption. Therefore, technology is one of the tools to shield such triggers and place the investor in a strategic position.

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Therefore, when analyzing the financial market, the BOVESPA Index (IBOVESPA) [4] is the leading performance indicator of stock exchanges on the B3. It comprises approximately 80% of the trades and is reassessed every four months. In other words, it is nothing more than the result of a theoretical portfolio of assets, a thermometer of how the investment market is doing in Brazil. Therefore, this primary performance indicator is a reference for an intelligent assessment of the financial market.

For this work, the strategy used is technical analysis that according to Piazza [12], [...] *It is the science that seeks, through the study of multifaceted records associated with mathematical and statistical formulations, applied to past and current prices, volumes, and open contracts of different financial assets, to provide, by analyzing recurring patterns, conditions that allow us to project the future price movement within a logic of higher probabilities.* [...]

Therefore, technical analysis is a study that observes the movement of the stock exchange intending to obtain information. Therefore, one method used in this type of analysis is Markov Chains, which, according to Bolson and colleagues [3], is a stochastic process, that is, a set of random variables that describes the behavior of this process

in a certain period and that the systematics for Markov Chains is that only the current experience can affect the following result. This work aims to use Markov Chains to observe the BOVESPA index.

Materials and Methods

The purpose of this work is to create a web service connector. For Daigneau [6], a web service provides the means to integrate different systems and expose reusable business functions via HTTP. They use HTTP as a simple method of transporting data, and in this sense, creating a web service connector to capture data from the BOVESPA index using a random selection of three websites: Infomoney, Investnews, and Valor Invest.

With the information obtained from IBOVESPA, modeling will be performed with Markov Chains since IBOVESPA is affected by stochastic values. In this sense, a Markov Chain is a set of random variables that describes the behavior of variables over a certain period [5].

This work is based on verifying the frequency of historical movement. Therefore, probability information helps in decision-making for investors who deal with these probabilities of the Stock Exchange. For this classification, descriptive scope with a quantitative approach was considered.

This work used an Artificial Neural Network (ANN) Classification model, the MLPClassifier, and compared this model alone and about itself with the insertion of modeling with Markov Chains: A study of the BOVESPA index, whose purpose was to create a reliable computational algorithm to assist in decision-making. Data preprocessing is necessary since Gorgens and colleagues [8] state that normalization is an approach that aims to homogenize the variables involved in the analysis. Thus, normalization was performed using Natural Logarithm, which, according to Zhang and You [19], is a local logarithm normalization method proposed to improve the accuracy of the local prediction of the ANN.

Markov Chains

Markov Chain is a mathematics model whose author, Andreyevich Markov, initiated studies about Russian theory methodology; it is known as the Markov Chain [3]. Only experience could affect the future state, and this is known as the Markovian Property. The authors emphasize that even if past events are not considered relevant to the future state, they are not ignored because the model uses the information from the past as a basis for the present state of the process.

Cechin and Cordo [5] describe that Markov Chain is a set of random variables, that is, a stochastic process that describes the behavior of variables $\{Xtn\} = \{x1, x2, ..., xn\}$ within a certain period T and that such a process is a Markov chain if the probability of occurrence of a future state depends exclusive on the present state that is if it is independent of past events.

The sequence P $\{Xn, n>0\}$ is said to be a Markov chain if for all state values $i0,i1,i2, ..., in \in I$:

$$P\{X_{n+1} = j \mid X_0 = i_0, X_1 = i_1, \ldots, X_n = i\} = P\{X_{n+1} = j \mid X_n = i\}$$

Where, $i0$, $i1$, $i2$, . . ., in are the states in the state set I. This kind of probability is called Markov chain probability. So, this setup indicates that regardless of its history prior to time n, the probability that it will transition to another state j depends only on state i.

Therefore, Bhusal [2] affirms that the transition probability, defined by the Markov chain, is called transition or jump probability from state i to state j.

$$P\{X_{n+1} = j \mid X_n = i\} = P_{ij}$$

This is known as one-step transition probability. If the transition probabilities defined above are independent of time n, then such an assumption is called a stationary Markov chain. Thus,

$$P\{X_{n+1} = j \mid X_n = i\} = P\{X_1 = j \mid X_0 = i\}P_{ij}$$

The transition probabilities Pij can be written or arranged in a matrix form as:

$$P = [p_{ij}], i, j \in I$$

The matrix P is called the transition probability matrix or stochastic matrix. The values from matrix P must be non-negative elements with row sum unity equals 1. Hence, The matrix P insists on non-negative elements with row sum unity. Hence,

$$0 \leqslant p_{ij} \leqslant 1 \text{ e } \sum_{j=1}^{n} p_{ij} = 1, \forall i \in j$$

Cechin and Corso [5] show that the transition probability can be represented in a matrix.

$$P = \begin{pmatrix} P_{11} & P_{12} & P_{13} & \dots & P_{1j} \\ P_{21} & P_{22} & P_{23} & \dots & P_{2j} \\ \dots & \dots & \dots & \dots & \dots \\ P_{i1} & P_{i2} & P_{i3} & \dots & P_{ij} \end{pmatrix}$$

When a Markovian process can go from one state to another, any in n-time steps are classified as an ergodic matrix. The stable probability state πj to an ergodic Markov Chain is represented by the equation represented above.

Gathering Data

Data collection was carried out by searching for historical data from the BOVESPA index, as previously reported, in which each piece of information was randomly selected between March 11, 2024, and August 30, 2024, totaling 4,166 pieces of data. All of this data found was stored in a SQLite Database for easy access and standard integration with the Python programming language. This data was used to perform the Markovian process. The data from IbovespaReal, IbovespaAjustado, DataHoraAtual, DataAtual, Porcentagem, and delay comprise the information stored in the SQLite Database. Therefore:

- IbovespaReal - Data collected from the period collected from the chosen website and contains decimal places;
- IbovespaAjustado - Adjustment made to use only the whole number;
- DataHoraAtual - Date and time of the collection;
- DataHoraAjustado - Date and time with the adjustment about the delay;
- DataAtual - Use only the current date;
- Delay - interval time of each data.

Making a Transition Matrix

For this work, the database was divided into 8 classes to perform data discretization since the Bovespa index deals with continuous values. The choice for these 8 classes, whose division strategy is used by the works cited on Markov Chains in this research, used a percentage of 0.5% between each class since there was not much volatility within the scope of variation during the day. In this sense, when evaluating the IBOVESPA, as seen in this work, it is a thermometer of how the investment market is in Brazil.

The intervals with this separation of 0.5% are between -2.0% and 2% since, when evaluating the database, it was noticed that there were no values below or above these values. Markov Chains do not have an initial quantity or limit to perform. The criterion for this research is based on the understanding that the smaller these distances, the better the refinement of the results will be.

Making a Webservice Connector

To search for the Bovespa indexes of the day, a data collector was used directly from three reliable websites: Infomoney, Investnews, and Valor Invest. Since these websites update in approximately 15 minutes, care must be taken to scrape the data without blocking the computer's Internet Protocol (IP) to continue.

In this sense, this web scraping-type connector was created with the request to randomly select among these websites. This schedule was created using the Schedule library and programmed to run every business day between 10:00 a.m. and 6:00 p.m. with an interval of between 10 and 15 minutes. The time chosen was because the counter opens and closes during this period, and the delay varies within this time range.

Metrics

For the process of measuring the classification results of a model, Prati and colleagues [13] state that: "*To induce a classifier, a supervised algorithm uses a sample of cases for which the proper classification is known. [...] Each case is labeled with a unique attribute called a class to distinguish cases among the possible classifications*."

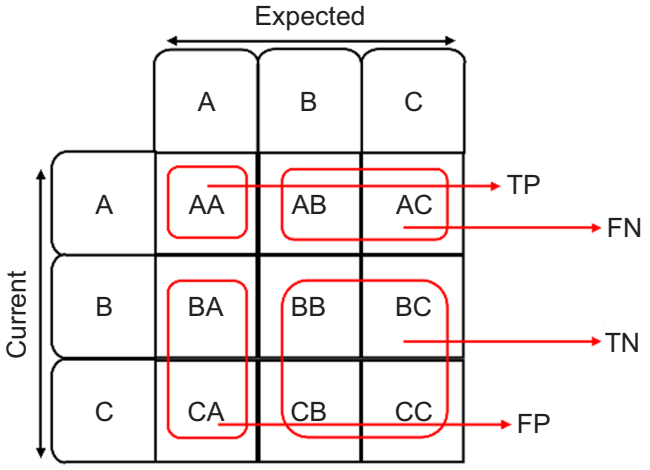
That said, to calculate Precision, Accuracy, Specificity, Recall, and F1-score, the Confusion Matrix is used (Figure 1) [17]. Wabang and colleagues [17] highlight this discussion as a binary classification problem. There are only two classes: positive and negative. What is the confusion matrix for? Ramos [14] explains that: "*The confusion matrix of a model provides a straightforward way to assess whether the model accurately predicts genuine and fraudulent transactions. [...] It displays the frequency of matches between observed and predicted classifications based on a given threshold*."

The model performance metrics [1] are:

Accuracy: The percentage of entire instances rightly predicted by the model.

$$Accuracy = \frac{tp + tn}{tp + tn + fp + fn}$$

Figure 1. Confusion matrix.



TP is True Positive, FP is False Positive, TN is True Negative, and FP is False Negative.

F1-score: This is a harmonic mean of precision and recall.

$$F1 - score = \frac{2\ x\ precision\ x\ recall}{precision + recall}$$

Specificity: This shows a model's ability to classify actual negative instances as negative [1]. Therefore, this proportion of negative instances rightly predicted divided the classifier out of the total instances that are actually negative.

$$Specificity = \frac{tn}{tn + fp}$$

Precision: According to Wabang and colleagues [17], the precision is the true positives divided by the total prediction.

$$Specificity = \frac{tn}{tn + fp}$$

Recall: It measures the fraction of true positives that were correctly classified.

$$Recall = \frac{tp}{tp + fn}$$

ROC Curve

According to Prati and colleagues [13], receiver operating characteristic is a method used for prediction evaluation. It was introduced for machine learning to evaluate classification models. The author explains that the most efficient way is to order all test cases according to the continuous value to generate the curve.

According to Santos and colleagues [15], the ROC Curve is a great tool for evaluating a balance between sensitivity and specificity across all possible cutoff points for prediction. The authors continue that the overall performance of a classifier can be evaluated by the area under the ROC curve (AUC): The higher the AUC (closer to 1), the better the model's performance. Therefore, AUC ROC is an excellent way to compare two or more models.

Results and Discussion

As shown in the previous session, the database was divided into 8 classes with a 0.5% interval between each class. There was no further discretization since data below -2% and above 2% were not counted. Then, the transition count for the Markov Chain was performed, as shown in Table 1.

After carrying the transition counting in Table 1, the transition matrix from the Markov Chain is demonstrated in Table 2.

When performing the transition matrix Markov Chain in Table 2, it has to calculate what means the initial vector is the probability of zero state from these 8 classes. The probability of occurrence can be obtained by counting from 4166 from Bovespa index data. The initial vector is indicated by $\pi(0)$ and given by $\pi(0) = (\pi(1), \pi(2), \pi(3), \cdots, \pi(8))$.

$\pi(1) = 16/4166 = 0.43\%$
$\pi(2) = 162/4166 = 3.89\%$
$\pi(3) = 495/4166 = 11.88\%$
$\pi(4) = 1001/4166 = 24.03\%$
$\pi(5) = 1612/4166 = 38.69\%$
$\pi(6) = 612/4166 = 14.69\%$
$\pi(7) = 222/4166 = 5.33\%$
$\pi(8) = 44/4166 = 1.06\%$

Table 1. Transitions counting to calculate the transition matrix.

	[-2.0~-1.5]	[-1.5~-1.0]	[-1.0~-0.5]	[-0.5~0.0]	[0.0~0.5]	[0.5~1.0]	[1.0~1.5]	[1.5~2.0]
[-2.0~-1.5]	7	7	2	1	1	0	0	0
[-1.5~-1.0]	7	115	25	1	14	0	0	0
[-1.0~-0.5]	2	29	363	60	40	1	0	0
[-0.5~0.0]	0	0	61	759	167	10	1	3
[0.0~0.5]	2	11	43	166	1249	122	19	0
[0.5~1.0]	0	0	1	9	122	461	19	0
[1.0~1.5]	0	0	0	2	16	17	177	10
[1.5~2.0]	0	0	0	4	2	1	6	31

Table 2. Markov chain transition matrix.

	[-2.0~-1.5]	[-1.5~-1.0]	[-1.0~-0.5]	[-0.5~0.0]	[0.0~0.5]	[0.5~1.0]	[1.0~1.5]	[1.5~2.0]
[-2.0~-1.5]	38.89%	38.89%	11.11%	5.56%	5.56%	0.00%	0.00%	0.00%
[-1.5~-1.0]	4.32%	70.00%	15.43%	0.62%	8.64%	0.00%	0.00%	0.00%
[-1.0~-0.5]	0.40%	5.86%	73.33%	12.12%	8.08%	0.20%	0.00%	0.00%
[-0.5~0.0]	0.00%	0.00%	6.09%	75.82%	16.68%	1.00%	0.10%	0.00%
[0.0~0.5]	0.12%	0.68%	2.67%	10.30%	77.48%	7.57%	1.18%	0.00%
[0.5~1.0]	0.00%	0.00%	0.16%	1.47%	19.93%	75.33%	3.10%	0.00%
[1.0~1.5]	0.00%	0.00%	0.00%	0.90%	7.21%	7.66%	29.23%	4.50%
[1.5~2.0]	0.00%	0.00%	0.00%	9.08%	4.55%	2.27%	13.64%	70.45%

The Markov Chain model suggests that the probability of states by many periods can be obtained by multiplying the probabilities transition matrix and the initial state vector $\pi (i + 1) = \pi (i) \cdot P$. Where $\pi (i)$ is the vector state given by equation 8 to the state i and P is the probability of matrix transition. When the Markovian process can go from one state to another, it reaches the state of the stationary condition and is described as an ergodic matrix. So to aid the stationary state in this paper was multiplied the transition matrix many times with the auxiliary computational and the Python language programming and obtained the stationary state with vector π = (0,43%, 3,89%, 11,89%, 24,1%, 38,63%, 14,67%, 5,32%, 1,06%).

MLPClassifier

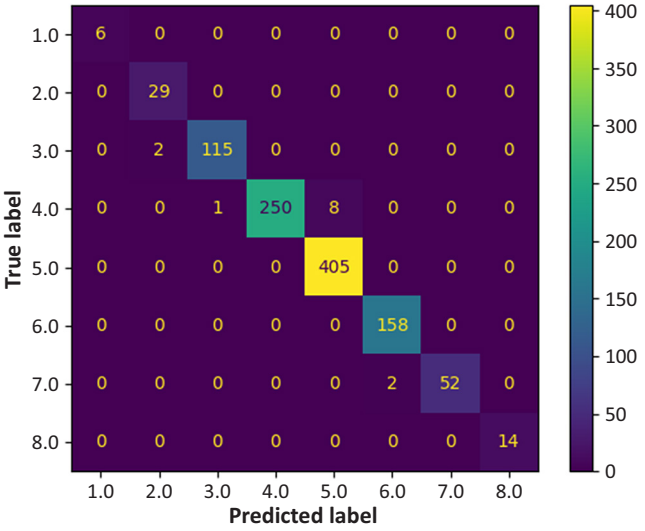
To perform the MLPCLassifier classification calculation, it is necessary to divide it into training and testing for this work. Ladi'c and Mandeki'c (2021) indicated the division using the language's library in the train_teste_split function at 75% and 25%, respectively, using the random_state = 20 parameters, as it was noticed that there was an improvement in not placing it. This library originates from open-source machine learning.

When applying training and testing with the MLPCLassifier model with just a few modifications to the standard:

- max_iter=500—Determines the number of epochs (how many times each data point will be used). By default, the maximum number is 200; however, the classifications were refined, and no improvements were made above this number.
- hidden_layer_sizes=150—The number of neurons in hidden layer 14. By default, the number is 100; however, the classifications were refined, and no improvements were made above this number.

This research used the confusion matrix, which, as explained in this paper, is a table that allows visualization of the classification algorithm's performance (Figure 2).

Figure 2. Confusion matrix MLPClassifier.



In this segment, its performance metrics were calculated according to Tables 3 and 4.

Analyzing Tables 3 and 4, classes 4 and 5 obtained the most errors in their classifications. Regarding false positives, class 5 obtained a value of 8, and class 4 obtained a 9. In any case, considering only these isolated numbers may lead to the understanding that there is little data, which is why the Classifications calculated from these results are interesting.

In this sense, analyzing, for example, the recall of class 2 with a result of 1.00 indicates that the model correctly classifies the true negatives. Therefore, these metrics depend on analyzing the type of financial investor and what information will be helpful to them.

The Roc curve corroborates all the other information, indicating that the closer the curve is to 1, the better the model's performance. Therefore, the lowest value found is in class 7. It is interesting to note that in this class, the model incorrectly classifies its true negatives, which corroborates the recall found, which is also the lowest among the others.

As this work continued, the ANN from the MLPClassifier library was inserted into the Markov Chains, and all the metrics performed in this session were compared to see if there were any improvements (Figure 3).

Table 3. Metrics from MLPClassifier model.

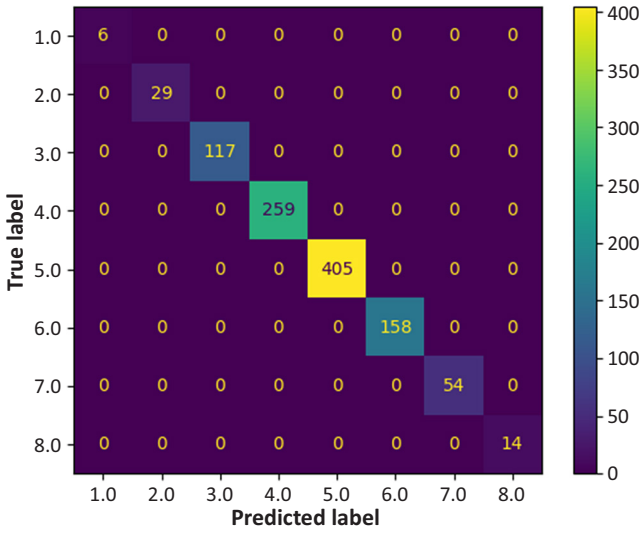
Classes	VP	FP	FN	VN
[–2.0, –1.5, 1]	6	6	6	1036
[– 1.5, –1.0, 2]	29	2	0	1011
[–1.0, –0.5, 3]	115	1	2	924
[–0.5, 0.0, 4]	250	0	9	783
[0.0, 0.5, 5]	405	8	0	629
[0.5, 1.0, 6]	158	2	0	882
[1.0, 1.5, 7]	52	0	2	988
[1.5, 2.0, 8]	14	0	0	1028

Table 4. Classification report from MLPClassifier model.

Classes	Precision	Recall	Accuracy	Specificity	F1	ROC
[–2.0, –1.5, 1]	1.0	1.0	1.0	1.0	1.0	1.0
[– 1.5, –1.0, 2]	1.0	1.0	1.0	1.0	1.0	1.0
[–1.0, –0.5, 3]	1.0	1.0	1.0	1.0	1.0	1.0
[–0.5, 0.0, 4]	1.0	1.0	1.0	1.0	1.0	1.0
[0.0, 0.5, 5]	1.0	1.0	1.0	1.0	1.0	1.0
[0.5, 1.0, 6]	1.0	1.0	1.0	1.0	1.0	1.0
[1.0, 1.5, 7]	1.0	1.0	1.0	1.0	1.0	1.0
[1.5, 2.0, 8]	1.0	1.0	1.0	1.0	1.0	1.0

The small classification errors that existed were eliminated with the insertion of Markov chains. Although small when analyzing Table 3, when calculating the existing classifications in Table 3, we check points for improvement. When inserting Markov Chains, there was a complete positive classification, thus eliminating the remnants of using only the MLPClassifier model.

Figure 3. Confusion Matrix MLPClassifier with Markov chain.



Conclusion

The creation of the web service connector to collect the movement of the BOVESPA index was effective since it can work in parallel with the construction of this work and others since the model created in Python collects the data directly from the database

and thus has no connection with this connector. The Markov Chain model to analyze the behavior of the BOVESPA index shows that it is entirely affected by stochastic factors. In this sense, the oscillation of the IBOVESPA occurred gradually, as seen in the transition matrix in the previous session.

This Markov Chain study is applied to predict the behavior of the IBOVESPA. The results are expressed in terms of the probability of a specific state in the future. The model does not provide absolute state results. The initial state vector and the transition matrices estimate the next steps in different states.

The MLPClassifier model proved satisfactory, given its classifications measured by performance metrics. The speed will depend on the number of hidden layers used. Including Markov Chains in the MLPClassifier model showed a refinement in the classification process of the model that already had a very high level of assertiveness.

References

1. Ampomah EK, Nyame G, Qin Z, Addo PC, Gyamfi EO, Gyan M. Stock market prediction with Gaussian naïve Bayes machine learning algorithm. Informatica 2021;45(2).
2. Bhusal MK. Application of Markov chain model in the stock market trend analysis of Nepal. International Journal of Scientific & Engineering Research 2017;8(10):1733-1745.
3. Bolson M, Borella L, Tomé F, Orlandin B, Corso L. Aplicação de cadeias de markov para análise de variação do dólar americano. XXXIX Encontro Nacional de Engenharia de Produção 2019;Abepro: 2019:1-13.
4. Brasil BAB Bolsa. Índice Bovespa, 2023. Retrieved 14.09.2023, from https://www.b3.com.br/pt_br/market-data-e-indices/indices/indices-amplos/ibovespa.htm
5. Cechin RB, Corso LL. High-order multivariate 46 markov chain applied in dow jones and ibovespa indexes. 47 Pesquisa Operacional 2019;39:205–223.
6. Daigneau R. Service design patterns: fundamental design solutions for soap/wsdl and restful web services. AddisonWesley 2012.
7. do Nascimento AM, Taissun AS, Lopes ÍMSF. Atalhos mentais na confluência entre a psicologia cognitiva e o serviço social: Alerta nas tomadas de decisões de assistentes sociais. Revista Científica do UniRios 2020:307-321.
8. Gorgens EB, Leite HG, Santos HN, Gleriani JM. Estimação do volume de árvores utilizando redes neurais artificiais. Revista Árvore 2009;33:1141–1147. doi: https://doi.org/10.1590/S0100-67622009000600016.
9. Ladic T, Mandekic A. Face mask classification using mlp classifier. Ri-STEM-2021 2021;10(68):77.
10. Madeeh OD, Abdullah HS. An efficient prediction model based on machine learning techniques for prediction of the stock market. In Journal of Physics: Conference Series 2021;1804:012008. doi: 10.1088/1742-6596/1804/ 65 1/012008
11. Mota FP. Modelo computacional para análise da motivação e envio de gatilhos em sistemas persuasivos: estudo de caso em processos de aprendizagem ubíqua. (Unpublished master's thesis) Universidade Federal do Rio Grande 2018.
12. Piazza MC. Técnicas de investimento para o mercado de ações. Novo Conceito 2008.
13. Prati RC, Batista G, Monard MC et al. Curvas ROC para avaliação de classificadores. Revista IEEE América Latina 2008;6(2):215–222.
14. Ramos JE Redes bayesianas aplicadas a modelagem de fraudes em cartão de crédito (Unpublished doctoral dissertation) 2015.
15. Santos HG, Nascimento CF, Izbicki R, Duarte YAO, Chiavegatto Filho P, Dias A. Machine learning para análises preditivas em saúde: exemplo de aplicação para predizer óbito em idosos de são paulo, brasil. Cadernos de Saúde Pública, 2019;35:e00050818.
16. Taha HA. Operations research: an introduction. 8th. ed. New Jersey: Pearson Prentice Hall 2007.
17. Wabang K, Nurhayati OD et al. Application of the naïve Bayes classifier algorithm to classify community complaints. Jurnal RESTI (Rekayasa Sistem dan Teknologi Informasi) 2022;6(5):872–876.
18. Zhang D, Zhang X. Study on forecasting the stock market trend based on stochastic analysis method. International Journal of Business and Management 2009;4(6):163–170.
19. Zhang T, You X. Improvement of the training and normalization method of artificial neural network in the prediction of indoor environment. Procedia Engineering 2015;121:1245–12.

Bioclimatic Variables Used in Predictive Modeling: A Literature Review for the Caatinga Biome

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Modeling species distribution is a predictive technique, and its search has increased due to the need to obtain rapid information for decision-making in the face of the loss and fragmentation of natural habitats, climate change, and anthropogenic actions. It is an important tool used for the conservation of species in different environments, and the Caatinga is among the environments that suffer from these threats, being a region with high temperatures, low precipitation, and high evapotranspiration, which makes it more vulnerable to climate change. This article aims to review the literature on the beginnings of predictive modeling, the area of knowledge that gave basis and existence to modeling methods, their development through computing, bioclimatic variables, and their applications in the Caatinga biome. The bibliographic survey was structured in publications found in the databases Scielo, Google Scholar, scientific journals, among other modalities, National Social Assistance Policy-PNAS, Rodriguesia, Ecological Modeling, Research and Development Society, Embrapa, Nature & Conservation, Ultrasound, Journal, Biodiversity Informatics, Nature, Intergovernmental Panel on Climate Change- IPCC, thesis, dissertation, Monograph, Nature, Ecology letters, Tutorial, Symposium, political politics research notebook, Research Brazilian Agriculture between the years 2003 to 2023. There were thirty-four scientific articles in twenty data sources. Computing was a great ally in the expansion of species distribution modeling processes that applied to the Caatinga, bringing significant gains and important results for this biome, being used to predict species occurrences in future scenarios, evaluate the influence of environmental variables, and potential distribution of endangered species.
Keyword: Predictive Modeling. Computing Environments. Contributions. Caatinga.

Species Distribution Modeling is a computational method that builds a representation of the conditions necessary for the survival of one or more species by combining occurrence data with environmental variables [1]. It is noteworthy that knowledge of geographic distribution has limitations, and this problem has contributed to the emergence of many studies.

According Barreto [2], the models of the potential distribution of species are tools that have emerged with the proposal to fill the gaps in knowledge about the geographic limits of the species of interest and assist in the formulation of new hypotheses about the mechanisms that determine the distribution of these species.

The interest in this type of modeling is due to the need for rapid and reasoned responses to the threats that the species has faced [1], seeking to define patterns of distribution of threatened, rare, and endangered species, assist in decision-making, predict impacts of climate change in future scenarios. The application of predictive modeling of species distribution as a tool for the study and conservation of biodiversity has been developed for decades with the integration of different areas of knowledge, the combination of various techniques, and the emergence of several methods and models to present more robust results.

This interest and need to describe, understand, and make predictions about the geographic and environmental distribution of species has been around for a long time [3], and knowing how the predictive process of modeling species distribution began is as important as its applications. In this sense, this article aims to present a literature review on the beginnings of predictive modeling, an area of knowledge that gave basis and existence to modeling methods, their development through computing, the use of bioclimatic variables, and their applications in the Caatinga biome.

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Materials and Methods

This review work included research in theses, dissertations, monographs, symposium, Scientific Initiation Congress, Intergovernmental Panel on Climate Change (IPCC), National Social Assistance Policy (PNAS), and several journals, Political Research, Brazilian Agricultural Research, Research, Society and Development, Ecological Modeling, Rodriguesia, Ecology Letters, Nature, Nature & Conservation, Computer Ultrasound of Biodiversity, totaling 34 works of scientific studies that brought the history, the beginnings of the work, and the interest in modeling, descriptions, conceptualizations, new techniques, and methods, from the simplest to the most advanced, and references to the modeling of the the bibliographic survey was obtained from the Scielo and Google Scholar databases, using bioclimatic variables to determine the distribution of species in the Caatinga.

The review used the terms "Predictive modeling of species distribution," "Applications of predictive modeling of species distribution," "Current challenges of predictive modeling," and "bioclimatic variables." The data were refined to include modeling studies of species distribution in the Caatinga biome.

The inclusion and exclusion criteria are indicated below.

Inclusion criteria: (1) publication of articles between the years 2003 and 2023; (2) selection of works with a history of pioneering contributions on the topic addressed, development in the computational field, concept of ecological niche, areas of knowledge bases, and that also contemplated technological advances; (3) approach to bioclimatic variables important for the Caatinga biome.

Exclusion Criteria: (1) publishing articles in a language other than Portuguese and English (i.e., only articles in English and Portuguese were accepted).

Results and Discussion

A little history of the species distribution modeling technique

Soberon and Peterson [4] agree that a species distribution results from its dispersal capacity and tolerance to the prevailing abiotic and biotic conditions. Abiotic factors (such as climate) provide the necessary conditions for a species' establishment, survival, and reproduction. This Understanding allows, through predictive models, the estimation of the distribution of a species based on its points of occurrence and the environmental information of the places already occupied by it.

Paglia and colleagues [5] showed modeling techniques from the simplest to the most complex, stating that species distribution models are based mainly on environmental conditions and are generated from a set of rules ranging from more straightforward mathematical solutions (Euclidean Distance, BIOCLIM), through statistical adjustments (Generalized Linear Models - GLM, Generalized Additive Models - GAM) to algorithms derived from artificial intelligence and search (Maxent, GARP, Neural Networks); The algorithms calculate the environmental similarity between the places of occurrence known to the species and other regions still unknown, and the places of more remarkable similarity will be considered as areas of high probability of occurrence.

Brito [6] stated that, although the application of predictive modeling has increased since the first studies in the 1960s, the interest in studying the influence of variables environmental impact on species distributions was mainly concentrated in the 1970s, 1980s, and 1990s, with the pioneering work of Austin in 1971, Nix and colleagues in 1977, Ferrier's simulations in 1984, the books by Verner and colleagues in 1986, Margules and Austin in 1991, the revisions by Franklin in 1995, and Austin in 1998 are references in the field of studies on modeling the distribution of species applied to conservation projects. The development of the models results from integrating biological

knowledge with various technologies, uniting areas such as ecology and computing to allow researchers to study the real and potential distribution of species.

For Guisan and Thuiller [7], these contributions were important in promoting a new approach, resulting in an increasing number of species distribution models proposed in the literature. In recent years, predictive modeling of species distribution has become an increasingly important tool for addressing various issues in ecology, biogeography, evolution, and, more recently, conservation biology and climate change. Species distribution models are based on the ecological niche theory. They can be defined as models that relate data on the occurrence or abundance of species in sites (distribution data) to information on the environmental characteristics of these sites (physical and chemical parameters) to identify areas with potential habitats for the target species [8].

Melo and colleagues [9] stated that Grinnell was the first to conceptualize and describe the niche of several species in 1917, referring to a spatial unit represented by the areas with climatic and habitat characteristics necessary for the occurrence of a species. Later, in 1927, Elton presented a niche definition more related to the functional role of the species in the community, emphasizing biotic factors as interactions between organisms. Currently, the most used is the one provided by Hutchinson (1957), who defined the niche as a hyperdimensional n-volume, that is, a set of multidimensional forms in space with conditions and resources that allow the existence of an organism.

Pinaya modeling of species distribution can exclusively use abiotic data [10]. Soberón and Nakamura [11] point out that, with the development of new modeling techniques, it has become possible to include other data sets, such as biotic aspects, which correspond to the interactions between species and their mutualistic partners, predators, and competitors occupying the same environment, as well as the spatial movements of individuals and populations that determine their occupation and dispersal dynamics.

Correlation of climatic variables in the modeling of species distribution in the Caatinga Biome

Dalapicolla [12] states that the most used variables for modeling are those of WorldClim, a total of 19 resulting from only two pieces of information: precipitation and temperature. Therefore, there is a lot of correlation between the 19 variables (one variable is influenced by another), and this is one of the main criticisms of its use. One solution pointed out by the author is to choose the variables that are less correlated with each other (variables that are not influenced by other independent variables).

Many authors seek to reduce the correlation or multicollinearity of these variables in their studies with various techniques and statistical tests.

According to Son and colleagues [13], Pearson's correlation test is a statistical measure used to quantify the linear relationship between two continuous variables that vary from -1 to 1. Thus, they recommend the use of weakly correlated variables and exclude those that present a strong correlation.

Another technique used is the Pocket Knife Test, which measures and evaluates the importance of the variables for the model, that is, which variable has the most significant influence on the distribution of the species and which will define the niche; in this way, the predictor variables can be classified according to their relative contribution to the elaboration of the model [14].

Pearson and colleagues [15] state that the Jackknife test is an approach that excludes a variable each time the model is executed. This allows us to assess which variable is most important to predict species distribution. Variables with gains close to 0 indicate poor contribution; close to 1 indicate good contribution, presenting highly correlated information on species occurrences [16].

Rodrigues [17] states that it is a sampling technique, as it uses subsamples built from the original sample of data to calculate the estimates.

Already, Vacari [18] shows it as a pre-analysis method that adjusts the models by eliminating repeated environmental or climatic variables at each run. This allows us to evaluate which variable is more important to predict species distribution. Other techniques are used, such as Principal Component Analysis (PCA), a method to choose the variables that most contribute to the species' distribution and are more independent [12].

Variance Inflation Factor (VIF) is a measure of statistics that indicates the degree of multicollinearity. A value equal to 1 indicates no multicollinearity; the higher the VIF value, the greater the presence of multicollinearity.

Several authors, with studies referring to the Caatinga biome, used strategies to eliminate correlated variables through statistical analysis or correlation tests when using bioclimatic variables.

Of the thirty articles researched, 20% of the authors applied Principal Component Analysis (PCA); 20% used all 19 bioclimatic variables; 20% used other correlation analyses (not identified); 20% Pearson correlation; 7% made use of specialized literature; 7% performed the Variance Inflation Factor; and another Jakknife test of 7% (Figure 1).

Many authors, with studies about to the Caatinga Biome, also used the bioclimatic variables of the Worldclim Project and strategies to eliminate the correlated variables (Table 1).

In the area of occurrence of the Caatinga Biome, where the semi-arid climate predominates, low rainfall and high temperatures are observed as predictive climatic variables.

Climatic seasonality, especially precipitation, influences the annual vegetation growth cycle (phenological cycle), directly correlating with annual climatic seasonality [19].

Rainfall seasonality quantifies the variation in precipitation during the year based on the standard deviation of the monthly averages. Precipitation is one of this biome's most important climatic variables, which influences the spatial and temporal distribution of vegetation, which in turn influences the regional climate from the feedback mechanism of energy flows (synergy) [19].

Native vegetation has evolutionary adaptations for survival in the face of seasonality and irregularities of rainfall, namely, leaf loss during the season, the annual life cycle of herbaceous plants, and metabolism that allows for plant water conservation. Gas exchange occurs only during the night through the opening of the stomata during this period [20].

Several regions of the Caatinga have rainfall volumes below 400mm in the rainy season; values

Figure 1. Strategies applied for eliminating redundant variables in species distribution modeling.

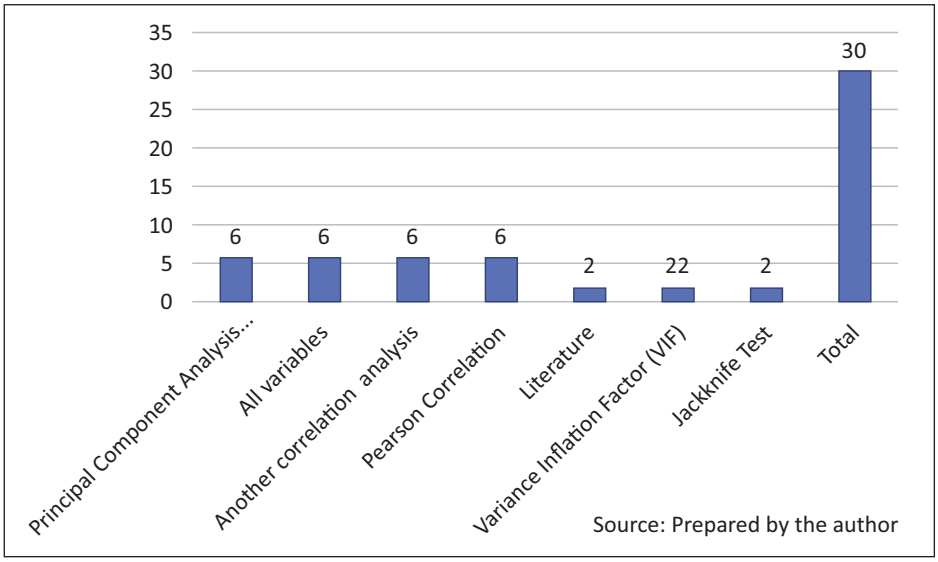

Table 1. Compilation of thirty studies related to the modeling of species distribution in the Caatinga biome.

Authors	Year	BIO 1	BIO 2	BIO 3	BIO 4	BIO 5	BIO 6	BIO 7	BIO 8	BIO 9	BIO 10	BIO 11	BIO 12	BIO 13	BIO 14	BIO 15	BIO 16	BIO 17	BIO 18	BIO 19
Almeida; Fabricante	2021	x	x					x					x		x	x			x	x
Andrade; Guedes	2023				x			x	x					x	x				x	x
Anjos, Miranda Ferreira	2019	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Batalha Filho; Waldschimidt; Alves	2011	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chagas	2018		x	x		x	x	x	x				x	x	x				x	x
Carvalho	2021	x	x	x	x								x		x					x
Cavalcante	2016			x		x					x		x			x	x			x
Vacalcante and colleagues	2019											x	x			x				
Cavalcante; Fernandes; Silva	2020													x		x	x			x
Costa	2021							x			x		x						x	x
Gomes-Silva; Leal	2021	x	x	x	x								x	x	x	x			x	x
Junior	2015	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lima	2019	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Matos	2022		x	x		x	x						x		x	x				
Mendonça	2022	x	x			x	x										x	x	x	x
Motta and colleagues	2017	x				x		x					x				x	x		
Nascimento	2019							x		x		x							x	x
Nogueira	2019	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Oliveira	2017	x	x	x									x		x					
Santos	2022				x			x					x		x	x	x	x	x	x
Santos and colleagues	2023	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Silva	2016	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Silva, Montes, Silva	2017	x			x		x	x				x								
Silva	2017	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Silva	2020		x	x					x	x					x	x			x	x
Silva	2022	x													x					
Silva, Costa, Teixeira	2022	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Sobrinho and colleagues	2019				x	x				x			x				x		x	x
Teixeira	2022	x											x				x	x		
Xavier	2020	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Bio 1 (Average annual temperature); Bio 2 (Diurnal temperature variation); Bio 3 (Isothermality); Bio 4 (Temperature seasonality); Bio 5 (Maximum temperature of the hottest month); Bio 6 (Minimum temperature of the coldest month); Bio 7 (Annual temperature range); Bio 8 (Average temperature of the wettest quarter); Bio 9 (Average temperature of the driest quarter); Bio 10 (Average temperature of the hottest quarter); Bio 11 (Average temperature of the coldest quarter); Bio 12 (Annual rainfall); Bio 13 (Rainfall of the wettest month); Bio 14 (Precipitation of the driest month); Bio 15 (Rainfall seasonality); Bio 16 (Rainfall of the wettest quarter); Bio 17 (Precipitation of the driest quarter); Bio 18 (Precipitation of the warmest quarter); Bio 19 (Coolest Quarter Precipitation).Source: Worldclim Project.

below this limit usually result in significant water deficits [21]. Other temperature-related variables are also widely used in modeling studies.

Dantas [22] highliths about high average annual temperatures with a long period of drought characterize the biome. Recent studies state that when the temperature is similar to or slightly higher than the local average ambient temperature, it affects the performance of plant photosynthesis and carbon capture in the Cerrado [23] - the same should occur in the Caatinga.

Several studies describe different responses of Caatinga seeds subjected to different temperatures, with a limit between tolerant and less tolerant seeds, which do not germinate, exposed to these conditions [22].

Conclusion

Species distribution modeling is a tool for implementing forest restoration projects, developing conservation strategies, protecting endangered or threatened species, identifying priority areas for conservation, conducting biogeographic analysis and biodiversity studies, analyzing the influence of bioclimatic variables on species, and predicting the impacts of climate change.

In the Caatinga Biome, the most observed bioclimatic variable was the precipitation of the coldest quarter - Bio 19 (25). The rainfall of the coldest quarter affects the distribution and density of vegetation in the Caatinga. During the coldest quarter, the amount of rainfall can determine the survival of certain plant species adapted to low humidity conditions, influence the germination, growth, and reproduction of these plants, contribute to the feeding of aquifers, and increase the availability of water surfaces, which are crucial for the local fauna and flora.

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References

1. Giannini TC, Siqueira MF, Acosta AL, Barreto FC, Saraiva AM, Alves-dos Santos I. Current challenges of predictive modeling of species distribution. Rodriguésia 2012;63:733–749. DOI: doi.org/10.1590/ 75; S2175-78602012000300017 76.
2. Barreto FCC. Modeling the potential distribution of species as a tool for conservation: selection and evaluation of algorithms and application with heliconius nattereri felder, 1865 (nymphalidae: Heliconiinae). Thesis, Federal University of Viçosa, 2008.
3. Amaro G, Fidelis E, da Silva R, Marchioro C. Effects of the extension of the study area on the potential distribution of species: A study with maxent models for raoiella indica hirst (acari: Tenuipalpidae) in Brazil. Technical Communiqué Boa Vista, RR Embrapa Roraima, 2022.
4. Soberon J, Peterson AT. Interpretation of models of fundamental ecological niches and areas of distribution of species, Biodiversity Informatics 2005.
5. Paglia A, Rezende D, Koch I, Kortz AR, Donatti C. Species distribution models in biodiversity conservation strategies and ecosystem-based adaptation to climate change. Nature and Conservation 2012;10(2):231–234.
6. Brito GRD. Application of predictive modeling of species distribution as a tool for the study of biodiversity. Assis: Universidade Estadual Paulista 2018:121. Dissertation Characterization and application of biological diversity.
7. Guisan A, Thuiller W. Predicting species distribution: offering more than simple habitat models. Letters of Ecology 2005;8(9):993–1009.
8. Oliveira JPC. Indicating paths: conceptual and methodological proposals in the modeling of environmental adequacy. Dissertation; University of the State of Mato Grosso, Nova Xavantina-MT, 2019.
9. Melo RC et al. Ecological niche modeling of species of the rhinella granulosa group (amphibians, anura, bufonidae): defining the limits of the current distribution. Captain Well: Federal Rural University of the Amazon, 66 p. 83 Monographs, Ecology 2019.
10. Pinaya JLD. Pre-analysis process for the modeling of species distribution, Dissertations, Digital Systems). Polytechnic School of the University of São Paulo, 2012, 2013, 112 p.
11. Soberón J, Nakamura M. Niches and distribution areas: concepts, methods and assumptions. Annals of the National Academy of Sciences 2009;106(Supplement 2):19644–19650.

12. Dalapicolla J. Tutorial of species distribution models: theoretical guide. Laboratory of Mastozoology and Biogeography, Federal University of Espírito Santo, Vitória. 2016. Recovered, 6, 27. Retrieved in http://blog.ufes.br/lamab/tutoriais
13. Son DBF,Rocha, EC Junior, Silva JAP, Ranulfo N, Barbosa JA, Silva, Batista M. Unraveling the mysteries of Pearson's correlation coefficient: The return, Leviathan| Cadernos de Pesquisa Política (São Paulo) 2014;(8):66–95.
14. Phillips SJ, Dudík M. Modeling of species distributions with maxent: new extensions and a comprehensive evaluation, Ultrasound 2008;31(2):161–175.
15. Pearson RG, Raxworthy CJ, Nakamura M, Townsend P. A Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar, Journal of Biogeography 2007;34(1):102–117. DOI: 10.1111/j.1365-2699.2006.01594.x.
16. Coelho GLN, Carvalho LMT, Gomide LR. Predictive modeling of the distribution of pioneer species in the state of Minas Gerais. Pesquisa Agropecuária Brasileira. 2016;51(3):207–214. DOI: 10.1590/S0100-204X2016000300002
17. Rodrigues FA. A reference method for predictive performance analysis of species distribution modeling algorithms. (Unpublished doctoral thesis). University of São Paulo, 2012.
18. Vacari TJ. Data pre-analysis methods for species distribution modeling, Monograph, State University of Western Paraná. Rattlesnake 2014.
19. Becerra JAB, Carvalho S, Ometto JJPHB. Relação das temporadaidades da precipitação e da vegetação no bioma caatinga: abordagem multitemporala, Annals XVII Symposium Brasileiro de Sensoriamento Remoto-SBSR, João Pessoa-PB, Brasil 2015;25:6668–6674.
20. Costa RC, Araújo FS. Density, germination and flora of the seed bank in the soil, at the end of the dry season, in a caatinga area, Quixadá, CE. Acta Botânica Basilica 2003;17(2):259-264.
21. Cuadra SV, Vitoria DC, de Oliveira AF, Reboita M, Monteiro JA. Precipitation in the rainy quarter in the caatinga biome region and the relationship with sea surface temperature. In: Congresso Brasileiro de Agrometeorologia. Catalão. Annals Catalan: CBAGRO: UFGO 2019;(9).
22. Dantas B. Germination of caatinga seeds in future climate. In: Symposium of the Caatinga biome. Annals. Petrolina: Embrapa Semiárido 2019;2:126–133.
23. Oliveira TCS, Garcia MN, Oliveira E, Domingues TF. Extending the 'one-point method' for estimates of leaf photosynthetic capacity to a wider temperature range. Journal of Experimental Botany 2023;74(3): 684–687. https://doi.org/10.1093/jxb/erac466.

Temporal Change in Land Use and Cover in the Municipality of Entre Rios, Bahia (Brazil)

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The objective of this article was to analyze changes in land use and land cover in Entre Rios, Bahia (Brazil), between 2002 and 2022, using data from MapBiomas to contribute to decision-making of environmental interest. The method consisted of a bibliographic review, geoprocessing, and remote sensing techniques using QGIS software and MapBiomas Collection 8, allowing a 20-year temporal analysis. The results of land use and occupation resulted in 5 classes: Group 1 - Forest (variation of 8.7%); Group 2 - Non-forest natural formation (variation of -3.2%); Group 3 - Agriculture (variation of -3.5%); Group 4 - Non-vegetated area (variation of 28.3%) and Group 5 - Water bodies (variation of -5.8%). It is concluded that, from 2002 to 2023, there were relevant changes in land use and occupation for Entre Rios- BA, emphasizing the increase in forestry, agriculture, urbanized areas, mining, and the reduction of water bodies.
Keywords: Land Use. MapBiomas. Geoprocessing. Sustainability.

Anthropogenic changes to the Earth's surface have caused significant transformations in land cover, which have profound implications for ecosystem structure and functioning. Thus, detecting these land use transformations constitutes a significant research challenge [1].

The Brazilian Atlantic Forest is considered one of the great biodiversity hubs on the planet. It has an estimated 20,000 plant species and a high degree of endemic species [2]. In view of this, the Brazilian government established the Pact for the Restoration of the Atlantic Forest in 2009 in an attempt to protect and minimize the anthropogenic impacts on this biome. This document describes some initiatives and actions to assist in efforts to conserve and restore the biome by 2050.

However, according to data from the Annual Report of the SOS Mata Atlântica Foundation and INPE (2022), from January to October 2022, accumulated deforestation was 48,660 hectares [3]. Bahia had the largest number of degraded areas, 15,814 hectares. Also, according to the report, agriculture was the main driver of deforestation, followed by urban expansion.

Given this scenario of increasing anthropogenic changes in the landscape, research considering land use and coverage dynamics can contribute to decision-making regarding urban planning and sustainable development [4].

According to the United Nations (UN, 2023) [5], the Sustainable Development Goals (SDGs) are a global call to action from all spheres of society so that by 2030, all people can live with a higher quality of life in all aspects. Goal 11 highlights "*making cities and human settlements inclusive, safe, resilient, and sustainable*" (UN, 2023).

In this sense, the objective of this article was to analyze the changes in land use and coverage in the municipality of Entre Rios (BA) between 2002 and 2022, using data made available by the Annual Mapping Project of Land Use and Coverage in Brazil - MapBiomas [6].

Materials and Methods

Geospatial data were acquired through the MapBiomas Brasil platform, which processes images from the Landsat satellite provided by Google Earth Engine and provides a historical series of annual maps of land use and land cover in Brazil from 1985 to the present. The initiative uses empirical and statistical methods (e.g., random forest

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and machine learning) to count the recent history of pixels and create the aforementioned maps [1].

In this article, data from collection 8, published in August 2023 and featuring 29 mapped classes, were used to obtain land use and coverage data. This collection reviews data from annual land use and cover maps in Brazil in a historical series from 1985 to 2022 on a scale of 30 m x 30 m [6].

MapBiomas maps the following land use and cover classes: Forest (Forest Formation, Savannah Formation, Mangrove, Wooded Restinga), Non-Forest Natural Formation (Flooded Field and Marshy Area, Grassland Formation, Apicum, Rocky Outcrop, Herbaceous Restinga, Other Non-Forest Formations). Agriculture (Pasture, Agriculture, Forestry, Mosaic of Uses, Beach, Dune and Sand). Non-Vegeted Areas (Urbanized Areas, Mining, Other Non-Vegeted Areas). Water Bodies (River, Lake and Ocean, Aquaculture) [6].

The images of the land use and land cover maps were downloaded in Geotiff format from the Google Earth Engine website (through the link directed by the MapBiomas website), where data from 2002 and 2022 were selected for the municipality of Entre Rios-BA.

As the files were obtained in gray scales, the data was reclassified using QGIS software version 3.10.13 to extract information on land use and land cover classes.

Study Area

The municipality of Entre Rios is located in the North Coast Economic Region of Bahia, approximately 165 km from the capital of Bahia, Salvador. According to data from IBGE (2022) [7], Entre Rios has a population of 38,098 inhabitants and a population density of 32.08 inhabitants /km². The climate of the municipality is Af, that is, humid tropical, according to the Köppen -Geiger classification and its main characteristics are: average temperatures above 18°C; the hottest months are from December to March with maximums of 29.9°C; coldest months are from July to October with minimums of 17.4°C. The average annual precipitation in the municipality is 1339 mm, with the months between March and August having the highest precipitation [8].

In addition, it has a territorial area of 1,187.766 km² [7] that extends from the coast towards the interior of the State. Entre Rios is located in the Costa dos Coqueiros Tourist Zone, with three beaches in its territory: Porto de Sauípe, Massarandupió, and Subaúma [8]. Due to the transformations in the territorial and economic dynamics initiated with the construction of the second section of the BA-099 (Green Line) on the North Coast of Bahia, and to preserve the environmental heritage contained in this region through the proper organization of territorial occupation and the development of activities aimed at tourism consciously and sustainably, the Conservation Unit (UC) of the Sustainable Use Group, Environmental Protection Area (APA) of the North Coast of Bahia was created through decree 1,046 of March 17, 1992 [9].

The APA covers part of the municipalities of "*Jandaíra, Conde, Esplanade, Entre Rios and Mata de São João, whose territorial area is comprised, to the North, by the border between the States of Bahia and Sergipe*" [9]. Approximately 16% of the UC area is contained in the municipality of Entre Rios - BA [10].

The predominant biome in the municipality of Entre Rios is the Atlantic Forest [7]. Regarding the water resources management unit, Entre Rios is located in the Recôncavo Norte and Inhambupe Hydrographic Basin [8].

Results

According to Cruz and colleagues (2021) [11], orbital image data are important sources for mapping land use and land cover, as they contribute to the analysis of natural and anthropogenic elements.

In their study of the spatiotemporal analysis of land use and coverage in Benevides—PA, Macedo, and Farias (2022) [12] reported that remote sensing proved an effective tool for analyzing and monitoring land use.

Thus, the dynamics of land use and coverage were carried out for the municipality of Entre Rios-BA in 2002 and 2022, defining a 20-year time series.

MapBiomas Database

We observed that the level 1 classes of predominant use in the municipality of Entre Rios - BA were: Agriculture with 71.40% (highlighting Pasture, Silviculture); Forest with 25.26% (highlighting the subclass Forest Formation, Savannah Formation, Arboreal Restinga); Non-vegetated area with 1.26% (highlighting Beach, Dune and Sand, Urbanized Area); Non-Forest Natural Formation with 1.91% (Flooded Field and Marshy Area); and Water Body with 0.16% (Figure 1).

In Figure 2, the characteristics of land use for the year 2022 show significant changes over these two decades. Figure 3 highlights the changes for level 1 classes. Thus, it was noted that Agriculture, still in the lead, reduced its percentage to 68.92%; forestry increased to 27.45%; non-vegetated area increased to 1.62%; Non-forest Natural Formation reduced to 1.85%, and Water Body reduced to 0.15%.

Figure 4 allows a more detailed analysis regarding the percentage changes that occurred over the period evaluated (2002-2022) for the more specific level classes.

Thus, although the percentage of Agriculture and Livestock decreased by 2,941 hectares (-3.5%), mainly due to the decrease in pastures (-28.9%), there was an increase of 63.4% in Forestry, with a notable 11,456 hectares more, as well as an increase in agriculture and crops, which together total 45 hectares more. Other relevant data that need to be highlighted are the 62.7% growth in urbanization, which represents an additional 314 hectares; the expansion of mining, which was not identified in the 2002 mapping but was shown on the current map at 26 hectares; and the 5.8% reduction in water bodies, corresponding to 11 hectares, which may indicate environmental impacts, such as silting of rivers and lakes.

According to Souza (2009) [13], the municipality of Entre Rios's hydrographic basins, composed of the main rivers Inhambupe, Subaúma, and Sauípe, are heavily degraded by deforestation and pollution caused by livestock farming, agriculture (especially forestry), and mining activities, in addition to recent real estate and tourism interventions on the coastal strip.

Corroborating the results found, Silva (2022) [14] analyzed the influence of the evolution of land use and occupation on evapotranspiration in hydrographic basins, where it was possible to observe that in the hydrographic basin where the degree of change in land use and occupation was significant, the change in evapotranspiration rates increased, which is an indication of more significant pressure on the basin's water availability.

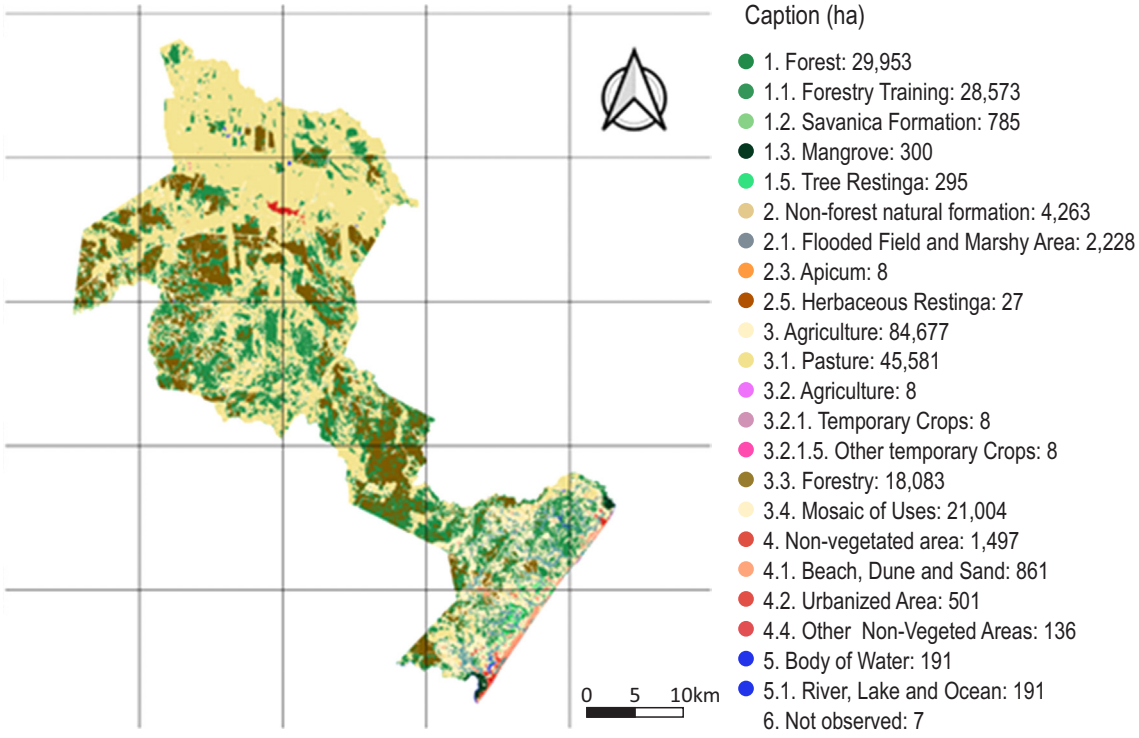
In addition, there were also reductions in Restinga Arbórea (-12.9%), Apicum (-50%), and Campo Alagado (-3.1%). Restingas have suffered over time from degradation and environmental losses in coastal regions due to the large and growing real estate and tourism development, as their environmental scenic beauty is an excellent attraction for these ventures [15].

The results also showed the relevance of geoprocessing, remote sensing, and technologies in general, especially the MapBiomas platform, as instruments to contribute to the temporal visualization of changes in land use and coverage, enabling studies in several areas, but especially in the environmental area [12].

Conclusion

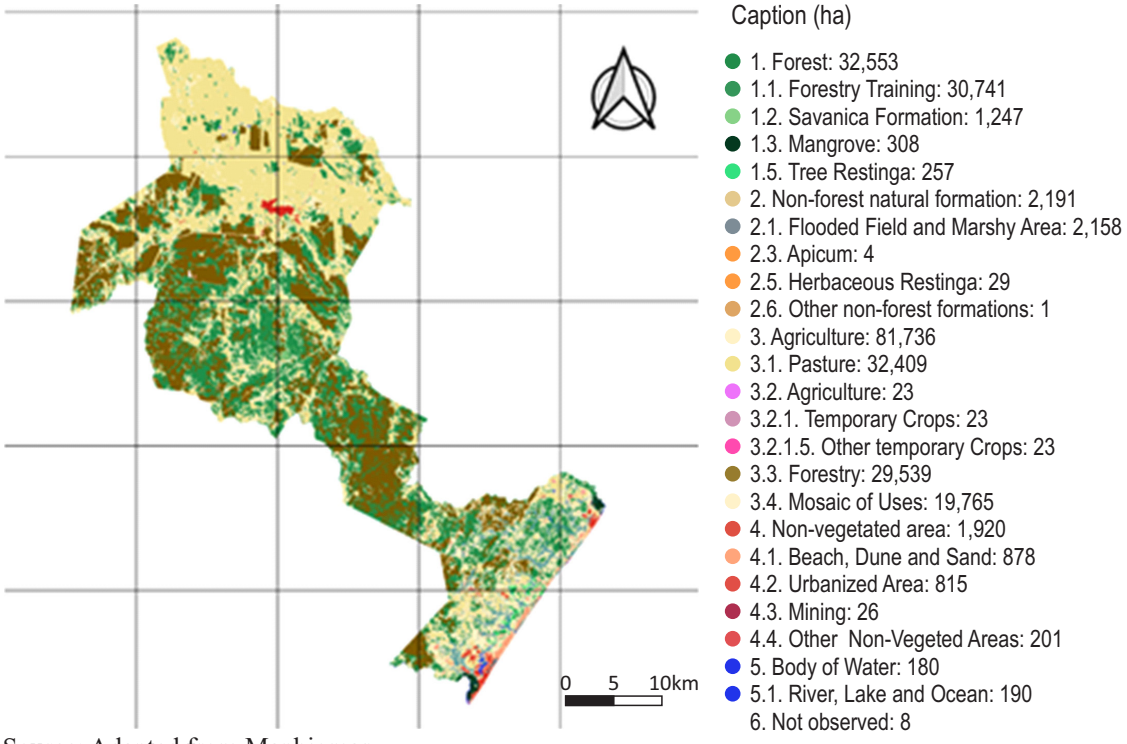
Therefore, from the mapping of land use and occupation, carried out through data made available by the MapBiomas platform and the use of the Qgis software, it was possible to perceive the changes that occurred in land use and occupation in the municipality of Entre Rios - Bahia (Brazil), in the period analyzed (2002-2022), with emphasis on the increase in forestry, agriculture, urbanized area, mining activity and the reduction of water bodies. Thus, the importance of monitoring natural resources is highlighted in the face of the challenges of reconciling economic, social, and environmental development.

Figure 1. Land use and land cover map of Entre Rios, Bahia, Brazil, 2002.



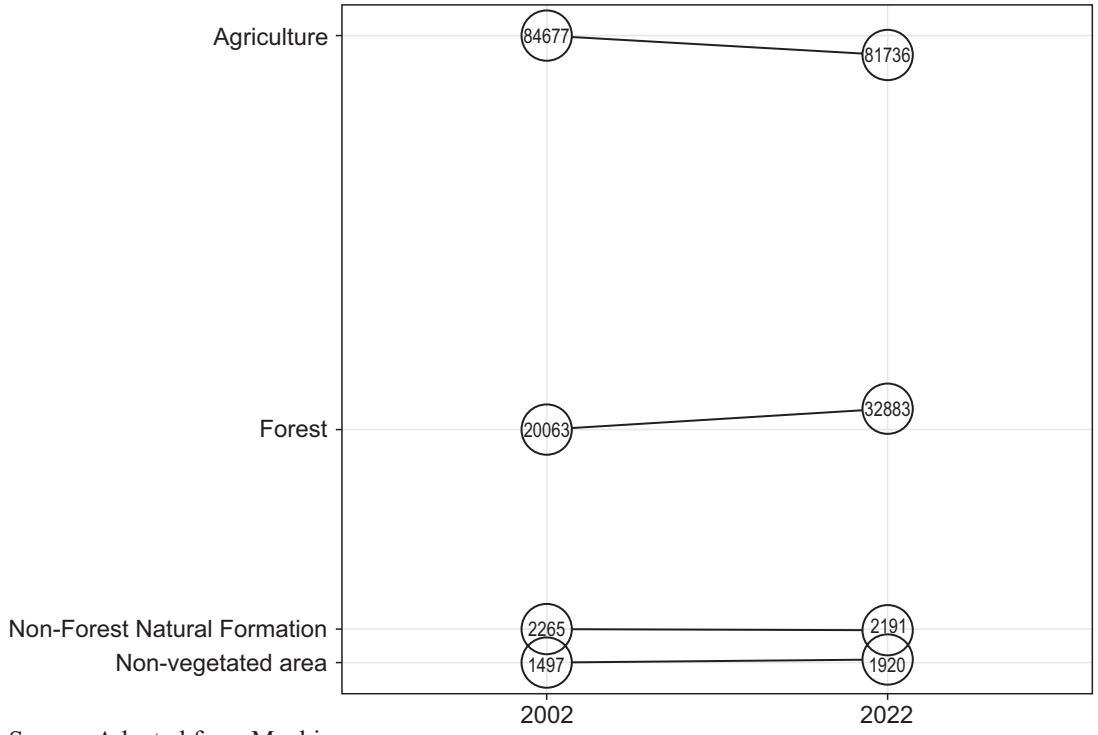
Source: Adapted from Mapbiomas.

Figure 2. Land use and land cover map of Entre Rios, Bahia, Brazil in 2022.



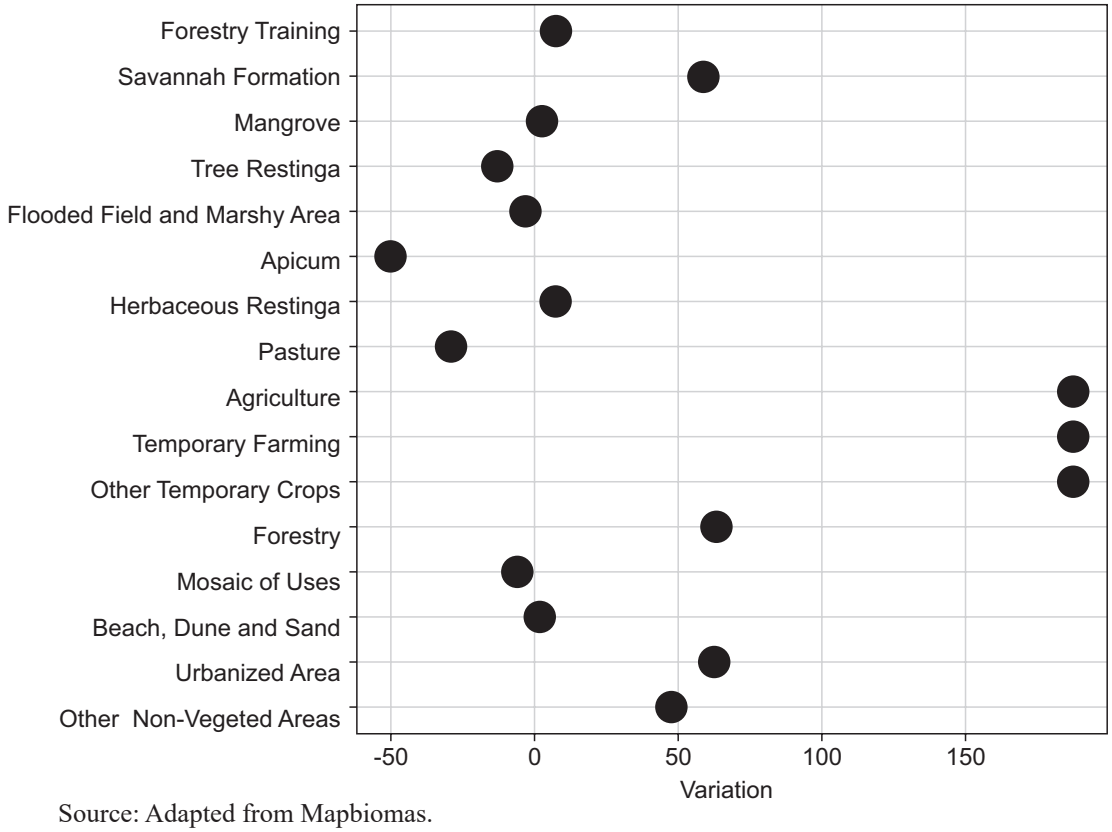
Source: Adapted from Mapbiomas.

Figure 3. Changes in level 1 classes between 2002 and 2022 in Entre Rios, Bahia, Brazil.



Source: Adapted from Mapbiomas.

Figure 4. Changes in specific classes between 2002 and 2022 in the municipality of Entre Rios -BA.



Source: Adapted from Mapbiomas.

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References

1. Rosa M, Shimbo JZ, Azevedo T. MapBiomas - Mapping the transformations of the Brazilian territory in the last three decades. VII Symposium on Ecological Restoration. Institute of Botany, São Paulo, 2019.
2. Siminski A, Zambiazi DC, Santos KL, Fantini AC. Dynamics of natural regeneration: implications for landscape restoration in the Atlantic Forest, Brazil. Frontiers in Forests and Global Change 2021;4:1-16. Available at: < http://dx.doi.org/10.3389/ffgc.2021.576908 >.
3. SOS Mata Atlântica Foundation. Annual Report 2022. Available at: <https://www.sosma.org.br/sobre/ relatorios -e- balancos />.
4. Conceição JMC, Sousa RS, Carvalho MFM. Pact for the restoration of the Atlantic Forest: reference for forest restoration concepts and actions – São Paulo: LERF/ ESALQ: Instituto BioAtlântica, 2009. Available at: < https://pactomataatlantica.org.br/glossario/ >.
5. United Nations in Brazil. The sustainable development goals in Brazil. Available at https://brasil.un.org/pt-br/ sdgs/11 2024.
6. MapBiomas Brasil. Available at: https://brasil. mapbiomas.org/downloads/ . Accessed on: 10/09/2023.
7. IBGE. Panorama Entre Rios. 2022. Available at: < https:// cidades.ibge.gov.br/brasil/ba/entre-rios/panorama.
8. City Hall. Technical study for the creation of a municipal conservation unit in the Massarandupió Dunes, coast of the municipality of Entre Rios, State of Bahia. Entre Rios, Bahia, 2019.
9. Bahia. Creates the environmental protection area of the north coast of the state of Bahia and contains other provisions. Decree No. 1,046 of March 17, 1992.
11. Cruz CLZ, Cruz CBM. Assessment of the thematic accuracy of land cover and use represented through Mapbiomas in Rio de Janeiro. GEOgraphia 2021;23(50).
12. Macedo AMS, Farias MGG. Spatio-temporal analysis of land use and cover in Benevides, PA. Advisor: Alan Nunes Araújo. 19 p. 2022. Course Conclusion Work - Article - Faculty of Geography, Institute of Philosophy and Human Sciences, Federal University of Pará, Belém, 2022. Available at: https://bdm.ufpa.br:8443/jspui/ handle/prefix/5902. Accessed on: 10/09/2023.
13. Souza MLC. Interests in the production of space on the North Coast of Bahia: Massarandupió and its surroundings. 2009. 160f. Dissertation (Graduate Program in Geography, Institute of Geosciences). Federal University of Bahia (UFBA), Salvador Bahia. Conservation Units in Brazil. Available at: < https:// uc.socioambiental.org/pt-br/arp/2075 >>. Accessed on 10/01/2023.
14. Silva BHL. Influence of the evolution of land use and occupation on evapotranspiration in river basins. Massarandupió restinga vegetation, Municipality of Entre Rios, BA, Brazil. Journal of Integrated Coastal Management 2022;12(2):239-251.
15. Menezes Silva S. Diagnóstico das restingas no Brasil. Universidade Federal do Paraná – Depto. de Botânica – Setor de Ciências Biológicas 2011:1-30.

Bibliometric Analysis of Ornithophilous Species of Bromeliaceae in the Atlantic Forest

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This bibliometric analysis quantified the articles published on ornithophilous species of Bromeliaceae in the Atlantic Forest biome, demonstrating the scarcity of studies and the need for work to reduce the knowledge of this plant-animal relationship in the state of Bahia (Brazil). The bibliometric analysis of ornithophilous species of Bromeliaceae in the Atlantic Forest in the time cut from 1996 to 2024, with the first filter of the expressions "ornithophilia, Bromeliaceae, Atlantic Forest", selected 251 articles from 819 authors in 96 journals from 23 countries, with Brazil highlighted by 111 articles (44%). The second filter with the term "pollination" generated 40 (15.9%) articles listed by national institutions. In Brazil, most of the surveys on ornithological pollination in Bromeliaceae were carried out in the Atlantic Forest (96%). The third filter for the final selection of articles published by authors of Brazilian institutions grouped only 8 (3%) articles from the initial total. The method is effective and limited, excluding articles published in the middle of the dissemination books in modest or low-cost journals. A non-factor of impact phase can also devalue research of regional or local relevance, leading to a distorted vision of the relevance of endemism.

Keywords: R Studio. Hummingbirds. Pollination. Citations. Brazilian Authors.

The Atlantic Forest is a biome rich in biodiversity of fauna and flora. The great diversity of the biome makes it possible for thousands of species that inhabit this environment to survive [1]. Ecological relationships maintain the trophic network and thus ensure the community's survival, development, and evolution. Ornithophilous plant species in the Atlantic Forest biome are abundant and sustain pollination syndromes in various plants and animals from different vegetation strata. The varied morphologies usually indicate the type of pollinator [2]. In this biome, Bromeliaceae predominates in the composition of families with ornithophilous species [3].

Among pollinators, insects and birds are important, with adaptations to plant species. About 10 to 15% of the angiosperms in a forest are ornithophilous plants with specific bird pollination characteristics, especially hummingbirds that use floral nectar as a food resource. Hummingbirds (Trochilidae family) make up the most significant pollinators among the vertebrates of the Neotropical belt and may be the primary pollinators of plant species with specific adaptations [2]. Species of the subfamily Phaethornithinae feed in the understory, and those of Trochilinae act in the canopy with less richness of ornithophilous plants [4-6].

The plants' characteristics, such as size, color, shape, and floral features, will indicate the pollinator type. For example, plant species pollinated by birds have tubular shapes, striking colors, no odor, relatively dilute abundant nectar, diurnal anthesis, and spatial separation of the nectariferous chamber about the stigmas and anthers [7].

This bibliometric analysis aimed to quantify the articles published on ornithophilous species of Bromeliaceae in the Atlantic Forest biome, demonstrating the scarcity of studies and the need for studies to reduce this knowledge gap.

Bromeliaceae: Adaptations and Ecosystem Services

The family Bromeliaceae Juss is a group of monocots that is extremely successful in

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neotropical environments. It is characterized by great diversity in terms of habits, modes of reproduction, and a significant role in the trophic web. About 3,547 species of 76 genera are described, in addition to another 550 infraspecific variations found from the south of the United States to Chile [8].

Bromeliads are perennial plants, usually with a short stem, forming a rosette that can be conspicuous or inconspicuous. They range in size from a few centimeters (*Tillandsia usneoides*) to more than 10 meters (*Puya raimondii*). Most species are epiphytic, but there are also terrestrial and saxicolous (growth on rock). The stem has short internodes, with leaves arranged in a spiral and dilated sheath. The inflorescences are terminal or pseudolateral, sympodial growth, and usually showy, playing an important role in attracting pollinators [5].

They also have an excellent adaptation to colonize new niches and environments, expanding their ecological possibilities. This is thanks to the most notable characteristic of the group, the trichomes modified into peltate scales that absorb water directly from the atmosphere, combined with the photosynthetic mechanism of the CAM (crassulacean acid metabolism) type [9].

Although most genera of Bromeliaceae are present in Brazil, with more than 85% being endemic [9,10], little is known about their reproduction, especially in relation to issues involving speciation and reproductive strategies. Recent research on pollination in the family indicates that bromeliads play a crucial role in the networks of plant-animal interactions [11].

Other intriguing aspect investigated in Bromeliaceae species is the quality of the nectar produced and its relationship with different types of pollinators. Recent research on nectar concentration in Bromeliaceae has drawn attention, as the sugar levels are consistently higher than in other families [2,12]. This underscores the family's importance as one of the main sources of resources for the pollinator community.

Among the pollination syndromes, the Bromeliaceae family includes ornithophilous species (birds), especially troquilophiles (hummingbirds), mesophiles (bees), chiropterophiles (bats), psychrophiles (butterflies), sphingophiles (moths), and even species pollinated by rodents, conferring a wide adaptive irradiation to the family [11].

The Bromeliaceae are recognized as one of the most important sources of resources for hummingbirds in the Atlantic Forest.

Hummingbirds are the main pollinators of the family, both in Brazil and in other Neotropical regions. To date, 51 species of hummingbirds have been recorded pollinating bromeliads, which includes the 34 (66.7%) species of the smaller, beautiful, and showy birds that occur in Brazil [2,11].

The importance of this work lies in presenting the current state of scientific production on plant-animal interaction between bromeliads and birds in the gap of this knowledge and its greater diffusion.

Materials and Methods

The method adopted was the bibliometric analysis of articles published in the Scopus, Web of Science, and Scielo databases over 28 years (1996 to 2024), using filters with terms ("ornithophilia, Bromeliaceae, Atlantic Forest, pollination") and search criteria (Brazilian authors) using the R algorithm.

Literature review is a method characterized by the use and analysis of scientific works published as articles, dissertations, theses, and books. This research uses secondary data to identify and describe results obtained by other authors on a given topic.

Bibliometric analysis is a quantitative and statistical technique for measuring indices of the production and dissemination of scientific knowledge [13]. On the other hand, systematic reviews are a comprehensive and detailed search method for identifying more comprehensive studies and significant gaps in published theoretical and methodological studies [14, 15].

The selection of articles was made using 3 filters of specific search terms and criteria: (1) identification of ornithophilous species of Bromeliaceae in Atlantic Forest by the expressions "ornitholyphilia, Bromeliaceae, Atlantic Forest" in the R Core Team for statistical analysis and generation of graphs and tables by the Bibliometrix package of the R 4.0.1 software; (2) refinement by titles or abstracts with the search term "pollination"; and (3) selection of articles published by authors from Brazilian institutions.

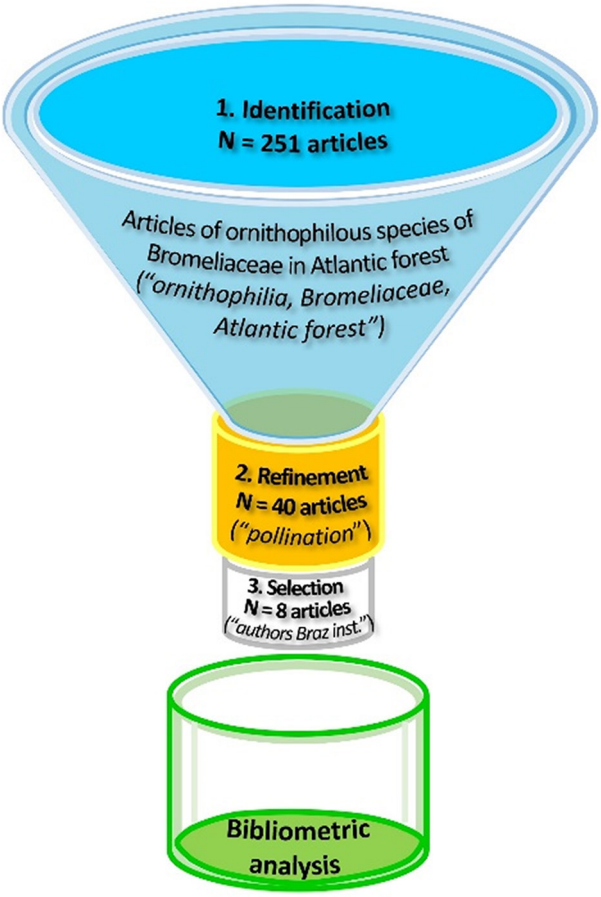
This use of successive filters (requirements) was recorded as a history of the research, following guidelines from a qualified quorum. This allowed clear visualization of why studies were excluded at different stages of the review and under which specific criteria. The qualified quorum is the minimum number of articles necessary for systematic review research to take place [16].

Results and Discussion

The bibliometric analysis of articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024, used three search filters. The first one, with 3 initial expressions "ornithophilia, Bromeliaceae, Atlantic Forest", selected 251 (100%) articles from 819 authors in 96 journals in 23 countries. The second filter, with the term "pollination", generated 40 (15.9%) articles related to ornithophilia and Bromeliaceae. The third and final filter got only 8 (3%) articles published by authors from Brazilian institutions (Figure 1).

In the first level, the highlight was Brazil (N=111, 44.0%), followed by Germany (N=31, 12.3%), the United States (N=29, 11.5%), the United Kingdom (N=17, 6.8%), Switzerland (N=12, 4.8%), Mexico (N=11, 4.4%), Argentina, Austria and Colombia (N=6, 2.4%), Spain and Sweden (N=4, 1.6%), Belgium, Chile and Italy (N=3, 1.2%), Panama, Peru and Uruguay (N=2, 0.8%), Australia, Canada, Costa Rica, Czech Republic, Guatemala and the Netherlands (N=1, 0.4%) (Figure 2).

Figure 1. Filter method for selecting articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024.



Nine of the selected articles had more than 60 citations, indicating greater scientific dissemination on the theme of interactions between bromeliads and birds as pollinators (Figure 3).

The analyzed articles have, on average, 5 authors, with two papers written by only 1 author. About 60 papers have international co-authors (24%). The average annual production was 8.94%. The journals with the highest h-index were the Botanical Journal of the Linnean Society, Biota Neotropica, and Rodriguésia. This index is an important metric that quantifies the productivity and impact of individual or group research based on the authors of the most cited articles (Table 1).

On the other hand, most of the articles were published in the journals Phytotaxa (N=24),

Figure 2. Scientific production by country of articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024.

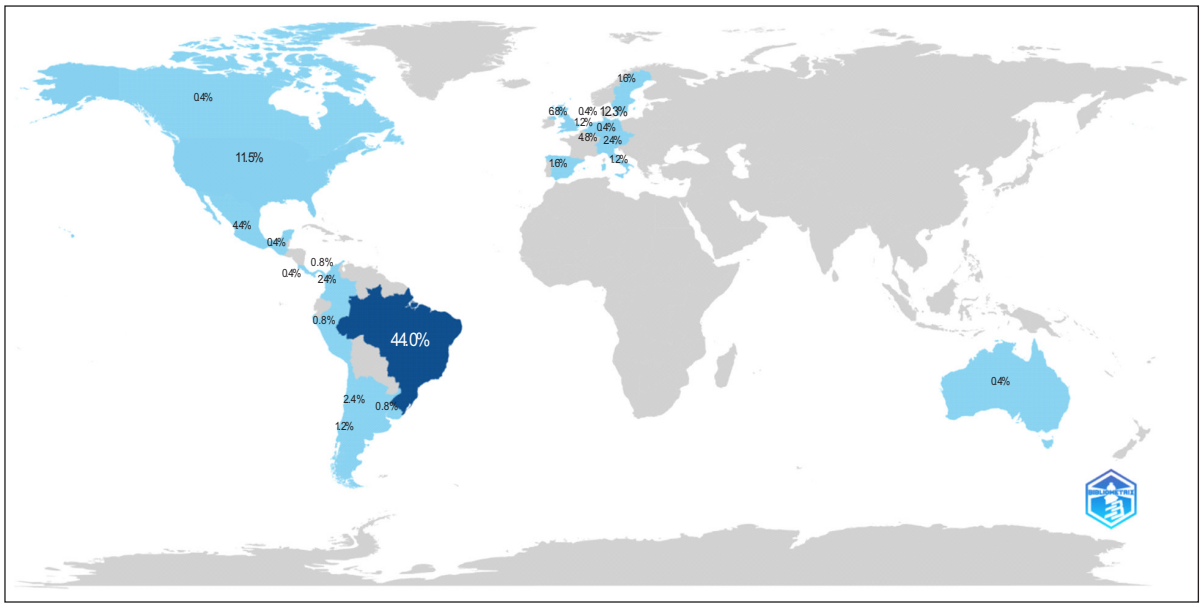
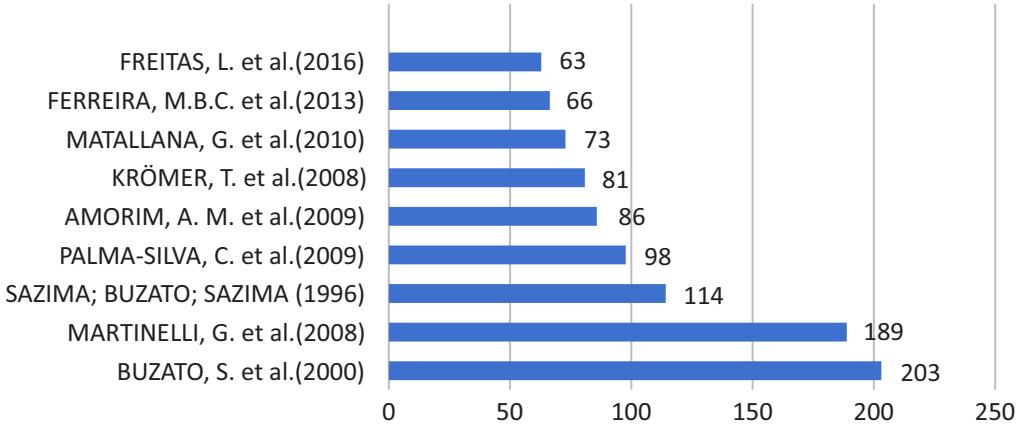


Figure 3. Nine articles with more than 60 citations were extracted from Bibliometrix.



Botanical Journal of the Linnean Society (N=22), and Rodriguésia (N=21), concentrating mainly on botany and plant systematics. This reflects the scientific production and the interest of the academic community in topics such as taxonomy, ecology, morphology, and evolution of plants (Table 1).

Phytotaxa is a journal focused on plant taxonomy, nomenclature, and phylogeny. Its high number of articles indicates a strong research production in the description and classification of new plant species, a fundamental field for the registration of biodiversity and the consequent need for conservation. The Botanical Journal of the Linnean Society is one of the most respected journals in botanical research. Rodriguésia is a Brazilian journal focused on botany, standing out as one of the most relevant journals for scholars

of neotropical flora, reflecting the rich biodiversity of Brazil and its importance for disseminating this knowledge.

The second filter with the expression "pollination" generated 40 (15.9%) articles listed by national institutions with scientific production in areas related to ornithophilia and Bromeliaceae. In Brazil, most research on pollination in Bromeliaceae was carried out in the Atlantic Forest (96%) [2,10,11,17-27], followed by 3 articles in the Amazon [28] and 1 article in the Pantanal [9]. No detailed studies were found on the pollination of Bromeliaceae by birds in Cerrado and Caatinga.

The survey of articles with more than 10 affiliated national authors showed 13 Brazilian public institutions, 12 universities (9 federal and 3 states), and 1 research institute, demonstrating the importance of development and investment agencies in guaranteeing teaching, research, and extension activities (Table 2).

The Federal University of Rio de Janeiro (UFRJ) led with 74 affiliated authors, evidencing its most significant contribution to research on ecological interactions between birds and bromeliads, driven by its botany and ecology programs. The Botanical Garden of Rio de Janeiro (JBRJ), associated with UFRJ, had 23 authors, being a reference in the research of Brazilian flora, especially with the great diversity of species and ecological interactions of birds that depend on bromeliads for food or nesting in the Atlantic Forest. Still, on the theme of bromeliad pollination by birds, other institutions also stood out, such as the Federal Universities of Rio Grande do Sul (UFRGS) with 41 authors, Juiz de Fora (UFJF) with 37 authors, and the Recôncavo da Bahia (UFRB) with 25 authors, in studies of biodiversity and landscape ecology (Table 2).

The other Federal Universities of Santa Catarina (UFSC), Espírito Santo (UFES), Alagoas (UFAL), Pernambuco (UFPE), and the Regional University of Blumenau (FURB) also appeared on the list with a relevant production, indicating a wide geographical coverage. This suggests that research on ornithophilia in bromeliads is spread across several regions of Brazil, reflecting the biogeographic distribution of the botanical family in different biomes and the birds that interact with them (Table 2).

State Universities, such as São Paulo (USP), Santa Cruz (UESC), and Campinas (UNICAMP), on the other hand, showed a few publications

Table 1. Selected journals with the most relevant articles by year and their h≥5) factor of impact.

Journal	N = 114 (article)	Year	h Index (h≥5)
Acta Botanica Brasilica	7	2001	5
Plant Biology	6	2003	6
American Journal of Botany	5	2005	5
Rodriguésia	21	2007	8
Botanical Journal of Linnean Society	22	2008	12
Biota Neotropica	13	2009	8
Systematic Botany	8	2010	6
Flora Morphology, Distribution, Functional Ecology of Plants	8	2011	5
Phytotaxa	24	2013	6

Table 2. Brazilian institutions with affiliated national authors (N≥10) of articles published from 1996 to 2024.

Brazilian Institution of Affiliation	Number of Authors (N ≥ 10)
Universidade Federal do Rio de Janeiro (UFRJ)	74
Universidade Federal do Rio Grande do Sul (UFRGS)	41
Universidade Federal de Juiz de Fora (UFJF)	37
Universidade Federal do Recôncavo da Bahia (UFRB)	25
Jardim Botânico do Rio de Janeiro (JBRJ)	23
Universidade Federal de Santa Catarina (UFSC)	21
Universidade Federal do Espírito Santo (UFES)	20
Universidade Federal de Alagoas (UFAL)	19
Universidade de São Paulo (USP)	17
Universidade Estadual de Santa Cruz (UESC)	16
Universidade Federal de Pernambuco (UFPE)	13
Universidade Estadual de Campinas (UNICAMP)	12
Universidade Regional de Blumenau (FURB)	11

above the metric established as a cut-off parameter, probably by environmental research. The UESC, located in Bahia, a state rich in biodiversity, had studies focused on the interactions of local flora and avifauna (Table 2).

The third filter for the final selection of articles published by authors from Brazilian institutions grouped 8 (3%) articles, presented a brief description of the main aspects dealing with the relationship between ornithophilous species of Bromeliaceae and their trochylophilic pollinators (hummingbirds) (Table 3).

Sazima, Buzato, and Sazima (1996), pioneers in this theme, observed native species of Bromeliaceae pollinated by hummingbirds in the Atlantic Forest in the Mantiqueira mountain. The predominant tubular flowers result in different pollen deposition sites on visiting hummingbirds' bodies, although mainly deposited in the beak. Four of the six species of hummingbirds are common and differ in beak size, body mass, and foraging preferences, reflecting on the preferred flower clusters. A hermit hummingbird and a trochylid hummingbird were the primary pollinators and shared the most flower species [12].

Schmid and colleagues (2011) and Magalhães and colleagues (2018) evaluated the floral biology and pollination syndrome of the bromeliad Aechmea nudicaulis in the Atlantic Forest in southern Brazil. The obligatory xenogamy reproductive system relies on pollinators. Most of the floral traits are characteristic of ornithophilia, and nectar production is adapted to the energy demands of hummingbirds. The pollination system involves birds and bees, ensuring a high probability of reproductive success [29,30]. Magalhães and colleagues (2018) compared the breeding systems between the generalist *A. nudicaulis* and the specialized *Vriesea neoglutinosa*. Single-visit experiments have shown that hummingbirds are

Table 3. Final selection of 8 (3%) articles by Brazilian authors affiliated with Brazilian institutions from 1996 to 2024.

Brazilian Institution	Authors (year)	Journal	Title
Universidade Estadual de Campinas (UNICAMP)	Sazima, Buzato and Sazima (1996)	Botanica Acta	An Assemblage of hummingbird-pollinated flowers in a montane forest in Southeastern Brazil.
	Nunes and colleagues (2018)	Acta Botanica Brasilica	Nectar ecology of the endemic epiphytic hummingbird-pollinated bromeliad *Vriesea altodaserrae*: secretion dynamics and pollinator visitation pattern.
	Zambonand colleagues (2019)	Botanical Journal of the Linnean Society	Nectar as manipulator: how nectar traits influence changes in *Aechmea vanhoutteana's* pollinator groups, a Brazilian Atlantic Forest bromeliad.
Universidade Federal do Rio de Janeiro (UFRJ)	Magalhães and colleagues (2018)	Botanical Journal of the Linnean Society	The relative importance of hummingbirds as pollinators in two bromeliads with contrasting floral specializations and breeding systems.
Universidade Federal de Santa Catarina (UFSC)	Schmid and colleagues (2011)	Plant Biology	Bimodal pollination system of the bromeliad *Aechmea nudicaulis* involving hummingbirds and bees.
	Kamke and colleagues (2011)	Flora	The importance of bees as pollinators in southern Brazil's short corolla bromeliad *Aechmea caudata*.
Universidade do Estado do Rio de Janeiro (UERJ)	Missagia and Alves (2015)	Zoologia	The rate of visitation by *Amazilia fimbriata* (Apodiformes: Trochilidae) influences seed production in *Tillandsia stricta* (Bromeliaceae).
Universidade de São Paulo (USP)	Pansarin and Pedro (2016)	Plant Biology (Stuttg)	Reproductive biology of a hummingbird-pollinated Billbergia: light influence on pollinator behavior and specificity in a Brazilian semi-deciduous forest.

more efficient than ants at pollinating *A. nudicaulis* and as efficient as bees and ants at *V. neoglutinosa* [30].

Kamke and colleagues (2011) stated that most bromeliad species are pollinated by vertebrates, especially hummingbirds and bats, which are important for the success of pollination in *Aechmea caudata* (Bromeliaceae) due to the frequency and efficacy measured by the number of seeds per single visit in secondary Atlantic Forest in southern Brazil. The authors recorded 16 species visiting the flowers, with bees being the most abundant and frequent taxon (91% of 647 visits) and *Bombus morio* the most common (41%). Although *A. caudata* is associated with ornithophilia, with tubular corollas and daily

nectar secretion, the only hummingbird species *Thalurania glaucopis* was unable to pollinate the flowers, with a low frequency of visits (2.5%) that did not favor pollen flow between conspecific bromeliads [31].

Missagia and Alves (2015) conducted a study in the Atlantic Forest in Rio de Janeiro, monitoring 30 flowers, of which 5 were analyzed for spontaneous self-pollination and the other 25 exposed to floral visitors, with the hummingbird *Amazilia fimbriata* identified as the only legitimate visitor of Tillandsia stricta (Bromeliaceae), with a visitation rate of 6.6 (±3.4) visits per flower. About 22 formed fruits and seeds, and 3 produced seeds without floral visits. A positive correlation was observed between the number of floral visits and the number of seeds produced (r^2=0.58, $p<0.01$) [32].

Pansarin and Pedro (2016) explored the reproductive biology and specificity of pollinators of the species *Billbergia distachia* in a semideciduous forest in southeastern Brazil, where it is exclusively pollinated by the hermit hummingbird species *Phaethornis eurynome*, which seeks floral nectar above the placenta, regardless of air temperature and humidity, and the visit is influenced only by daylight [33].

Nunes and colleagues (2018) studied the nectar ecology of the endemic epiphytic bromeliad *Vriesea altodaserrae*, which is dependent on hummingbirds for its sexual reproduction, and the nectar composition is consistent with most hummingbird-pollinated species. The rhythm of nectar secretion did not influence the frequency of hummingbird visits, being visited by two-thirds of the hummingbird species at the study site, with emphasis on the subfamily Trochilinae, suggesting a specialization of this group and the importance of this endemic bromeliad as a keystone species in areas of the highland Atlantic Forest [34].

Zambon and colleagues (2019) recorded nectar production dynamics in Aechmea vanhoutteana and hummingbird, bee, and butterfly species. The volume of nectar and the amount of sugar also showed significant spatial and temporal variations during floral anthesis, which were related to increased bee visits. This aspect is crucial for the species' reproductive strategy, as bees can fly greater distances than hummingbirds, despite both having territorial behaviors [35].

For all the above, bibliometric analysis is an efficient tool for selecting articles from journals with a high impact factor, allowing the identification of publications that have greater influence and relevance in the researched area.

In addition, bibliometric analysis tends to prioritize the number of citations to the detriment of the quality of articles, which can lead to the undervaluation of innovative or emerging research that has not yet been widely cited [13].

However, it proved to be a limiting method by not including articles published in restricted means of dissemination, such as modest or low-cost journals. The emphasis on the impact factor (citations) can devalue research of great regional relevance or of a smaller scale that can be crucial in advancing local knowledge or specific areas of knowledge. Not considering the contribution of articles to scientific and social practice or their application in practical contexts can also lead to a distorted view of the relevance of endemic studies.

Conclusion

The bibliometric analysis of articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024, used three search filters: (1) Three initial expressions ("ornithophilia, Bromeliaceae, Atlantic Forest") selected 251 (100%) articles from 819 authors in 96 journals of 23 countries, with emphasis on Brazil (N = 111, 44%). (2) The term "pollination" generated 40 (15.9%) articles related to ornithophilia and Bromeliaceae. (3) The filter of authors from Brazilian institutions grouped only 8 (3%) articles.

In Brazil, most of the research on pollination in Bromeliaceae was carried out in the Atlantic Forest (96%). The survey of articles with more than 10 affiliated national authors showed 13 Brazilian public institutions, 12 universities (9

federal and 3 states), and 1 research institute, demonstrating the importance of development and investment agencies in guaranteeing teaching, research, and extension activities. The Federal University of Rio de Janeiro (UFRJ) led by 74 affiliated authors, evidencing its most significant contribution to research on ecological interactions between birds and bromeliads, driven by its botany and ecology programs. Therefore, bibliometric analysis is an efficient tool but limiting as it does not include articles published in restricted means of dissemination, such as modest or low-cost journals. The emphasis on the impact factor (citations) can devalue research of great regional relevance or, on a smaller scale that can, play a crucial role in advancing local knowledge or specific areas of knowledge. Not considering the contribution of articles to scientific and social practice or their application in practical contexts can also lead to a distorted view of the relevance of endemic studies.

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References

1. Fundação SOS Mata Atlântica. INPE, Instituto Nacional de Pesquisas Espaciais. Relatório Técnico: Atlas dos remanescentes florestais da Mata Atlântica. Período 2019-2020. São Paulo 2021:1-39.
2. Leone FR. Plantas ornitófilas com enfoque em *Sinningia sceptrum* (Mart.) Wiehler (Gesneriaceae), em fragmento de Floresta Atlântica: aspectos reprodutivos e rede de interações mutualísticas. Dissertação (Botânica), Universidade Federal de Viçosa. Minas Gerais, 64 p., 2011.
3. Buzato S, Sazima M, Sazima I. Hummingbird-pollinates flora at three Atlantic Forest sites. Biotropica, Lawrence 2000;32(4):824-841.
4. Feinsinger P, Colwell RK. Community Organization among Neotropical nectar feeding birds. American Zoologist, Thousand Oaks 1978;18(4):779-795.
5. Grantsau R. Os beija-flores do Brasil. Rio de Janeiro: Editora Nova Fronteira 1989:912.
6. Rocca MA, Sazima M. Ornithophilous canopy species in the Atlantic Rainforest of southeastern Brazil. Journal of Field Ornithology, New Ipswich, 2008;79(2):130-137.
7. Araújo FP. Estudo comparativo de duas espécies ornitófilas em borda de uma ilha de mata de galeria, Uberlândia-MG. Dissertação (Ecologia e Conservação de Recursos Naturais), Universidade Federal de Uberlândia, Minas Gerais, 2005, 52 p.
8. Butcher D, Gouda CS. Encyclopedia of Bromeliads. University Botanical Gardens, Utrcht, 2017.
9. Araújo AC. Flora, fenologia de floração e polinização em Capões do Pantanal Sul Mato-Grossense. Tese (Ecologia) Universidade Estadual de Campinas, Campinas 2001, 90 p..
10. Martinelli G. Reproductive biology of Bromeliaceae in the Atlantic rainforest of Southeastern Brazil. Thesis. University of St. Andrews, Scotland, 1994, 197 p.
11. Siqueira Filho JA, Machado IC. Biologia reprodutiva de *Canistrum aurantiacum E. Morren* (Bromeliaceae) em remanescente da floresta atlântica, Nordeste do Brasil. Acta Botânica Brasílica 2001;15(3):427-444.
12. Sazima I, Buzato S, Sazima M. An Assemblage of hummingbird-pollinated flowers in a montane forest in Southeastern Brazil. Botanica Acta 1996;109:149-160.
13. Guimarães AJR, Moreira PSC, Bezerra CA. Modelos de inovação: análise bibliométrica da produção científica. Brazilian Journal of Information Science 2021;15:6.
14. Pickering C, Byrne J. The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. Higher Education Research & Development 2014;33(3):534-548.
15. Torraco RJ. Writing integrative literature reviews: Using the past and present to explore the future. Human Resource Development Review 2016;15(4):404-428.
16. Dybå T, Dingsøyr,T. Strength of evidence in systematic reviews in software engineering. In: Proceedings of the Second ACM. IEEE, International Symposium on Empirical Software Engineering and Measurement 2008:178-187.
17. Alves MAS, Rocha CFD, Sluys MV, Bergallo HGC. Guildas de beija-flores polinizadores de quatro espécies de Bromeliaceae de Mata Atlântica da Ilha Grande, RJ, Brasil: composição e taxas de visitação. In: Alves MAS, Silva JMC, Van Sluys M, Bergallo HG, Rocha CFD (Orgs.). A ornitologia no Brasil: Pesquisa atual e perspectivas. Rio de Janeiro: Editora da UFRJ 2000;185:171-185.
18. Araújo AC, Fischer EA, Sazima M. Floração sequencial e polinização de três espécies de Vriesea (Bromeliaceae) na região de Juréia, sudeste do Brasil. Revista Brasileira Botânica 1994;17:113-118.

19. Araújo AC. Beija-flores e seus recursos florais numa área de planície costeira do litoral norte de São Paulo. Dissertação (Ecologia) Universidade Estadual de Campinas, Campinas 1996, 69 p.
20. Fischer EA. Polinização, fenologia e distribuição espacial de Bromeliaceae numa comunidade de Mata Atlântica, Litoral Sul de São Paulo. Dissertação (Ecologia) Universidade Estadual de Campinas, Campinas, 1994, 80 p
21. Lopes AV. Polinização por beija-flores em remanescente da Mata Atlântica Pernambucana, Nordeste do Brasil. Tese (Biologia Vegetal) Universidade Estadual de Campinas, Campinas, 2002, 126 p.
22. Martinelli G. Biologia reprodutiva de Bromeliaceae na Reserva Ecológica de Macaé de Cima. In: Lima HC, Guedes-Bruni RR. (Eds.). Serra de Macaé de Cima: diversidade florística e conservação em Mata Atlântica. Instituto de Pesquisas do Jardim Botânico do Rio de Janeiro, 1997:213-250.
23. Ruschi A. A polinização realizada pelos Trochilídeos, a sua área de alimentação e o repovoamento. Boletim do Museu de Biologia, Professor Mello-Leitão. Biologia 1949;2:1-51.
24. Siqueira Filho JA, Machado IC. Biologia floral de Hohenbergia ridleyi (Baker) Mez (Bromeliaceae). Bromelia 1998;5:1-13.
25. Sluys MV, Stotz DF. Patterns of hummingbird to Vriesea neoglutinosa in Espírito Santo, southeastern Brazil. Bromelia 1995;2(3):27-35.
26. Snow DW, Snow BK. Feeding ecology of hummingbirds in the Serra do Mar, Southeastern Brazil. El Hornero Rev. de Ornitología Neotropical 1986;12:286-296.
27. Snow DW, Teixeira DL. Hummingbirds and their flowers in the coastal mountains of Southeastern Brazil. Journal Für Ornithologie 1982;123:286-296.
28. Nara AK. Biologia floral e polinização de quatro espécies de Bromeliaceae de ocorrência em vegetação de baixio na Amazônia Central. Dissertação (Ciências Biológicas) Universidade do Amazonas, Instituto Nacional de Pesquisas da Amazônia, Manaus, 1998, 82 p.
29. Schmid S, Schmid VS, Zillikens A, Harter-Marques B, Steiner J. Bimodal pollination system of the bromeliad Aechmea nudicaulis involving hummingbirds and bees. Plant Biology (Suppl. 1) 2011;13:41–50.
30. Magalhães AFP, Maruyama PK, Tavares LAF, Martins RL. The relative importance of hummingbirds as pollinators in two bromeliads with contrasting floral specializations and breeding systems. Botanical Journal of the Linnean Society 2018;20:1-11.
31. Kamke R, Schmid S, Zillikens A, Lopes BC, Steinera J. The importance of bees as pollinators in the short corolla bromeliad Aechmea caudata in southern Brazil. Flora 2011;206:749-756.
32. Missagia CCC, Alves MAS. The rate of visitation by *Amazilia fimbriata* (Apodiformes: Trochilidae) influences seed production in *Tillandsia stricta* (Bromeliaceae). Zoologia 2015;32(3):260–262.
33. Pansarin ER, Pedro SRM. Reproductive biology of a hummingbird-pollinated Billbergia: light influence on pollinator behavior and specificity in a Brazilian semi-deciduous forest. Plant Biology (Stuttg) 2016;18(6):920-927.
34. Nunes CEP, Briet J, Galetto L, Sazima M, Amorim FW. Nectar ecology of the endemic epiphytic hummingbird-pollinated bromeliad *Vriesea altodaserrae*: secretion dynamics and pollinator visitation pattern. Acta Botanica Brasilica 2018;32(3):479-486.
35. Zambon V, Agostini K, Nepi M, Rossi ML, Martinelli,A. P, Sazima M. Nectar as manipulator: how nectar traits influence changes in pollinator groups of Aechmea vanhoutteana, a bromeliad from the Brazilian Atlantic Forest. Botanical Journal of the Linnean Society 2019;20:1-13.

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Font Type	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial	Times or Arial
Number of Words – Title	120	90	95	85	70	60	120	90
Font Size/Space-Title	12; double space	12; double space	12; double space	12; double space	12; double space	12; double space	12; double space	12; double space
Font Size/Space-Abstracts/Key Words and Abbreviations	10; single space	10; single space	10; single space	10; single space	-	-	10; single space	10; single space
Number of Words – Abstracts/Key Words	300/5	300/5	200/5	250/5	-	-	300/5	300/5
Font Size/Space-Text	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space	12; Double space
Number of Words – Text	5,000 including spaces	5,500 including spaces	2,500 including spaces	1,000 including spaces	1,000 including spaces	550 including spaces	5,000 including spaces	5,500 including spaces
Number of Figures	8 (title font size 12, double space)	3 (title font size 12, double space)	2 (title font size 12, double space)	2 (title font size 12, double space)	-	2 (title font size 12, double space)	8 (title font size 12, double space)	8 (title font size 12, double space)
Number of Tables/Graphic	7 title font size 12, double space	2 title font size 12, double space	2(title font size 12, double space)	1(title font size 12, double space)	-	-	7 title font size 12, double space	4 title font size 12, double space
Number of Authors and Co-authors*	15	10	5	10	3	3	15	10
References	20 (font size 10,single space	30(font size 10,single space	15 (font size 10,single space)	10 (font size 10,single space)	10 (font size 10,single space	5(font size 10,single space	20 (font size 10,single space	20

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