Using AI for the Identification of Tree Species of Economic Importance

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Abstract

This study explores the application of drone technology and object detection models to map Brazil nut trees (*Bertholletia excelsa*) within the Amazon rainforest canopy. Utilizing UAVs, survey mission planning, and open source object detection models, which are algorithms designed to identify and locate objects within images, I aim to accurately detect and segment Brazil nut trees from drone images. I will use these detections/segmentions to create workflows to produce maps of a study area with shapefiles of Brazil Nut tree segmentations within it. This approach could enhance our understanding of Brazil Nut tree distribution, which is crucial for conservation efforts, sustainable harvest planning, and repopulation initiatives.

Introduction

The Amazon rainforest is a critical component of the global ecosystem, hosting a vast array of biodiversity and playing a crucial role in regulating the Earth's climate. Among the many species of trees that populate the Amazon rainforest, the Brazil nut tree (Bertholletia excelsa) holds significant ecological and economic importance. Brazil nut trees are a key species in the Amazonian ecosystem, contributing to the forest's structural complexity and serving as a vital resource for numerous animal species, including humans. Economically, Brazil nuts are a major non-timber forest product, providing income for local communities and contributing to the regional economy. In 2019, the export value of Brazil nuts from Peru was approximately $35 million USD, highlighting its substantial contribution to the local economy (Sears et al., 2021). Recently, Brazil Nut demand has increased in Peru where exports of Brazil nuts reached 575 tons in March 2024, marking a 3% increase compared to the 551 tons shipped in the same month the previous year (Agraria, 2024). This industry not only provides livelihoods for thousands of families but also represents a critical component of the non-timber forest products sector in Peru, which is a vital part of the country's sustainable development strategy (Zuidema, 2020). In the broader context of the Peruvian economy, Brazil nut harvesting plays a crucial role in the agricultural and forestry sectors, supporting both economic growth and environmental conservation efforts (Ocampo-Ariza & Castellanos-Castro, 2020). Despite their importance, Brazil nut trees face threats from overharvesting of Brazil nuts, which hampers natural regeneration processes and poses a risk to their long-term sustainability creating reduced recruitment of Brazil nut trees and a demographic bottleneck where pre-reproductive trees are absent (Peres et al., 2003; Zuidema & Boot, 2002; Scoles &

Gribel, 2011).

The advent of unmanned aerial vehicles (UAVs) has revolutionized environmental monitoring and research and generated new possibilities for species detection and monitoring.
This research aims to utilize drone/UAV images of the forest canopy to train an object detection and segmentation algorithm for identifying Brazil nut trees. Specifically, I plan to employ the YOLOv8 (You Only Look Once) algorithm, which is renowned for its real-time object detection capabilities and high accuracy. The objective of this study is to develop a custom model capable of detecting Brazil nut trees within drone imagery and to evaluate the feasibility and optimal survey parameters for this approach.

Detecting Brazil nut trees from drone imagery can provide a scalable and efficient method for monitoring these valuable resources. By integrating Yolos' machine learning techniques with high-resolution aerial imagery, I aim to develop a robust tool that can assist in the sustainable management of Brazil nut trees. This technology has the potential to support conservation efforts by identifying overharvested areas and guiding reforestation initiatives, ensuring the long-term sustainability of Brazil nut trees in the Amazon rainforest.

Identifying and monitoring Brazil nut trees is therefore critical for conservation efforts, sustainable harvesting practices, and effective reforestation planning. The ability to accurately detect and map Brazil nut trees can help in managing these resources more effectively, ensuring that the ecological and economic benefits they provide are maintained.

In order to develop and validate a drone-based system for the detection and mapping of Brazil nut trees in the Amazon rainforest using the YOLOv8 algorithm, the objectives of this project are:

1. To capture high-resolution drone imagery of the Amazon rainforest canopy using the DJI Mavic Air 2S.
2. To train a custom object detection and segmentation model using the YOLOv8 algorithm for identifying Brazil nut trees.
3. To evaluate the accuracy and feasibility of the model in detecting Brazil nut trees from drone images.
4. To determine the optimal survey parameters (e.g., altitude, overlap, time of day) to maximize detection accuracy.
5. To assess the potential applications of this technology for conservation efforts, sustainable harvesting, and reforestation planning.

Methods

I will utilize a DJI Air 2S drone equipped with Map Pilot Pro software for mission planning, OpenDroneMap (ODM) for generating georeferenced 2D orthomosaics and YOLOv8 algorithms for detection and segmentation from drone images.

Drone and Software Setup

I will utilize the DJI Air 2S equipped with a high-resolution camera that offers a practical and efficient tool for capturing detailed images of the forest canopy. This drone features a 1-inch CMOS sensor, a 22mm focal length, and a 20MP camera, providing high-quality imagery suitable for detailed analysis and mapping. (DJI, 2021) Map Pilot Pro software was employed for precise drone mission planning, ensuring comprehensive coverage of the study area.

Data Acquisition

Drone flights are conducted over predetermined areas within the Amazon rainforest, focusing on regions known for Brazil Nut tree presence. The flights will be scheduled during optimal weather conditions to minimize interference and ensure clear imaging and minimize the visibility of shadows.

Georeferenced 2D Orthomosaic Generation

Post-flight, captured images aer processed using OpenDroneMap (ODM) software to create georeferenced 2D orthomosaics. ODM utilizes photogrammetry techniques to stitch individual images into seamless, georeferenced mosaic maps, providing accurate spatial information of the study area.

Observer Agreement and Annotation Validation

To ensure the accuracy of the annotations used for training the YOLOv8 model, a preliminary assessment of observer reliability was conducted. A sample of 20 randomly selected drone images was independently labeled by both a knowledgeable professional and myself. The goal was to identify and mark the locations of Brazil Nut trees within the images. The annotations were then compared to assess the level of agreement between the two observers. The comparison revealed a 96% agreement rate, demonstrating a high level of inter-observer reliability. This high concordance indicates that my ability to accurately identify and annotate Brazil Nut trees in drone images is reliable, reducing the need for extensive ground truthing of every labeled tree.

Image Processing and Analysis

Post-flight, captured images were processed using YOLOv8 algorithms, chosen for their effectiveness in object detection and segmentation tasks. YOLOv8 algorithms were implemented to identify and delineate Brazil Nut trees within the acquired drone imagery.

Training and Validation

The YOLOv8 model is trained on a dataset comprising annotated images of Brazil Nut trees within the Finca Las Piedras property bounds. Training involved iterative refinement to enhance the model's accuracy and robustness in detecting Brazil Nut trees by tuning hyperparameters and testing the models validity using data from different elevations and days with different environmental factors including time of day and cloud cover.

Quantification and Analysis

I will assess the accuracy of Brazil Nut tree detection by using a validations set of annotated images and the validation outputs of the yolo algorithm: Precision and Recall, F1 Score and Average Precision (AP). Precision and Recall measures how many of the detected objects are correct (precision) and how many of the actual objects are detected (recall). The F1 Score measures the harmonic mean of precision and recall, providing a single metric to show the trade-off between precision and recall. The Average Precision (AP) is a metric used to summarize the precision-recall curve and quantifies the models performance over all possible thresholds of confidence for detections.

Results

The integration of high-resolution drone imagery, precise mission planning with Map Pilot Pro, and advanced detection algorithms, such as YOLOv8, successfully enabled the accurate segmentation and detection of Brazil nut trees within the Amazon rainforest canopy. The YOLOv8 model identified and segmented Brazil nut trees with high accuracy, as demonstrated by the consistent and reliable detection outputs observed across multiple validation datasets. This process resulted in the generation of reliable spatial data, which can now be utilized to create georeferenced shapefiles for further analysis in a GIS environment. These outcomes confirm the effectiveness of the approach and its potential application in large-scale mapping and conservation efforts.

Model Training and Validation

- Dataset Composition: The dataset used for training and validating the YOLOv8 model consisted of a total of 1,576 images. These images were split into three sets: 1,380 images for training, 126 images for validation, and 70 images for testing. To enhance the model's generalization capability, data augmentation techniques were applied to the training set. Each training example was augmented to generate three outputs. The augmentations included:
    - Flip: Horizontal and Vertical
    - Rotation: Between -9° and +9°
    - Shear: ±10° Horizontal, ±10° Vertical
    - Noise: Up to 0.74% of pixels

- Training Parameters: The model was trained using the default YOLO hyperparameters over 300 epochs. This configuration was selected based on the balance between performance and computational efficiency.

- Training Performance: During the training process, the model's performance was monitored using the standard metrics provided by the YOLOv8 framework. The model showed a steady decrease in loss over the epochs, indicating effective learning and convergence.

Model Evaluation Metrics

Average Precision (AP): The trained YOLOv8 model achieved the following evaluation metrics:

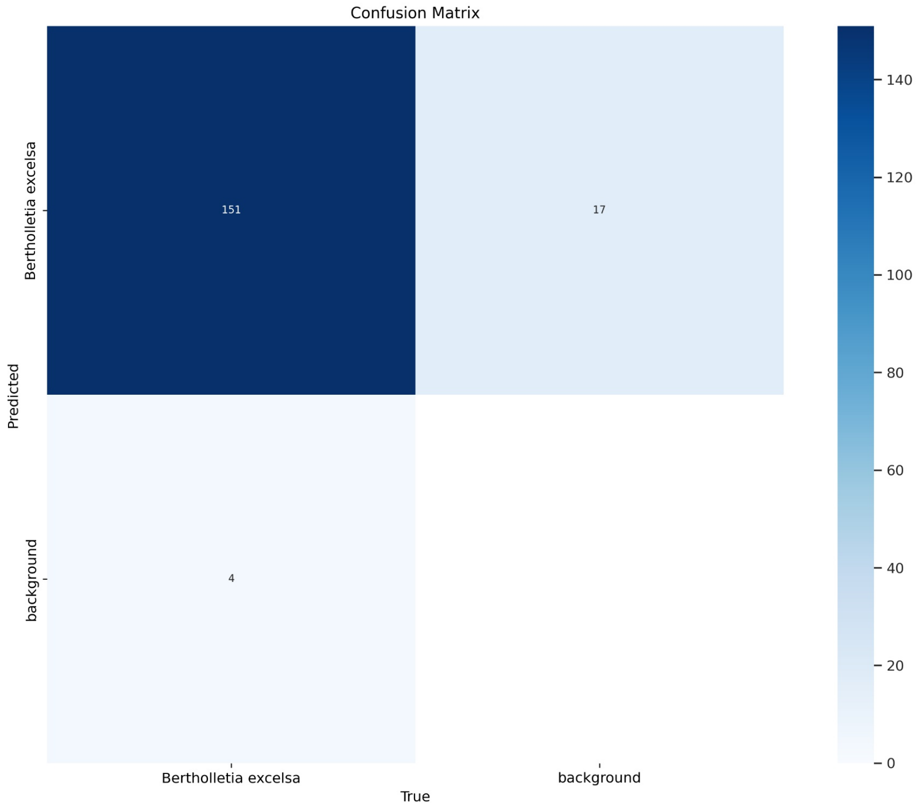
- metrics/mAP50-95(M): 0.8943
- metrics/mAP50(M): 0.96961

These results indicate that the model performed with high precision across different intersection-over-union (IoU) thresholds, with particularly strong performance at IoU=0.5. The high mAP scores demonstrate the model's robustness in detecting and segmenting Brazil nut trees within the drone imagery, reflecting its ability to accurately localize the trees while maintaining a low false positive rate.

The confusion matrix for the YOLOv8 model's performance on the validation set is as follows:

- True Positives (Top Left: 151): The model correctly identified 151 instances of Brazil nut trees. This indicates that the model was able to accurately detect the presence of Brazil nut trees in the majority of cases.
- False Positives (Top Right: 17): There were 17 cases where the model incorrectly identified an object as a Brazil nut tree when it was not. This suggests that while the model is generally accurate, there is still a degree of over-detection, possibly due to the complexity of the canopy environment or similar-looking objects being misclassified as Brazil nut trees.
- False Negatives (Bottom Left: 4): The model failed to detect 4 instances of Brazil nut trees, classifying them as non-trees. The low number of false negatives indicates that the model has a strong ability to identify Brazil nut trees when they are present, though there is still room for improvement to ensure no trees are missed.
- True Negatives (Bottom Right: 0): The matrix indicates 0 true negatives, but this is expected in a binary classification

Figure 1: Confusion matrix for the YOLOv8 model's performance



task focused on detecting a specific class (Brazil nut trees) versus the background. Therefore, this does not negatively impact the overall evaluation but rather indicates the model's focus on identifying Brazil nut trees.

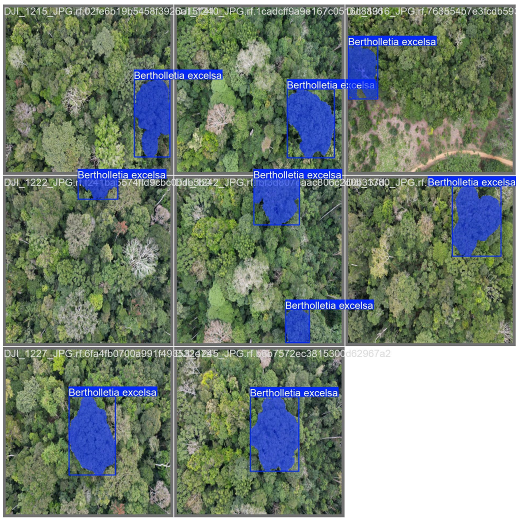
The confusion matrix reveals that the YOLOv8 model is highly effective at detecting Brazil nut trees, as evidenced by the high number of true positives and the low number of false negatives. However, the presence of 17 false positives suggests that the model occasionally confuses other objects with Brazil nut trees. This could be due to the presence of other tree species or objects within the canopy that share visual similarities with Brazil nut trees, leading to misclassification. The high true positive rate is encouraging, but the false positive rate highlights the need for further refinement, potentially through additional training data or further tuning of the model's thresholds to reduce over-detection. Additionally, analyzing the specific instances where false positives occurred could provide insights into improving the model's accuracy, possibly by adjusting the augmentation strategies or increasing the diversity of training data.

Detection and Segmentation Outputs

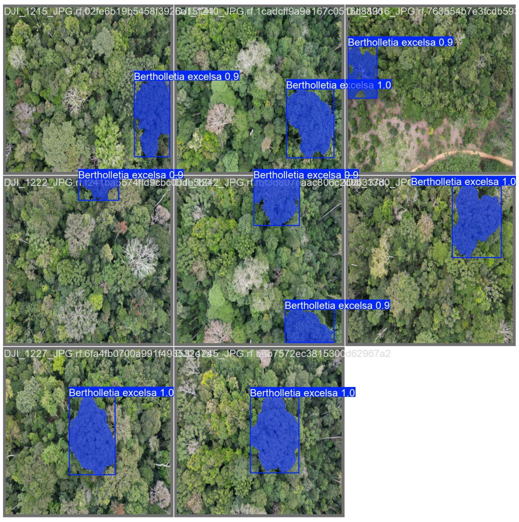
The exact match between the predicted outputs (val_batch0_pred) and the ground truth labels (val_batch0_labels) demonstrates the model's strong performance in this particular case. It accurately identified the Brazil nut trees without any false positives, false negatives, or incorrect segmentations.

The identical nature of the val_batch1_labels and val_batch1_pred images further underscores the model's ability to reliably detect and accurately segment Brazil nut trees in the validation dataset. This consistency suggests that the model is not only effective in isolated instances but can also maintain high accuracy across different validation batches.

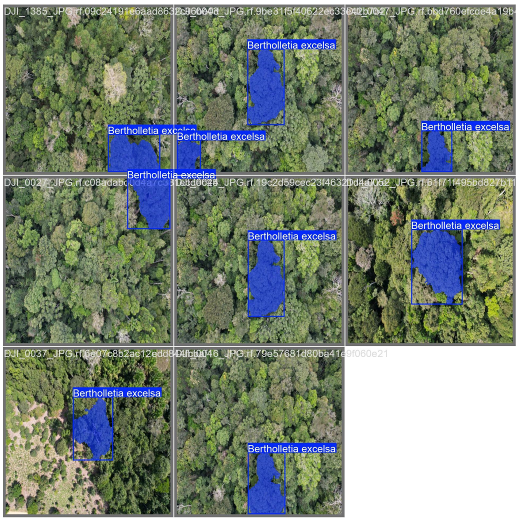
Figure 2: Detection and Segmentation Outputs



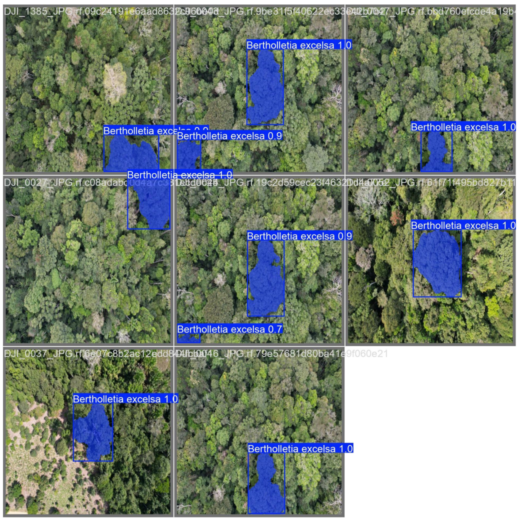
val_batch0_labels



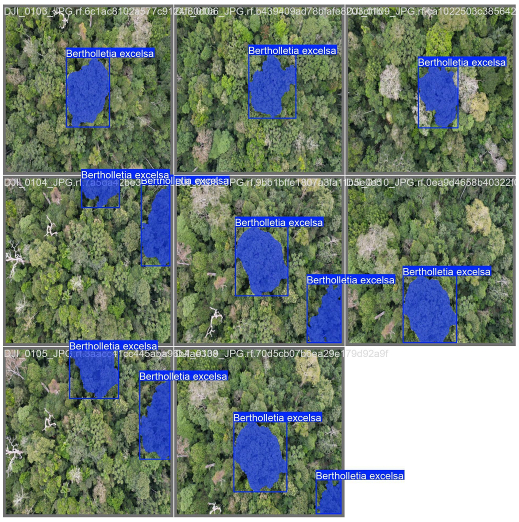
val_batch0_predictions



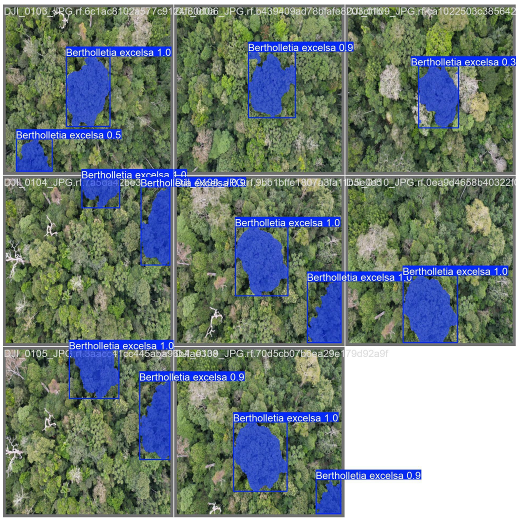
val_batch1_labels



val_batch1_pred



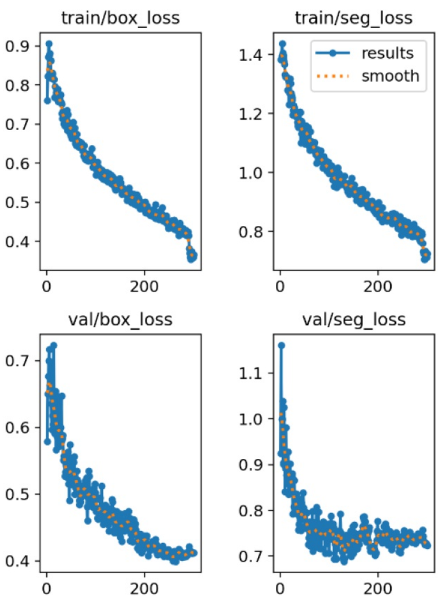
val_batch2_labels

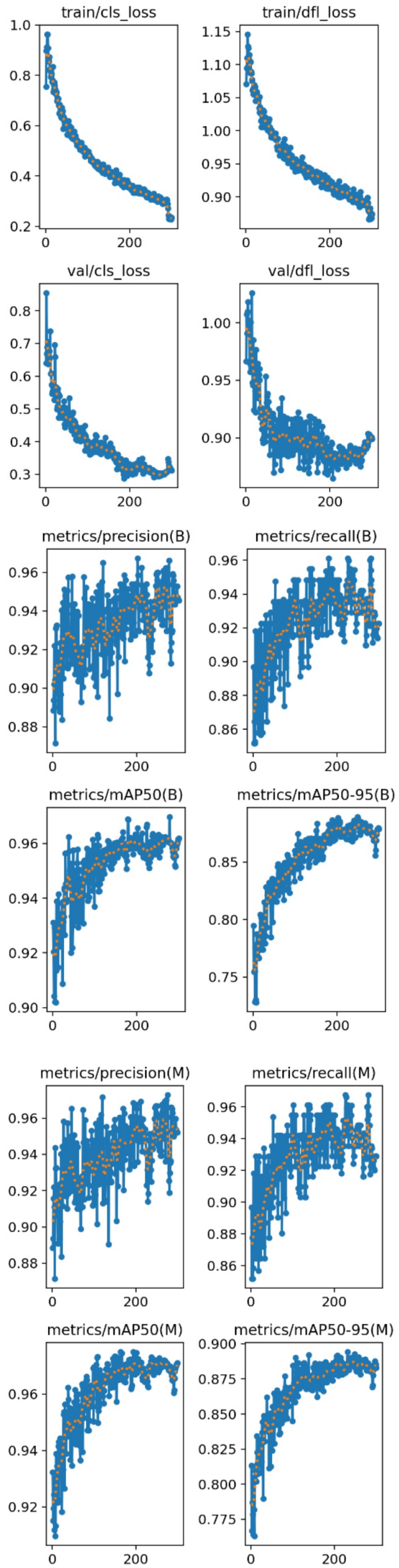


val_batch2_pred

In the val_batch2 images, the model's prediction (val_batch2_pred) shows two segmentations in the top left corner, while the ground truth label (val_batch2_labels) shows only one. This discrepancy suggests that the model identified an additional Brazil nut tree that was not included in the original annotations. This could be an instance where the model correctly identified a Brazil nut tree that was missed during the manual annotation process. Alternatively, it could indicate a false positive where the model incorrectly segmented an area as a Brazil nut tree. If the additional segmentation is indeed a true positive (i.e., a Brazil nut tree that was not annotated), it highlights the model's sensitivity and ability to detect trees that may be overlooked by human annotators. However, if it is a false positive, it indicates a potential area where the model may need further refinement to reduce over-segmentation.

Figure 3: Detection and Segmentation Metrics





Discussion

The results of this study demonstrate that the integration of high-resolution drone imagery, precise mission planning with Map Pilot Pro, and the advanced detection algorithms of YOLOv8 were successful in accurately detecting and segmenting Brazil nut trees within the Amazon rainforest canopy. However, while the model performed well under the specific conditions it was trained and tested on, there are several factors that must be addressed to improve its robustness and generalizability.

Limitations of Current Model and Future Directions

All the training and validation data used in this study were captured at a consistent altitude of 100 meters above ground level. While this approach provided a controlled environment for model training, it also introduced limitations. For a more robust model, it is essential to train and validate on a diverse set of images that include varying conditions. Future work should incorporate images taken at different times of day, under various climatic conditions, and from multiple angles. Additionally, using different camera types, terrains, and underlying vegetation will help ensure that the model can generalize across different environmental scenarios. This variety in data will help the model become less sensitive to specific conditions and improve its performance in real-world applications.

Georeferenced Segmentations and GIS Integration

While the current study demonstrated the feasibility of detecting and segmenting Brazil nut trees, further steps are needed to translate these detections into georeferenced data that can be utilized for spatial analysis in GIS. The creation of georeferenced drone images through photogrammetry is a critical next step. By generating georeferenced segmentations, each detected tree can be accurately placed within a spatial framework, allowing for the creation of shapefiles that represent the exact locations of the trees.

Merging these shapefiles into a single layer will enable the comprehensive mapping of Brazil nut tree distributions. Given that drone images often have significant overlap (typically 80% or more), this method also offers the advantage of cross-referencing segmentations from different angles. If a tree is partially missed in one image due to poor segmentation, it can be corrected by incorporating segmentations from other angles. This multi-angle approach could significantly improve the accuracy and completeness of the resulting maps.

Potential for Automated Web Application

One of the promising directions for future development is the creation of a web application where users can upload data from automated drone missions. The application could then process these data to generate detection segmentations and corresponding shapefiles as outputs. Additionally, the application could return the georeferenced images, which would be invaluable for further spatial analysis and integration into broader conservation efforts. Such a tool would democratize access to advanced detection and mapping capabilities, making them available to a wider audience, including researchers, conservationists, and forest managers.

Broader Implications and Conclusion

This study represents a significant step forward in leveraging UAV technology and advanced object detection algorithms for environmental monitoring. The ability to accurately detect and map Brazil nut trees has important implications for conservation, sustainable harvest planning, and reforestation initiatives. By refining the model to handle more diverse data and integrating it into geospatial frameworks, this approach could provide a powerful tool for managing Brazil nut tree populations in the Amazon rainforest and other critical ecosystems.

In conclusion, while the model performed well in controlled conditions, expanding the range of data inputs and advancing the georeferencing of detected segmentations will be essential for creating a truly robust and versatile tool. The potential to develop an automated platform that integrates these capabilities could transform the way we monitor and manage valuable forest resources, ensuring their sustainability for future generations.

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