SAF-ADAPT

South Africa / Flanders Climate Adaptation Research and Training Partnership

RESEARCH BRIEF
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Monitoring Invasive Alien Plant Species Using Drone and Sentinel-2 Imagery in Tembe Elephant Park, South Africa

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RESEARCH OVERVIEW

Tembe Elephant Park (TEP) is a protected area located in the Province of KwaZulu-Natal, South Africa, which presents critical problems in the management and control of some invasive alien plant species (IAPS), including Parthenium hysterophorusand Flaveriabidentis. These invaders have the ability to outcompete native vegetation, monopolize resources such as water and nutrients, and alter fire regimes, leading to significant ecological changes, but also economic and social challenges in TEP. As a result, effective monitoring and management strategies are required.

Effective management of IAPS in protected areas like TEP requires precise monitoring and mapping to optimize eradication programs. Traditional field-based surveys, while essential for ground-truth data collection, can be resource-intensive and may not provide comprehensive spatial coverage. To address this, remote sensing technologies using Unmanned Aerial Vehicle (UAV) or drone, and satellite imagery (Sentinel-2) can be used as valuable tools for large-scale and detailed monitoring of IAPS. These technologies allow for the frequent and extensive collection of data, providing a means to detect and map the distribution of invasive species across diverse landscapes in TEP.

IAPS IN TEMBE ELEPHANT PARK

Some Invasive alien plant species have been introduced and established within TEP. Despite numerous eradication programs, some IAPS such as *P. hysterophorus*, and F. bidentis (Fig. 1), continue to be problematic. The TEP management plan prioritizes the control and eradication of IAPS to conserve native biodiversity, allocating significant funds annually (100,000 ZAR per year). Currently, TEP manages IAPS expansion with the application of an herbicide, which is applied once or twice a year, depending on the park's budget. Despite these efforts, positive outcomes have been limited.

PROJECT SUMMARY

This study aimed to map the distribution of invasive species Parthenium hysterophorus and Flaveria bidentis in Tembe Elephant Park using drone imagery and Sentinel-2 satellite imagery. The research objectives included assessing the feasibility of using these imagery types for mapping, identifying key classification variables, evaluating the accuracy of three classifiers, and generating a classification map for future management plans.

KEY FINDINGS

- **Spectral separability and combination methods enhanced variable selection**, with Digital Elevation Model (DEM) being crucial for optimizing classification models across all classifiers.
- Extremely Random Trees (EXT) demonstrated the **highest accuracy for both drone and satellite imagery**. EXT also provided the best accuracy per class, particularly for *P. hysterophorus* and F. bidentis.
- The generated classification map identified 221 pixels as *P. hysterophorus* and 20 as *F. bidentis*. The **model's accuracy was validated by field observations**, showing agreement in species distribution.
- Sentinel-2 imagery had **limitations in detecting early-stage infestations due to its resolution**, whereas high-resolution drone imagery was more effective. Accurate mapping is essential for invasive species control, aiding reserve managers in informed decision-making for intervention and resource allocation.

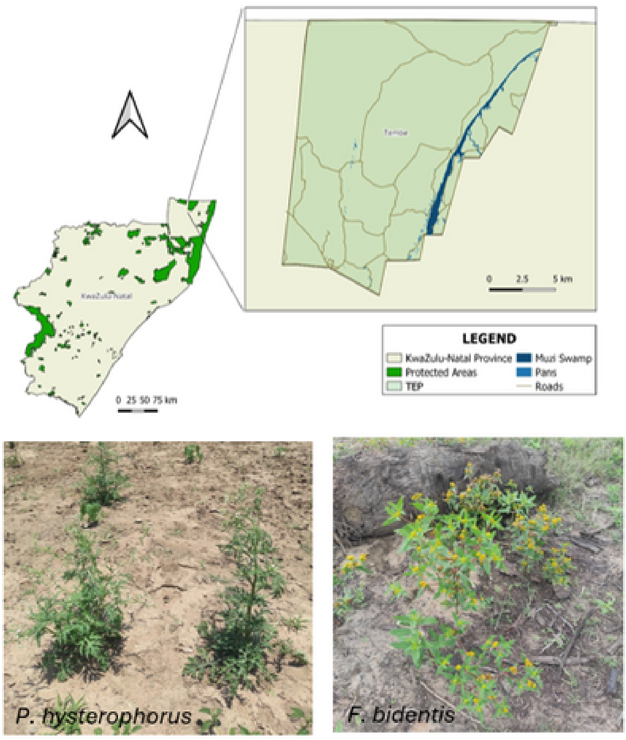

Figure 1. Top: Study area - TEP. Down: Non-native species of interest

UAV AND SATELLITE IMAGERY

UAVs are a good option for IAPS monitoring primarily because they can offer high-quality resolution data at relatively low costs, the relative ease of revisit times, and their ability to access difficult sites provide flexible data acquisition of high spatial and temporal resolution at low cost. Furthermore, satellite imagery is useful for land cover classification, and IAPS monitoring, because of its capacity to cover large areas, provide extensive spectral dataset, and due to temporally datasets can be obtained (Rees, 2012).

In addition, thanks to the development of new algorithmic classification models such as Random Forest (RF), Extremely Random Trees (EXT), and Support Vector Machine (SVM), classification maps and monitoring of IAPS can be generated with good precision and be useful for making decisions regarding the IAPS management. However, the identification of herbaceous IAPS is still challenging due to its size and requires considering some aspects such as the flowering time and the size of coverage that the IAPS present in the study area.

RESEARCH OBJECTIVE

The novel approach taken in this study aims to use drone imagery and publicly available medium-resolution Sentinel-2 imagery to conduct a supervised classification of the study by leveraging the accuracy of RF, SVM, and EXT for P. hysterophorus and F. bidentis discrimination and land cover types in TEP. For this study, four research objectives can be stated:

- To examine the feasibility of mapping *P. hysterophorus* and *F. bidentis* in TEP using drone imagery and satellite imagery.
- To identify the most important variables in the classification for both IAPS.
- To evaluate the accuracy among three different classifiers (RF, SVM, and EXT) for drone imagery and satellite imagery for each classification class.
- To generate a classification map including the two IAPS for future management plans regarding invasive species in TEP.

Figure 2. Drone flight setup during fieldwork

METHODS

The study was carried out in Nov 2023 and covered the entire area of TEP, placing more emphasis on areas near roads, wetlands, floodplains, areas infested with IAPS, and the main entrance. A total of 82 flights were carried out over different areas. Of this total, 49 drone flights were processed, seven of them containing the presence of any of the IPAS of interest. On the other hand, a satellite image was processed. For the classification of the different land cover types, a general categorization was carried out, obtaining 7 categories: Forest, Bare soil, Grassland, Water, Build-up area, P. hysterophorus, and F. bidentis. Regarding spectral variables, both spectral and environmental variables were used: 10 spectral bands, 15 vegetation indices, and the Digital Elevation Model (DEM).

To optimize the classifiers, an exploratory analysis was carried out on their spectral separability and multicollinearity, and the all combinations method was used to find the best combination of variables. Three different classifiers RF, EXT, and SVM were used, which were evaluated with different methods (F1 score, Confusion Matrix, Kappa Value, and Gini Importance Score. Finally, a classification map was made with the classifier that presented the best accuracy. A general workflow is shown in Fig. 3.

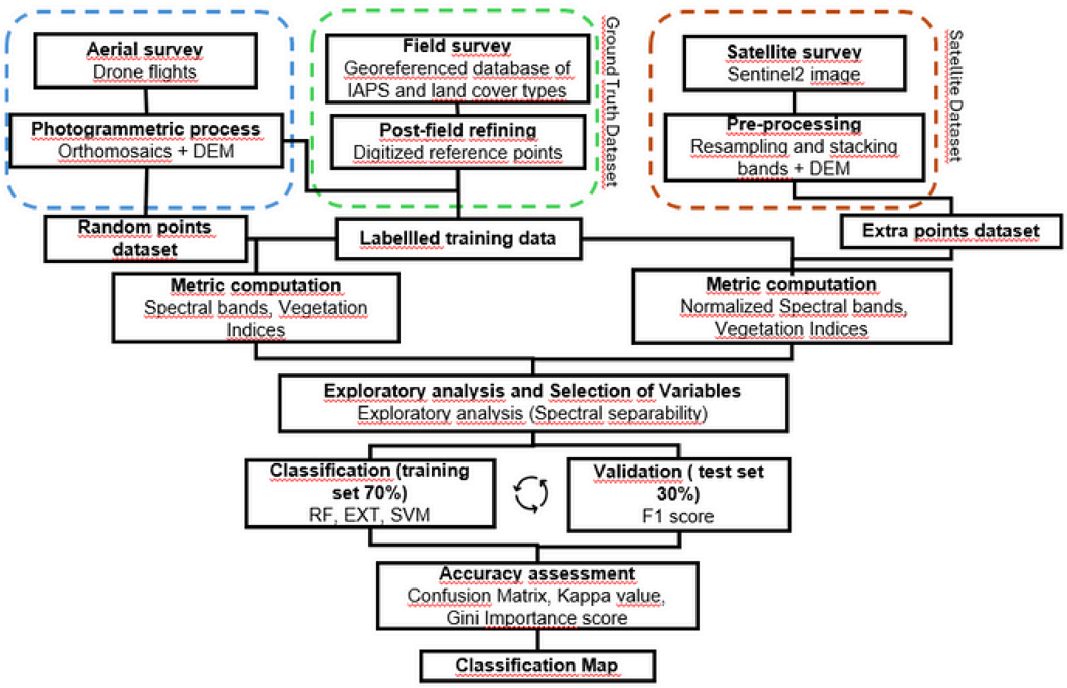

Figure 3. General workflow

KEY FINDINGS

- Spectral separability and all combination methods allow for a better selection of the variables Table 1.
- DEM provides valuable information to optimize classification and discrimination models between classes. It is among the top variables for all classifiers.
- For both drone imagery and satellite imagery, the classifier that showed the best accuracy was Extremely Random Trees, followed by Random Forest and Support Vector Machine. In the case of drone imagery, an accuracy of 84%, 82%, and 66% was obtained. For satellite imagery 90% and 91% respectively.
- The classifier with the best accuracy per class was EXT, obtaining an accuracy of 77% for P. hysterophorus and 40% for F. bidentisand reasonable user and producer accuracies (Fig. 4). This model was used to generate the classification map (Fig 5).

- The classification map shows the different land cover types for TEP. Moreover, it shows 221 pixels classified as P. hysterophorus and 20 as F. bidentis (Fig 5).

- By comparing the classification pixels with the observations made in the field, it is possible to notice the agreement of distribution of the species. P. hysterophorushas a presence around the main entrance of TEP and in open areas dominated by bare soil and grasslands. For its part, F. bidentishas a distribution near the Muzi swamp where a few individuals of P. hysterophoruswere also recorded (Fig 6).

- The classification map shows the different land cover types for TEP. Moreover, it shows 221 pixels classified as P. hysterophorus and 20 as F. bidentis (Fig 5) the fact that it is not the greatest period of proliferation and a relatively short time after having applied the eradication measure.

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- Despite the expectation of broader distribution, the invasive species were less widespread due to the timing of data collection and ongoing eradication efforts, highlighting the effectiveness of the model in identifying areas prone to invasion.

- The study found that Sentinel-2 imagery is limited in detecting early stages of infestations of invasive species due to its resolution, areas where IAPS coverage is low classifiers can not discriminate correctly these classes. High-resolution drone imagery proved more effective for early detection and monitoring.

- Accurate mapping is crucial for controlling the spread of invasive species and the maps generated can significantly aid reserve managers in making informed decisions regarding intervention and resource distribution.

Table 1. Best variable combination per classifier and model

Classifier	UAV model
RF	band 1, band 2, band 3, band 4, DEM, SAVI
EXT	band 1, band 3, band 5, DEM, NDVI
SVM	band 2, DEM, NDVI, VARI, NDRE

Classifier	Sentinel-2 model
RF	band 1, band 2, band 3, band 6, band 7, band 8, band 11, DEM, REP, SR, YVIMSS, NDWI, GNDVI, GVMI, GARI
EXT	band 1, band 2, band 3, band 8, DEM, REP VARI

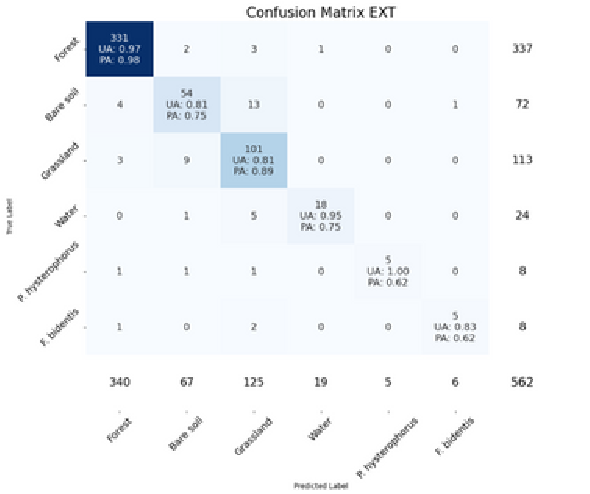

Figure 4. Confusion matrix for EXT classifier using Sentinel-2 imagery

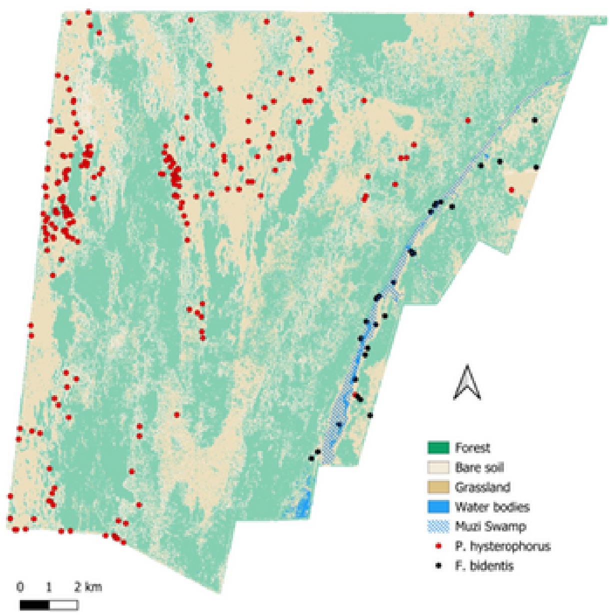

Figure 5. Classification map for Tembe Elephant Park

RECOMMENDATIONS

For future improvements, the study recommends enhancing ground truth data collection, especially during the flowering season, and using multi-temporal imagery to capture seasonal variations. Monitoring invasive species independently rather than collectively can also improve accuracy by reducing noise and confusion with other land cover types.

This approach ensures that the models are robust and effective in providing detailed insights into the distribution and impact of invasive species, facilitating more efficient and sustainable management strategies in TEP and similar protected areas.

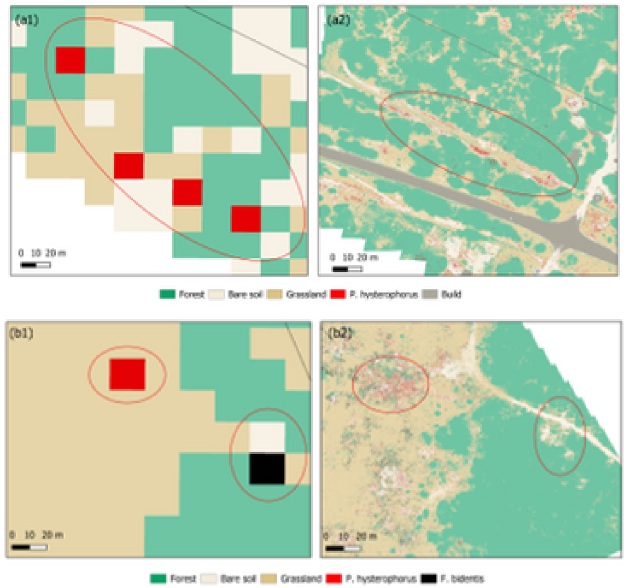

Figure 6. Areas where target species were recorded. a) TEP main entrance (1) Map derived from Sentinel-, (2) Map derived from drone. b) Nearby to Muzi swamp (1) Map derived from Sentinel-2, (2) Map derived from drone

CONCLUSION

This study demonstrates the effectiveness of combining advanced remote sensing technologies with machine learning classifiers to monitor and manage invasive alien plant species (IAPS) in protected areas. Using UAV and Sentinel-2 imagery along with classification algorithms (RF, EXT, and SVM), the research successfully identified and mapped invasive species such as P. hysterophorus and F. bidentis. The EXT classifier outperformed RF and SVM by effectively using spectral features to enhance classification accuracy.

The results provide detailed spatial maps showing the distribution of invasive species and land cover types within the Tembe Elephant Park. These maps are invaluable for targeted conservation efforts, allowing for optimized resource allocation and better management strategies, reducing the need for extensive field surveys.

The study highlights the scalability and adaptability of these methodologies to other protected areas with similar challenges. Future research should focus on improving ground truth data, gathering multi-temporal data, and addressing class imbalances to further refine these models. This approach offers a robust framework for more effective and sustainable conservation practices globally.

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