Monitoring the invasion of Campuloclinum Macrocephalum (Less) DC plants using a novel MaxEnt and Machine Learning ensemble in the Cradle Nature reserve, South Africa

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Abstract

The proliferation of non-native plant species has caused significant changes in global ecosystems, leading to a surge in international interest in the use of remote sensing technologies for both local and global detection applications. The Greater Cradle Nature Reserve, a UNESCO World Heritage Site, is facing a decline in its global status due to the spread of pompom weeds, affecting its biodiversity. A significant reduction in grazing capacity leads to the displacement of game animals and the replacement of native vegetation. We used Sentinel-2A multispectral images to map the distribution of pompom weeds. At the nature reserve from 2019 to 2024, which allowed us to distinguish it from other land cover types and determine the appropriateness of the habitat. The SVM model provided 44% and 50.7% spatial coverage of pompom weed at the nature reserve in 2019 and 2024, respectively, whereas the RF model yielded 31.1% and 39.3%, respectively. The MaxEnt model identified both soil and rainfall as the most important environmental factors in fostering the aggressive proliferation of pompom weeds at the nature reserves. The MaxEnt predictive model obtained an area under curve score of 0.94, indicating outstanding prediction model performance. Classification of above 75%, indicating that they could distinguish pompom weeds from existing land cover types. For sustainable environmental management, this study suggests using predictive models to effectively eradicate the spatial distribution of invasive weeds in the present and future.

Keywords *Campuloclinium macrocephalum (Less.)* DC, Sentinel-2A, MaxEnt model, Machine learning models, Cradle Nature Reserve, South Africa

Climate Change

Climate Change (CC) has gained global attention, it is projected that global temperatures could rise by 1.5° C (2.7°F).

Environmental changes driven by climate change are visible globally: frequency of veld fires, extreme weather events, changing rainfall patterns and disturbance of ecosystems by invasion of alien invasive plants (AIP).

Integrated Environmental Monitoring: Biodiversity

One of the documented key contributors of anthropogenic activities related to global environmental change is the invasion of ecosystems by invasive alien plants (AIPs).

The Alien Plants are non-native plants introduced into a new locations intentionally or accidentally by humans.

The invasion of AIPs have economic and ecological effects, altering the functioning of indigenous ecosystem.

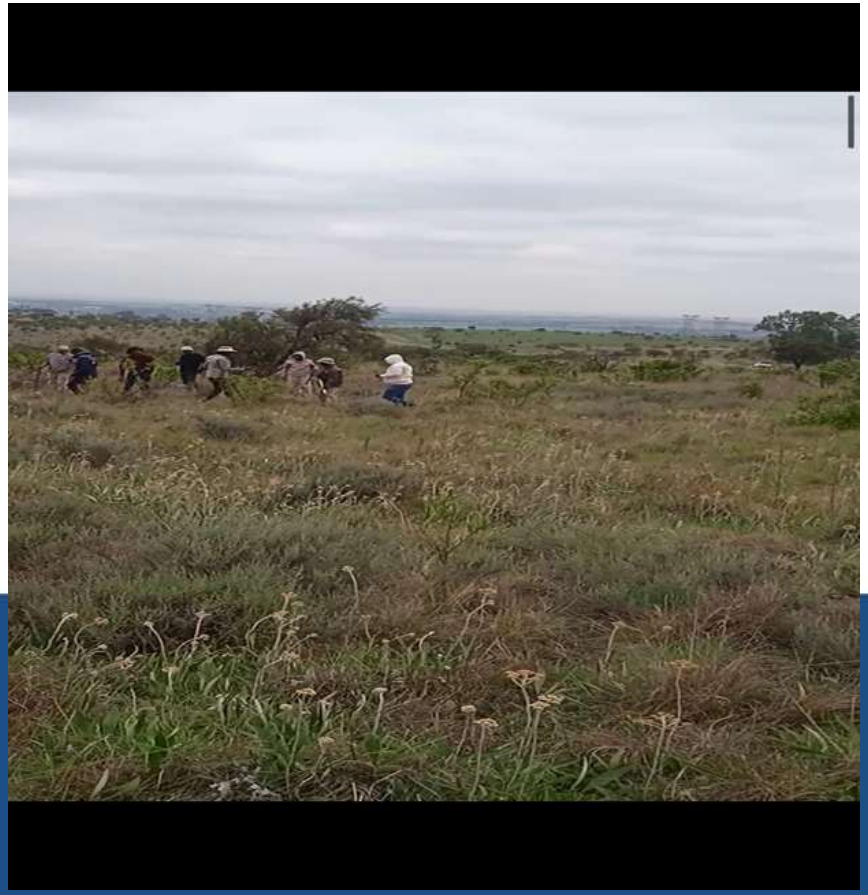
The AIPs are considered the second largest cause of biodiversity loss (N.B)

Consequences of Alien Invasive Plants in SA

- Compete with indigenous vegetation for space & water retention ** SA water scare country.
- Reduce rangeland capacity for livestock & game animals: Thus, threatens Biodiversity.
- Necessitates veld fires.
- R600 million spent on rehabilitation & control measures.

Control Measures

- Mechanical, Chemical & Biological control measures.



Remote Sensing Technology: Biodiversity Monitoring.

- The application of remote sensing offered an opportunity in natural resources monitoring.

- The availability of satellite products e.g ESA Sentinel-2, WorldView and UAVs improved on land monitoring purposes. They improved the science of obtaining comprehensive spatial data on the distributions of AIPs, counteracting the traditional methods of site surveying which are expensive and time consuming.

- Timely and accurate spatial data on AIPs is required, to enhance knowledge on the spatial trend patterns of IAPs. To inform best environmental practices, allocate resources to mitigate and management of AIPs.

Space Science: NASA Constellations

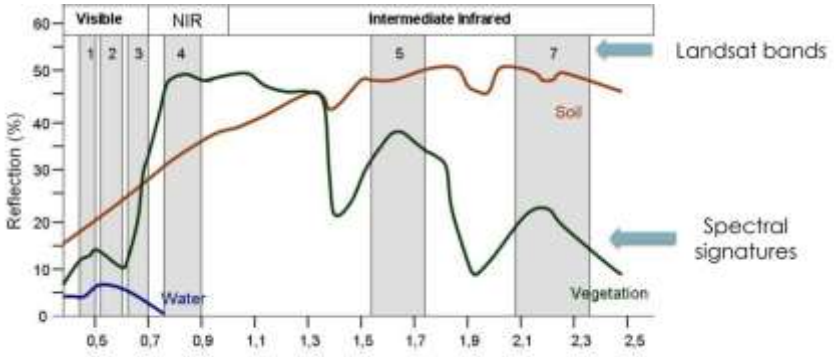
ESA Sentinel Missions

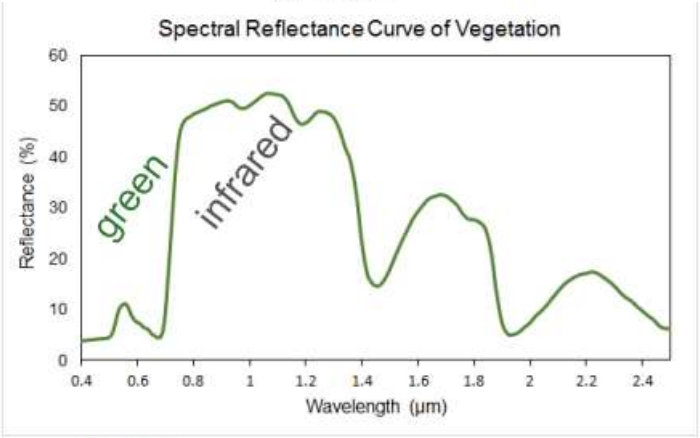
Remote Sensing: Spatial & Temporal Resolutions

Satellite	Spatial Resolution	Temporal Resolution
Landsat 8	30m	16 days
MODIS (Terra + Aqua)	250m, 500m, 1000m	1 to 2 days
VIIRS	375-m	12 hours
AVHRR	1100m	<1 day
Sentinel-2	10m, 20, 60m	5 days
Ikonos	0.8m, 3.2m	< 3 days
SPOT-7	1.5m, 6m	As low as 1 day

Remote Sensing: Detection & Monitoring of AIPs

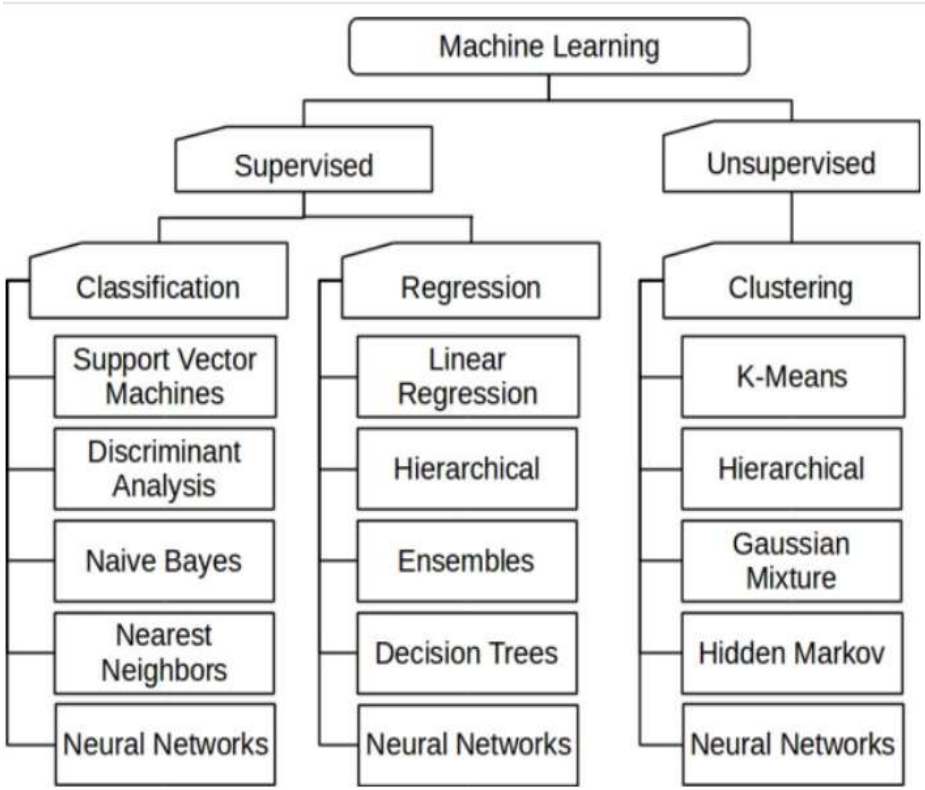
Spectral Signatures





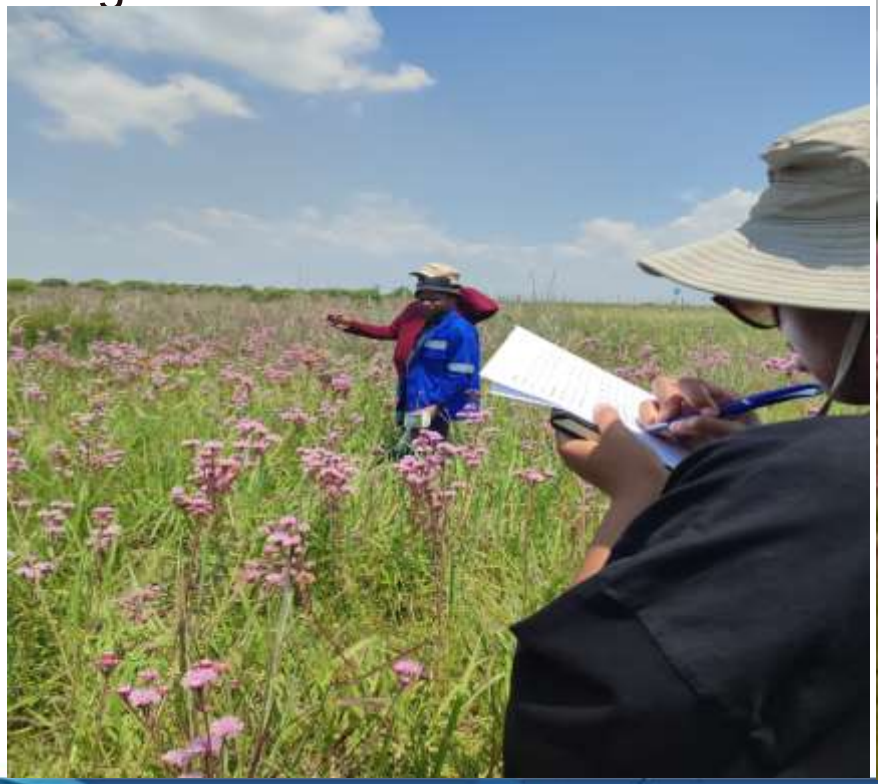
blue red

Classification Algorithms



Target Species

The Campuloclinium macrocephalun (Less) DC alternatively known as pompom weed is a foreign hemicryptohytic herb that invades disturbed rangelands.

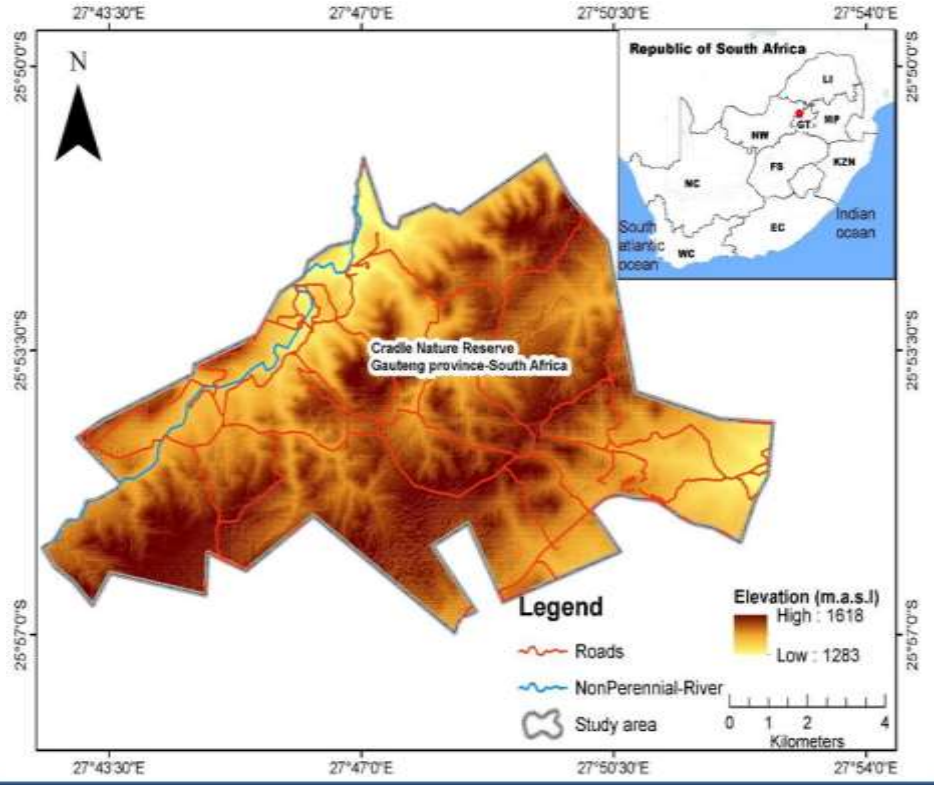


Target Species Description

- The Pompom weed is native to Central and South America.
- The perennial erect herb is 1.3m-1.5m high. It flowers in spring and then dies in winter.
- The weed has fluffy pink flowerheads, with light green leaves that are scattered around the full length of the green stem and clustered at the base of the plant to form like a rosette (McConnachie et al., 2011).
- In South Africa, pompom weed was introduced in the 1960s for ornamental purposes.
- Stats: 7 out of 9 provinces of South Africa pompom weed has been recorded.
- Gauteng province recorded high infestations.

Study Area: The Cradle Nature Reserve

The Greater Cradle Nature Reserve is a UNESCO declared world heritage site in Krugersdorp, northwest of Gauteng province



Problem Statement

- The Greater Cradle nature reserve is a preserved site with a significant cultural value and variety of biodiversity.

- The pompom weed is a declared category 1b “exotic weed” in South Africa. it is threatening the conservation of grassland and savannah biomes in the highveld.

- The Pompom weed infestation at the UNESCO declared world heritage site is causing environmental degradation and threatening the biodiversity.

- The uncontrolled expansion of invasive pompom weed lowers the grazing capacity for the game animals, forcing the game animals to migrate. In such the nature reserve loses its significance and the accorded world status. Thus, the Gauteng tourism is compromised subsequently leading to loss of employment due to less revenue generated.

- The **aim** of this study: To model the spatial distribution of Campuloclinium macrocephalum (Less) DC at the Cradle nature reserve using Sentinel-2 MSI product.

- The **objectives** of the study are as follows:
- (i) To assess the efficacy of support vector machines (SVM) and random forests (RF)to accurately detect Campuloclinium macrocephalum (Less) DC against the existing species using Sentinel-2 multispectral data from 2019 to 2024.

- (ii) To model Campuloclinium macrocephalum (Less) DC using MaxEnt species distribution model to strengthen the machine learning findings.

- (iii) To recommend effective invasive plants eradication measures.

Materials & Methodology

Field Data Collection

Sentinel-2 Acquisition

Band	Resolution	Central Wavelength	Description
B1	60m	443 nm	Ultra blue
B2	10m	490 nm	Blue
B3	10m	560 nm	Green
B4	10m	665 nm	Red
B5	20m	705 nm	Visible & NIR
B6	20m	740 nm	Visible & NIR
B7	20m	783 nm	Visible & NIR
B8	10m	842 nm	Visible & NIR
B8A	20m	865 nm	Visible & NIR
B9	60m	940 nm	SWIR
B10	60m	1375 nm	SWIR
B11	20m	1610nm	SWIR
B12	20m	2190nm	SWIR

Machine Learning Classification Algorithms

Support Vector Machine

- Supervised machine learning.
- Defines a **hyperplane** that segregates the data of different classes.
- Adopted **Kernel function** concepts.
- Ability to overcome high dimensionality & performs well with small training samples.

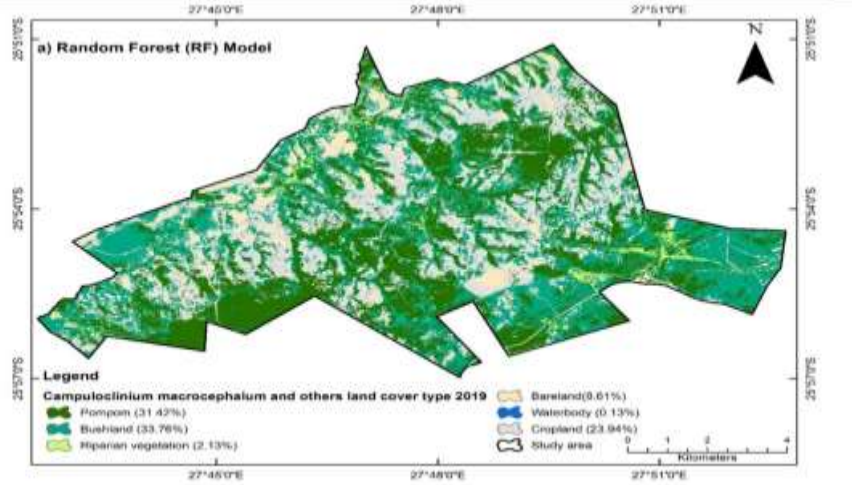
Random Forests

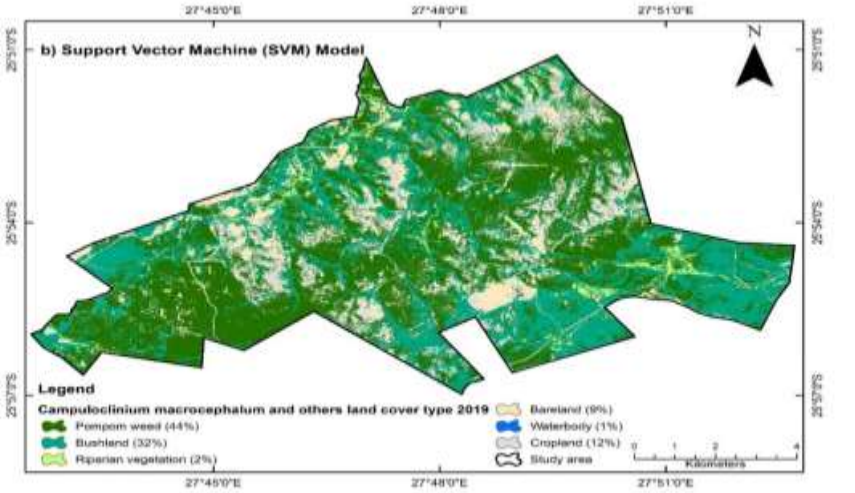
- A tree regression-based supervised model.
- It creates decision trees based on the input data samples.
- During classification it **votes** for the class with high input data.
- The greater number of trees, the higher accuracy and problem solving ability.

MaxEnt Species Distribution Modelling

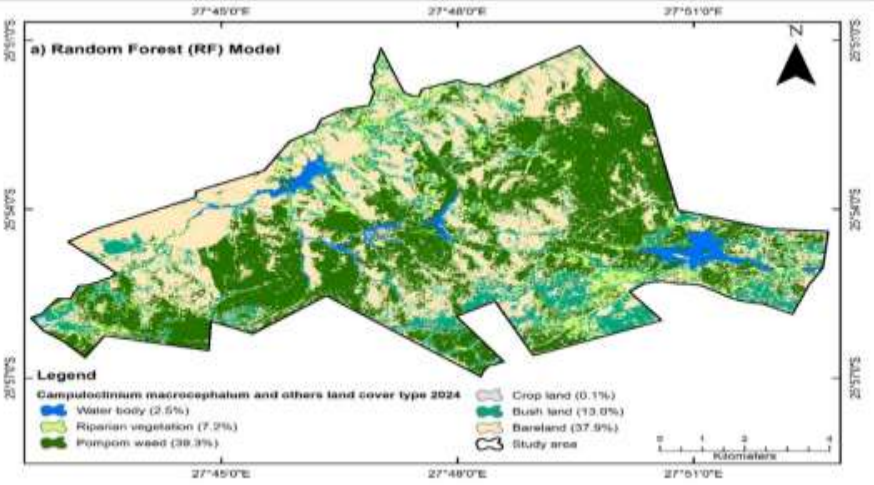
- Species distributions models (SDM) frequently used in ecological studies.
- Ability in forecasting current & future spatial distributions of IAPs.
- MaxEnt SDM open source software, computer efficiency & uses presence-only data (i.e GPS of target species).
- Environmental data(i.e rainfall, soil, temp, elev) downloaded from NASA Power Data.
- The AUC assess the performance of MaxEnt SDM

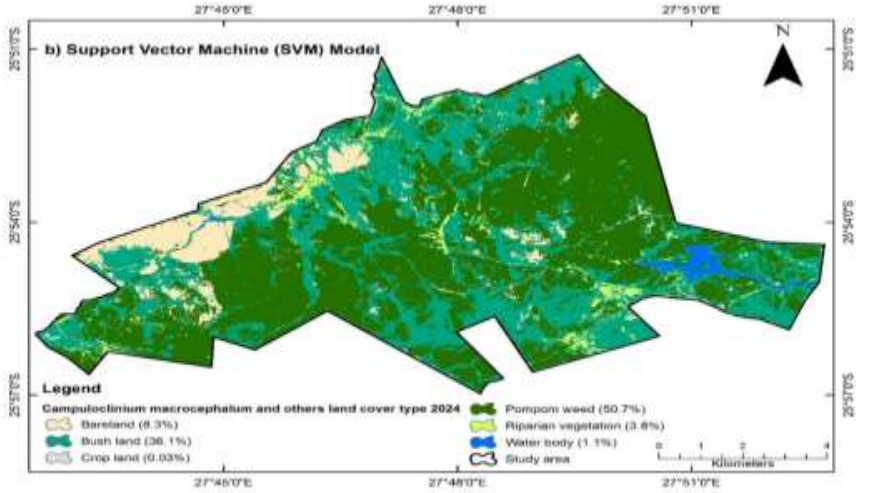
2019


a) Random Forest (RF) Model
Legend
Campuloclinium macrocephalum and others land cover type 2019
Pompom (31.42%)
Bushland (33.76%)
Riparian vegetation (2.13%)
Bareland(0.61%)
Waterbody (0.13%)
Cropland (23.94%)
Study area
Kilometers

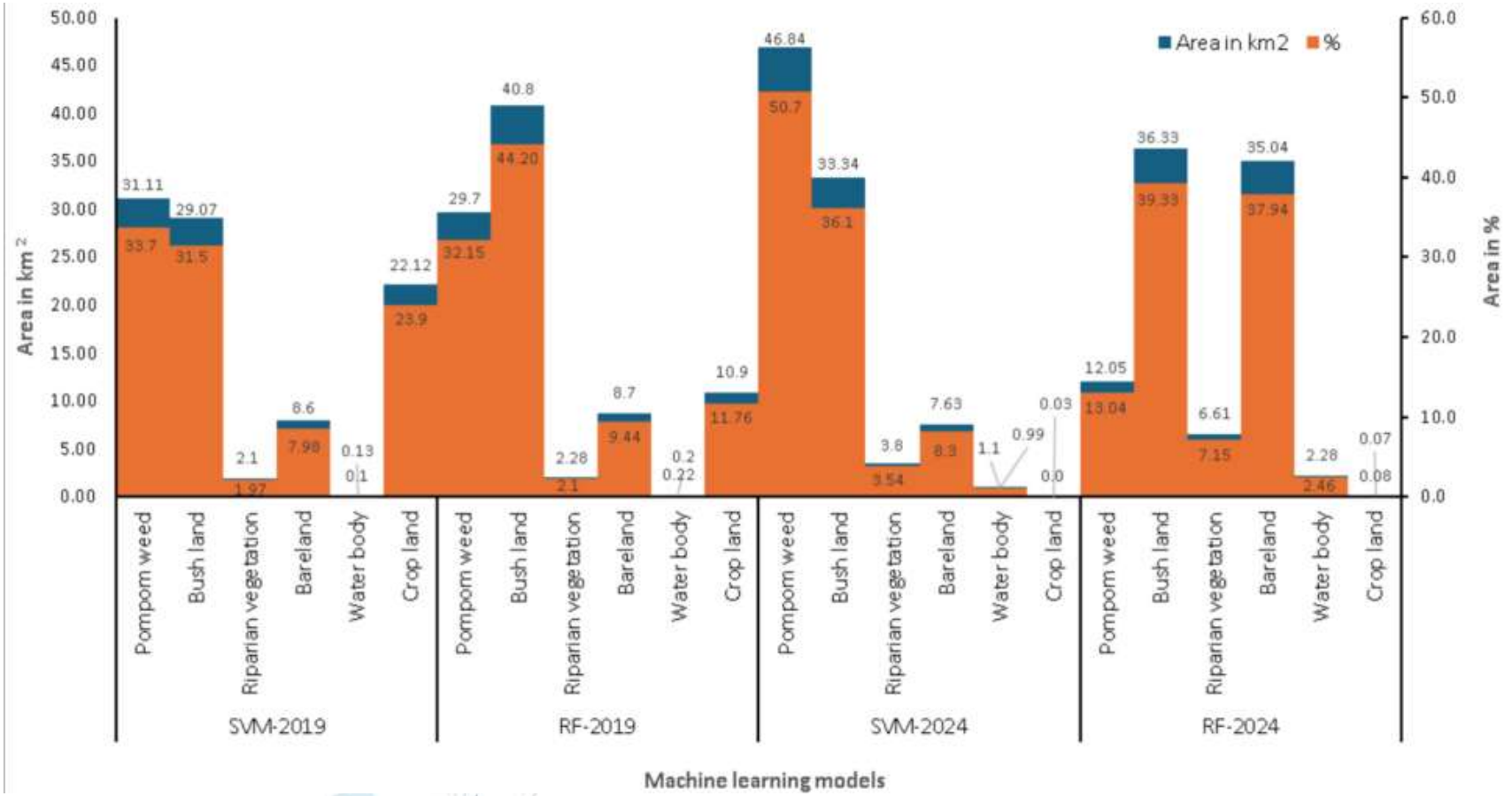

b) Support Vector Machine (SVM) Model
Legend
Campuloclinium macrocephalum and others land cover type 2019
Pompom weed (44%)
Bushland (32%)
Riparian vegetation (2%)
Bareland (9%)
Waterbody (1%)
Cropland (12%)
Study area
Kilometers

2024

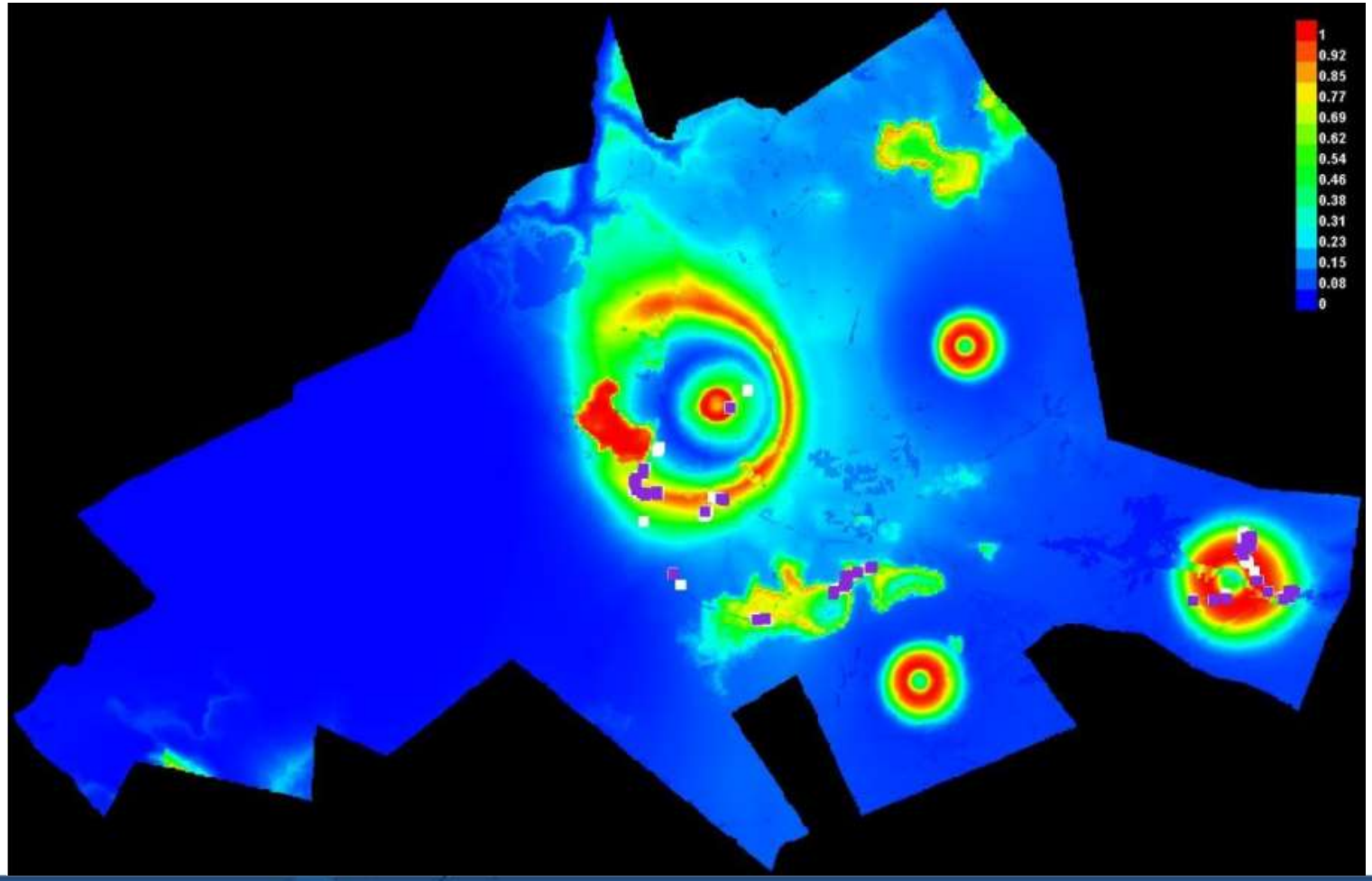

a) Random Forest (RF) Model
Legend
Campuloclinium macrocephalum and others land cover type 2024
Water body (2.5%)
Riparian vegetation (7.2%)
Pompom weed (39.3%)
Crop land (0.1%)
Bush land (13.6%)
Bareland (37.9%)
Study area
Kilometers


b) Support Vector Machine (SVM) Model
Legend
Campuloclinium macrocephalum and others land cover type 2024
Bareland (8.3%)
Bush land (38.1%)
Crop land (0.03%)
Pompom weed (50.7%)
Riparian vegetation (3.8%)
Water body (1.1%)
Study area
Kilometers

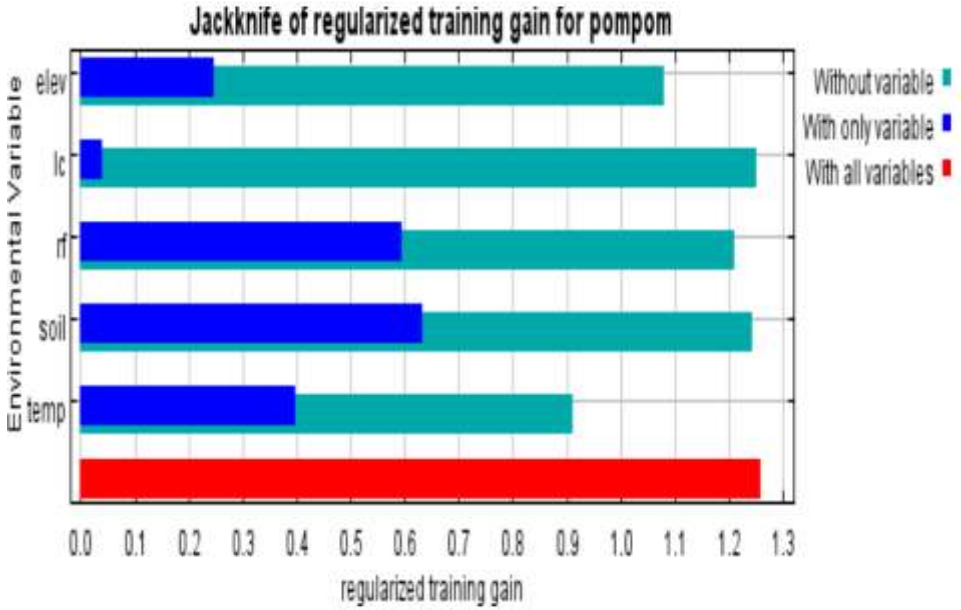
Changes in Areal Coverage

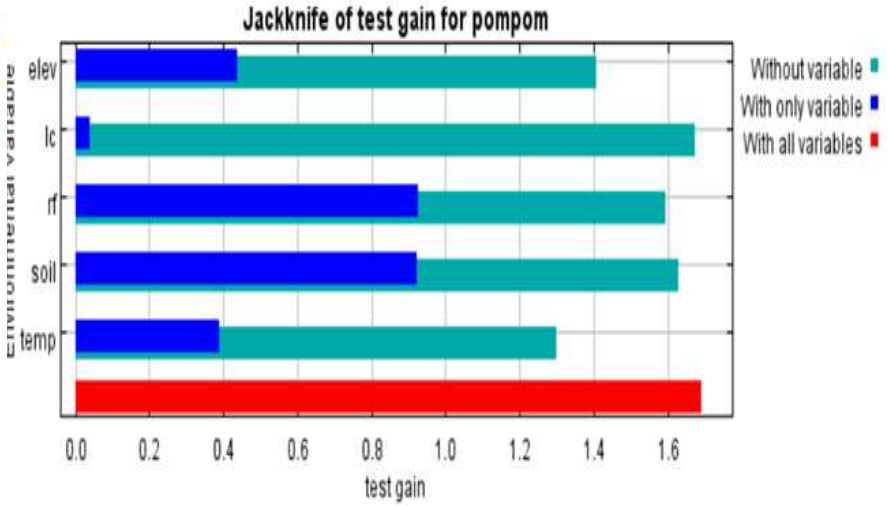


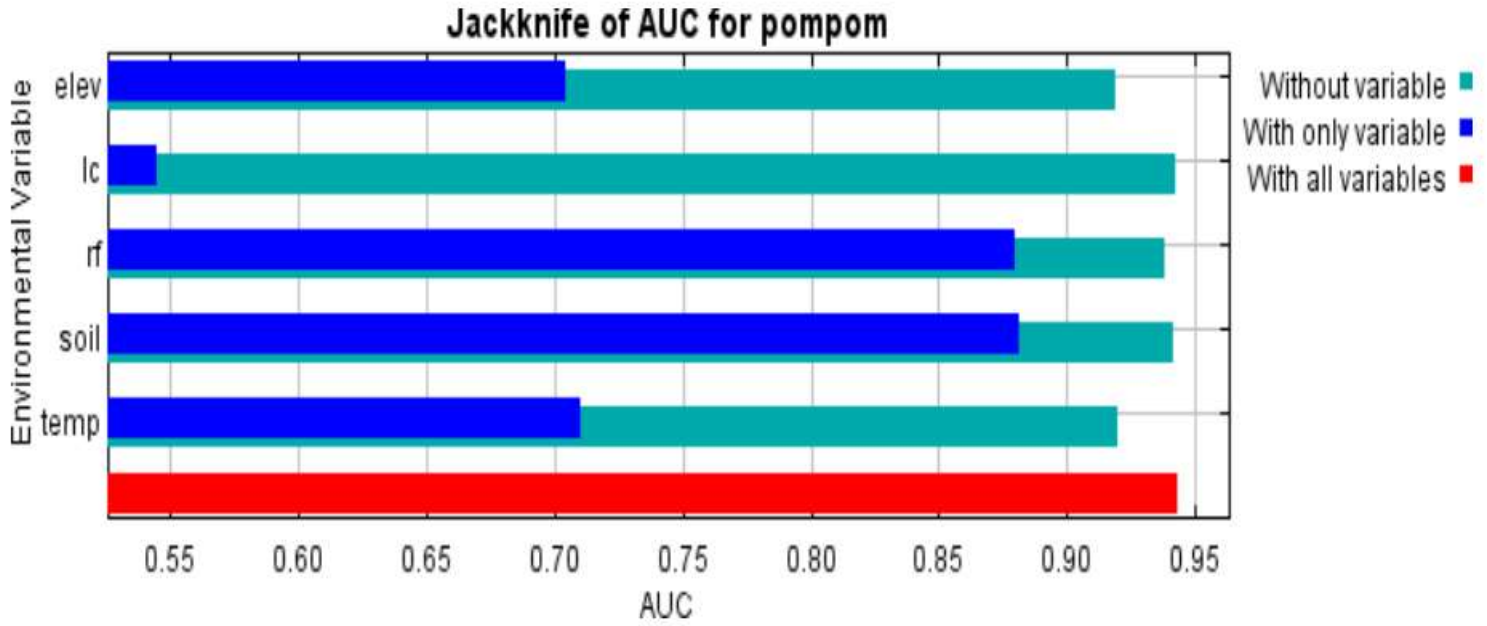
MaxEnt Prediction Model: Pompom Weed



MaxEnt model based: Analysis of Environmental factors



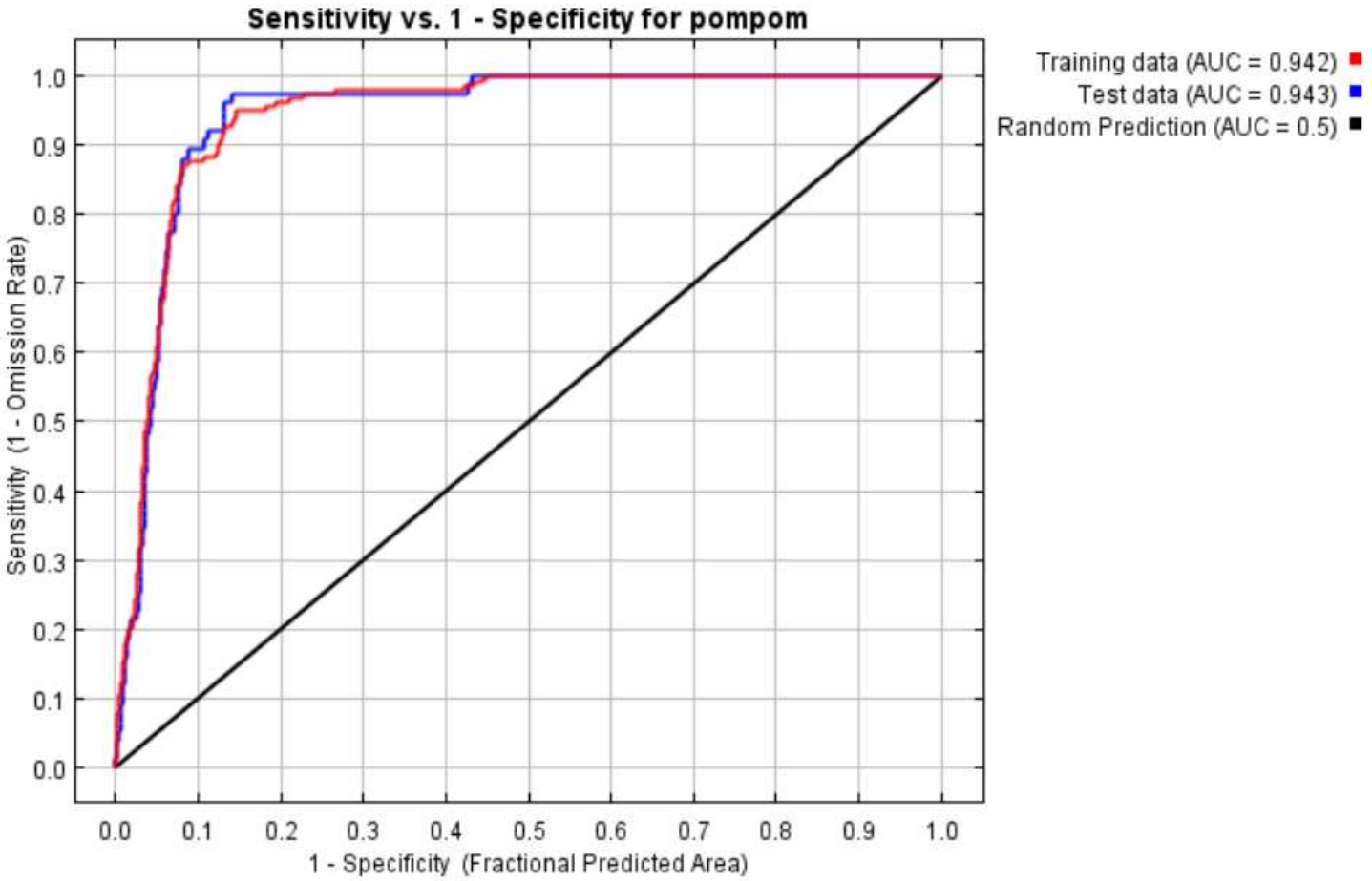



Jackknife of AUC for pompom
Environmental Variable
elev
lc
rf
soil
temp
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
AUC
Without variable
With only variable
With all variables

Analysis of each environmental variable contributions to pompom

Environmental Variables	% Contributions	Permutation Importance
Soil	44.8	39.3
Temperature	29.8	30.3
Rainfall	14.3	21.2
Elevation	10.7	8.7
Land Cover	0.4	0.5

MaxEnt SDM Evaluation



Findings of the study

- The encroachment of Pompom weed rapidly increased in the nature reserve from 2019 and 2024.
- Support Vector Machine (SVM) was a robust classification model in accurately detecting Pompom weed against the co-existing vegetation.
- Environmental factors: Soil & rainfall were identified as significant contributors to Pompom weed infestation.
- Based on Predictive model: Rehabilitation should be prioritized on areas identified as High habitat suitability.

Findings of the study: Continued

- The nature reserve soil chemistry needs to be investigated.
- Land disturbances during road construction and carbon feeding from vehicles can explain the infestations of pompom weeds along roadsides.
- The findings of this study recommend further research to determine whether the carbon from automobiles causes Pompom weed infestations along roadsides.

Take-Out From the Study: Remote Sensing

- The power of remote sensing technology to obtain spatial data on IAPs.
- The effectiveness of Remote Sensing in mapping spatial distribution of IAPs (Local Based).
- The advantage of obtaining historical data: To perform change detection purposes i.e the historical patterns to understand the spreading of IAPs altering land coverage.
- Sentinel-2 MSI: The red edge band played a key role in Pompom weed detection at the Cradle nature reserve.

Prediction Models: Environmental Factors

- Mapping spatial distribution of IAPs alone, is not sufficient in addressing the complexies in rapid encroachment of IAPs.
- Environmental factors needs to be investigated in assisting the germination and habitat suitability of IAPs.
- The MaxEnt prediction model is effective in providing accurate estimations of IAPs based on past climate & current environmental factors.

Thank You

“I can Do all things through Christ who strengthens me”
Philippians 4:13