Federal Ministry for Economic Affairs and Climate Action

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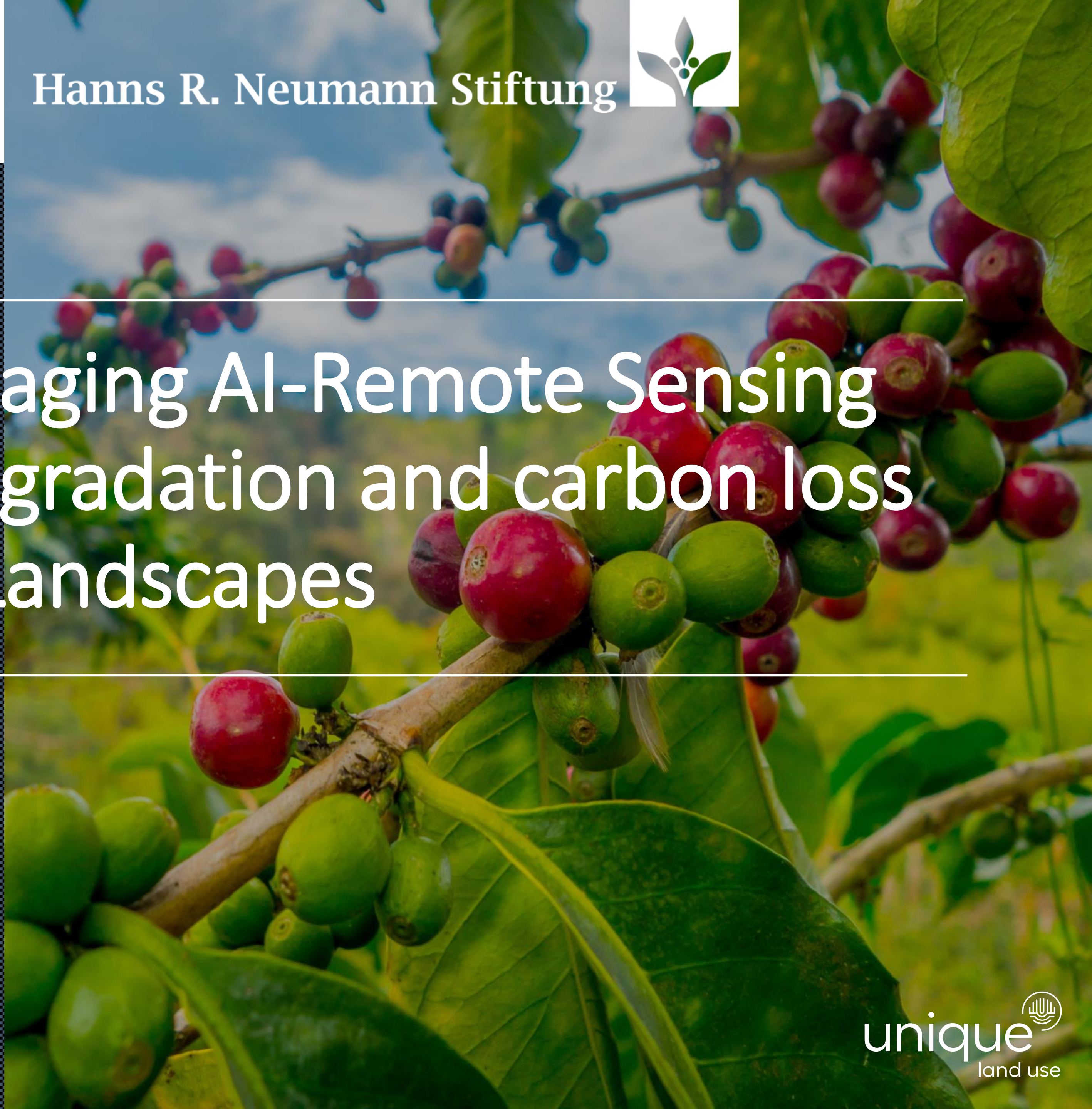

Smart Forests: Leveraging AI-Remote Sensing to combat Forest Degradation and carbon loss in Ethiopian Coffee Landscapes

Dr Michelle Kalamandeen
Katja Weyhermüller
Dr Johannes Pirker

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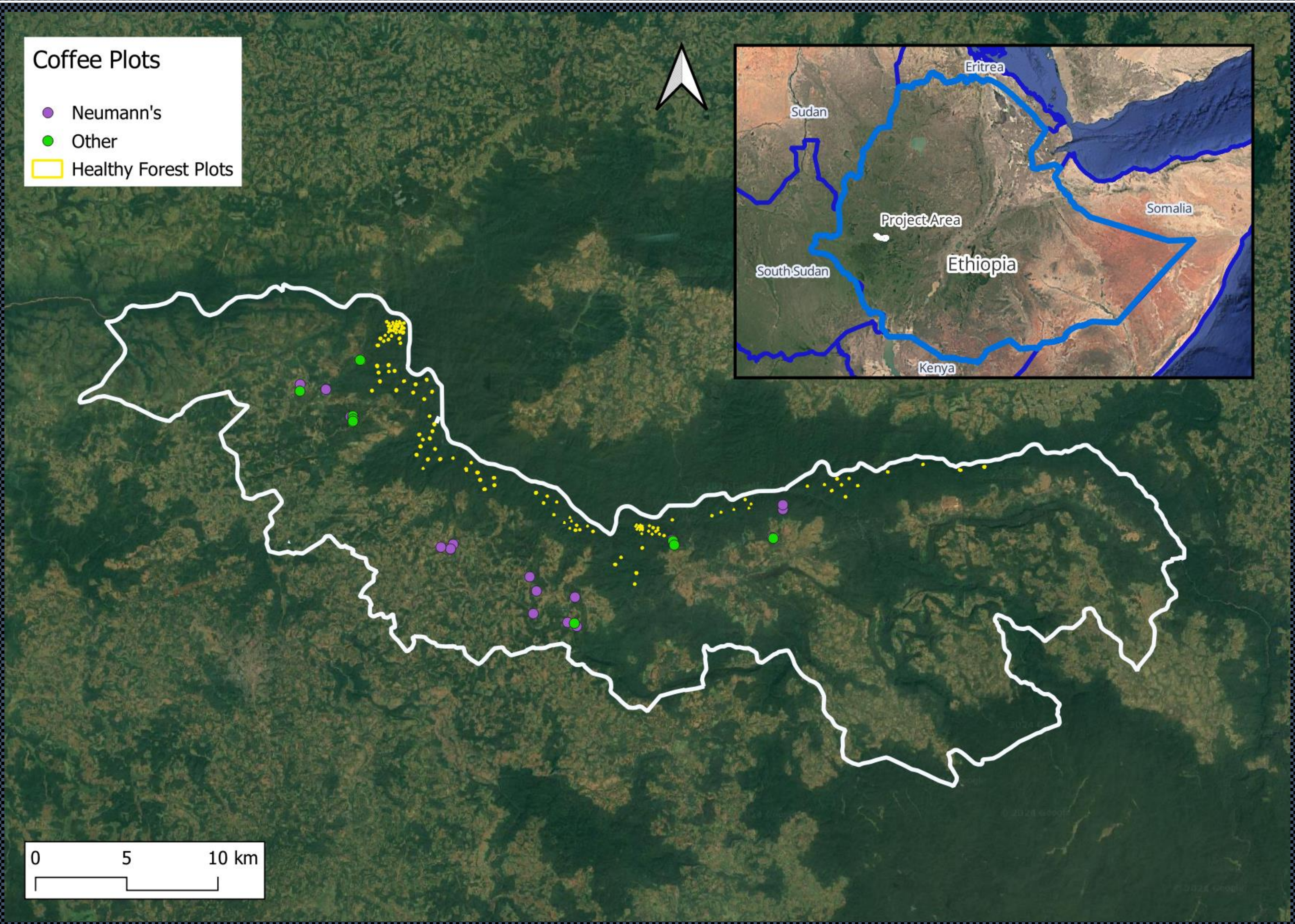
unique land use

Introduction

- Forest degradation not only leads to significant carbon loss but also threatens biodiversity, disrupts water cycles, and undermines sustainable agriculture.
- In Ethiopia, population growth and agricultural expansion, particularly in coffee-growing regions, have placed immense pressure on forest ecosystems.
- Our project focuses on leveraging AI and remote sensing technology to address these challenges by monitoring and mitigating forest degradation in Ethiopian coffee landscapes.
- By combining advanced neural networks with satellite imagery, we aim to provide a robust, data-driven solution for managing forest health, promoting sustainable coffee agroforestry, and reducing carbon emissions.

Site Location



We examined

- 13 Baseline or Unmanaged Coffee plots
- 17 managed (Neumann's) Coffee plots
- 110 Healthy Forest plots

to compare forest health and degradation over time.

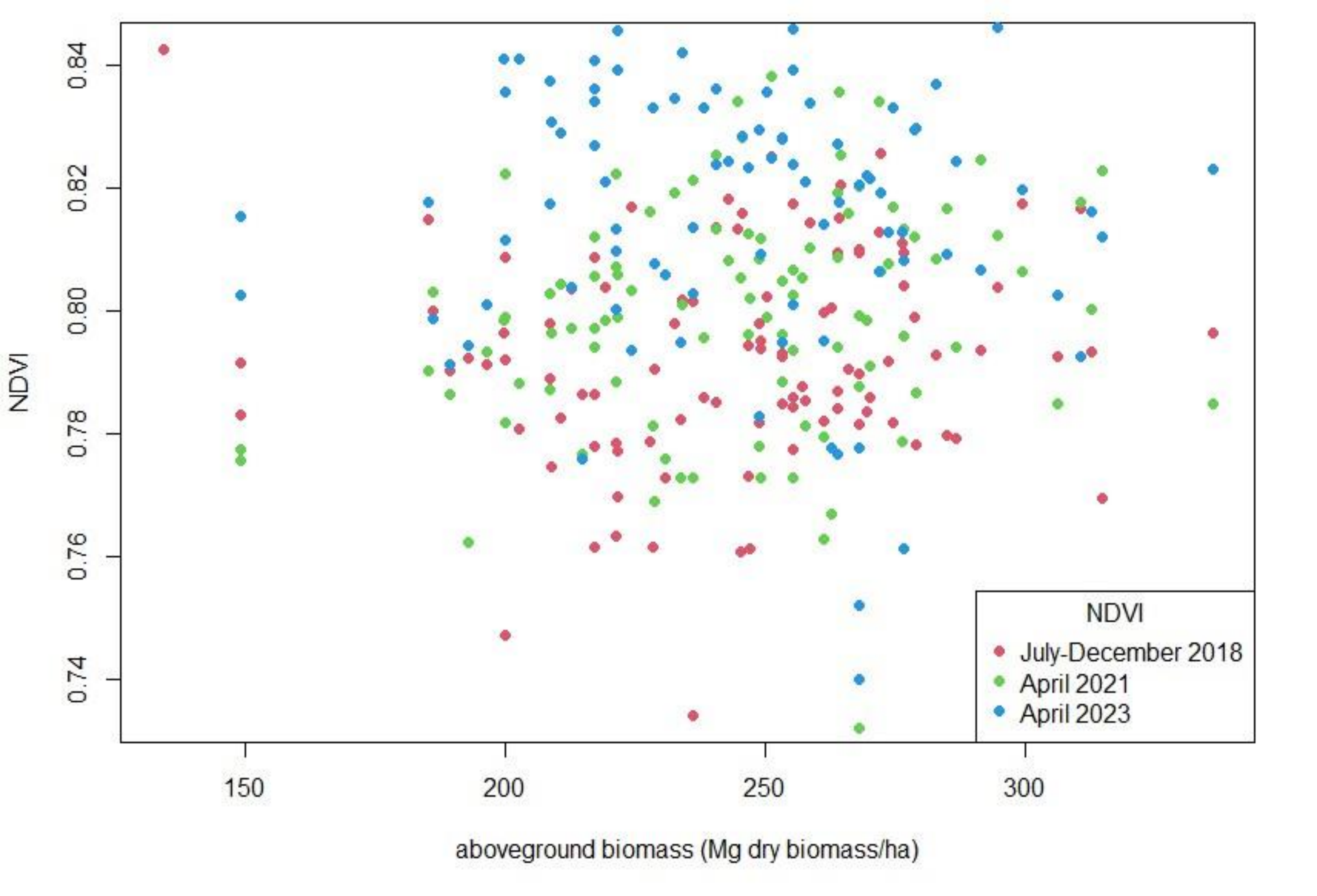
Objectives

1. Evaluate the Effectiveness of Forest Management: Assess whether forest management interventions have successfully reduced degradation rates on the coffee plots managed by partnering farmers.
2. Monitor Degradation Over Time: Evaluate forest degradation trends using various vegetation indices between 2020 and 2023 to track changes.
3. Estimate Biomass and CO2 Emissions: Quantify biomass changes across the area of interest (AOI) and estimate CO2 emissions from managed and baseline coffee plots to establish a baseline for emissions assessment.

Method

1. We examined the relationship between NDVI (Normalized Difference Vegetation Index) from Sentinel-2 satellite imagery and field biomass data to establish a baseline understanding of forest health in coffee plots.
2. Using a neural network model, we predicted NDVI values based on biomass data from healthy forest plots. The model was trained with historical data to understand the complex relationships between biomass and vegetation health.
3. We reclassified Sentinel-2 NDVI maps for the entire area of interest using the NDVI values predicted by the neural network, improving the accuracy of the maps and providing a clearer picture of current forest health.
4. To assess forest degradation between 2020 and 2023, we analyzed different vegetation indices (NDVI, NDWI, and EVI) to help us detect degradation patterns related to vegetation cover and water stress.
5. Finally, we estimated biomass changes over time (2020–2023) and calculated the associated CO_2 emissions for both managed and baseline coffee plots. This allowed us to assess the environmental impact of forest degradation in these areas.

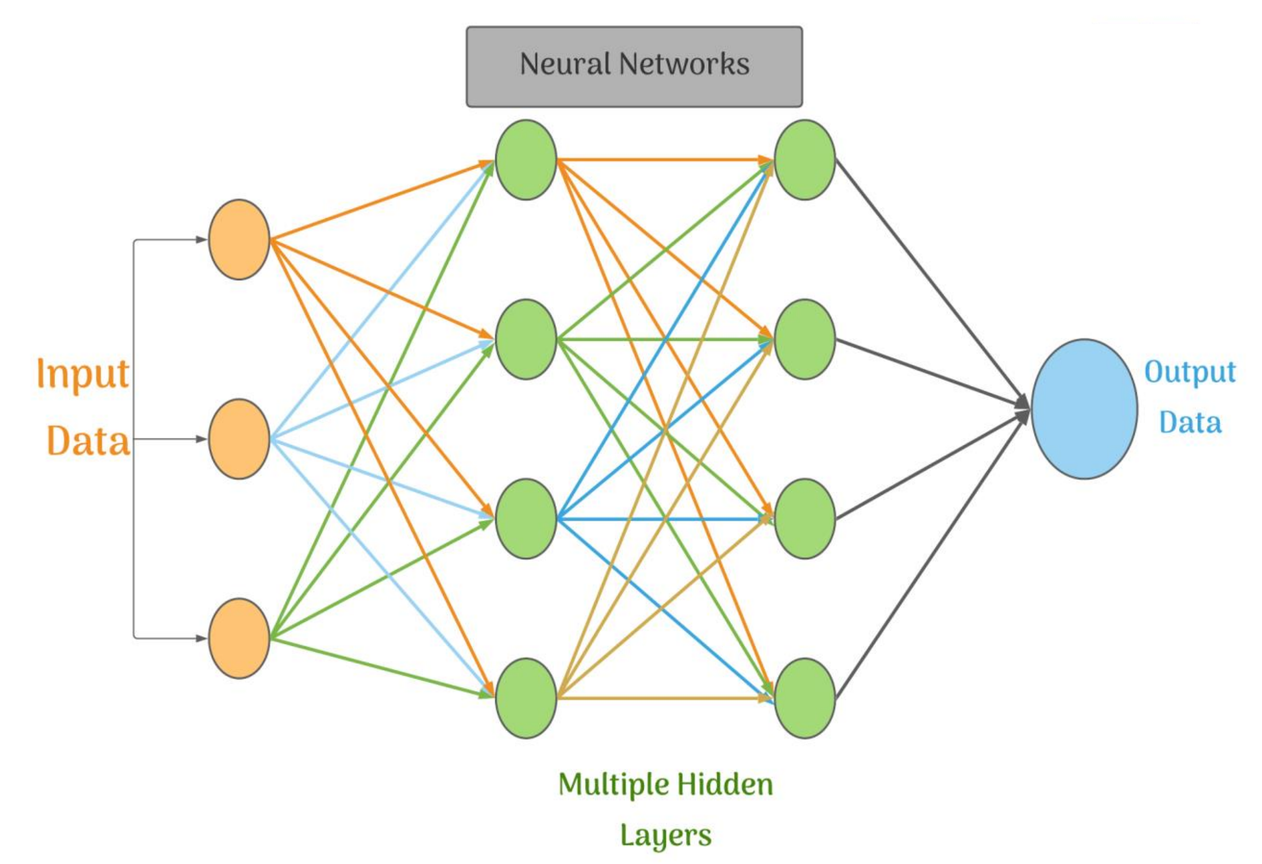
Relationship between NDVI & Biomass in Coffee Plots



- We found that the relationship between field data (biomass) and NDVI (vegetation health) was inconsistent. In some cases, lower biomass had higher NDVI values, meaning more analysis is needed to accurately assess forest health.
- Examined traditional regression models to establish baseline performance:
  - *Linear regression*
  - *Polynomial regression*
  - *Generalized Additive Models (GAM)*
  - *Cubic polynomial regression, among others.*

Using Neural Networks to Predict NDVI in Coffee Plots

- Type of machine learning model
- We used a neural network model—an advanced computer program that learns from data. It analyzed relationships between biomass and NDVI to make more accurate predictions about forest health.



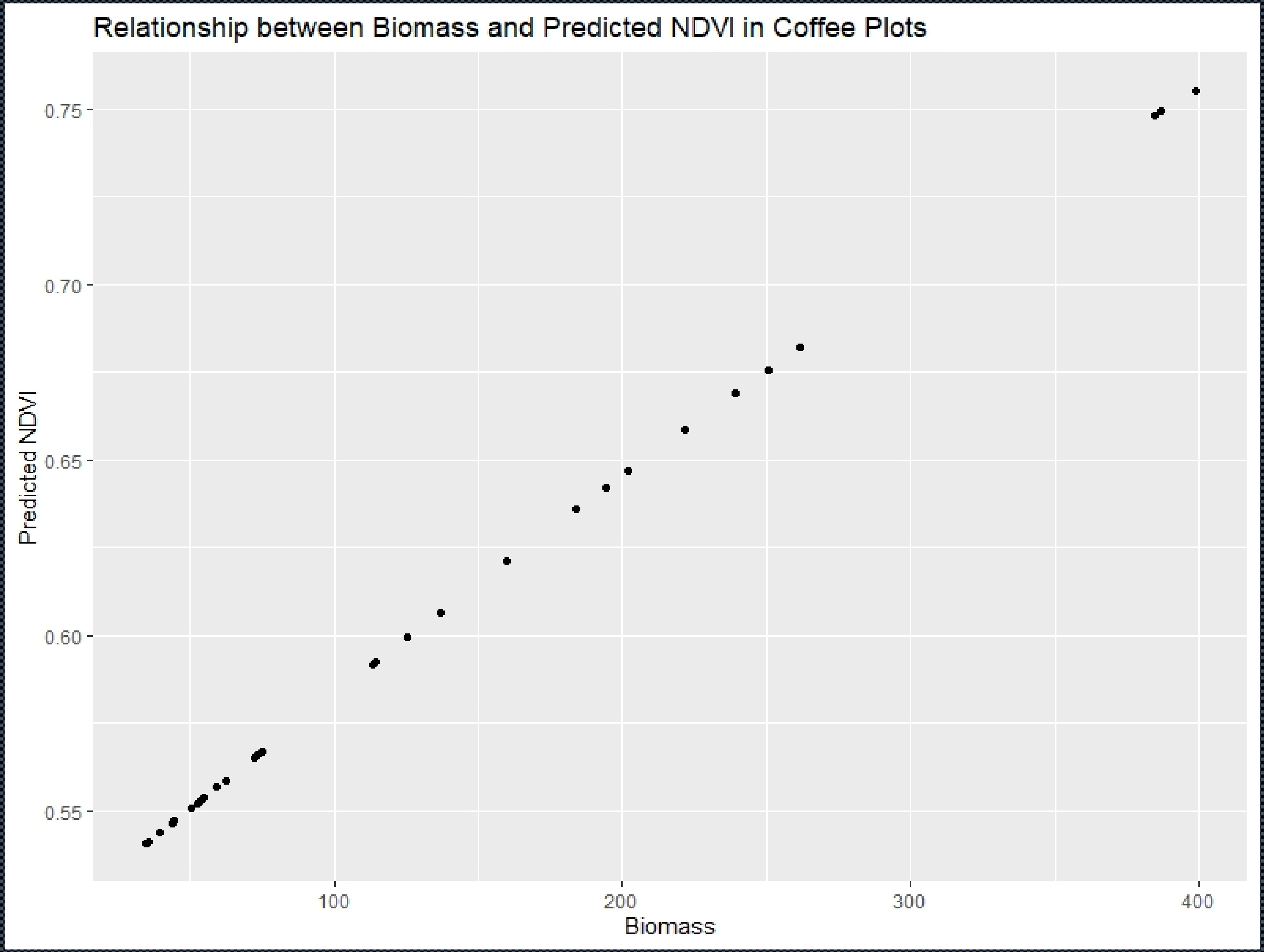
Input layer: data being fed into the network is the biomass values from the coffee plots

Hidden layer: there are 2 hidden layers, each with 64 units (neurons). These neurons look for patterns in the data and use a decision-making function called ReLU (Rectified Linear Unit). This function helps the network figure out which information is important and which is not, allowing it to focus on the meaningful patterns in the data.

Output layer: the result is the predicted NDVI values based on the biomass data.

The model is trained (fit) using the healthy forest data (x = biomass and y = NDVI) for 100 epochs.

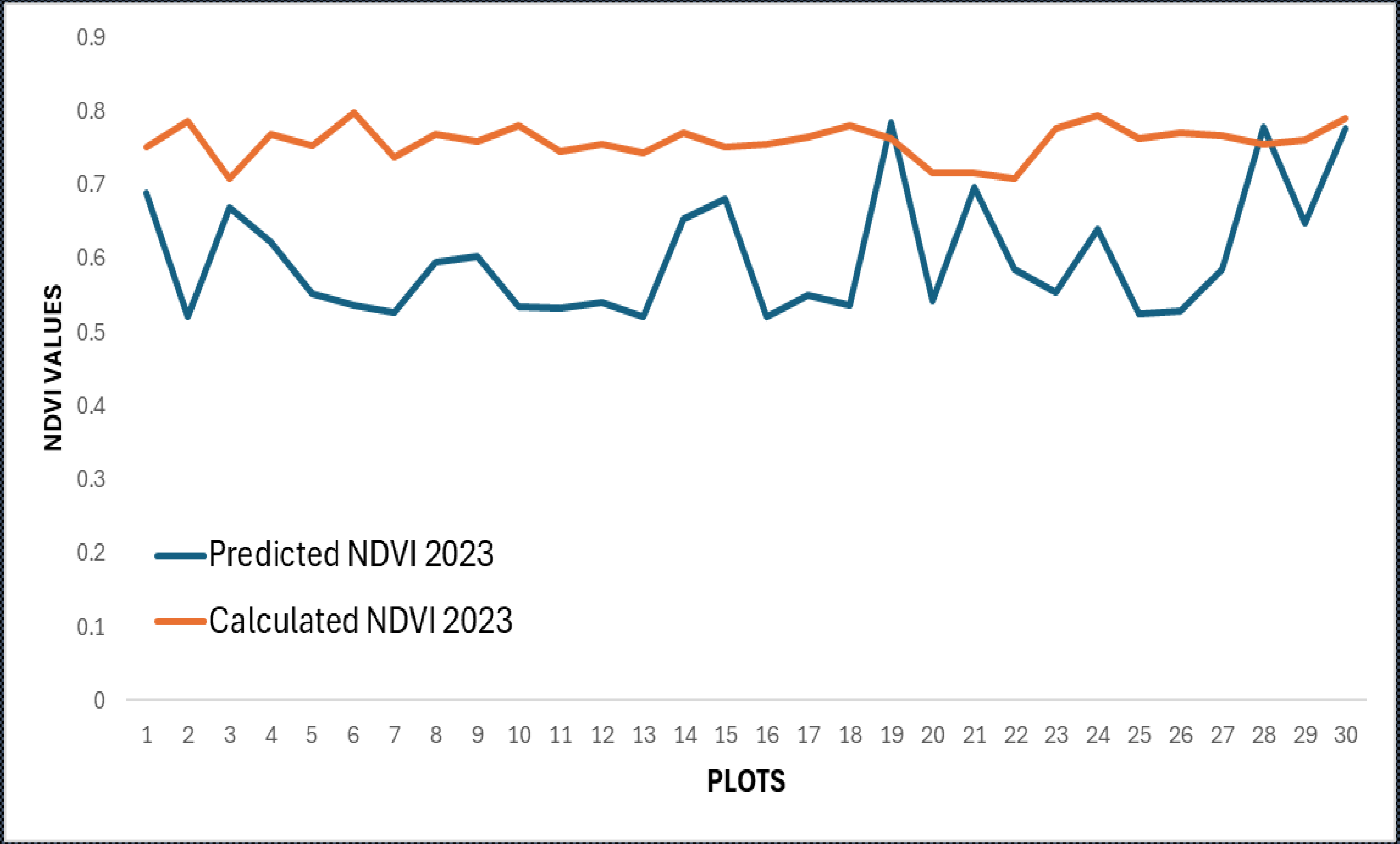
Relationship between NDVI & Biomass using Neural Networks



Mean Squared Error (MSE): 0.0003
Root Mean Squared Error (RMSE): 0.017
Mean Absolute Error (MAE): 0.01
R-squared (R^2): 0.97

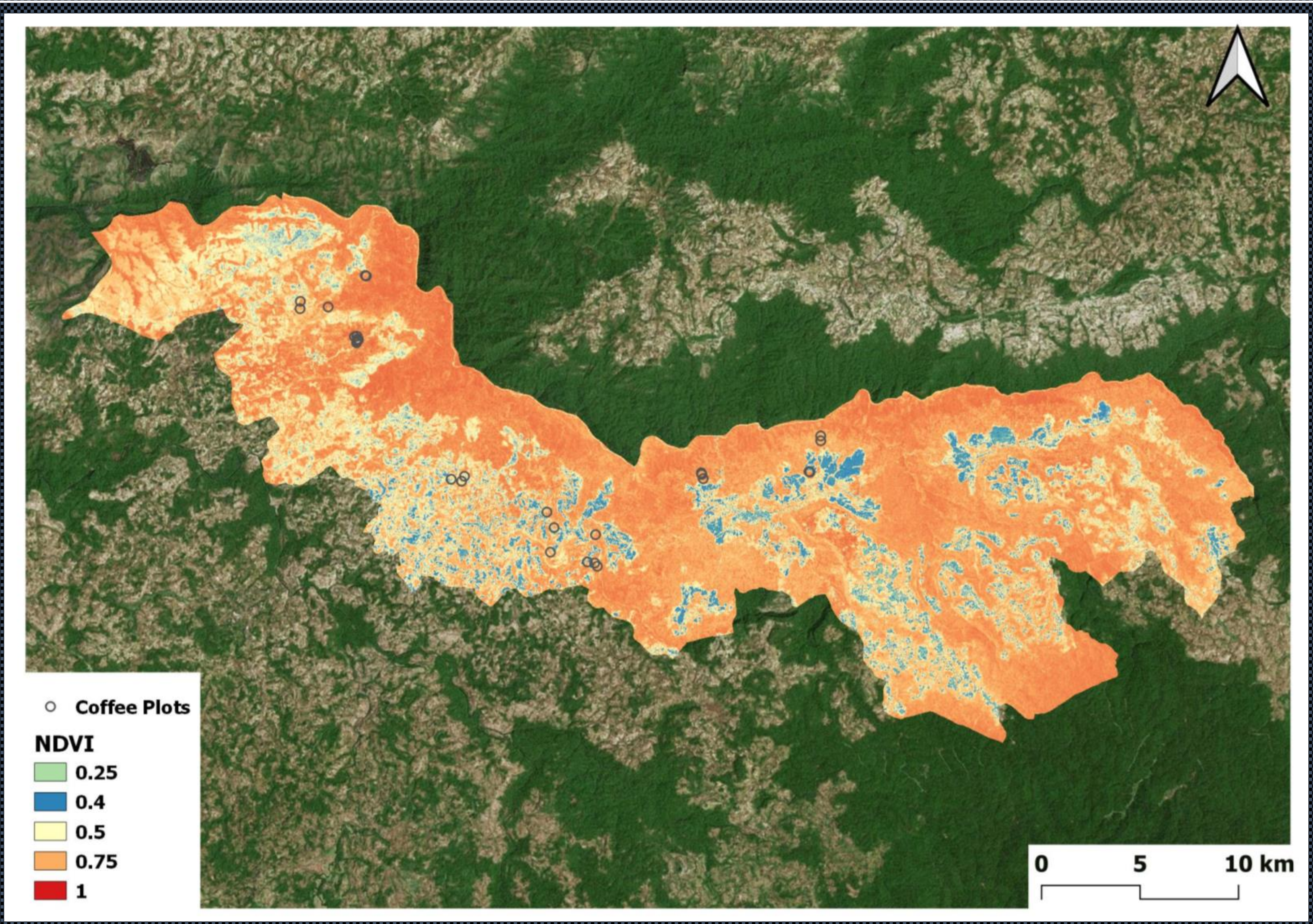
Our model performed well, with a very small error (MSE) and a high level of accuracy ($R^2 = 0.97$), meaning it can predict forest health from biomass data with confidence.

Reclassify NDVI using Predicted NDVI



- Example of NDVI values reclassification for 2023 Sentinel 2 imagery based on the Neural Network

Reclassify NDVI using Predicted NDVI



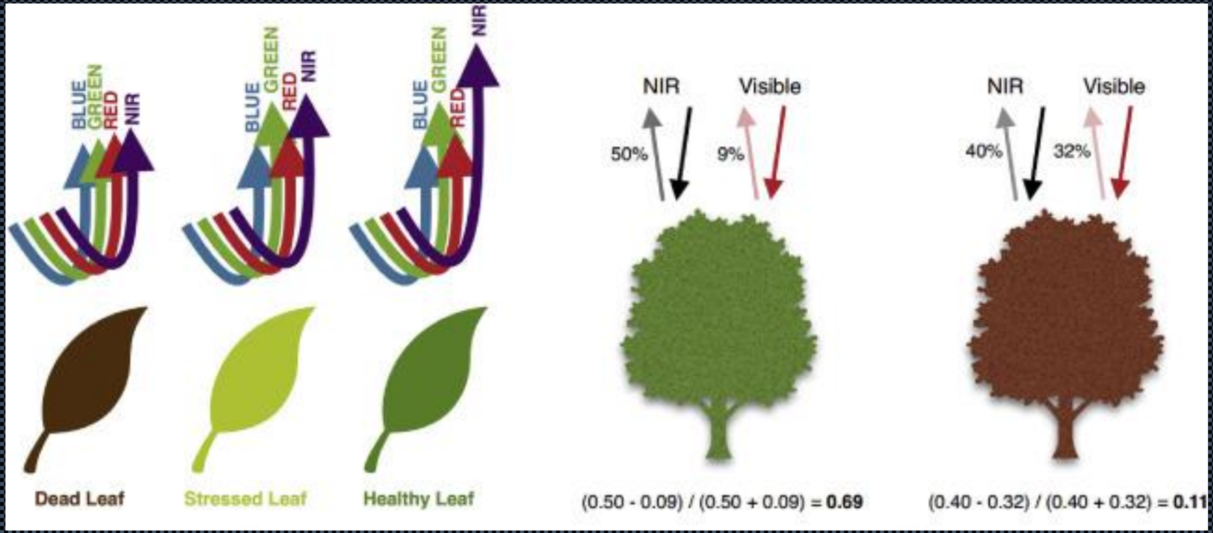
- Sentinel 2 imagery at 10m resolution
- We used the predicted NDVI values to update satellite maps of forest health, improving accuracy. This process helps us see where forests are degrading and where they're recovering

Degradation Mapping

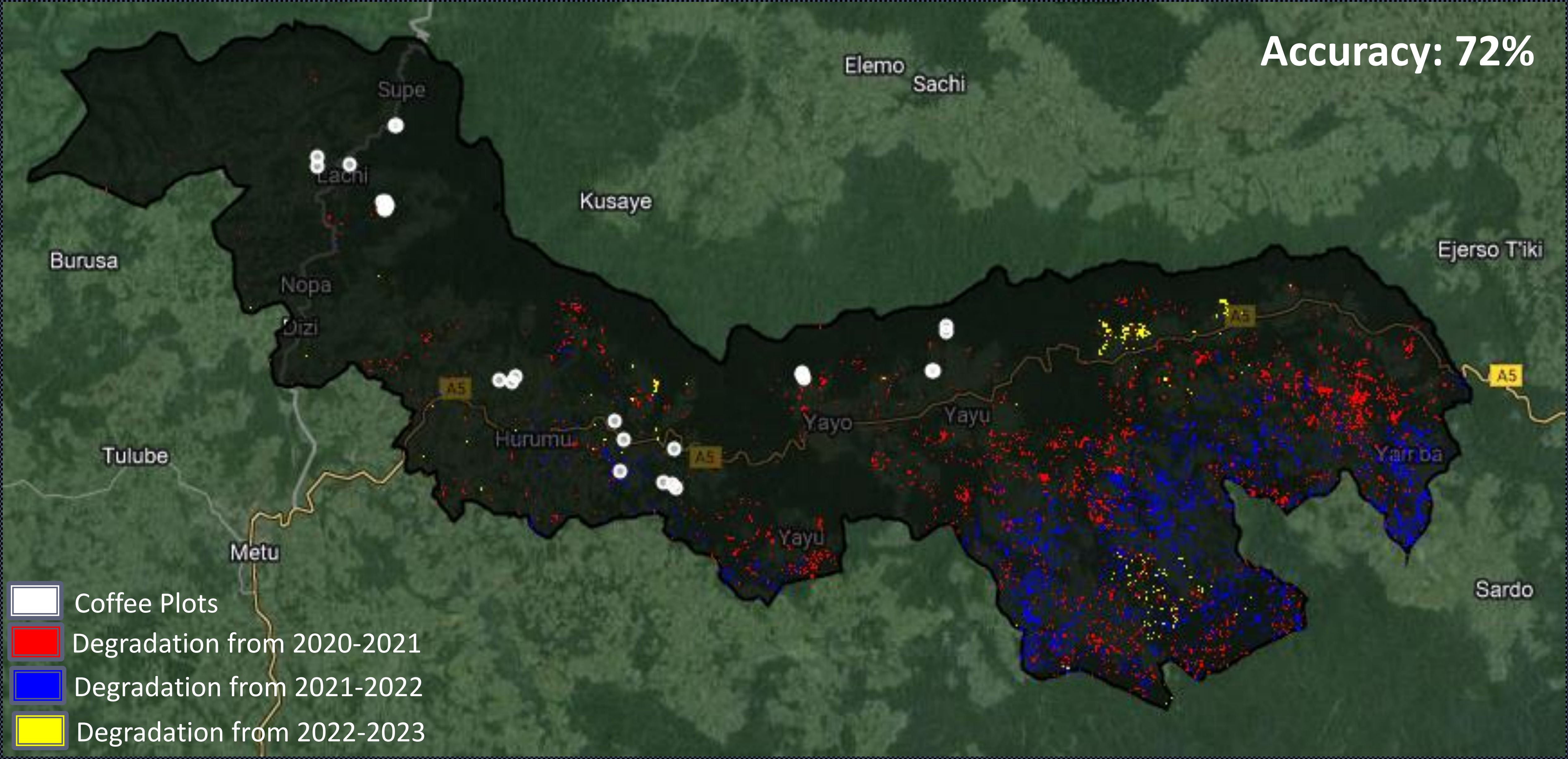
- NDVI assess density of green vegetation, indicating its health and vigor.
- BUT unable to detect changes in vegetation such as water stress or chlorophyll content
- Need to couple NDVI with other indices e.g.

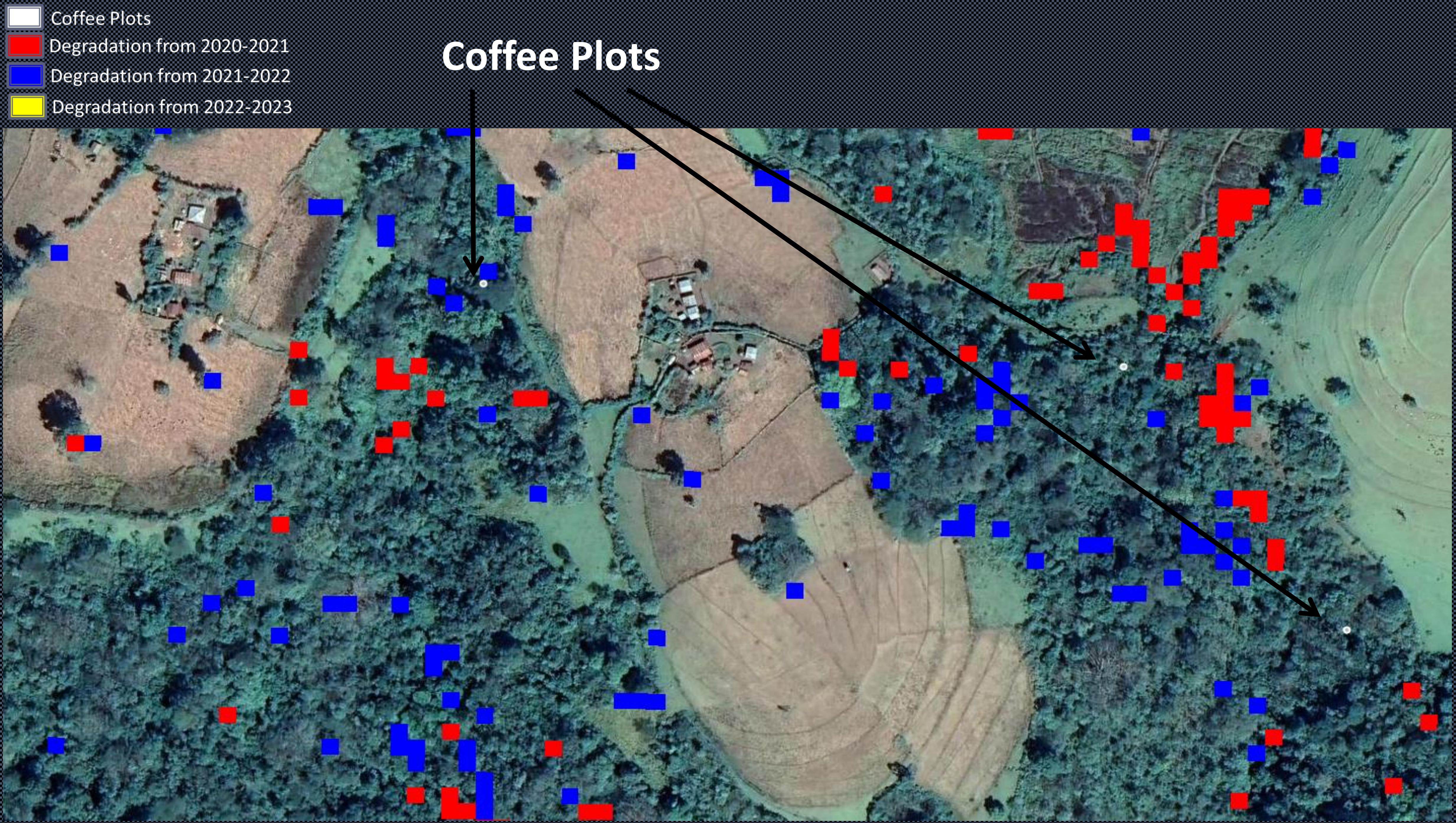
(1) Normalized Difference Water Index(NDWI): sensitive to changes in water content within vegetation and soil (e.g., moisture levels, which can be indicative of stress in vegetation or changes in hydrological patterns due to degradation).

(2) Enhanced Vegetation Index (EVI): enhances sensitivity in areas with dense vegetation (including dense canopies or high levels of aerosols). It also corrects for atmospheric influences, making it more robust in areas with atmospheric interference.

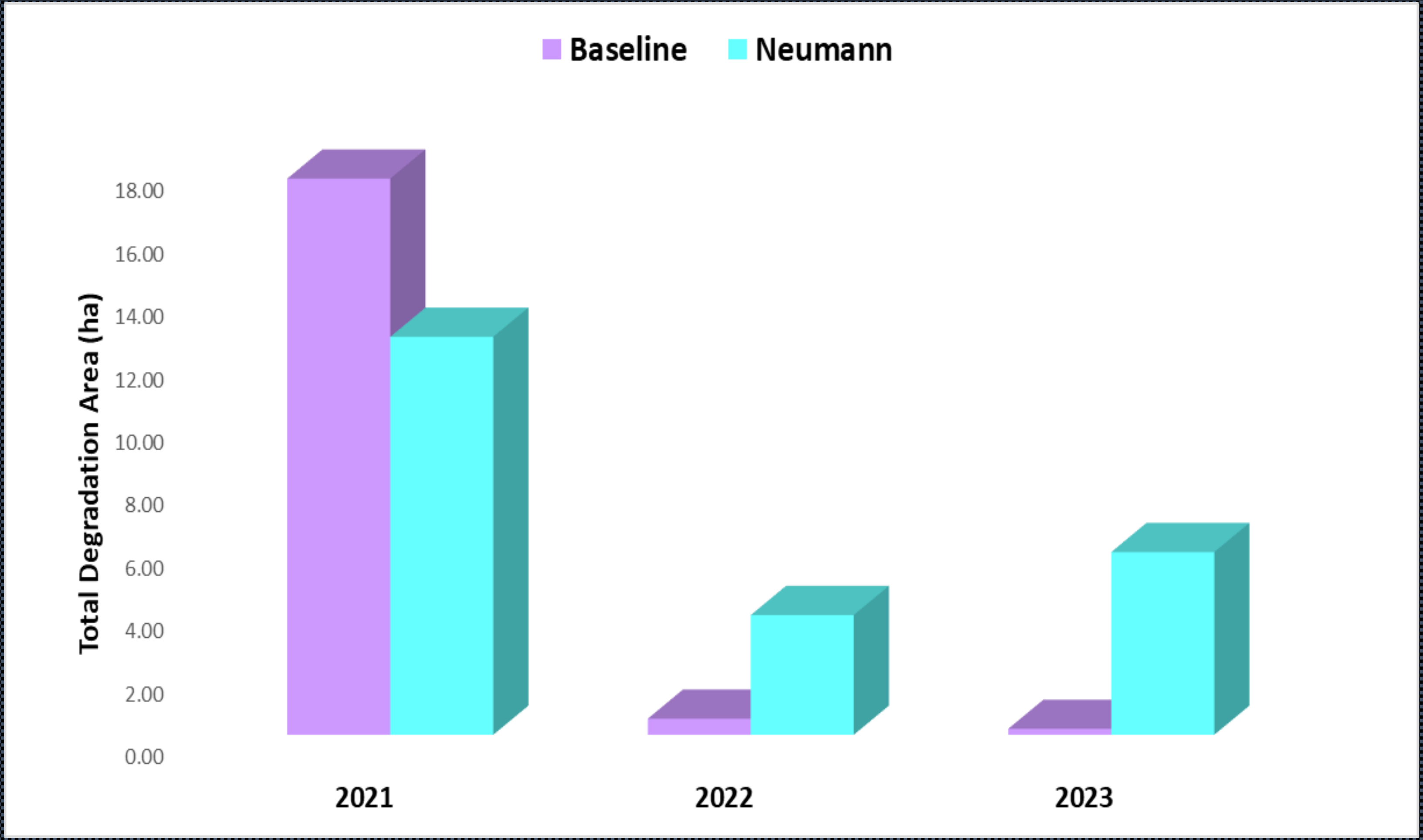


Degradation Mapping using NDVI, NDWI & EVI Thresholds




Coffee Plots
Degradation from 2020-2021
Degradation from 2021-2022
Degradation from 2022-2023
Coffee Plots

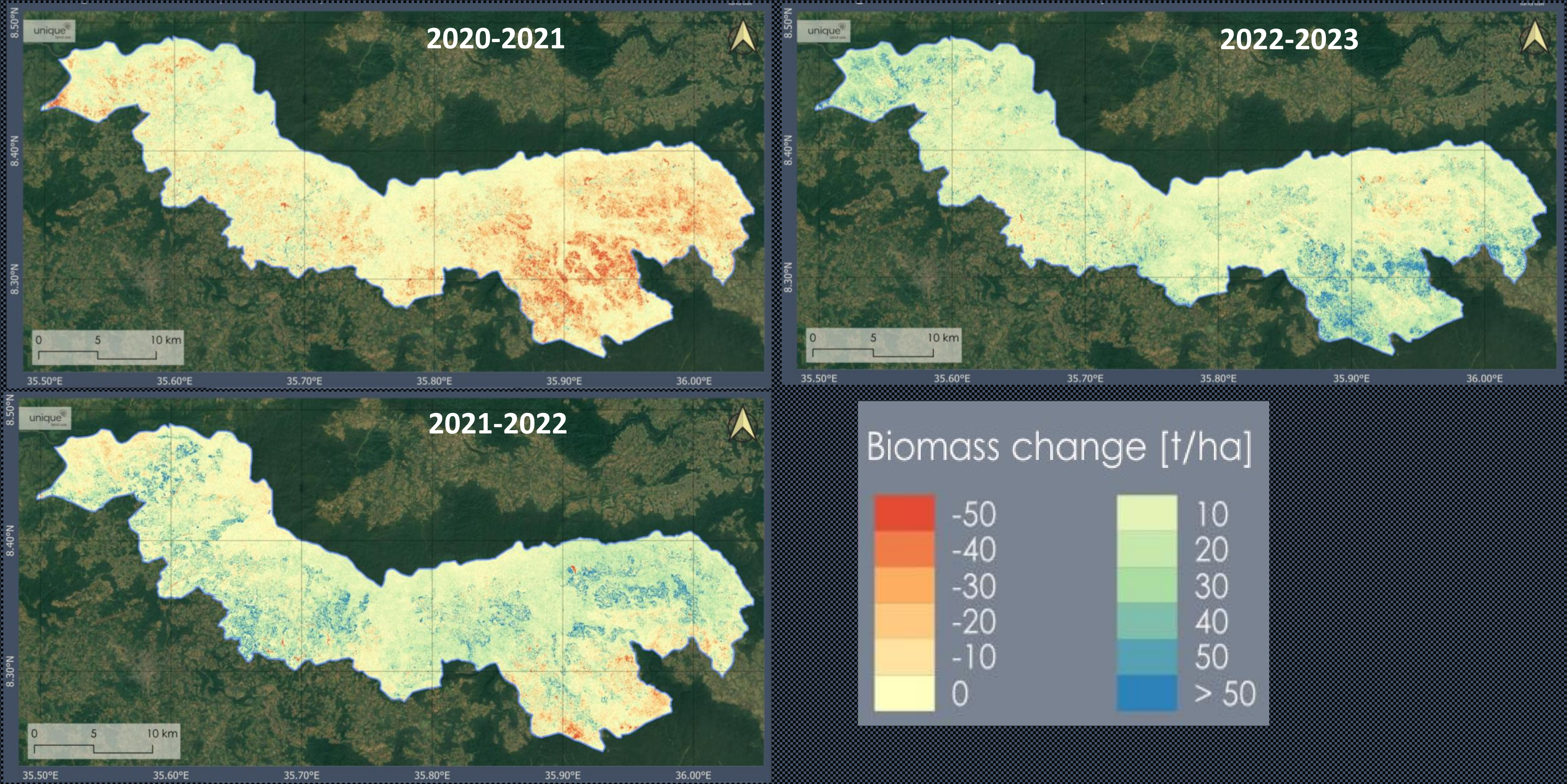
Estimating Area (ha) of Degradation (2021-2023)



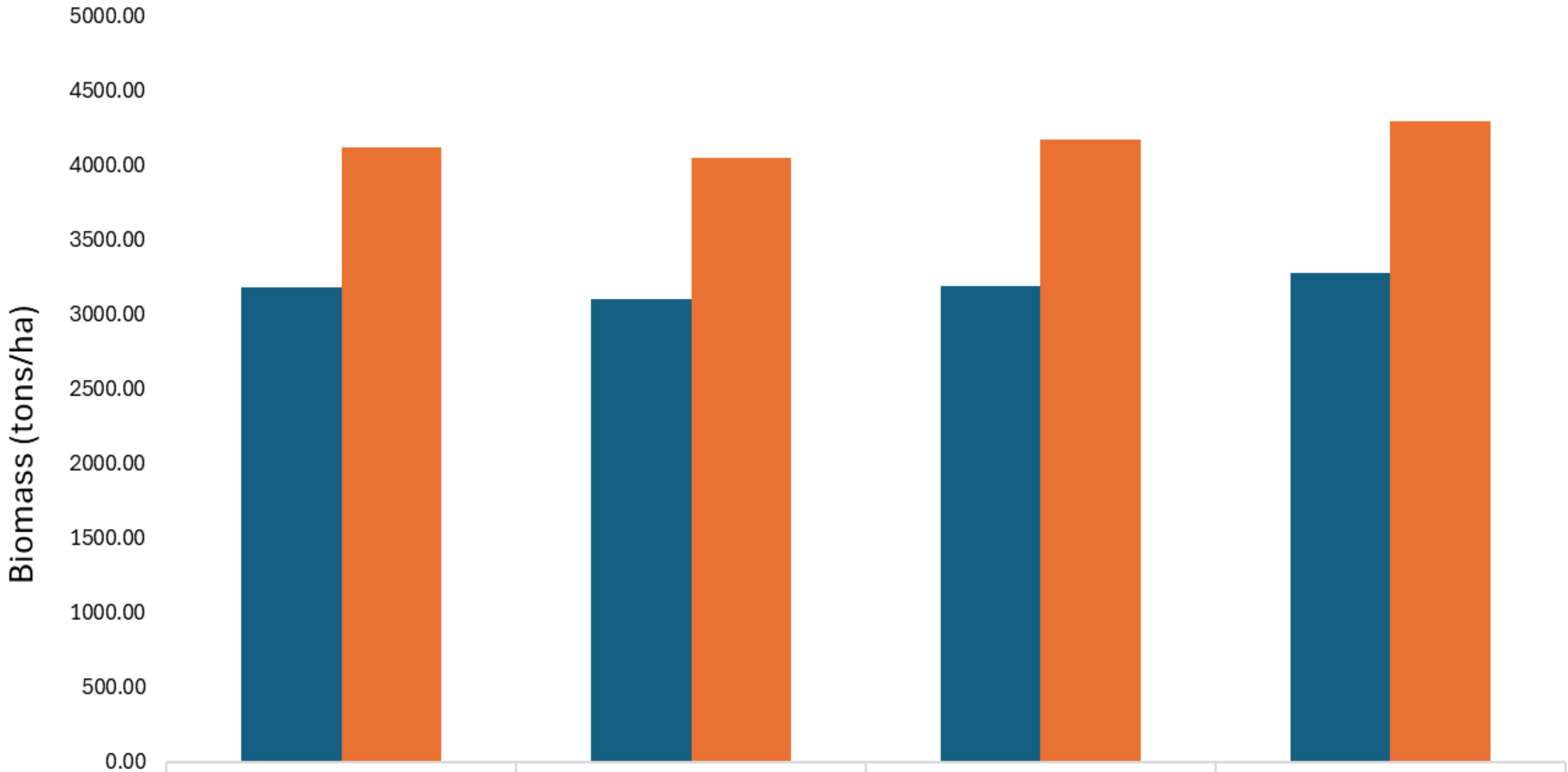
Based on the # of pixels, in 2021, 2022, and 2023, Neumann's coffee plots exhibited reduced degradation in total area (hectares) across time.

However, for 2022 and 2023, the Baseline coffee plots showed more reduction than Neumann's plots.

Estimating Biomass Change



Estimating Biomass Change

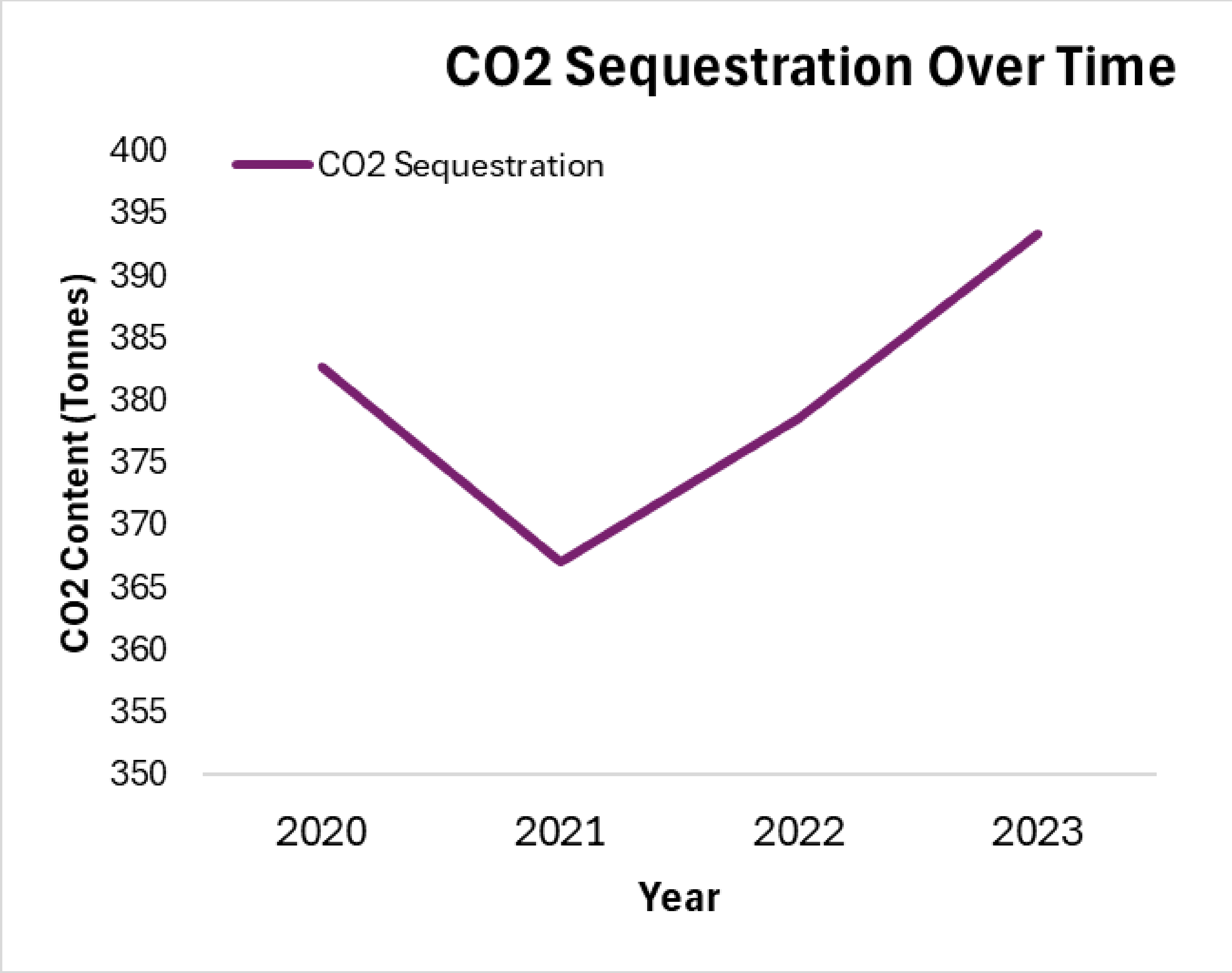


	2020	2021	2022	2023
Baseline	3175.83	3098.63	3186.39	3273.61
Neumann	4114.33	4051.73	4171.70	4292.52

Managed plots remained stable or showed biomass increases, suggesting effective conservation practices.

Changes in biomass over time are directly related to carbon storage, helping to quantify CO_2 emissions and the environmental impact of forest degradation.

Estimating CO_2 Sequestration Over Time (2020 – 2023)



In 2021, forests had the lowest CO_2 sequestration due to reduced biomass. By 2023, CO_2 sequestration increased significantly as the forest recovered and stored more carbon.

This trend reflects the fluctuations in biomass and carbon sequestration rates in managed and unmanaged coffee plots. The increase in stored carbon is positive for climate mitigation efforts, though it also highlights the importance of protecting these forests to avoid future carbon release.

Discussions

- The analysis showed that forest management interventions have had mixed results on reducing degradation rates. Neumann's or Managed coffee plots exhibited reduced degradation in total area over time, particularly from 2021 to 2023. However, baseline coffee plots showed slightly more reduction in some cases, suggesting that both managed and unmanaged plots require careful attention. This finding highlights the importance of continuous monitoring to assess the long-term impact of management practices.

- By using NDVI, NDWI, and EVI indices, we were able to monitor degradation trends between 2020 and 2023. The results show a clear recovery in forest health post-2021, with an increase in biomass and reduced degradation.

- Our estimates of biomass changes and CO_2 sequestration provided key insights into the environmental impact of forest degradation:2021 showed the lowest potential CO_2 content, likely due to reduced biomass and stored carbon. This suggests less carbon was available for release through degradation.

- By 2023, CO_2 content was at its highest, reflecting greater carbon sequestration due to increased biomass. This trend indicates an improving ecosystem with more carbon stored in the forest.

- The rise in potential CO_2 content after 2021 is linked to forest recovery and biomass growth, pointing to successful carbon capture. However, this also underscores the importance of protecting forests from future degradation, as any loss in biomass would result in significant carbon emissions.

Key Insights

- **Healthy forests capture more carbon, helping fight climate change:** The relationship between biomass and carbon storage is critical for climate mitigation. An increase in biomass leads to more carbon being sequestered, contributing to the reduction of atmospheric CO2. However, forest degradation risks reversing these gains.

- **Effectiveness of Management:** The varying results between managed and unmanaged plots indicate that while interventions have been effective in some cases, there is still room for improvement. A more tailored approach to forest management may be necessary to ensure consistent reductions in degradation.

- **AI and Remote Sensing for Monitoring:** Leveraging AI and remote sensing has proven effective in monitoring forest health and carbon sequestration in Ethiopian coffee landscapes. While forest recovery is evident, consistent management and protection efforts are critical to sustaining these gains and preventing future degradation, ensuring long-term climate resilience.


Thank you!
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