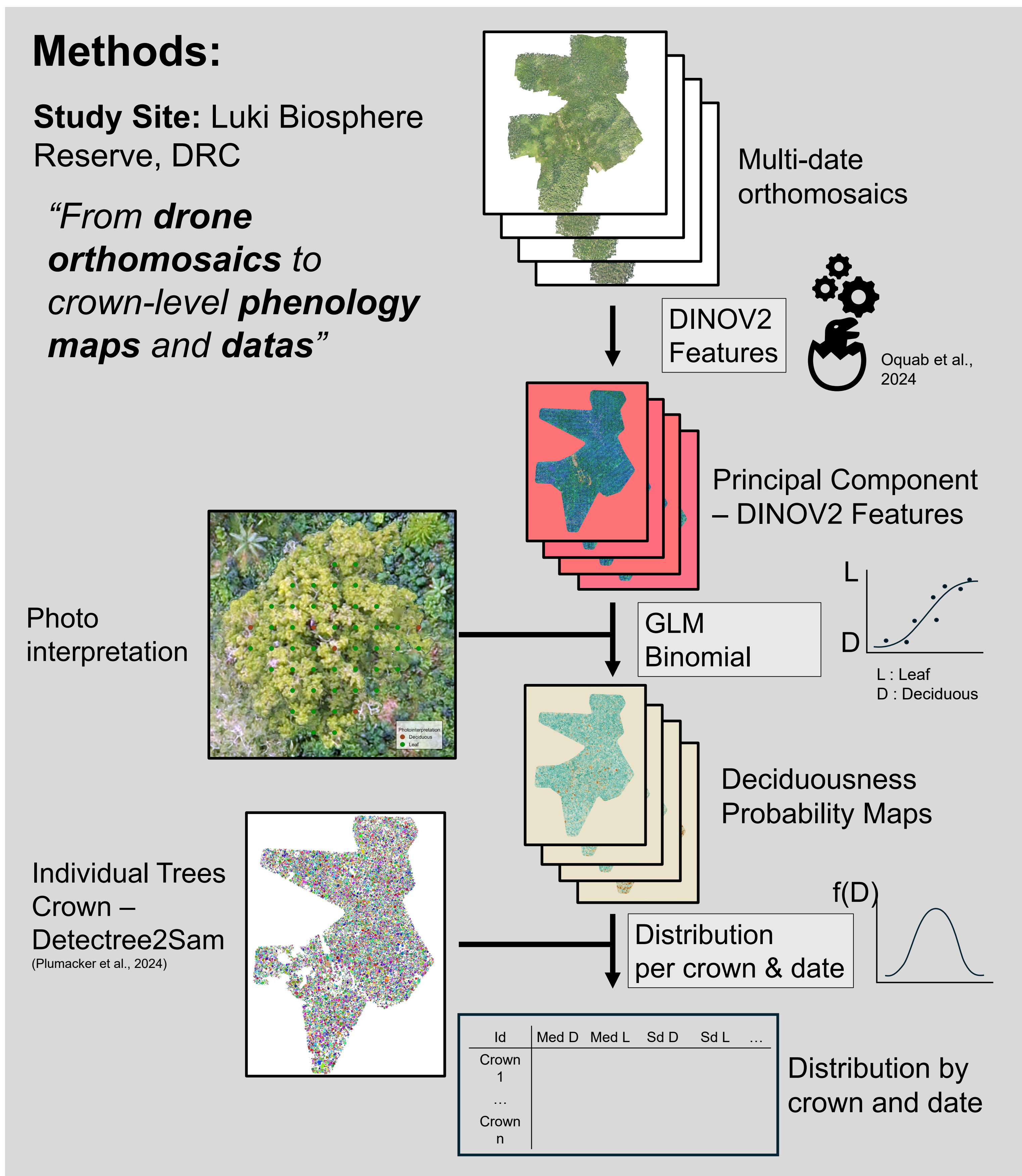# Drone to the bone: unveiling canopy deciduousness in Congo forests
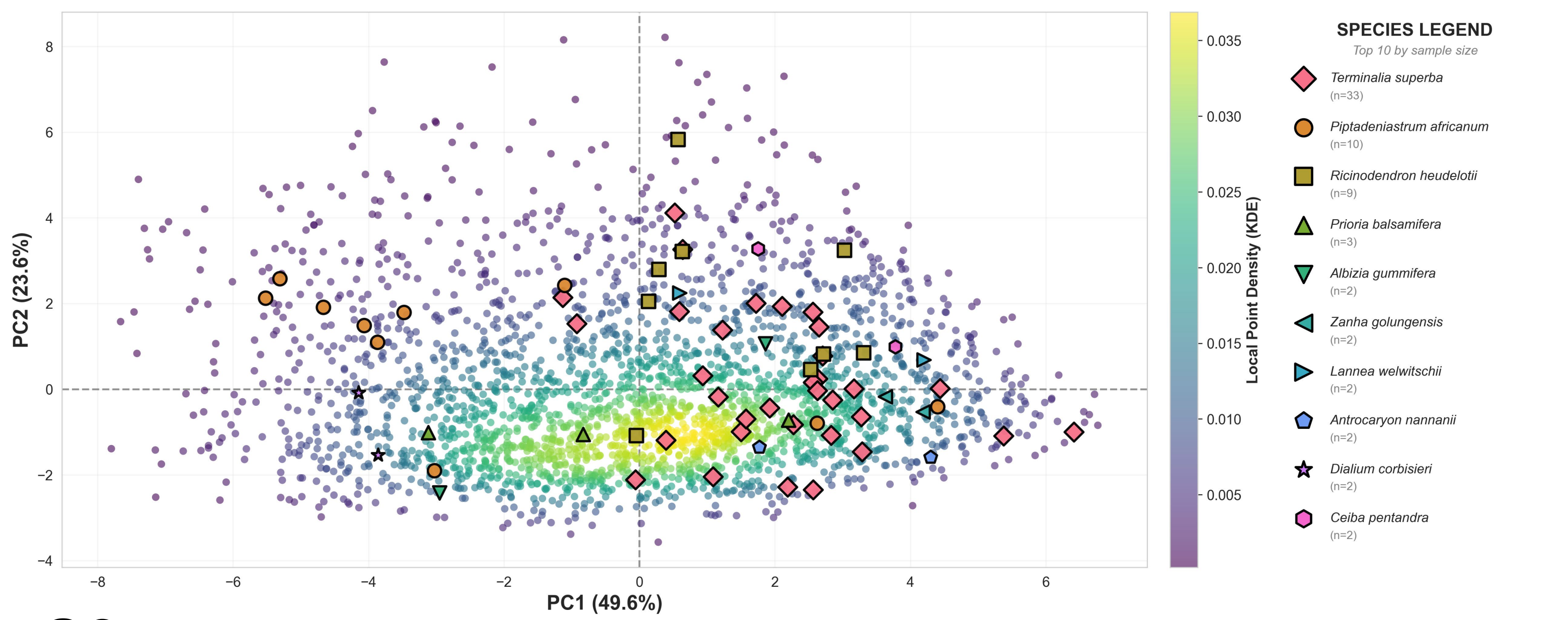
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Context: The Congo Basin forests stand out from other tropical forests due to their comparatively drier climate (<2000 mm/year) and the clear alternation of dry and wet seasons. Increasing aridification raises concerns about the future resilience of these critical ecosystems. Leaf phenology is a key adaptation to water stress. With recent advances in drone-based remote sensing and deep learning, it is now possible to map forest phenology over large areas at a resolution fine enough to track individual crowns. The spatial and temporal patterns of deciduousness provide direct insight into tree adaptation strategies and reveal phenological diversity both between and within species—while these spatio-temporal dynamics remain poorly understood in the Congo Basin.
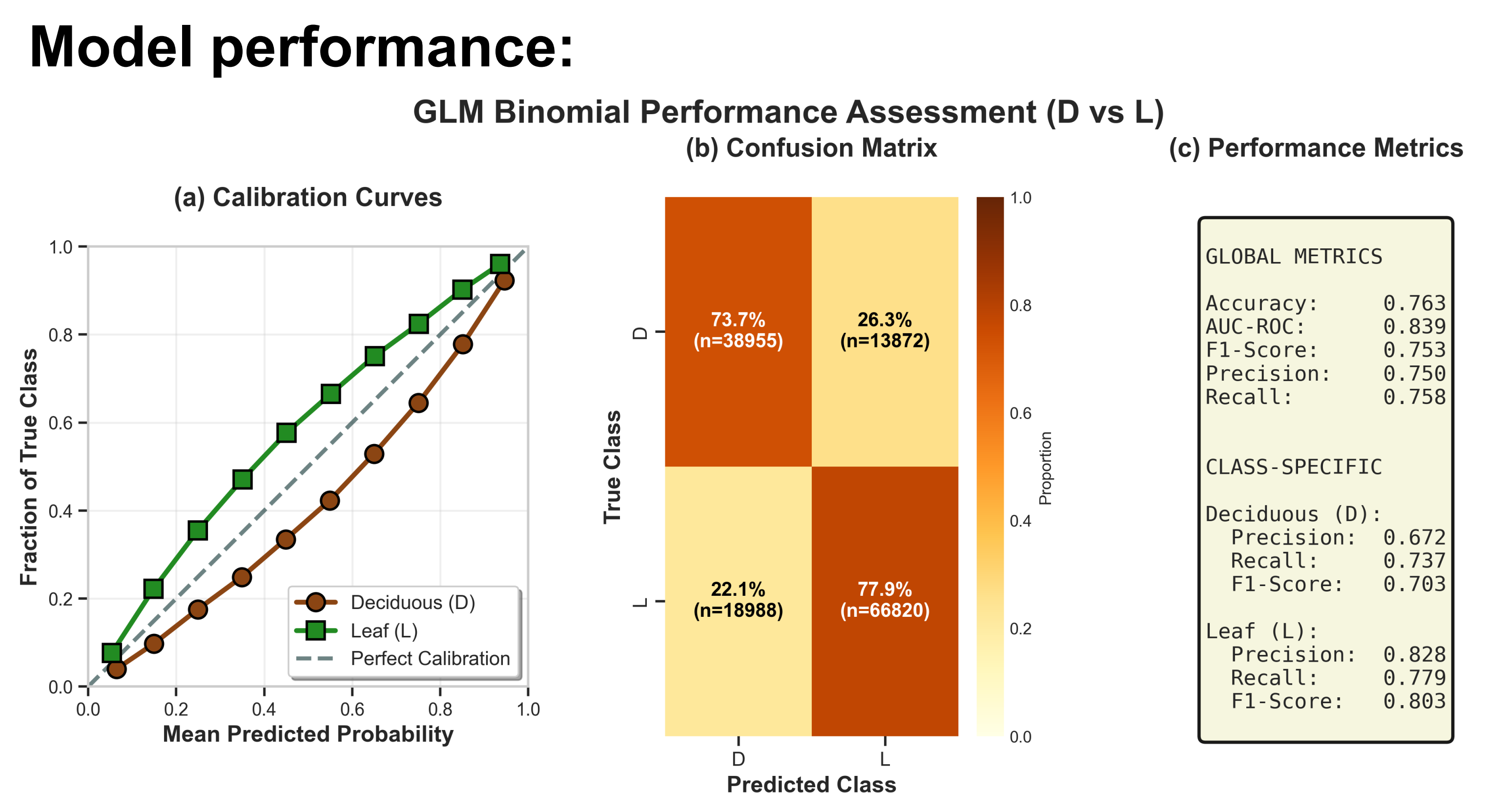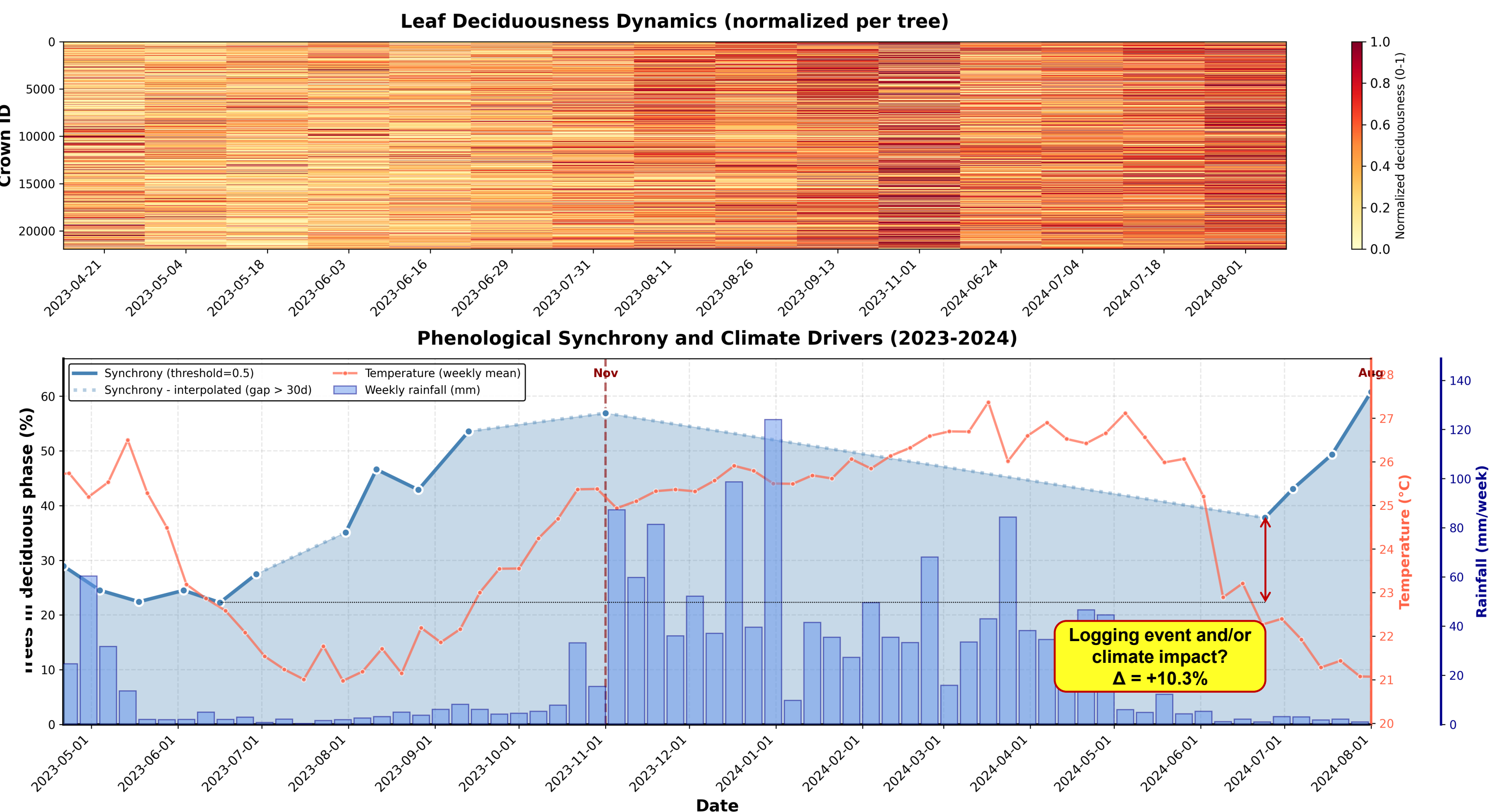
Research questions:

To **map** and **characterize deciduousness** patterns at individual **tree crown level** in Congo Basin forests, addressing two key questions:
Q1. Does deciduousness represent discrete phenological types or a continuum of adaptive strategies in Congo Basin forests?
Q2. Do tree crowns exhibit **temporal synchrony** in leaf phenology, or do they follow **distinct timing trajectories**?

Methods:

Study Site: Luki Biosphere Reserve, DRC

*"From **drone orthomosaics** to crown-level **phenology maps** and **datas**"*

Photo interpretation

Individual Trees Crown – Detectree2Sam
(Plumacker et al., 2024)

Multi-date orthomosaics

DINOV2 Features — Oquab et al., 2024

Principal Component – DINOV2 Features

GLM Binomial

L : Leaf
D : Deciduous

Deciduousness Probability Maps

f(D)

Distribution per crown & date

Id	Med D	Med L	Sd D	Sd L	...
Crown 1					
...					
Crown n					

Distribution by crown and date

Model performance:

GLM Binomial Performance Assessment (D vs L)

(a) Calibration Curves

(b) Confusion Matrix

		D	L
True Class	D	73.7% (n=38955)	26.3% (n=13872)
	L	22.1% (n=18988)	77.9% (n=66820)

Predicted Class

(c) Performance Metrics

```
GLOBAL METRICS

Accuracy:   0.763
AUC-ROC:    0.839
F1-Score:   0.753
Precision:  0.750
Recall:     0.758


CLASS-SPECIFIC

Deciduous (D):
Precision:  0.672
Recall:     0.737
F1-Score:   0.703

Leaf (L):
Precision:  0.828
Recall:     0.779
F1-Score:   0.803
```

Q1: Tree crowns in Luki forest are distributed along a **continuous phenological gradient** without forming discrete groups. Species show extensive overlap, with high **intra- and inter-specific variability**. This demonstrates that deciduousness represents a spectrum of adaptive strategies rather than easily distinguishable categories.

Point Density Map (PC1-PC2) with Species Overlay

SPECIES LEGEND
Top 10 by sample size
- Terminalia superba (n=33)
- Piptadeniastrum africanum (n=10)
- Ricinodendron heudelotii (n=9)
- Prioria balsamifera (n=3)
- Albizia gummifera (n=2)
- Zanha golungensis (n=2)
- Lannea welwitschii (n=2)
- Antrocaryon nannanii (n=2)
- Dialium corbisieri (n=2)
- Ceiba pentandra (n=2)

Q2: Deciduousness appears to **accumulate progressively** during prolonged dry periods rather than occurring as synchronized events. The November 2023 maximum **may reflect cumulative drought stress**, with individual trees potentially responding **asynchronously** based on their water access and tolerance thresholds.

Leaf Deciduousness Dynamics (normalized per tree)

Phenological Synchrony and Climate Drivers (2023-2024)

Logging event and/or climate impact? Δ = +10.3%

Perspectives:

- **Increase flight frequency** to capture multiple phenological cycles
- **Calibrate** the model across **multiple** Central African **sites**
- **Remove** dead and logged trees of the analysis
- Link phenology to **environmental drivers**
- Combine drone and satellite data for **regional monitoring**

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