OAK RIDGE National Laboratory

Drivers of Phenological Patterns and Variability in Heterogeneous Tropical Vegetation

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U.S. DEPARTMENT OF ENERGY

Objectives

- What are the dominant patterns of vegetation phenology and their spatio-temporal variations across the diverse tropical region?
- What are the vegetation functional traits and environmental drivers that influence the vegetation phenology in tropical vegetation?
- How do phenological responses to inter- and intra-annual variability in meteorological conditions vary across heterogeneous vegetation types and regions of the tropics?

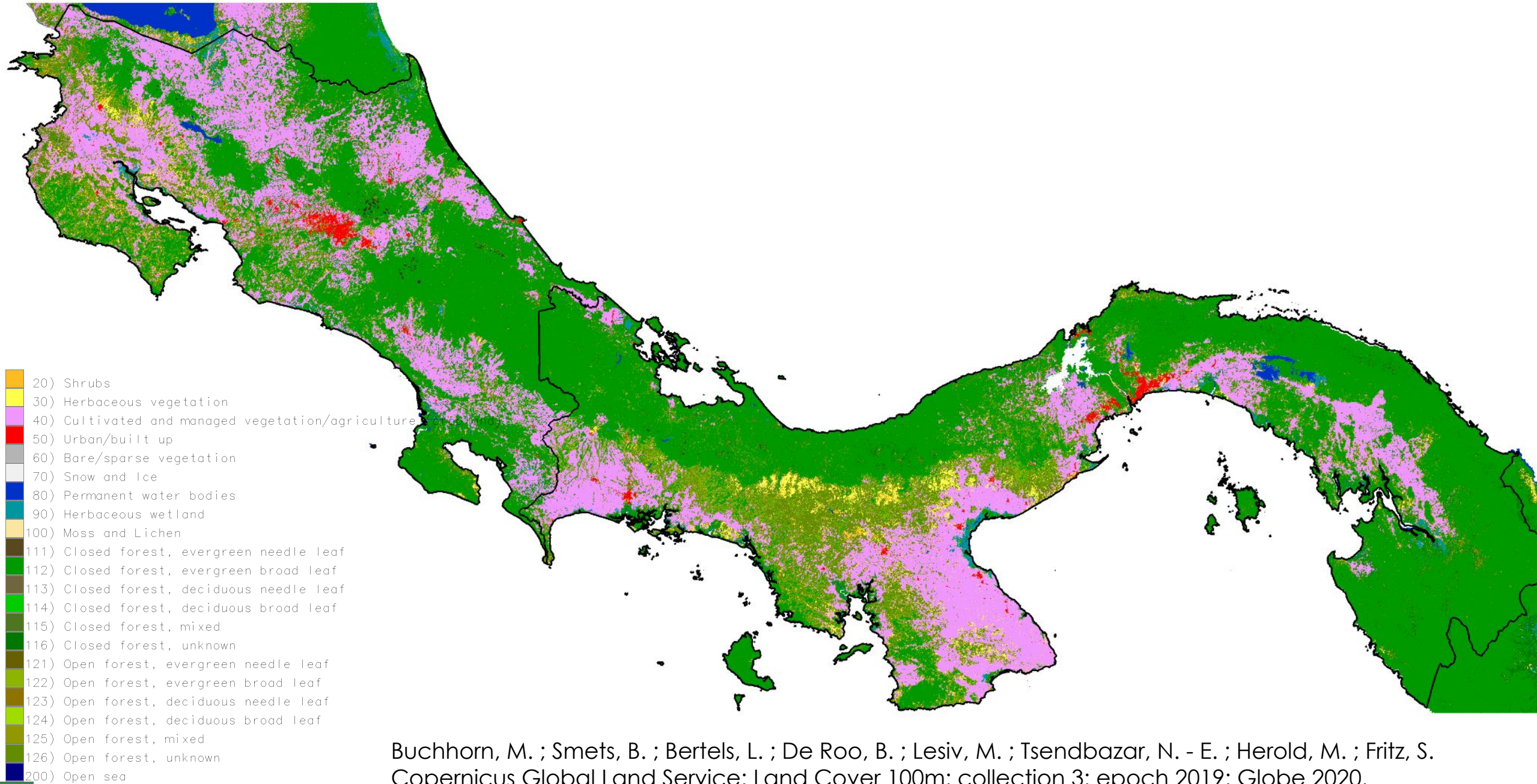
Summary

- **What are the dominant patterns of vegetation phenology and their spatio-temporal variations across the diverse tropical region?**
  - High spatio-temporal resolution land surface phenology from Sentinel-2 allows identification of dominant patterns of phenology.
  - Comparison with available land cover map shows the spatial heterogeneity in their spatial distribution, phenology and variability.
- **What are the vegetation functional traits and environmental drivers that influence the vegetation phenology in tropical vegetation?**
  - Phenological patterns and variability show strong relationships between vegetation/land cover types and vegetation structure.
  - Moisture availability and temperature are strongest meteorological drivers of phenology.

Summary

- **How do phenological responses to inter- and intra-annual variability in meteorological conditions vary across heterogeneous vegetation types and regions of the tropics?**
  - Croplands, herbaceous and shrubs show most inter- and intra-annual variability in phenology, and vulnerability to meteorological conditions.
  - Evergreen/deciduous forests have relatively stable phenology.
  - Open forests (intermixed with other land cover types) show higher variability compared to closed forest.

Study Region: Costa Rica and Panama

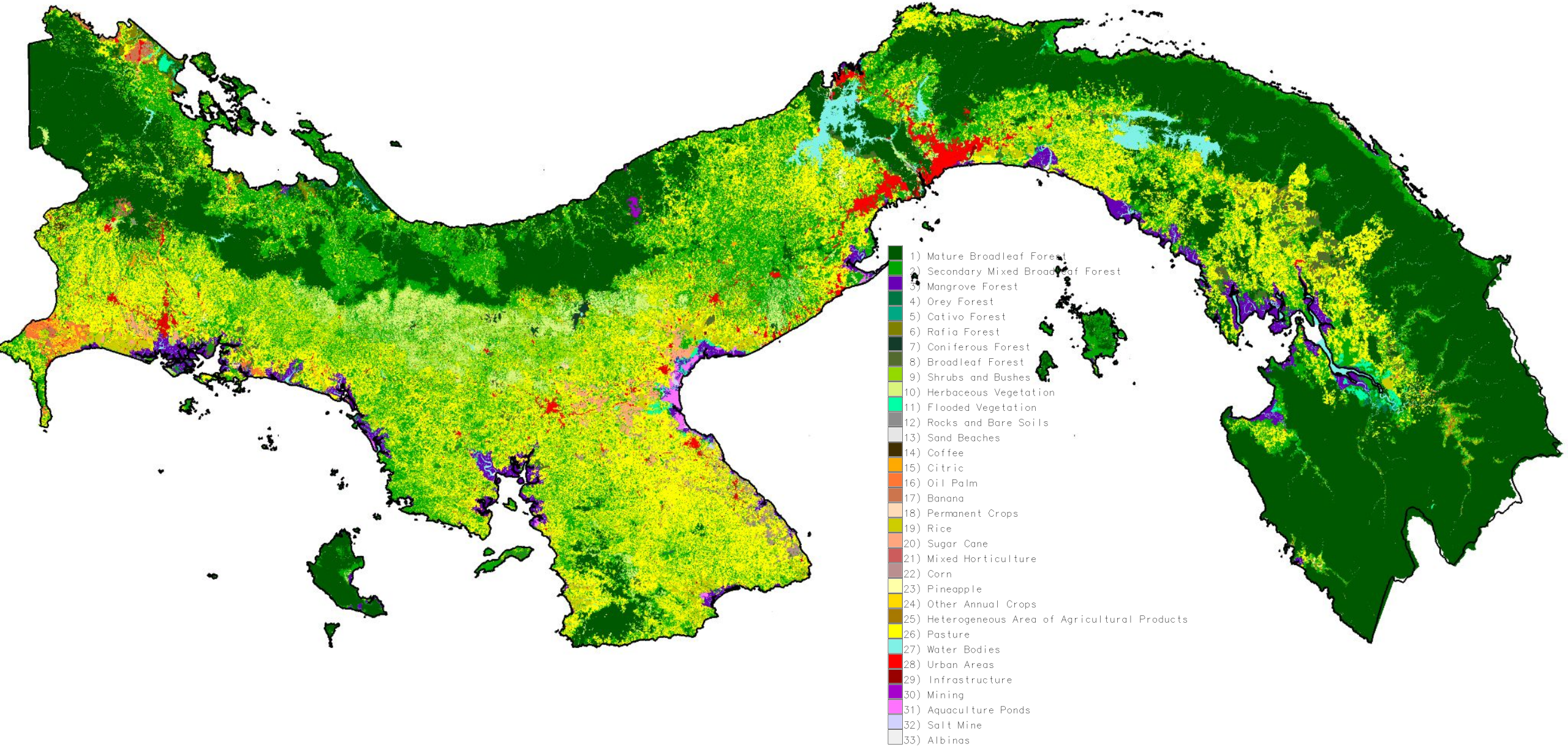


Buchhorn, M. ; Smets, B. ; Bertels, L. ; De Roo, B. ; Lesiv, M. ; Tsendbazar, N. - E. ; Herold, M. ; Fritz, S. Copernicus Global Land Service: Land Cover 100m: collection 3: epoch 2019: Globe 2020.

Land Cover/Vegetation in Costa Rica and Panama

Class	Costa Rica [% rea]	Panama [% area]
Shrubs	0.75	0.62
Herbaceous vegetation	1.30	2.39
Cropland	29.76	19.73
Urban	1.15	0.67
Bare	0.0	0.0
Water	2.59	1.10
Wetland	1.53	1.43
Evergreen Broadleaf, Closed	44.64	53.46
Deciduous Broadleaf, Closed	0.03	0.0
Mixed, Closed Forest	0.03	0.0
Closed Forest	1.52	2.47
Evergreen Broadleaf, Open	4.81	4.77
Deciduous Broadleaf, Open	0.02	0.0
Mixed, Open Forest	0.0	0.0
Open Forest	11.88	13.25

Land Cover in Panama



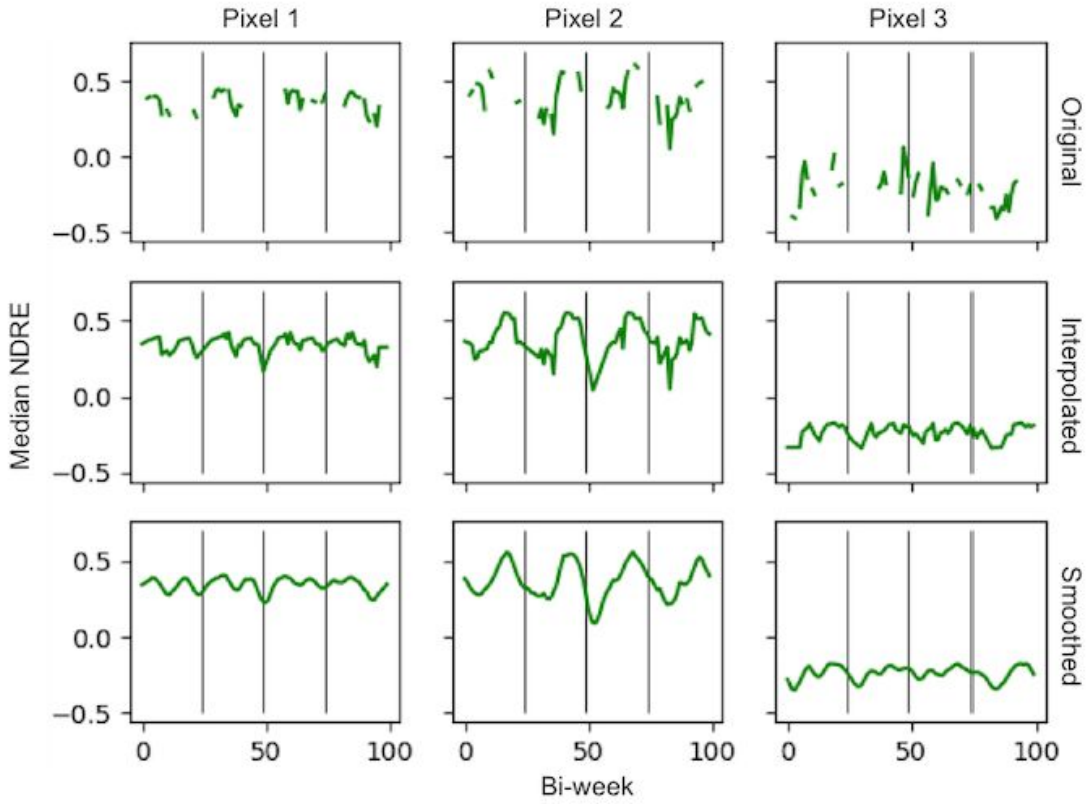
Satellite remote sensing

- Sentinel-2 time series for the period 2017–2022.
- Normalized Difference Red Edge Index (NDRE):

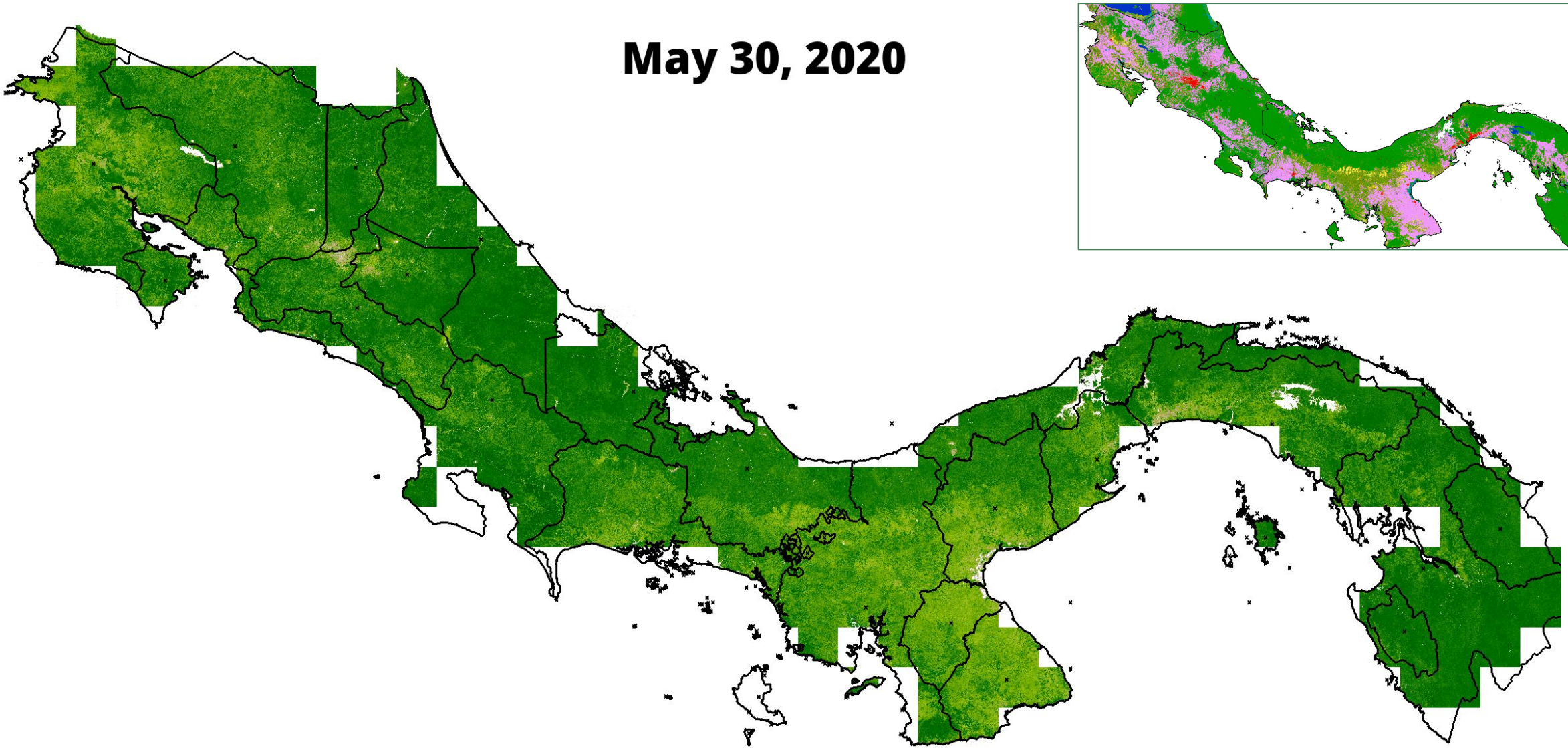
  NDRE = (NIR – RE) / (NIR + RE) | NDRE = (B8 – B5) / (B8 + B5)
- Spatial resolution: 20m
- Temporal resolution: 15 days
- Data processing:
  - NDRE data processing, cloud/shadow removal performed within Google Earth Engine platform.
  - Rest of the analysis were conducted on our own clusters.
- This is a big data problem: ~324 million 20 m pixels (x 150 time intervals)

Noise filtering and gap filling

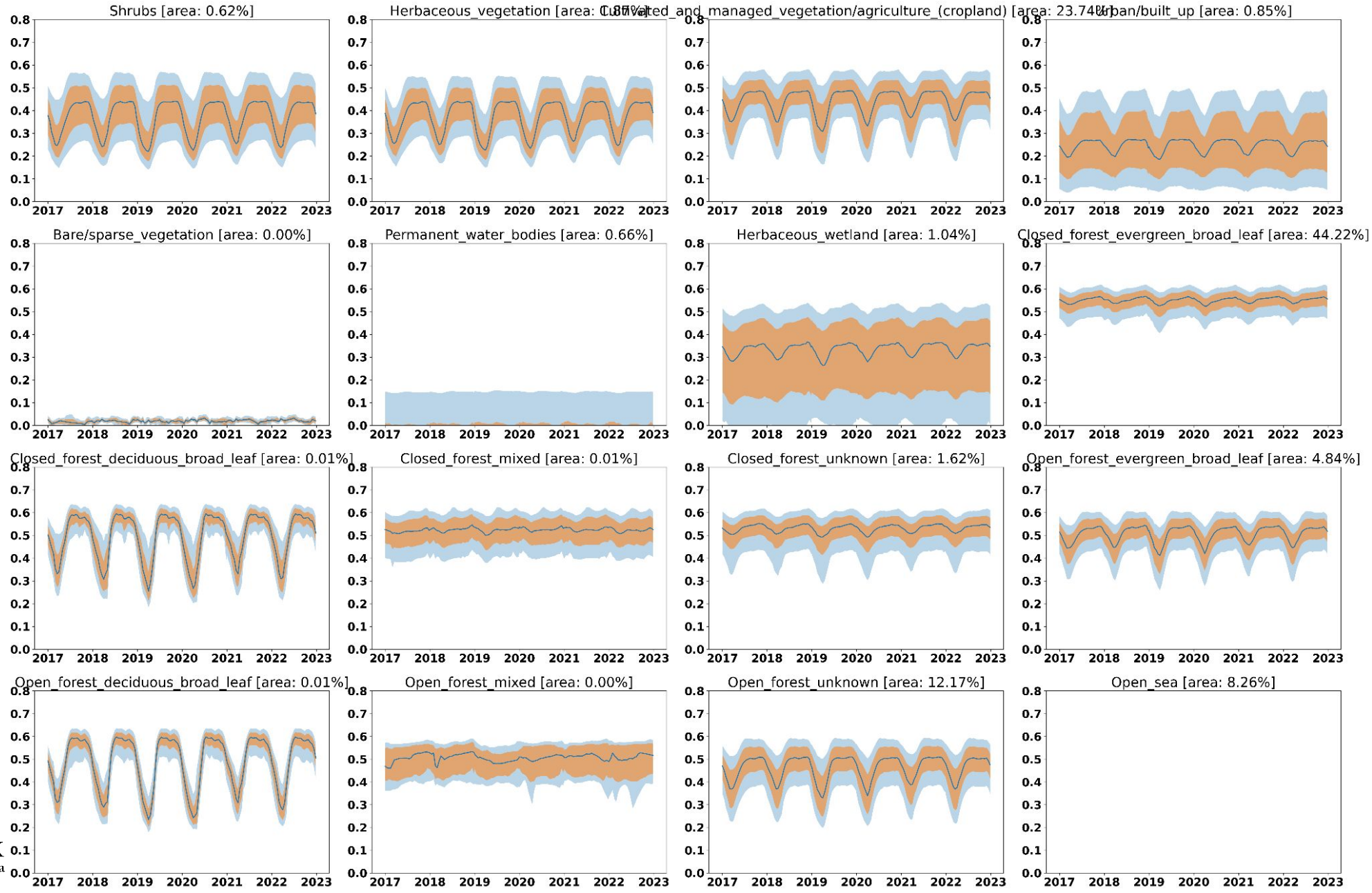
- NDRE data are noisy in space and time and require corrections/processing.
- We developed and applied a workflow to identify and filter noisy data, a regression based gap filling,
- Savitzky-Golay filter for smoothing [which we ended up not using].



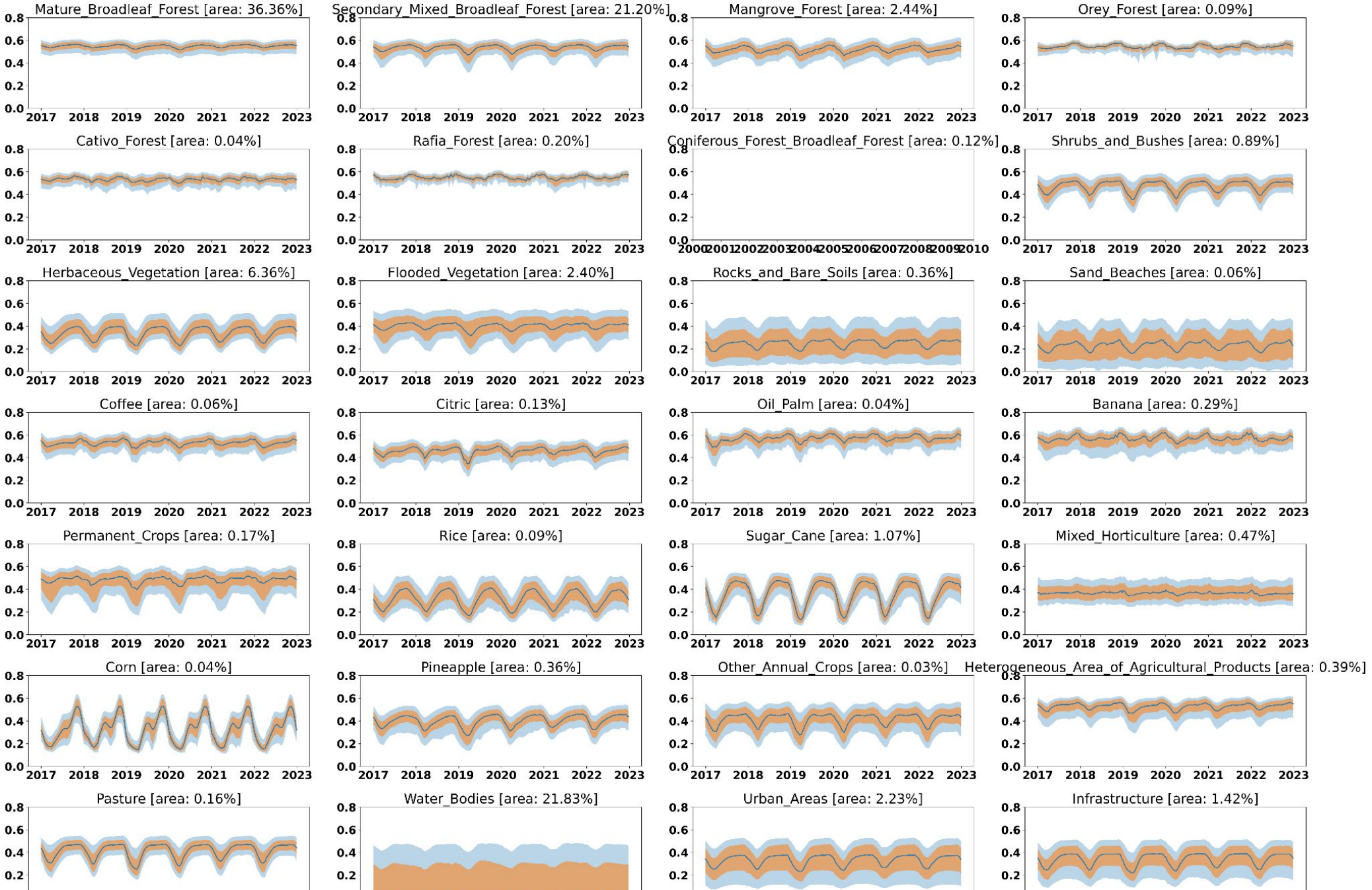
Time series of land surface phenology (NDRE)



Phenological variability across land cover types: Costa Rica + Panama

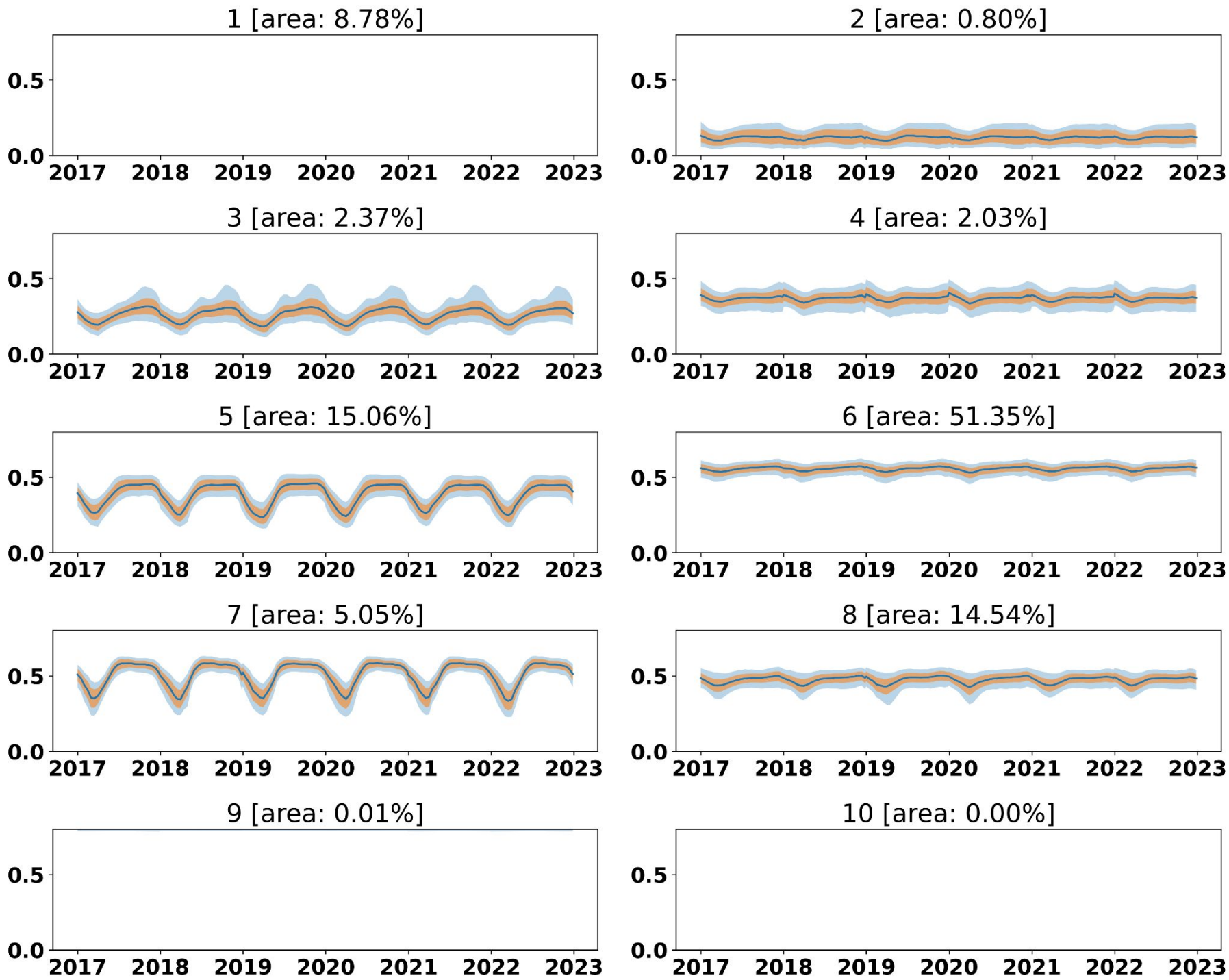


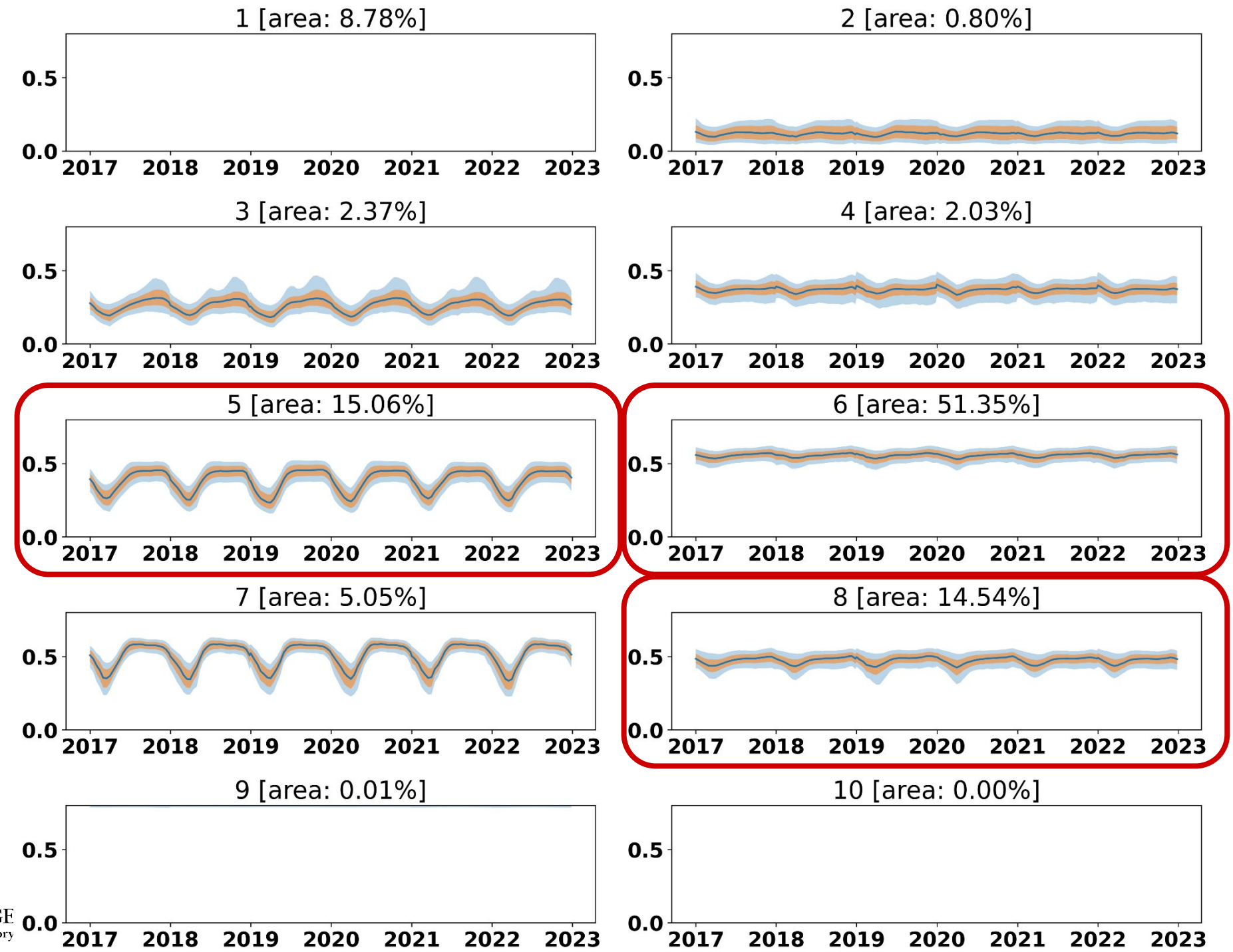
Phenological variability across landcover types: Panama



Classification of phenoregions

- We applied a hierarchical clustering (showing k=10 today) to identify the dominant phenological patterns based on land surface phenology.
- Dynamic clustering thru time – based on annual phenological signature.
- Without using any information about geographical or land cover information.
- Dynamic spatio-temporal phenoregions implicitly captures effects of climate, vegetation type/structure/traits and disturbance processes.


1 [area: 8.78%]
2 [area: 0.80%]
3 [area: 2.37%]
4 [area: 2.03%]
5 [area: 15.06%]
6 [area: 51.35%]
7 [area: 5.05%]
8 [area: 14.54%]
9 [area: 0.01%]
10 [area: 0.00%]
0.0
0.5
2017
2018
2019
2020
2021
2022
2023


1 [area: 8.78%]
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4 [area: 2.03%]
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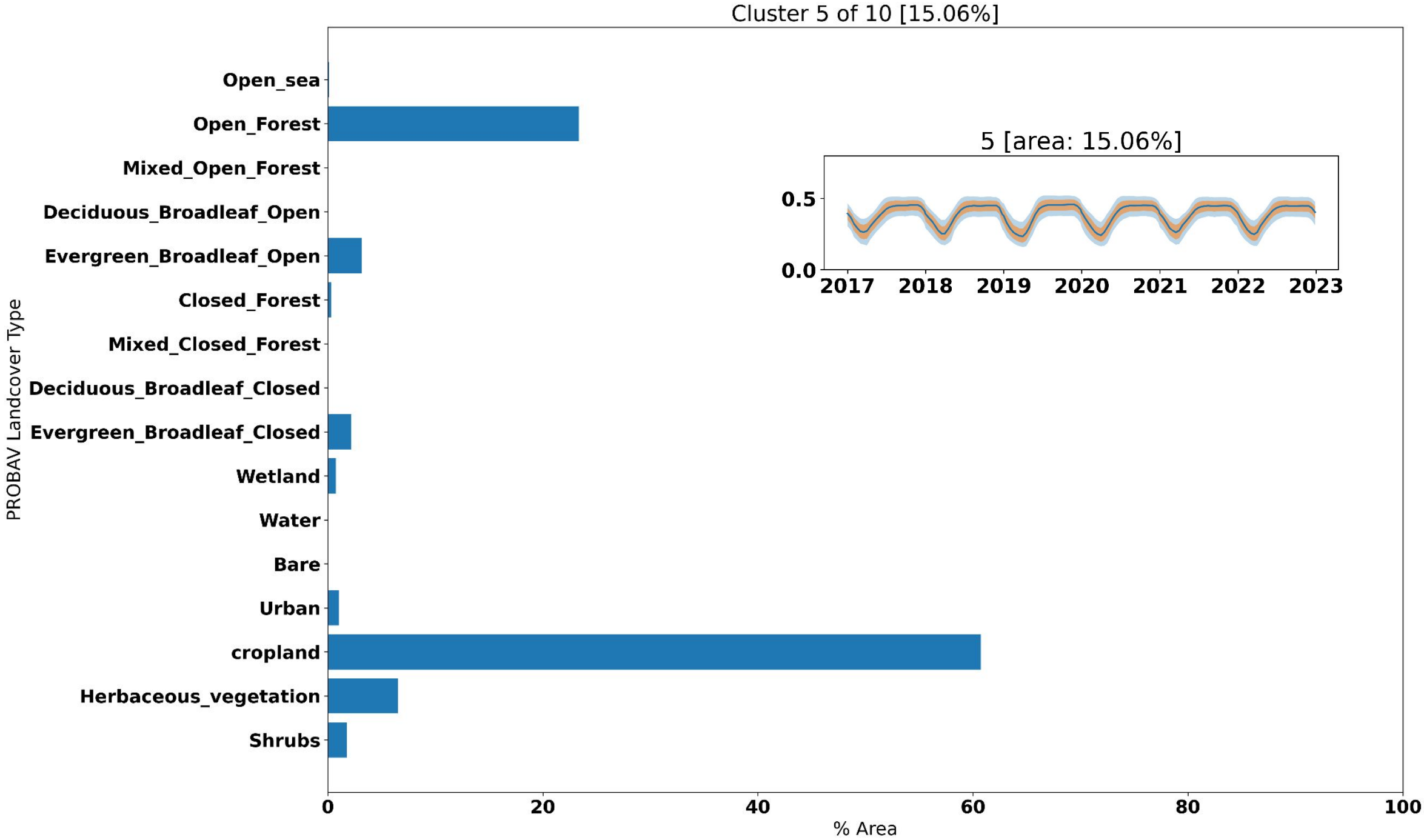
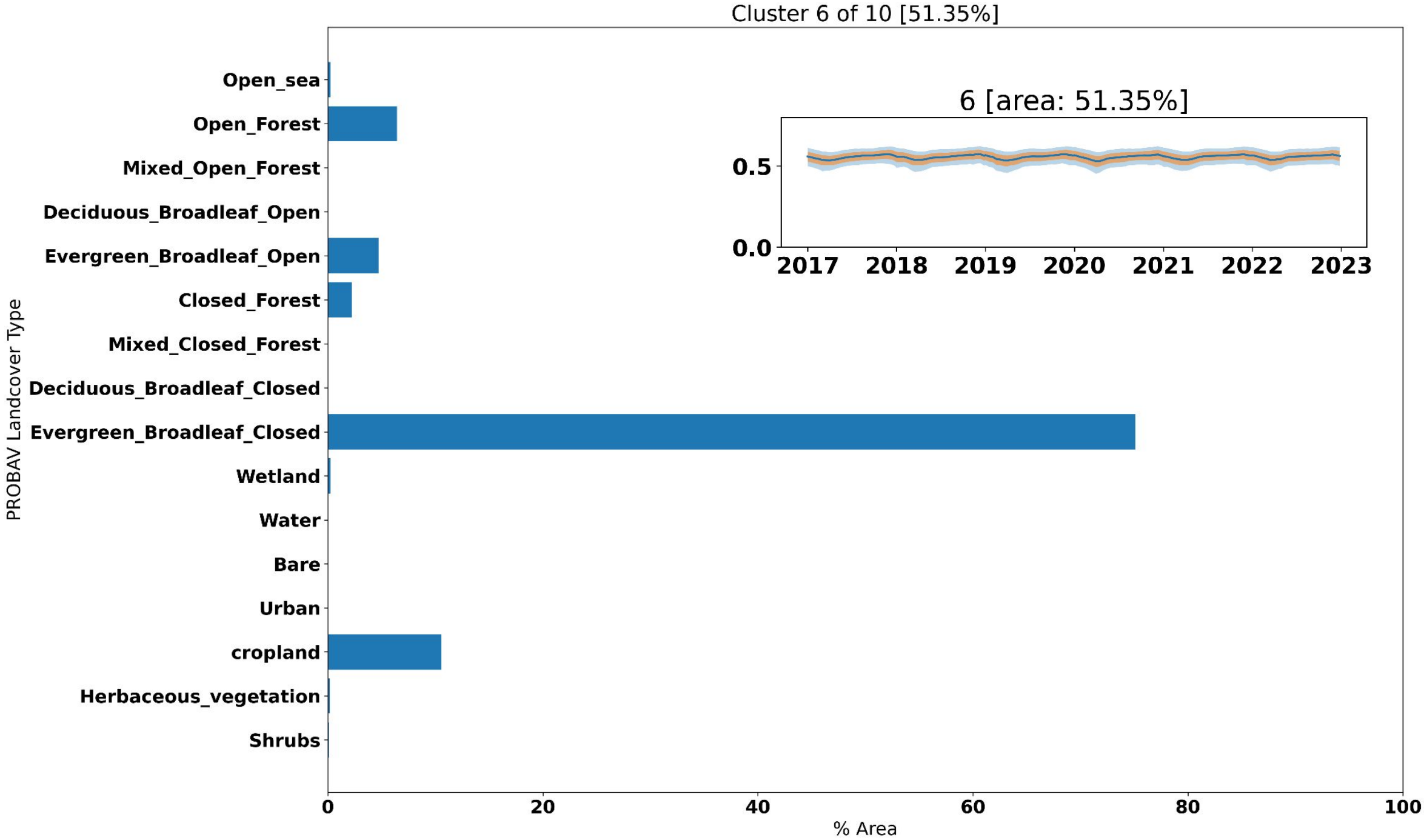
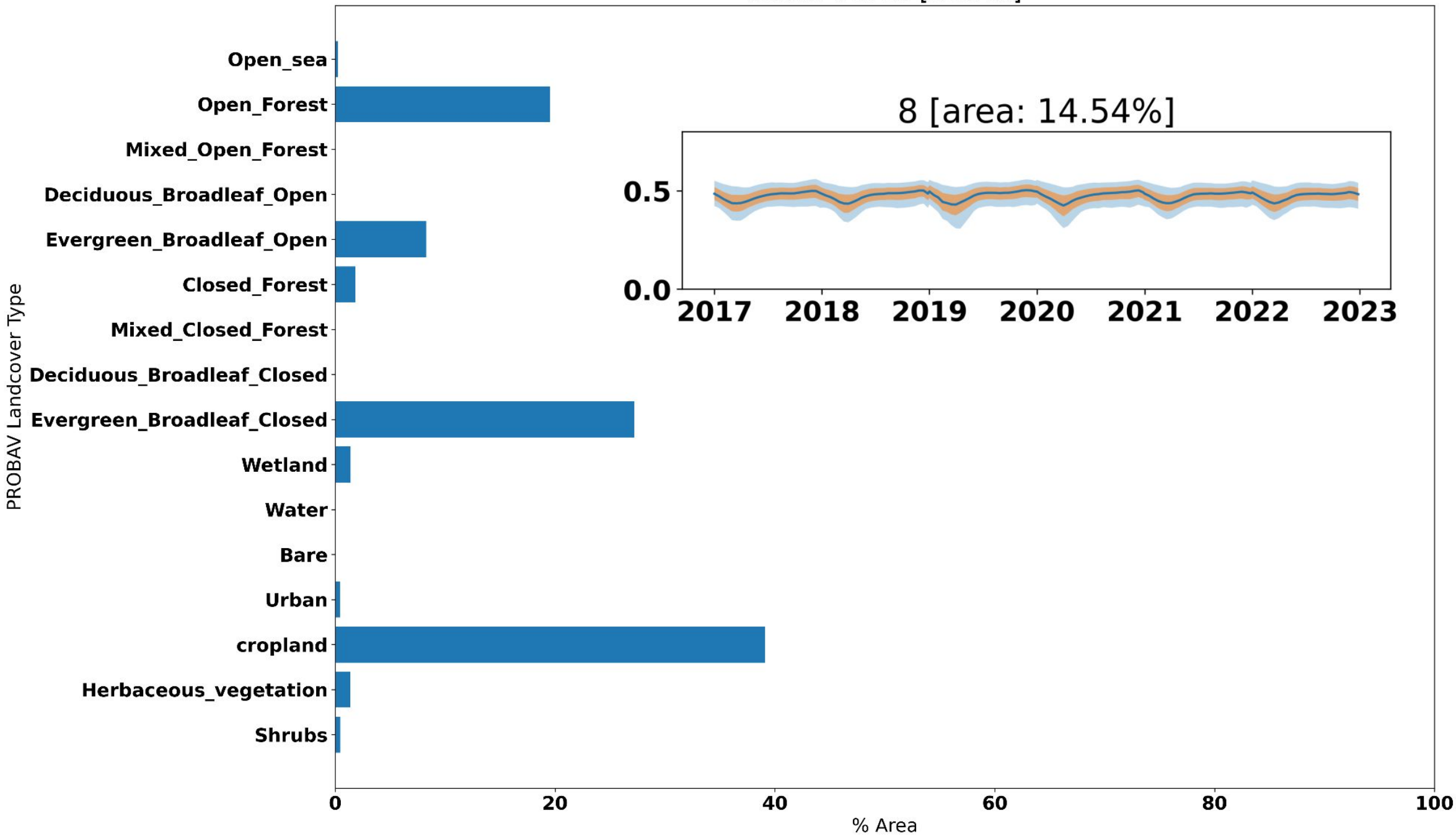
9 [area: 0.01%]
10 [area: 0.00%]
0.0
0.5
2017
2018
2019
2020
2021
2022
2023


Cluster 5 of 10 [15.06%]
Open_sea
Open_Forest
Mixed_Open_Forest
Deciduous_Broadleaf_Open
Evergreen_Broadleaf_Open
Closed_Forest
Mixed_Closed_Forest
Deciduous_Broadleaf_Closed
Evergreen_Broadleaf_Closed
Wetland
Water
Bare
Urban
cropland
Herbaceous_vegetation
Shrubs
PROBAV Landcover Type
0
20
40
60
80
100
% Area
5 [area: 15.06%]
0.5
0.0
2017
2018
2019
2020
2021
2022
2023


Cluster 6 of 10 [51.35%]
6 [area: 51.35%]
0.5
0.0
2017
2018
2019
2020
2021
2022
2023
PROBAV Landcover Type
Open_sea
Open_Forest
Mixed_Open_Forest
Deciduous_Broadleaf_Open
Evergreen_Broadleaf_Open
Closed_Forest
Mixed_Closed_Forest
Deciduous_Broadleaf_Closed
Evergreen_Broadleaf_Closed
Wetland
Water
Bare
Urban
cropland
Herbaceous_vegetation
Shrubs
0
20
40
60
80
100
% Area


Cluster 8 of 10 [14.54%]
8 [area: 14.54%]
0.5
0.0
2017
2018
2019
2020
2021
2022
2023
PROBAV Landcover Type
Open_sea
Open_Forest
Mixed_Open_Forest
Deciduous_Broadleaf_Open
Evergreen_Broadleaf_Open
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Deciduous_Broadleaf_Closed
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Wetland
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Herbaceous_vegetation
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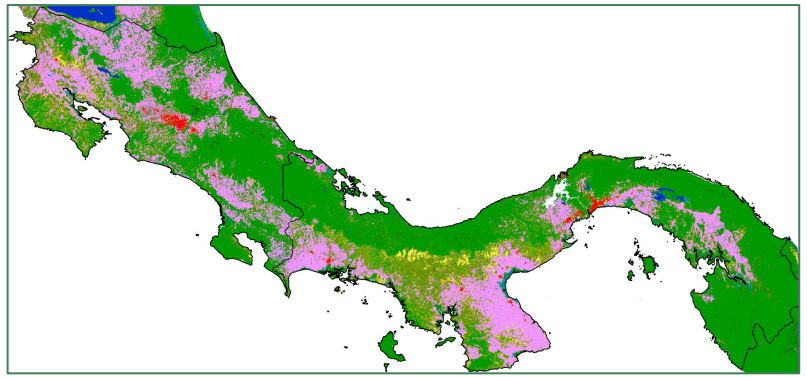
0
20
40
60
80
100
% Area

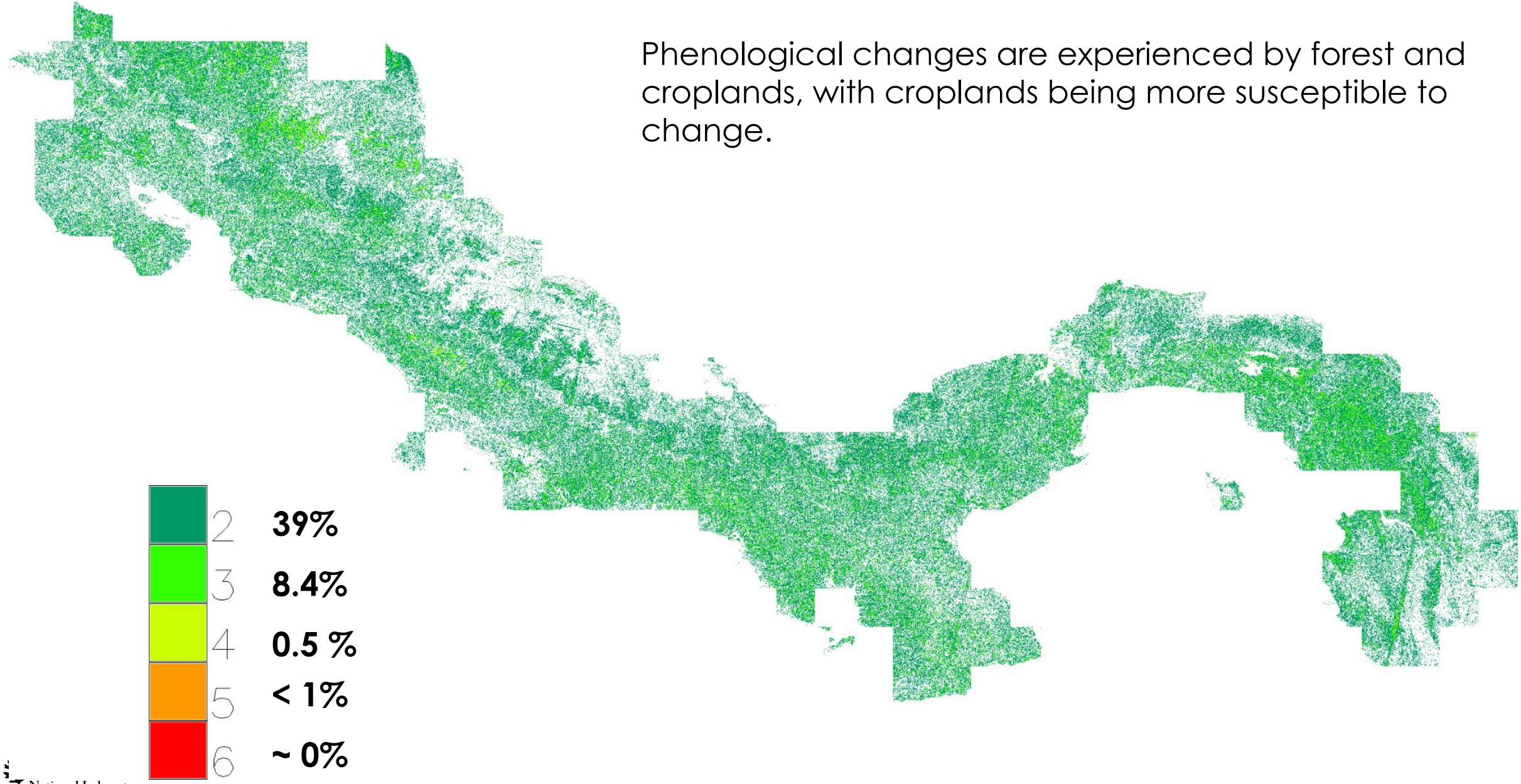
Spatial patterns of dynamic phenoregions

2017



Where are changes happening?

Phenological changes are experienced by forest and croplands, with croplands being more susceptible to change.



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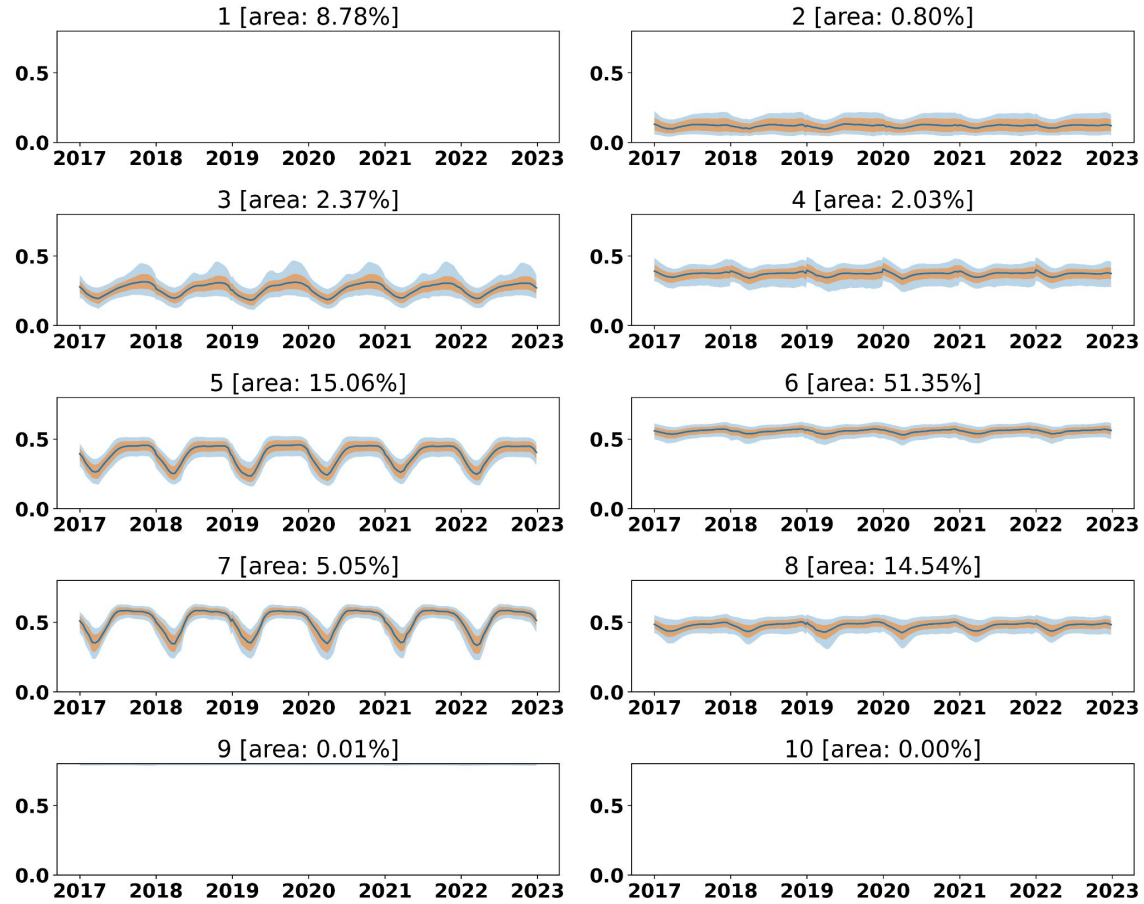
What transitions have occurred between 2017-2022



2017-2022

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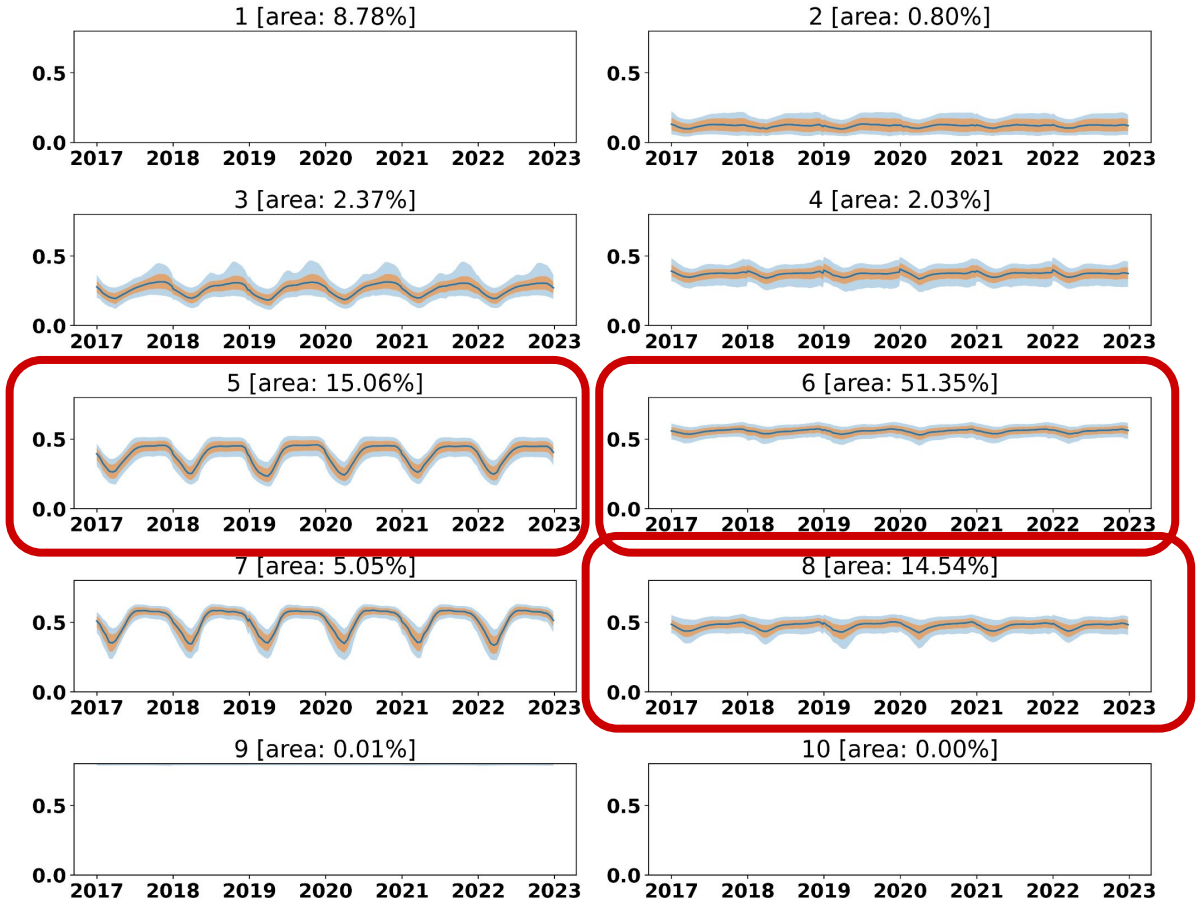


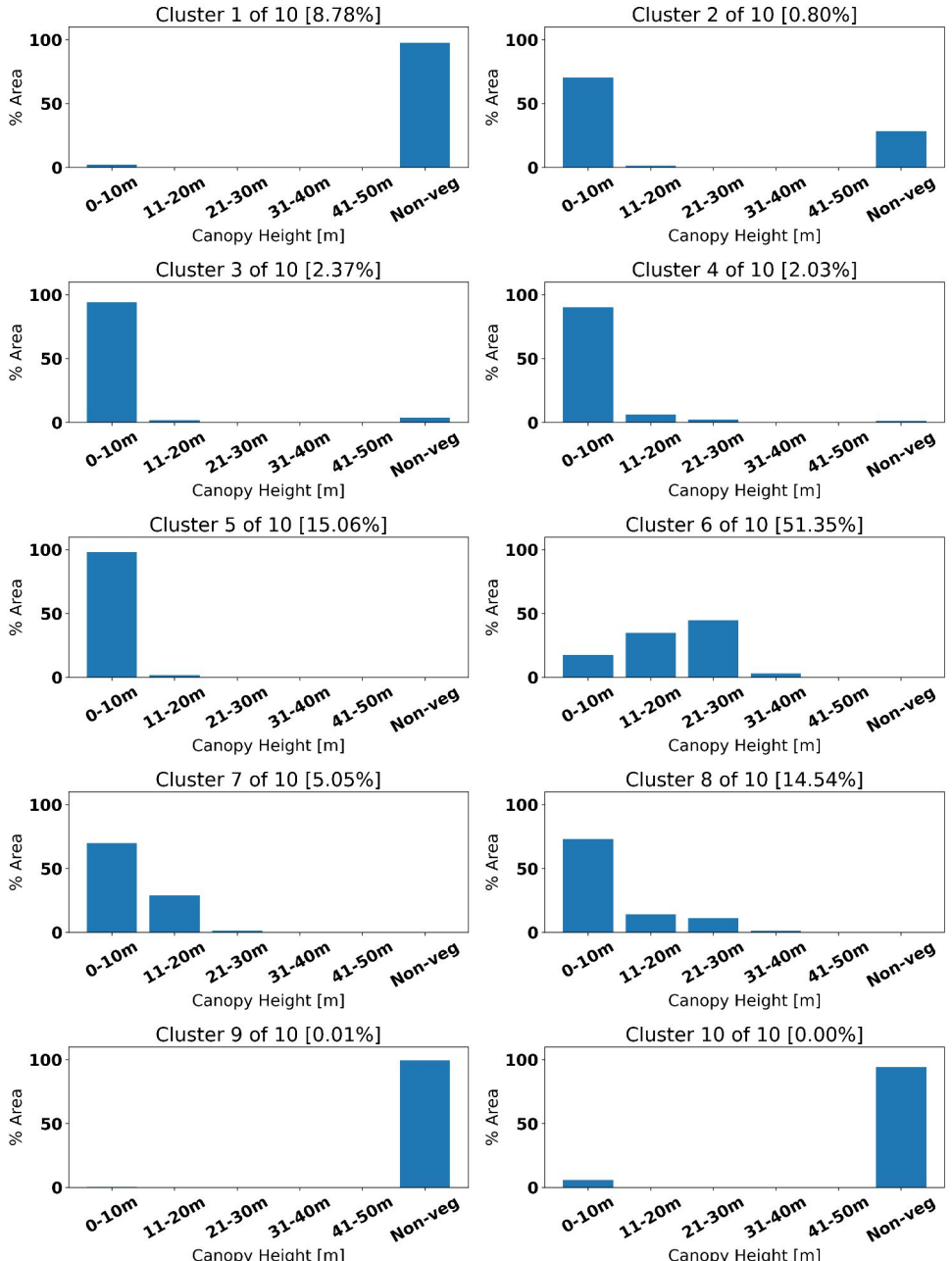
2017-2022

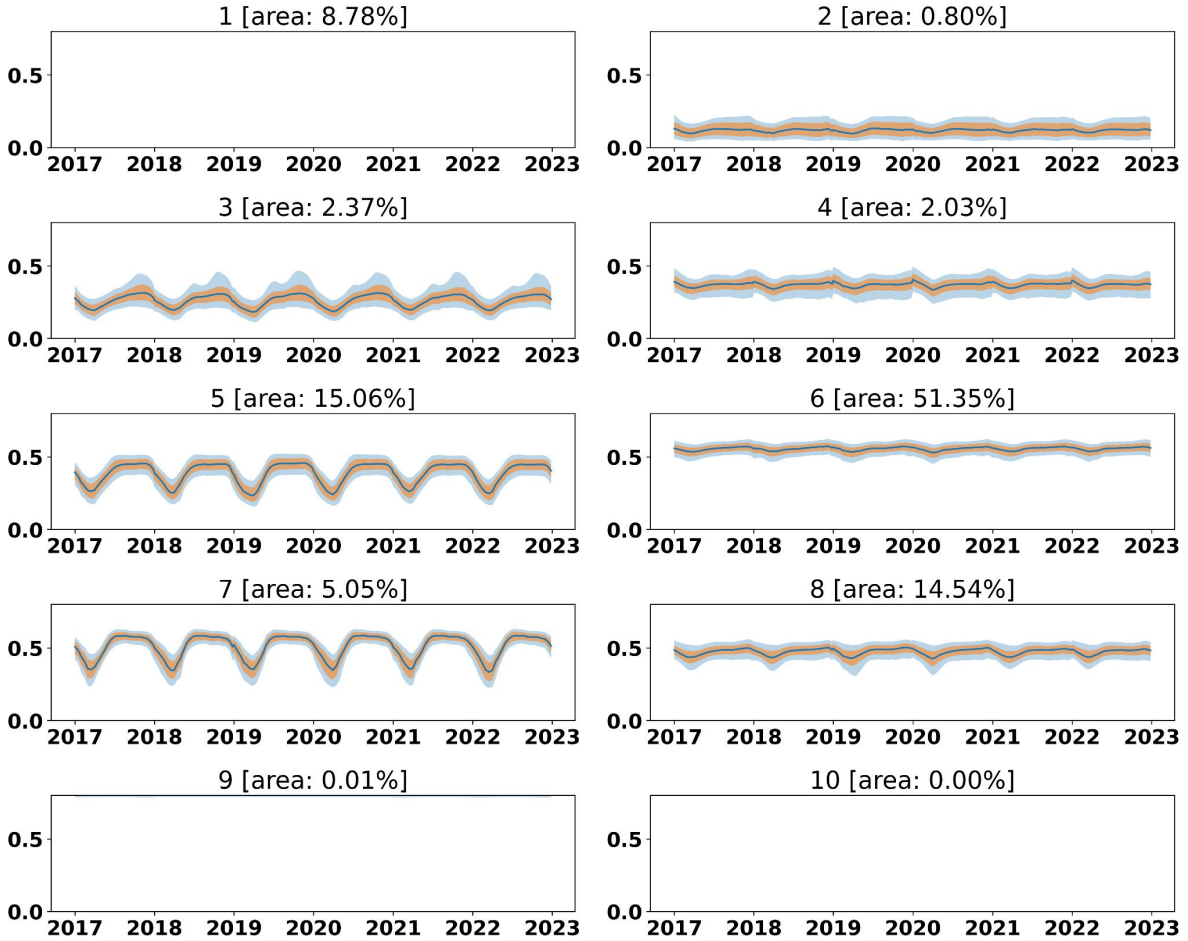
Some phenoregions (vegetation types) are more stable (or transient) than the others.

What are the drivers of changes?

- Magnitude of phenological changes experienced by vegetation at any location are often influenced by
  - Vegetation characteristics
    - Vegetation type
    - Vegetation structure
  - Climatic conditions
    - Air temperature, precipitation, soil moisture, radiation, evapotranspiration, vapor pressure deficit
- What are the patterns of traits/environmental controls across the study region?

Low height vegetation show higher variability





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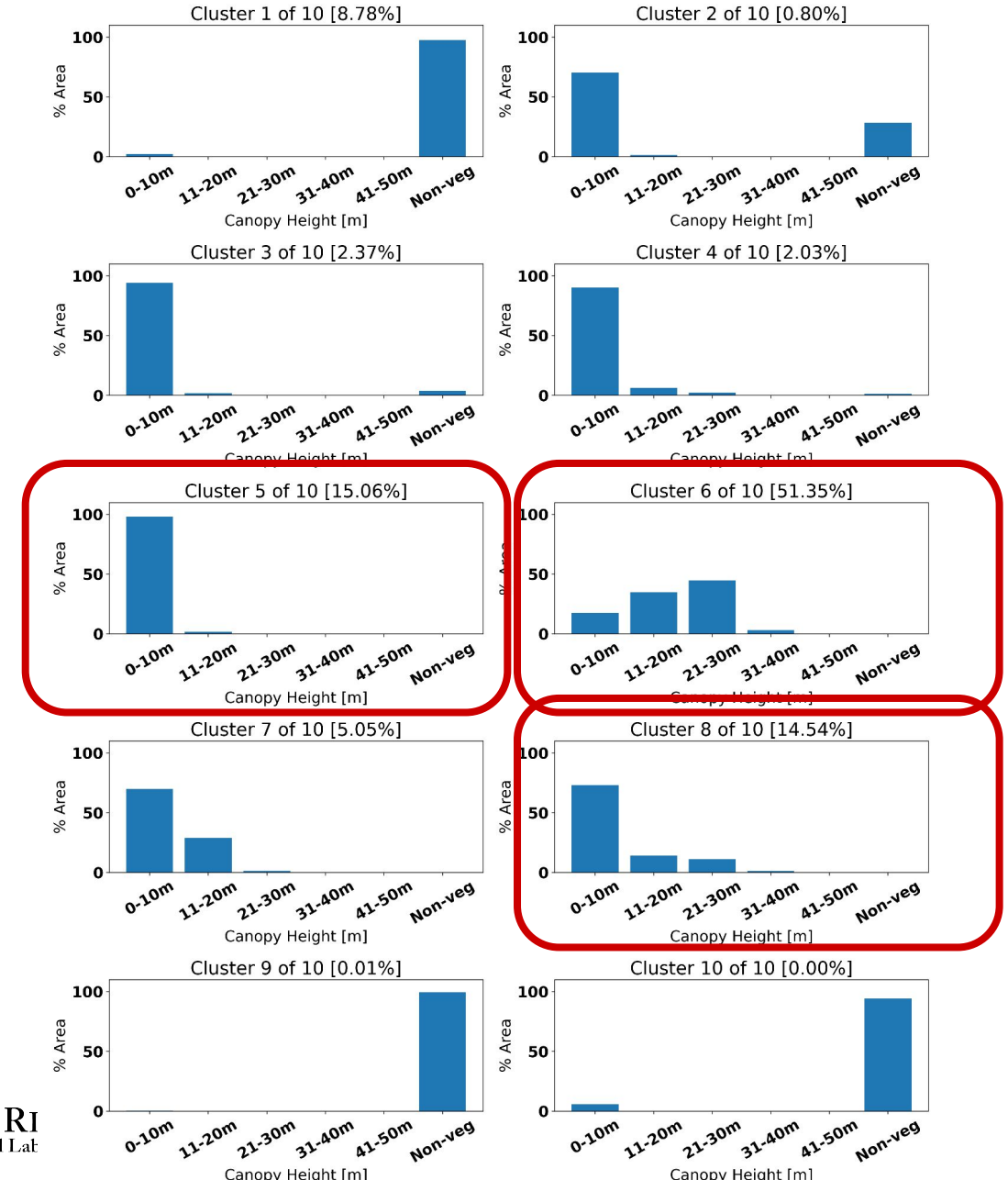

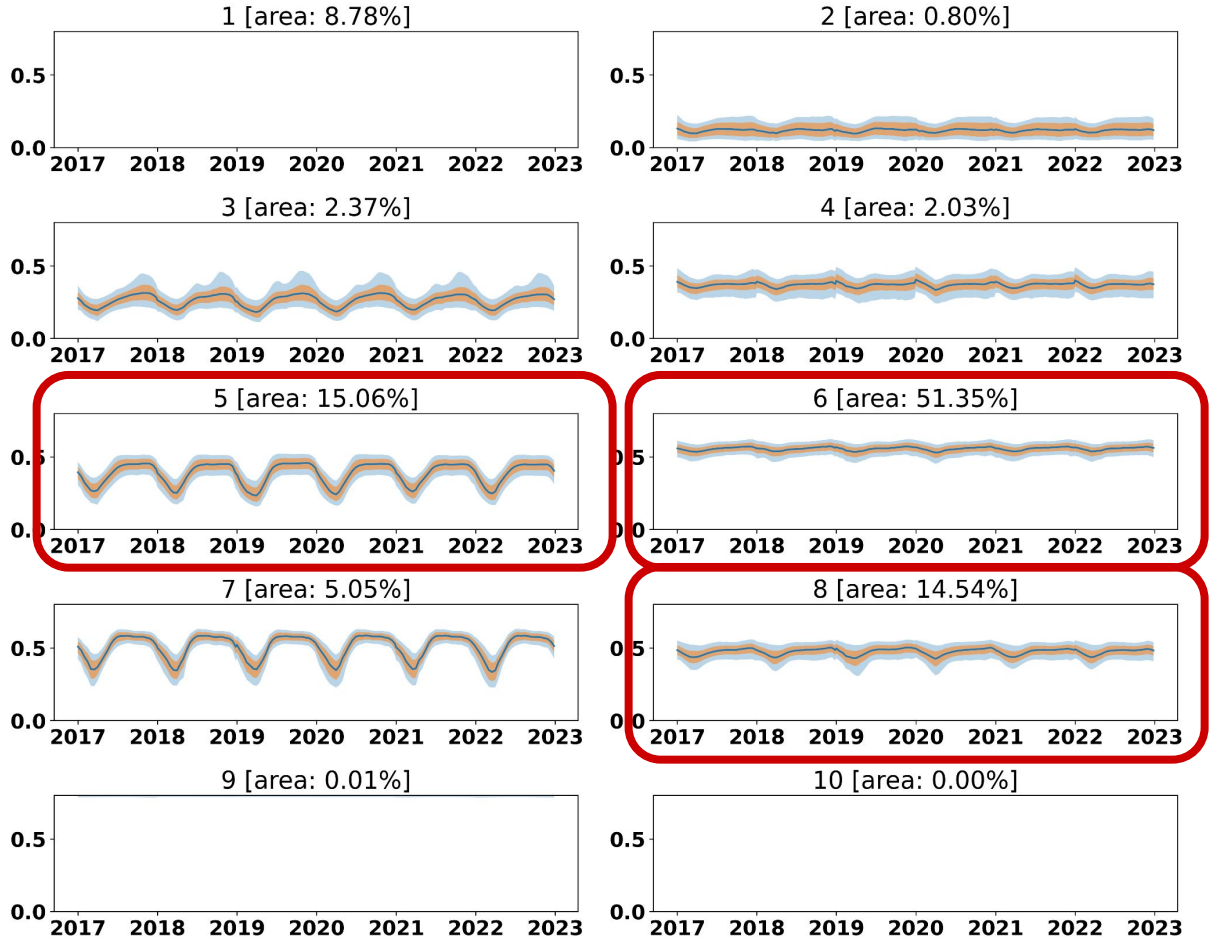

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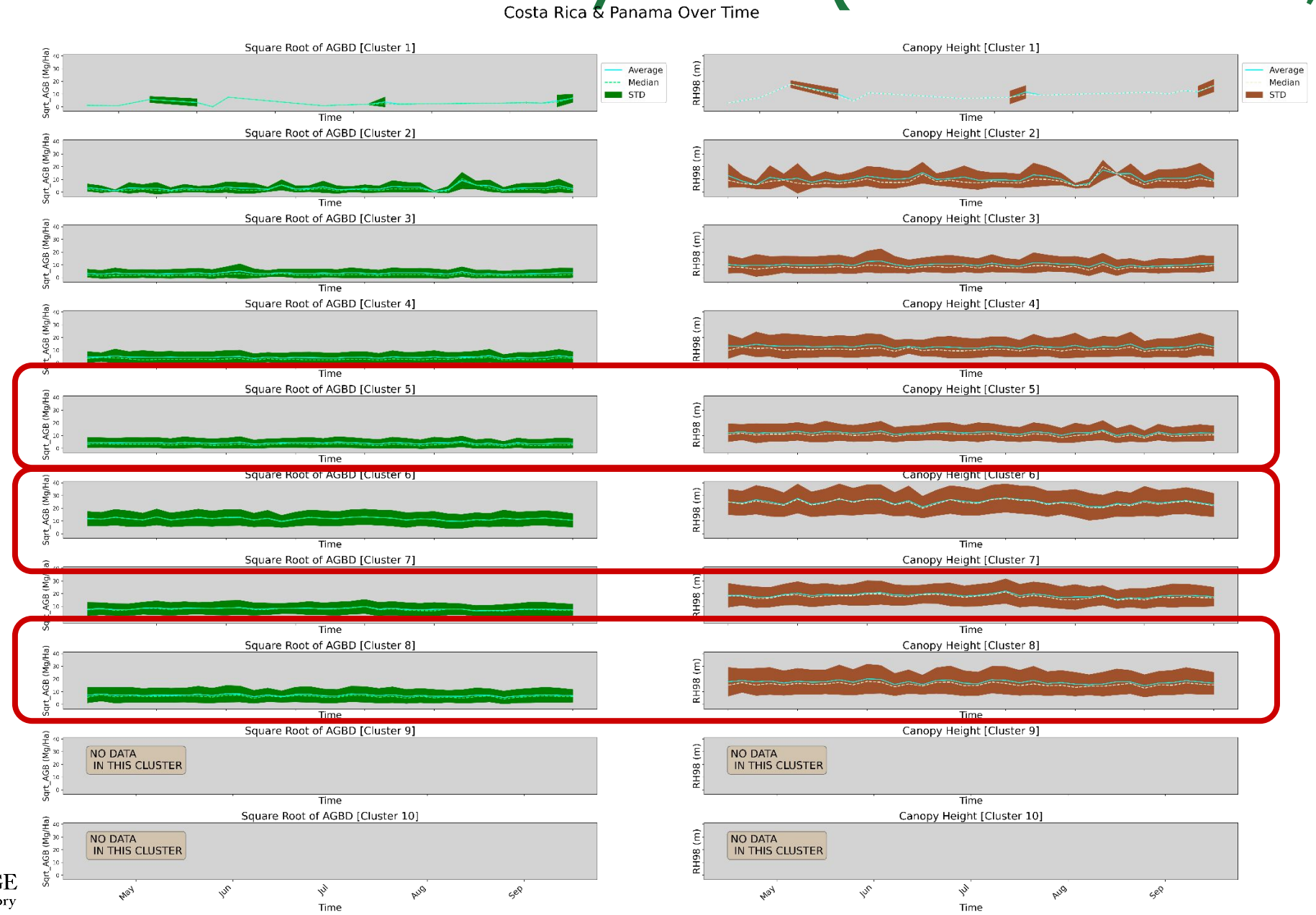
Vegetation structure is dynamic (NASA GEDI L2A, L4A)



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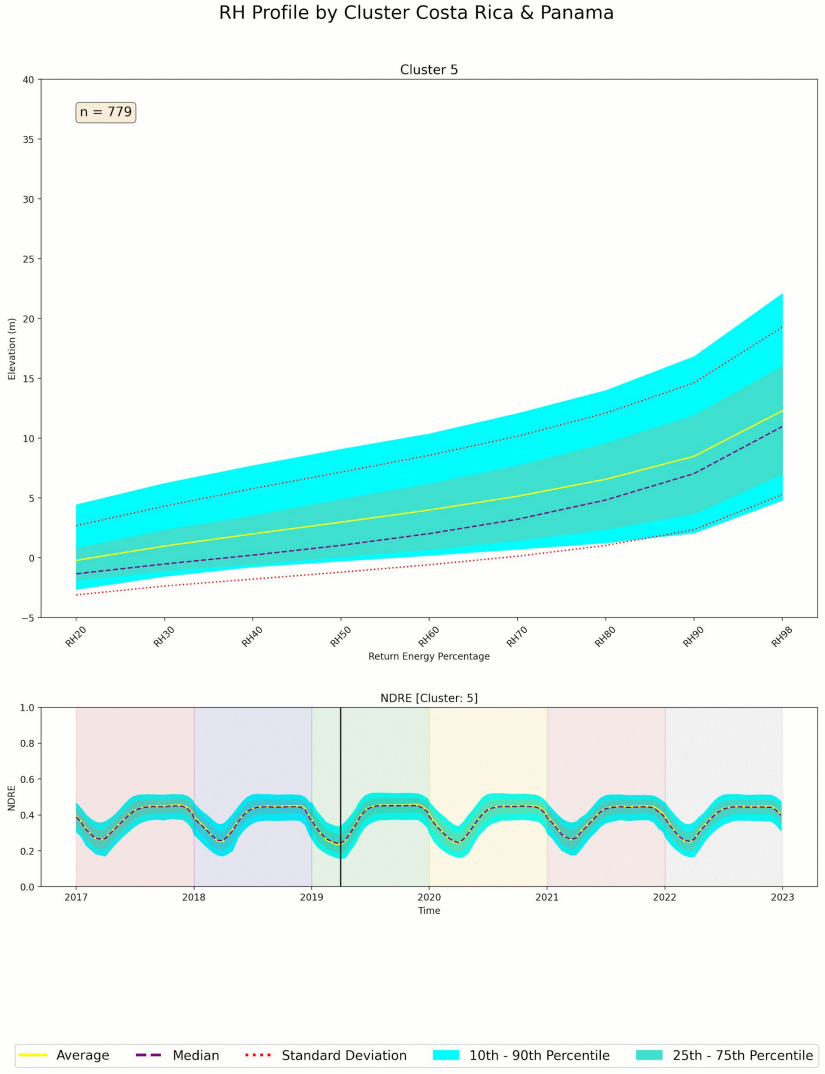
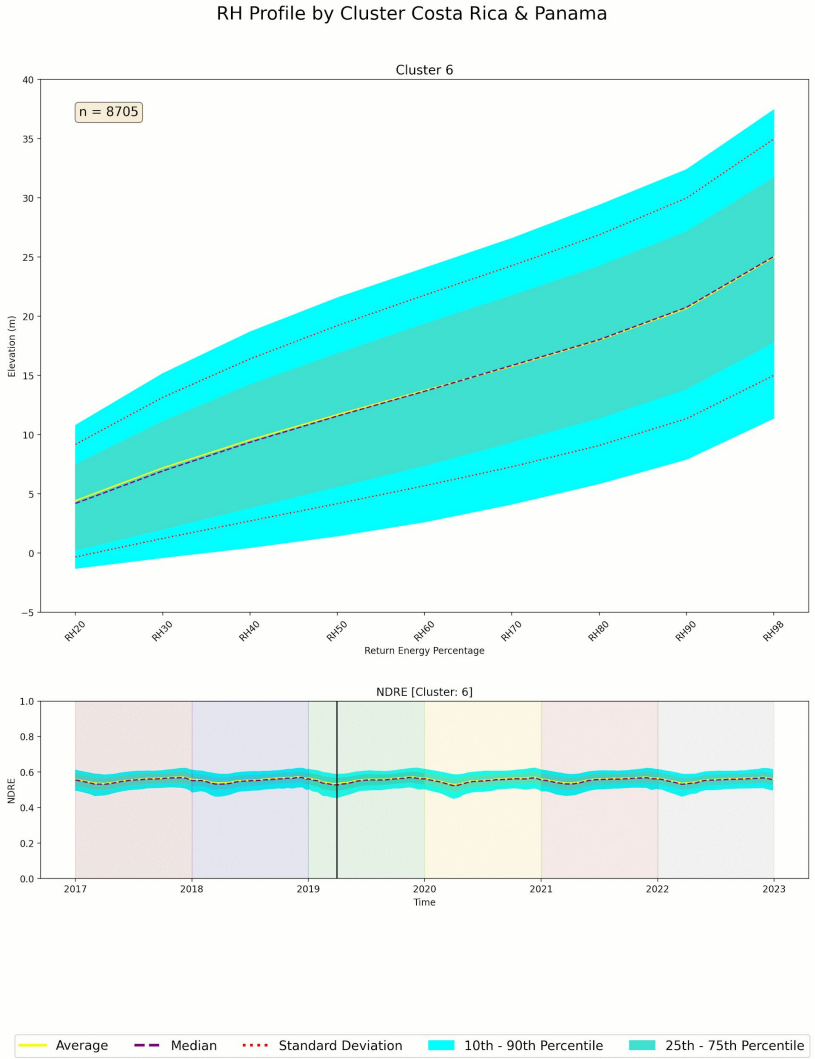
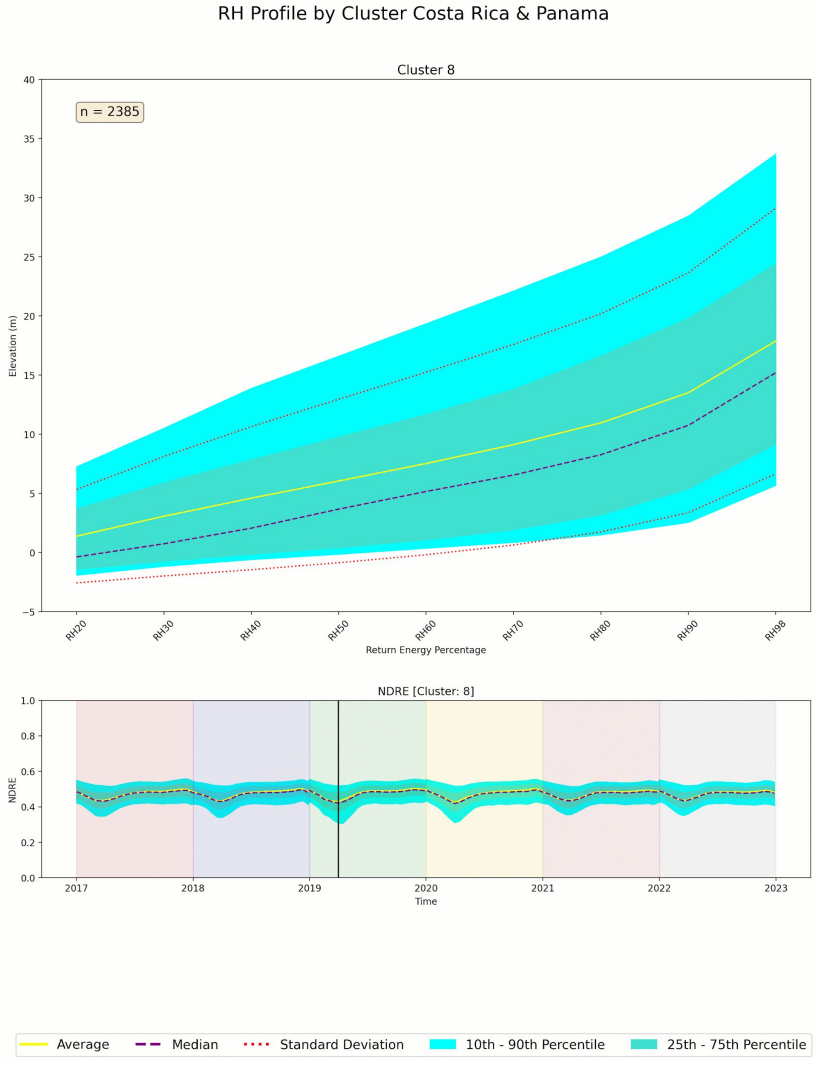
Vegetation structure is dynamic (NASA GEDI L2B)







Structural changes occur along the full vertical canopy profile.
NOTE: GEDI sampling bias introduces some artifacts

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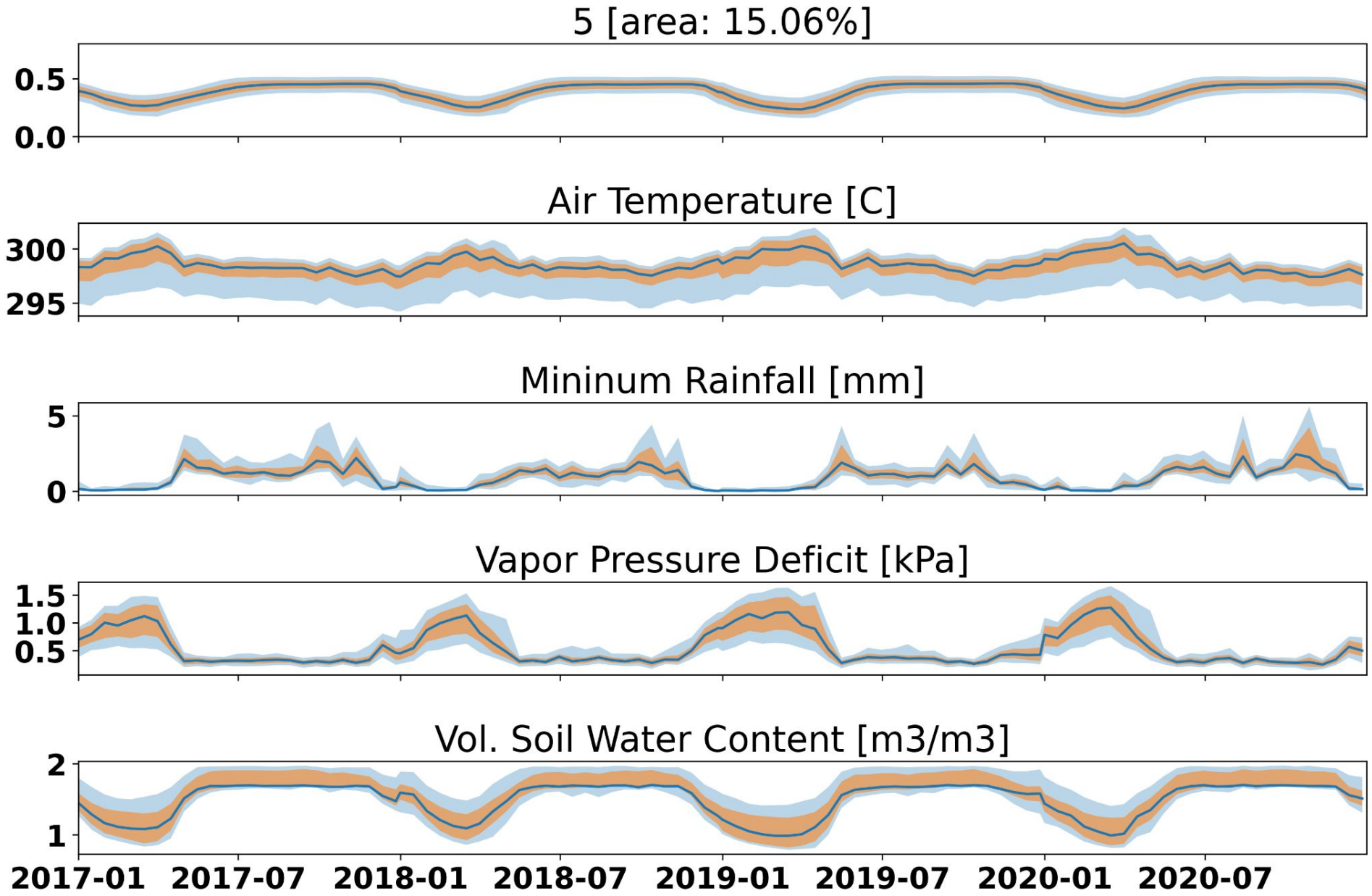
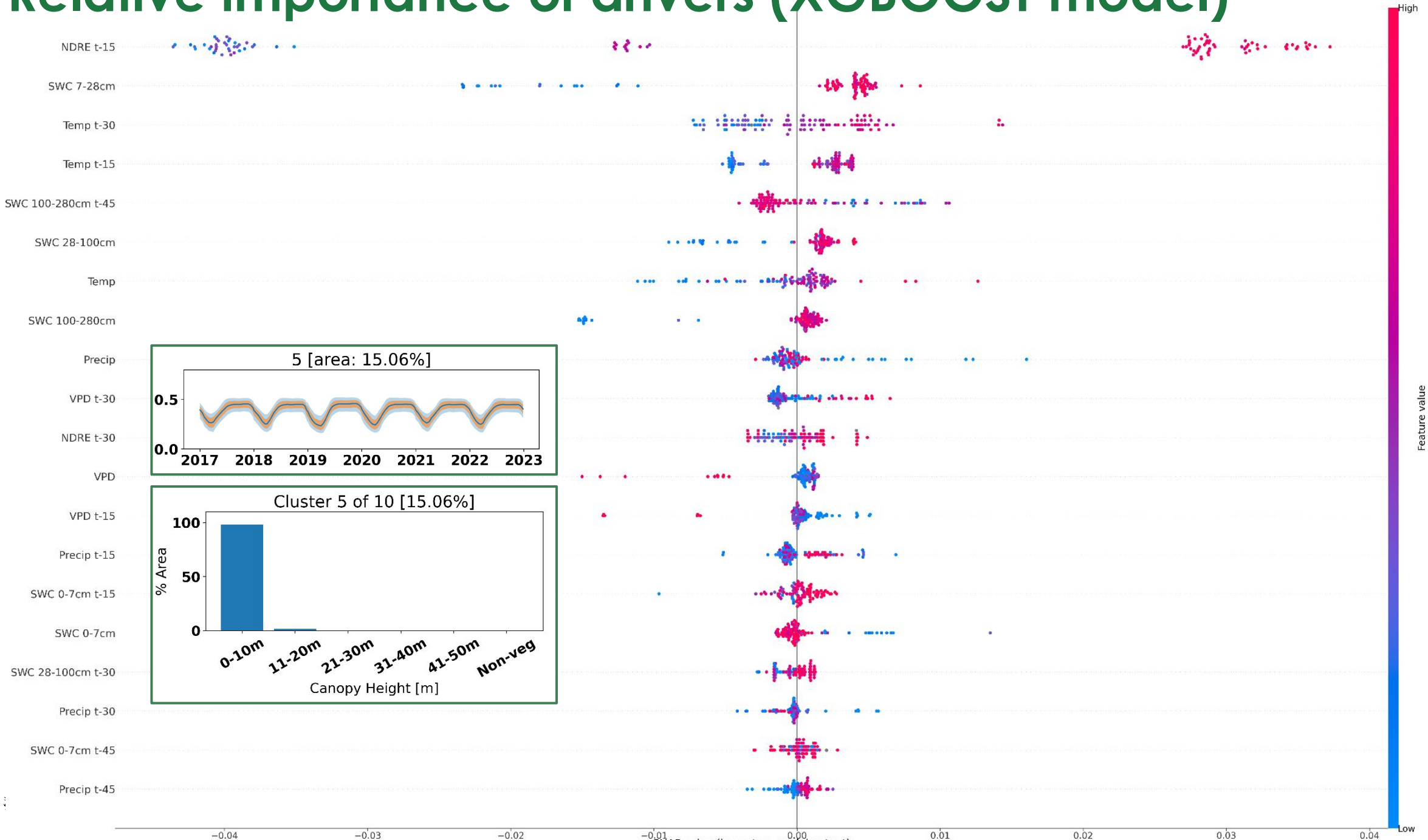
Meteorological conditions are key control of phenology

- We analyzed climate reanalysis time series from ERA5-Land
  - Temperature, Precipitation, Soil Moisture (for 4 soil levels), Radiation, Evapotranspiration, Vapor Pressure Deficit
  - Spatial resolution: 0.10 degree (~9km) – regridded to S2 20m
  - Temporal resolution: 15 days (aggregated from hourly)
- Extreme Gradient Boosting (XGBoost) modeling [still ongoing]
  - between meteoroglogical drivers and NDRE
  - considered lags of upto 45 days
  - SHapley Additive exPlanations (SHAP) approach for relative controls by drivers
  - grid search for hyperparameter tuning
  - applied to each 20m pixel

Meteorological conditions are key control of phenology



Relative importance of drivers (XGBOOST model)



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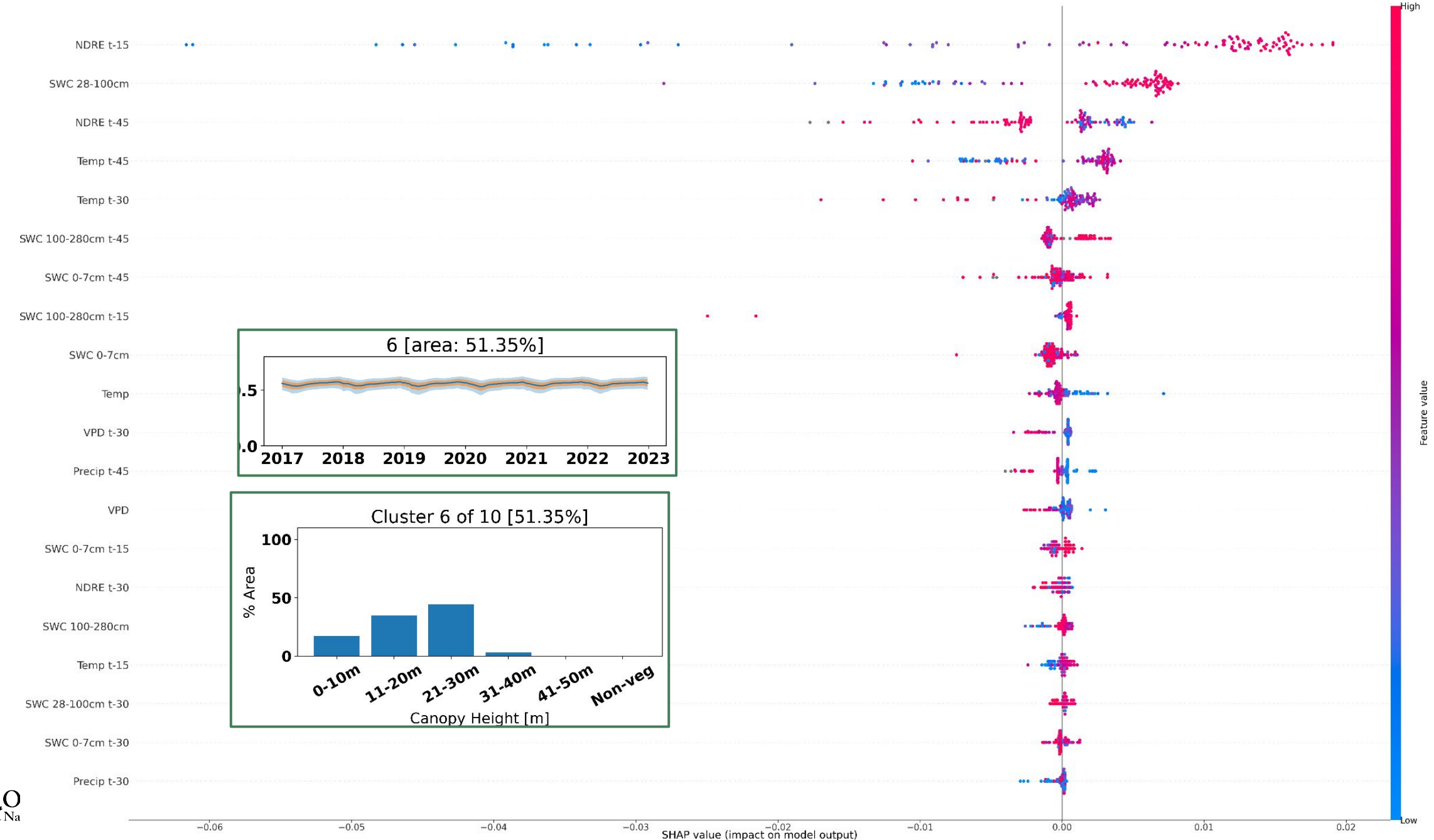

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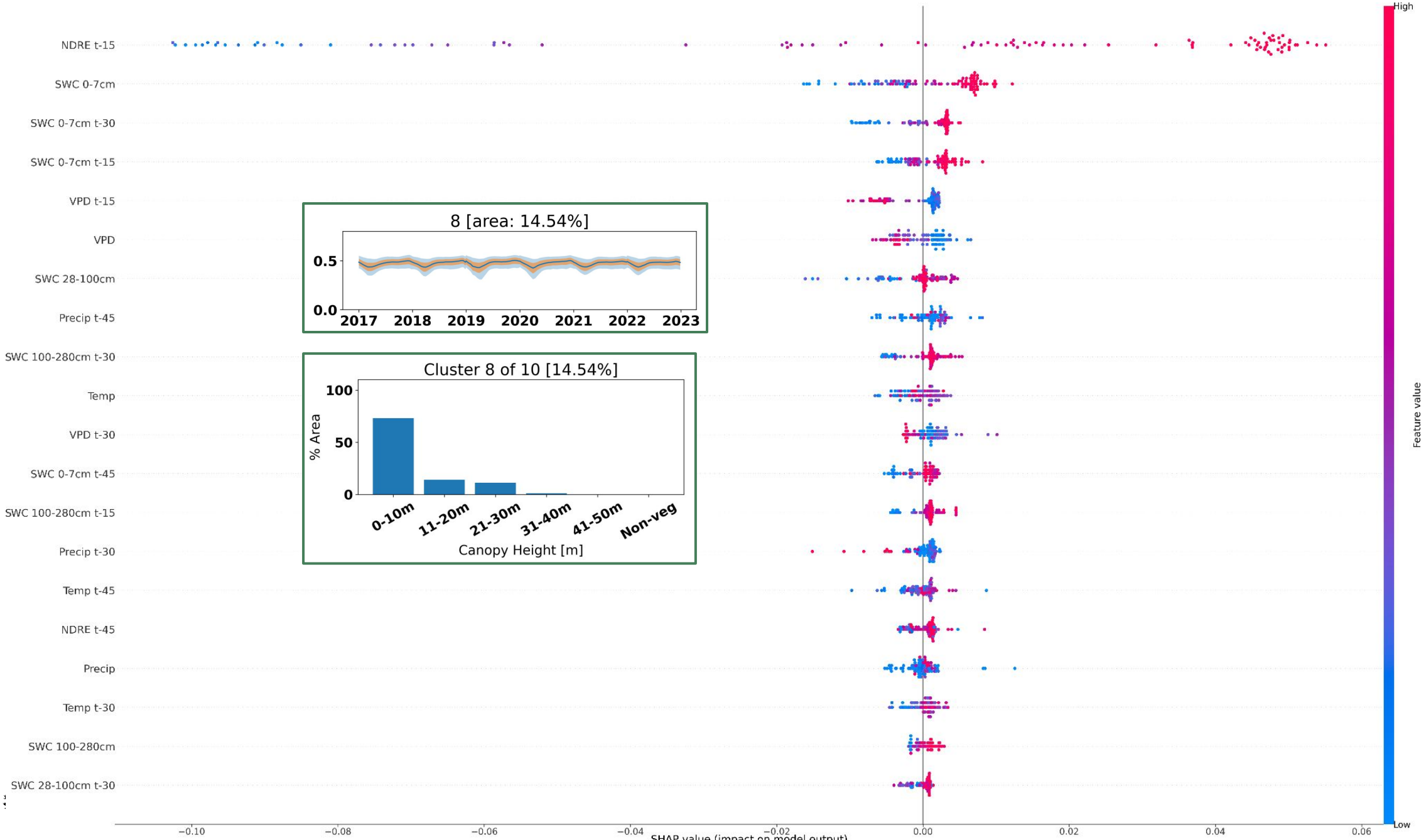

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