Plant trait estimation in a forest ecosystem from hyperspectral satellites through machine learning and hybrid approaches

Cinzia Panigada

Tagliabue G., Verrelst J., Soria J.L., Candiani G., Boschetti M., Morata M., Gentili R., Savinelli B., Vignali L., Gallia L., Picchi V., Calzone A., Colombo R., Rossini M.

University of Milano - Bicocca, Department of Earth and Environmental Sciences, Italy

EARSeL

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Background

The recently launched and upcoming hyperspectral satellites are opening unprecedented opportunities for plant trait mapping, which are important to monitor forests (e.g. functional biodiversity, forest condition,..)

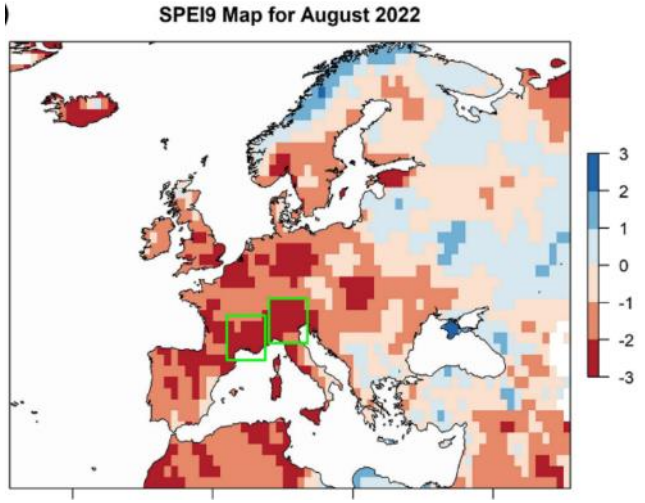
PRISMA, launched in March 2019, featuring 240 spectral wavebands from 400 to 2500 nm, gave the opportunity to test new-generation models on real images

Plant traits retrieval from spaceborne data has been tested more on agricultural crops than in forest. Model calibration and validation is still challenging

Study Objectives

Objective: To test a workflow for retrieving plants traits from satellite hyperspectral data in natural forest ecosystems

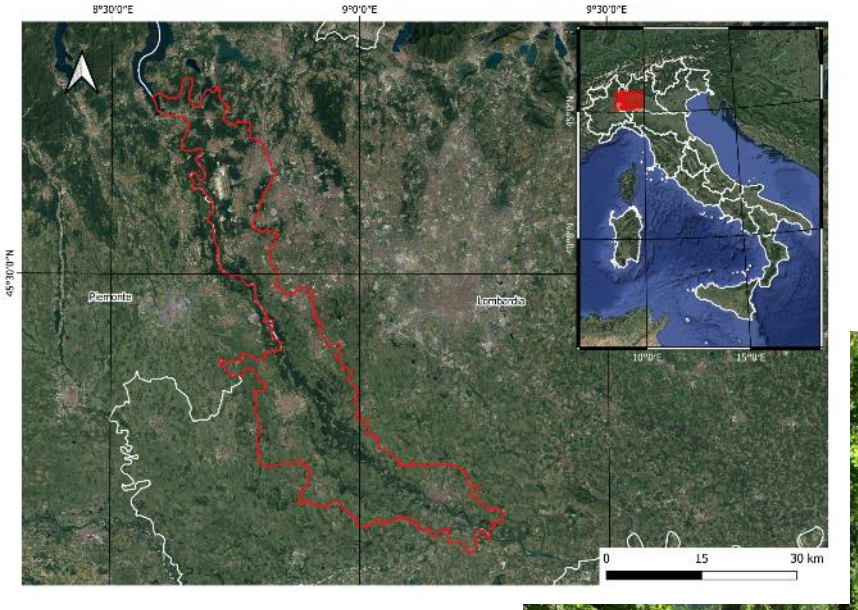
- Leaf chlorophyll content (LCC)
- Leaf carotenoid content (Ccx)
- Leaf nitrogen content (LNC)
- Leaf water content (LWC)
- Leaf mass area (LMA)
- Leaf area index (LAI)



Faranda et al., *2023*

- To investigate and compare machine learning approaches and hybrid approaches that combine RTM and MLRA
- To discuss the effect of Northern Italy drought (August 2022) on plant traits

Study Area

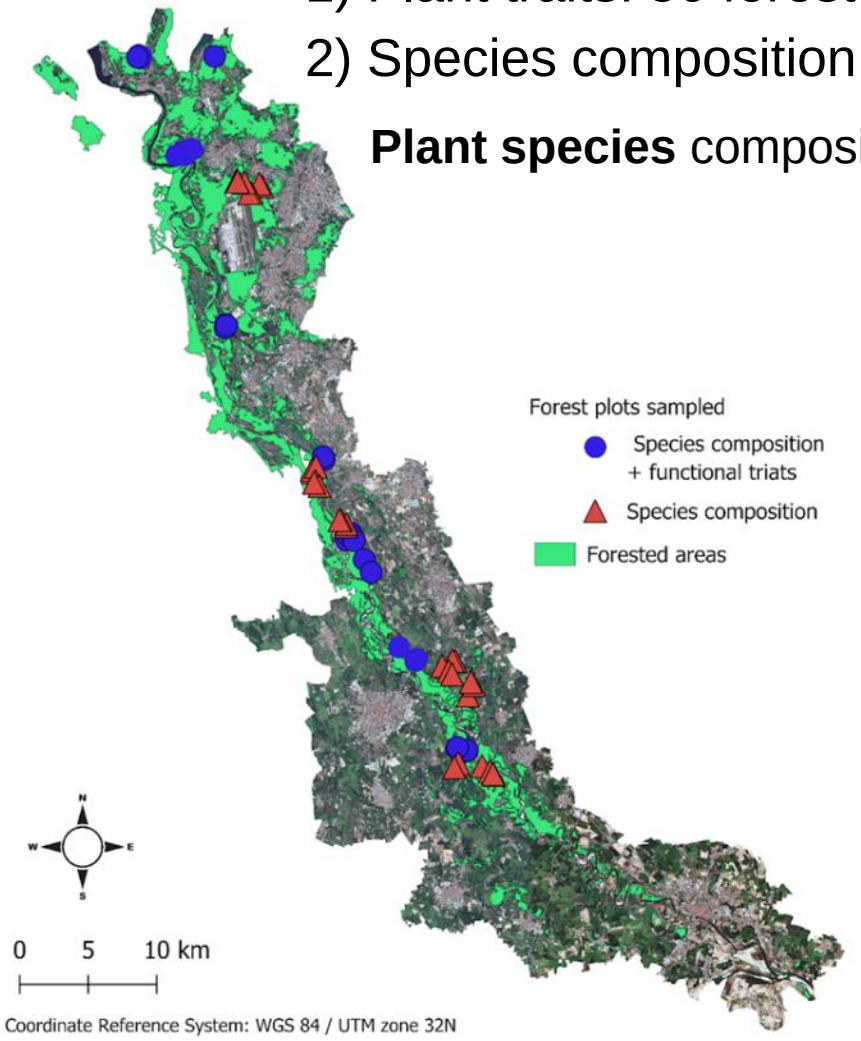


- Temperate mixed forest located in northern Italy (~918 km^2)
- Dominated by oak (typically *Quercus robur* L.) and hornbeam (*Carpinus betulus* L.), with alder (*Alnus glutinosa* L.), sweet chestnut (*Castanea sativa* Mill.), conifers (*Pinus spp.),* and invasive species (*Prunus serotina* Ehrh. and *Robinia pseudoacacia* L.)

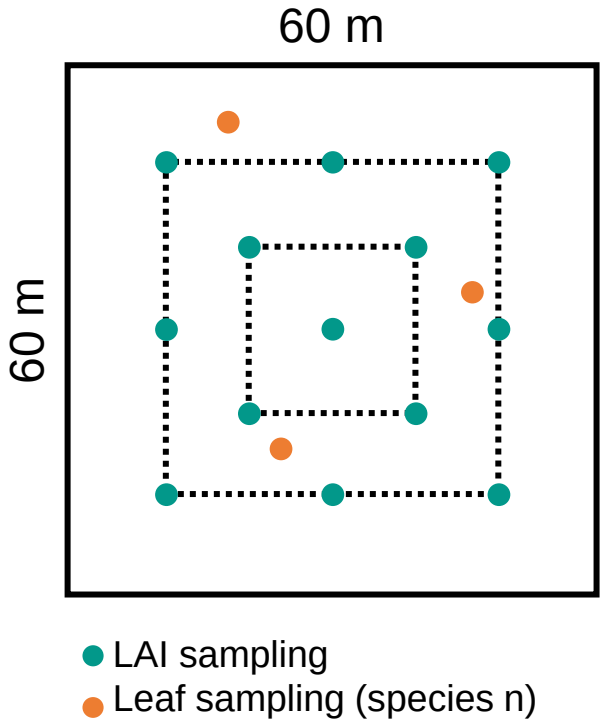
Field measurements

1) Plant traits: 50 forest plot (30 × 30 m), sampled in June and September 2022
2) Species composition: 63 forest plot (30 × 30 m)

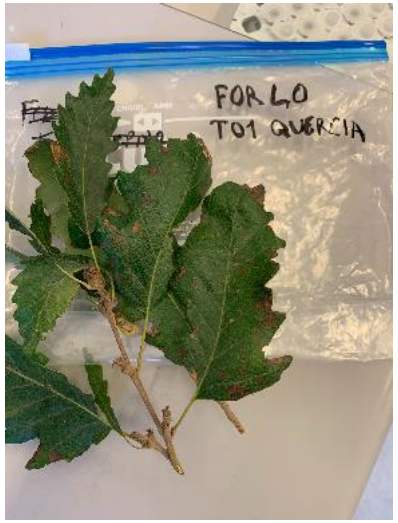
Plant species composition and abundance at tree, shrub, and herbaceous level



LAI estimation: upward and downward digital hemispherical photos (13 picture per plot)



Field measurements



210 trees (three samples for tree)
from the dominant tree species

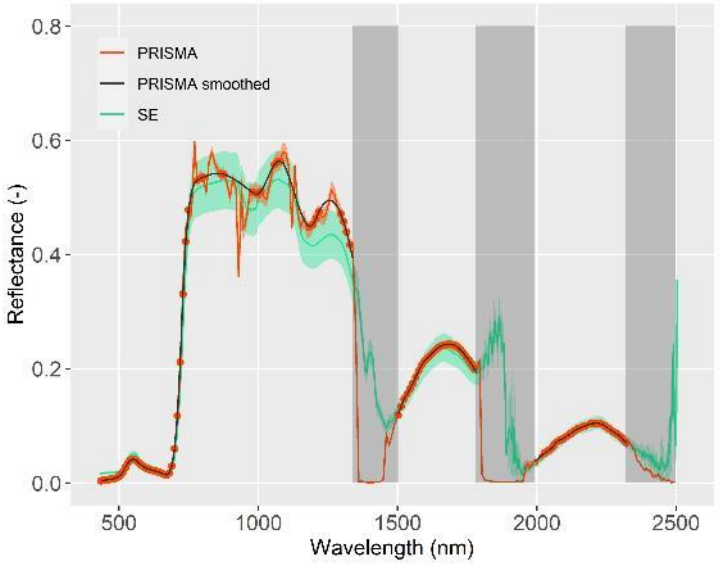
Laboratory analysis:
LCC, LWC, LMA, LNC

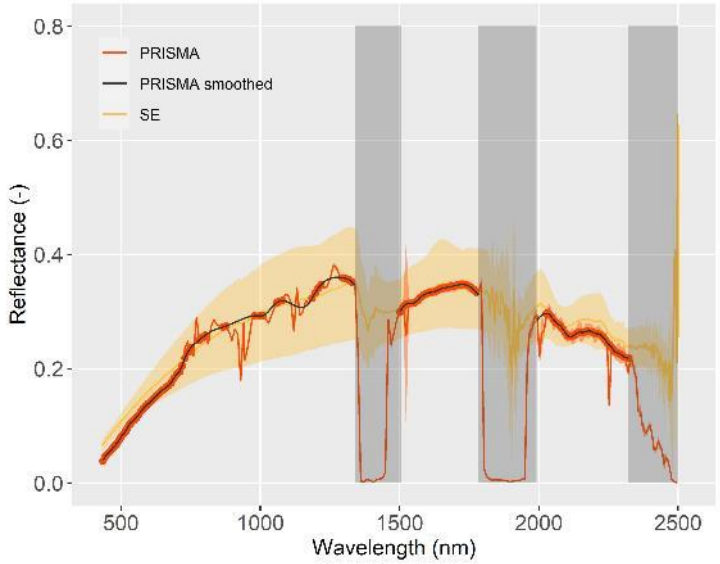
PRISMA images acquisition

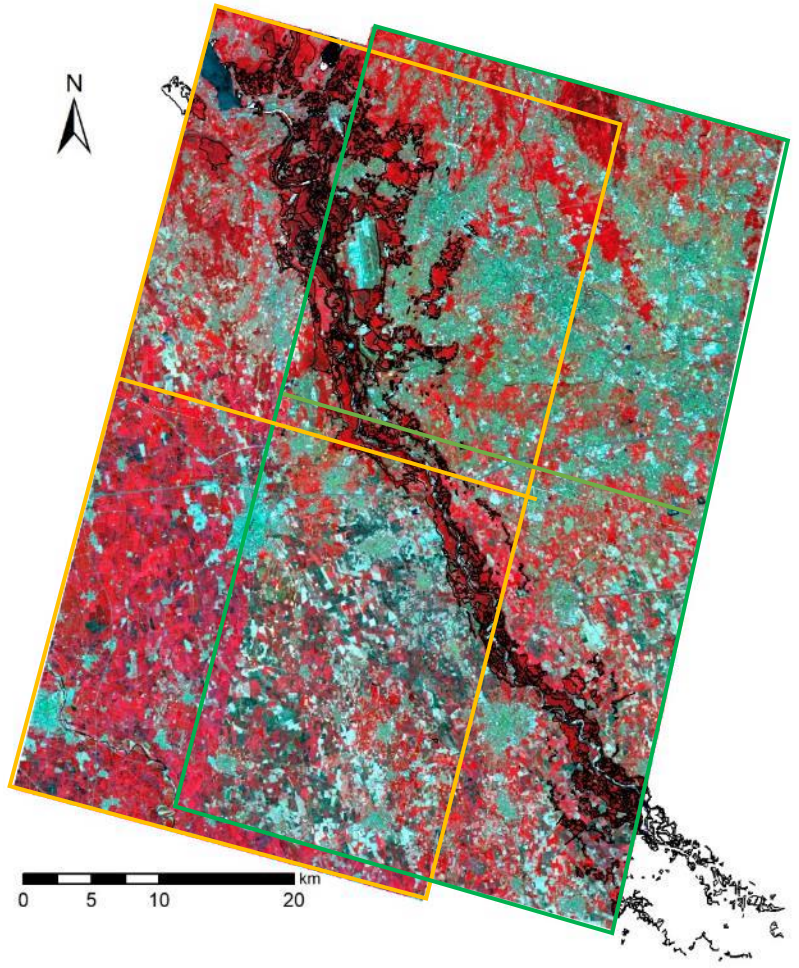
Two PRISMA mosaics of June and September 2022 (4 tiles each) were collected at different vegetative stage to capture plant trait variations from early summer to early fall.

PRISMA pre-processing

1. Spectral smoothing according to Tagliabue et al. (2022)
2. Image co-registration with S2 using AROSICS (Scheffler et al. 2017)



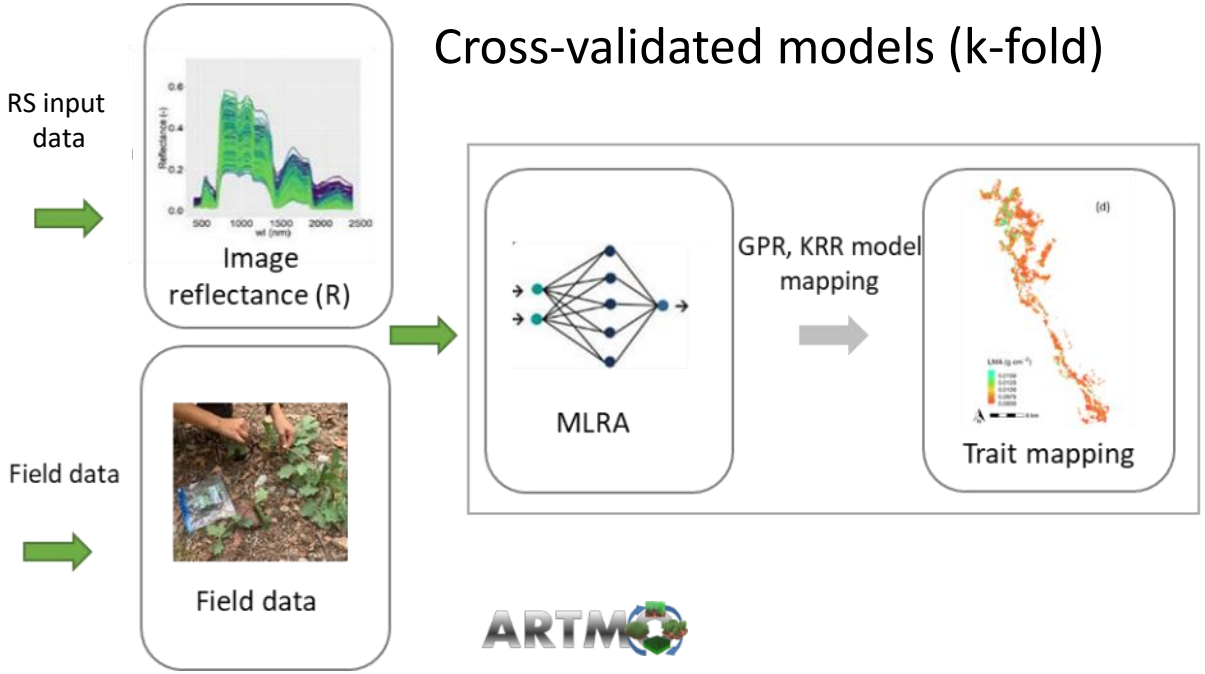




Retrieval of plant traits using MLRA vs HYBRID models

Machine learning regression algorithms

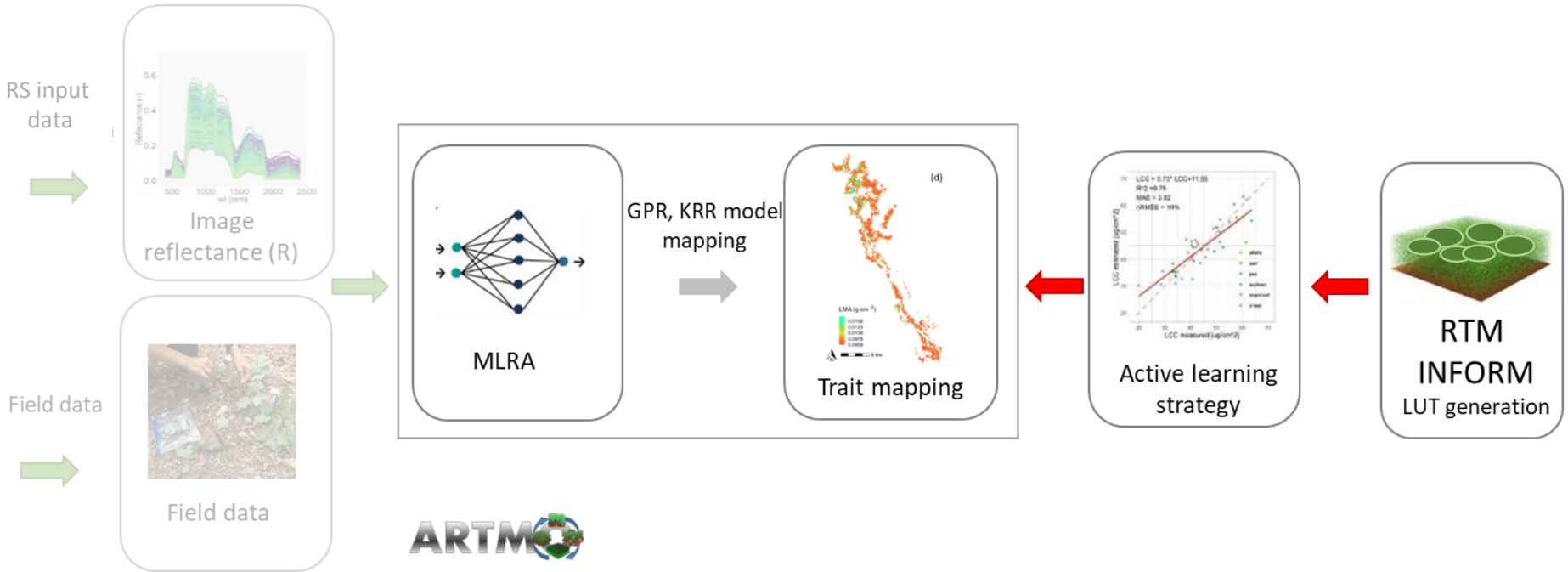
- Gaussian Processes Regression (GPR)
- Neural Networks (NN)
- Partial Least Squares Regression (PLSR)
- Support Vector Regression (SVR)
- Kernel Ridge Regression (KRR)
- Principal component regression (PCR)



Retrieval of plant traits using MLRA vs HYBRID models

Hybrid approach = RTM + MLRA

- RTM to produce the LUT spectra → simulation of 2000 spectra with PROSPECT-PRO (Feret et al. 2021) + INFORM (Schlerf and Atzberger, 2006)



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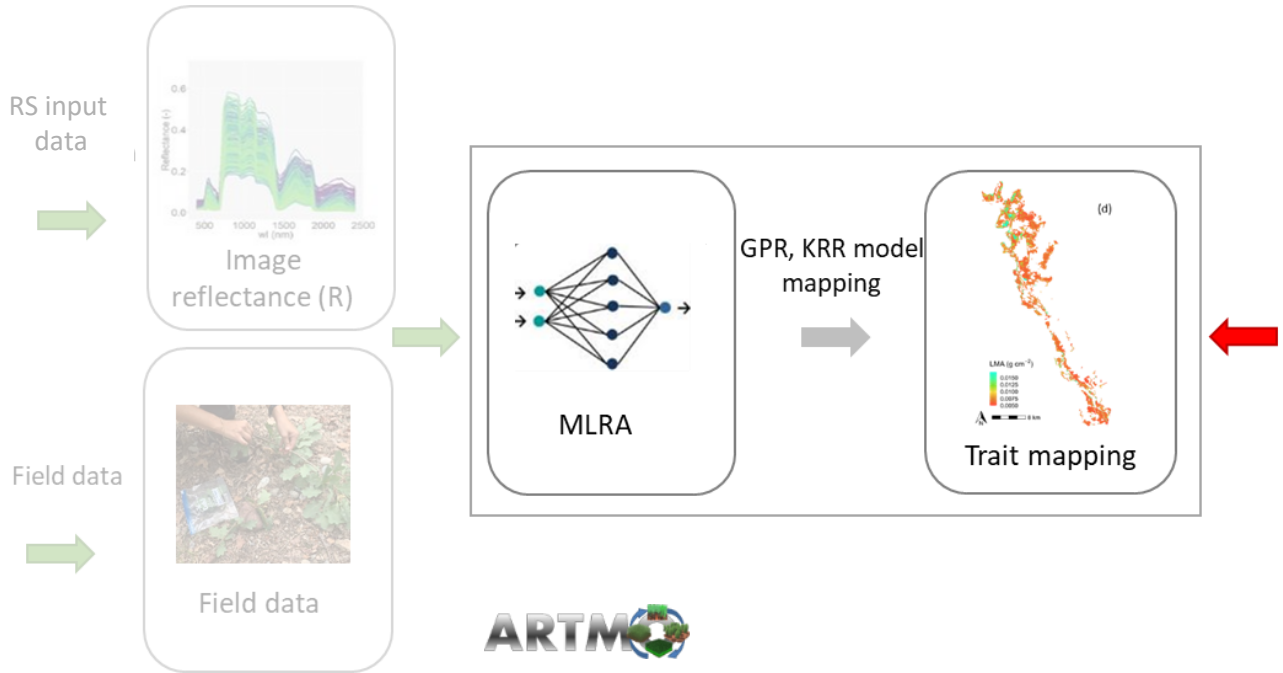


Model	Variable		Unit	Range
PROSPECT-PRO	N	Leaf structural parameter	unitless	1.2-1.8
	LCC	Leaf chlorophyll content	$\mu g\,cm^{-2}$	20-70
	C_{cx}	Leaf carotenoid content	$\mu g\,cm^{-2}$	0-20
	C_{anth}	Leaf anthocyanin content	$\mu g\,cm^{-2}$	0-5
	C_{bp}	Brown pigment content	$\mu g\,cm^{-2}$	0
	C_p	Leaf protein content	$g\,cm^{-2}$	0.0001-0.0015
	CBC	Carbon-based constituents	$g\,cm^{-2}$	0.001-0.006
	LWC	Leaf water content	$g\,cm^{-2}$	0.001-0.03
INFORM	LAI	Single tree leaf area index	$m^2\,m^{-2}$	0.5-6
	LAIu	Leaf area index of understory	$m^2\,m^{-2}$	0-2
	ALA	Average leaf angle	deg	30-50
	Sd	Stem density	ha^{-1}	200-400
	h	Tree height	m	20
	Cd	Crown diameter	m	2-10
	α_{soil}	Soil scaling factor	unitless	0.1-0.4
	skyl	Fraction of diffuse radiation	unitless	0.1
	SZA	Sun zenith angle	deg	30
	OZA	Observer zenith angle	deg	0
	RAA	Relative azimuth angle	deg	0

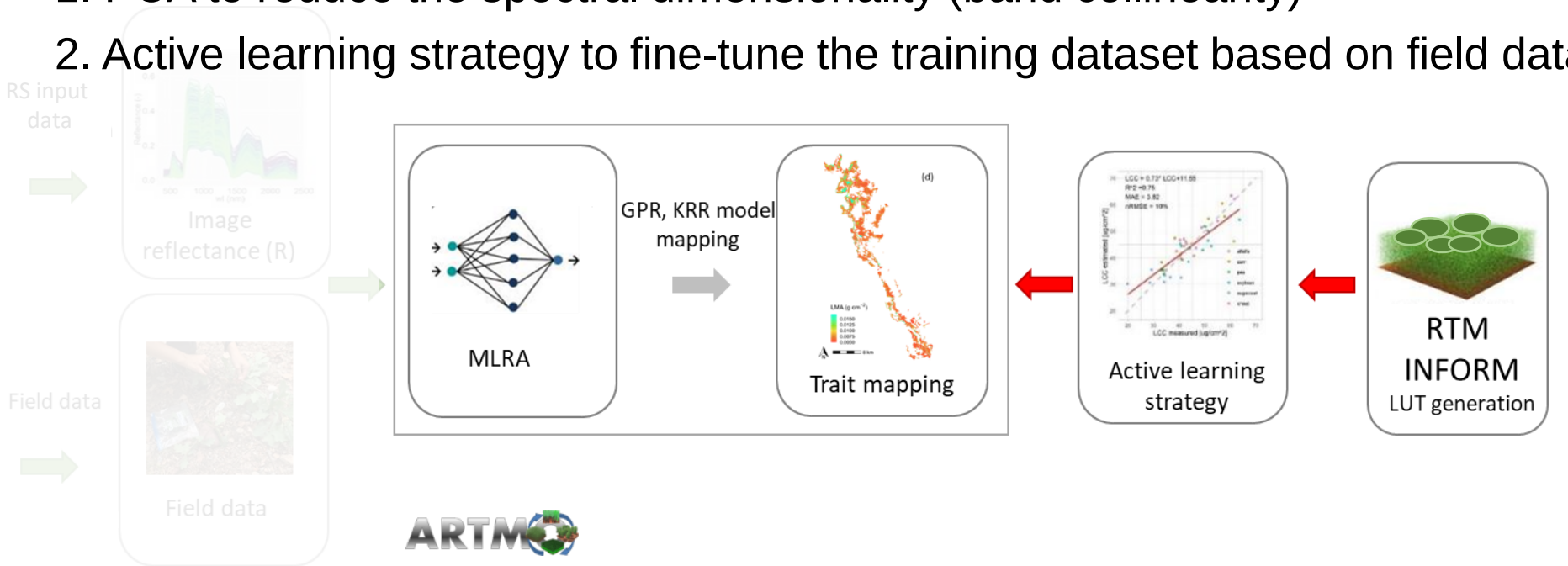
Model parameters

Retrieval of plant traits using MLRA vs HYBRID models

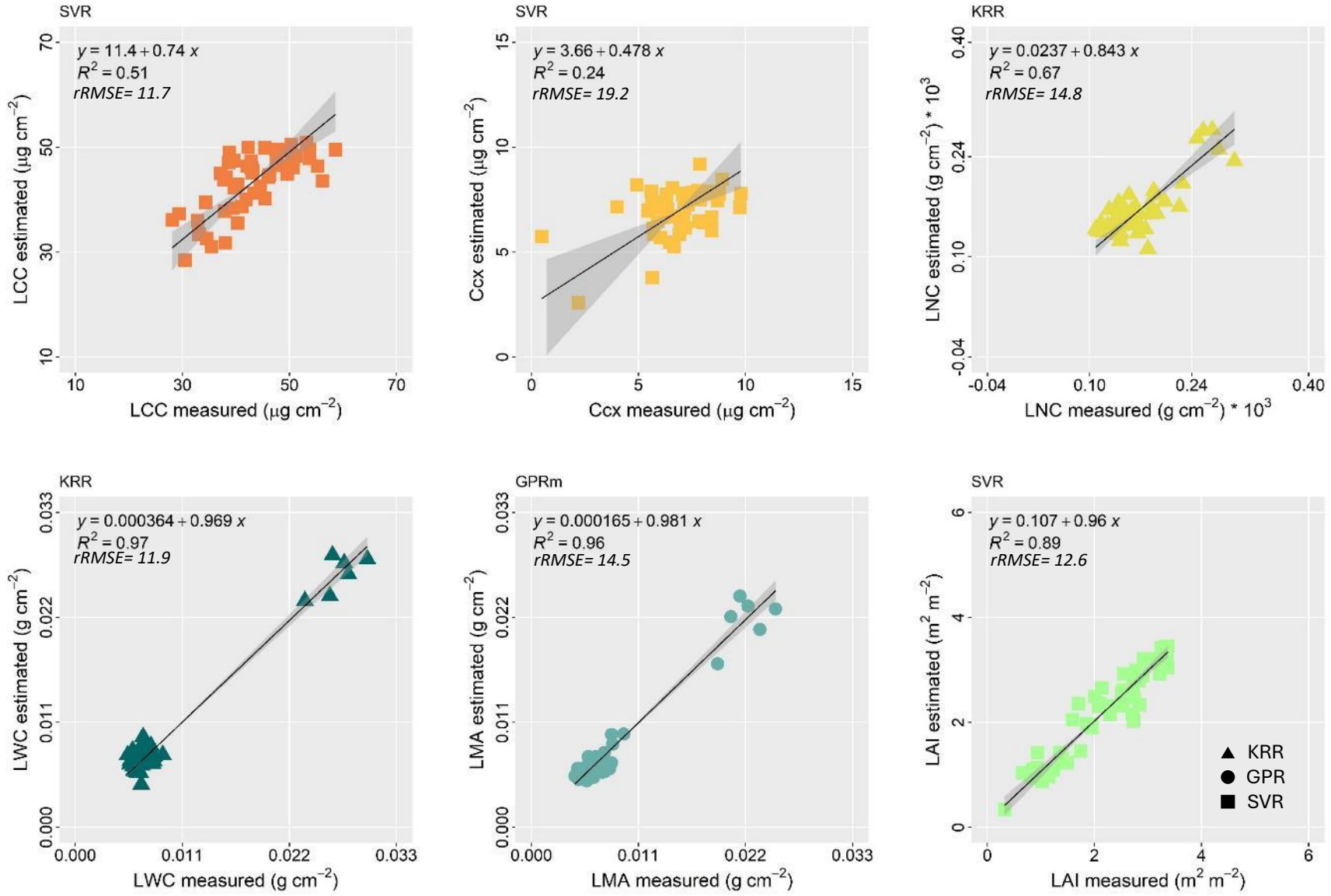
Hybrid approach = RTM + MLRA

- **RTM to produce the LUT spectra** → simulation of 2000 spectra with PROSPECT-PRO (Feret et al. 2021) + INFORM (Schlerf and Atzberger, 2006)
- **MLRA as retrieval algorithm** → kernel based ML considered the best performing algorithms (Verrelst et al. 2018)
- **Algorithm optimization:**

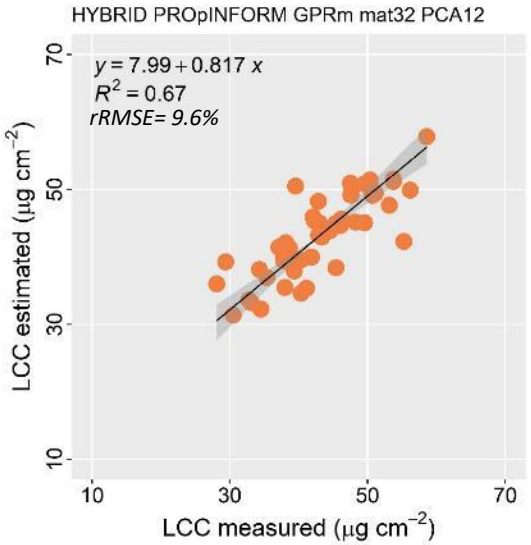
  1. PCA to reduce the spectral dimensionality (band collinearity)
  2. Active learning strategy to fine-tune the training dataset based on field data

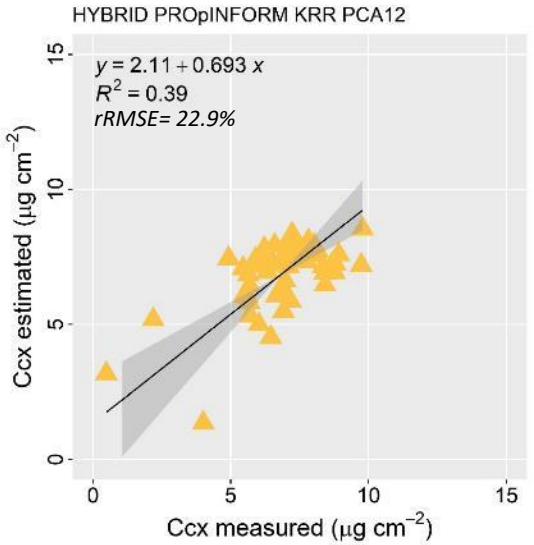


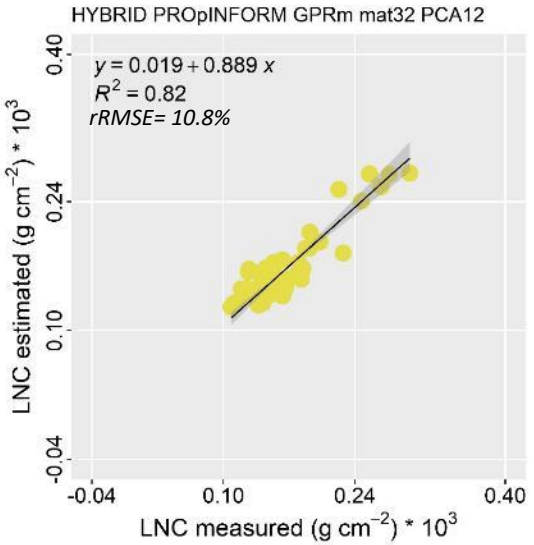
Results – Plant traits from MLRA

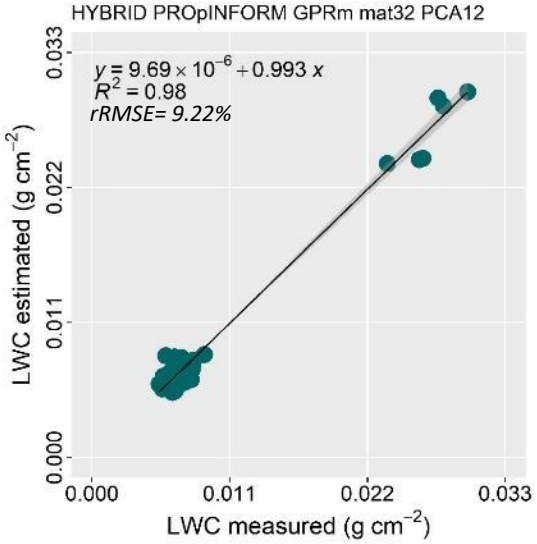


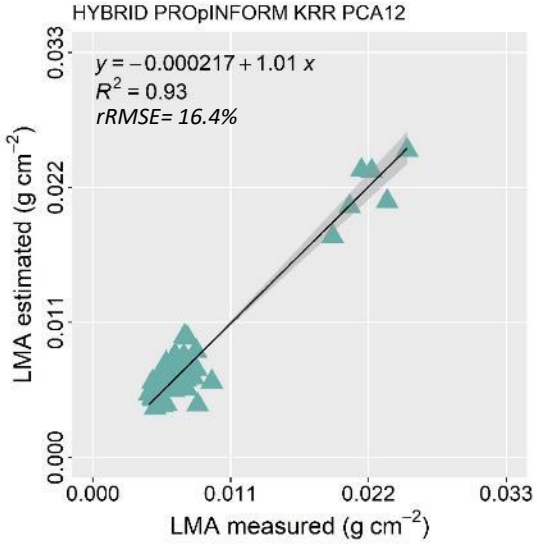
Results – Plant traits from HYBRID models

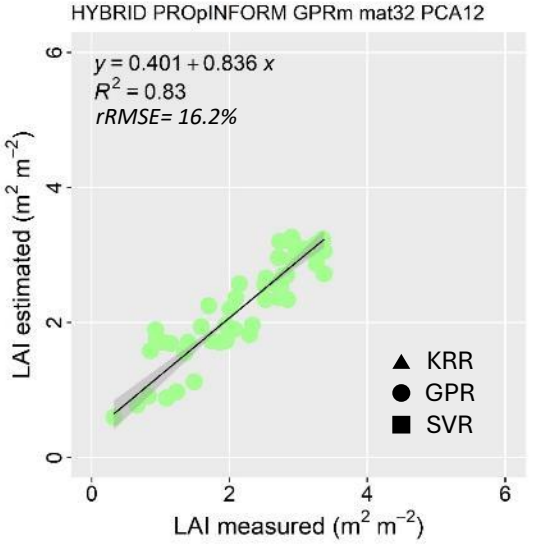






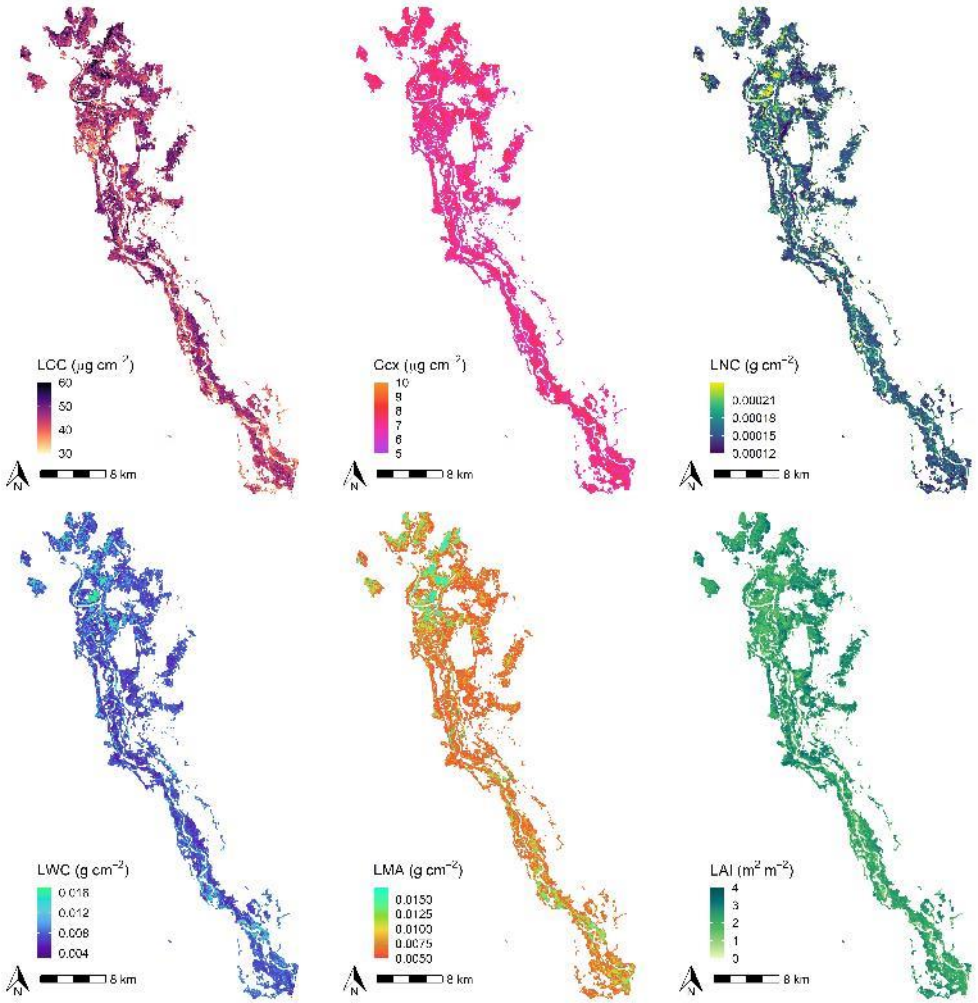




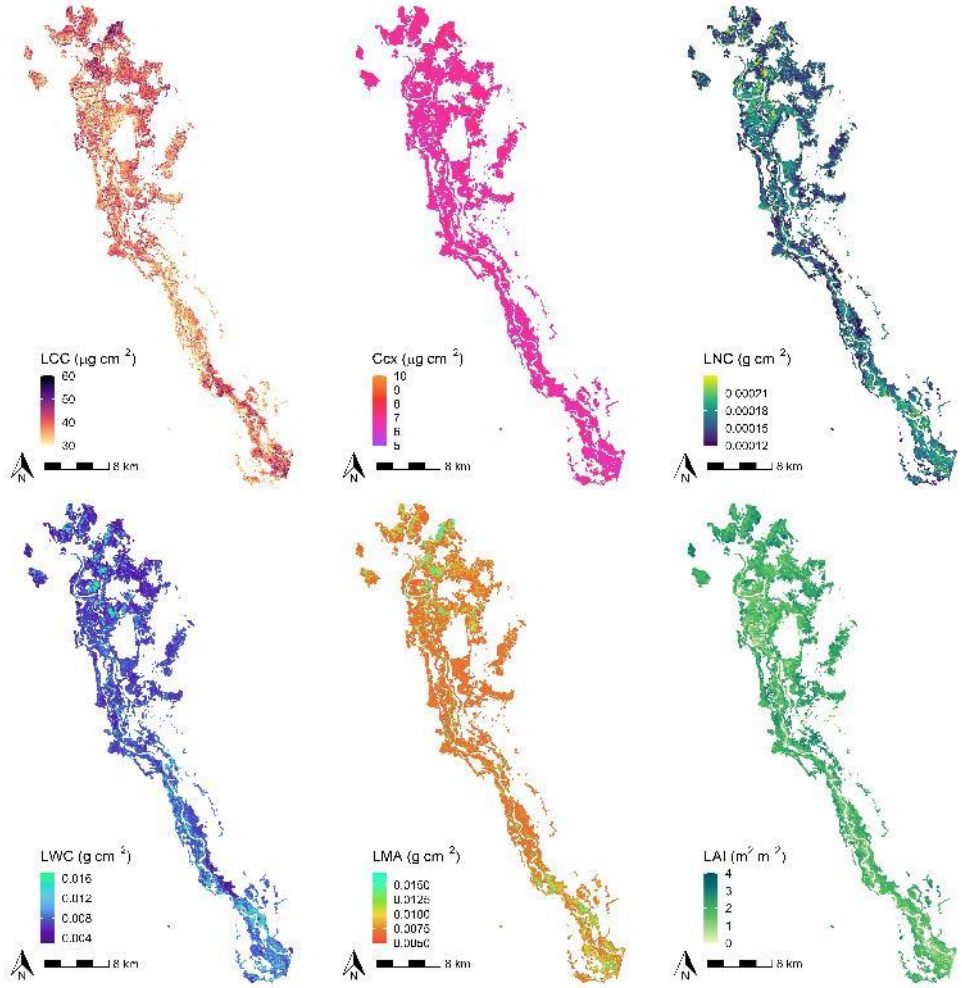


Results – Plant traits maps of the Ticino Park

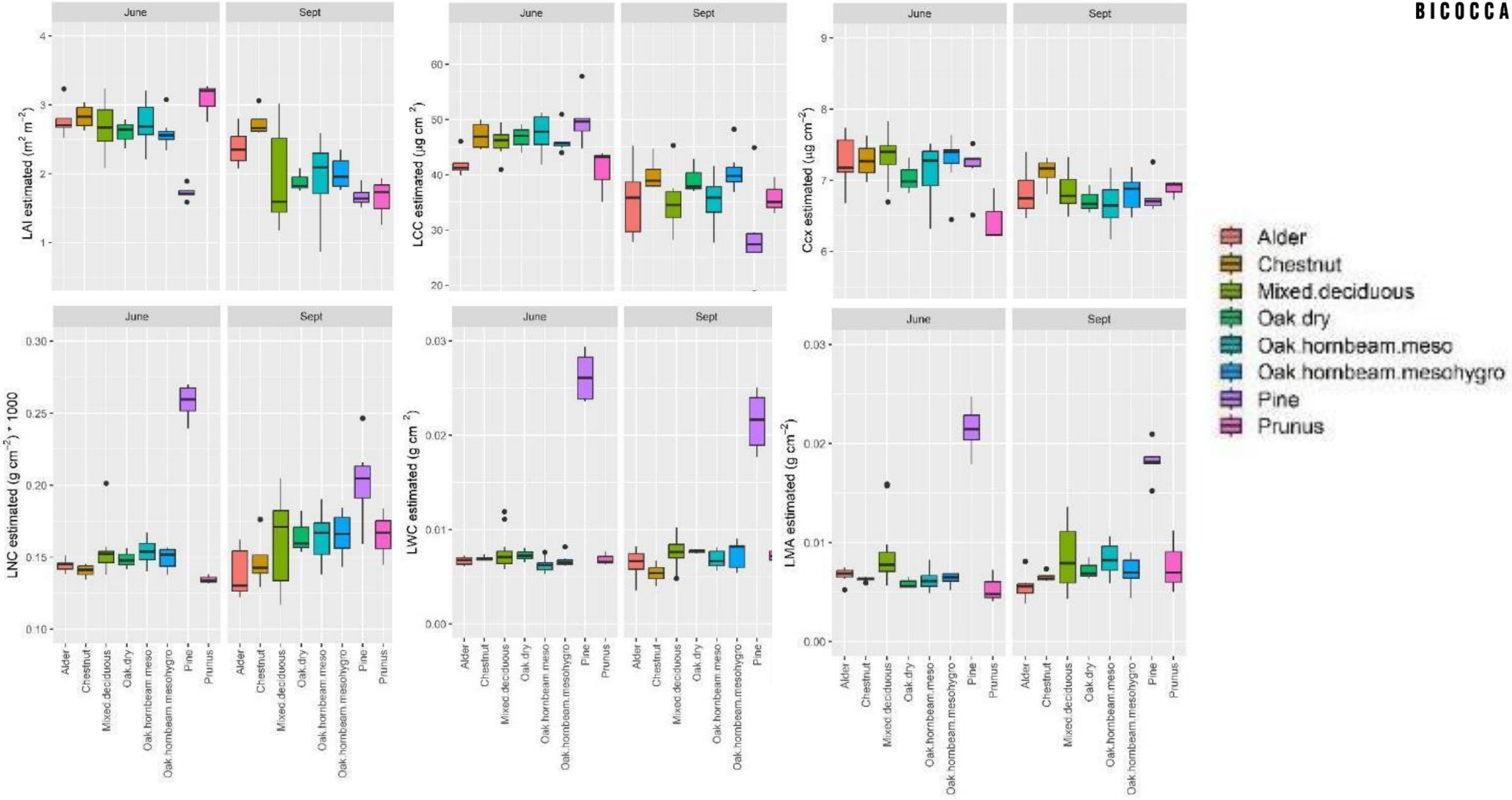
June 2022



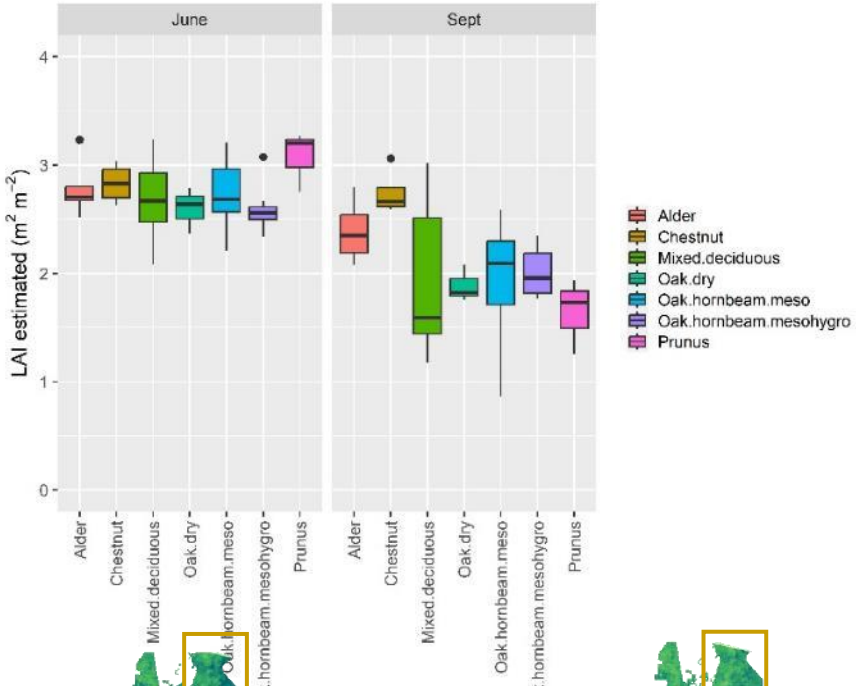
Sept 2022

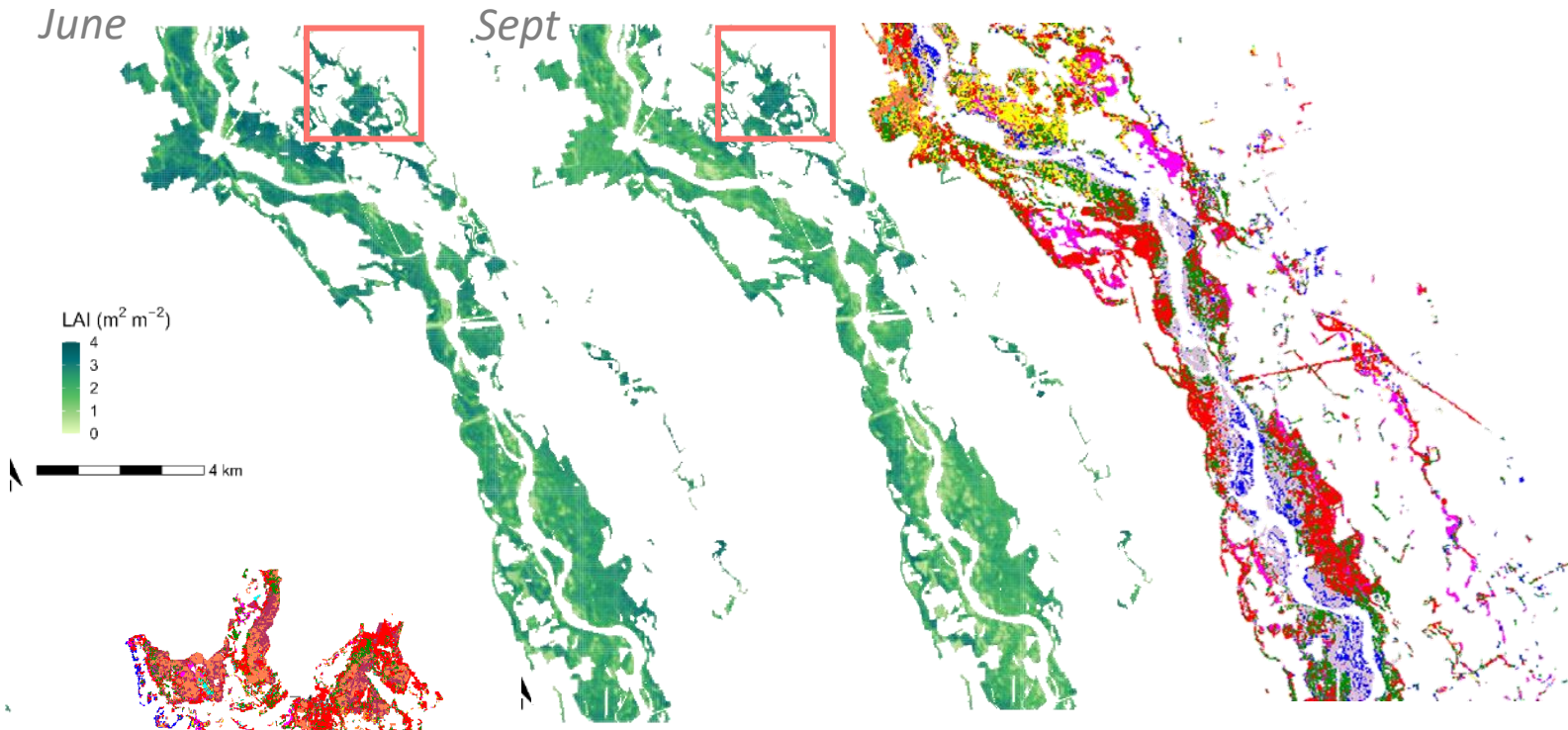


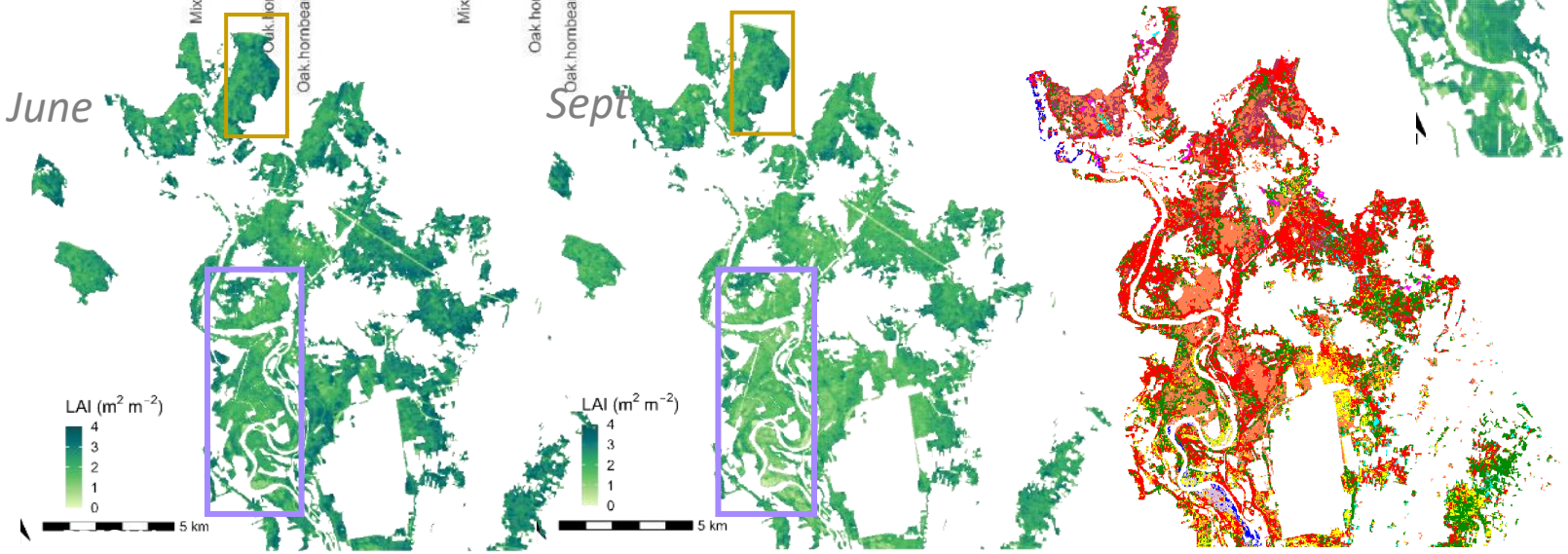
Results – Plant traits decrease in the Ticino Park



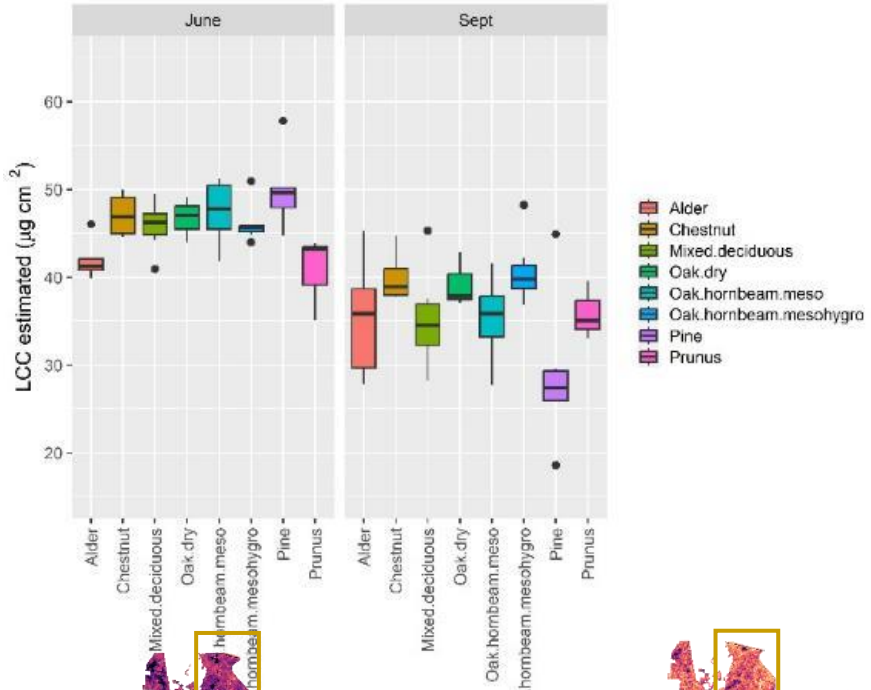
Results – LAI decrease

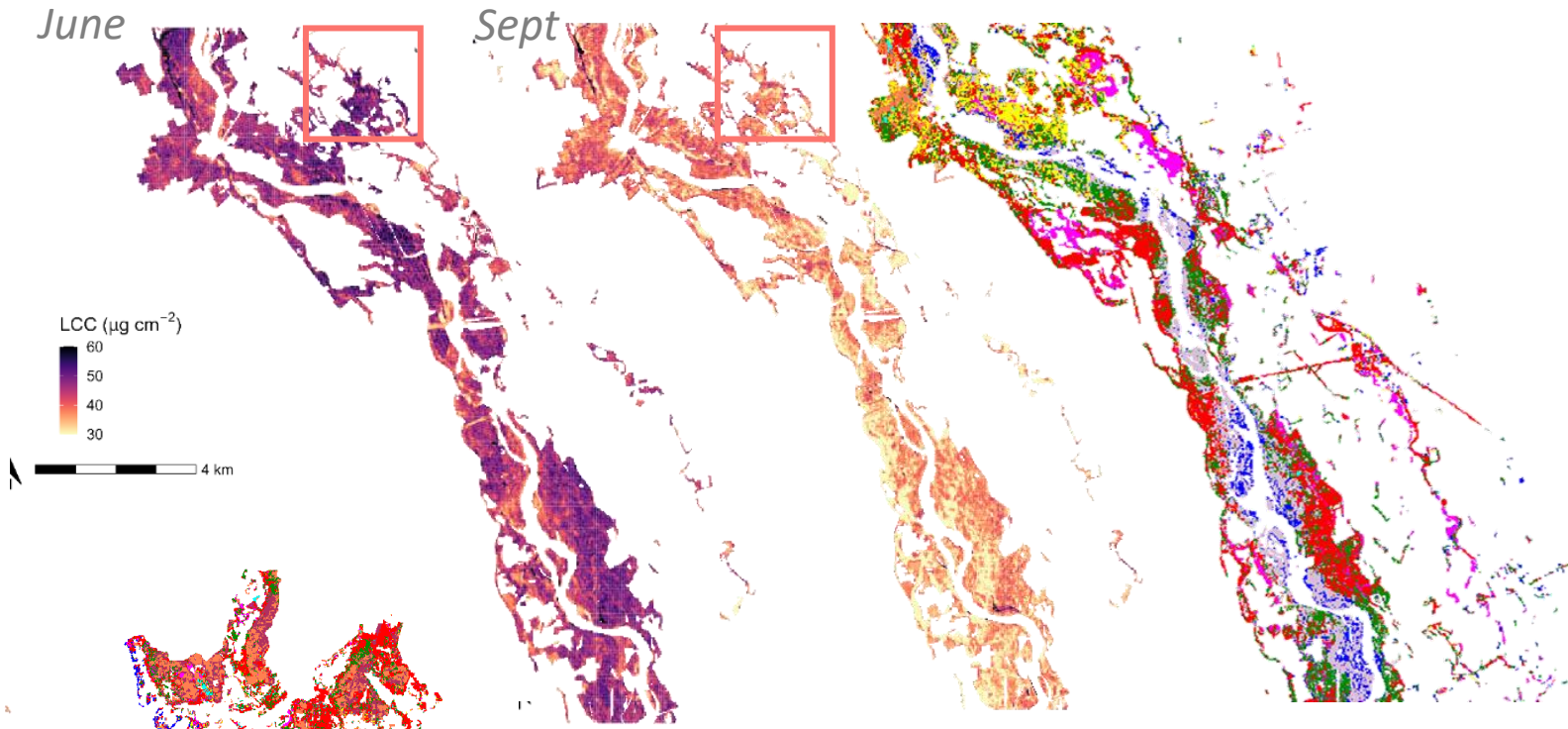


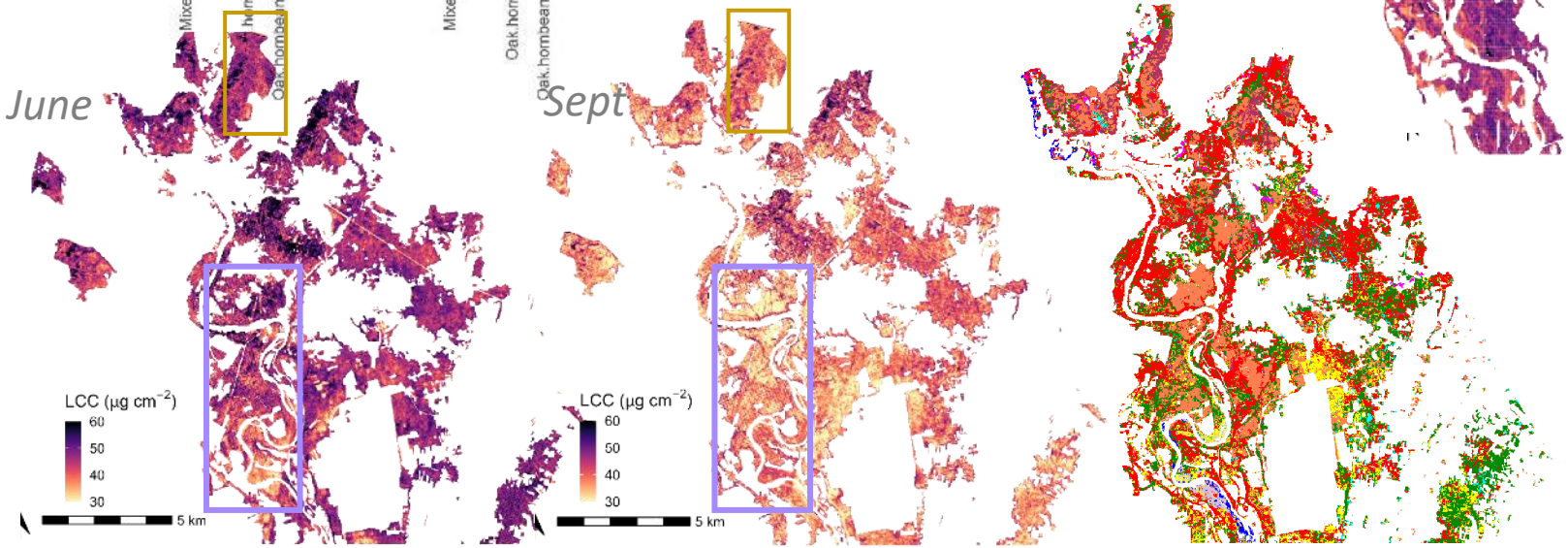


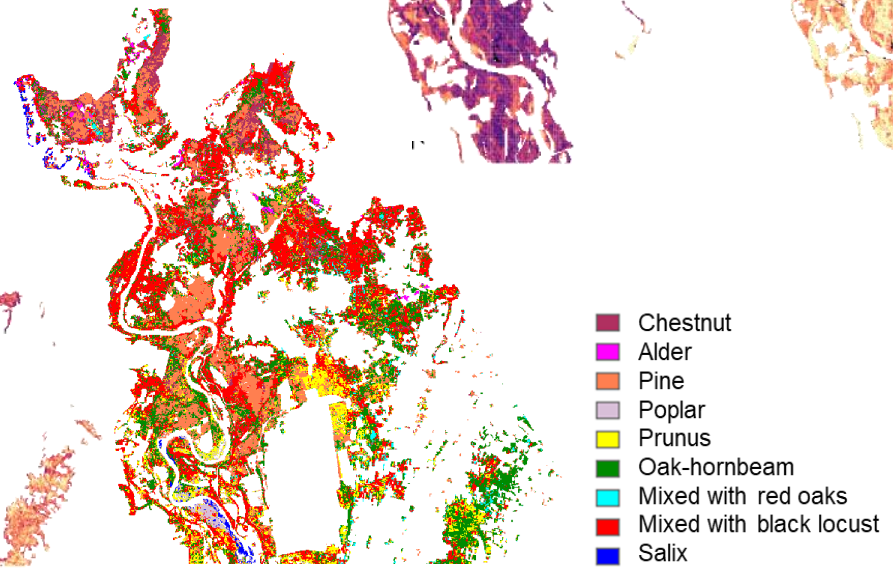


Results – LCC decrease









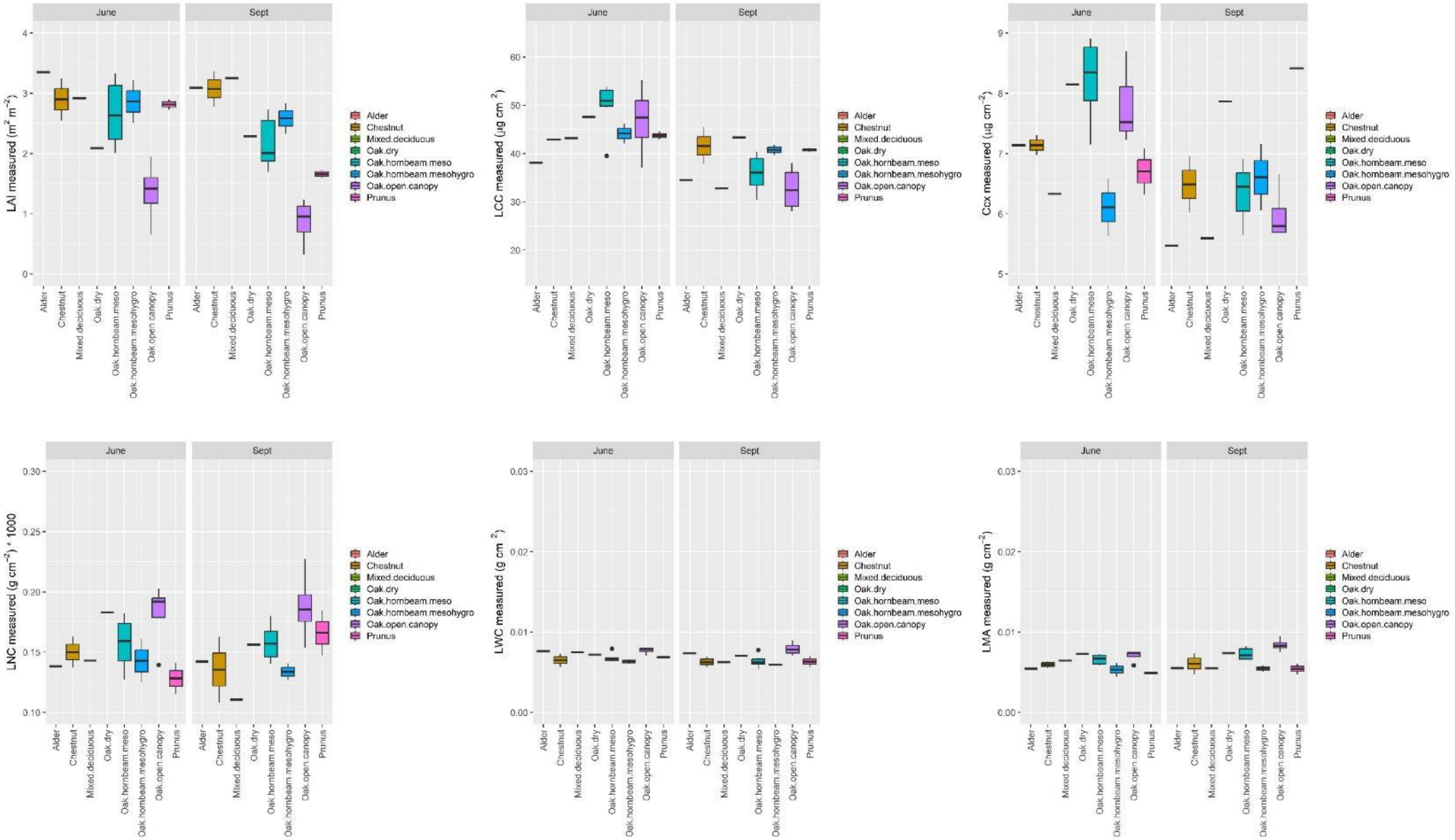
Chestnut
Alder
Pine
Poplar
Prunus
Oak-hornbeam
Mixed with red oaks
Mixed with black locust
Salix

Conclusions

- MLRA and HYBRID models showed high performances in retrieving plant traits in complex forest ecosystems also at the leaf level
- HYBRID approaches work well with INFORM RTM and AL methods to tune the model. More investigation on scale effect through 3D modelling could better explain how canopy architecture affects the retrieval, particularly in open canopy environments
- PRISMA successfully captured the early senescence induced by drought occurred in August 2022
- Need to keep on improving the robustness of both MLRA and HYBRID retrieval workflows with more datasets from different geographical areas to improve trait variability

THANK YOU FOR THE ATTENTION

cinzia.panigada@unimib.it

This research was conducted within the PRIS4VEG project funded by ASI "PRISMA SCIENZA" program

Plant traits - ground data