Integrating ALS Data and the 3-PG Model to Simulate Climate Change Impacts on Eucalyptus Management Units in Northern Portugal

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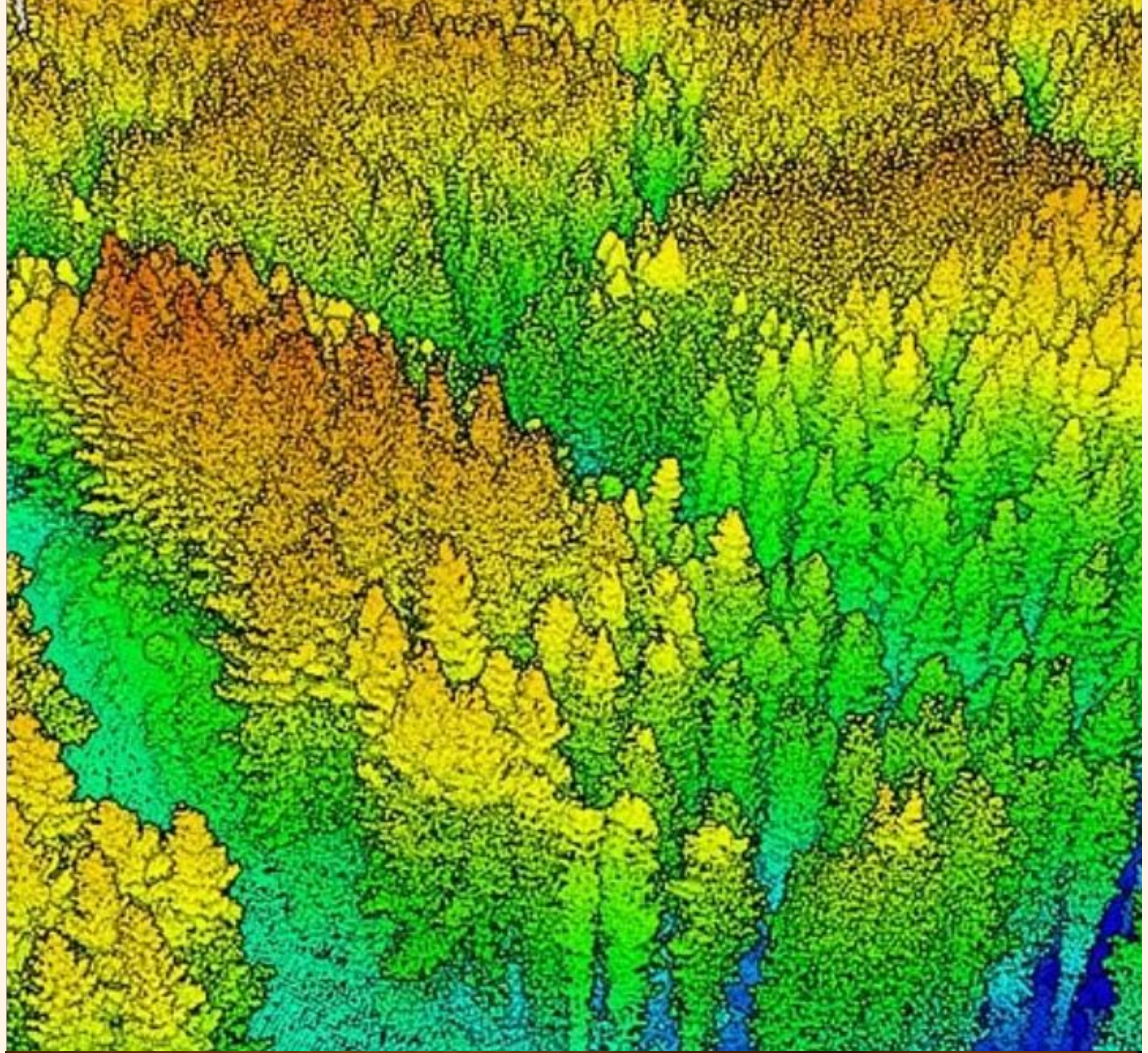
Symposium on Ecosystem Services, Forest Management and Decision Making

Introduction

- Recurrent wildfires require more adaptive forest management strategies

- ALS enables accurate, large-scale structural characterization of forest stands

- 3PG simulates forest growth under varying climatic scenarios and management conditions



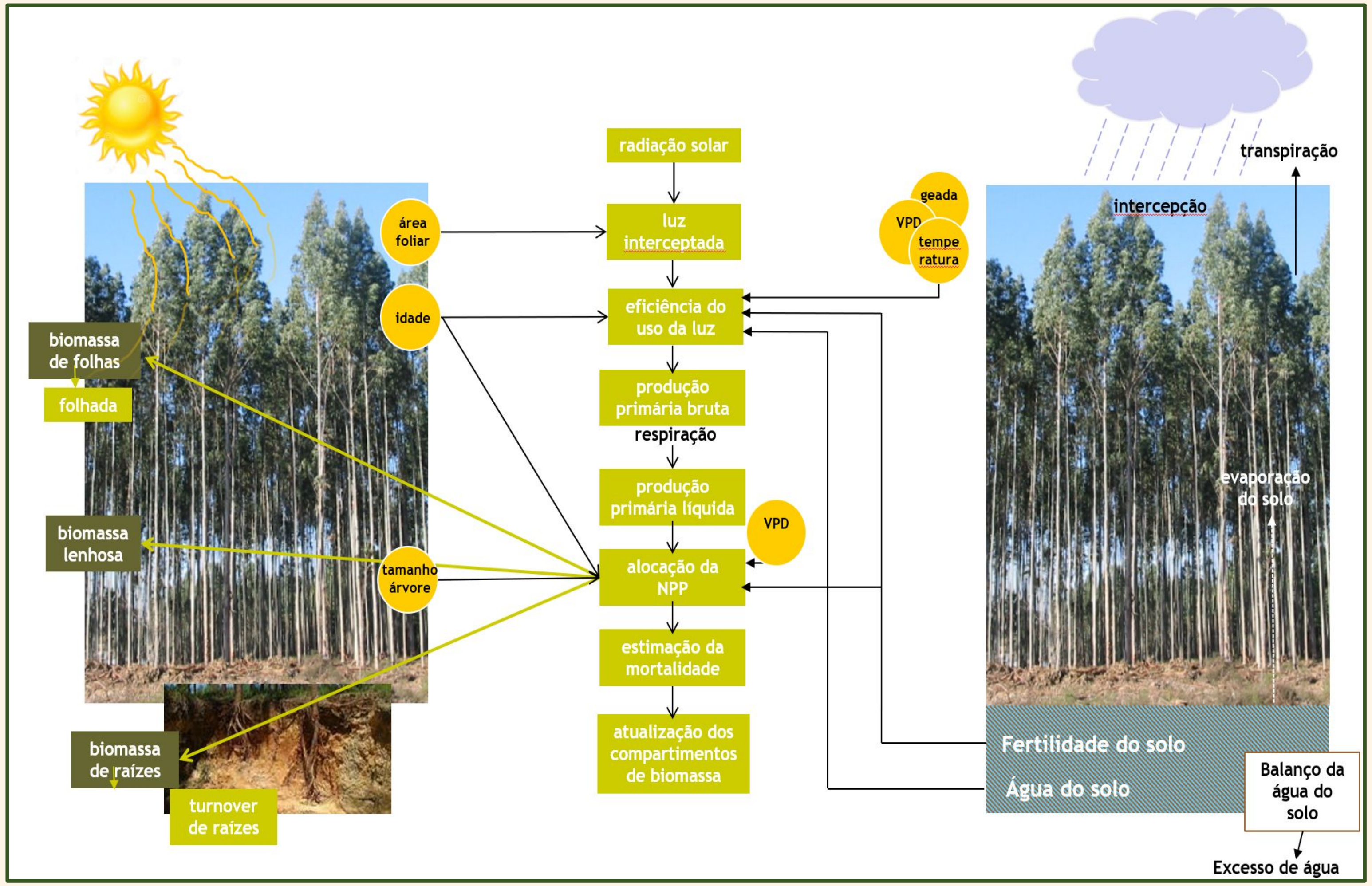
Source: RTP arquivos. Wildfire in Castelo de Paiva – PT, 2017

What the 3-PG model is?

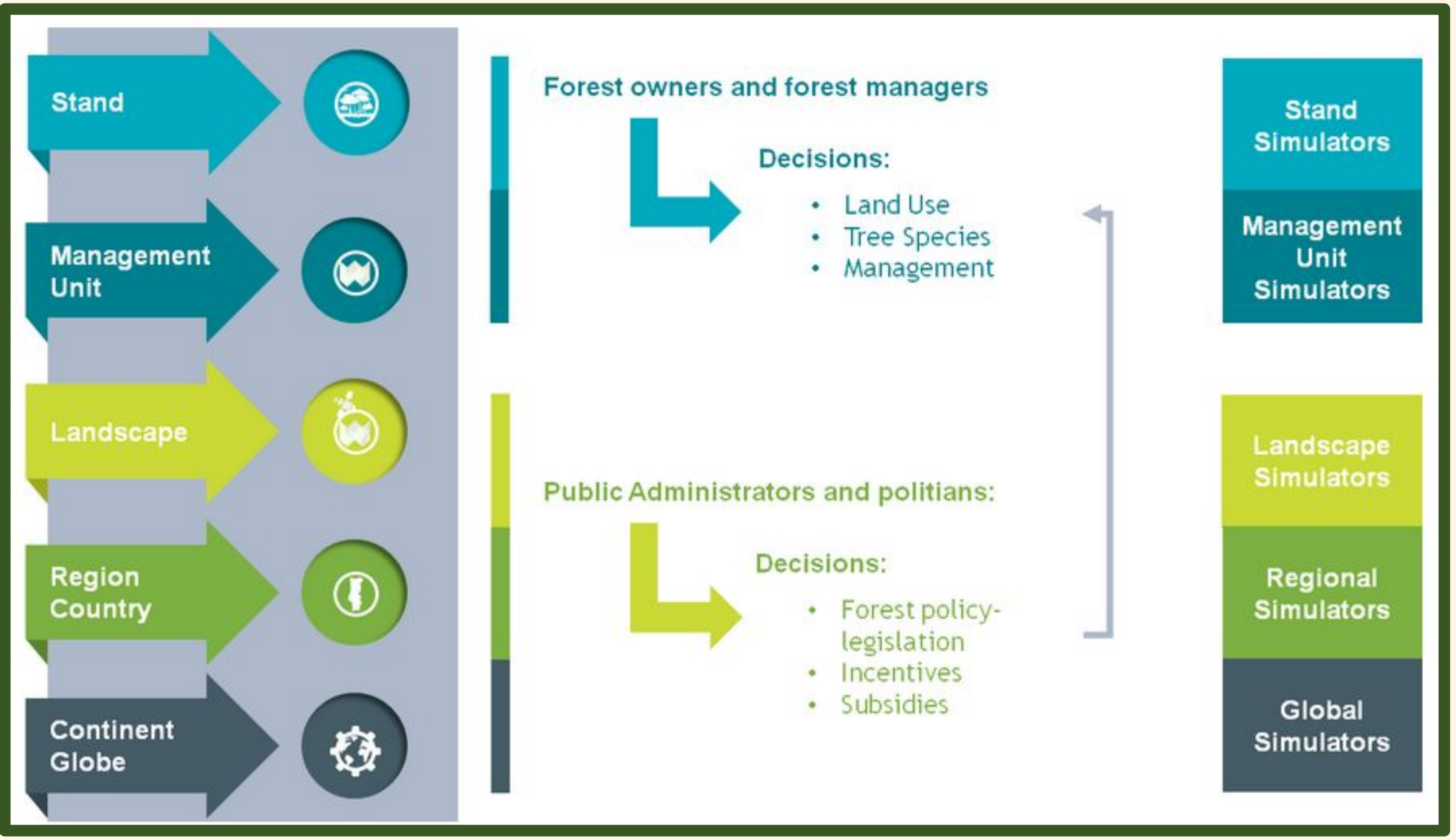
A process-based forest growth model (**P**hysiological **P**rinciples **P**redicting **G**rowth)

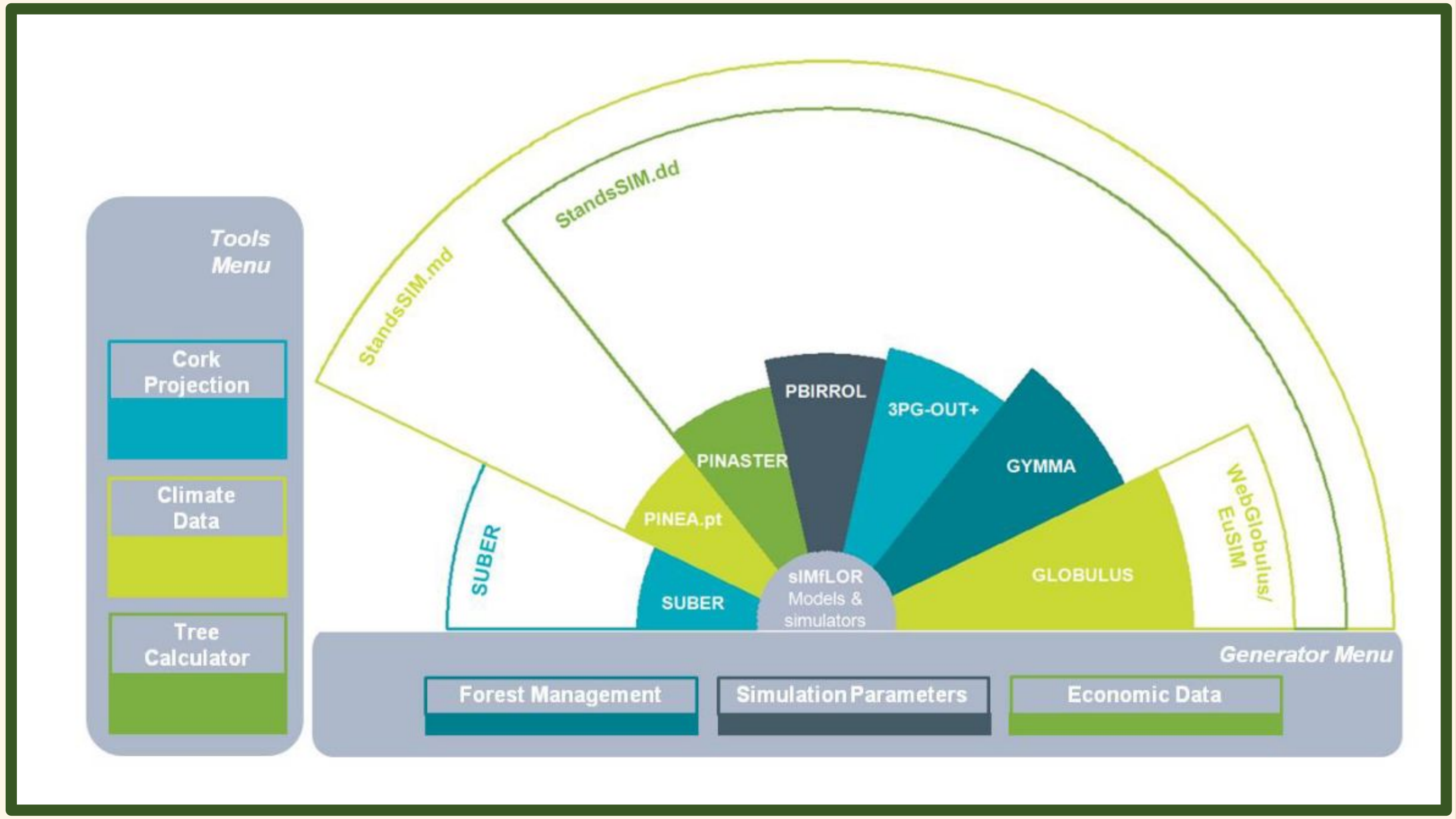
Simulates monthly biomass production, water balance, and stand development

Integrates Climate, soil, and stand variables to estimate growth under changing conditions



StandsSIM: The Portuguese forest simulator





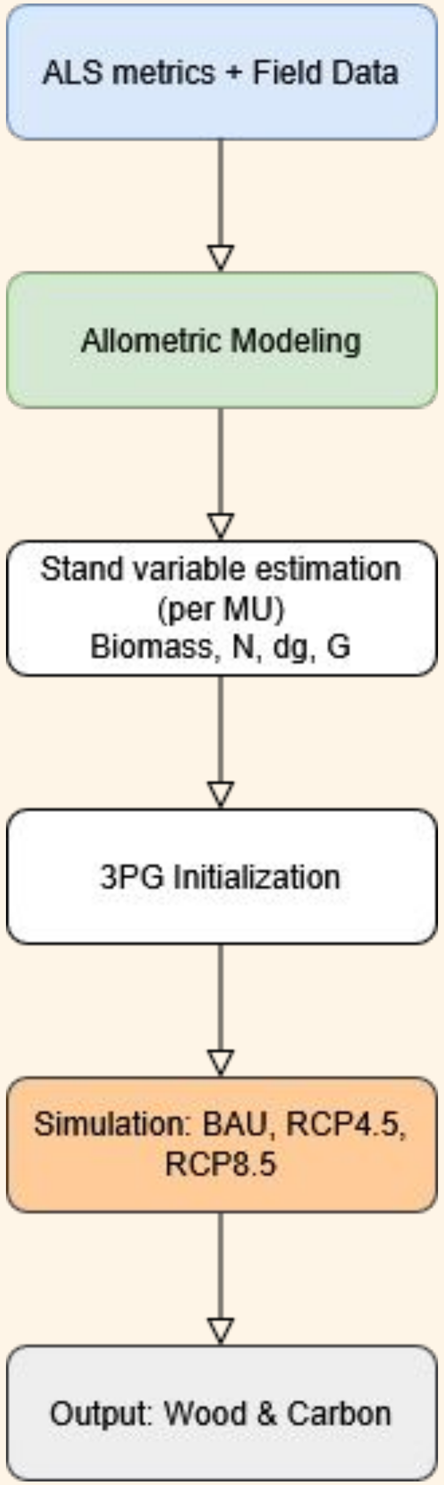
Available in: https://www.isa.ulisboa.pt/cef/forchange/fctools/en/SimflorPlatform/simulators

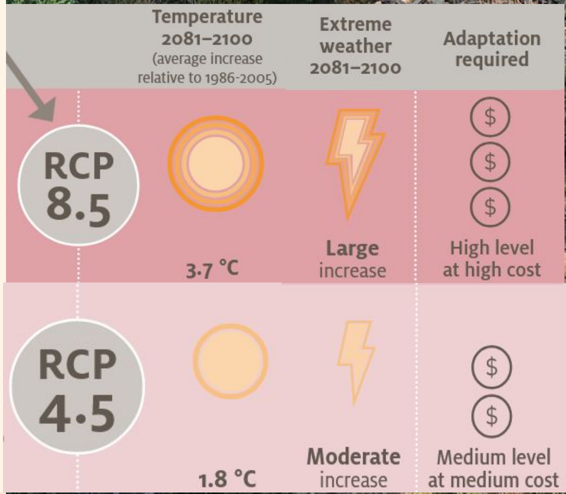
Objectives

Estimate stand-level variables from ALS and field data to initialize the 3PG model

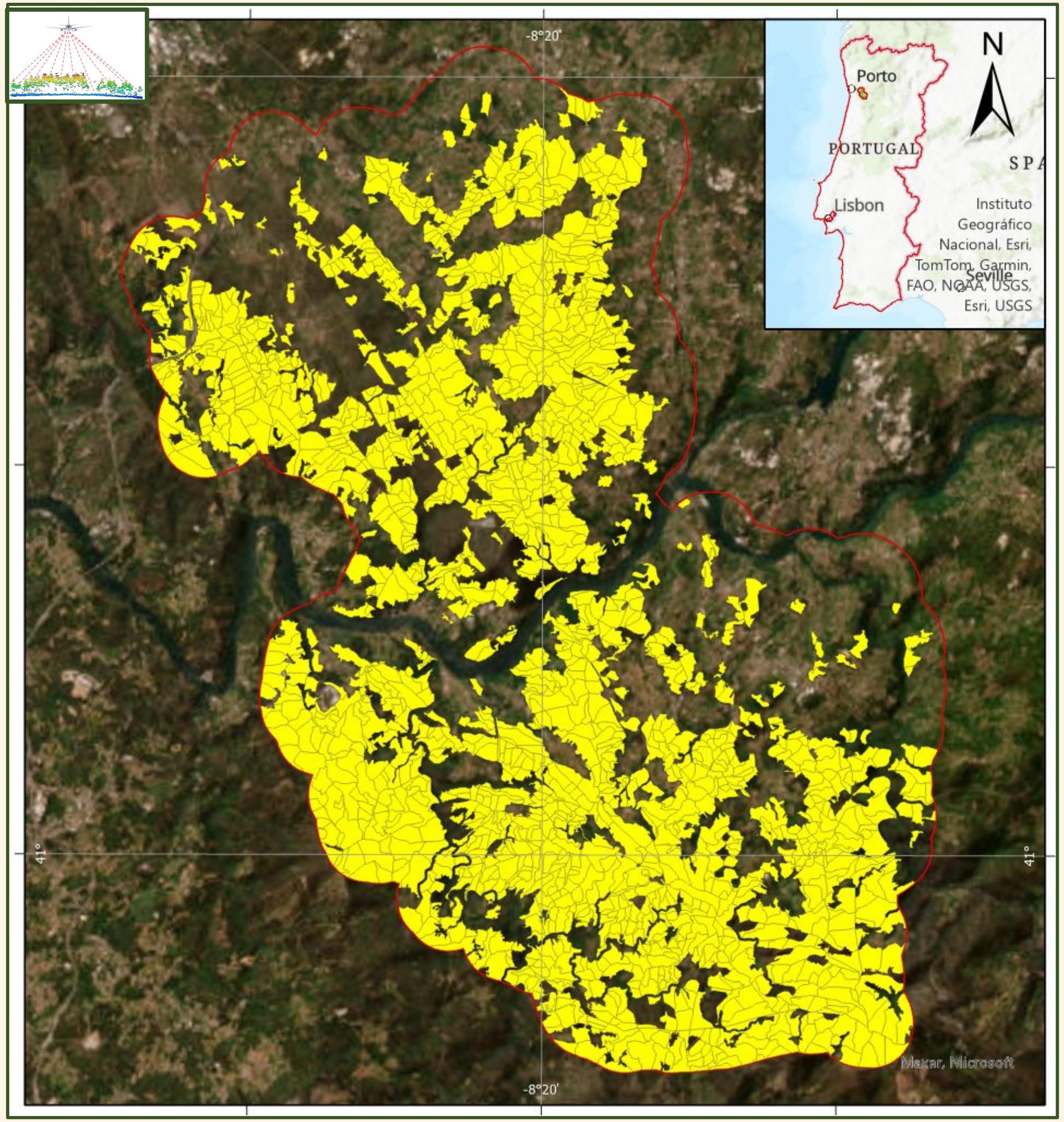
Simulate climate change impacts on eucalyptus management units (MUs)

Evaluate wood production and carbon sequestration under three climate scenarios





Study area



Location: Join management area (ZIF), Northern Portugal

Dominated by *Eucalyptus globulus* plantations

Eucalyptus coverage: 134.28 km^2, across 1444 (MUs)

Elevation range: 99.6 to 719.38 m; Slope range: 6° to 34°

LiDAR acquisition: June 2022. Point density: 5 pts/m^2

Methodology - Input data

		Tipo de povoamento	Escala (Metodologia)	
			Regional	Talhão (>25 ha)
LiDAR Aéreo	0.5- 2 ptos/m2	*Povoamentos regulares densos/plantações monoespecíficas (i.e Eucalipto, P.pinaster)*	ABA	ABA
		Povoamentos irregulares/mixtos/densos (i.e Mixtos Quercineas)	ABA	ABA
	> 2 ptos/m2	*Povoamentos abertos (i.e dehesas/montado/pinheiro manso)*	ITC	ITC
		Povoamentos regulares densos/plantações monoespecíficas	ITC/ABA	ITC/ABA

- Stand initialization and variable estimation
  - Using R Sequential Replacement algorithm to search the subset of predicted variables
  - Modelling stand variables from ALS data (ABA approach)

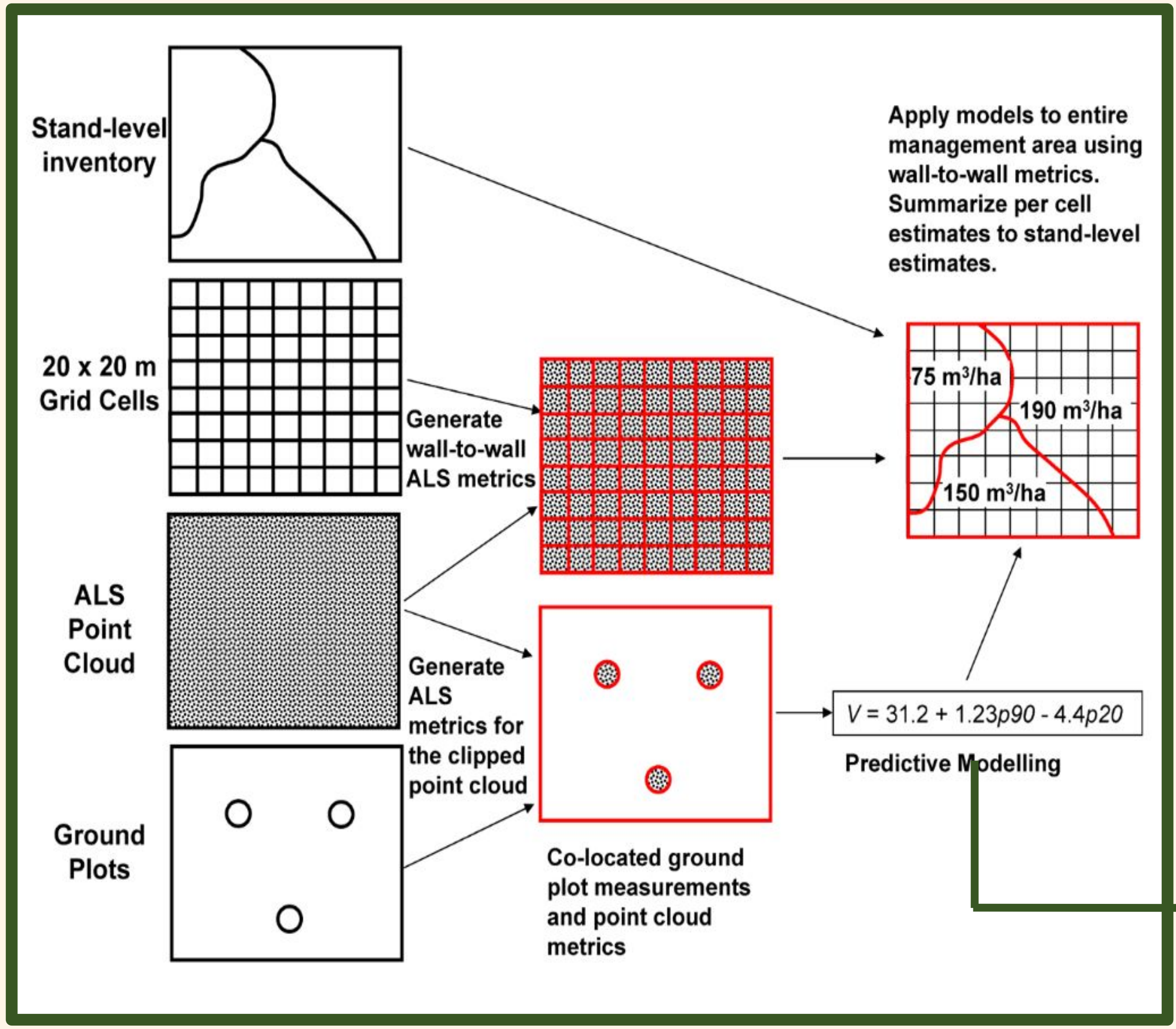
Management Units (Mus)

Metrics to raster

Point cloud

summer 2022

Ground measurements



Map Algebra

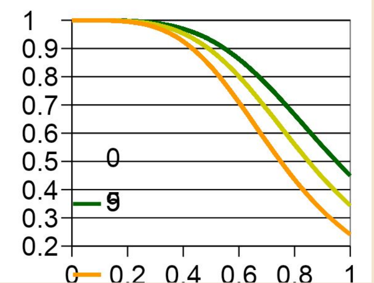
Wall-to-Wall estimation

Predictive modeling

Metrics for the clipped point cloud

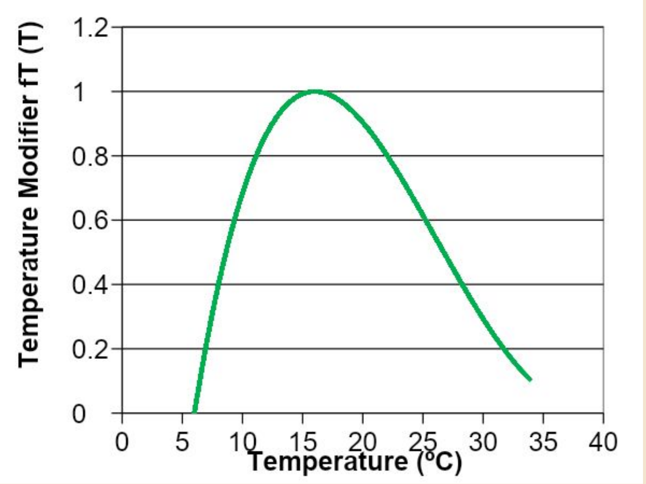
Stand variables (ABA)
- Ww
- Wbr
- Wl
- Wb
- dg
- N

Other stand variables
- Wr
- G
- cycle
- **age**



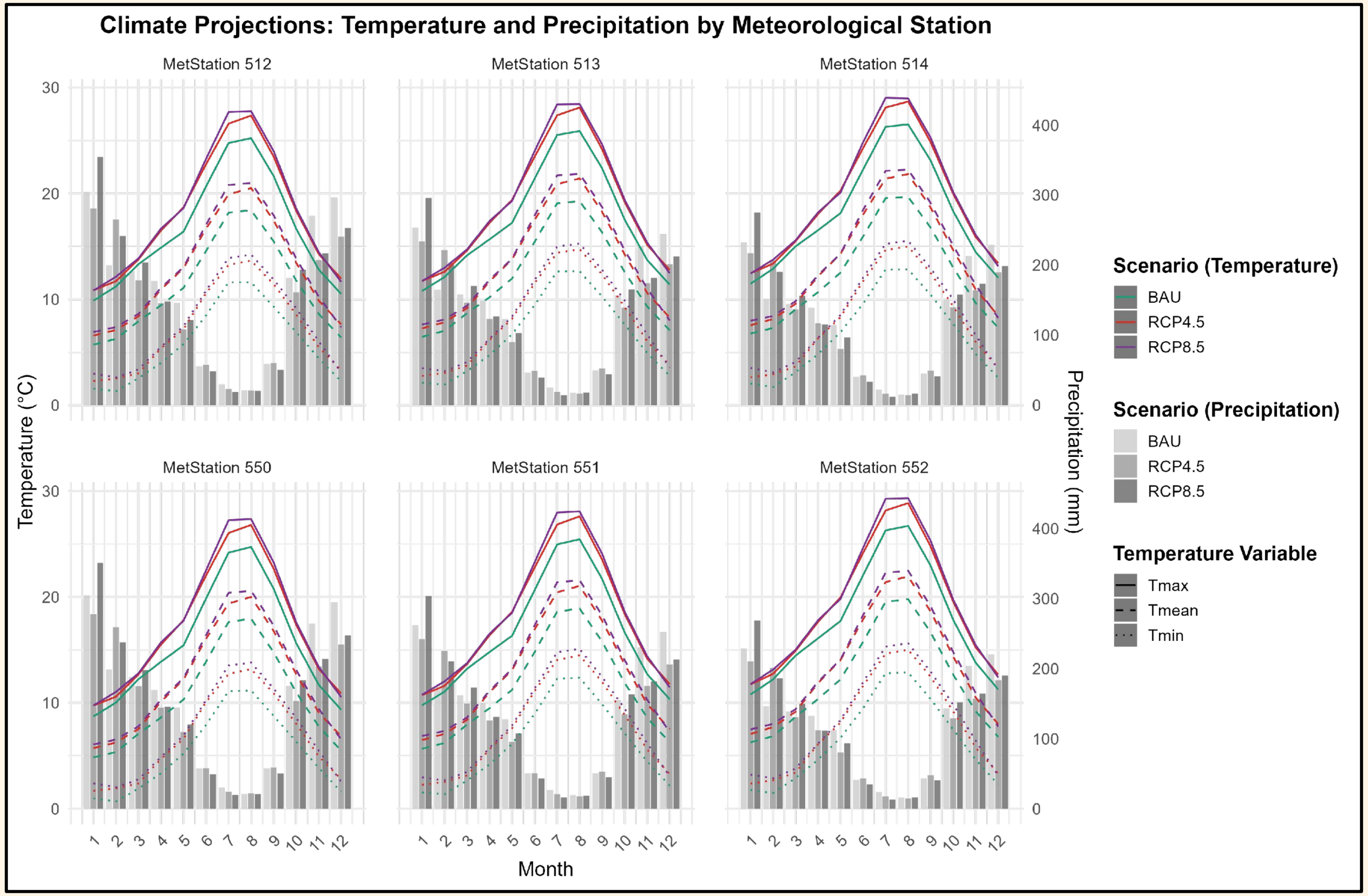
White, J.C., Wulder, M.A., Varhola, A., Vastaranta, M., Coops, N.C., Cook, B.D., Pitt, D., Woods, M., 2013. A best practices guide for generating forest inventory attributes from airborne laser scanning data using an area-based approach. The Forestry Chronicle 89, 722–723.

Methodology - Input data



$$f_T(T) = \left(\frac{T - T_{min}}{T_{opt} - T_{min}}\right)\left(\frac{T_{max} - T}{T_{max} - T_{opt}}\right)^{(T_{max}-T_{opt})/(T_{opt}-T_{min})}$$

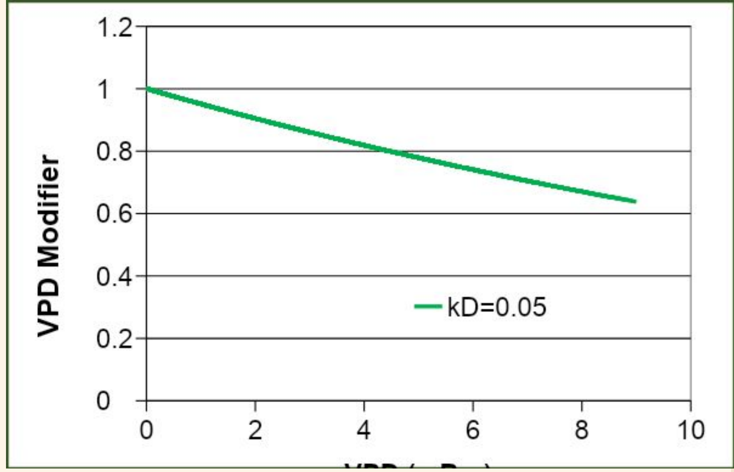
- Climate data
  - Temperature and precipitation (Clipick)



- Monthly projections of Temperature (Tmin, Tmean and Tmax) and precipitation
- Climate scenarios: BAU, RCP 4.5, RCP 8.5
- Historical baseline: 1971-2000, Future period: 2036-2065
- Clipick: Climate Change Web Picker

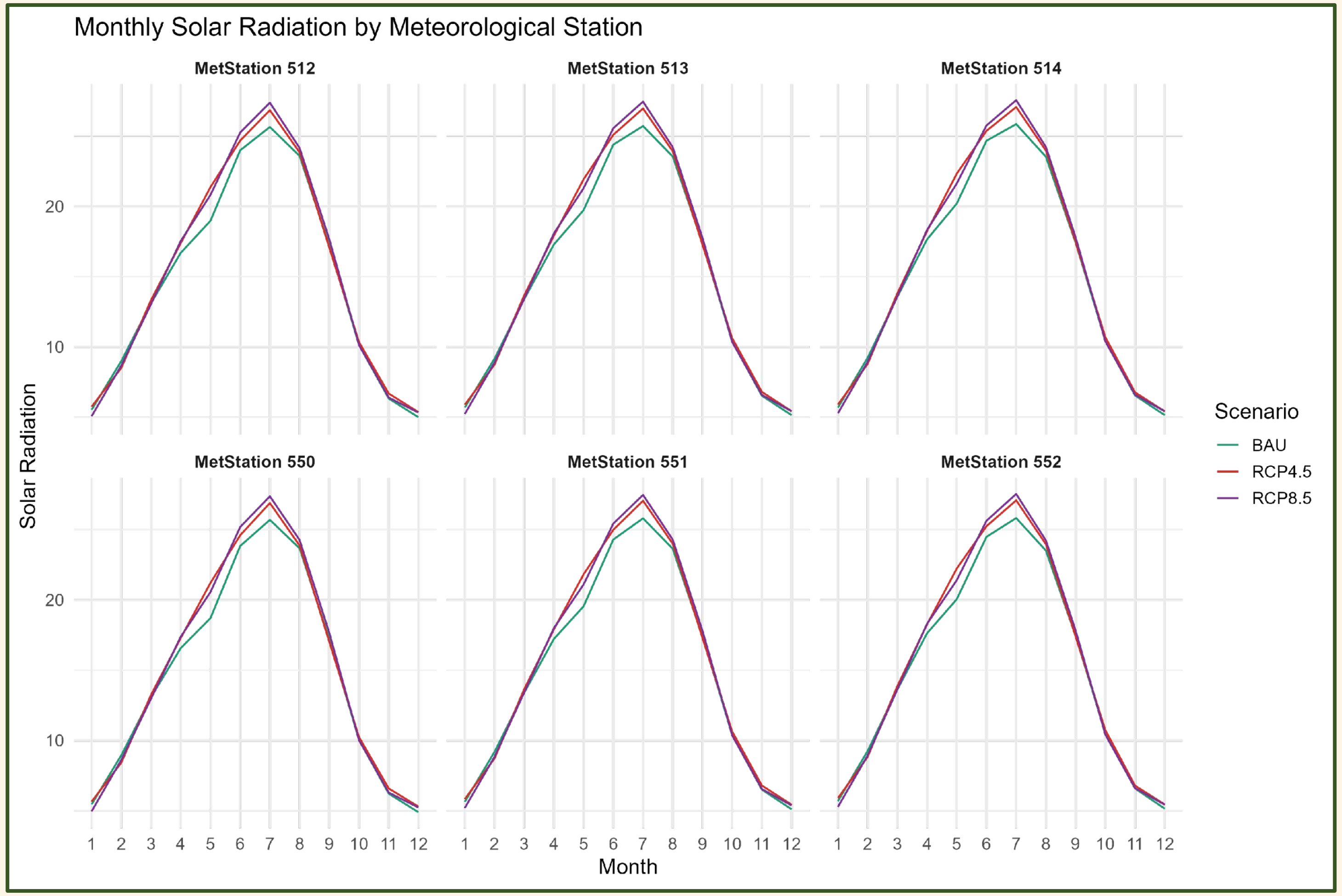
Methodology - Input data

- Climate data
  - Solar Radiation and VPD (Clipick)

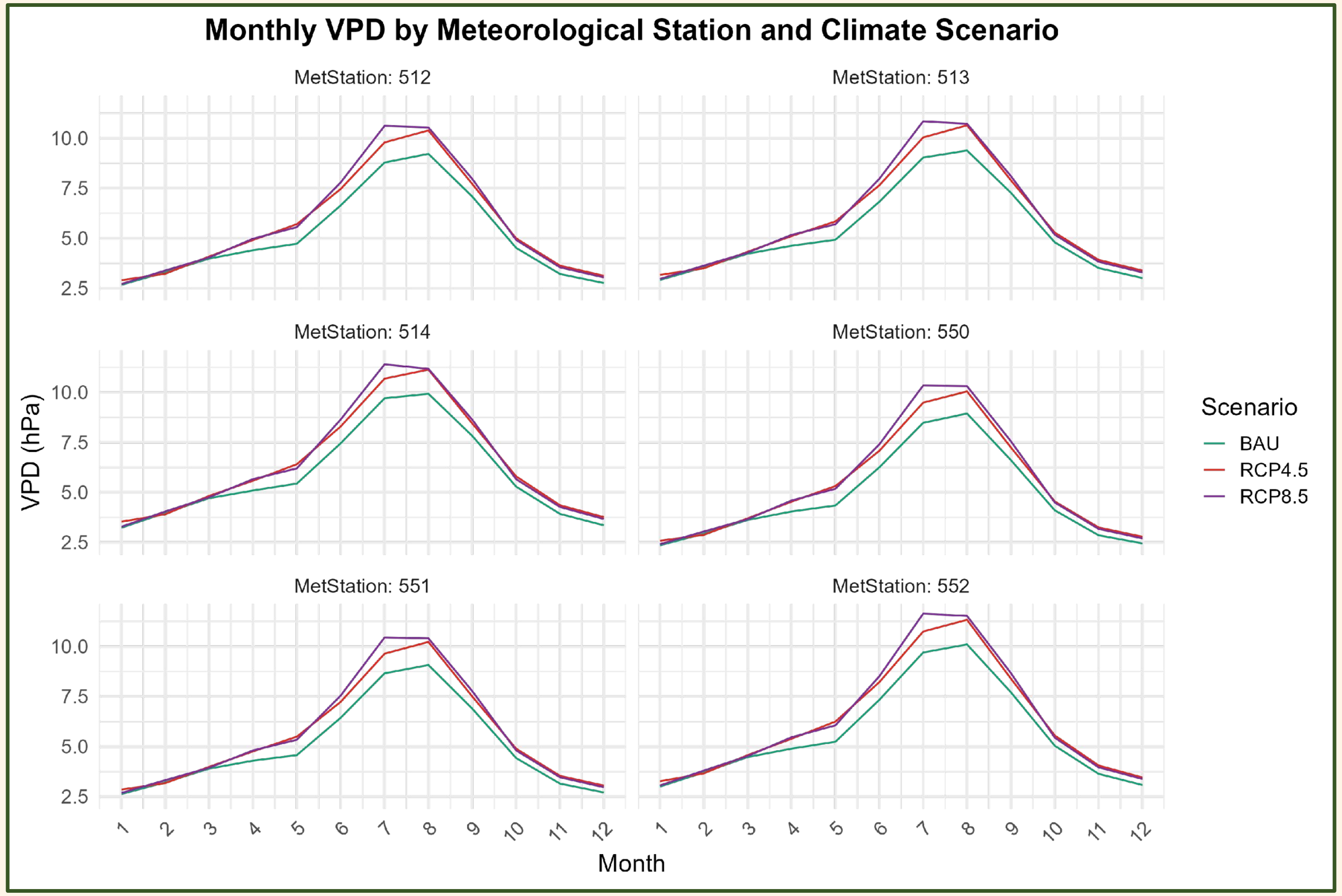


$$f_{VPD}(D) = e^{-k_D D}$$

1. Monthly Solar radiation

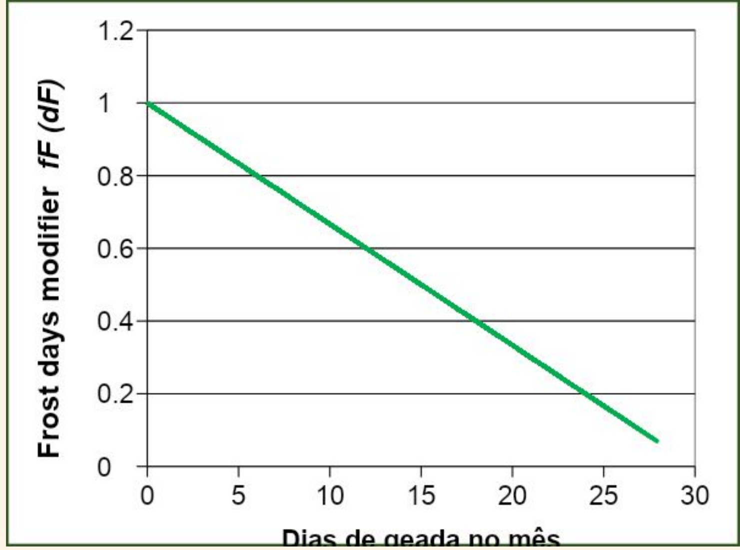


2. Monthly Vapor Pressure Deficit (VPD)



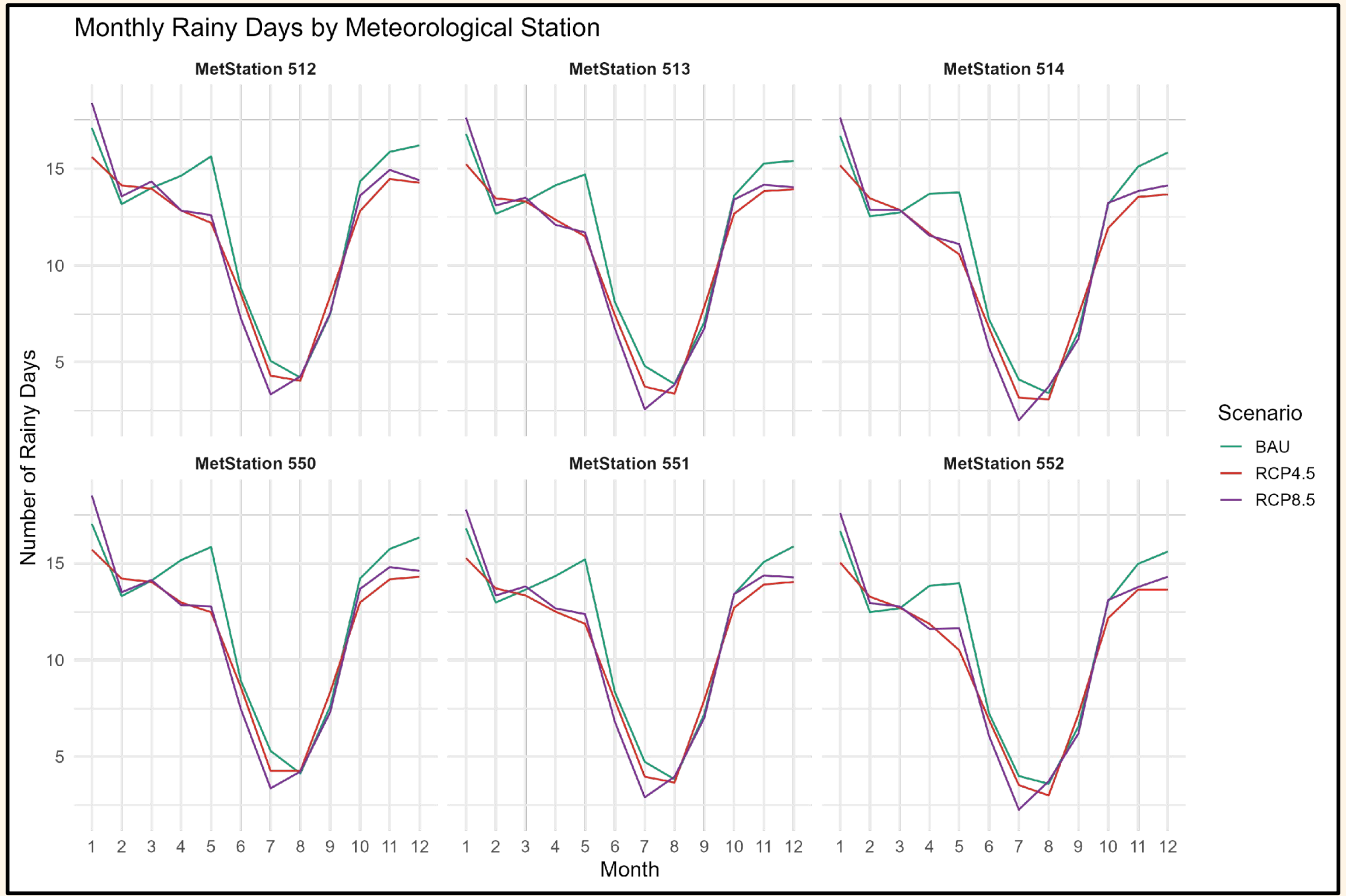
Methodology - Input data

- Climate data
    - Rainy and Frost Days

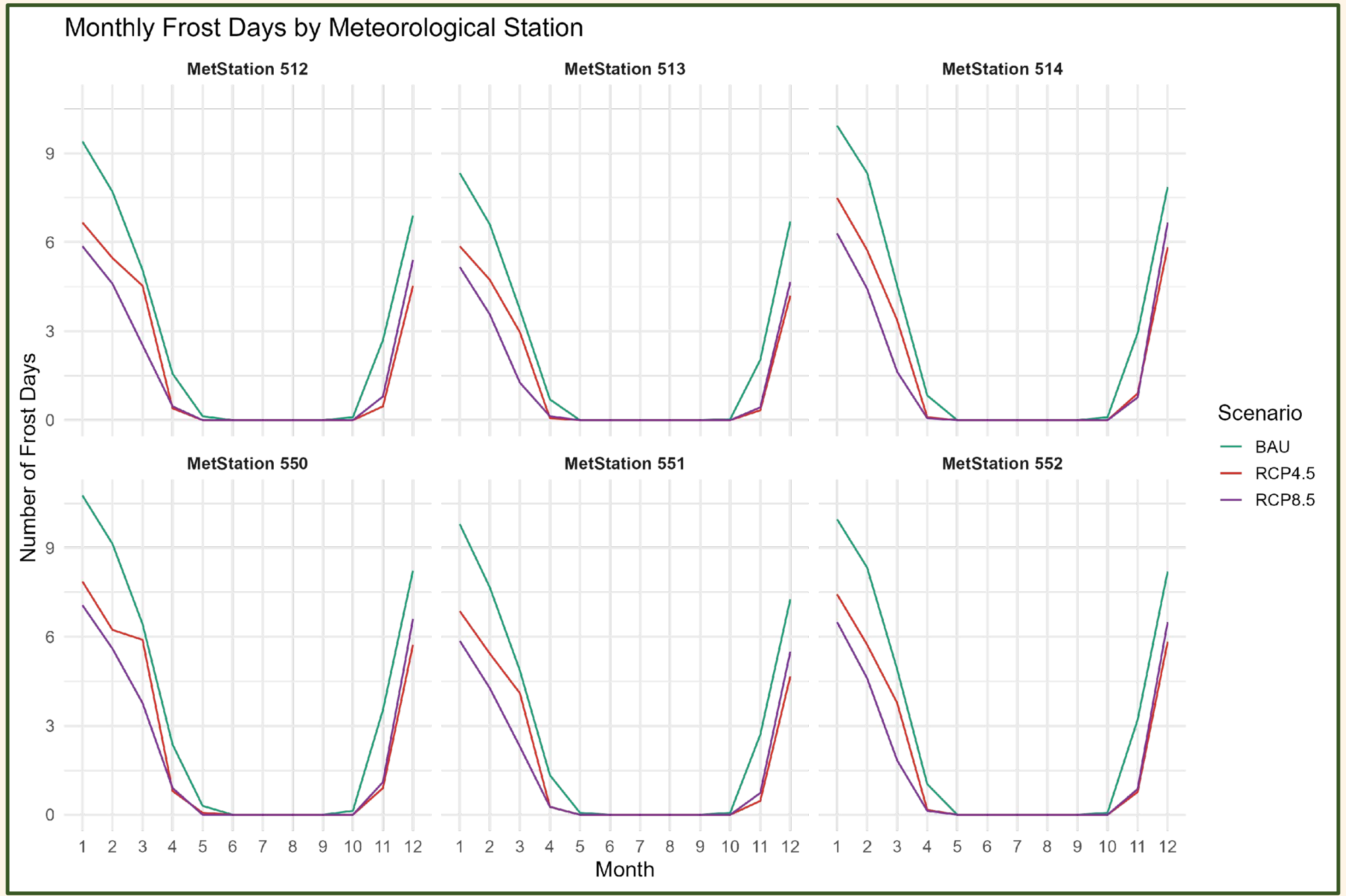


$$f_F(d_F) = 1 - k_F(d_F/30)$$

1. Monthly Rainy Days

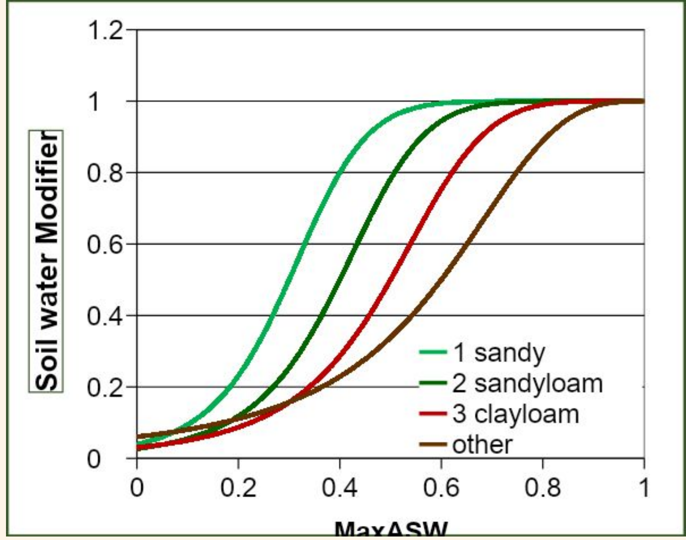


2. Monthly Frost Days



Methodology - Input data

- Description of Site (latitude) and Soil characteristics



$$f_{SW}(\theta) = \frac{1}{1 + \left[\left(1 - \theta/\theta_x\right)/c_\theta\right]^{n_\theta}}$$

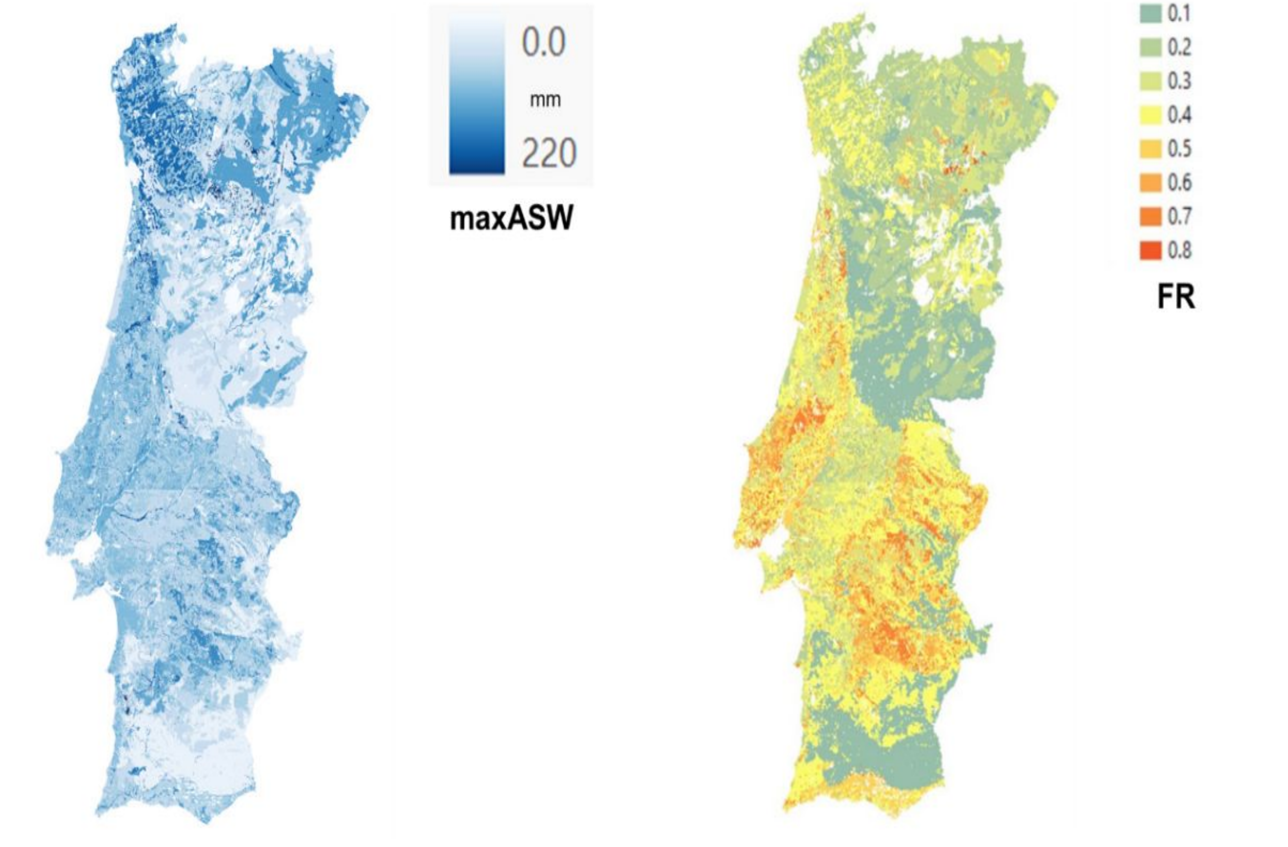


Figure 1 - MaxASW and FR values for the different locations of Portugal. Areas shown in white represent urban areas, water mirrors and watercourses, rocky outcrops or areas with insufficient information to calculate these parameters.

a) MaxASW and Soil Fertility (FR)

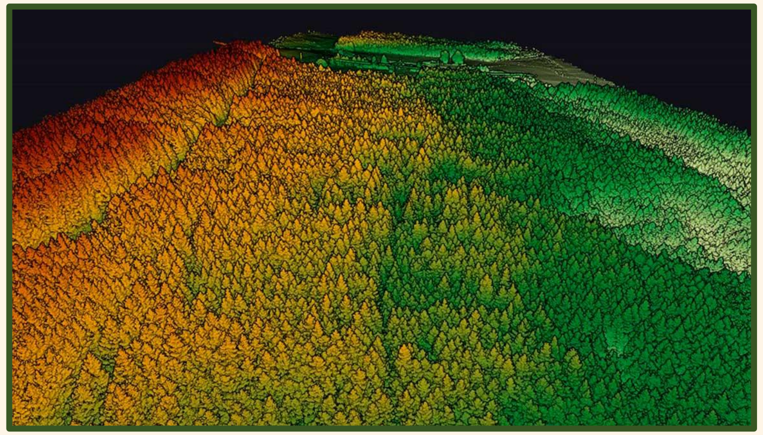
- FR (0-1) and maxASW: Derived from a National georeferenced soil database

b) Soil texture

- Soil Class index: Sandy, Sandy Loam, Clay Loam and Clay. Source: USDA Soil Texture

Nunes, J.D., Magalhães, J., Barreiro, S., & Tomé, M. (2024). Georeferenced soil database for running country-level forest growth simulations using the 3-PG process-based model.

Results



Models selected

- **Using R Sequential Replacement algorithm to search the subset of predicted variables**

Dependent variable	Independent variable	R^2	adj R^2	AIC	VIF	mean_p	mean_ap	rp_p95	rp_p05	r2p
dg	P99, zpcum7	0.68	0.65	108.4	1.32	0.04213	1.0481896	1.6209	-1.7955	0.5417
N	zpcum6, ElevIQ	0.869	0.86	378	1.85	5.36139	105.68729	204.95	-193.66	0.8079
Wl	pzabov2, zsqmean	0.879	0.87			-0.02246	1.2705994	3.0025	-3.5852	0.7791
Ww	zsqmean, CC	0.961	0.958			0.12057	4.352398	11.096	-10.232	0.9298
Wbr	pzabov2, zq40, zq80	0.896	0.888			0.05161	0.6827188	1.3506	-1.8892	0.7989
Wb	zsqmean, CC	0.936	0.931			0.11945	0.7677651	2.2297	-1.4099	0.8327

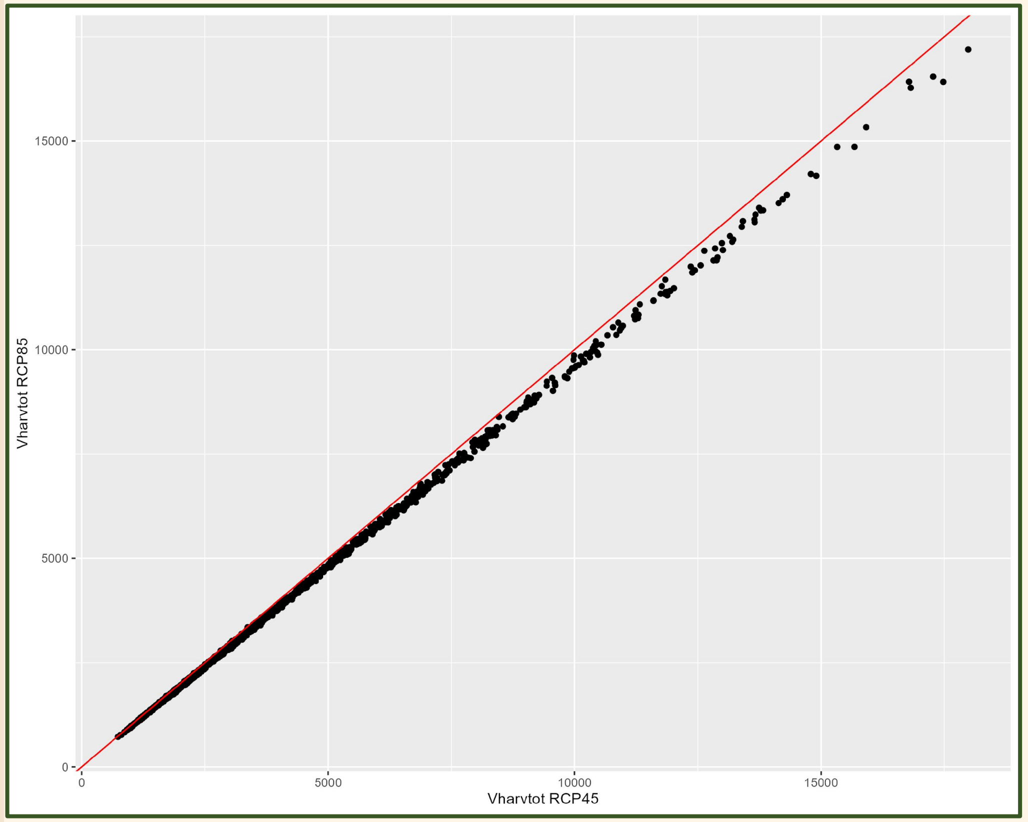
- R^2: coefficient of determination, and Adjusted R^2
- AIC: Akaike Information Criterion
- VIF: Variance Inflation Factor
- mean_p: Mean of PRESS residuals
- mean_ap: Mean of absolute PRESS residuals
- Rp_p95: 95th percentile of PRESS residuals
- Rp_p05: 5th percentile of PRESS residuals
- R2p: Predictive R^2 based on PRESS residuals (internal cross-validation)

Results

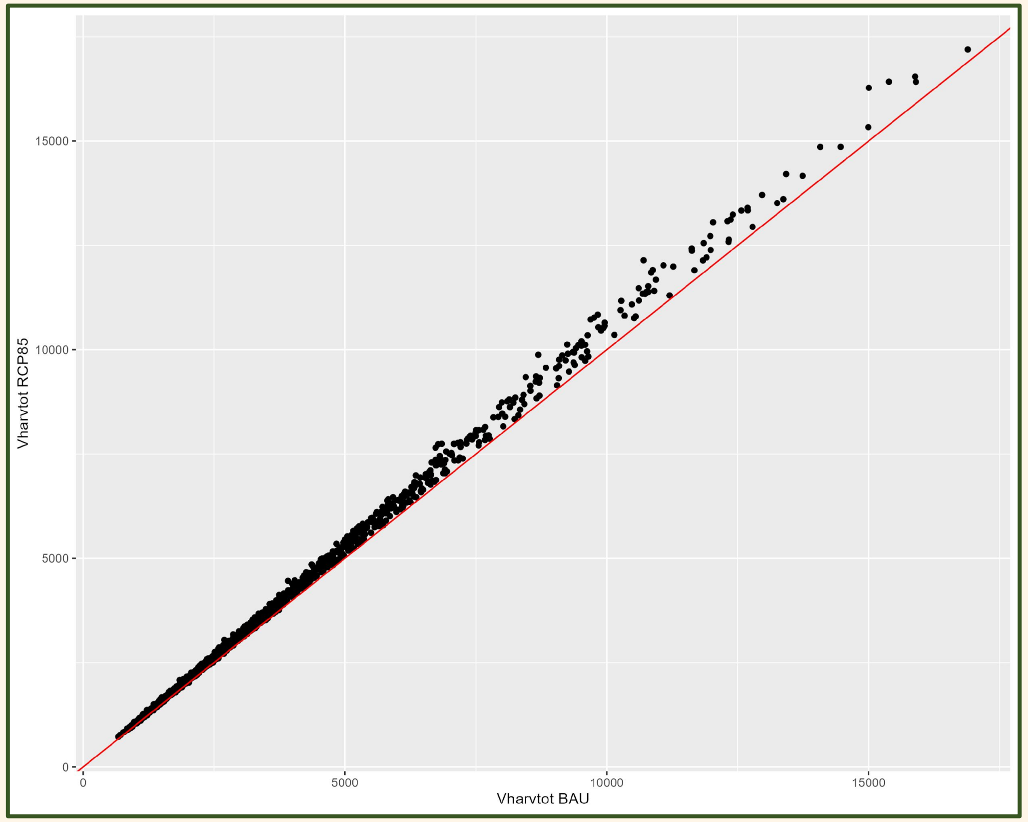
- Scenario comparison (Volume harvested)

  - Total harvested volume between scenarios: RCP4.5 > RCP8.5 > BAU
  - Each dot represents a Management unit

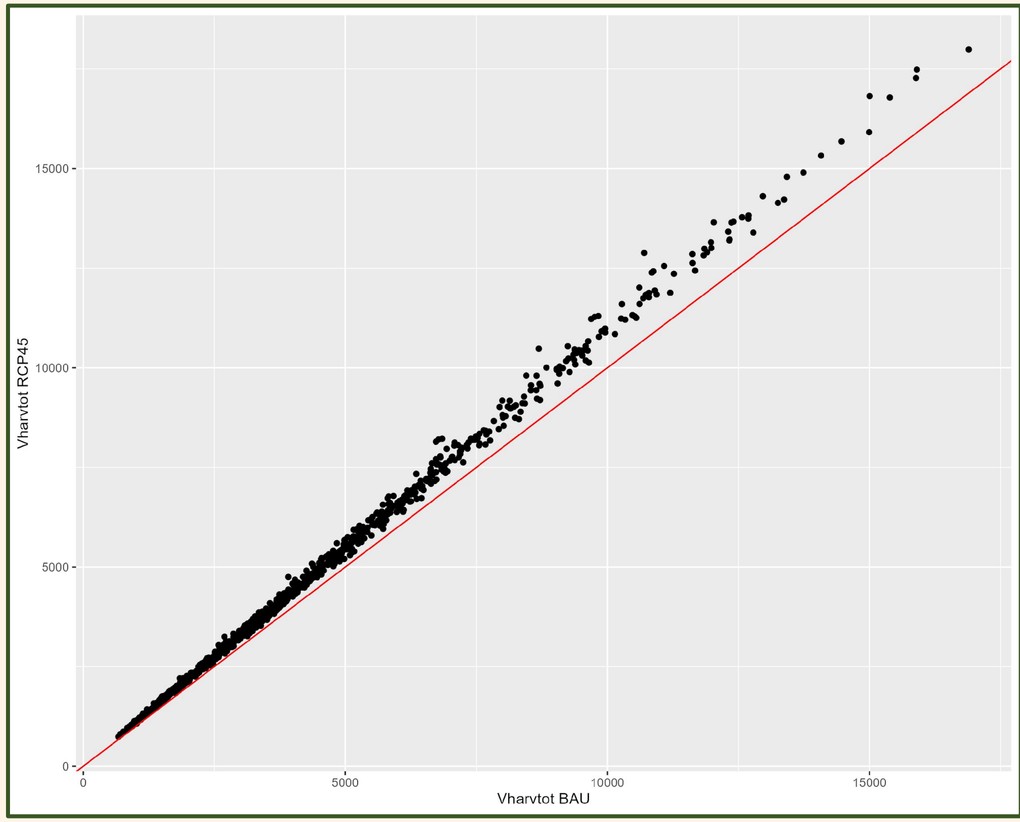
RCP8.5 < RCP4.5:



RCP8.5 > BAU



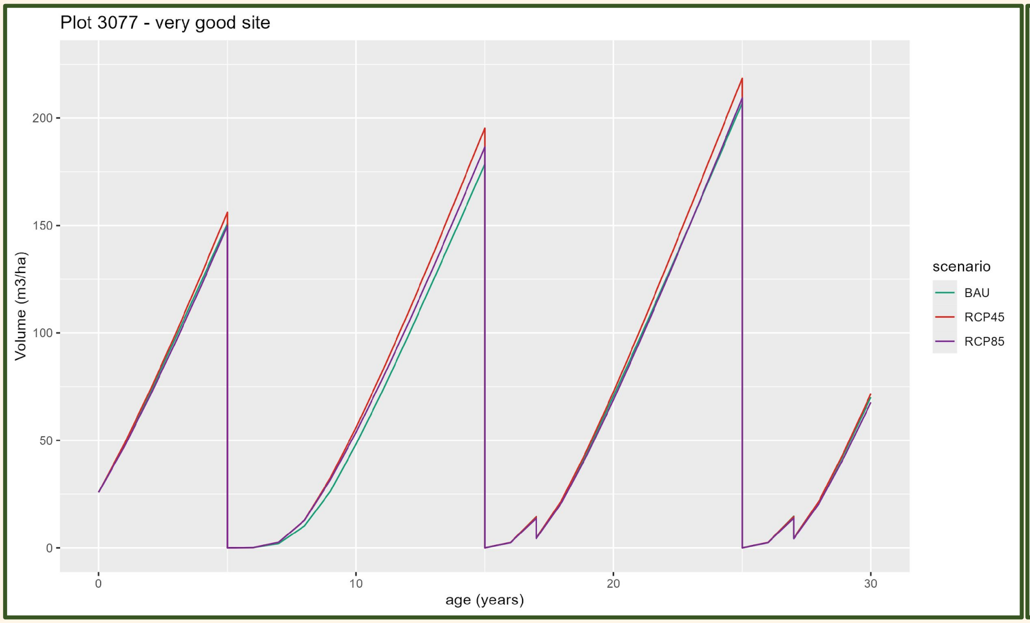
RCP4.5 > BAU



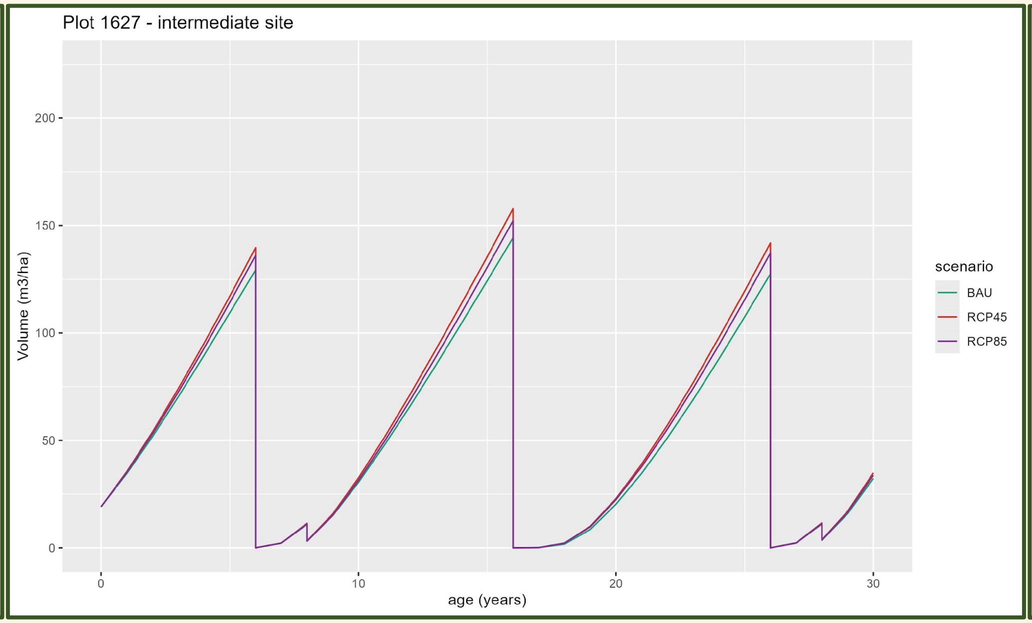
Results

- Simulated Volume over time by scenario (30 years)

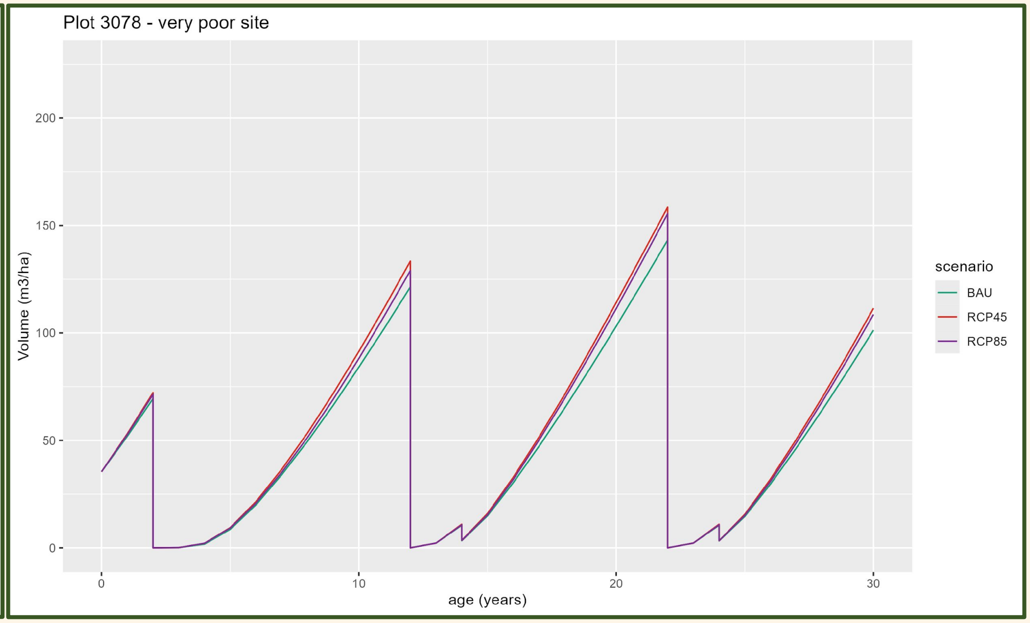
MU 3077



MU 1627



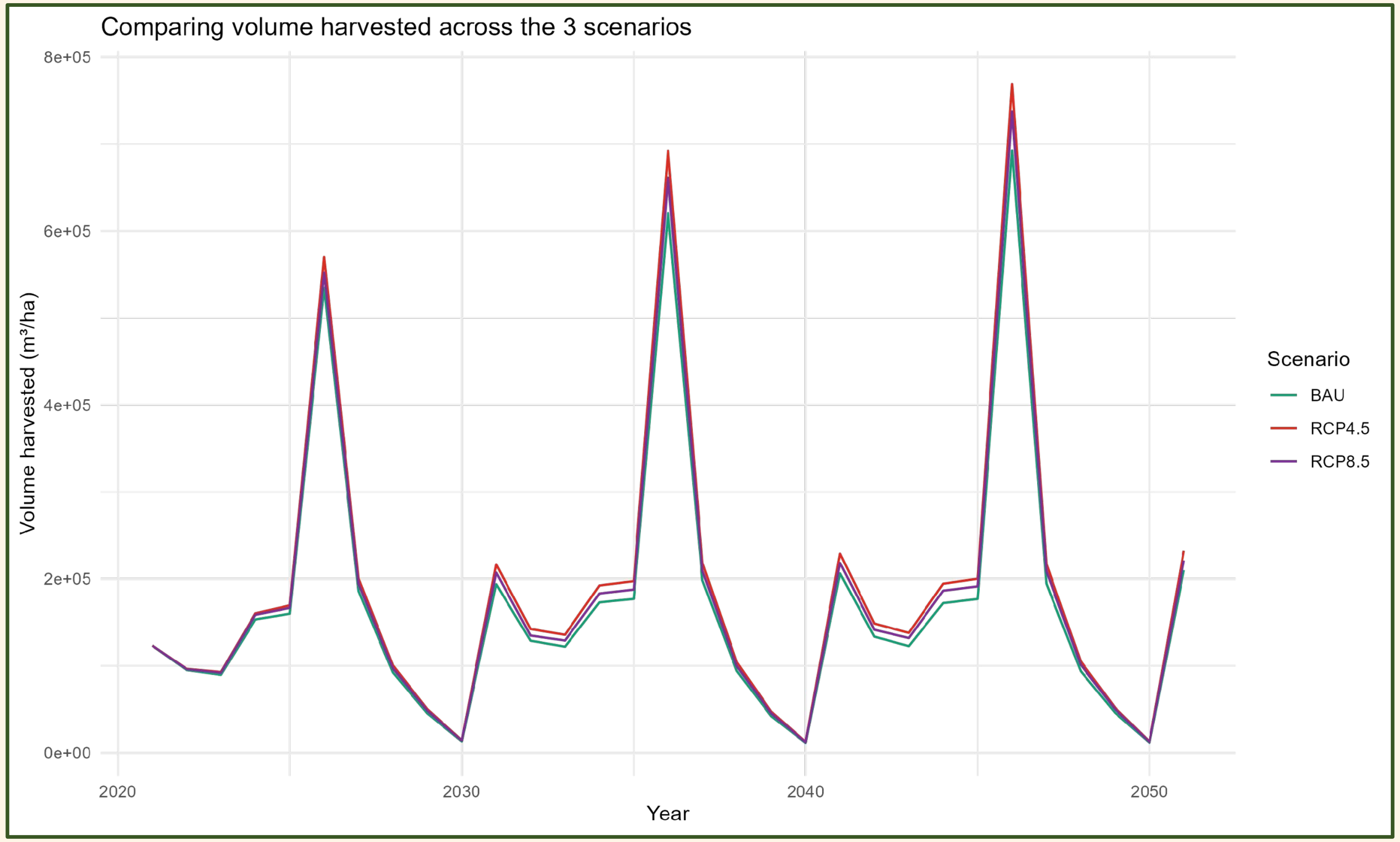
MU 3078



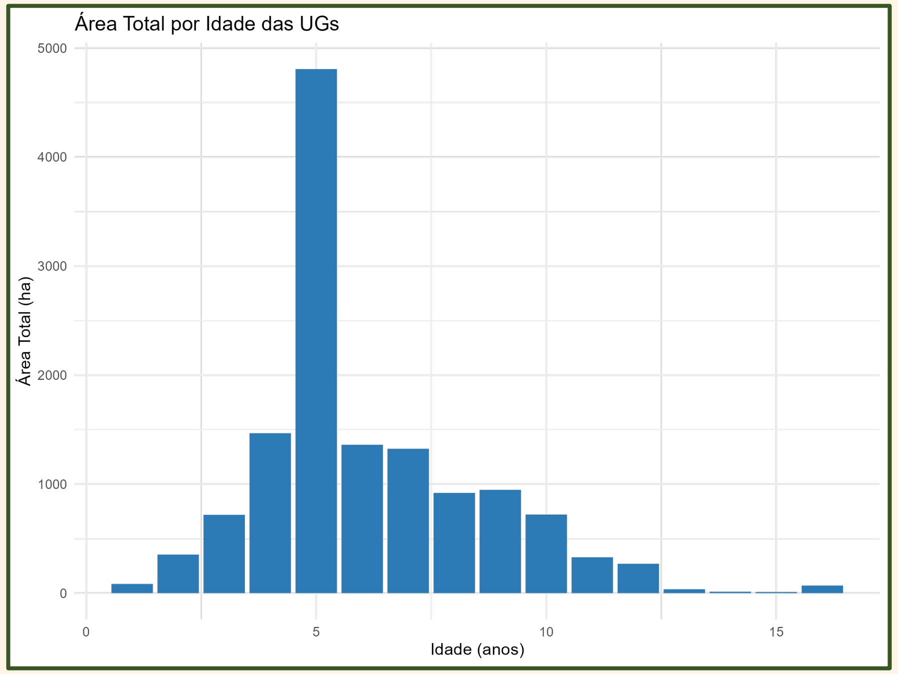
- Fixed harvested interval (10-year rotation) were applied across all MUs
- Total harvested volume in three different Management Unit: RCP4.5 > RCP8.5 > BAU

Results

- Comparing volume harvested across the 3 scenarios



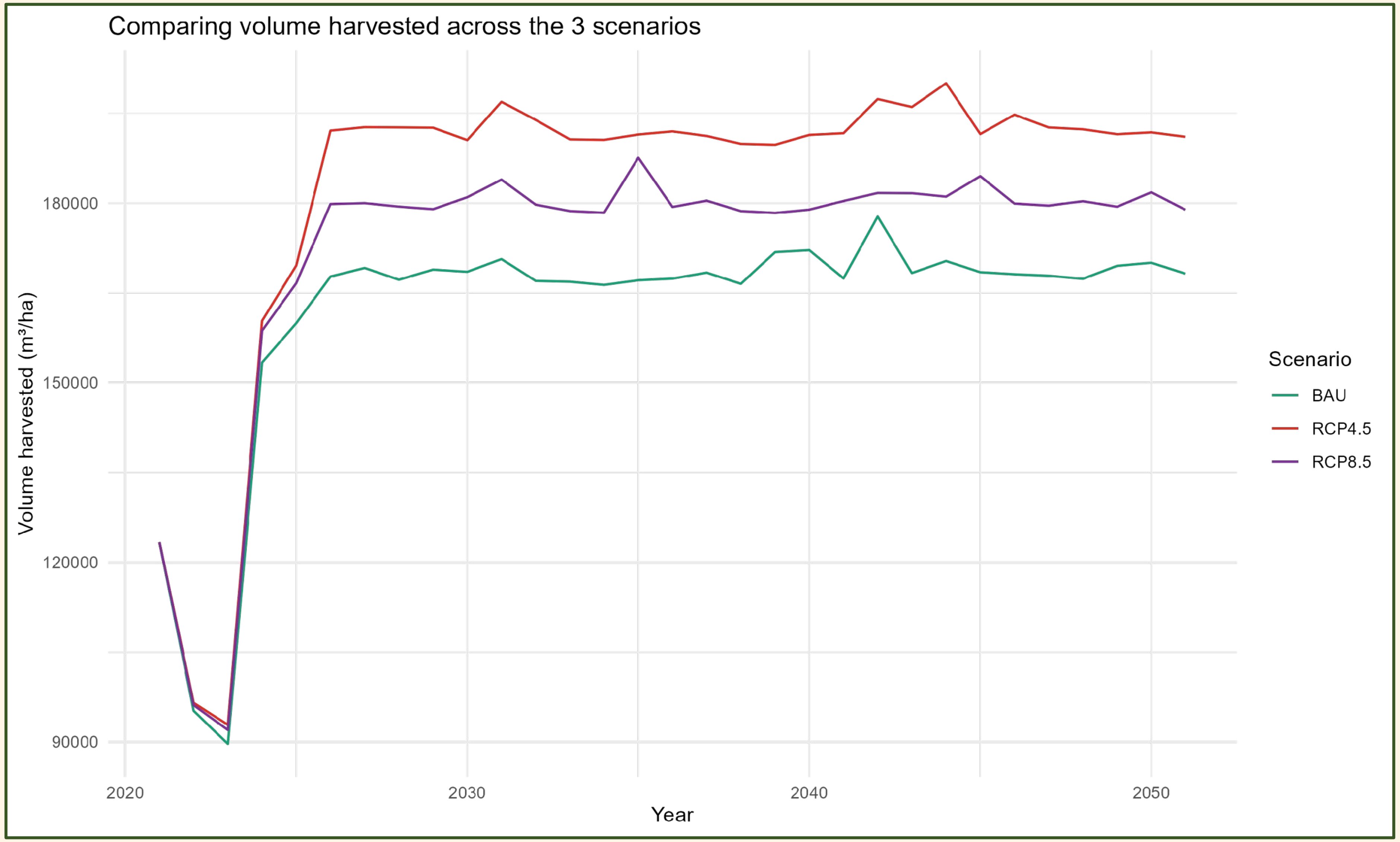
- This age concentration stems from recent wildfires disturbances



- The harvested peaks are consequence of rotation, and current age structure
- As these stands reach harvested age (~15 years), they mature simultaneously, causing the volume spike

Results

- Comparing volume harvested constraints across the 3 scenarios



To ensure a more homogeneous distribution of harvested volume over time:

- The average harvested volume over 30-year period was calculated for each scenario:

  (a) BAU (140 m^3/ha)

  (b) RCP4.5 (160 m^3/ha)

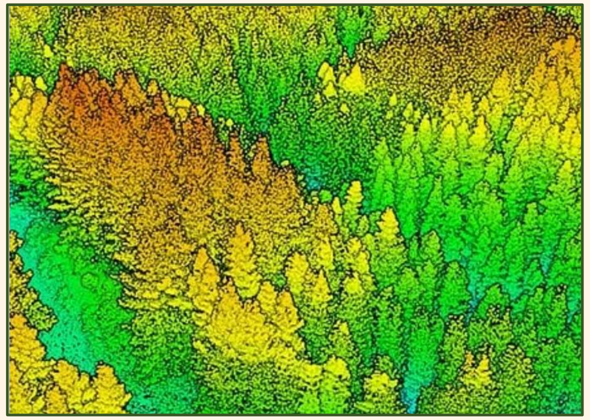
  (c) RCP8.5 (150 m^3/ha)

- These values were used as fixed annual maximum constraint for each scenario

Discussion

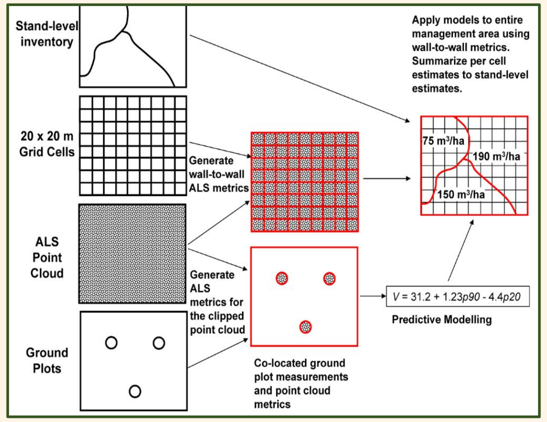
- **Unexpected? Perhaps Not.**
  - Productivity with RCP 4.5 > RCP8.5 > BAU in Northern Portugal
  - Already anticipated by Santos Pereira et al. (2005), using the GOTILWA+ model
  - Cooler baseline temperature -> no heat stress
- **Why?**
  - Winter Warming -> Faster Growth
  - Net effect - > Higher Productivity
- **But…**
  - Gains likely restricted to Coastal areas with humid summer

Discussion



Airborne laser scanning

ALS data provides detailed insights into forest structure.

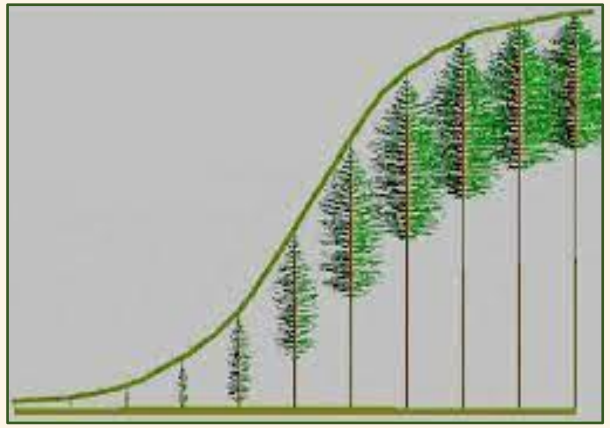


Estimating stand variables

ALS and ground forest inventory sampling data.

Stand-Level Characterization in each MU

Stand variables such as Ww, Wbr, Wb, Wl, Wr, N, dg and G.



Insights on Dynamics in each MU

Forest stand simulators (3PG model) to simulate growth and yield under RCP scenarios: BAU, RCP4.5 and RCP8.5

Forest fire simulators: FlamMap and cell2fire

Support fuel management strategies such as thinning or understory cleaning.

3PG model and wildfire risk

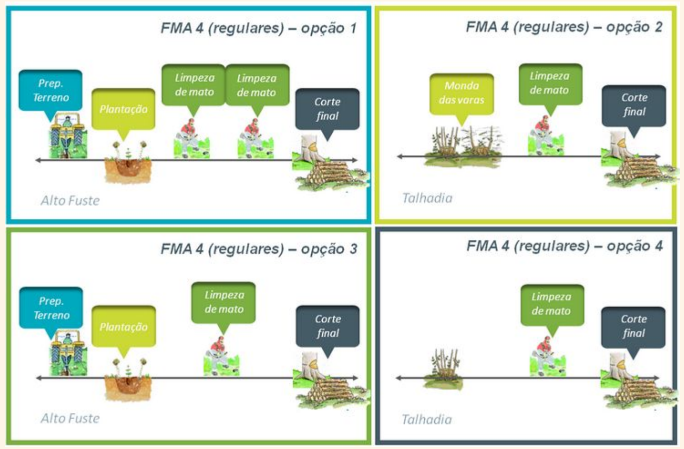
- 3PG does not simulate fire directly, but its **outputs** inform fire risk models
- Basal area (output from 3PG) is a **key input** for understory biomass estimation
- Higher basal area reduces understory growth due to shading, while higher **T** may increase shrub growth
- These variables affect **fuel load and continuity**, influencing fire behavior
- Results support fuel management strategies such as **thinning or understory cleaning**

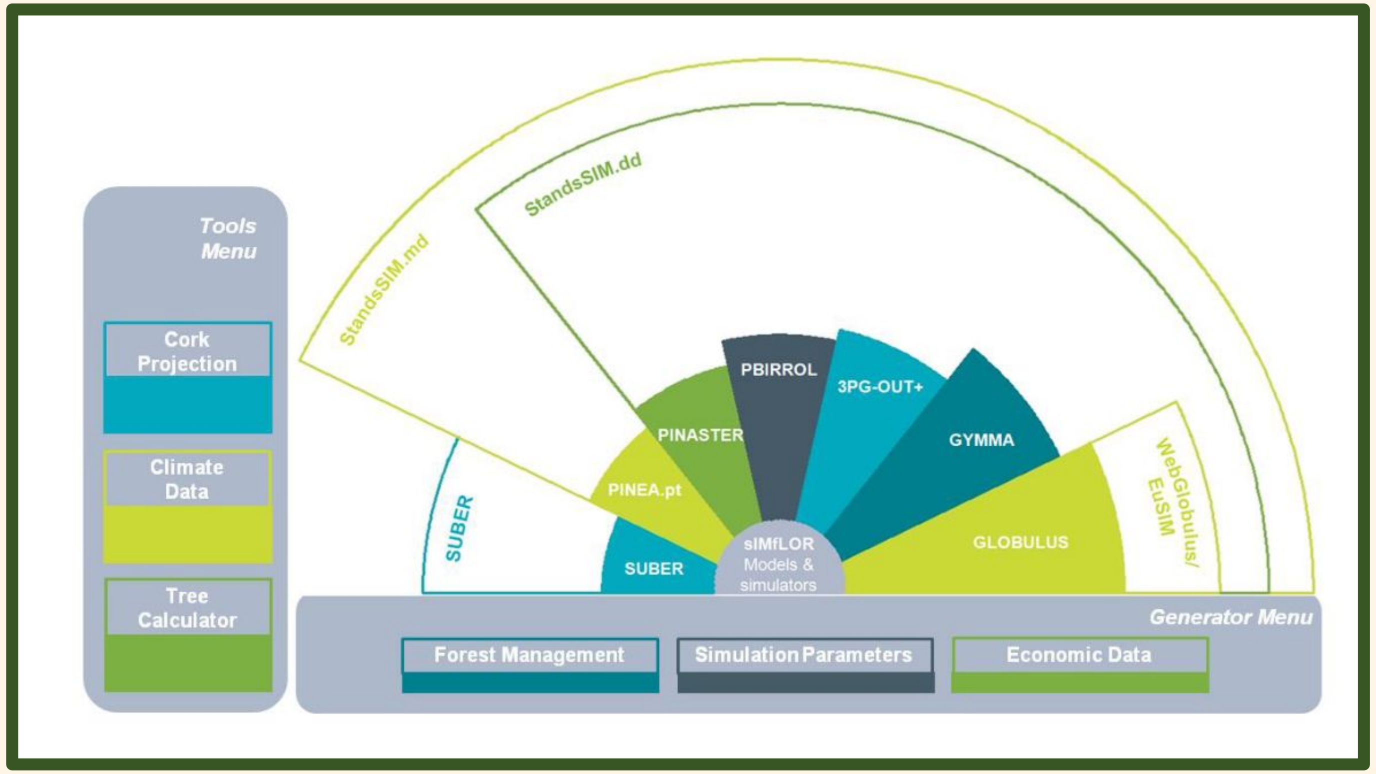
Implications for Forest Management

- The integration of ALS and the 3PG model provides valuable inputs for:

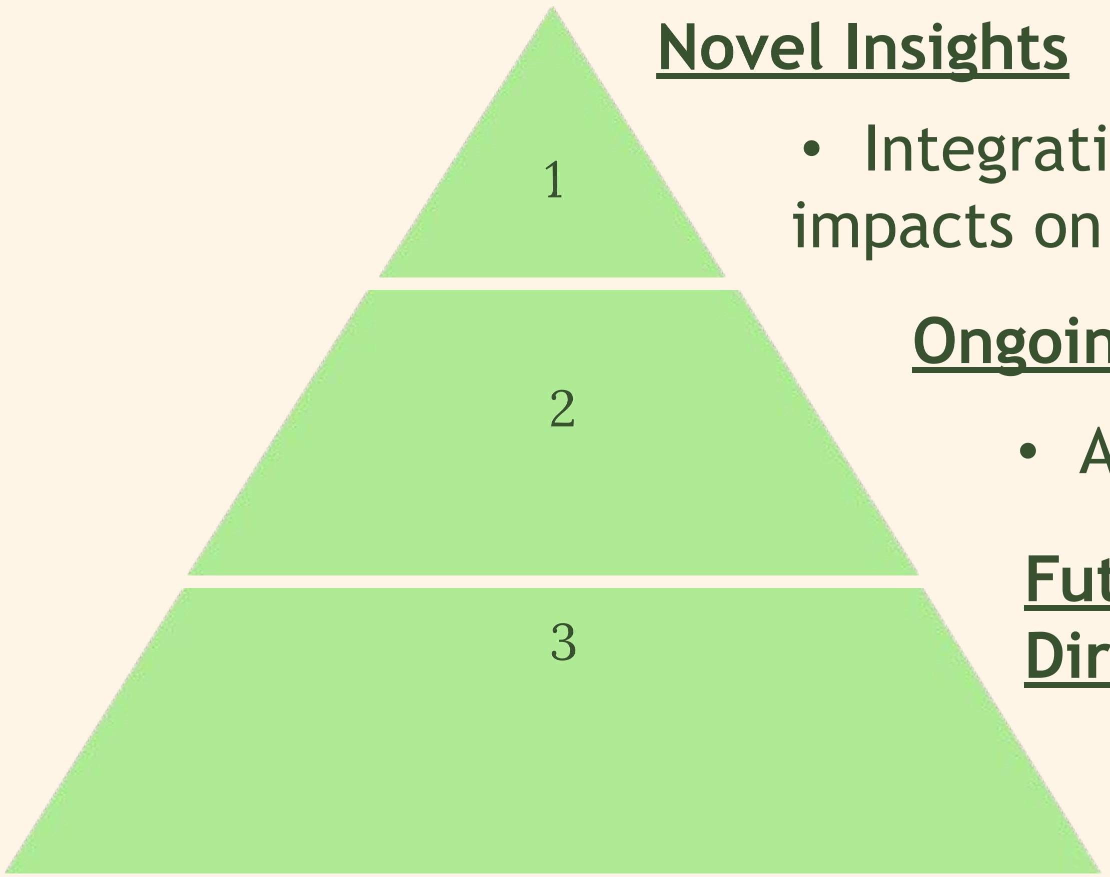
- Adaptive silvicultural planning

- Fire behavior modeling and risk assessment tools





Conclusion and Future Research Directions



Novel Insights

- Integrating ALS data and the 3-PG model to simulate climate changes impacts on Eucalyptus MUs in Northern Portugal

Ongoing

- Average standing carbon stock and Available soil water

Future Directions

- Calculate additional indicators such as landscape-level biodiversity
- Perform multi-objective optimization to balance trade-offs

OBRIGADO!!!

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