Generating fire risk variables from satellite images: fuel and vulnerability

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Fuel types and fuel parameters

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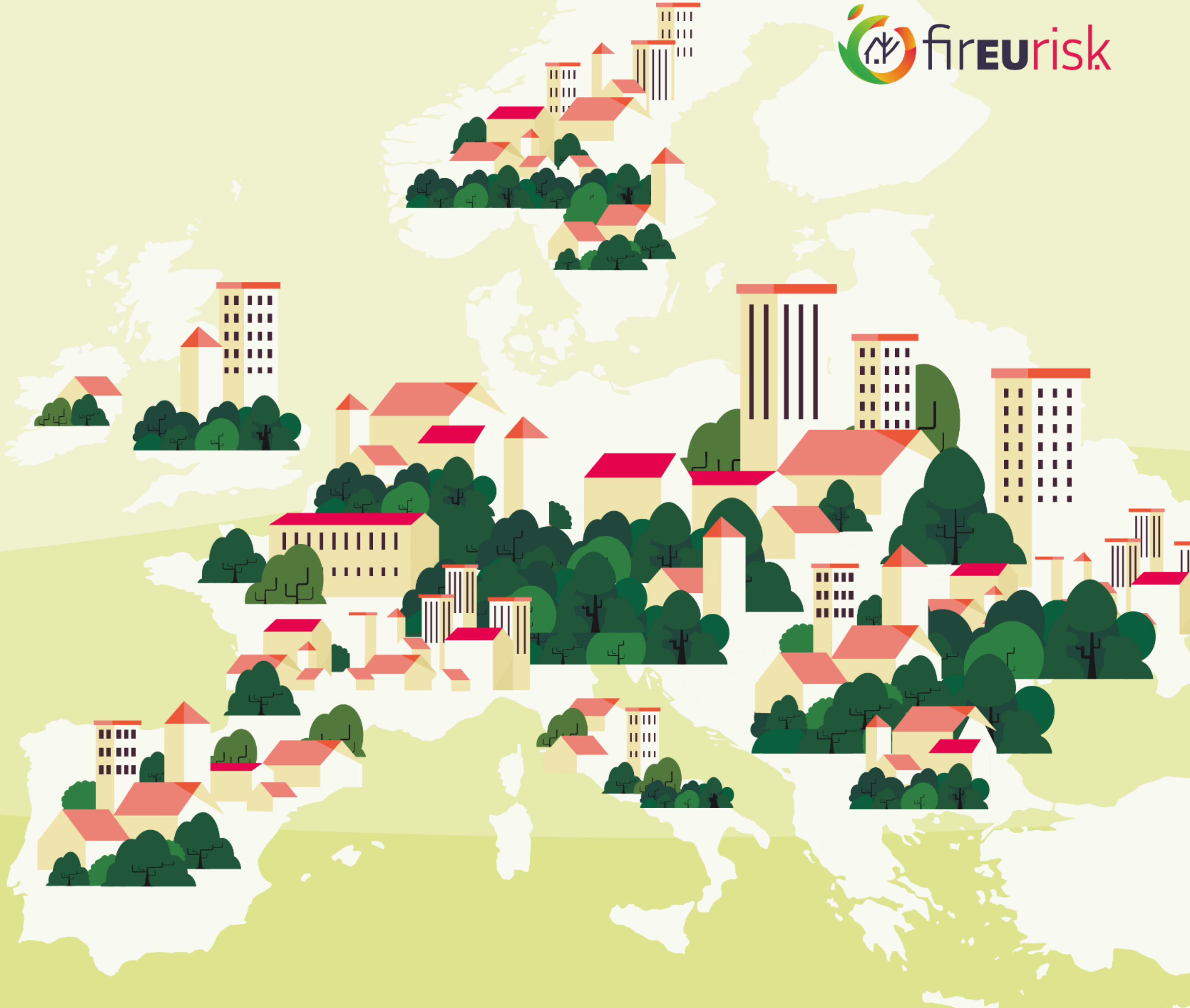

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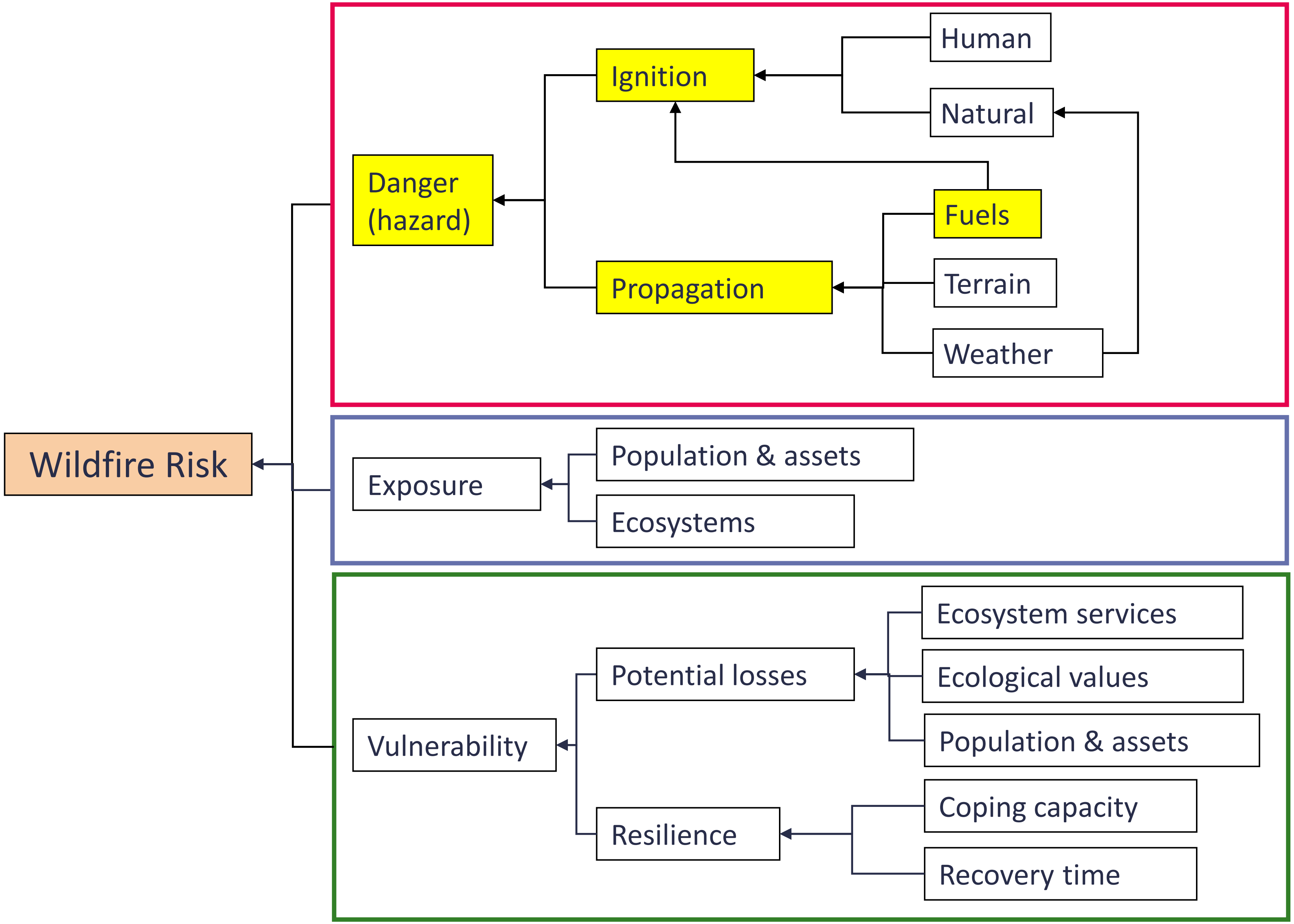

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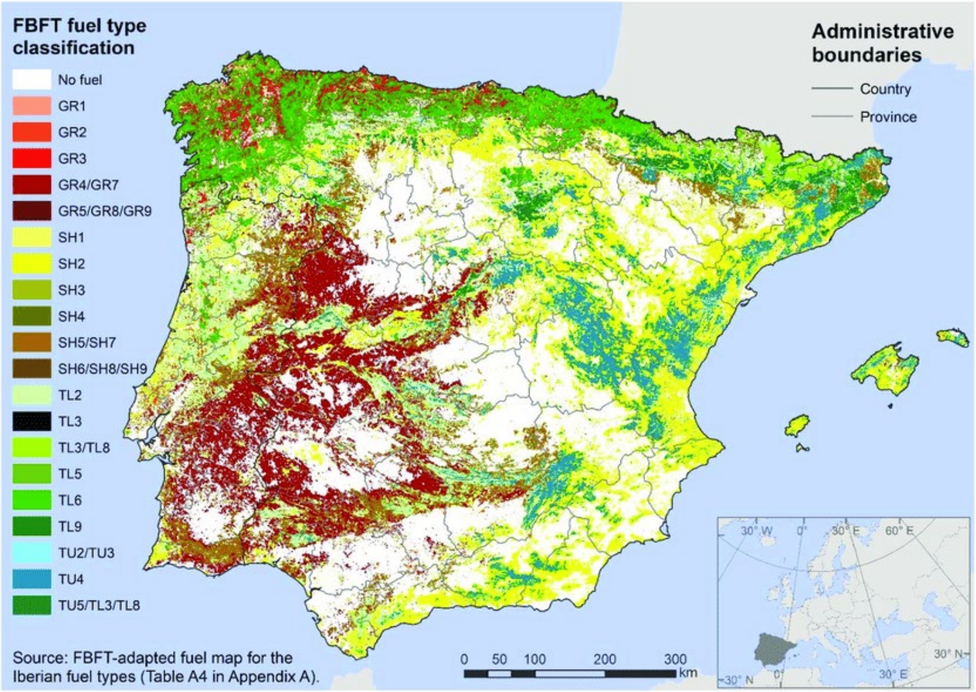
Fuel types and fuel parameters

- **Fuel types:** vegetation with similar fire behaviour (categories)

- **Fuel parameters:** Numerical parameters required to model fire behaviour (height, load, particle size, etcetera).



Aragoneses and Chuvieco (2021): https://www.mdpi.com/2571-6255/4/3/59

Fuel Model	Typical Fuel Complex	Fuel Loadings		
		Fuel 1-Hr	Fuel 10-Hr	Fuel 100-Hr
2	Timber (grass and understory)	2	1	0.5
3	Tall grass (2.5 feet)	3.01	0	0
4	Chaparral	5.01	4.01	2
6	Dormant brush, hardwood slash	1.5	2.5	2
7	Southern rough	1.13	1.87	1.5
8	Closed timber litter	1.5	1	2.5
9	Hardwood litter	2.92	0.41	0.15

Kabli et al (2015): https://www.mdpi.com/1999-4907/6/6/2148/htm

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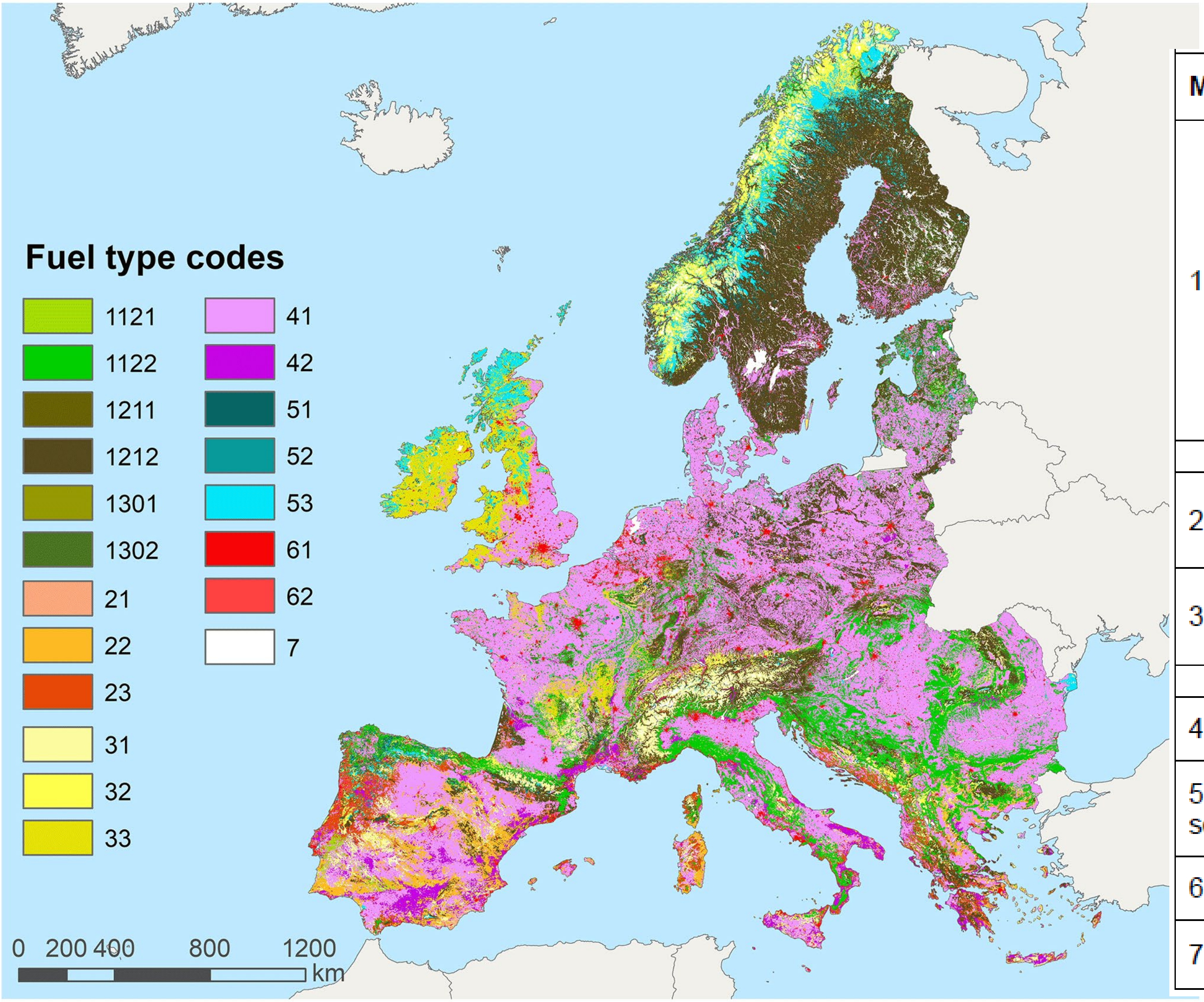
European fuel type map



Main fuel type	Leaf type/ Type	Phenology	Fractional cover (%)
1. Forest	11. Broadleaf	111. Evergreen	1111. Open [15-70%)
			1112. Closed [70-100%)
		112. Deciduous	1121. Open [15-70%)
			1122. Closed [70-100%)
	12. Needleleaf	121. Evergreen	1211. Open [15-70%)
			1212. Closed [70-100%)
		122. Deciduous	1221. Open [15-70%)
			1222. Closed [70-100%)
	13. Mixed		1301. Open [15-70%)
			1302. Closed [70-100%)
	Fuel depth		
2. Shrubland	21. Low [0-0.5m)		
	22. Medium [0.5-1.5m)		
	23. High (≥ 1.5m)		
3. Grassland	31. Low [0-0.3m)		
	32. Medium [0.3-0.7m)		
	33. High (≥ 0.7m)		
	Type		
4. Cropland	41. Herbaceous		
	42. Woody (shrub-tree)		
5. Wet and peat/ semi-peat land	51. Tree		
	52. Shrubland		
	53. Grassland		
6. Urban	61. Continuous fabric: urban fabric (≥ 80%)		
	62. Discontinuous fabric: vegetation and urban fabric [15-80%)		
7. Nonfuel			

Hierarchical

Europe's diversity

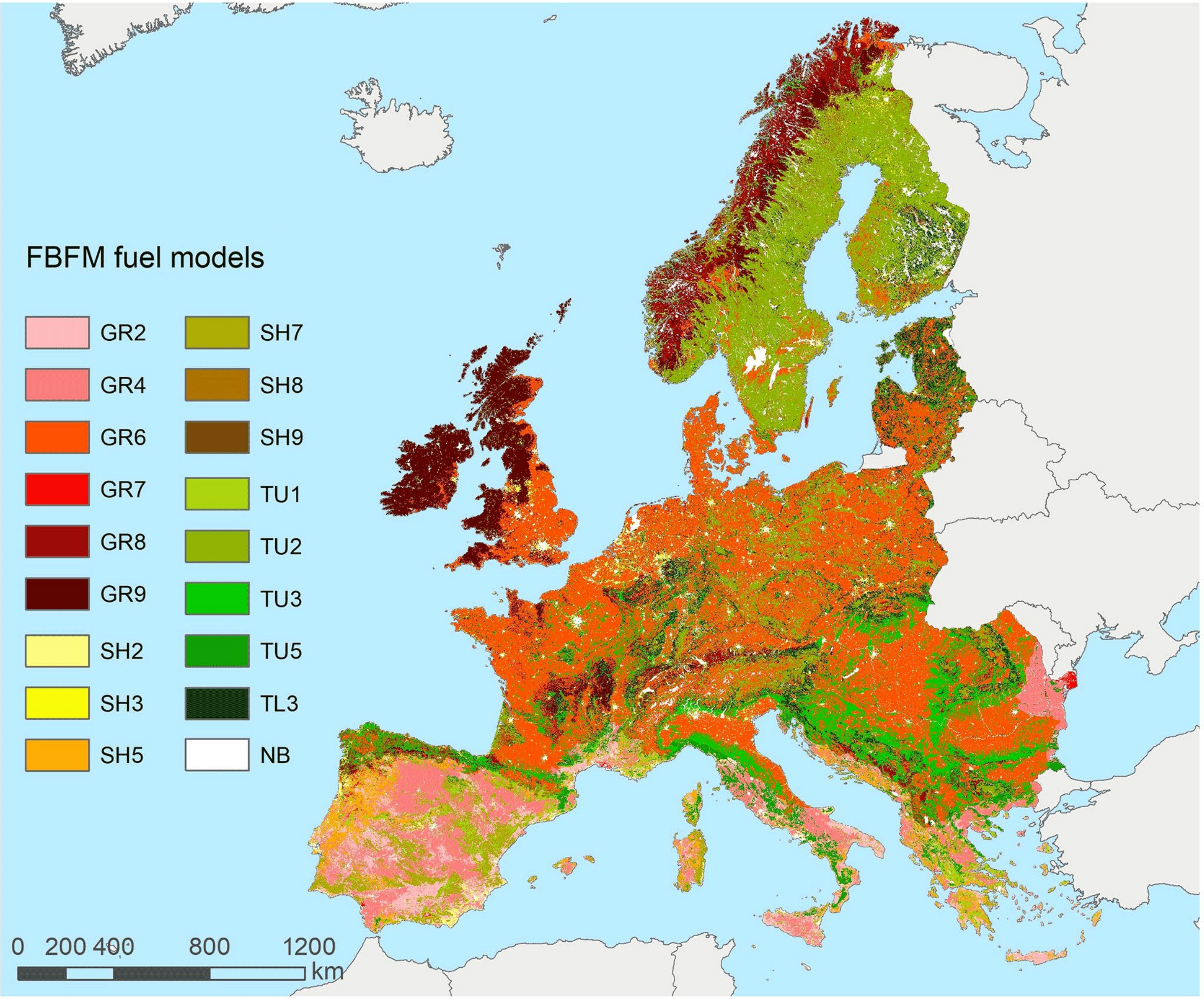
Surface and crown fuels

1 km resolution

Aragoneses et al. 2023 https://doi.org/10.5194/essd-15-1287-2023

First assignment of standard fuel models

- Crosswalk from FirEUrisk fuel types to FBFM fuel models (Scott and Burgan, 2005)
- Use of expert knowledge
- Only **surface** fuels



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Crown fuel parameters and used data

fireEUrisk

- Forest canopy fuel parameters to be estimated – useful for fire behaviour modelling:
  - Canopy mean height
  - Canopy cover
  - Canopy base height

  METHOD 1: Derived metrics from GEDI LiDAR

  - Canopy fuel load
  - Canopy bulk density

  METHOD 2: Raw GEDI LiDAR waveforms

MORE COMPLEX PARAMETERS:
Vertical distribution of fuel

- Forest inventory data
- Discrete waveforms: airborne LiDAR → calibration of models
- Full-waveforms (continuous pulse of energy): satellite LiDAR (GEDI mission) → interpolation for wall-to-wall maps
  - Almost global coverage

GEDI ECOSYSTEM LIDAR

https://gedi.umd.edu/

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Method 1 : Calibration of GEDI-based models from GEDI metrics

Forest inventory data and input airborne LiDAR (ALS)

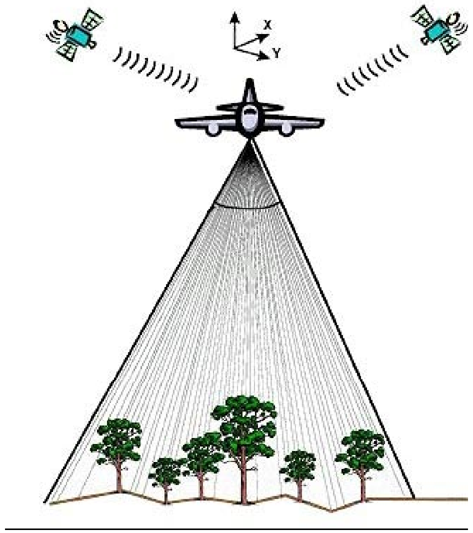
Spain -> 4 areas
Germany -> 2 areas
Slovenia -> 1 area

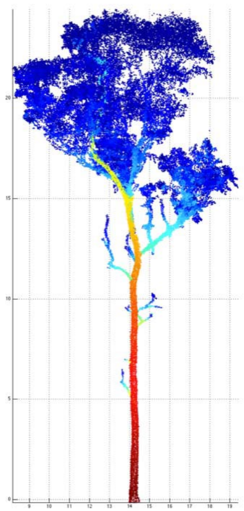
Clip by forest plots

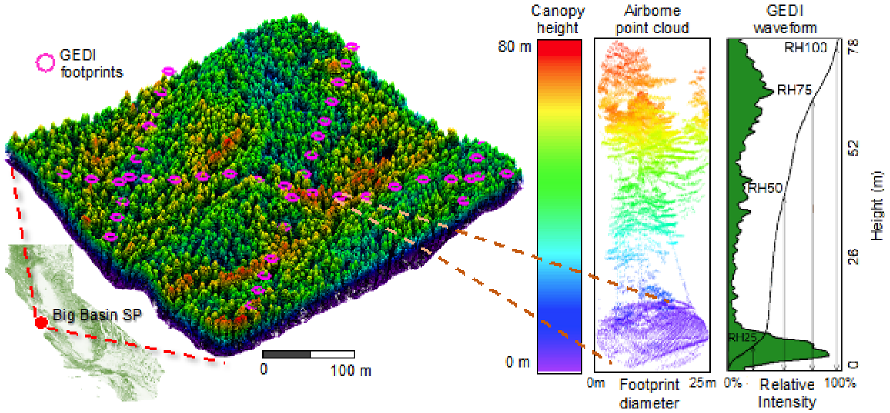
Simulate satellite GEDI-like waveforms

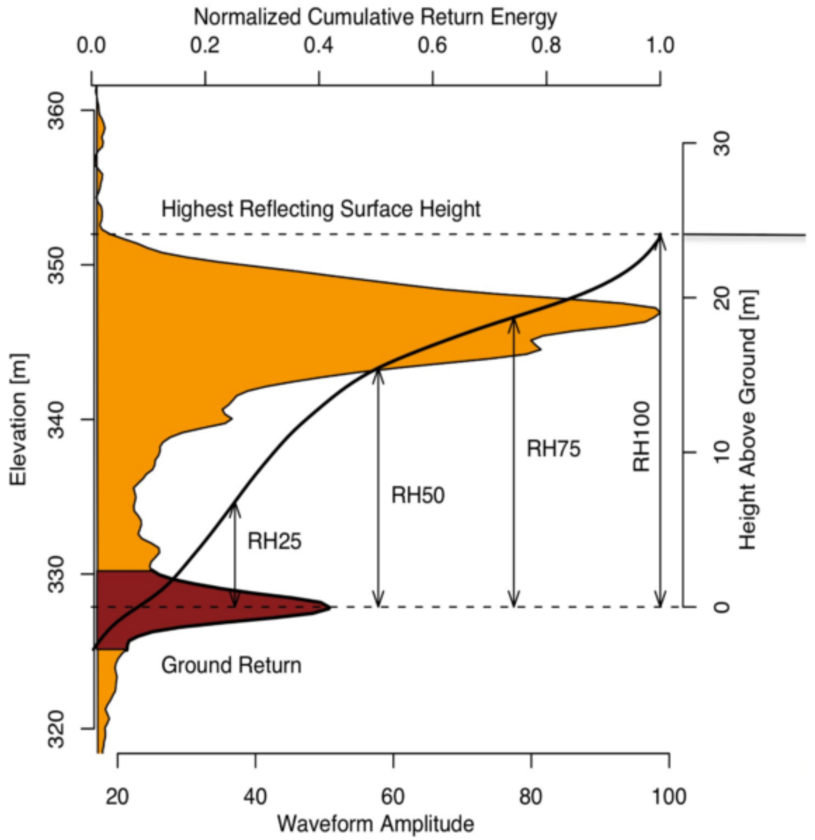
Simulation -> Extract metrics (RHs, ground, canopy cover,…)

GEDI-based model using reference data from ALS and forest inventory









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Crown fuel parameters and used data

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- Forest canopy fuel parameters to be estimated – useful for fire behaviour modelling:

• Canopy mean height • Canopy cover • Canopy base height	**METHOD 1:** Derived metrics from GEDI LiDAR
• Canopy fuel load • Canopy bulk density	**METHOD 2:** Raw GEDI LiDAR waveforms

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GEDI
ECOSYSTEM LIDAR

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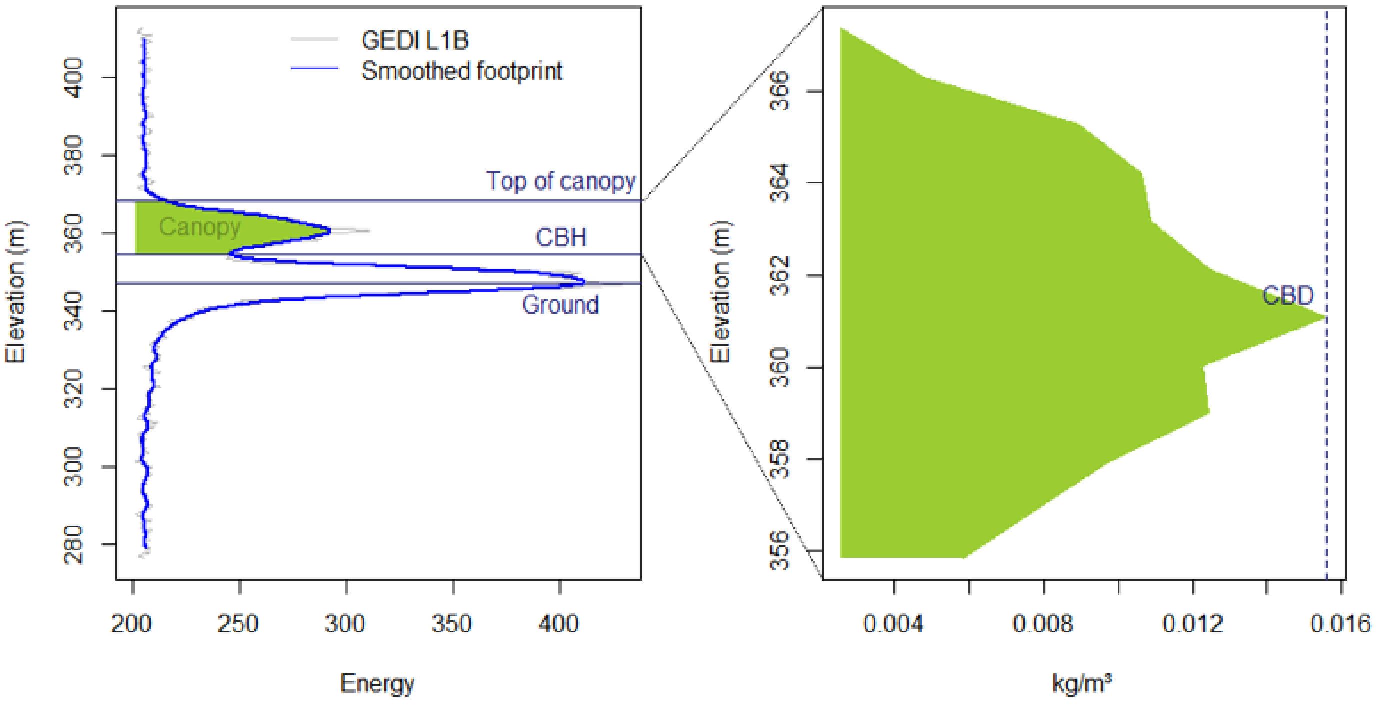
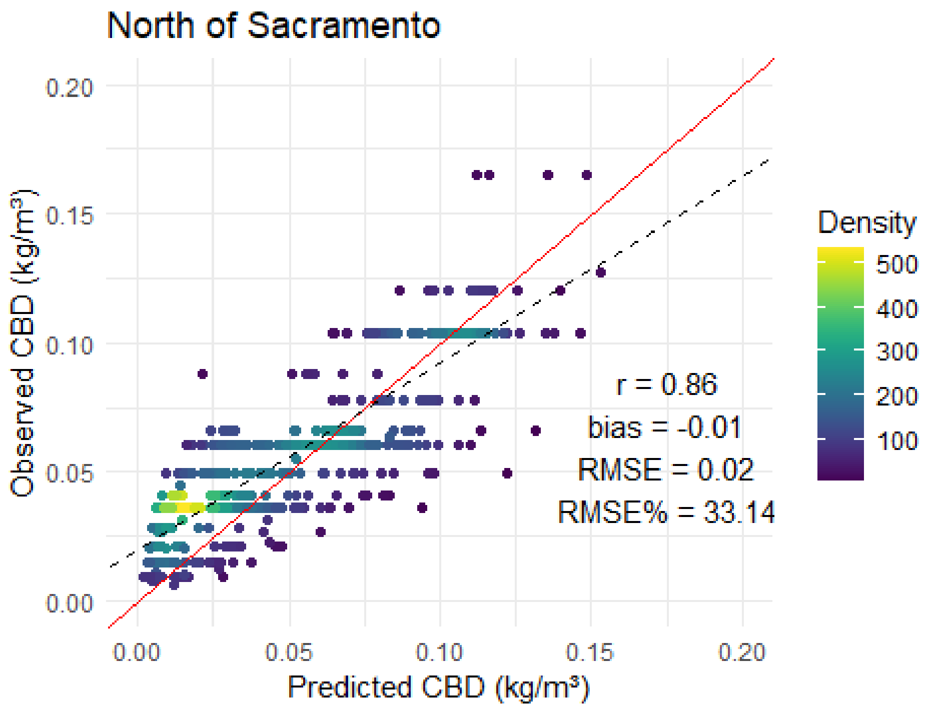
Method 2 : Analysis of raw GEDI waveform

- **Canopy fuel load**
  - LAI/ SLA (speficif Leaf Area)
- **Canopy bulk density**
  - Get canopy Fuel Vertical Profile (FVP)
  - CBD as maximum of the FVP/SLA





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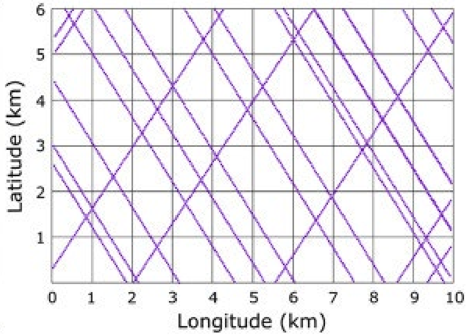
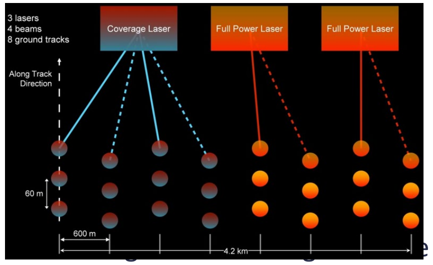
Final step: Interpolation model of GEDI data

Next step: Use spaceborne GEDI data to derive forest canopy height and cover

But we need to **interpolate** because GEDI data is not spatially continuous





1 **Inverse distance weight (IDW) interpolation** of GEDI data

Forest fuel polygons with spacebrone GEDI footprints

92 % forest under 51.6ºN

2 **Random forest & K-nearest neighbout regression models** of GEDI + multispectral+ RADAR data + biopysical variables

Forest fuel polygons without spaceborne GEDI footprints

(small polygons under 51.6ºN and all polygons above 51.6ºN, GEDI coverage)

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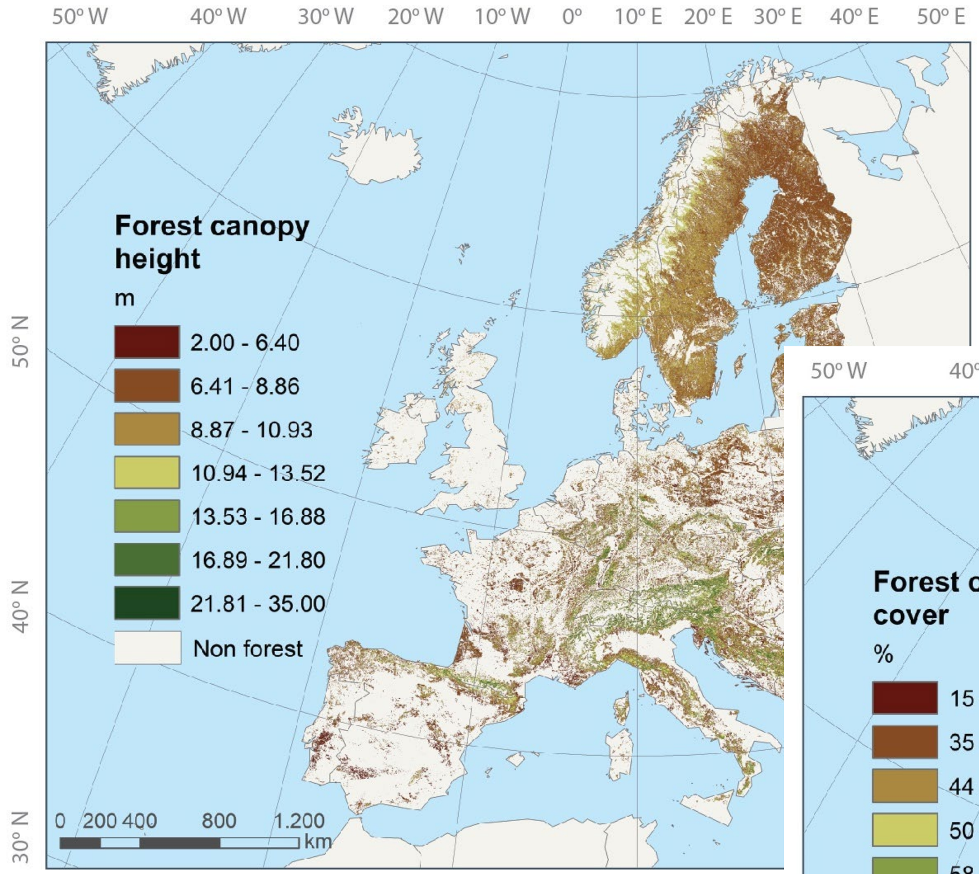
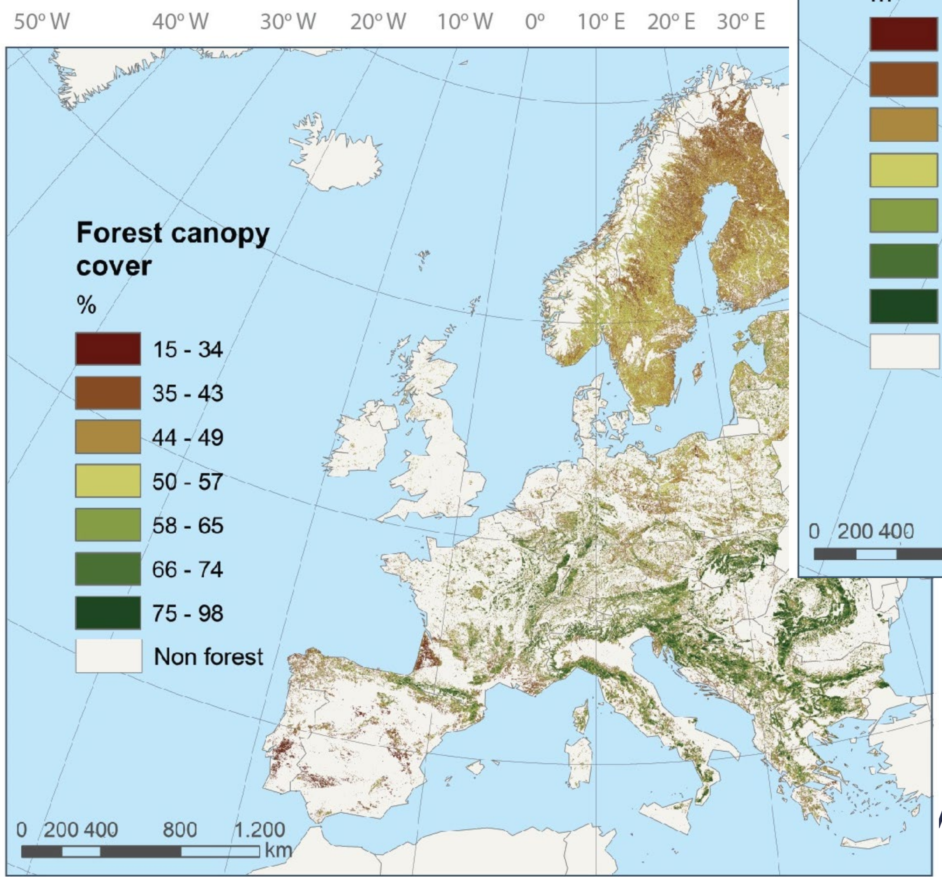
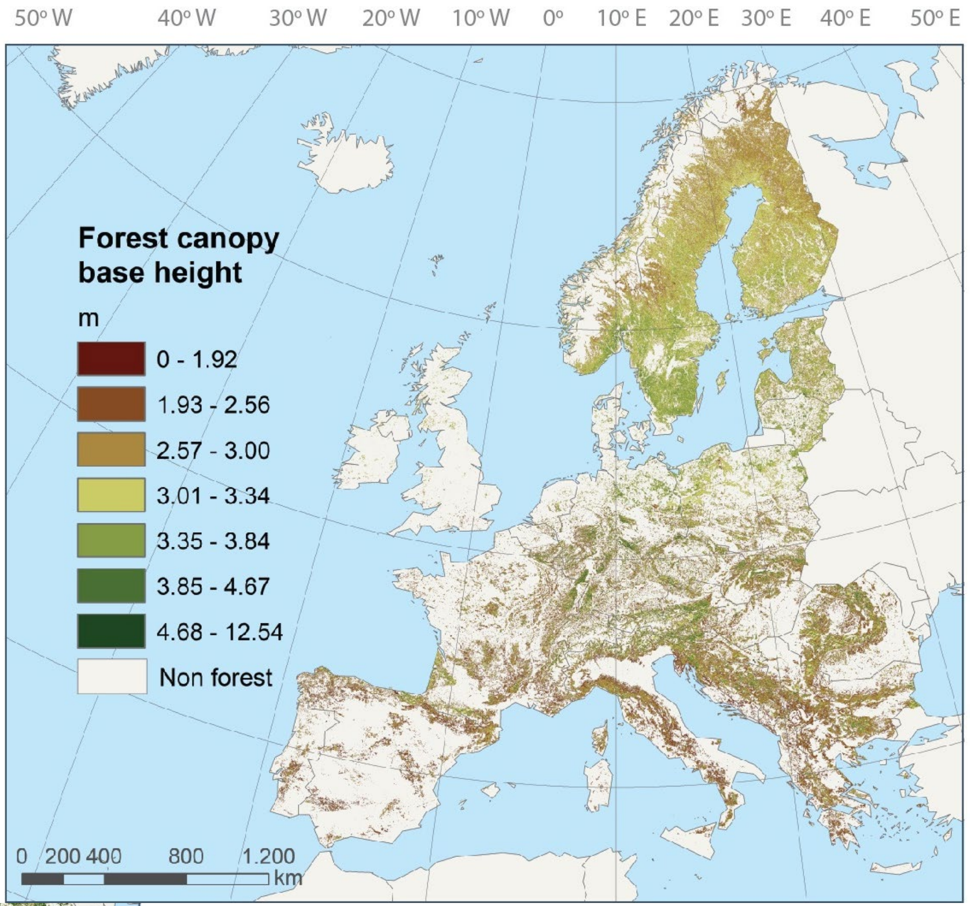
Final results: wall-to-wall maps on canopy parameters







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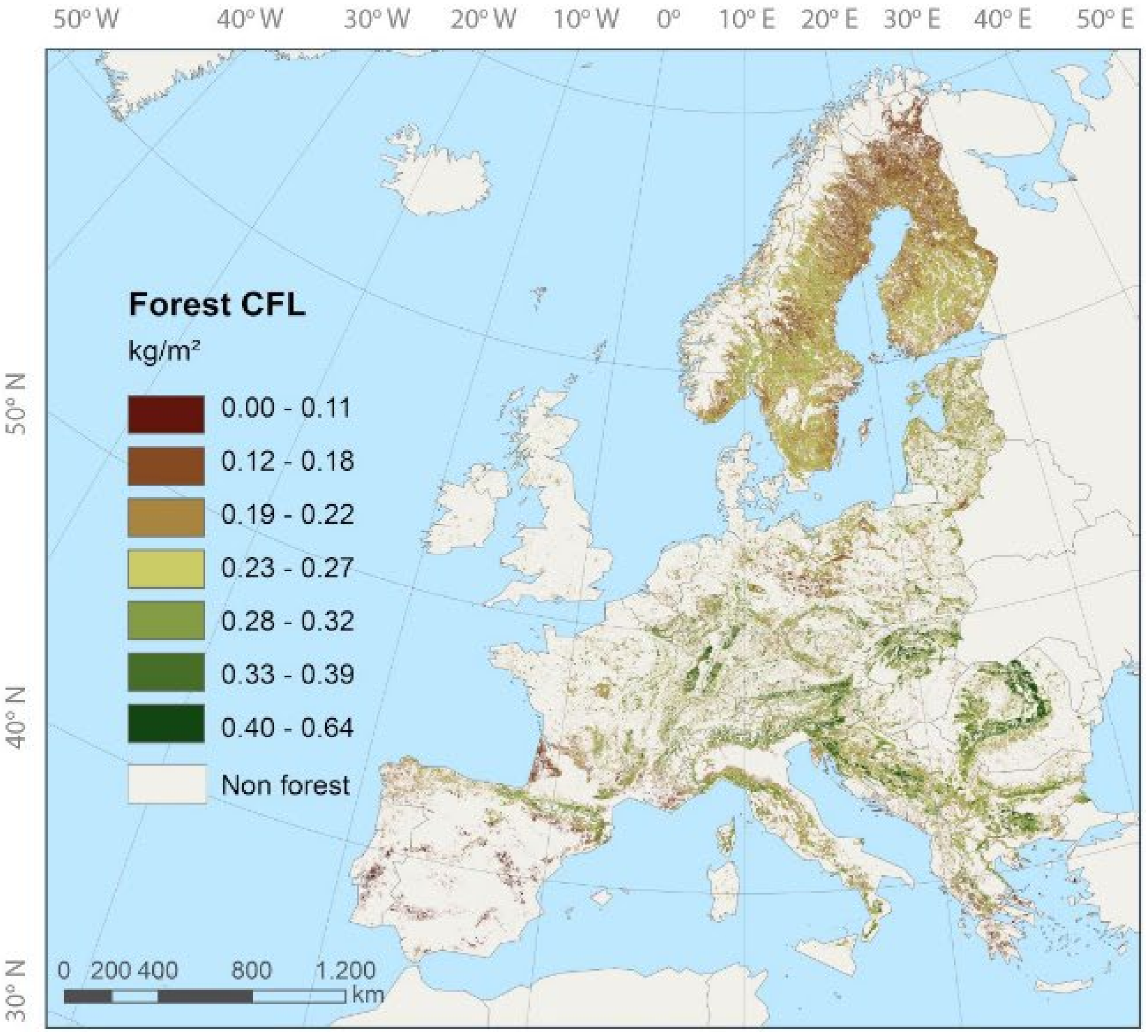
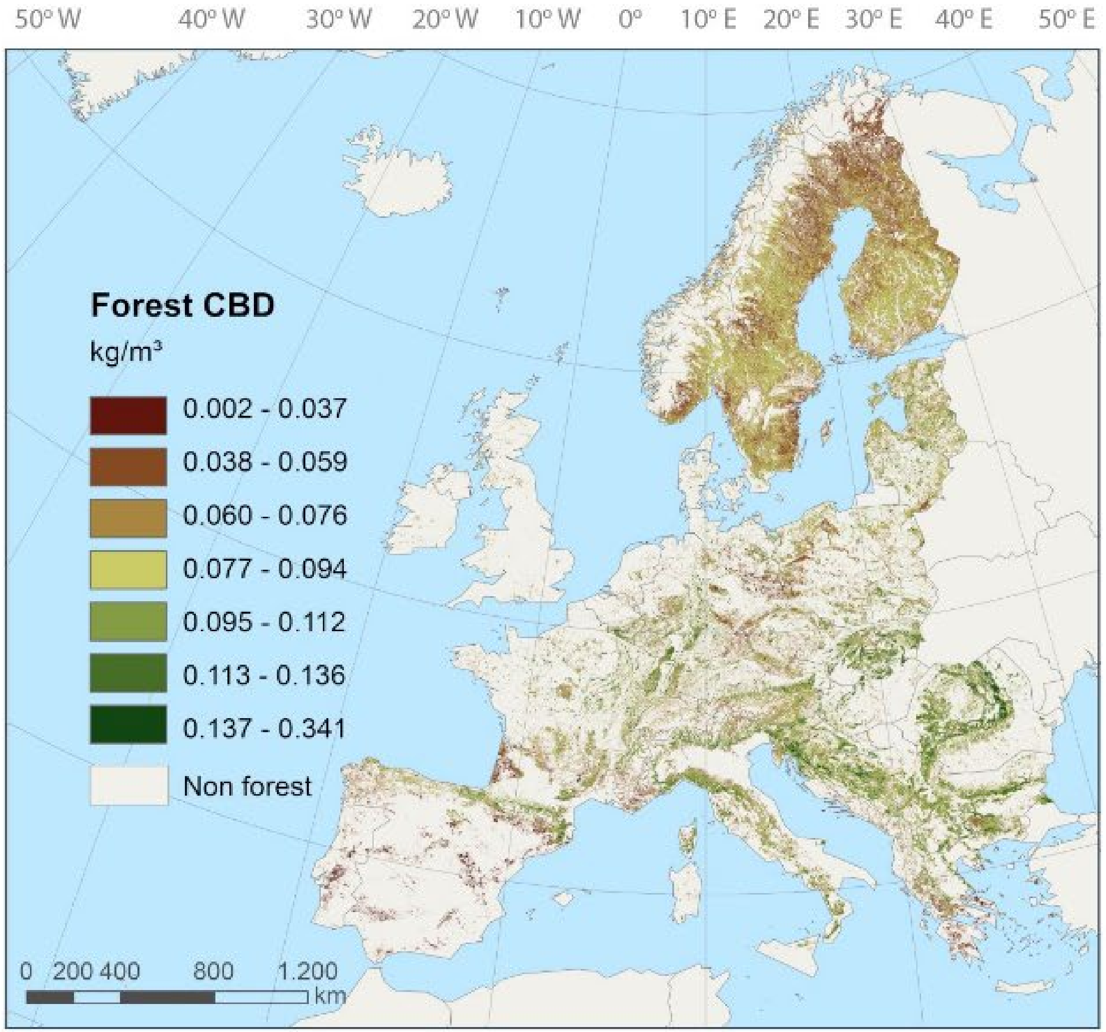
Final results: wall-to-wall maps on canopy parameters





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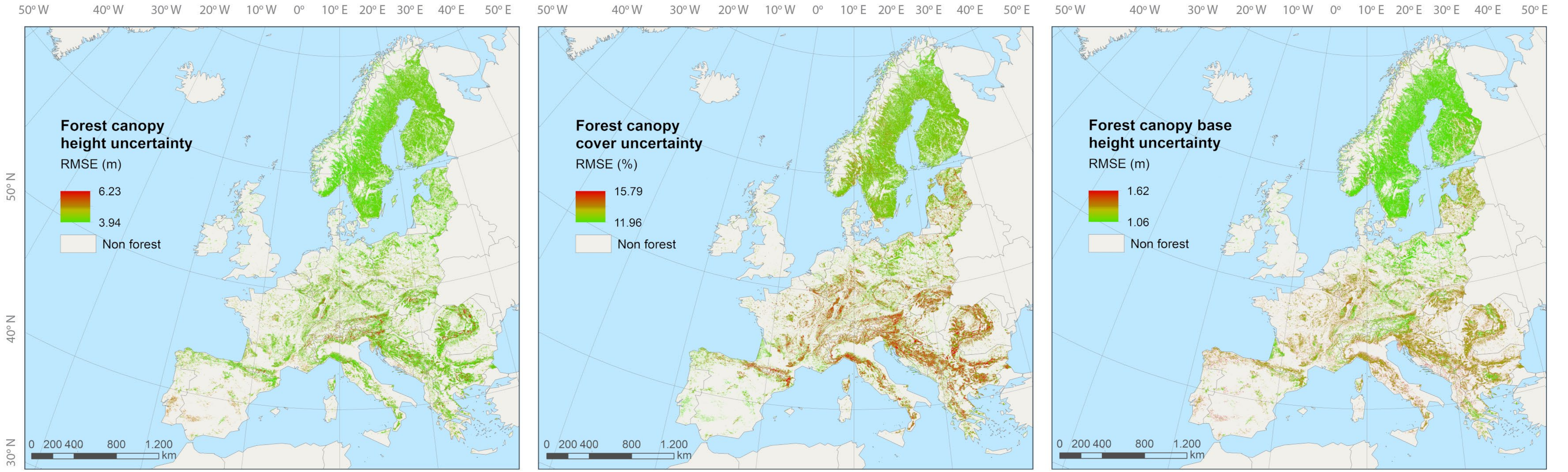
Generation of uncertainty maps

Steps

- Generation of reference data
- Calibration of GEDI models
- Extrapolation (IDW or RF)

→ Propagation of independent errors



Final set of available layers

firEUrisk

- **Open Access in public repository**
  - Aragoneses, Elena; Garcia, Mariano; Chuvieco, Emilio, 2022, "FirEUrisk_Europe_fuel_map: European fuel map at 1 km resolution", https://doi.org/10.21950/YABYCN, e-cienciaDatos
  - Elena Aragoneses; Mariano García; Emilio Chuvieco, 2024, "FirEUrisk_canopy_fuel_parameters: canopy height, canopy cover and canopy base height", https://doi.org/10.21950/KTALA8, e-cienciaDatos, V1

- **Methodology and details in scientific papers**
  - Aragoneses, E., García, M., Salis, M., Ribeiro, L. M., & Chuvieco, E. (2023). Classification and mapping of European fuels using a hierarchical, multipurpose fuel classification system. *Earth System Science Data*, *15*(3), 1287-1315.
  - Aragoneses, E., García, M., Ruiz-Benito, P., & Chuvieco, E. (2024). Mapping forest canopy fuel parameters at European scale using spaceborne LiDAR and satellite data. *Remote Sensing of Environment*, *303*, 114005.

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Wildfire Vulnerability

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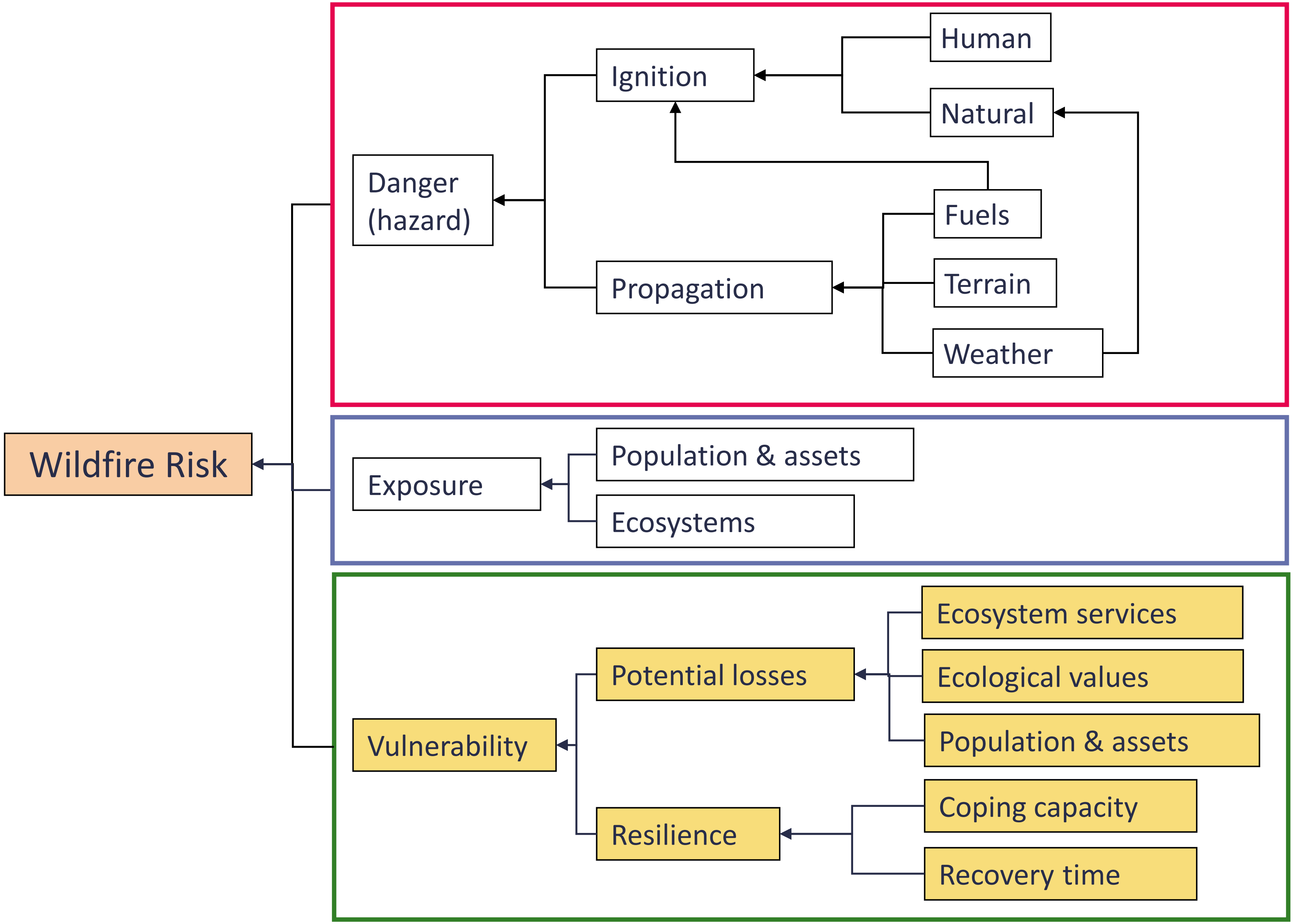

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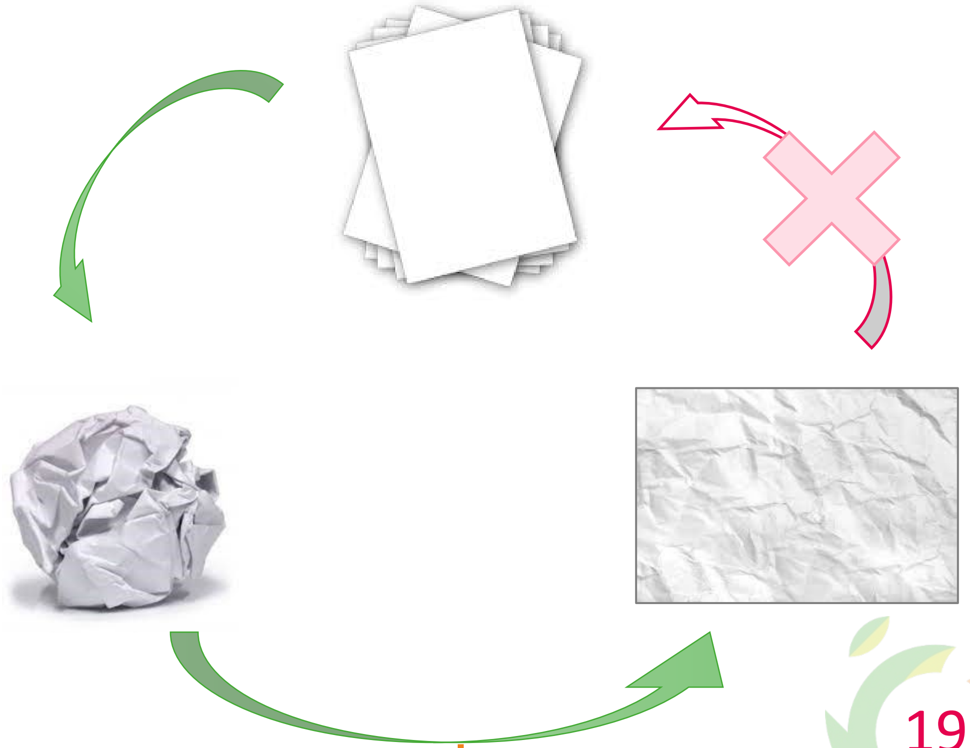
Objective

Wildfires have a significant impact on **ECOLOGICAL VULNERABILITY.**

… Vulnerability framework refers to a structured approach or model used to **UNDERSTAND AND ASSESS THE POTENTIAL LOSSES AND RESILIENCE OF COMMUNITIES AND SYSTEMS TO THE IMPACT OF NATURAL HAZARDS** such as wildfires

This study focuses on **developing a method to integrate and asses the ecological vulnerability to wildfires** at the European scale by characterising the **ecological values**, the **coping capacity** and **resilience** (**recovery**) of the ecosystems.



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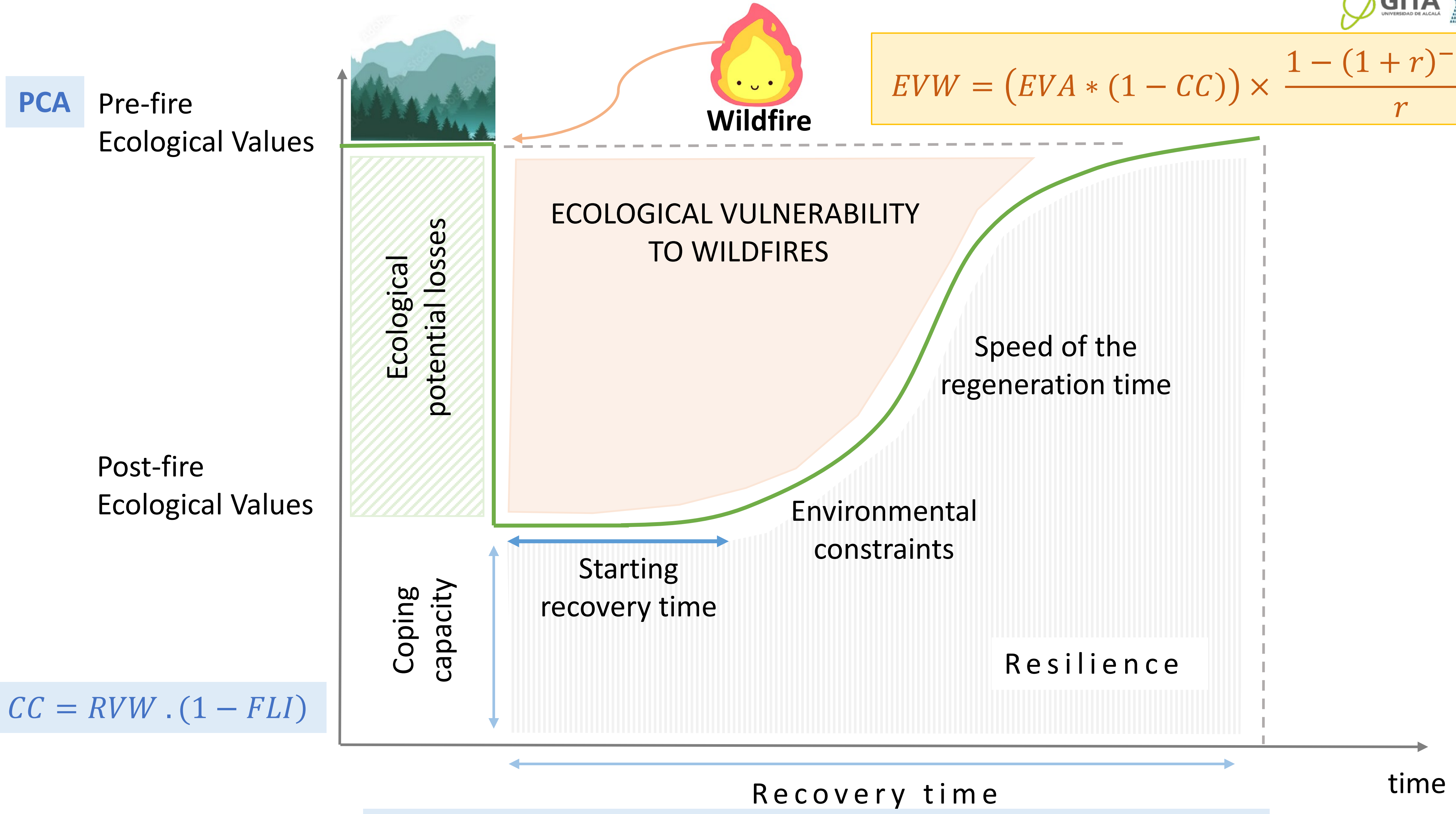
$$EVW = \left(EVA * (1 - CC)\right) \times \frac{1 - (1 + r)^{-\ln RT}}{r}$$

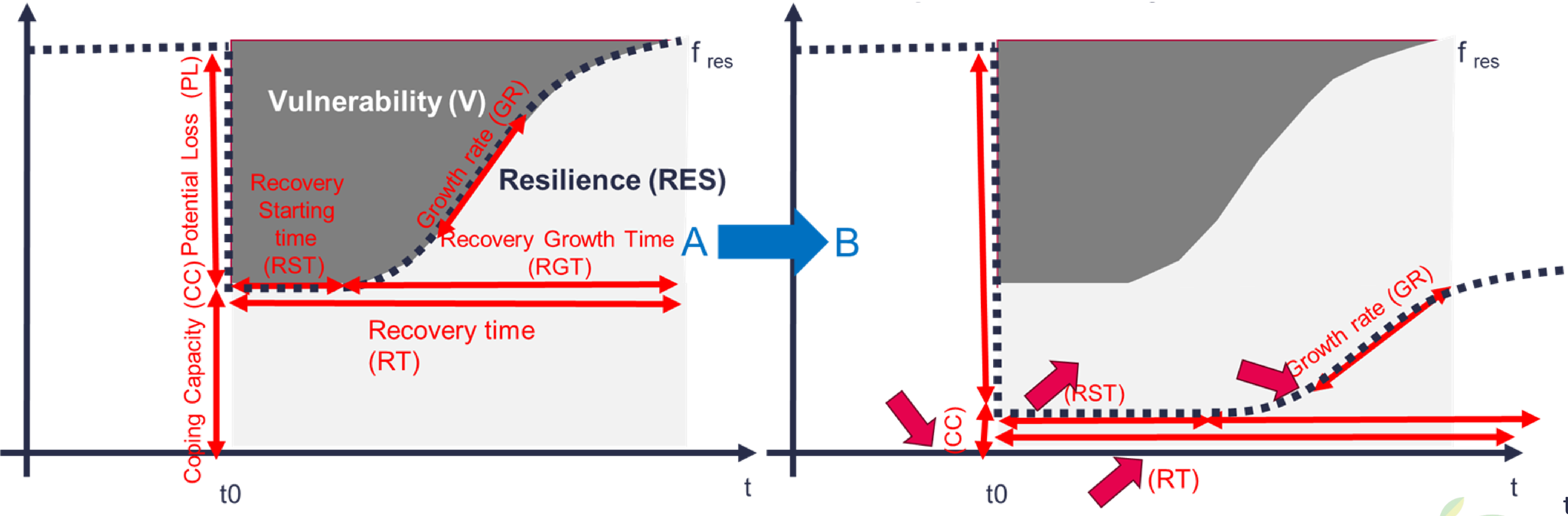


$$CC = RVW\,.\,(1 - FLI)$$

$$RT = 1\Big/\sum_{i=1}^{n} TPHMi \quad . \quad \sum_{i=1}^{n} TPHMi\ x\ (RGT.ARTm\,.ARTt + RT.ARTc)$$

General concepts & background

Potential variabilities in CC & RT and the subsequent Vulnerability



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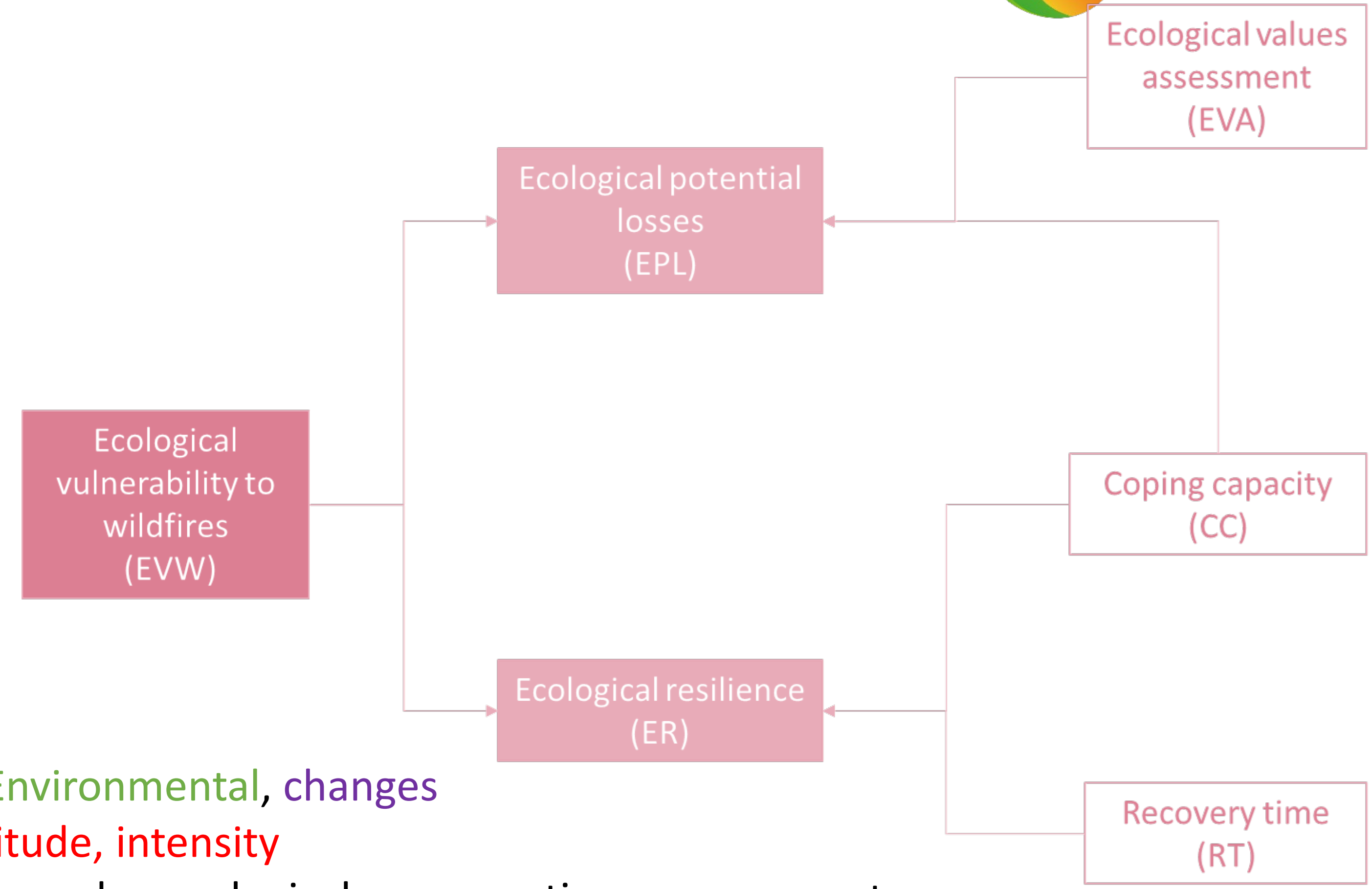
Ecological vulnerability to wildfires

fireEUrisk

Several data, several interactions…



Variables brief summary

+ 50.000 sp modelling → Maxent
10 Time series databases → Climatic, Environmental, changes
Fire Regime variables → Severity, magnitude, intensity
Conditions → Forest Management, topography, geological, conservation management

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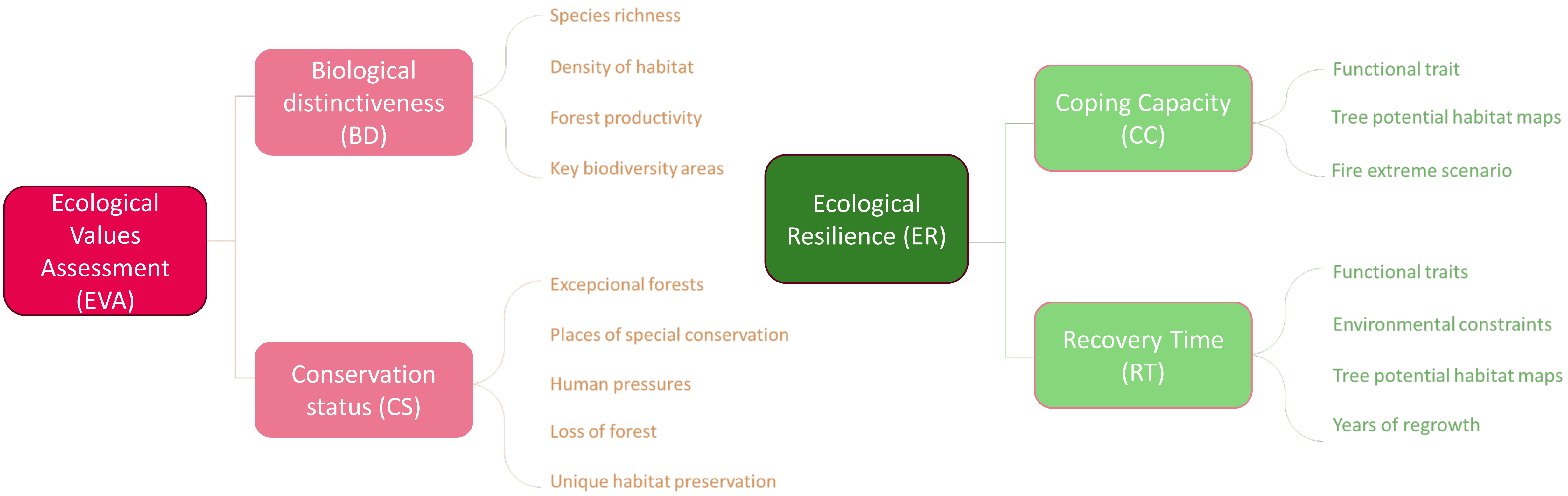
Ecological vulnerability to wildfires: components

fireEUrisk



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Ecological value map

The **Ecological Value Map (EVA)** is a tool designed to assess and represent the ecological importance of different areas by evaluating two primary factors: **Biological Distinctiveness (BD)** and **Conservation Status (CS)**.

Biological Distinctiveness (BD)

Refers to the **uniqueness** and **structural biodiversity** of an ecosystem.

Ecosystems with **high BD** provide **critical ecosystem functions** and **contribute to biodiversity conservation**.

Species Richness

Input: vectorial layers of mammals (278 sp.), birds (711sp.) reptiles (156 sp.), amphibians (96 sp.), vascular plants (20.000 sp.)
Source: UICN
Method: Raster Spatialization of occurrence based on IUCN data. Sum.
Up-to-date: Last updated 27th June 2024

Density of Habitat

Input: raster layer of biomass (g/Cm²)
Source: JRC-Forest
Method: Transformed to 1 kilometre using a weighted average approach
Up-to-date: 2010

Forest Productivity

Input: raster layer of specific leaf area (mm2 mg−1), leaf dry matter content (g g−1), leaf nitrogen content and leaf phosphorus content (mg g−1)
Source: Moreno-Martínez et al., (2018)
Method: normalising each variable, sum at the pixel level of the carbon, nitrogen and phosphorus cycle production values
Up-to-date: 2018

Key Biodiversity Areas

Input: vectorial layer
Source: Potapov et al., (2008)
Method: to 1km resolution
Up-to-date: 2020

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Ecological value map

fireurisk

KEY COMPONENT: CONSERVATION STATUS (CS)

Assesses the current condition of ecosystems and the threats they face.

Exceptional forests

- **Input:** vectorial layer of intact forest landscapes
- **Source:** Potapov et al., (2008)
- **Method:** to 1km resolution
- **Up-to-date:** 2016

Places of special conservation

- **Input:** vectorial layer of protected areas
- **Source:** UNEP, IUCN, WCMC
- **Method:** protected areas classified under IUCN categories I–IV, assigning 1 where a WDPA was located and 0 where it was not
- **Up-to-date:** 2023

Human pressures

- **Input:** vectorial layer of fragmentation of the territory due to human infraestructures, road, railways and human assessments
- **Source:** UNEP, Oak Observatory
- **Method:** Density of railways, roads and population density
- **Up-to-date:** 2021

Loss of forest

- **Input:** raster layers of vegetation loss
- **Source:** Hansen et al., (2013)
- **Method:** Sum of the pixels that contain forest losses
- **Up-to-date:** 2013

Unique habitat preservation

- **Input:** vectorial raster of species from the Red List
- **Source:** IUCN
- **Method:** category of "critically endangered", "endangered", and "vulnerable", aggregated at pixel level
- **Up-to-date:** 2020

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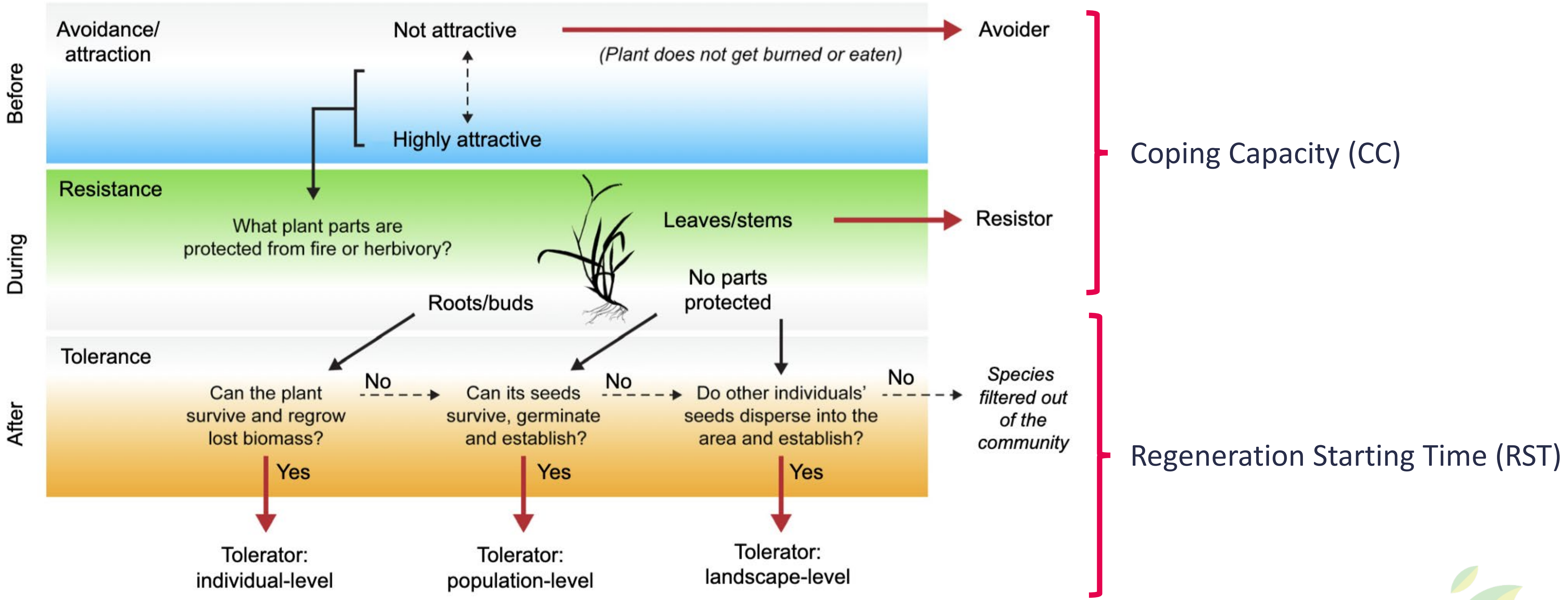
Ecological basis for post-fire resilience

Plant life-history strategies *(Archibald et al. 2019, New Phytol.)*



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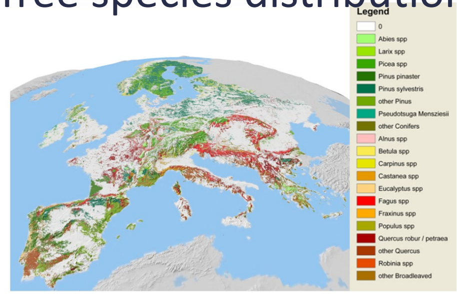
Processing Chain for EU Resilience Map

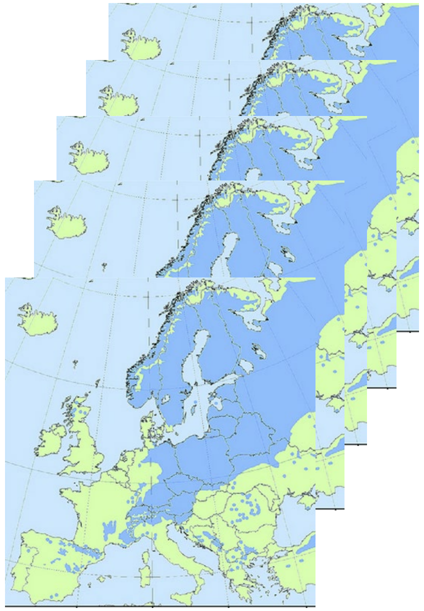
COPING CAPACITY

Tree species distribution

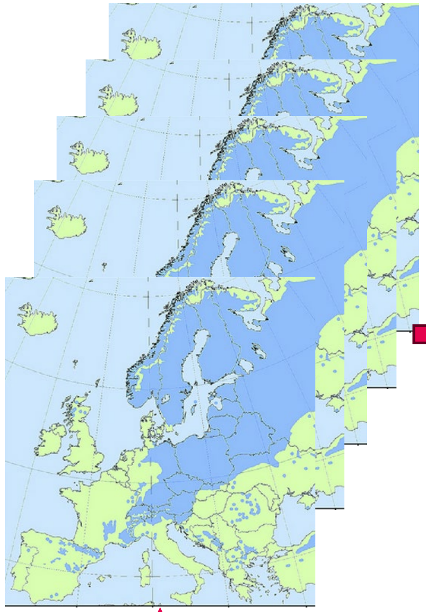


Corine Land Cover

Species presence maps

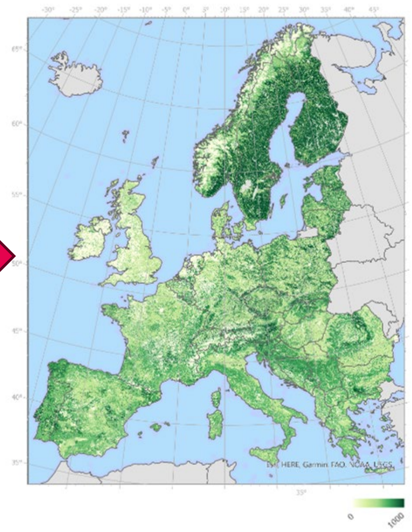


Species Resistance (0-1)



Mean

Coping Capacity Map (0-1000)



Resistance traits:

69 tree species

Bark Thichkness

Tree height

Basal Crown Height

Rescaling 0-1

Mean (species)

Fire Line Intensity Map

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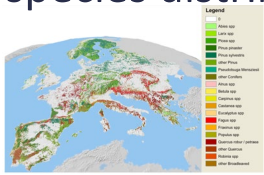
Processing Chain for EU Resilience Map

RECOVERY TIME

Tree species distribution



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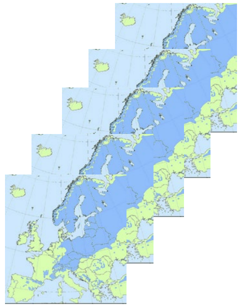


Regeneration traits (69 trees):

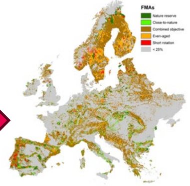
Sprouting

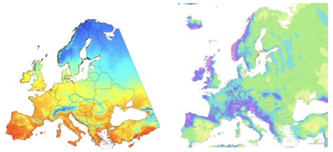
Dispersal

Recovery Starting Time (RST)

+

Environmental constraints



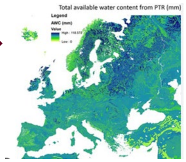


Growth traits (69 trees):

Tree height

Growth rate

Recovery Growth time (RGT)



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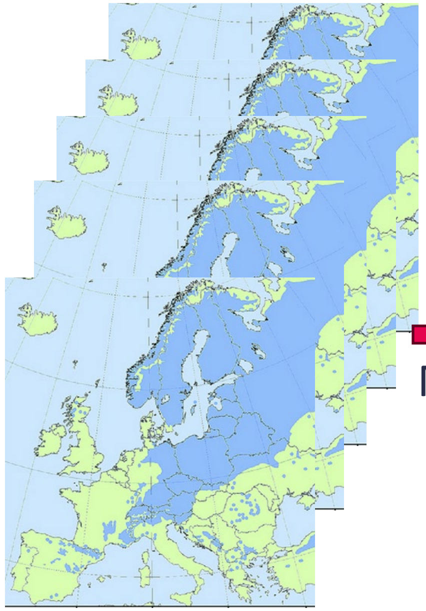
Recovery Time (RT)

Species RT (years)



Mean

Recovery Time (years)

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Product

INTEGRATION METHOD

- **First principal component → Synergies** between **BD** and **CS**
- **Ecological Value Map:** Continental level: 1km
- **Adapted to different spatial levels:** Versatile tool for various stakeholders
- **Up-to-date:** Depends of the refresh sources

AVAILABILITY

Arrogante-Funes, F., Mouillot, F., Moreira, B., Aguado, I. & Chuvieco, E. (2024). Mapping and assessment of ecological vulnerability to wildifres in Europe. Fire Ecology. In press.

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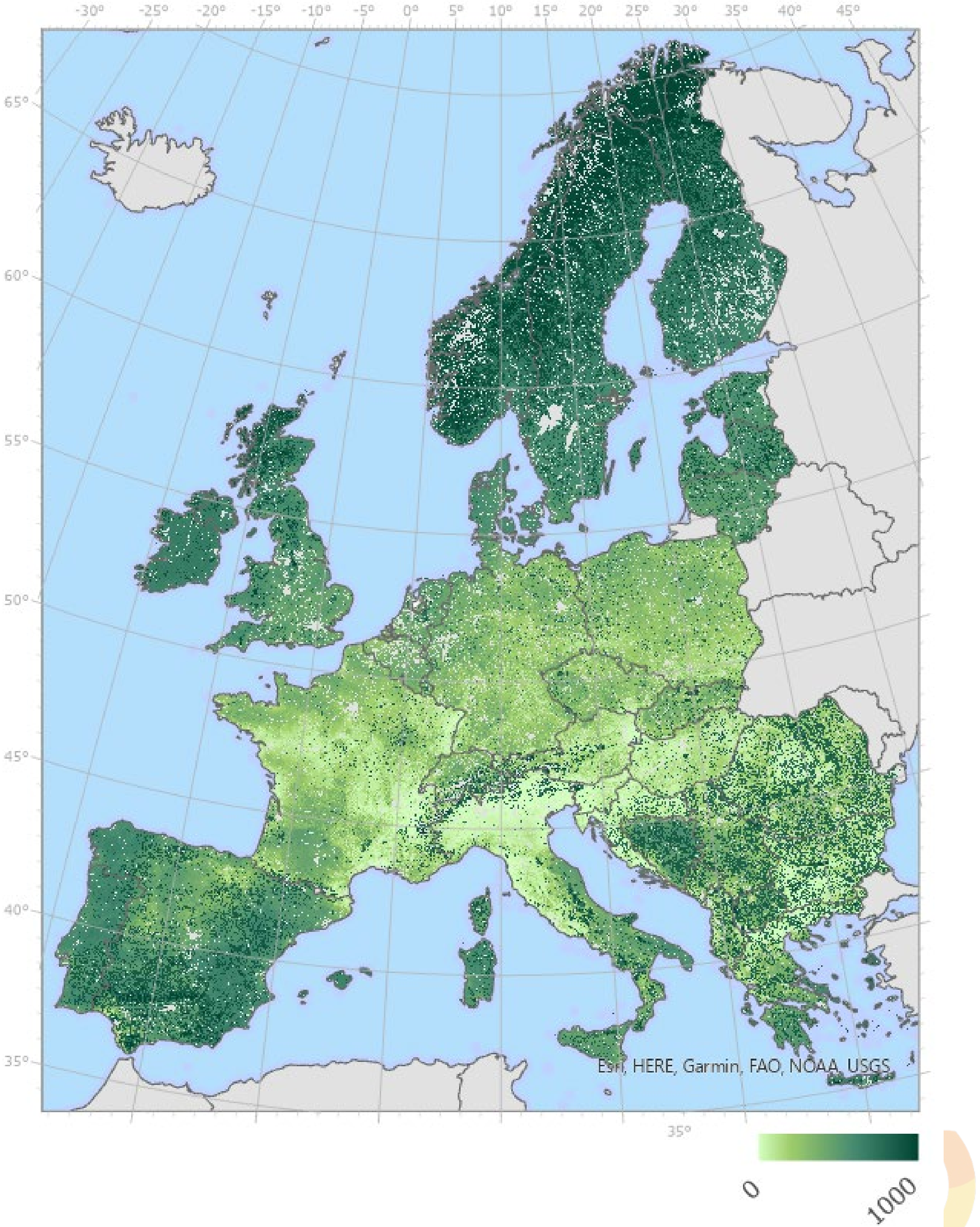

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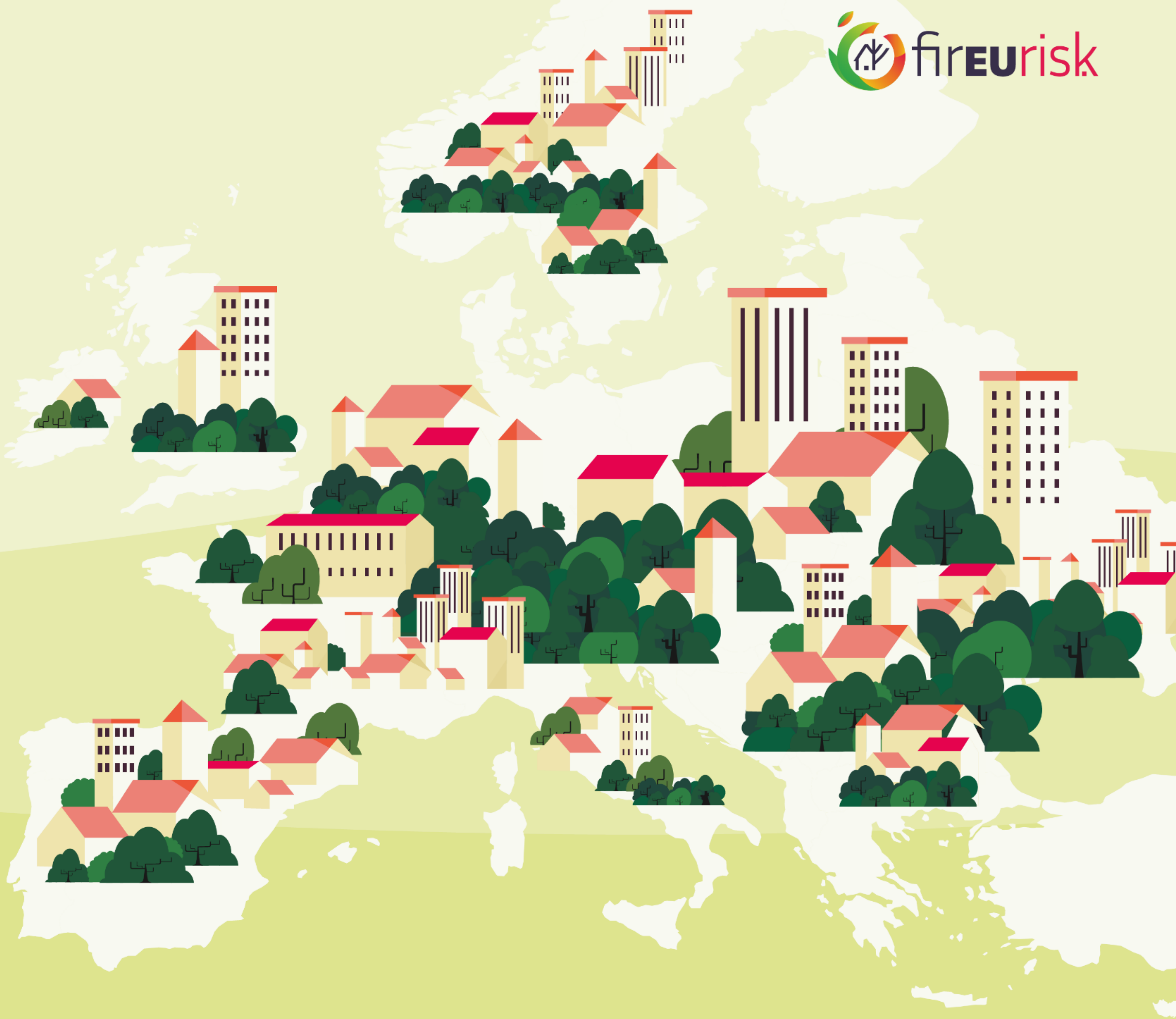

Thank you!

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