Fusing MODIS and Landsat to assess Trends in fire regime in mainland Spain from 2001-2021

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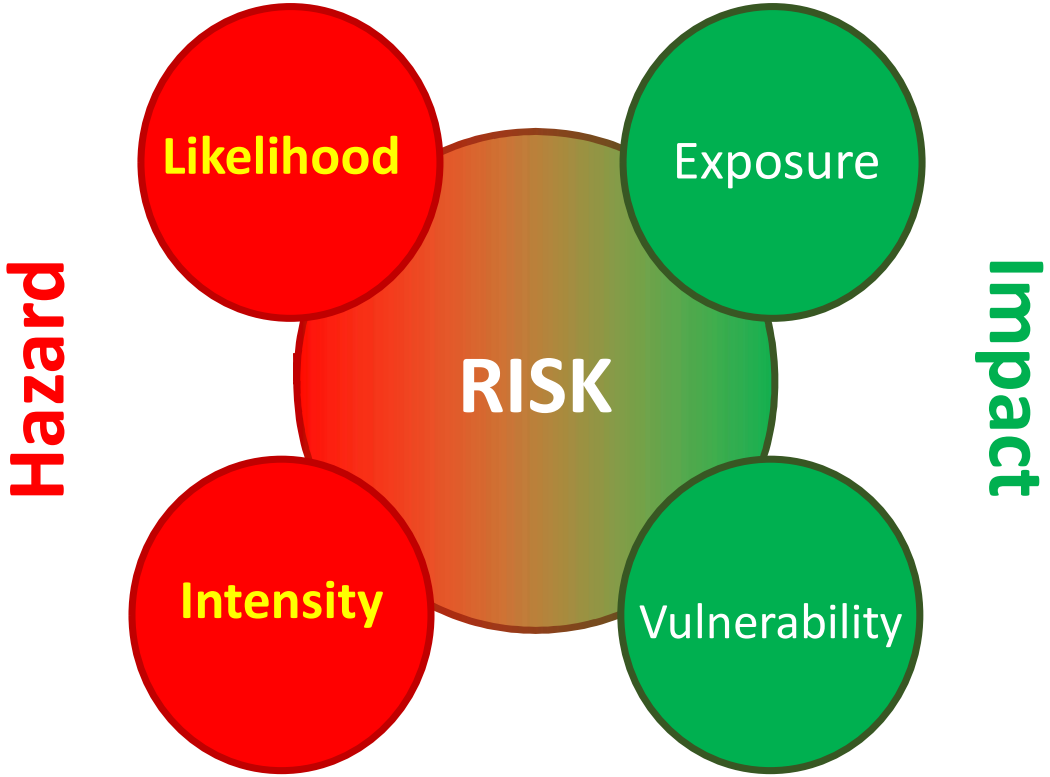
INTRODUCTION

Fire is an essential component of the dynamics of many ecosystems, and is one of the most recurrent disturbances in the Mediterranean biome. Particularly large fires, cause significant social and economic losses and significantly alter the composition and structure of forests affecting ecosystem processes. It is necessary to have available **improved fire prevention tools**.



FIRE RISK ASSESSMENT is a fundamental part of prevention, as pre-planning resources require objective tools to monitor ***when and where a fire is most likely to occur, or when it will have the most negative effects.***

FOREST FIRE RISK can be defined as the **multiplicative interaction** between the ***hazard*** (probability and intensity of a fire) and its ***impact*** (exposure and vulnerability)

OBJECTIVES

1. Estimate Fire LIKELIHOOD and INTENSITY:

Providing **reliable "burned pixels"** to accomplish fire mapping at a large scale (mainland Spain) using Landsat images

2. **To carry out different classification processes to separate unburned-burned areas and the different severity levels of burning**

2. **To assess the temporal trends of different fire regime properties** fusing monthly burned areas from MODIS (MCD64A1) and Landsat for mainland Spain from 2001 to 2021

MATERIAL

Monthly Burnt Area MODIS product MCD64A1 v.6 (2001-2021)

https://lpdaac.usgs.gov/products/mcd64a1v006/

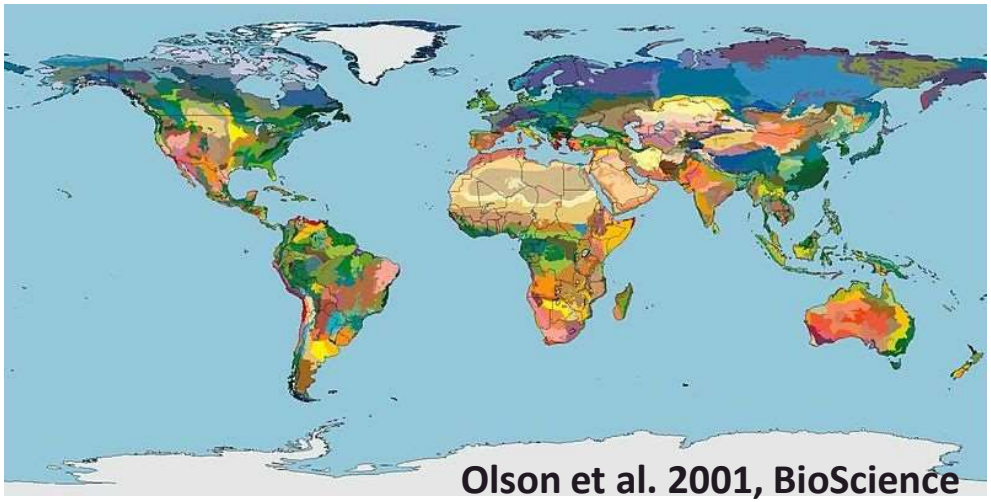
- The Terra and Aqua combined MCD64A1 Version 6 Burned Area data product is a monthly, global gridded 500 meter (m) product containing per-pixel burned-area and quality information.

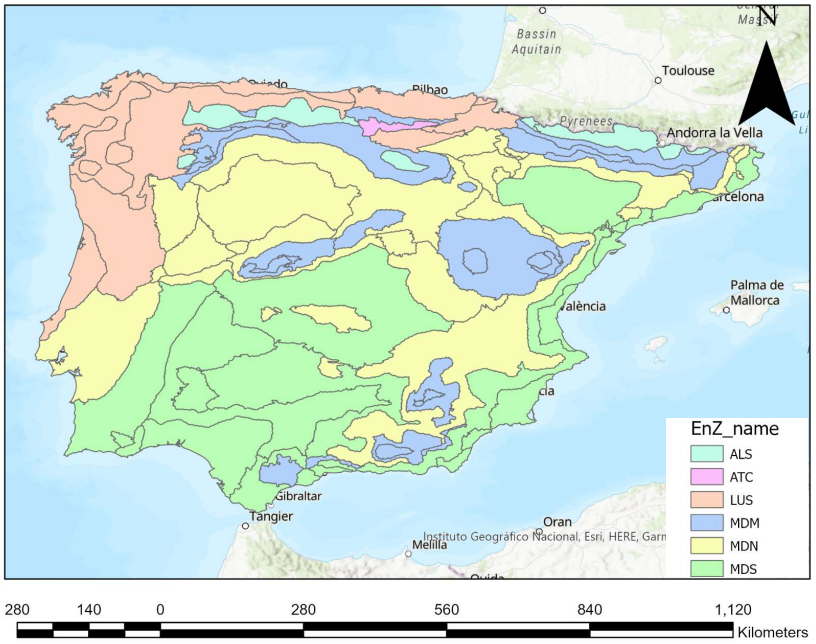
- The MCD64A1 burned-area mapping approach employs 500 m Moderate Resolution Imaging Spectroradiometer (MODIS) Surface Reflectance imagery (burn sensitive Vegetation Index (VI)) coupled with 1 kilometer (km) MODIS active fire observations.

- The data layers provided in the MCD64A1 product include **Burn Date, Burn Data Uncertainty, Quality Assurance**, along with First Day and Last Day of reliable change detection of the year.

MATERIAL

Terrestrial Ecoregions of the World



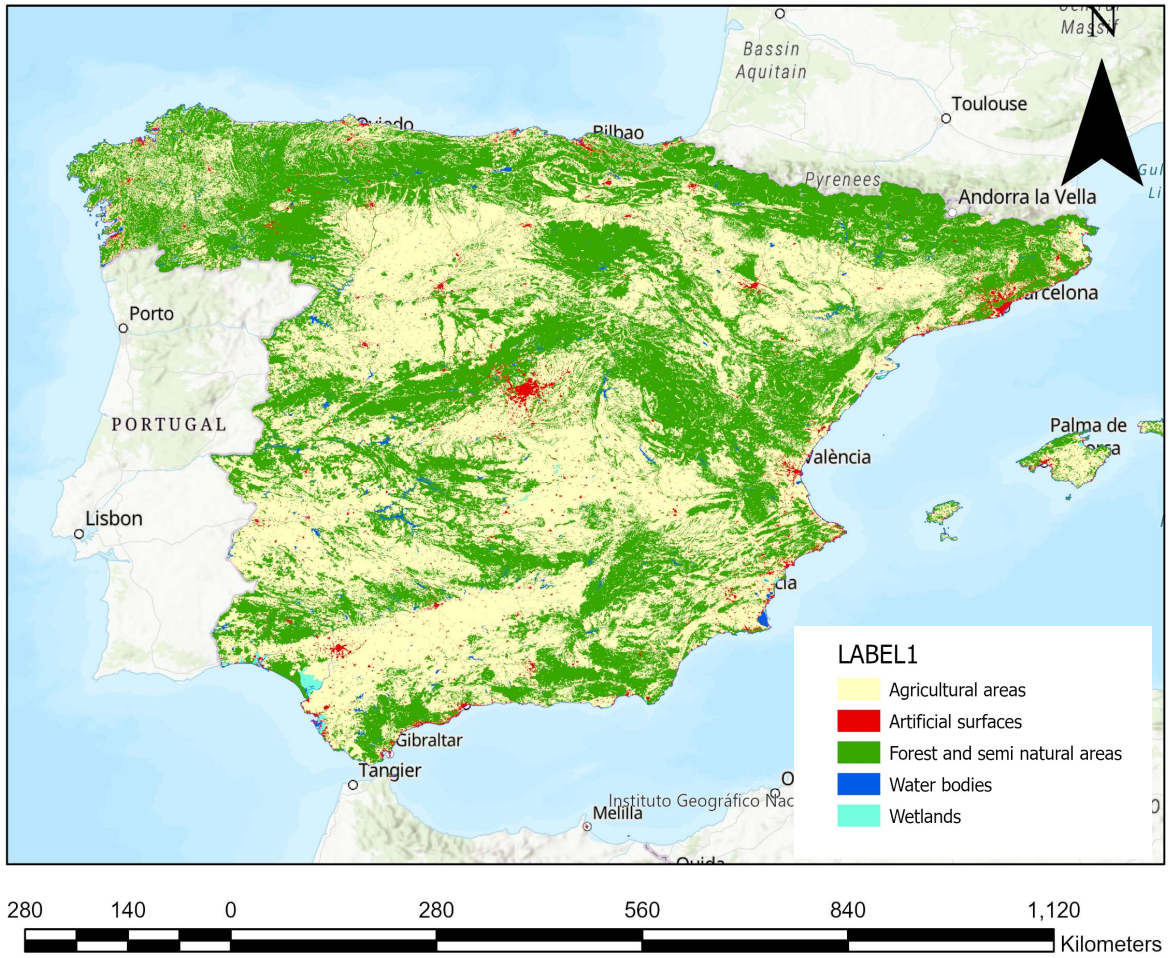


- This map depicts the 825 terrestrial ecoregions of the globe. Ecoregions are relatively large units of land containing distinct assemblages of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change.

- Ecoregions are nested within two higher-order classifications: biomes (14) and biogeographic realms (8). Together, these nested classification levels provide a framework for comparison among units and the identification of representative habitats and species assemblages.

MATERIAL

CORINE LAND USE- LAND COVER MAPS



https://land.copernicus.eu/pan-european/corine-land-cover

Corine Land Cover (CLC) is a European project that delimits and describes land cover for the whole of Europe. It started in 1985, generating the first product in 1990. Subsequent updates have been made in 2000, 2006, 2012 and 2018.

The reference scale is 1:100,000 and the minimum mapping unit is 25 ha. The legend addresses the description of both land cover and land use, using a hierarchical nomenclature at 3 levels of information with 44 different classes

METHODOLOGY

1. Obtaining monthly burned areas from MCD64A1 v6 MODIS

MODIS (MCD64A1)
Monthly Burnt Area (2001-2021)

MODIStsp: A Tool for Automatic Preprocessing of MODIS Time Series

1.1 Temporal series (.Rmd)
12 bands (months)
(Julian day and uncertainty)

1.2 Reading Rmd.
Raster conversion

2. Extract only pixels with the **date**

3. Convert Julian day into **calendar day**
3.1. Join date + uncertainty

4. Convert burned pixels into **"fire events"** (clump)

5. Convert raster to **polygons**

5. 1. Join all months by year

6. Annual intersection between "fire events" and:
- Prefire vegetation: (CORINE 00-06-12-18)
- Ecoregions (Olson)

Fires until 2006 (CORINE 00)
Fires 2007-2012 (CORINE 06)
Fires 2013-2018 (CORINE 12)
Fires from 2019 (CORINE 18)

7. Fire history properties
input: all fires joined
output: annual fires with its own fire history

Years of burning
Recurrence (times burned)
Fire Interval (years between consecutive fires)
Time since fire (years)

METHODOLOGY

2. Obtaining Landsat-derived spectral vegetation indices over MODIS fires

1. GEE (Google Earth Engine)
Annual summer Landsat composites
(1st June to 30th September)
Prefire images: max NBR
Postfire images: min NBR

(Over MODIS burned pixels)

Pre- and Post-fire indices:
NDVI and NBR

$$NDVI = \frac{\rho_R - \rho_{IRC}}{\rho_R + \rho_{IRC}} \qquad NBR = \frac{\rho_{IR} - \rho_{SWIR}}{\rho_{IR} + \rho_{SWIR}}$$

Severity indices:
dNBR, RBR and RdNBR

$$dNBR = \left((NBR_{prefire} - NBR_{postfire}) * 1000\right) - dNBR_{offset}$$

$$RBR = \frac{\Delta NBR}{NBR_{pre} + 1001} \qquad RdNBR = \frac{dNBR}{|(NBR_{prefire})|^{0.5}}$$

Image date
Epoch format (01/01/1970)

2. Vectorize Landsat pixels over MODIS fires (points 30 m)

3. Extract Landsat values over MODIS fires

4. Filter Landsat values

Composite issues: Postfire Landsat date ≥ Postfire date (MODIS)
Prefire Landsat date < Postfire Landsat date
Spatial issues: Landsat pixels within fire events
Spectral issues: NBR pre > NBR post

5. Convert Epoch date into Julian day and calendar date

METHODOLOGY

3. Spectral separability of MODIS burned areas based on Landsat imagery

1. **Pre- and post-fire Landsat information** (**NDVI & NBR**) together in the same columns

ID_pixel	fire_ID	NDVI_pre	NDVI_post
1	1	0.35	-0.23
2	1	0.37	-0.28
3	1	0.42	-0.31
4	1	0.38	-0.11
5	1	0.45	0.01
....	....	....	....
n	n	n	n

ID_pixel	fire_ID	NDVI	status
1	1	0.35	prefire
2	1	0.37	prefire
3	1	0.42	prefire
4	1	0.38	prefire
5	1	0.45	prefire
....	....	....	prefire
1	1	-0.23	postfire
2	1	-0.28	postfire
3	1	-0.31	postfire
4	1	-0.11	postfire
5	1	0.01	postfire
....	....	....	postfire
n	n	n	postfire

2. **Scaling variables** (Z-score)

3. Landsat Classification (Unburned-Burned)

Classification algorithms

- K-means
- CLARA (k-medoids)
- Fuzzy: soft k-means (probabilities)

4. ANOVA post hoc

Kruskal-Wallis Dunn test

5. Filter classification results

1. Each pixel is classified in a class with similar spectral behavior in all classifiers.
2. The probability of class membership (Fuzzy classifier) being ≥ 60 %.

METHODOLOGY

4. Spectral separability of Severity levels based on Landsat imagery

1. Postfire Landsat information (dNBR, RBR & RdNBR)

ID_pixel	fire_ID	dNBR	RBR	RdNBR
1	1	300	255	2500
2	1	350	287	3209
3	1	421	356	3686
4	1	566	477	5089
5	1	740	650	7055
....	....	....	....	....
n	n	n	n	n

2. **Scaling variables** (Z-score)

3. Landsat Classification (Low-Moderate-High)

Classification algorithms

- K-means
- CLARA (k-medoids)
- Fuzzy: soft k-means (probabilities)

4. ANOVA post hoc

Kruskal-Wallis Dunn test

5. Filter classification

1. Each pixel is classified in a class with similar spectral behavior in all classifiers.
2. The probability of class membership (Fuzzy classifier) being ≥ 60 %.

METHODOLOGY

5. Trends analysis: Fire regime properties

Annual aggregated fire metrics
Annual fire number
Monthly fire number (June-September)
Annual burned area
Monthly burned area (June-September)
Percentage of burned area by vegetation types
Percentage of burned area by ecoregions
Percentage of burned area by vegetation types in each ecoregion
Gini Index of annual fire size
Gini Index of monthly fire size
Percentiles of annual fire size (P5, P50, P90, P95)
Percentiles of monthly fire size (P5, P50, P90, P95)
Median of annual RBR
Median annual RBR by vegetation types
Median annual RBR by ecoregions
Median annual RBR by vegetation types in each ecoregion
Percentiles of annual RBR (P5, P50, P90, P95)
Percentiles of annual RBR by vegetation types (P5, P50, P90, P95)
Percentiles of annual RBR by ecoregions (P5, P50, P90, P95)
Percentiles of annual RBR by vegetation types in each ecoregion (P5, P50, P90, P95)
Percentage of burned area by severity classes (RBR low, moderate, high)
Percentage of burned area by severity classes in each vegetation type
Percentage of burned area by severity classes in each ecoregion
Percentage of burned area by severity classes in each vegetation type and ecoregion

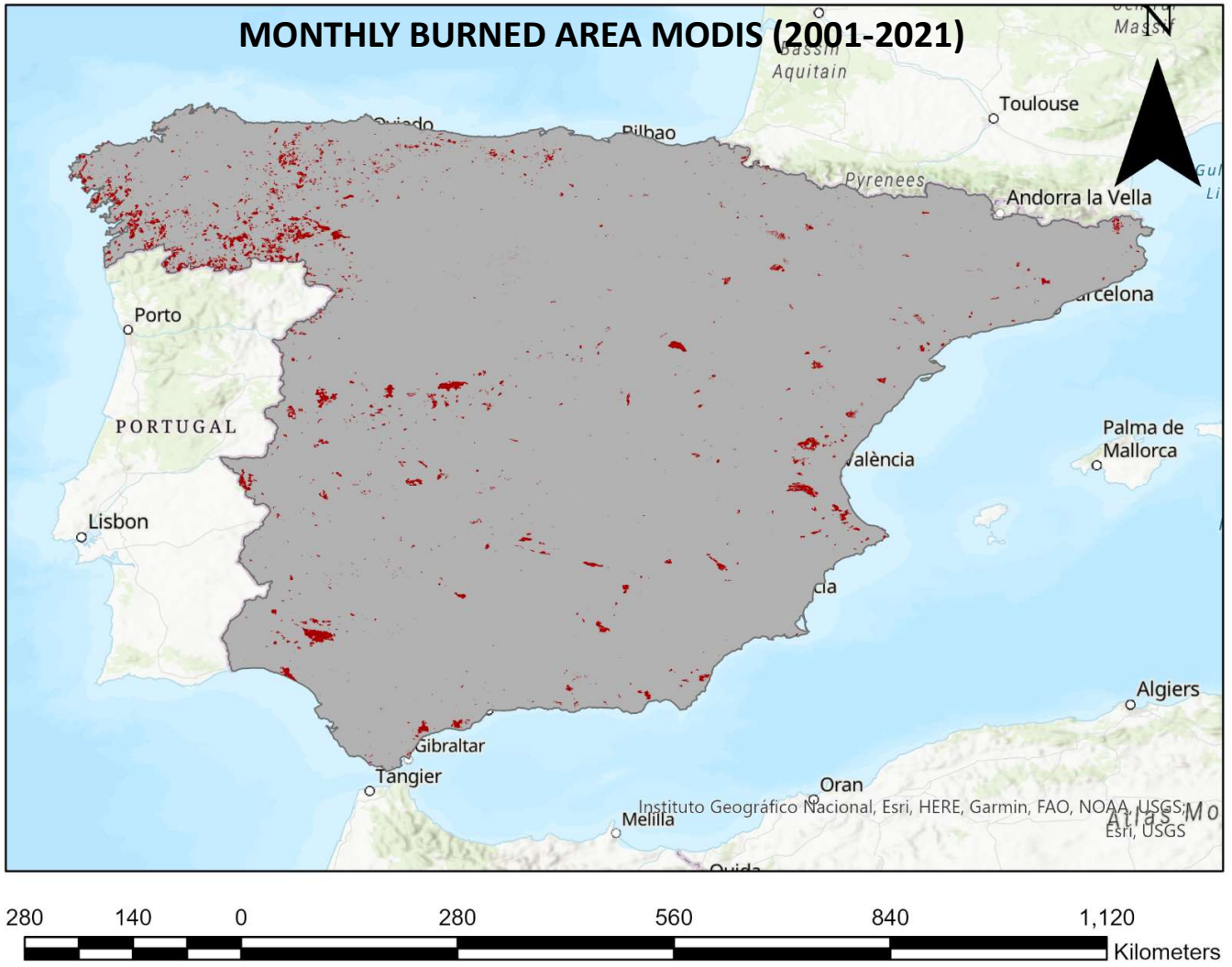
1. **Annual aggregation** of variables

2. **Fill gaps** (10-25 %)

3. **Trend analysis**
(Modified Mann Kendall test)

RESULTS

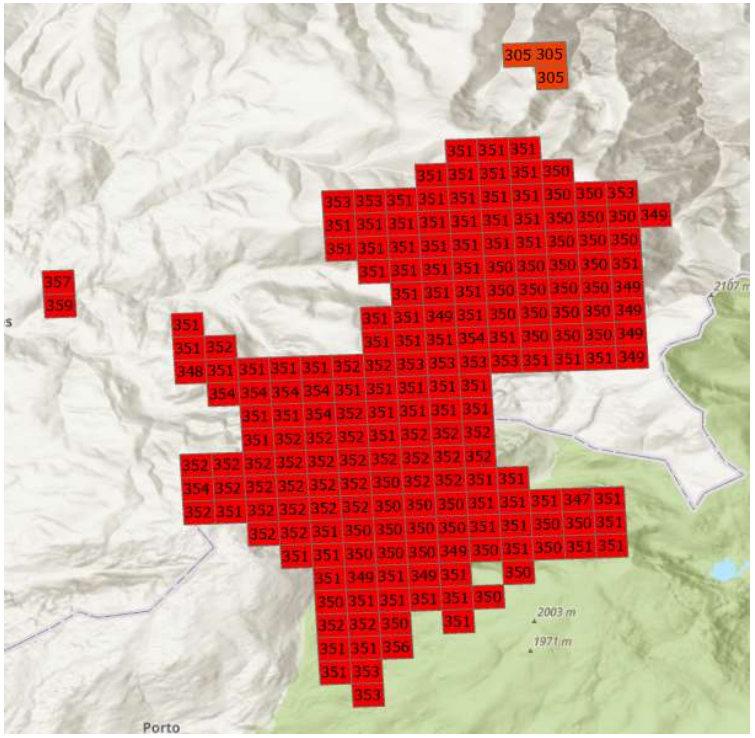
1. Obtaining monthly burned areas from MCD64A1 v6 MODIS



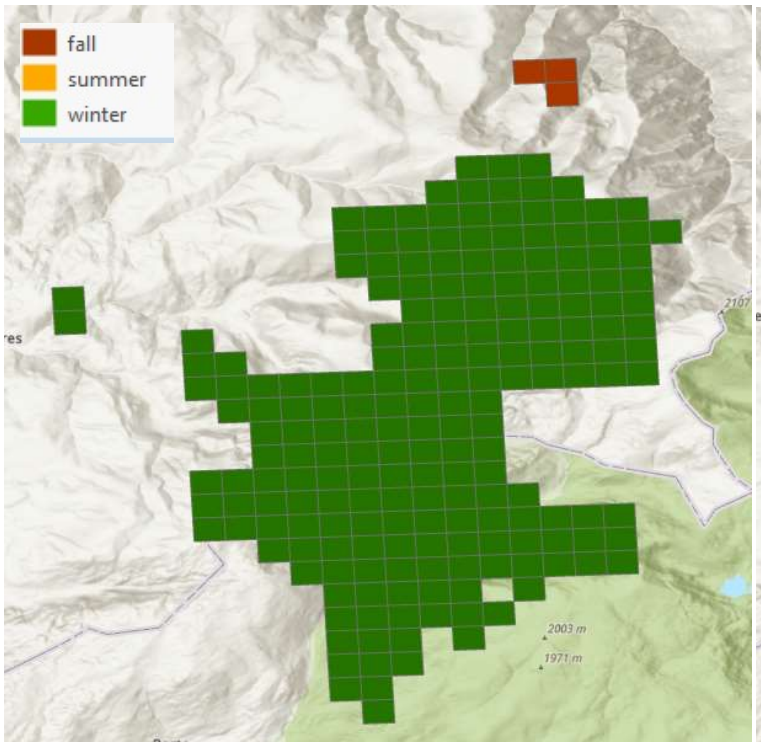
RESULTS

1. Obtaining monthly burned areas from MCD64A1 v6 MODIS

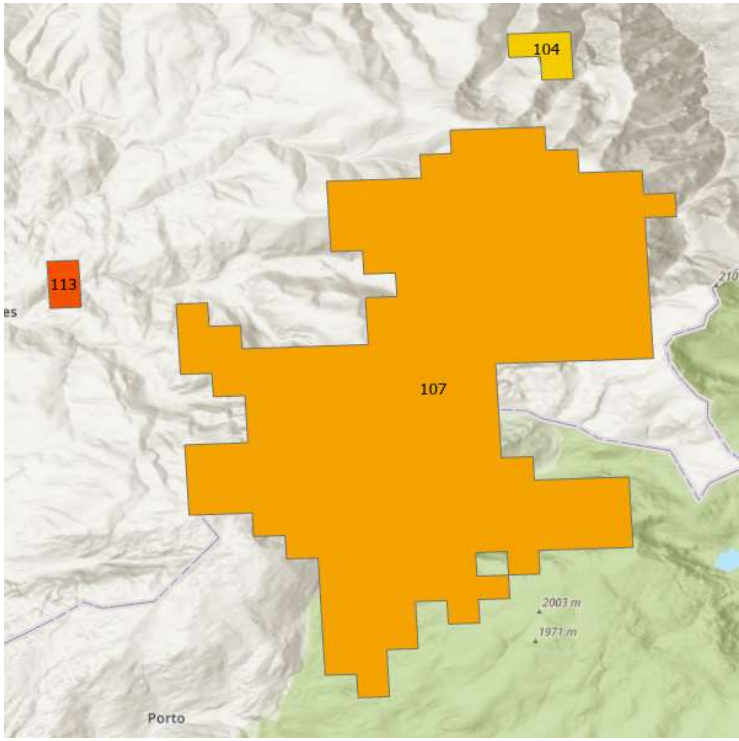
JULIAN DATE



CALENDAR DATE + SEASON



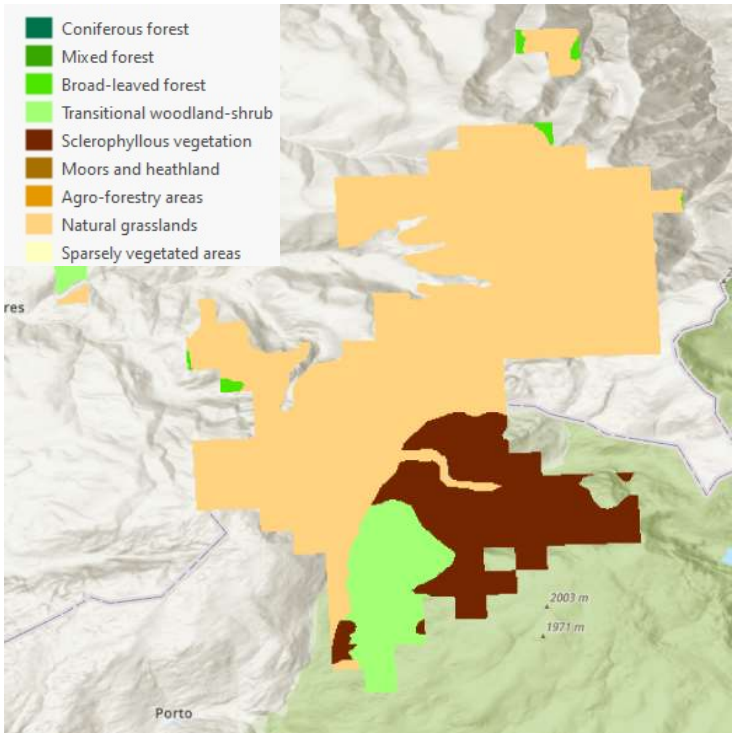
FIRE EVENTS (CLUMP)



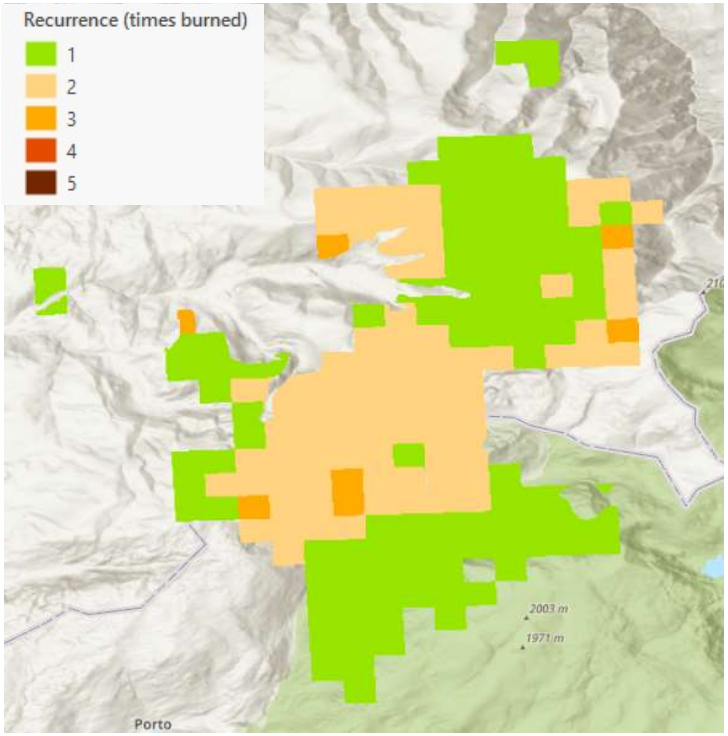
RESULTS

1. Obtaining monthly burned areas from MCD64A1 v6 MODIS

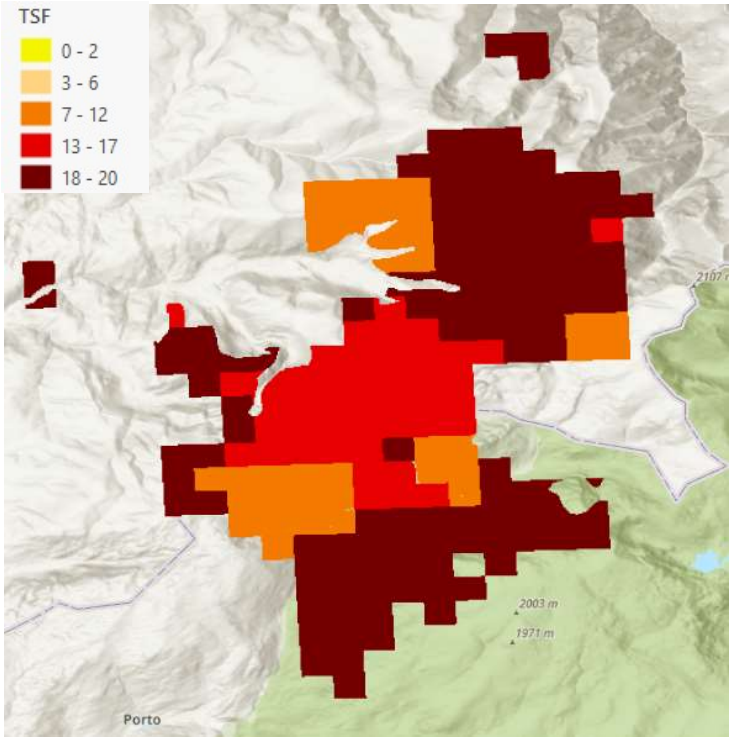
PREFIRE VEGETATION (CORINE)



FIRE RECURRENCE



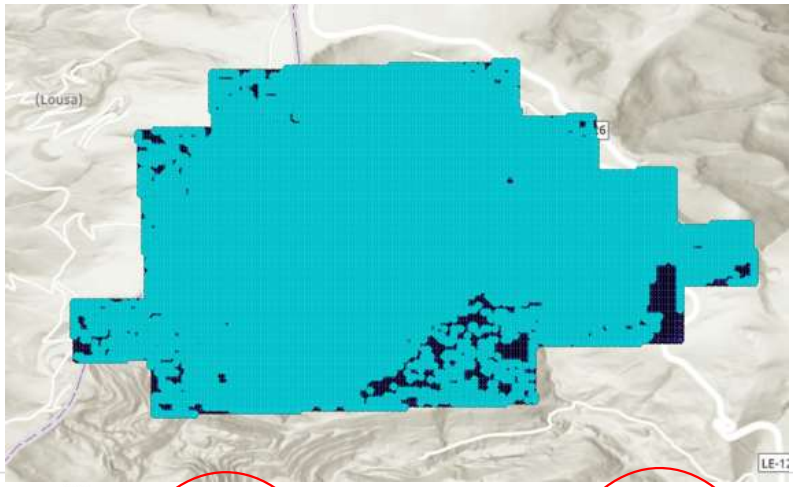
TIME SINCE LAST FIRE (YEARS)

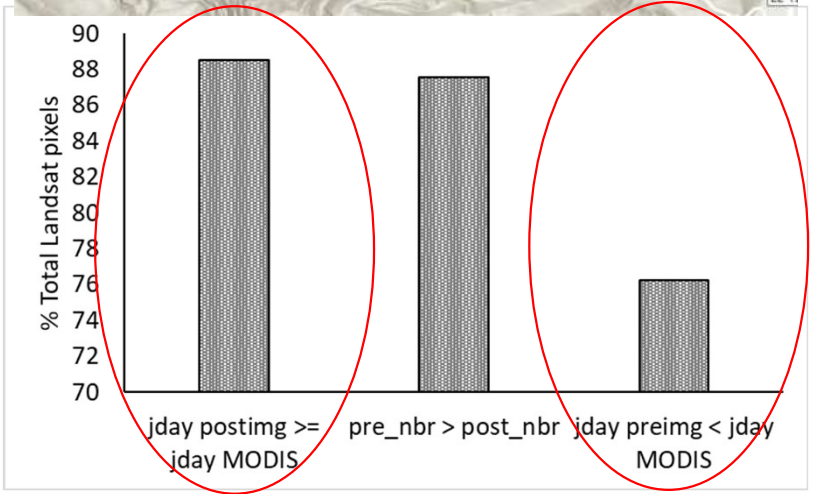


RESULTS

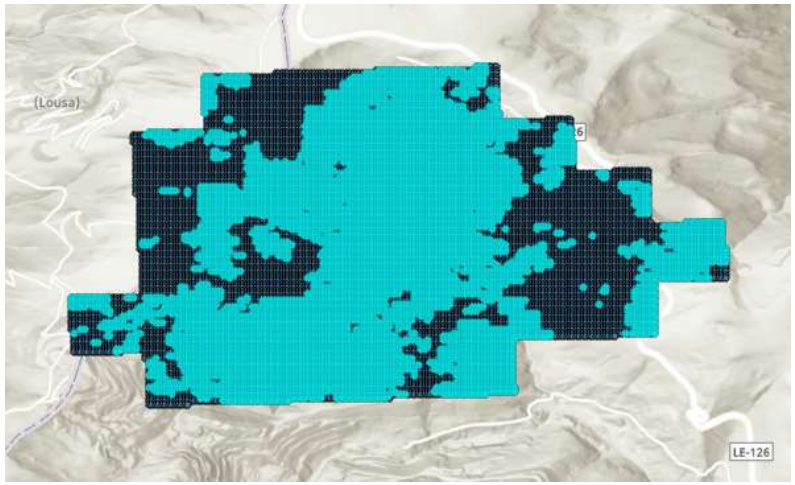
2. Obtaining Landsat-derived spectral vegetation indices over MODIS fires

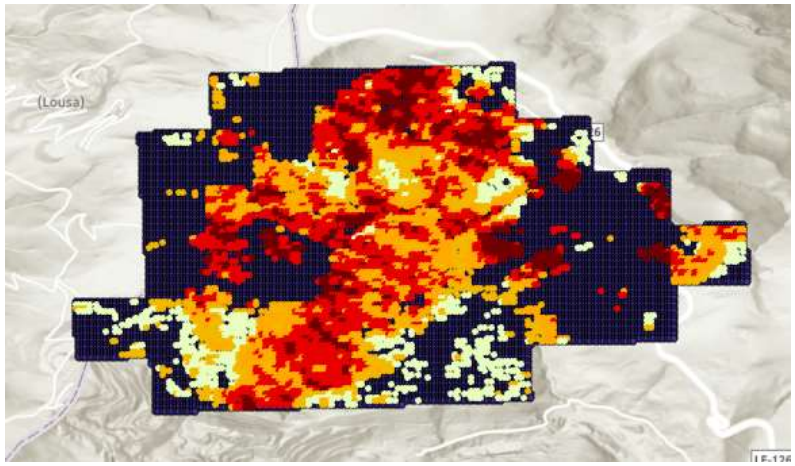
Postfire Julian day (LANDSAT) ≥ MODIS date





Prefire Julian day < Postfire Julian day (LANDSAT)

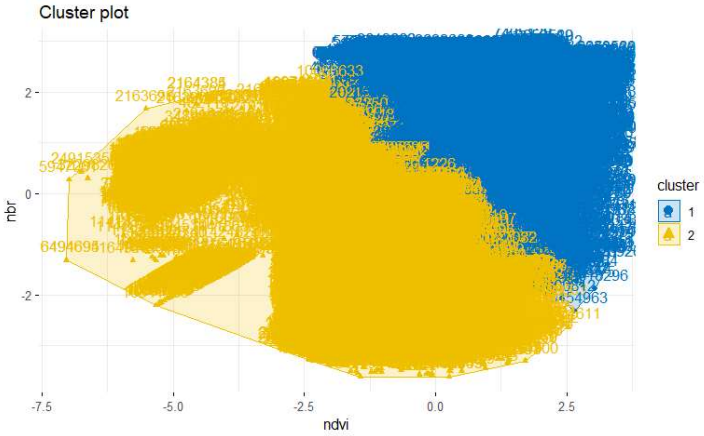




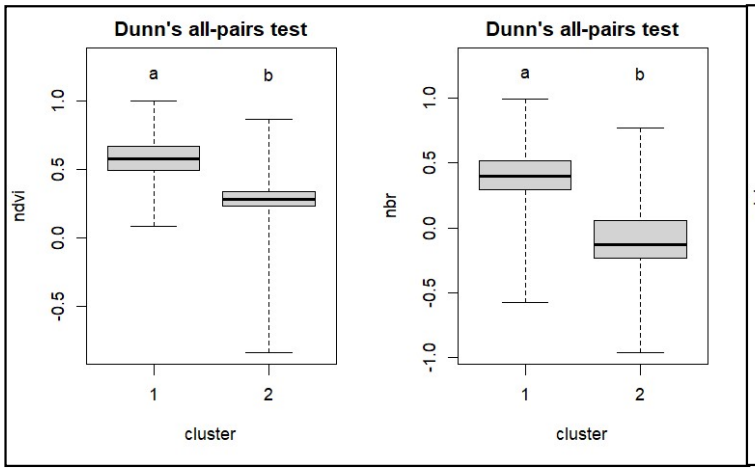
RESULTS

3. Spectral separability of MODIS burned areas based on Landsat imagery

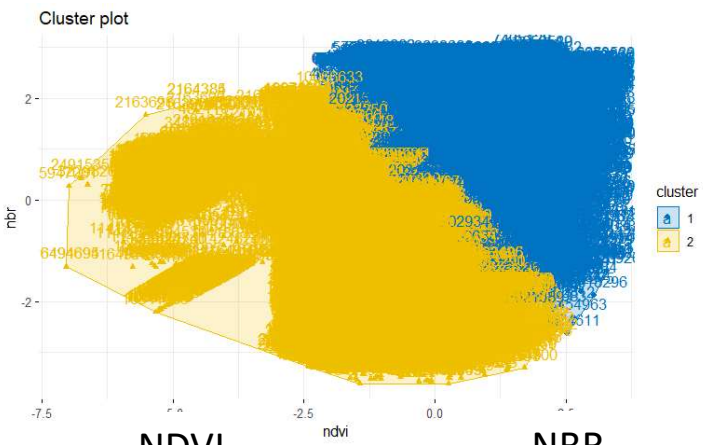
K-MEANS



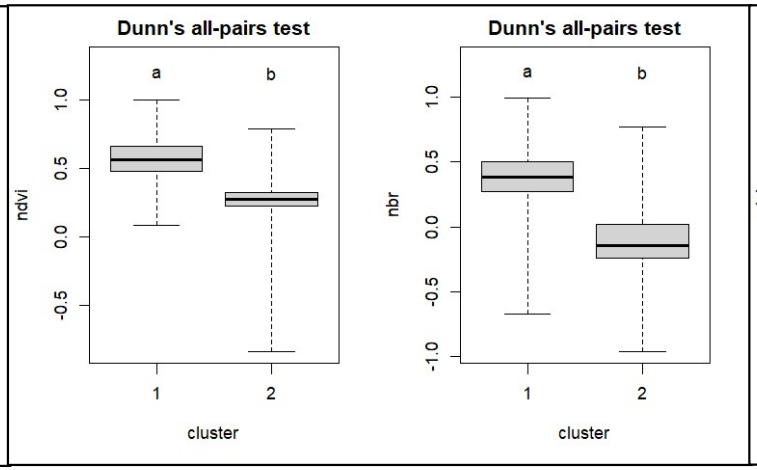
NDVI NBR



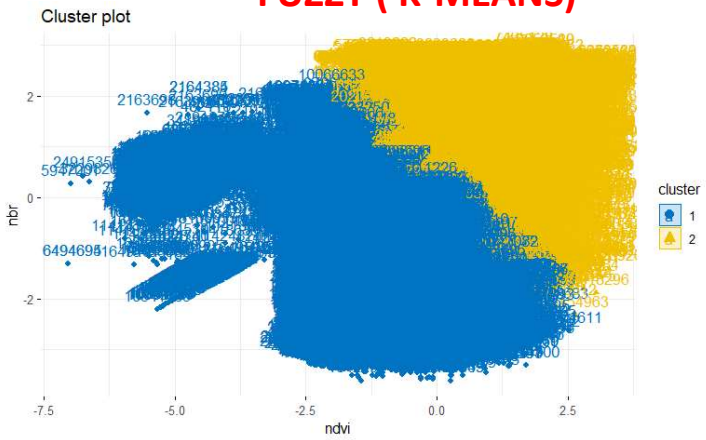
CLARA (K-MEDIODS)



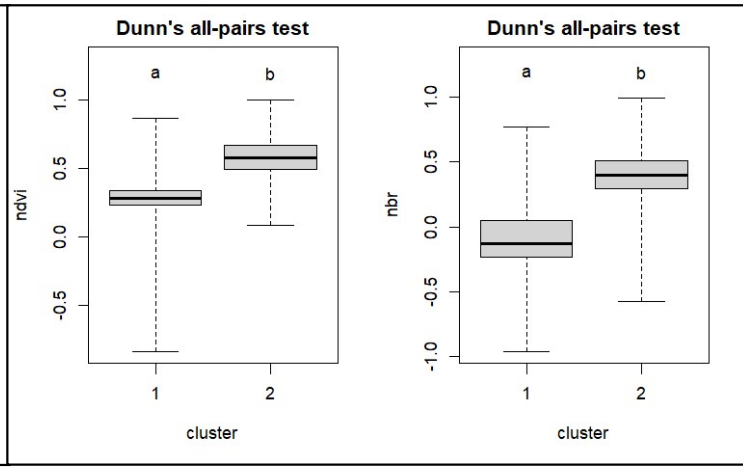
NDVI NBR



FUZZY (K-MEANS)

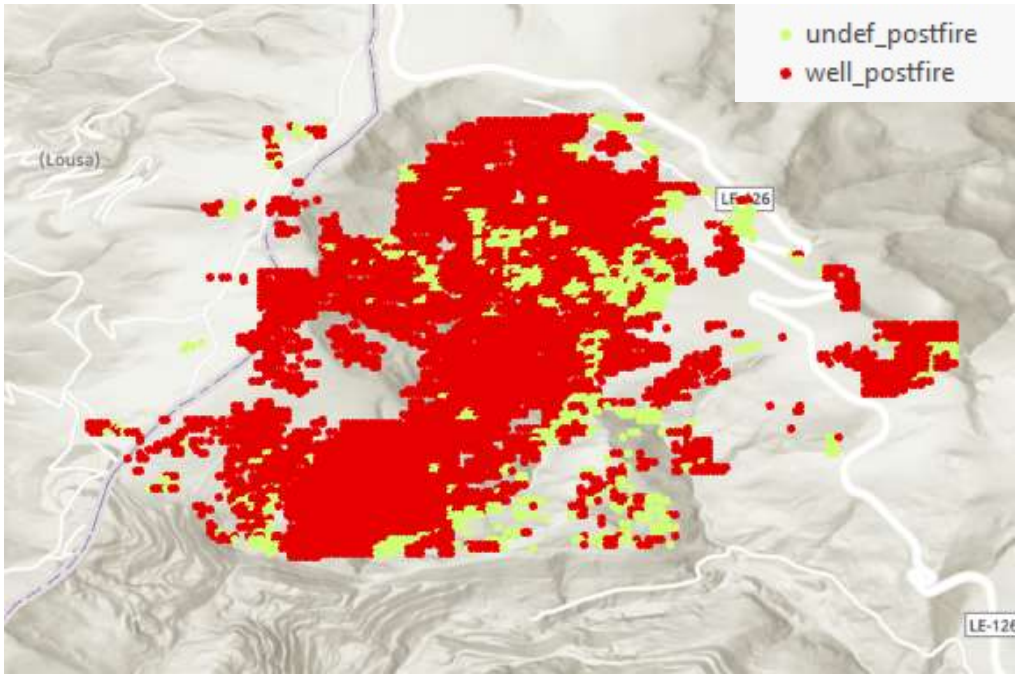


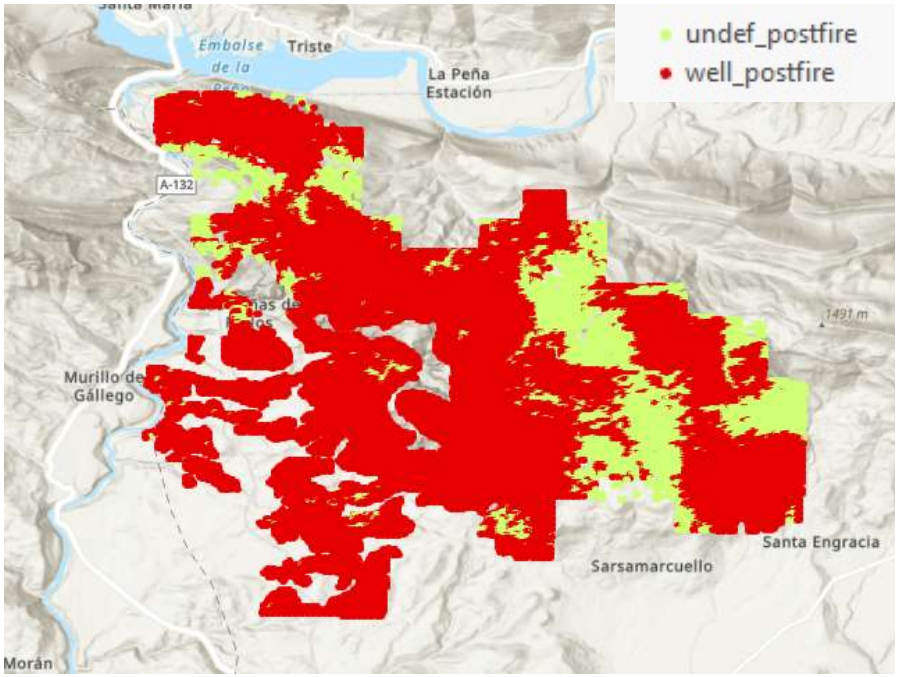
NDVI NBR



RESULTS

3. Spectral separability of MODIS burned areas based on Landsat imagery

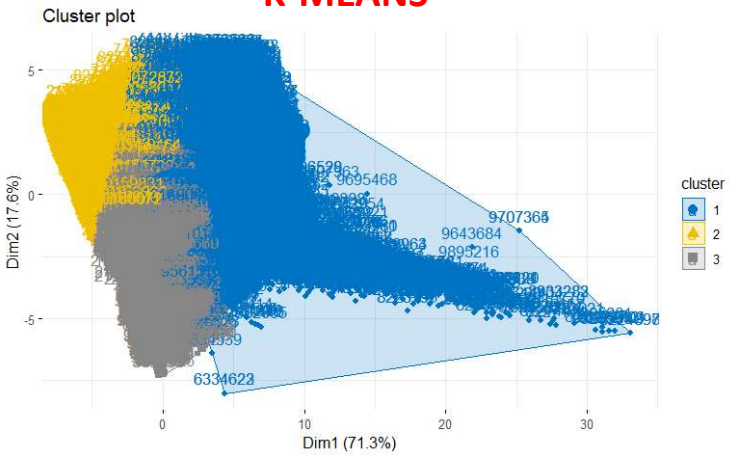


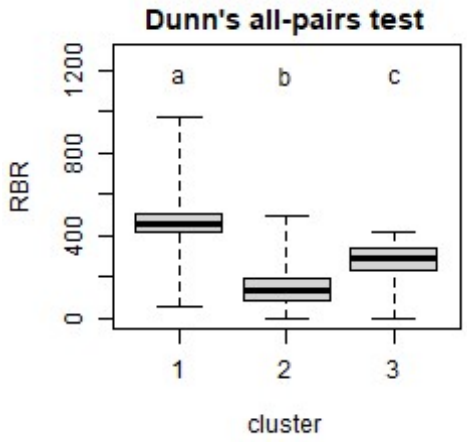


RESULTS

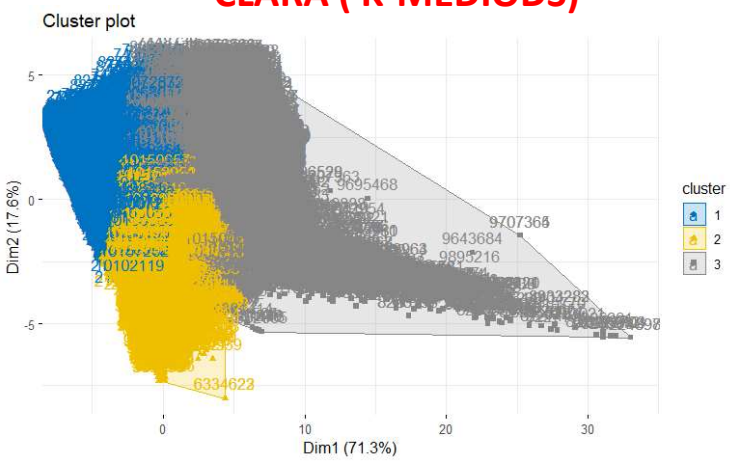
4. Spectral separability of Severity levels based on Landsat imagery

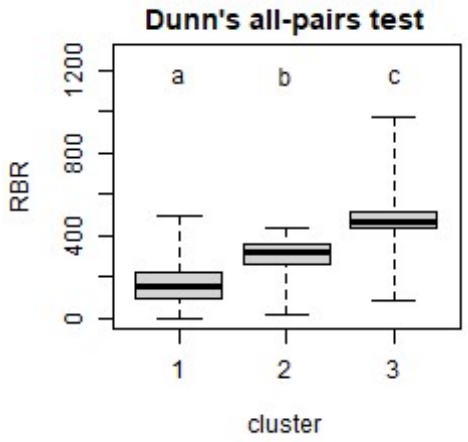
K-MEANS



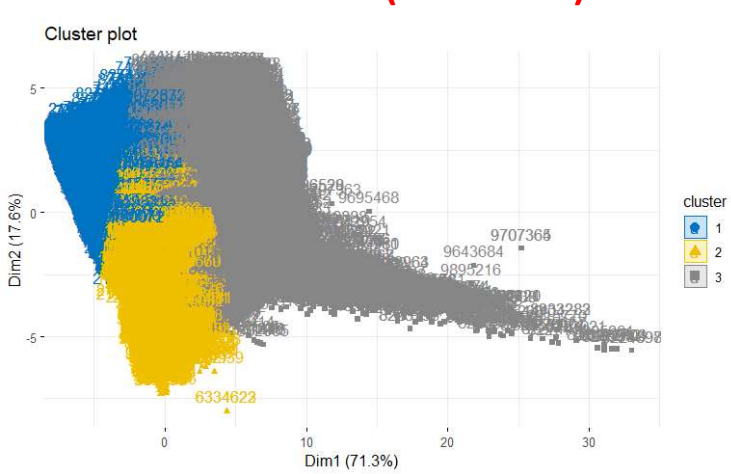


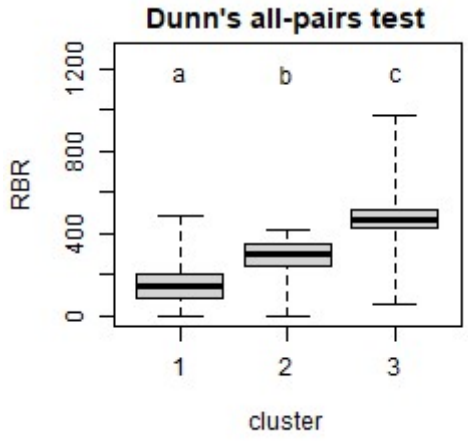
CLARA (K-MEDIODS)





FUZZY (K-MEANS)

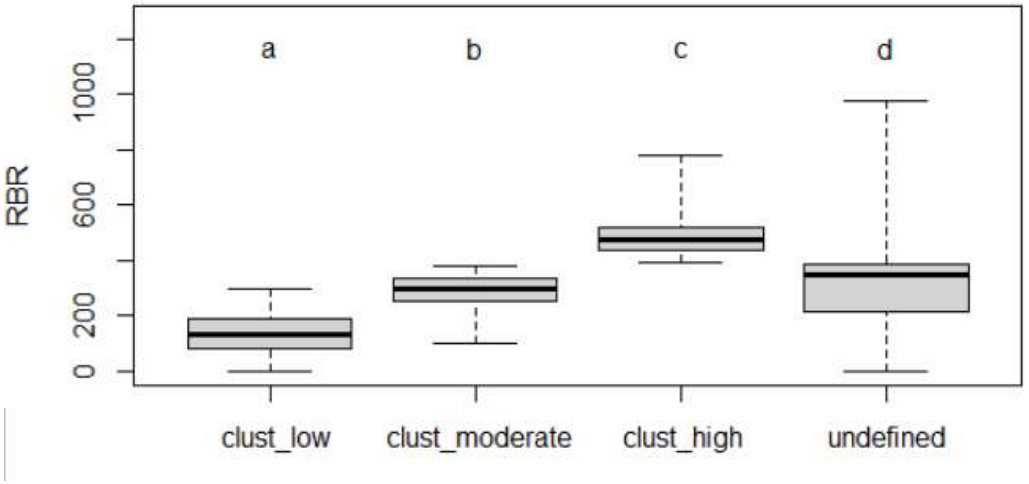


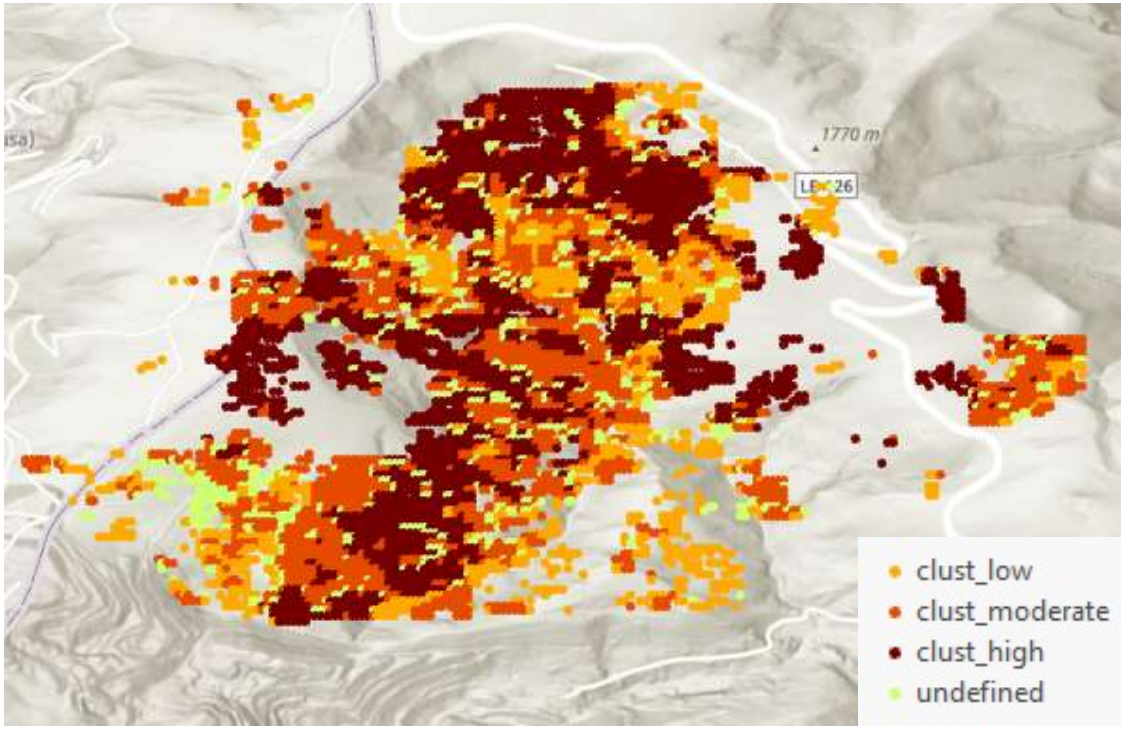


RESULTS

4. Spectral separability of Severity levels based on Landsat imagery

SEVERITY CLASSES (FIRES 2001-2021)

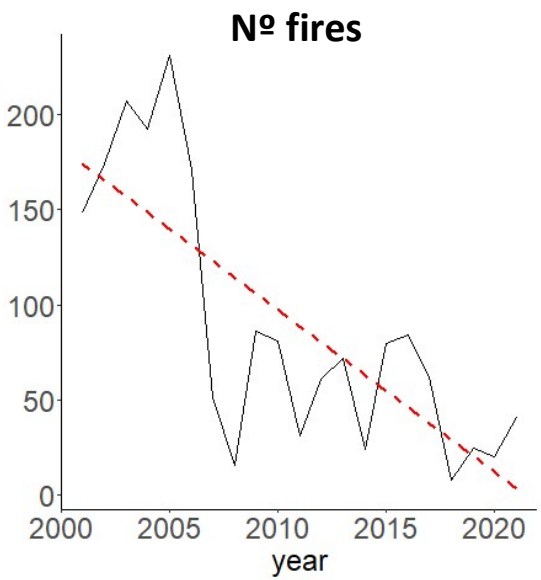


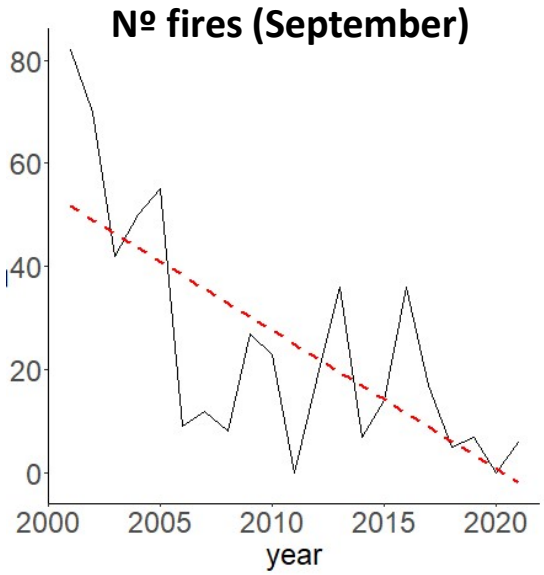


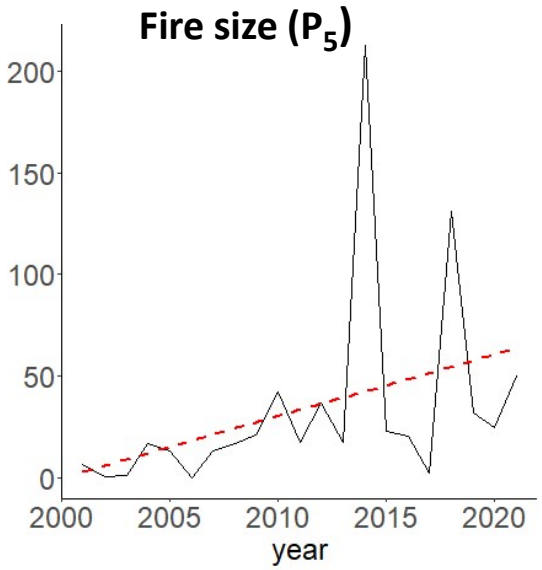
RESULTS

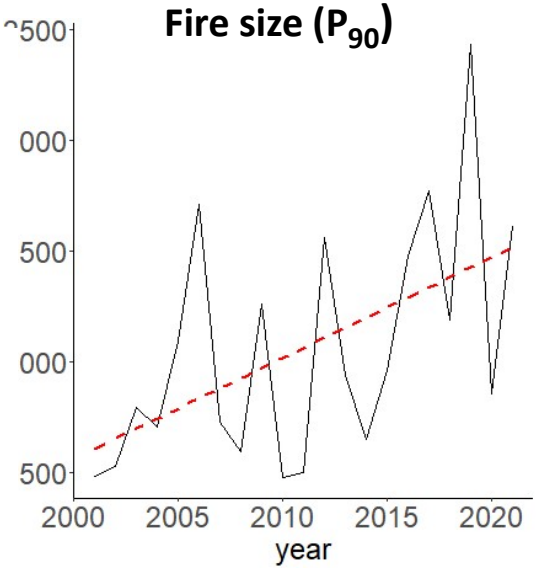
5. Trends analysis: Number of fires and fire size

Variables < 10% gaps









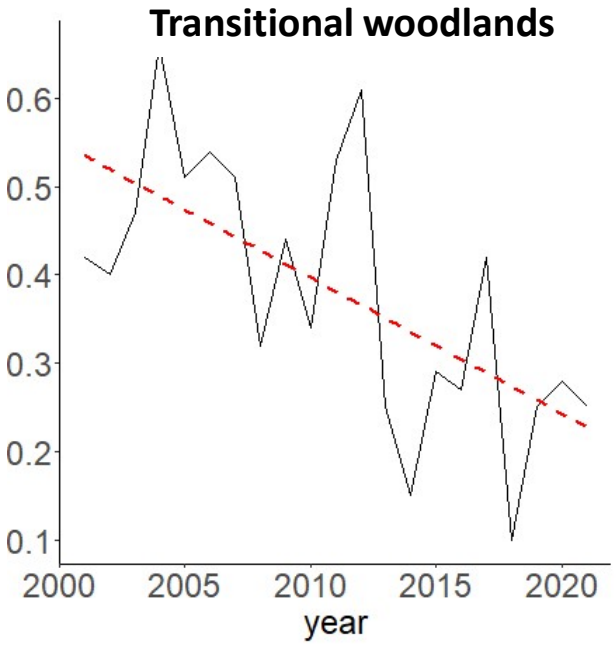
Number of Fires	Tau	p value
nfires	-0.50	0.02
nfires_month8	-0.48	0.00
nfires_month9	**-0.53**	**0.00**

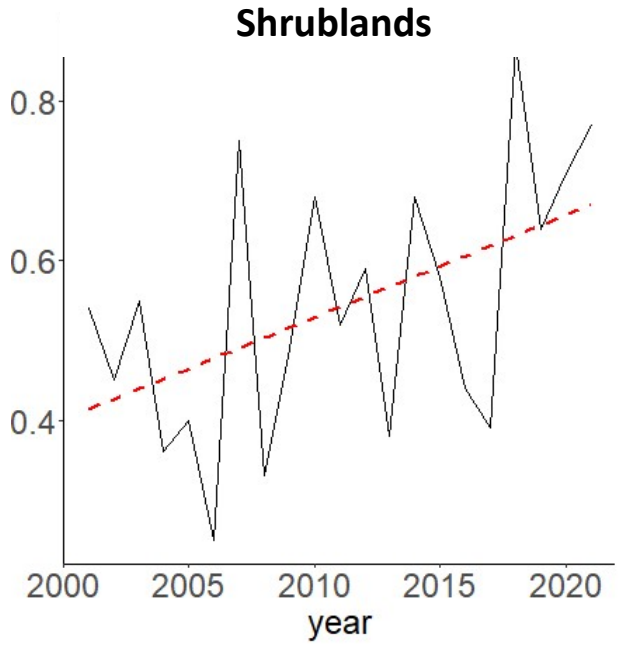
Percentiles of fire size	Tau	p value
P90	**0.39**	**0.01**
P95	0.29	0.02
P5_month7	**0.53**	**0.00**
P5_month8	0.39	0.01

RESULTS

5. Trends analysis: Percentage of burned area

Variables < 10% gaps



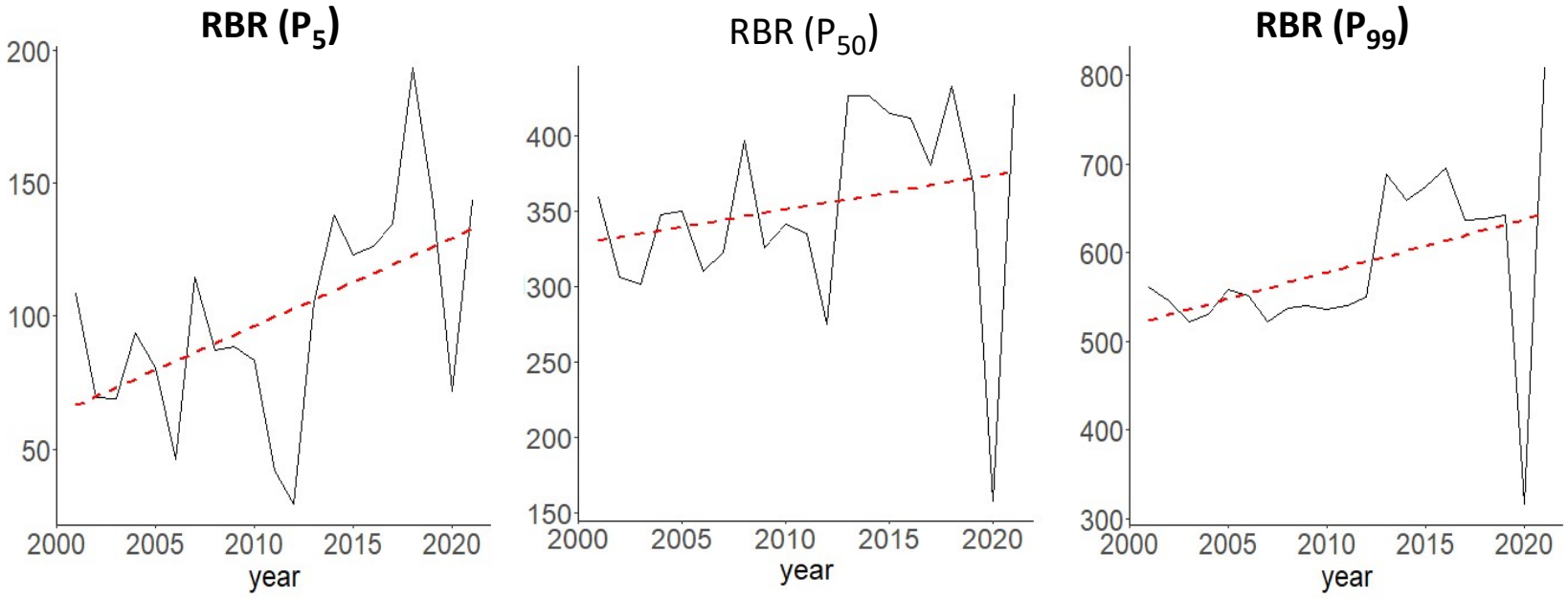


Percentage of burned area	Tau	p value
Agroforestry	-0.30	0.00
Agroforestry_MDS	-0.29	0.00
Shrubs	**0.32**	**0.05**
Sparse_veg	0.24	0.01
Transit_wood	**-0.43**	**0.01**
Transit_wood_MDS	**-0.36**	**0.02**

RESULTS

Variables < 10% gaps

5. Trends analysis: Fire severity (Percentiles RBR)

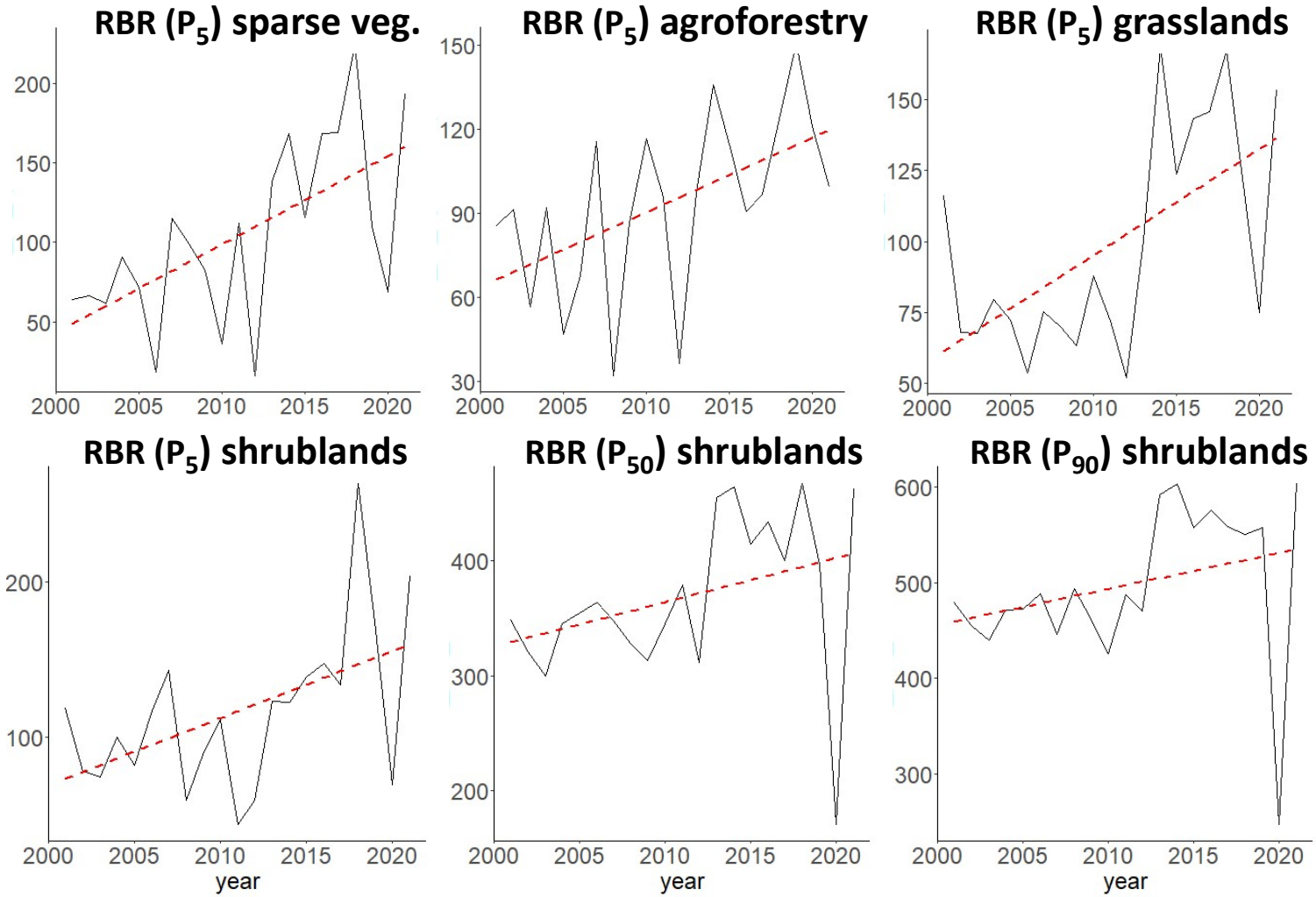


Median RBR	Tau	p value
RBR_p5	**0.39**	**0.01**
RBR_p50	0.31	0.05
RBR_p99	**0.36**	**0.02**

RESULTS

5. Trends analysis: Fire severity (Percentiles RBR)

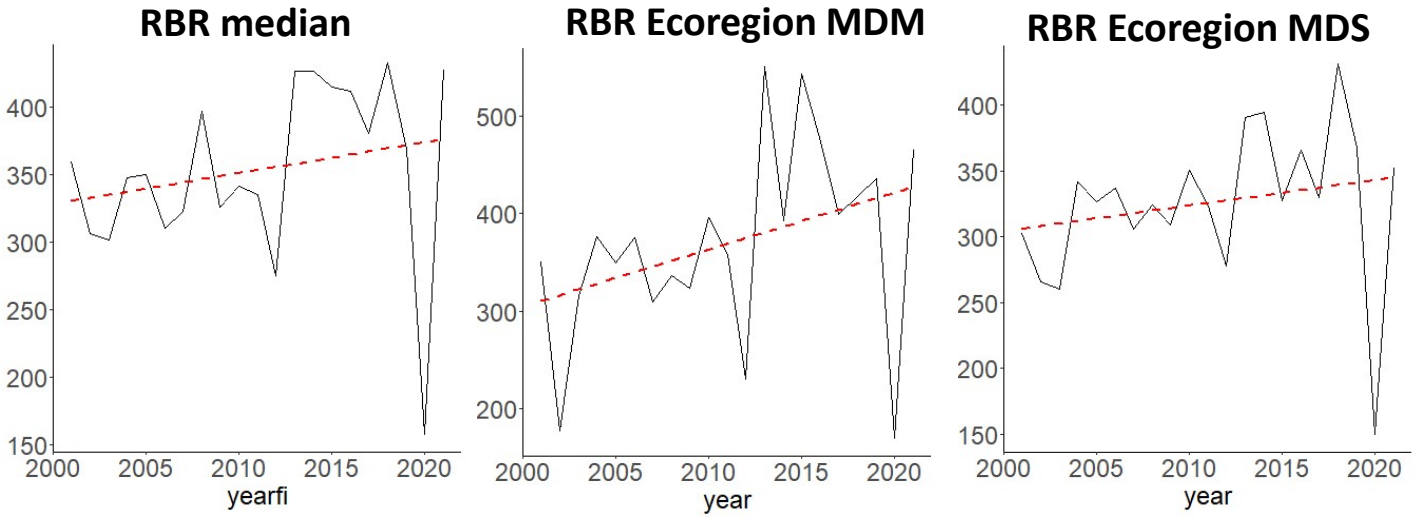
Variables < 10% gaps

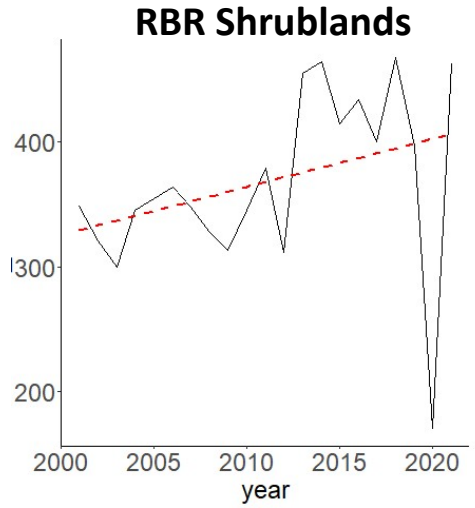


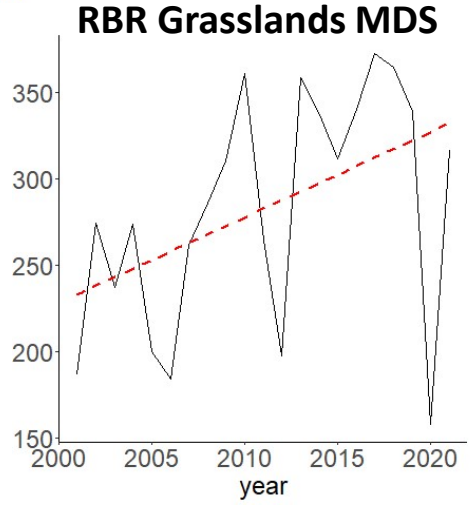
RESULTS

5. Trends analysis: Fire severity (median RBR)

Variables < 10% gaps





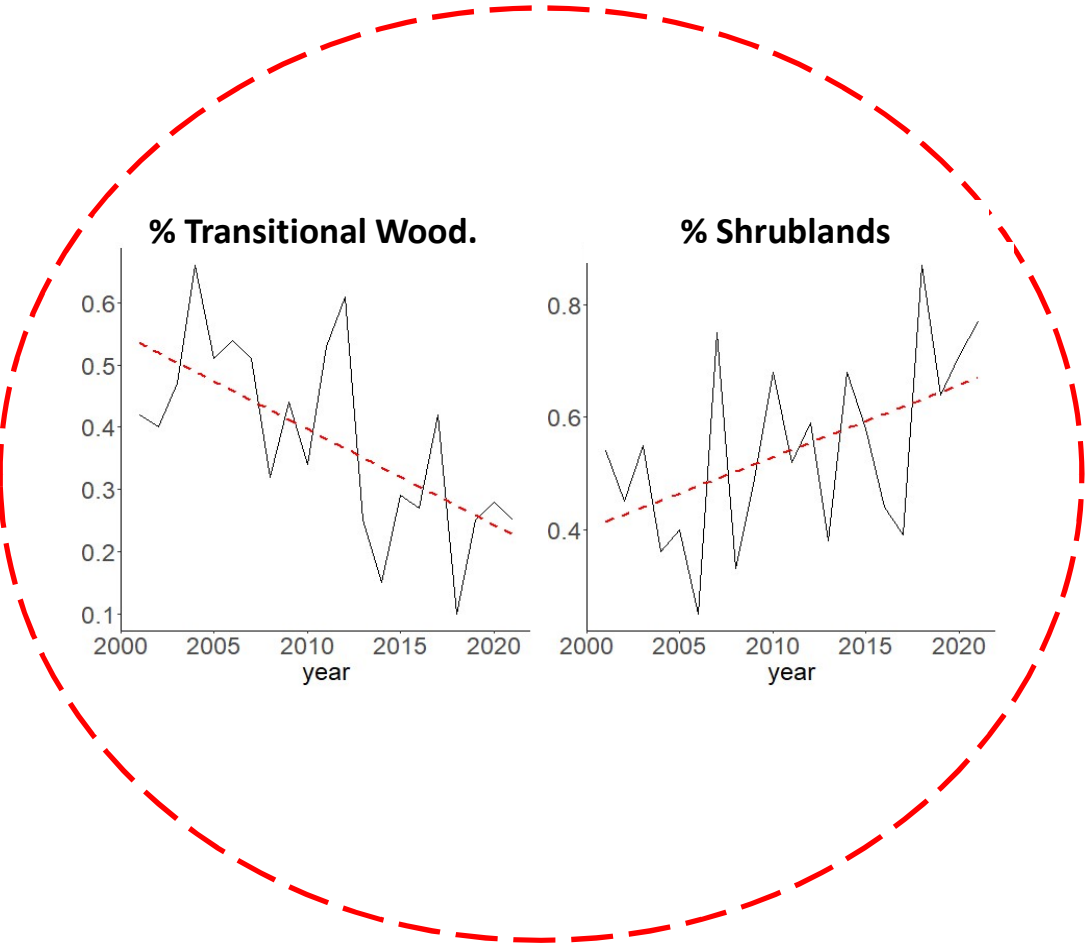


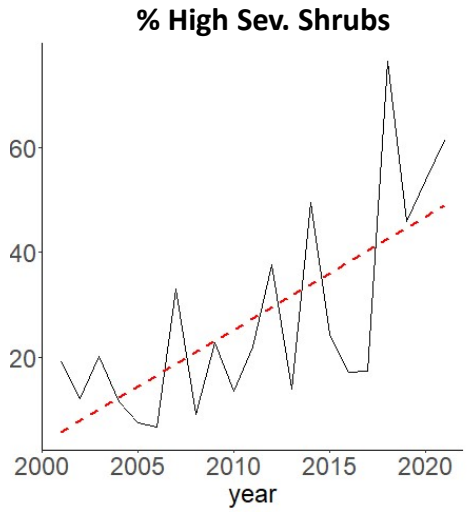
Median RBR	Tau	p value
RBR	0.31	0.05
RBR_MDM	0.35	0.03
RBR_MDS	0.34	0.03
RBR_shrubs	0.35	0.03
RBR_grass_MDS	**0.37**	**0.02**

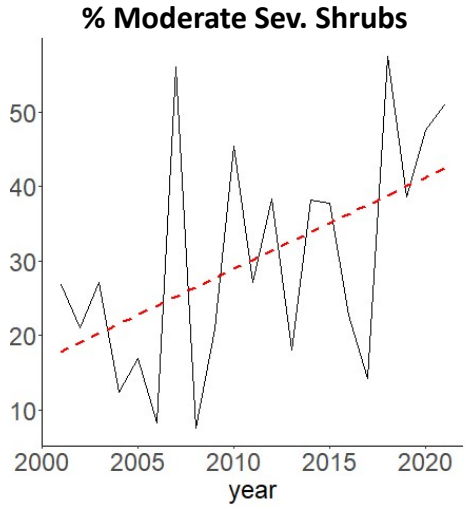
RESULTS

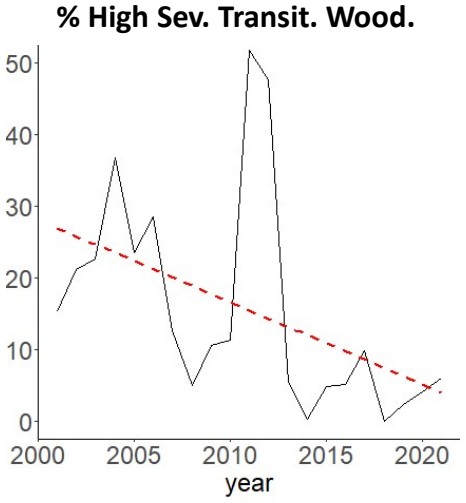
5. Trends analysis: Fire severity classes (% burned)

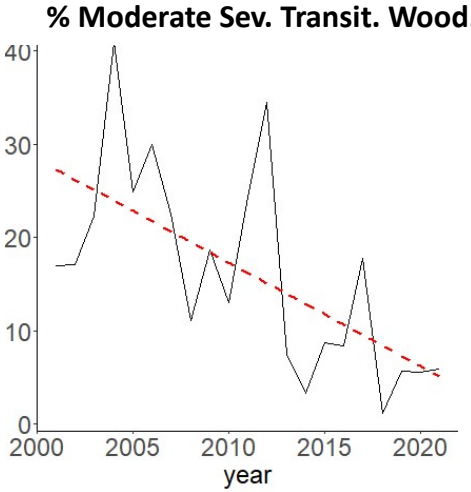
Variables < 10% gaps











DISCUSSION

The Landsat images "composites" in GEE are key for characterizing the burned areas: the day of max. NDVI/NBR could occur after the fire date (maybe because some pixels were burnt in spring).

Fusing MODIS-Landsat allows estimating with high accuracy the burned areas ommitting "false" or "unburned" pixels.

The use of **3 different classification methods** assures high confidentiality but this approach can be very restrictive as it has been show here with the "undefined" burned pixels.

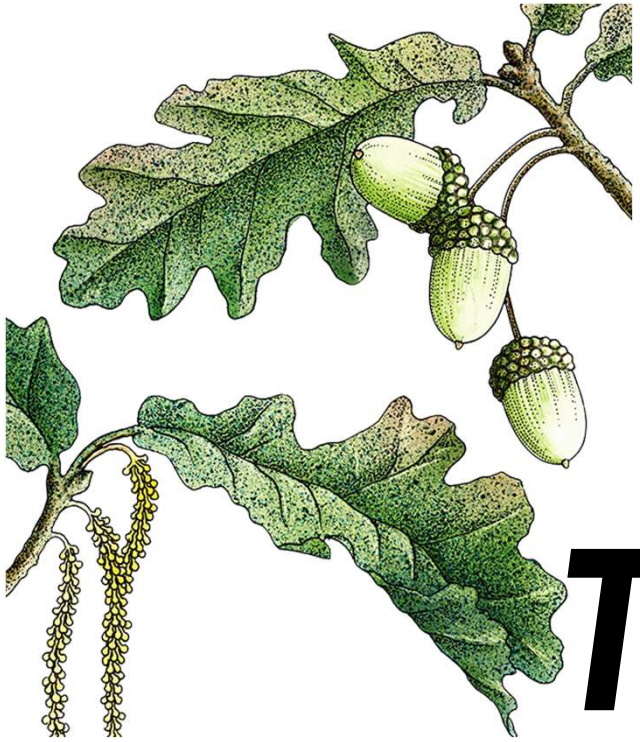
Time series of the burnt index (RBR) from Landsat as well as those of "fire activity" were noisy due to the short lenght of the series and the high interannual variability.

The number of fires has significantly decreased over time. On the contrary, **fire size** was increasing (both 5th and 95th percentiles).

The proportion of burned shrublands grew in all ecoregions, but especially in the Mediterranean ones; whereas the proportion of burned forests was decreasing.

The median RBR, as well as their percentiles, augmented, especially in treeless areas located in Mediterranean ecoregions.

The percentage of areas burned with high severity (based on standard thresholds) was expanding mainly due to the increase in the percentage of shrublands burning more severely.



THANK YOU