*Supplementary Data*

# A Diachronic Analysis of a Changing Landscape on the Duero River Borderlands of Spain and Portugal Combining Remote Sensing and Ethnographic Approaches

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## SUPPLEMENTARY DATA

### Aerial photography consulted

1. 1 *Vuelo Americano Serie A* (1945-1946): Aerial photography conducted by the United States Air Force. This was used largely for the Portuguese side of the Duero as the next in the series, Serie B, is inaccessible for Portugal.

2. *Vuelo Americano Serie B* (1956-1957): Aerial photography conducted by the United States Air Force. This was used extensively for their resolution and quality as the earliest photographs for the Spanish portion of the study area.

3. *Vuelo Nacional* (1980-1986). Aerial photography conducted by the Spanish National Geographic Institute (ING). Despite the availability of the *Interministerial* Aerial Photography Series ranging from 1973-1986, these were largely found to be taken in the early to mid 1980s on this area and of less quality than the same time range and better quality *Vuelo Nacional* Series.

4. *Vuelo Quinquenal* (1998-2003). Aerial photography conducted by ING. This series was the first that provided color photography and provided the next available time range.

5. PNOA orthographic photos of 2005, 2011, 2014, 2017. This aerial photography arose from the Spanish National Aerial Orthophotographic Plan (PNOA) in the early 2000s. These time periods correspond to all the dates available for this region of study.

The aerial photography discussed here can be consulted at https://fototeca.cnig.es/ and downloaded at https://centrodedescargas.cnig.es/CentroDescargas/index.jsp#. [64]

Other sources included a shapefile designed and prepared by the Servicio Territorial de Medio Ambiente in Zamora, Spain of the regional Junta de Castilla y Leon government specifically for this project detailing with polygons the specific wildfire burn areas on the Spanish side of the study as well as their dates of occurrence. This shapefile allowed for more precision through the exclusion of large swaths of landscape in the study area that had been burnt in wildfires from 2000 to the summer of 2019. Similarly, the graphic representation of the history of wildfires on the Portuguese side of the Duero was provided by the Revisão do Plano Director Municipal de Miranda do Douro: Anexo A – Áreas Florestais Percorridas Por Incêndio. This detailed map provided polygons of burn areas from 2005 to 2013. It is downloadable at: https://ssaigt.dgterritorio.gov.pt/i/Planta_de_condicionantes_30901_29.jpg.

Finally, ground truthing with numerous pedestrian surveys often with local residents was conducted in the Spring, Summer, and Winter months from 2017 to 2019 to improve accuracy, to verify any discrepancies, and allow the researchers a familiarity and knowledge of the landscape.

**Spectral indices**

Spectral indices are arithmetic combinations of spectral bands, which quantitatively represent a certain terrain attribute of interest (e.g., vegetation, snow, etc.). To determine multitemporal vegetative change in the area three spectral indices were computed for each time increment scene: (1) Normalized Difference Vegetation Index (NDVI), (2) Normalized Burn Ratio (NBR), and (3) Bare Soil Index (BSI).

$$NDVI = \frac{\rho_{NIR}-\rho_R}{\rho_{NIR}+\rho_R} \quad (1)$$

$$NBR = \frac{\rho_{NIR}-\rho_{SWIR-2}}{\rho_{NIR}+\rho_{SWIR-2}} \quad (2)$$

$$BSI = \frac{(\rho_R+\rho_{SWIR-1})-(\rho_{NIR}+\rho_B)}{(\rho_R+\rho_{SWIR-1})+(\rho_{NIR}+\rho_B)} \quad (3)$$

Where, $\rho_B$ represents the surface reflectance in the blue band (band TM1, 0.45-0.52 μm), $\rho_R$ in the red band (band TM3, 0.63-0.69 μm), $\rho_{NIR}$ in the near infrared band (band TM4, 0.76-0.90 μm), $\rho_{SWIR-1}$ in the first short wave infrared band (band TM5, 1.55-1.75 μm) and $\rho_{SWIR-2}$ in the second short wave infrared band (band TM7, 2.09-2.35 μm).

NDVI is probably the most used vegetation index [69] and has been used as an indicator of the presence of healthy vegetation, mostly sensitive to the greenness and photosynthesis activity of leaves and vegetation constituents. Its values are bounded between -1 and 1, with higher values indicating a larger presence of healthy vegetation. Terrain land-covers typically take positive NDVI values whereas water surfaces and snow might take negative values. Bare soils obtain low NDVI values (0.1-0.2), shrubs intermediate values around 0.2-0.5, while mature crops and forests might reach higher values up to 0.8-1.0 [69]. NDVI has been extensively used for many applications, including the inference of bulk vegetation variables like LAI or biomass, yet its main limitation is that it rapidly saturates with dense vegetation, so for applications involving woody vegetation some other indices might be more appropriately related to biomass [66]. In particular, the NBR [67] has been proven to be an interesting index, not only for the estimation of wildfire damage in forests, but also to identify changes of all sorts in forested areas [70]. NBR positively correlates with woody vegetation biomass, so negative values indicate the absence of woody vegetation (e.g., burnt areas) and values close to 1 forests with large biomass. Finally, the BSI [68] enhances the response of bare soil areas, fallow lands and areas of sparse vegetation with a predominant soil background response. The values for these indices were computed for the image time series analysis. From each scene the statistics of vegetation indices were extracted for the whole study area and the different administrative units of interest (Figure 1, Tables 1 and 2), and their temporal trends were evaluated. Given the scene acquisition dates (mid-summer), an increase in NDVI or NBR time series might indicate a regrowth of natural vegetation, scrubland, and chaparral forest, respectively. On the other hand, an increase in BSI might indicate an increase of agropastoral lands that at this time of the year are mostly bare and dry. This analysis was performed using SNAP 8.0 for image processing, ArcGIS 10.3.1 for visualization and Rstudio 1.4 for image statistical analysis.

**Vegetation indices analysis**

Normalized Difference Vegetation Index (NDVI), Bare Soil Index (BSI), and Normalized Burn Ratio (NBR) were calculated for the study area to examine temporal fluctuations and change in vegetative landcover and then extracted for each of the municipal case studies. Although not definitive for making final conclusions on landcover change, the vegetation indices employed were a preliminary analysis to investigate the land cover trends. This preliminary analysis complemented the more comprehensive supervised landscape classification discussed in the manuscript.

*Vegetation indices in greater study area*

All three indices registered little change between beginning and end years (Table 1). NDVI saw very little fluctuation with moderate values indicative of grassland and shrubland vegetation with beginning and end readings at 0.301 and 0.302, respectively. Normalized Burn Ratio values provided information in changes in vegetative cover as well, but mainly related to woody vegetation. In addition, they are important markers of fire events and vegetation recovery in the municipalities' landscape history. Positive values closer to 1 signify increased vegetative, woody biomass, with a value of 1 indicating dense forest, while negative values signify the inverse, a scarcity of woody vegetation. NBR registered low but positive trends throughout the time analysis. After fluctuation between years beginning with 0.090 in 1984 with a peak of 0.144 in 2003, there was a slight decline to 0.085 in 2018.

Bare Soil Index values have a range between -0.4 to 0.4. Where the BSI is low, it represents the presence of vegetation on the landscape and the inverse could signify bare soil as result of burn, previously harvested plots, or sparsely vegetated parts of the terrain that remain very dry in the late summer. Often used together with NDVI, it correlates well with the NDVI results. BSI results were also consistent throughout the time range in the greater study area beginning with 0.152 in 1984, declining slightly in the late 80s and through the 1990s but never lower than 0.144 and finally finishing the time frame with a reading of 0.151 in 2018.

**Table S1.** Vegetation indices for the greater study area

| Year | NDVI | NBR | BSI |
|---|---|---|---|
| 1984 | 0.301 | 0.090 | 0.152 |
| 1988 | 0.297 | 0.063 | 0.146 |
| 1993 | 0.302 | 0.106 | 0.144 |
| 1998 | 0.303 | 0.097 | 0.146 |
| 2003 | 0.300 | 0.144 | 0.153 |
| 2008 | 0.301 | 0.101 | 0.150 |
| 2013 | 0.296 | 0.097 | 0.150 |
| 2018 | 0.302 | 0.085 | 0.151 |

*Vegetation indices per Municipality*

NDVI

With 1 being the highest and representing forest and mature crops, none of the municipalities demonstrated a calculation higher than 0.37 (Figure 1), this was expected because of the time of the year of satellite acquisitions. All municipalities, with exception of Constantim-Cicouro, in all years fluctuated between 0.25 and 0.31. In Portugal, a decrease in NDVI, although slight, was detected in Vila Chã de Braciosa, Miranda do Douro, and

Ifanes-Paradela. Constantim-Cicouro municipality was the exception with all years above 0.3 and demonstrated a rise in NDVI from 1984 registering at 0.37 in 2018. In Spain, NDVI tended to be slightly lower than Portugal registering closer to 0.25 rather than 0.3. Spanish municipalities registered very minimal decrease in NDVI from 1984 to 2018 with a very minor increase in the municipality of Fariza.

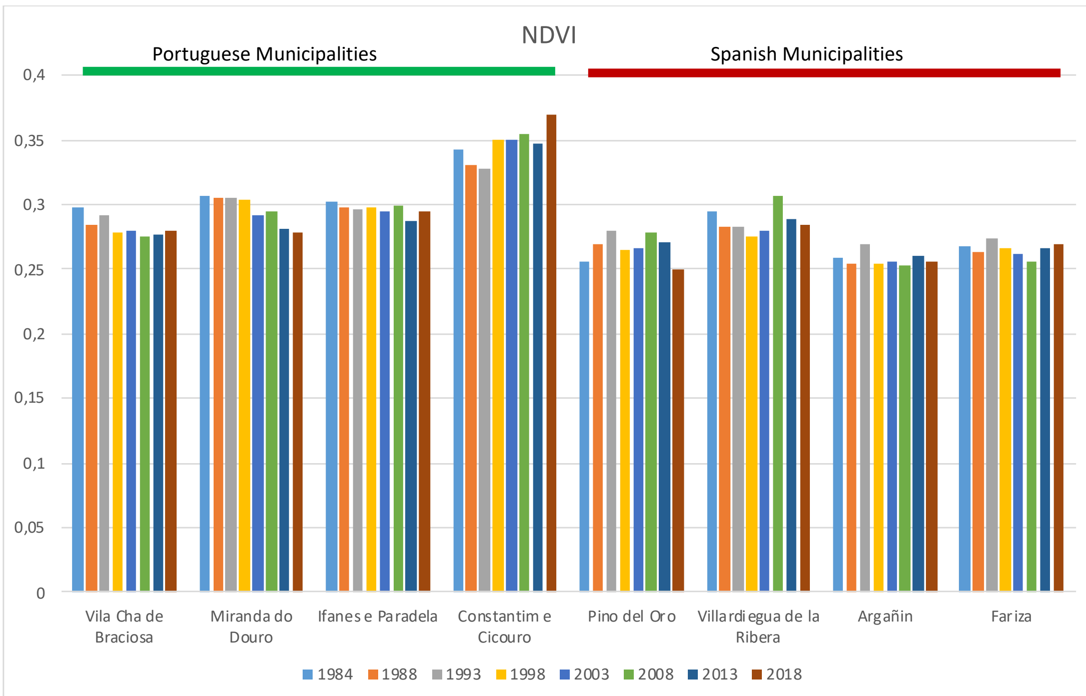


**Figure S1.** Normalized Difference Vegetation Index (NDVI) calculated for study area municipalities (1984-2018).

BSI

In the Portuguese municipalities the BSI registered lower than in Spain. In both countries within the study area, there was no extreme temporal variation however (Figure 2). Constantim-Cicouro was again additionally notable with an even lower BSI than the rest of the Portuguese municipalities as well as demonstrating the lowest results of all the municipal case studies. All of the Spanish municipalities demonstrated higher BSI than in Portugal. In Portugal, only Constantim-Cicouro registered a decrease in the BSI between 1984 and 2018. All others saw a slight increase. In Spain, Argañin and Fariza had negligible, barely detectable decreases between 1984 and 2018 while Pino del Oro and Villardiegua de la Ribera registered slight increases.

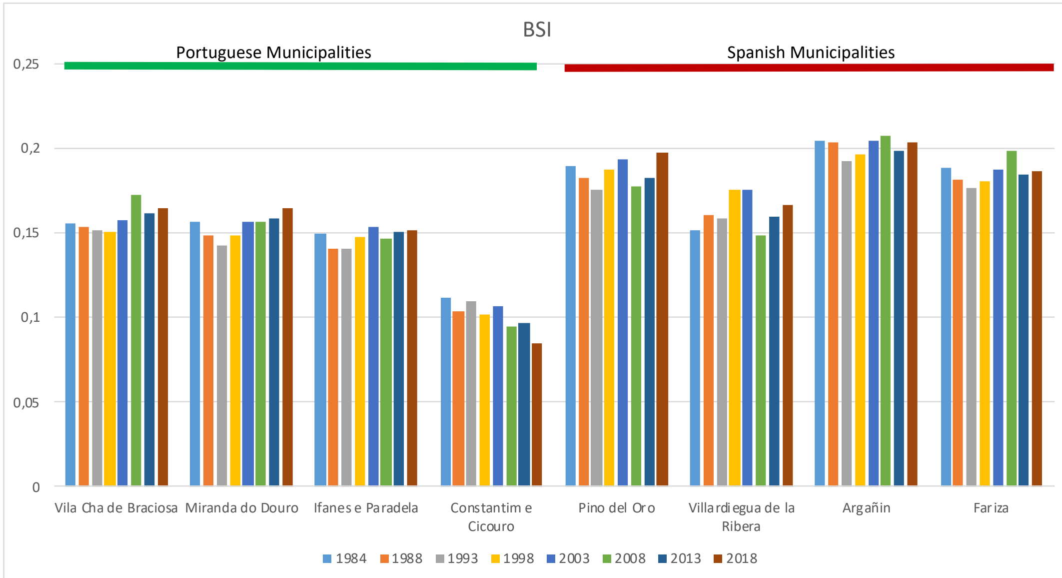


**Figure S2.** Bare Soil Index (BSI) calculated for study area municipalities (1984-2018)

NBR

None of the municipalities registered above Constantim-Cicouro's 0.24 in 2003 with the Normalized Burn Ratio (Figure 3). Again Constantim-Cicouro appeared as the municipality with the highest level of forest biomass even registering an increase between 1984 and 2018. Argañin and Fariza registered negligible increases between 1984 and 2018. Portugal again, in comparison to the Spanish municipalities, demonstrated higher vegetation biomass with less dramatic fluctuation between years. In the period between 1984 and 1988 negative values are registered for Argañin and Fariza at -0.039 and -0.014, respectively indicating wildfire events.

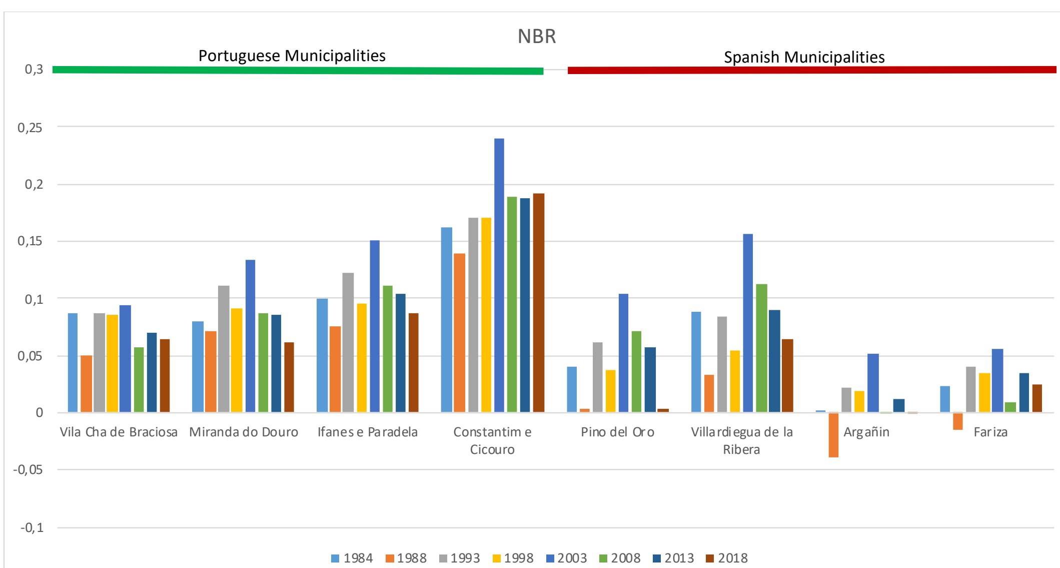


**Figure S3.** Normalized Burn Ratio (NBR) calculated for study area municipalities (1984-2018)