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Environmental and socioeconomic factors of abandonment of rainfed and irrigated crops in northeast Spain

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ABSTRACT

Changes over the last century in the economic model of European countries and the development of the market economy have led to intense shifts in land occupation patterns. Agricultural abandonment is an important consequence of these processes and has modified natural and cultural landscapes, involving side-effects for society. Understanding how environmental and socio-economic factors influence the abandonment process can provide useful insights for managing investments, whether from the public or the private sector. In Spain, the Pyrenees and the Ebro Depression are two differentiated areas in terms of land-use dynamics, particularly in terms of the agricultural model carried out. In this paper we have analyzed the agricultural abandonment in these areas during the 1987–2012 period in relation to several potential explanatory factors. The analysis focuses on the abandonment of rainfed and irrigated herbaceous crops in order to derive specific explanations according to the crop type and geographical region. Crop covers were classified from four Landsat scenes, and conditions were described by topographic variables, human factors and drought occurrence. Boosted regression trees (BRT) were used to identify the most important variables and to describe the relationships between agricultural abandonment and key factors. Topography derived variables were found to be the main determinants, except for irrigated crops in the Ebro Basin, where locational factors play a more important role. BRT models allowed us to identify other significant patterns such as: the vulnerability of irrigated crops to drought; the higher dependence of agricultural activity in the Pyrenees on internal networks; pattern shifts of land abandonment in the analyzed sub-periods, and; evidence of the importance of economic diversification for maintaining cropland.

1. Introduction

In the 20th century, especially during the second half, economic growth and development of mass markets in Europe resulted in a depopulation of marginal areas and a densification of those areas better placed to supply the expanding cities and industrialized zones (Collantes & Pinilla, 2004; Fielding, 1989). Agricultural land abandonment and intensification have continued to be widespread land-use changes since then (Ramankutty & Foley, 1999), especially in the Mediterranean area (Gerard et al., 2010).

Land abandonment has been treated as a phenomenon involving negative or positive effects according to the analysis approach and/or the territorial context (Benayas, Martins, Nicolau, & Schulz, 2007; Keenleyside et al., 2010; MacDonald et al., 2000). Soil erosion and reduced water yield of catchments are some of the most conspicuous issues that have been frequently addressed in the Mediterranean area, which is more prone to these problems (Gallart & Llorens, 2004; García-Ruiz, 2010; Kosmas et al., 2015; López-Moreno et al., 2006). There are also associated benefits, like soil and nutrient recovery and carbon sequestration due to vegetation re-growth in abandoned lands (Molinillo et al., 1997; Schröter et al., 2005; Tiessen, Salcedo, & Sampaio, 1992). The effect of cropland abandonment on landscape structure has been reported as a disturbance that can positively affect landscape connectivity and increase forest species (Beilin et al., 2014; Farina, 2008; Navarro & Pereira, 2015). In addition, other analyses have shown a positive association between abandonment and rural development (Beilin et al., 2014). On the other hand, several studies have reported the negative effects on biodiversity (Bezák & Halada, 2010; Farina, 2008; Halada, Evans, Romão, & Petersen, 2011), highlighting the importance of the seasonal-disturbance regime of croplands in

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maintaining the diversity and environmental range of species. Fire occurrence is another negative effect, especially regarding woodland recovery (Lloret, Calvo, Pons, & Díaz-Delgado, 2002; Moreira et al., 2011). Finally, during the last decade special attention has been paid to the drivers of agricultural abandonment, including environmental and socioeconomic variables as explanatory variables in statistical-based methods (Gellrich & Zimmermann, 2007; Serra, Pons, & Saurí, 2008; Lieskovský et al., 2014; Sang, Dramstad, & Bryn, 2014; Pazúr et al., 2014). These approaches are very useful for determining patterns of land abandonment and for identifying which places are more prone to being abandoned within a given territory.

The above-mentioned issues are especially relevant for land abandonment analyses in a country like Spain, which has high land-use heterogeneity due to its topographic and climatic spatial variability, and a long and complex human history. Spain, and the Mediterranean in general, has followed intense land cover dynamics that have led to high heterogeneity of land occupation patterns. Moreover, in recent decades the region has also been particularly influenced by climate change dynamics (IPCC 2007, 2013; Vicente-Serrano et al., 2014). However, apart from some works describing the phenomenon through landscape metrics for relatively small areas (e.g., Bielsa, Pons, & Bunce, 2005), there are few detailed analyses of the conditions leading to agricultural abandonment in Spain, and more specifically, focused on the likelihood of abandonment based on empirical data.

In mountainous regions like the Spanish Pyrenees, the ecological succession of vegetation has advanced after a general abandonment of traditional activities (Cohen, Varga, Vila, & Barrassaud, 2011; García-Ruiz, 1990; Lasanta, Vicente-Serrano, & Cuadrat-Prats, 2005; Roura-Pascual, Pons, Etienne, & Lambert, 2005; Serra, Vera, Tulla, & Salvati, 2014) driven by the combination of the rural exodus and the physical constraints to modernization (Benayas et al., 2007; Collantes & Pinilla, 2004). The cultivated area is mainly divided into cereals and fodder production. After the decline of the traditional system, based on a subsistence economy, cereals were less competitive (as a food supply) and have become an important source of fodder, while other forage crops and managed meadows have increased their area due the abandonment of transhumance in most counties (García-Ruiz & Lasanta, 1993; IAEST; IDESCAT). The expansion of tourism in this region has led to economic readjustments in rural households. Many areas maintain a balanced symbiosis between tourism and agricultural production (Cánoves, Villarino, Priestley, & Blanco, 2004), but livestock farming and land cultivation have clearly decreased in the areas with more touristic development (Garcia-Ruiz et al., 1996; 2011). In contrast, modernization (strong mechanization and limited labor) and agricultural intensification have taken place in other geographical regions of Spain, such as the Ebro Depression, a semi-arid region where modern irrigation systems have been developed since the middle of the 20th century (Pinilla, 2006). During the economic liberalization and capitalist development of Spain, this region was better placed to benefit from the expansion of industrialization and external markets, and the modern irrigation techniques increased the productivity of croplands. At the same time, this process contributed to the depopulation and agricultural abandonment in the Spanish Pyrenees due to the construction of reservoirs in valleys to supply the irrigated lands (Duarte, Pinilla, & Serrano, 2014; Pinilla, 2006). Non-irrigated lands are mainly used to cultivate winter cereals, and although they occupy a greater extent of land, output per hectare for irrigated crops (mostly maize) is 5–6 times higher (Pinilla, 2006). Land intensification is a common trend in the Mediterranean fringe of Spain, and although it leads to higher crop yields, its environmental and social viability depends on the pressures on the landscape and external market fluctuations (Nainggolan et al., 2012).

Although the external factors that have led to agricultural abandonment in Spain have already been described in several works, as we mentioned above, there are still few studies on the internal factors (Lasanta et al., 2017) controlling this phenomenon. Here, we analyze the influence of a series of internal environmental and socioeconomic factors on the land abandonment in northeast Spain from 1987 to 2012. In order to determine particularities regarding types of land cultivation and territorial contexts, the analysis differentiates between the abandonment of rainfed and irrigated crops in the Spanish Central Pyrenees and the Central Ebro Basin. Two sub-periods have been included in the analysis, 1987–2002 and 2002–2012, in order to take into account the variability in human and climatic factors. The ambits correspond to refined land-cover classifications of Landsat scenes. The importance of several factors and how they influence cropland abandonment was analyzed using boosted regression trees (BRT), also known as stochastic gradient boosting (Friedman, 2001, 2002; Hastie and Tibshirani, 2009). This relatively new machine-learning technique (Breiman, 2001), in which hundreds or thousands of decision trees (Breiman, Friedman, Stone, & Olshen, 1984) are sequentially and progressively fitted, has been demonstrated to have a high prediction performance (Crase, Liedloff, & Wintle, 2012; Elith, Leathwick, & Hastie, 2008, 2006; Kawakita, Minami, Eguchi, & Lennert-Cody, 2005; Leathwick, Elith, Francis, Hastie, & Taylor, 2006) for the following main reasons: this approach does not assume any data distributions or data models, but rather it aims to determine dominant patterns by combining many classification trees; it identifies relevant variables and complex interactions; it is much less influenced by correlated information or irrelevant variables than other statistical approaches; it produces stable predictions (variance reduction); and it provides graphical depictions of the relationship between the response variable and predictors. We found this method particularly useful for multicausal scenarios, given its capacity to define the role played by the explanatory factors, even when the contribution (relative weight/importance) is low.

The general aim of this work is to better understand the internal conditions that lead to agricultural abandonment. We consider this study as groundwork for the development of sectoral studies and to improve the decision-making process for policy making and land management. Thus, the main objectives of this study are to determine: 1) the most important internal factors in the abandonment of rainfed and irrigated crops in two geographical regions, the Spanish Central Pyrenees and the Central Ebro Basin; and 2) the role of key factors in identifying particularities within each type of land cultivation and territorial context.

2. Material and methods

2.1. Study areas

Two areas of northeast Spain were included in this work as different scenarios for model development. These areas are within the limits of land-cover classifications of four Landsat scenes, identified by their path-row: 198-030, 198-031, 199-030 and 199-031 (Fig. 1).

The first study area corresponds to the mountainous region of the Spanish Central Pyrenees and, as previously explained, it is representative of an extensive and less-developed (less mechanized) agriculture. It includes areas with altitudes from 600 m up to the Spanish border with France (reaching altitudes of 3000 m and more), although in some locations the perimeter at its lower altitudinal limit has been adapted to natural boundaries with the Central Ebro Valley. Interior valleys below 600 m are also included within this geographical

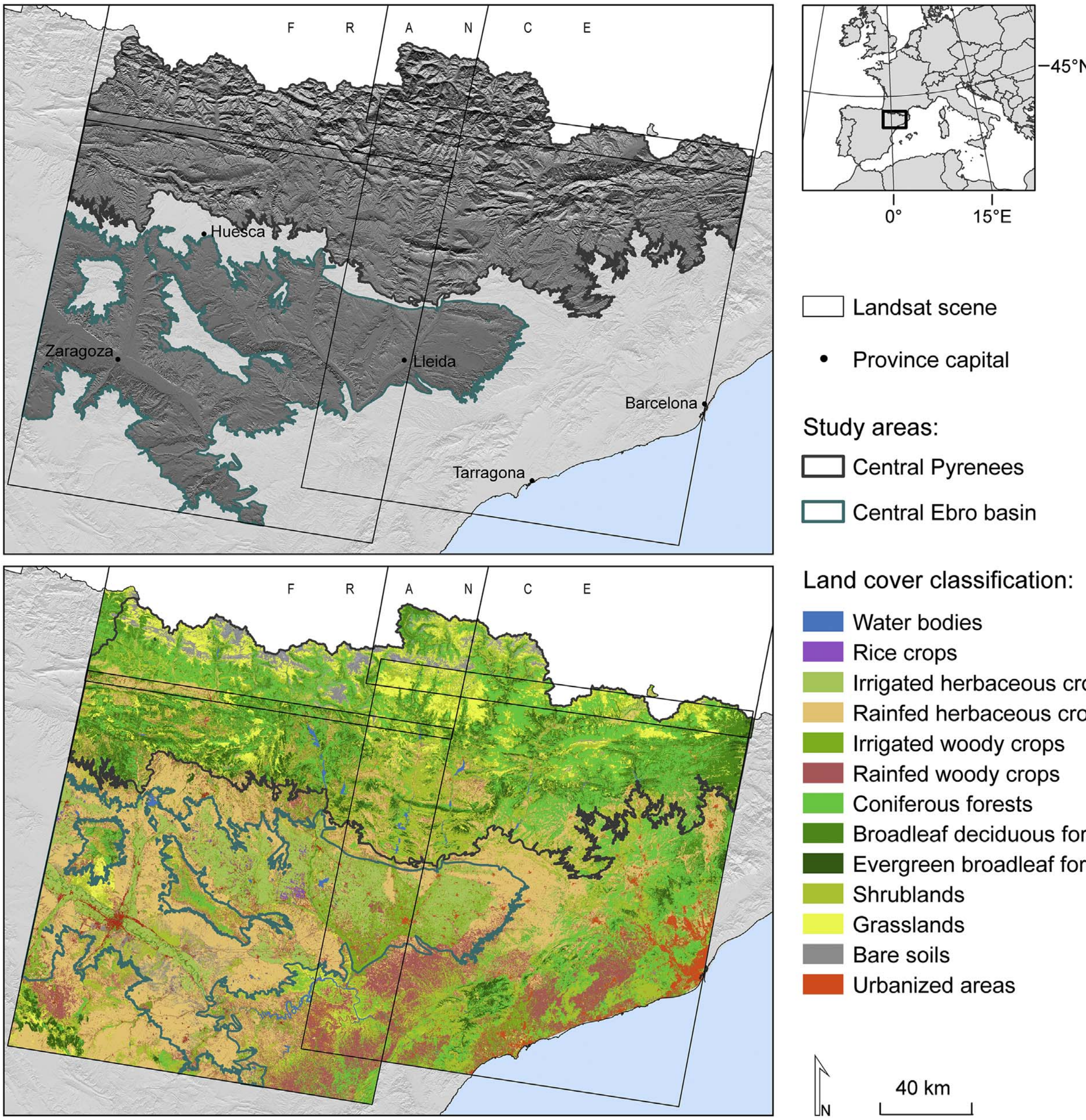

Fig. 1. Study areas.

region. The area is influenced by a continental climate (although the eastern Pyrenees also have a Mediterranean influence) and the altitude introduces a temperature and precipitation gradient. The predominant rainfed crops are barley and rye, generally located in the lower areas. Irrigated crops, such as forage plants, are mainly linked to the livestock farming and the local meat and dairy processing industry. The second area exemplifies the development and intensification of agriculture in the Central Ebro Valley. This region is defined by the area below 450 m elevation, and low-range interior mountains or those connected with mountain massifs were excluded in order to form a more homogeneous geographical region. The area has a continental climate with a marked semi-arid influence. Wheat and other feed cereals linked to intensive animal husbandry are the main rainfed crops in this area, while maize production is associated with modern irrigation systems.

2.2. Obtaining land abandonment areas and sampling

Agricultural land abandonment areas were obtained by classifying Landsat imagery at 30 m resolution following the methodology described in Vidal-Macua, Zabala, Ninyerola, and Pons (2017), in which a hybrid classification scheme is implemented. In our case, the k-nearest neighbor (kNN) classifier was used to obtain both multi-temporal training and test areas and to use them in final classifications (Fig. 2). Each land-cover map refers to a five-year period, so classifications are composed of a set of dates in which the central years are 1987, 2002 and 2012. This allowed us to obtain a suitable representation of the

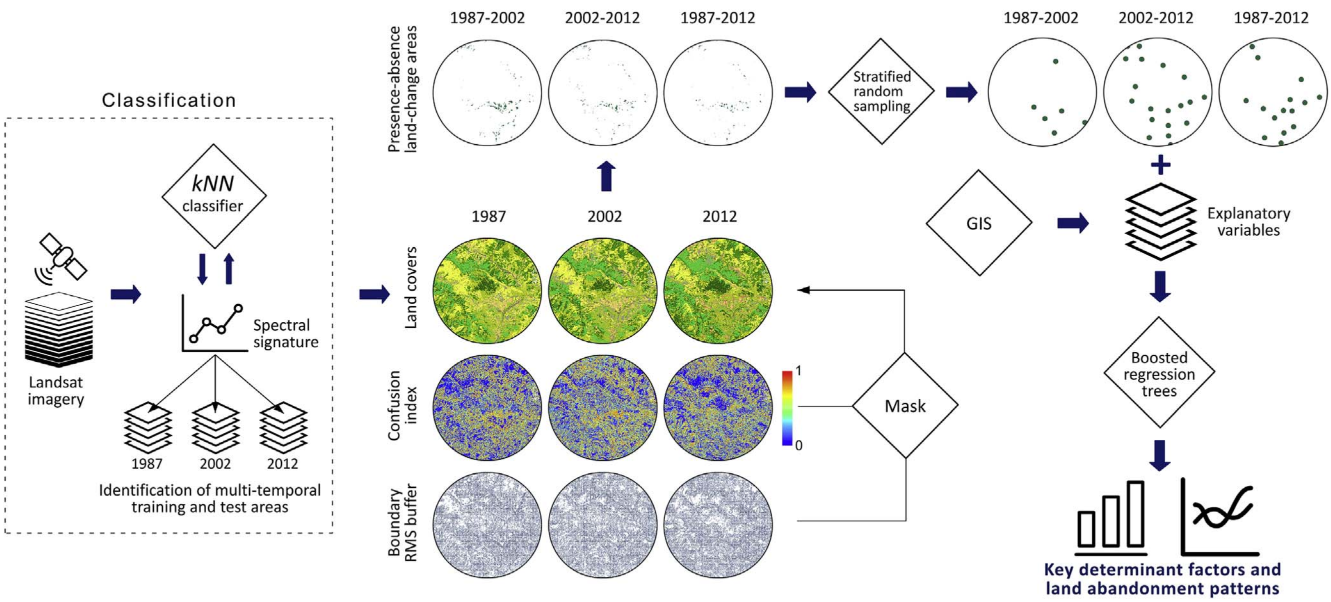

Fig. 2. Methodological workflow (black icons designed by Noun Project, 2017).

Table 1
Mean producer accuracy (PA) and mean user accuracy (UA) by land cover category.

	PA	UA
Irrigated herbaceous crops	88.23	92.33
Rainfed herbaceous crops	96.58	95.93
Coniferous forests	96.38	97.33
Broadleaf deciduous forests	94.76	91.78
Broadleaf evergreen forests	89.96	77.28
Shrublands	88.08	88.38

seasonal phenological variation of crops because dates from March to September were included in each five-year period. The level of disaggregation for crop covers included woody and herbaceous crops, differentiating between irrigated and rainfed regimes. From the three land-cover maps (1987, 2002 and 2012), we computed land cover map changes for the periods: 1987–2002, 2002–2012 and 1987–2012.

Land abandonment was considered as woody vegetation encroachment or afforestation in agricultural plots. We selected irrigated and rainfed herbaceous crops as the land covers to be monitored due to the scarcity of abandonment events detected in woody crops. After a photointerpretation analysis of 20% randomly selected cases (orthophotos 1987, 1988, 2004, 2005, 2014 and 2015 at 1:5000 scale), many transitions to grassland cover (which could have scattered shrubs) were interpreted as a cessation of activity in the 1987–2002 period, but some of these turned out to be fallow stages and plots were cultivated again in 2012. Changes from crop to woody covers (shrublands or forests) were found to be stable transitions since woody plant encroachment in 2002 continued in 2012 (except cases related to changes to impervious surfaces in 2012). Therefore, changes from herbaceous crops to shrublands or forests covers between two dates were selected as abandoned areas. Mean producer accuracy (i.e. for a given category, the percentage of pixels in test areas which have been correctly classified) and mean user accuracy (i.e. for a given category, the percentage of pixels on the classified map which correctly appears in test areas) of the three land cover classifications (1987, 2002, 2012) are shown in Table 1, although natural vegetation covers were treated as one entire category to identify abandoned crop covers.

In order to avoid, as far as possible, including misclassified pixels in the statistical analysis, classifications were filtered using a confusion index (Burrough, van Gaans, & MacMillan, 2000; Lewis, Brown, & Tatnall, 2000; Tapia, Stein, & Bijker, 2005; Álvarez-Martínez, Stoorvogel, Suárez-Seoane, & de Luis Calabuig, 2010). This index was calculated with the kNN algorithm in which the nearest training pixels (k-nearest neighbors) to each target pixel (to be classified) are identified by means of the Euclidean distance in the data space (Vidal-Macua et al., 2017). Values of this index range from 0 to 1, so that values close to 1 indicate high confusion between at least two classes, and values close to 0 represent high certainty for a classified pixel. We used a threshold of 0.5 so that pixels classified with a confusion index over this value where masked to exclude them from the land-cover maps.

A second mask was created to remove misregistration in land-cover polygon boundaries. This situation is related to some unavoidable location inaccuracy after the geometric correction (that cannot provide a zero planimetric error), and therefore, to false positive or negative changes between land-cover classifications (Pons, Serra, & Saurí, 2003) in pixels being at the borders between polygons. To solve this, classification polygon boundaries were eroded with a 20 m buffer mask according to the average RMS error of the geometric correction of the imagery. More details about this methodology can be found in Serra, Pons, and Saurí (2003).

Table 2
Number of presence events by study area and period.

	Rainfed herbaceous crops	Irrigated herbaceous crops
	Presence events	Presence events
Pyrenees		
1987–2002	1361	648
2002–2012	2197	735
1987–2012	2039	857
Central Ebro Basin		
1987–2002	392	42
2002–2012	308	46
1987–2012	505	169

Table 3
Explanatory variables.

Variable code	Description	Units
Altitude	Altitude	Meters
Slope	Terrain slope	Degrees
Curv	Overall terrain curvature	Dimensionless
VRM	Terrain roughness	Dimensionless
TWI	Topographic Wetness Index	Dimensionless
Win_SRad	Winter solar radiation	10 kJ m^{-2}·day^{-1}
Sum_SRad	Summer solar radiation	10 kJ m^{-2}·day^{-1}
Dist_ProCa	Cost distance to province capitals	Meters
Dist_UrbA	Cost distance to urban areas	Meters
Dist_SecRo	Cost distance to secondary roads	Meters
Dist_MajRo	Cost distance to major roads	Meters
P_20_55	Population between 20 and 55 years old	Percentage
P_m55	Population aged 55 years or over	Percentage
RNI	Rate of natural increase	(births-deaths)·100/ population size
AWU	Worked hours on an agricultural holding (1800 h = 1 AWU)	AWU/population size
AcCap	Accommodation capacity	n° of beds/population size
Wr_ALF[a]	Workers in primary sector	Wr_ALF/population size
Wr_InE[a]	Workers in industry and energy sector	Wr_InE/population size
Wr_Bld[a]	Workers in building sector	Wr_Bld/population size
Wr_Ser[a]	Workers in services sector	Wr_Ser/population size
S6_80_02_5 (example)	Every drought variable is coded as follows: "S6" - First two digits indicate the SPEI time-scale (6 or 24) "80_02" - Span of years used to calculate drought occurrence "5" - Last digit indicates drought episode duration	Number of drought episodes

[a] These variables were only used in the periods 2002–2012 and 1987–2012 due to the unavailability of data before 2002.

Finally, classifications were overlaid to identify abandonment of irrigated and rainfed crops for the two ambits (Central Pyrenees and Central Ebro Valley) and three periods (1987–2012, 1987–2002 and 2002–2012), which resulted in 12 initial models to be evaluated. We considered crop-cover changes as absence/presence events. Areas where the crop cover remained stable between two dates were treated as absences, and those where there were changes to vegetation covers were treated as presences. Once the abandoned and non-abandoned areas were established, stratified random sampling was carried out maintaining the prevalence (the same number of points) between the two types of events. Points were randomly selected for each event class with a minimum distance of 1 km between points. As expected, there were far fewer abandonment events in the Central Ebro Basin (Table 2). Therefore, for irrigated herbaceous crops in the Central Ebro Basin, we only considered the 1987–2012 period to develop the land-abandonment model. The same number of absence events as presence events were selected for all cases.

2.3. Explanatory variables

A set of variables was chosen (Table 3) to be included as explanatory factors for agricultural abandonment in the studied areas. The intention was to identify the most important variables and use statistical inference to describe the abandonment according to the value range of the variables. The MiraMon 8.1 (Pons, 2006), ArcGis 10.1 (ESRI 2012) and SAGA 2.1.2 (Conrad et al., 2015) software were used to calculate these variables.

2.3.1. Topography-derived variables

These variables are related to physical and environmental factors that could influence agricultural abandonment. The intention was to determine how the agricultural activity is affected by the environmental variability derived from the topography and its vulnerability in different topo-climatic contexts. Slope, curvature and terrain roughness can be used as proxies of the physical constraints to agricultural production, as well as the topography effect on the amount of incident solar radiation can help to identify thresholds in crops performance since solar radiation is related to factors such as the water evapotranspiration.

A 10 m Digital Elevation Model (DEM) was created from 1:5000 map sheets of the Aerial Orthophotography National Plan 2010 (PNOA) and the following variables were derived from it:

- Altitude in meters above sea level.
- Terrain slope in degrees.
- Overall terrain curvature (dimensionless). The 0 value means no curvature in a typical range from −5 to 5, where negative values represent concave curves and positive values indicate convex curves.
- Terrain roughness (dimensionless), using the Vector Ruggedness Measure (Sappington, Longshore, & Thompson, 2007), for which values close to 0 represent flat areas in an approximate range from 0 to 0.20 in our ambits.
- Topographic Wetness Index (dimensionless), which is a DEM-based soil moisture index (Beven & Kirkby, 1979; Kopecký & Čížková, 2010; Sörensen et al., 2006) that generally ranges from 3 to 30, where higher values indicate higher moisture availability.
- Winter and summer solar radiation (units in 10 kJ m^{-2}·day^{-1}), which calculates the total amount of incident solar radiation for each pixel at winter and summer solstice dates, following the methodology of Pons and Ninyerola (2008).

2.3.2. Distance variables

Four variables were obtained as a measure of land accessibility: cost distance to province capitals, urban areas, major roads and secondary roads. Cost distance is calculated for each cell as the lowest accumulative cost to the nearest target feature (urban areas, major roads, etc.) weighting the Euclidean distance by the slope (ESRI, 2012) and an impedance factor to movement depending on cell values (such as major roads, secondary roads or background) given a cost surface.

2.3.3. Municipality-level information

Nine variables were elaborated from INE (Spanish Statistical Office) data at a municipality level as factors that can influence agricultural abandonment:

- Percentage of population between 20 and 55 years old. We relate this age group to the economically active population.
- Percentage of population aged 55 years or over. Economically inactive population taking into account possible early retirements.
- Rate of natural increase. The birth rate minus the death rate by population size. For these first three variables, the fifth year prior to the last year of each period was chosen as the reference year (1997 and 2007).
- Annual work units. This variable relates hours worked on an agricultural holding to population size (http://ec.europa.eu/eurostat/statistics-explained/index.php). These data are only available for the Agricultural Census of 1999 and 2009.
- Accommodation capacity. The number of beds in tourist accommodations divided by population size. Given the restricted

availability of these data, the reference years are 2000 and 2010.

- Four variables accounting for the number of workers in the primary sector (agriculture, livestock and fishing), industry and energy sector, building sector and services sector, weighted by population size. These variables were used only in the 2002–2012 and 1987–2012 periods, evaluating additional models, because data before 2002 were unavailable.

2.3.4. Variables representing recurrent drought episodes based on the Standardized Precipitation Evapotranspiration Index

A set of variables indicating recurrent drought episodes was generated based on the Digital Topo Climatic Drought Atlas of the Spanish Iberian Peninsula (Domingo-Marimon, 2016). The Atlas includes a set of Standardized Precipitation Evapotranspiration Index (SPEI) maps at 100 m spatial resolution for the entire Iberian Peninsula from 1950 to 2012. The SPEI (Vicente-Serrano, Beguería, & López-Moreno, 2010) is based on precipitation and mean temperature (to estimate potential evapotranspiration) and quantifies water deficits for multiple timescales. The values are standard deviations and negative values indicate less than average precipitation, i.e. drought events, while positive values indicate greater than average precipitation, i.e. wet events. A threshold of SPEI ≤ -1 was selected to identify drought conditions, which end as soon as the SPEI > -1 again. The index can be computed at several timescales corresponding to drought specific conditions.

A first set of variables was generated using SPEI at a 6-month timescale from 1980 to 2012 as indicative of the medium-term moisture condition, to first identifies anomalies in the water streamflow. A second set of variables was generated using SPEI at a 24-month timescale from 1980 to 2012 as indicative of the long-term moisture condition, to identify reservoir level and ground water level anomalies. For both sets, the number of drought episodes (SPEI ≤ -1) with durations of a minimum of 4, 5, 7 or 8 consecutive months, as representative lengths that may cause harmful effects, were counted for the period 1980–2012. The number of drought episodes was also counted for year spans of 15 and 10 years from 1987 to 2012. Therefore, the year spans used were: 1980–2012, 1997–2012 and 2007–2012. In addition, the analysis was performed using two shorter sub-periods, 1987–2002 and 2002–2012, and their corresponding year spans: 1980–2002, 1987–2002, 1992–2002 and 1980–2012, 1997 2012 and 2002–2012 respectively. Including several year spans allows us to analyze how a greater or lesser drought frequency influences forest dynamics and whether recent droughts (during the last 10 years) have had any effect on transition.

2.4. Variable subset selection

A collinearity analysis was carried out before the models were run to avoid the presence of correlated drought variables and to reduce processing times. The initial set of 24 drought variables was resized for each model using an alternative way to correlate coefficient estimates. We used Variance Inflation Factors (VIF) and a VIF threshold of 5 as other authors recommend (Zuur et al., 2009; O'brien 2007; James, Witten, Hastie, & Tibshirani, 2013).

2.5. Data analysis

To identify the most important variables and to quantify their influence on land abandonment we used boosted regression trees (BRT). BRT is a tree-based method combined with the strength of boosting (Breiman et al., 1984; Freund & Schapire, 1996; Hastie and Tibshirani, 2009; James et al., 2013). By boosting, hundreds or thousands of trees are built using a random fraction of the observations in each new tree, using a different random subset of variables in each of them. Trees are not fitted individually but additively because each new tree is fitted to the residuals of the previous tree. The procedure to sequentially build trees is based on a series of rules that weigh observations depending on their error rate after the previous tree is fitted (Friedman, 2002; Hastie and Tibshirani, 2009). Each new tree is focused, then, on observations that have been poorly predicted.

The bag fraction is the BRT parameter that controls the randomly selected observations for each new tree. We used a bag fraction of 0.5 (50% of the observations) as suggested in Friedman (2002) and Elith et al. (2008) after several testbeds were applied. The other main parameters of the BRT models are: tree complexity, learning rate and number of trees. Tree complexity is the number of splits allowed for fitting at each iteration (tree) and is related to the interaction level between variables. A tree complexity of 1 means that all trees are composed of single candidate variable (which might differ from one tree to another) and no interaction with other variables is allowed. Instead, an overly complex tree (involving many variables) could overfit the training data and devalue predictions in a test dataset. The learning rate parameter works like shrinkage techniques in other linear models (James et al., 2013; Hastie and Tibshirani, 2009), scaling the contribution of each new term (i.e. the constituent trees) in the additive model by a factor between 0 and 1. A low learning rate allows more complex trees to be added gradually without overfitting the model, thus diverse interaction structures are taken into account in the additive model. Finally, the optimal number of trees depends on the choice of the two previous parameters. Normally, low learning rates, in a range of 0.001–0.01, imply that the number of trees needs to be increased to achieve a good performance (James et al., 2013; Elith et al., 2008; Hastie and Tibshirani, 2009), although a validation procedure is recommended (Ridgeway, 2007). Prediction for a single observation is the sum of predictions over all trees weighted by the learning rate.

BRTs were applied in R software using the *dismo* package (Elith et al., 2008), which is based on the *gbm* package (Ridgeway, 2007). In order to determine the best parameterization for each crop-cover abandonment model, we ran a model for all possible combinations of learning rates 0.001, 0.0025, 0.005, 0.01, 0.015, 0.03 and tree complexities from 1 to 5. For each of these models the optimal number of trees was identified by a 10-fold cross-validation (Elith et al., 2008), setting the maximum to a 15 000-tree model. Once the optimal number of trees had been identified, the predictive performance was recorded using the deviance (Friedman, 2002; Ridgeway, 2007; Elith et al., 2008; Hastie and Tibshirani, 2009). We calculated the deviance by applying a 10-fold cross-validation, and the model with the lowest deviance value was selected to obtain and interpret the results. In addition, in the results section we show the prediction performance of the selected models (those with the lowest deviance) again using a 10-fold cross-validation to represent the ROC (Receiver Operating Characteristic) curve and to calculate the AUC (Area Under the Curve) score (Fawcett, 2004; Hanley & McNeil, 1982; Pontius & Parmentier, 2014). This procedure allows to evaluate the robustness of the selected models by checking the balance between true positives (fraction of presence events that are correctly identified) and false positives (fraction of absence events that are incorrectly classified as presence events). The ROC curve represents this balance for all possible probability thresholds in order to find the optimal one that maximizes the true-positive rate and minimizes the false-positive rate. The AUC is a summary metric that quantifies this balance in a range of 0–1 (Fawcett, 2004), where values close to 1 indicate a high predictive performance.

The initial results showed that slope and terrain roughness (*VRM*)

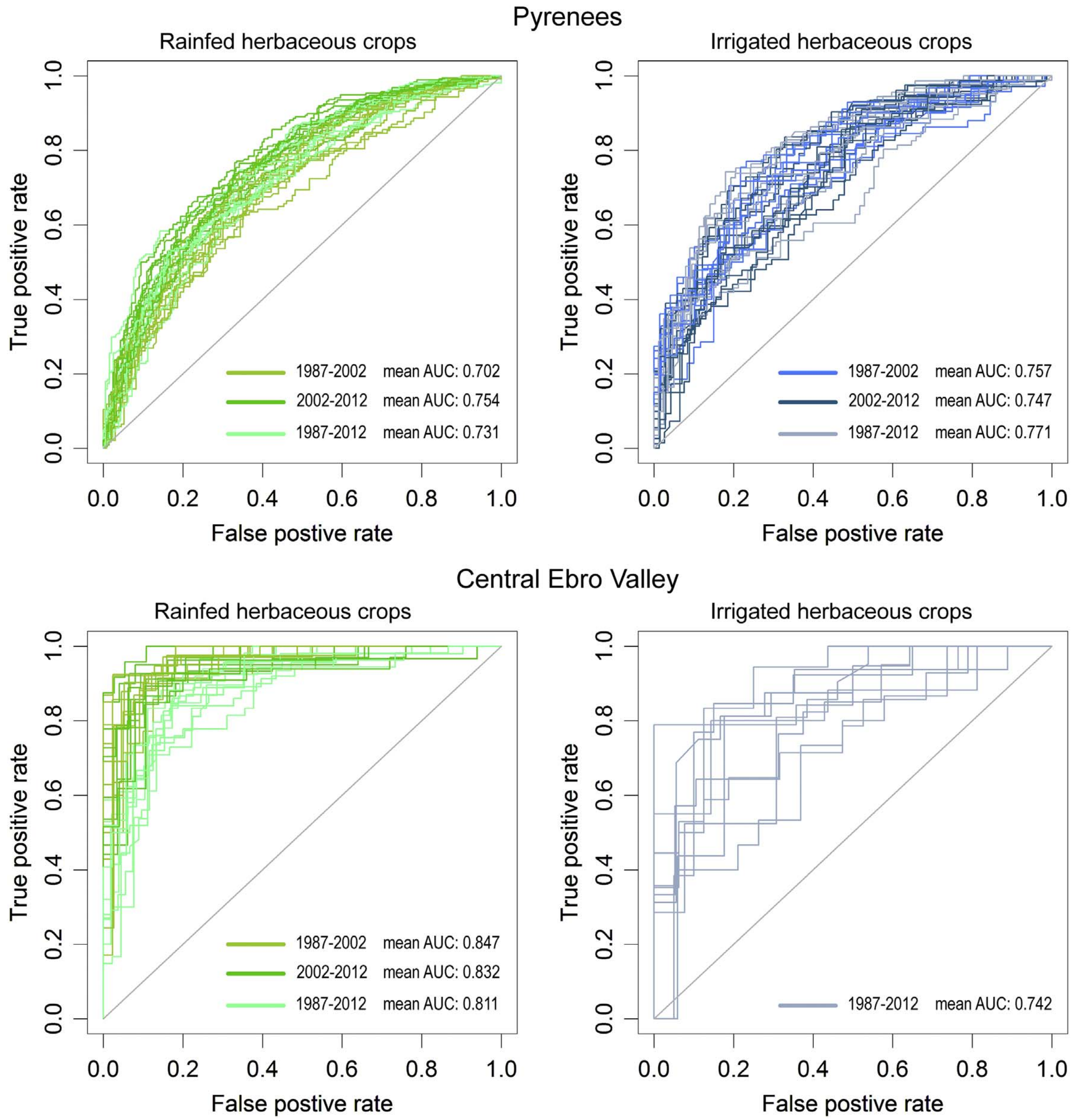

Fig. 3. ROC curve and AUC score calculated with the 10-fold cross-validation. Models with the lowest deviance value that do not include Slope and VRM variables.

were the variables that contributed most notably in almost all models (Figure A1 and Figure A2), so we decided to run an additional model that did not include these predictors. In other words, once the importance of slope and terrain roughness had been recognized, removing them from the analysis makes it more likely that other variables can appear as important contributors and, consequently, other interacting schemes may fit the models. Finally, we analyzed the results including the variables *Wr_ALF*, *Wr_InE*, *Wr_Bld* and *Wr_Ser* in models of the periods 2002–2012 and 1987–2012. Then, the results focused on models that did not include slope or *VRM* and models that considered the number of workers by economic sector.

To interpret the results, the importance of the predictors in the BRT models was determined by considering their contributions in the additive model. The relative importance was measured based on the number of times a predictor was selected for splitting, weighted by the squared improvement to the model as a result of each split, and averaged by the number of trees (Friedman & Meulman, 2003; Hastie and Tibshirani, 2009). Then, results were scaled between 1 and 100.

The probability of a land abandonment event was modeled via the *logit* of a logistic regression (James et al., 2013; Elith et al., 2008). The relationship between the land abandonment and an explanatory variable was interpreted using dependence plots, which is a visualization of the fitted functions in a BRT model. This graphical output shows the effect of an explanatory variable after the average effects of all other variables are accounted for, using the weighted tree traversal method described in Friedman, 2001 (Ridgeway and Ridgeway, 2004). Thus, these plots show which areas are most likely to be abandoned regarding the value range of the variables.

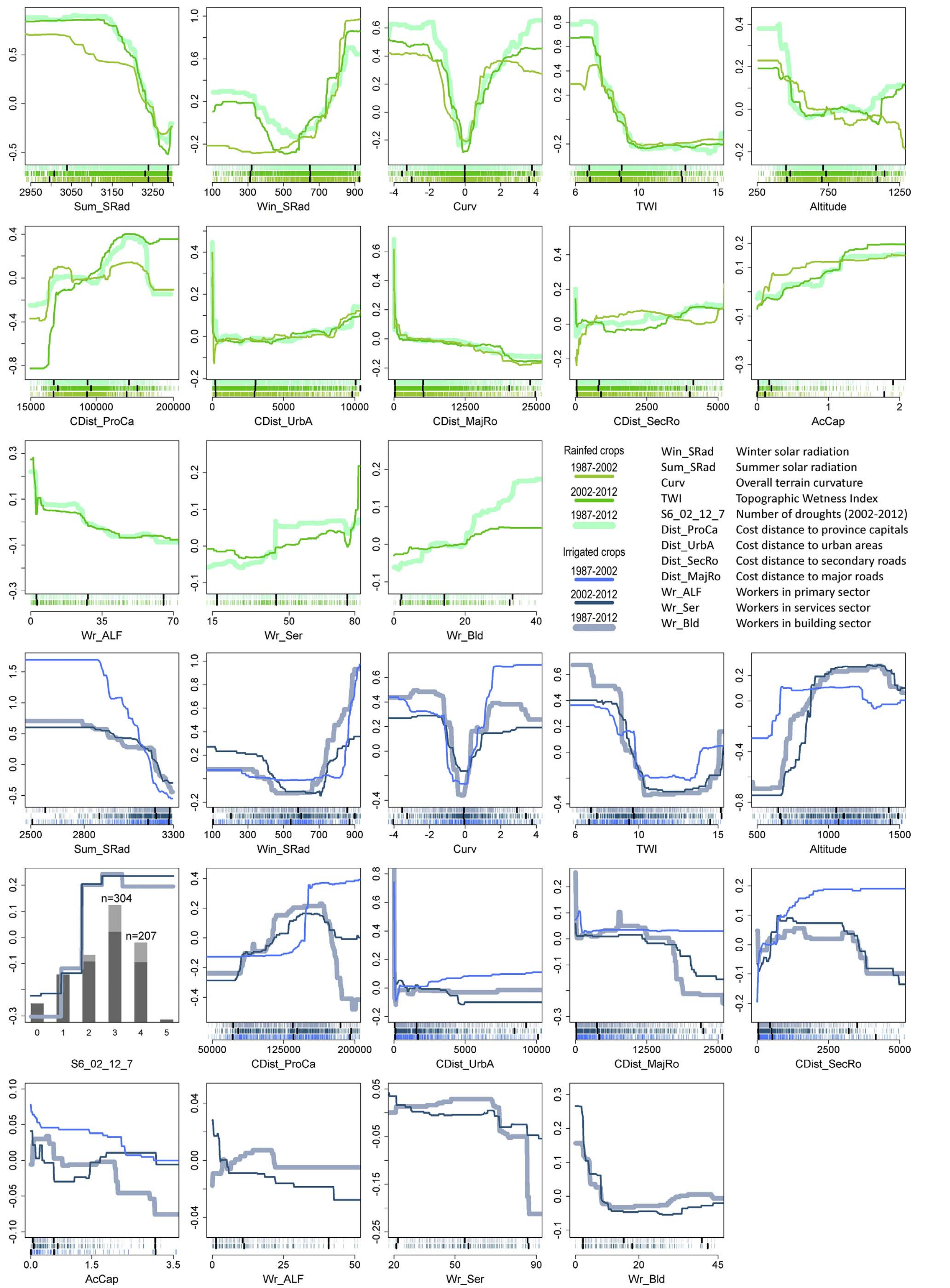

Fig. 4. Dependence plots for agricultural abandonment in the Central Spanish Pyrenees. The density of presence events is represented by vertical lines above the x-axes, and overlaid solid black ticks depict the 0.05, 0.5 and 0.95 percentiles.

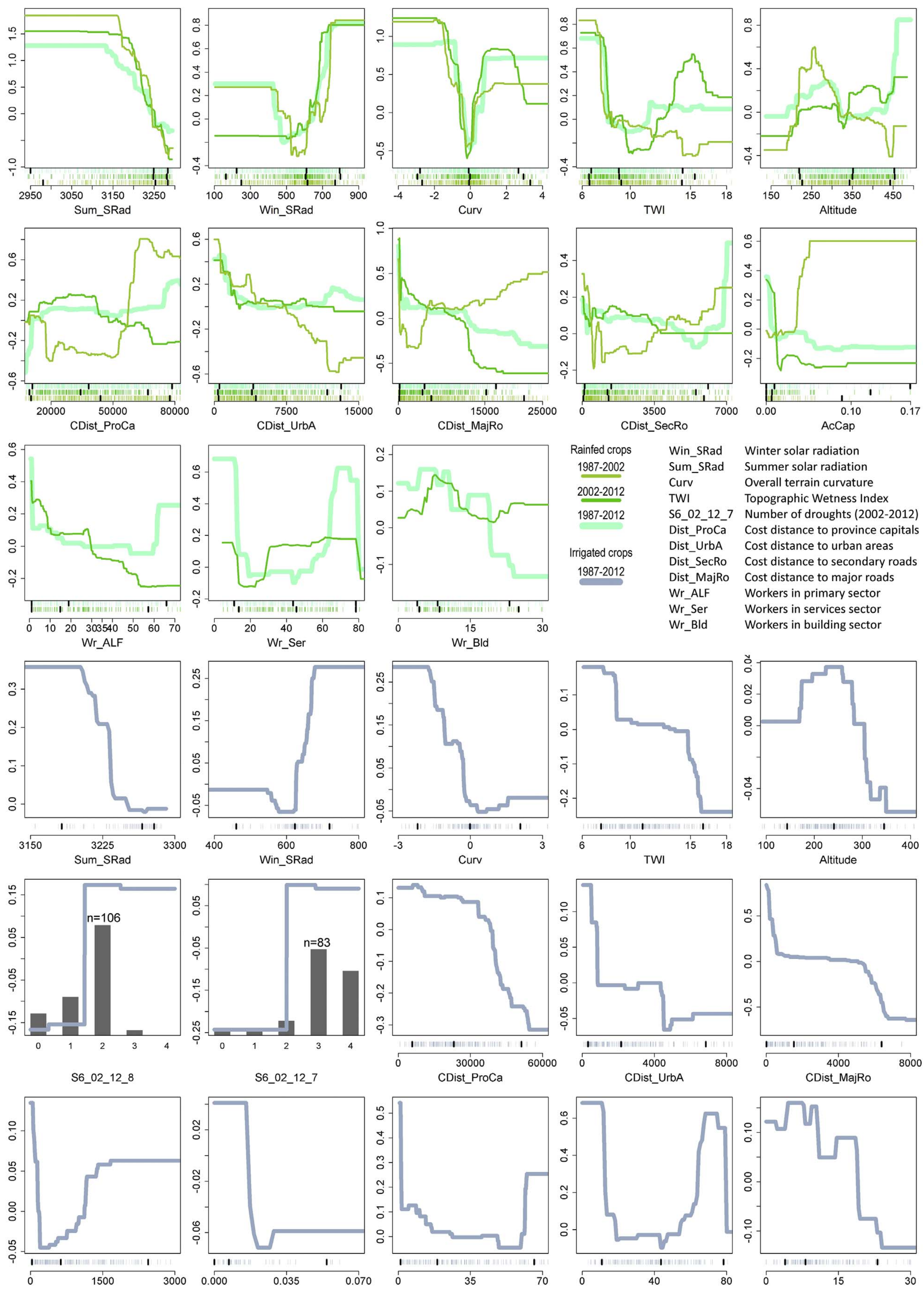

Fig. 5. Dependence plots for agricultural abandonment in the Central Ebro Basin. The density of presence events is represented by vertical lines above the x-axes, and overlaid solid black ticks depict the 0.05, 0.5 and 0.95 percentiles.

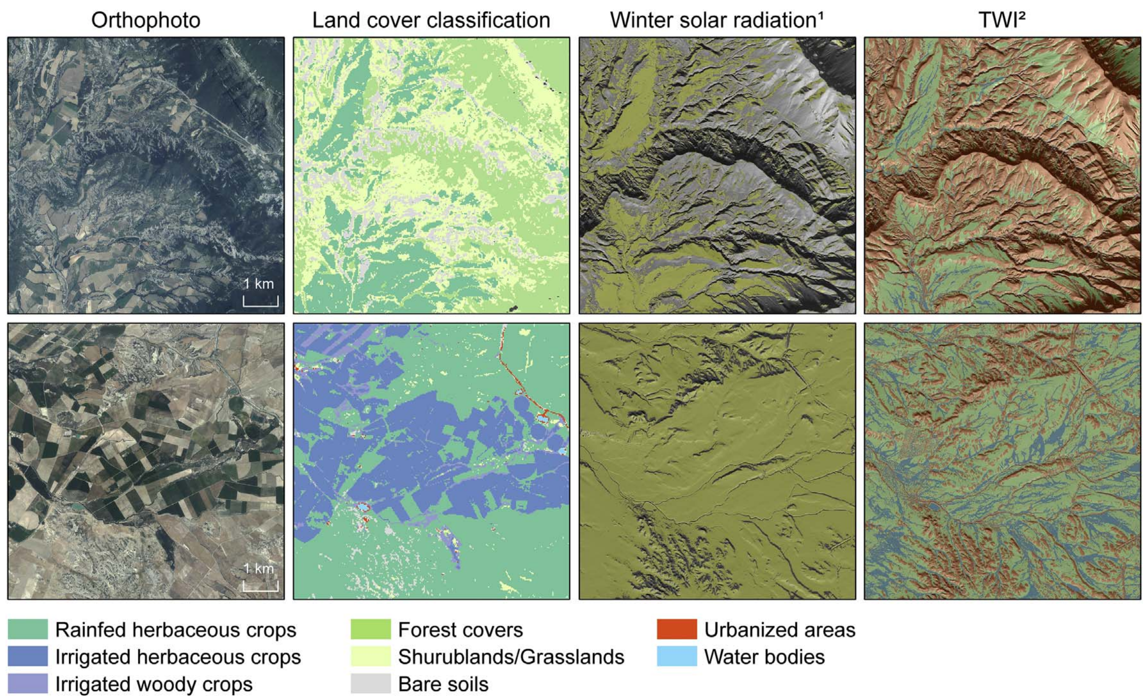

Fig. 6. Land cover classification, solar radiation and TWI spatial distribution in a representative area of the Central Pyrenees (top row) and Central Ebro Basin (bottom row). [1] *Win_SRad*: yellow color depicts low fitted values of land abandonment (between 500 and 700 10 kJ m^{-2}·day^{-1}). [2] *TWI:* red color depicts high fitted values of land abandonment in all models (below 9), green color depicts low fitted values (from 9 to 12.5), and blue color depicts high fitted values of abandonment of rainfed crops in the Central Ebro Basin (above 12.5). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3. Results and discussion

All models have AUC scores above 0.70 (Table A1 of the Appendix). Fig. 3 shows the ROC curves and AUC scores calculated with the 10-fold cross-validation for the models that do not include the slope and VRM variables.

To synthesize the results, our analysis focuses on the five most important environmental and socioeconomic variables (Figure A3 and Figure A4 of the Appendix), and places emphasis on those with interpretable response patterns. In addition, we also include relevant information from models that include the variables *Wr_ALF*, *Wr_InE*, *Wr_Bld* and *Wr_Ser* (Figure A5 and Figure A6). Explanations are based on the fitted function that lies between the percentiles 0.5 and 0.95 of predictor values in presence events.

3.1. Environmental variables

Overall, the slope and terrain roughness (*VRM)* are the main explanatory variables in land abandonment. In models that do not include these two variables (Fig. 4 and Fig. 5), other environmental variables such as solar radiation (*Sum_SRad* and *Win_SRad*), terrain curvature (*Curv*) and Topographic Wetness Index (*TWI*) are the most important predictors, except for in the models of irrigated crops in the Central Ebro Basin, where *CDist_MajRo* retains 26% of the information. The response to these environmental variables is represented by patterns that depict the suitability of the terrain for agricultural activity (Gellrich & Zimmermann, 2007; Stoebner & Lant, 2014; Pazúr et al., 2014, Lieskovský et al., 2014). The influence of slope, terrain roughness and curvature on agricultural abandonment is related to accessibility to the land and the constraints to mechanization, intensification and, in general, agricultural production. The *Curv* dependence patterns for crops of the Central Basin (Fig. 5) suggest that concave curvatures tend to be more abandoned, which can be related to the development of poorly drained soils and the salinity problems linked to the lithology of the Ebro Depression (Herrero & Snyder, 1997; Nogués, Herrero, Rodríguez-Ochoa, & Boixadera, 2000; Pinilla, 2006). In this area, the topographic effect on water runoff represented by the *TWI* has an influence on rainfed crops (2002–2012 period) that could be related to the former causes. Like the other cases, these crops tend to be abandoned when there are low *TWI* values (indicating that soil moisture favors agricultural production), although there is a threshold for the concentration of soil moisture above which the effects could be negative (Fig. 6). Then, concave curvatures, which are prone to high soil moisture concentrations, could be an important constraint for rainfed crop production in the 2002–2012 period. The vulnerability to concave curvatures is also reflected in the irrigated crops of the Central Ebro Basin. On the other hand, flat valley bottom areas and gentle southern slopes are less likely to be abandoned in relation to the amount of incident solar radiation (Fig. 6).

Finally, it is worth pointing out that variables quantifying drought occurrence have a higher relative influence on abandonment of irrigated crops than on rainfed crops in both study areas for the periods 2002–2012 and 1987–2012. The most important drought variables (within the 5 first environmental variables) are *S6_02_12_7*, with a relative importance of 6–6.5% in the Pyrenees, and *S6_02_12_7* and *S6_02_12_8*, with a relative importance of 6.2% and 6.9% respectively in the Central Ebro Basin. While for rainfed crops, the maximum relative importance of drought variables is below 2.5%. Looking at the dependence plots, this means that the occurrence of medium-term droughts (SPEI at a 6-month timescale) of at least 7–8 months' duration is positively associated with abandonment of irrigated crops during the last decade (2002–2012). We consider these results as evidence of the decrease in efficiency of agriculture in these areas (García-Ruiz, López-Moreno, Vicente-Serrano, Lasanta, & Beguería, 2011). In the Mediterranean basin, in which the two study areas are located, an increase in temperatures has been reported while precipitation has remained stable or has decreased (López-Moreno, Beguería, & García-Ruiz, 2006; del Río et al., 2011; 2012). This has led to an increase in droughts (IPCC 2007, 2013; Vicente-Serrano et al., 2014) and a consequent reduction in crop yields, as has also been reported for other regions (Craft, Mahmood, King, Goodrich, & Yan, 2013). Similarly, it has resulted in a decrease in the water yield in the Ebro Basin (García-Ruiz et al., 2011; López-Moreno et al., 2011), which affects water supplies to irrigated lands. Moreover, high evaporation rates could increase salinity problems linked to irrigation (Metternicht & Zinck, 2008).

3.2. Distance and socioeconomic variables

The influence of cost distance to roads and urban areas can be interpreted differently according to the study areas. In the Pyrenean region (Fig. 4), remoteness from province capitals (*CDist_ProCa*), where external markets are located, is known to be one of the main determinants of land abandonment, which is reflected in the fitted functions for irrigated and rainfed crops. However, it should be noted that during the 1987–2002 period, the highest fitted values of abandonment for rainfed crops are related both to the nearest and the furthest distances from province capitals. Urban growth in other cities and villages (promoted by land-use conversion) seems to be the cause of the highest probabilities of abandonment for crops that are adjacent to built-up areas (*CDist_UrbA*). Outside this ring, land suitability tends to decrease as *CDist_UrbA* increases, especially for rainfed crops and during the 1987–2002 period for irrigated crops. This pattern is also reflected in the accessibility to secondary roads. It is reasonable to state therefore that these patterns reflect features of a local-based economy. The secondary road network connecting villages with small cities in this mountainous region configures a small-scale socioeconomic network (Benayas et al., 2007; Osawa, Kohyama, & Mitsuhashi, 2016). Locational factors could be decisive in maintaining farm household incomes when the farming workforce is elderly and/or without successors (MacDonald et al., 2000). Reducing costs leads to more isolated plots being abandoned or to land-use intensification around secondary roads and urban areas (Pointereau et al., 2008). On the other hand, the effect of isolation from province capitals and accessibility to major roads can be linked to large-scale forces of change (Benayas et al., 2007). Farm households in highlands are less influenced by modernization and agricultural competitiveness is lower due to the physical constraints. Alternatively, locations near major roads are more suitable for services and industrial activities connected with the main markets and, at the same time, they have more access to the demand from bigger cities. In this context, land owners are better able to adjust their economies to new opportunities.

The response to location factors in the Central Ebro Basin differs from that of the Pyrenees mainly due to the variability in patterns between periods. The results suggest that the land abandonment process in the Central Basin (Fig. 5) has had at least two chronological stages, which is clearly manifested in the rainfed crop models. During 1982–2002, abandonment occurred mostly as cost distance to the province capital and roads increased, although the closest locations were also abandoned. In the 2002–2012 period, the pattern shifted and abandonment clearly increased as cost distance decreased. This could be explained by supposing that cropland abandonment was a gradual process where remote plots were first abandoned due to their unfavorable location with respect to the economic network. However, other socioeconomic factors must be taken into account. After Spain's accession to the European Union (EU) in 1986, the Central Ebro Basin was one of the areas most affected by land-retirement programs of the Common Agricultural Policy (CAP) during the 1990–2000 period (Meza and Albisu 1996; Baylis, Peplow, Rausser, & Simon, 2008), which was a measure for production control and environmental protection. With these considerations, it is logical to suppose that less accessible plots would be the first ones to be abandoned. The attraction of the urban labor-market and new opportunities linked to favorable accessibility increased in importance during the 2002–2012 period as causes for croplands being abandoned, which is also reflected in irrigated crop patterns. This pattern can also be associated with the land conversion process, as is reported for other regions that have undergone urban expansion (Jiang, Deng, & Seto, 2012; Liu et al., 2017). Thus, abandonment did not only occur in marginal areas but also in accessible locations (Gellrich, Baur, Koch, & Zimmermann, 2007; Hatna & Bakker, 2011), which is also reflected in the *CDist_UrbA* plot. Access to secondary roads still plays an important role for irrigated crops, which may be due to the maintenance of irrigation infrastructures and production being more present in external markets (Pinilla, 2006).

In the Central Pyrenees, there are significant differences between rainfed and irrigated crops regarding variables related to economic sectors. Abandonment of rainfed crops is clearly more likely in those municipalities with a higher proportion of population working in the service industry (*Wr_Ser*) and building sector (*Wr_Bld*). Moreover, the probability of abandonment increases as accommodation capacity increases (*AcCap*). Development of alternative sectors to farm activities could then replace the source of incomes in rural households (Melendez-Pastor, Hernández, Navarro-Pedreño, & Gómez, 2014). Patterns in irrigated crops are less clear and even an opposite trend can be detected. These results suggest that socioeconomic diversification could enhance the viability and the capacity to adapt of irrigated crop production, which is consistent with other studies (Dax, 1998; Dax et al., 1995; MacDonald et al., 2000; Petrou, Pantziou, Dimara, & Skuras, 2007; Strijker, 2005). It could be considered that the value-added product of irrigated crops is higher than rainfed crops. As we mentioned before, irrigated crops in the Pyrenees are linked to livestock and the derived dairy products, which supply the internal market (at a small-scale), but are also highly valued by the seasonal tourism. At the same time, the services and building sectors also benefit from tourism, and seasonal complementary activities to agriculture raise the incomes of farm households. Nonetheless, special attention should be paid to activities such as tourism in order to minimize the possible negative impacts on these traditional land-uses and the related cultural landscape (Marín-Yaseli & Lasanta, 2003; Petrou et al., 2007); and like tourism, any land-use change or intensification should be developed on the basis of sustainable land-allocation decisions (Tenerelli & Carver, 2012).

In the Central Basin, the development of the services sector seems to have led to an economic adaptation during the years after EU accession (1987–2002), which is reflected in a higher probability of abandonment of rainfed crops as accommodation capacity (*AcCap*) increases (Fig. 5). On the other hand, the building sector (*Wr_Bld*) seems to have a significant weight in maintaining agricultural activity for both irrigated and rainfed crops, while new opportunities linked to the services sector (*Wr_Ser*) could promote agricultural abandonment. In other words, the economy of agricultural households could depend on part-time jobs related to the urban growth of the last decades and be completely readjusted through full-time work in the services sector. However, the Ushaped response pattern suggests that very low proportions (below the 0.5 percentile) of employees in the services sector are also associated with high land abandonment rates (Gellrich & Zimmermann, 2007) so that the least diversified municipalities are less able to maintain primary sector activities.

4. Conclusions

Agricultural abandonment in northeast Spain has been analyzed using BRT multivariate models. The study differentiates between abandonment of rainfed and irrigated crops in two different territorial contexts. Physical constraints derived from topography variables were shown to be main determinants of abandonment in all models except for irrigated crops in the Central Ebro Basin, where accessibility to major roads and province capitals are the factors that contribute most. BRT fitted functions have also allowed us to gain insights into the role played by other environmental and socioeconomic variables and to detect pattern shifts between the analyzed crops and periods.

Our results suggest that the increase in drier conditions predicted for the future could lead to lower yields in irrigated lands, especially in the Central Ebro Basin, where there has been a large investment into agricultural intensification through modern irrigation systems. Moreover, vegetation re-growth after abandonment of traditional activities in the Pyrenees decreases water run-off, which reduces reservoir storage and the water yield of the Ebro Basin (García-Ruiz et al., 2011; López-Moreno and García-Ruiz, 2007, López-Moreno et al., 2011, 2013). Thus, planning and land-management strategies should be efficiently designed in order to reduce environmental and social costs (Fernández-Comuñas and Arrojo 2000; García-Ruiz et al., 2011).

In a general way, land suitability in terms of other environmental factors is reflected by similar patterns for the two types of crops, although whether conditions are more or less favorable may vary depending on the interactions between variables (such as the response to terrain curvature and the Topographic Wetness Index) and other site features not accounted for in the study (e.g. lithology).

Socioeconomic conditions defining where abandonment occurs can be interpreted as due to diverse underlying causes, which in many cases are reflected in polarized patterns. From our results, it appears that agricultural activity in the Pyrenees is more dependent on accessibility to internal markets and networks, especially for rainfed crops. However, off-farm opportunities linked to favorable locations also seem to promote land abandonment. This is clearly manifested in the Central Ebro Basin where, in addition, an inflexion point between the two periods suggests that during the 2002–2012 period there was a readjustment of rural household economies (those where abandonment occurred) towards less traditional roles that are more dependent on the infrastructures and urban networks. The greater presence of CAP aids during the period 1987–2002 could explain this pattern shift, especially in the case of winter cereals, which are generally more dependent on these policies. In this sense, the integration of other socioeconomic determinants as, for example, the crop prices variability (Stoebner & Lant, 2014), could improve land-abandonment models, helping to interpret temporal and spatial pattern shifts. On the other hand, this study points out that economic diversification could contribute to the maintenance of cropland and, in general, to embed professional sectors into the rural context. This can be decisive in mountainous regions like the Pyrenees, where agriculture is more vulnerable to remoteness from external markets and the main urban areas.

Land abandonment is not always characterized by a linear relationship with the determinant factors, and it has been shown that this is even more evident when different types of land cultivation and territorial contexts are compared. Whatever the ultimate objectives in managing the rural environment, multidisciplinary approaches must be followed in order to gain an overall view, taking into account that a diverse range of territorial scales and thematic areas could be affected by the decisions made. The evaluations and perceptions of the inhabitants of these areas should be included in the decision-making process.

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Appendix

Table A1
AUC score by model. Rejected models in grey.

Pyrenees	Rainfed herbaceous crops			Irrigated herbaceous crops		
	1987–2002	2002–2012	1987–2012	1987–2002	2002–2012	1987–2012
Including Slope and VRM	0.728	0.781	0.760	0.779	0.775	0.798
Not including Slope and VRM	0.702	0.754	0.731	0.757	0.747	0.771
Including Workers by sector[a]		0.755	0.733		0.747	0.770
Central Ebro Valley						
Including Slope and VRM	0.867	0.867	0.833			0.767
Not including Slope and VRM	0.847	0.832	0.811			0.742
Including workers by sector[a]		0.824	0.815			0.727

[a] Wr_ALF, Wr_InE, Wr_Bld and Wr_Ser variables.

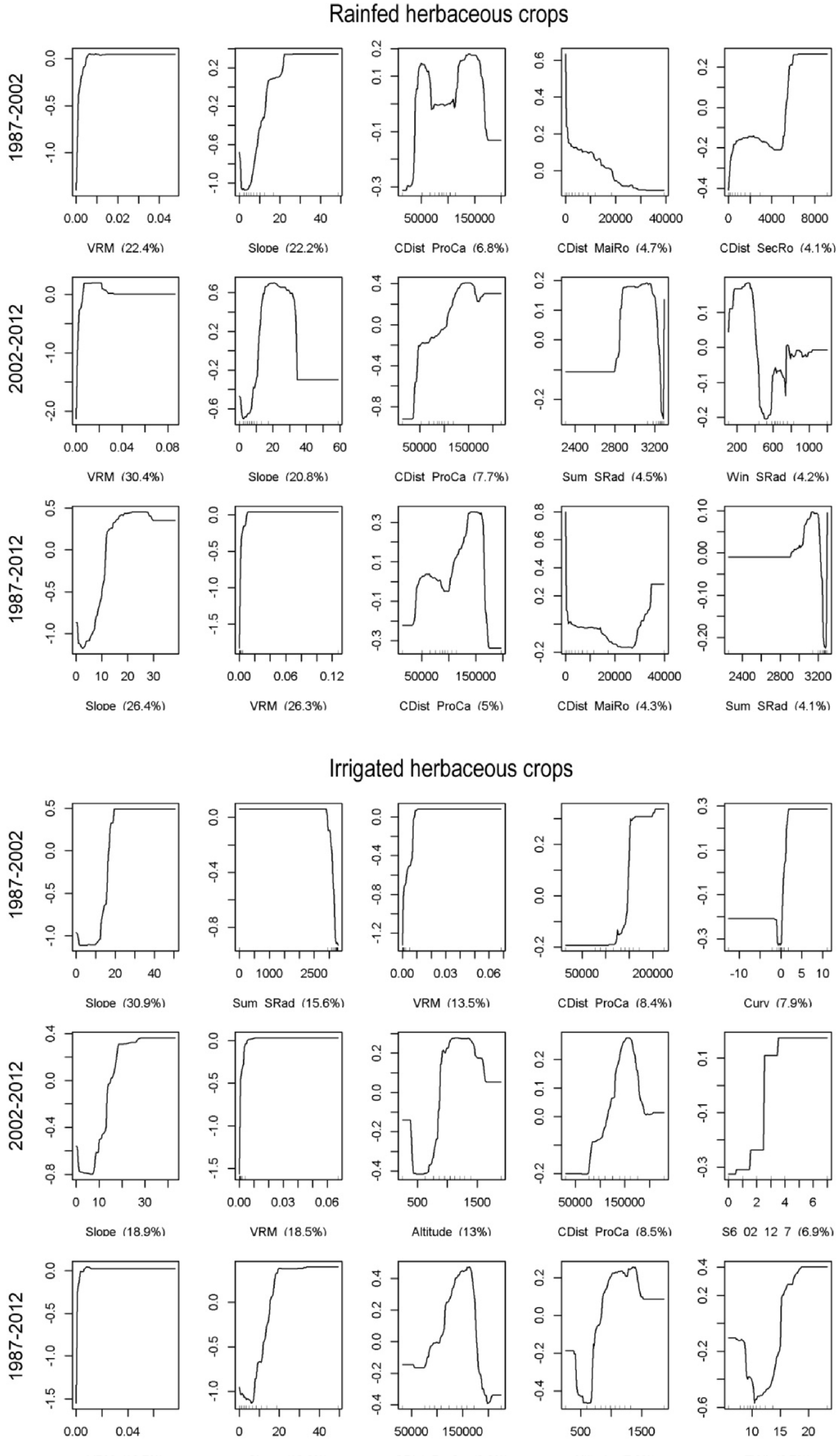

Fig. A1. Dependence plots and relative importance for the five most important variables in models that include Slope and VRM. Central Spanish Pyrenees.

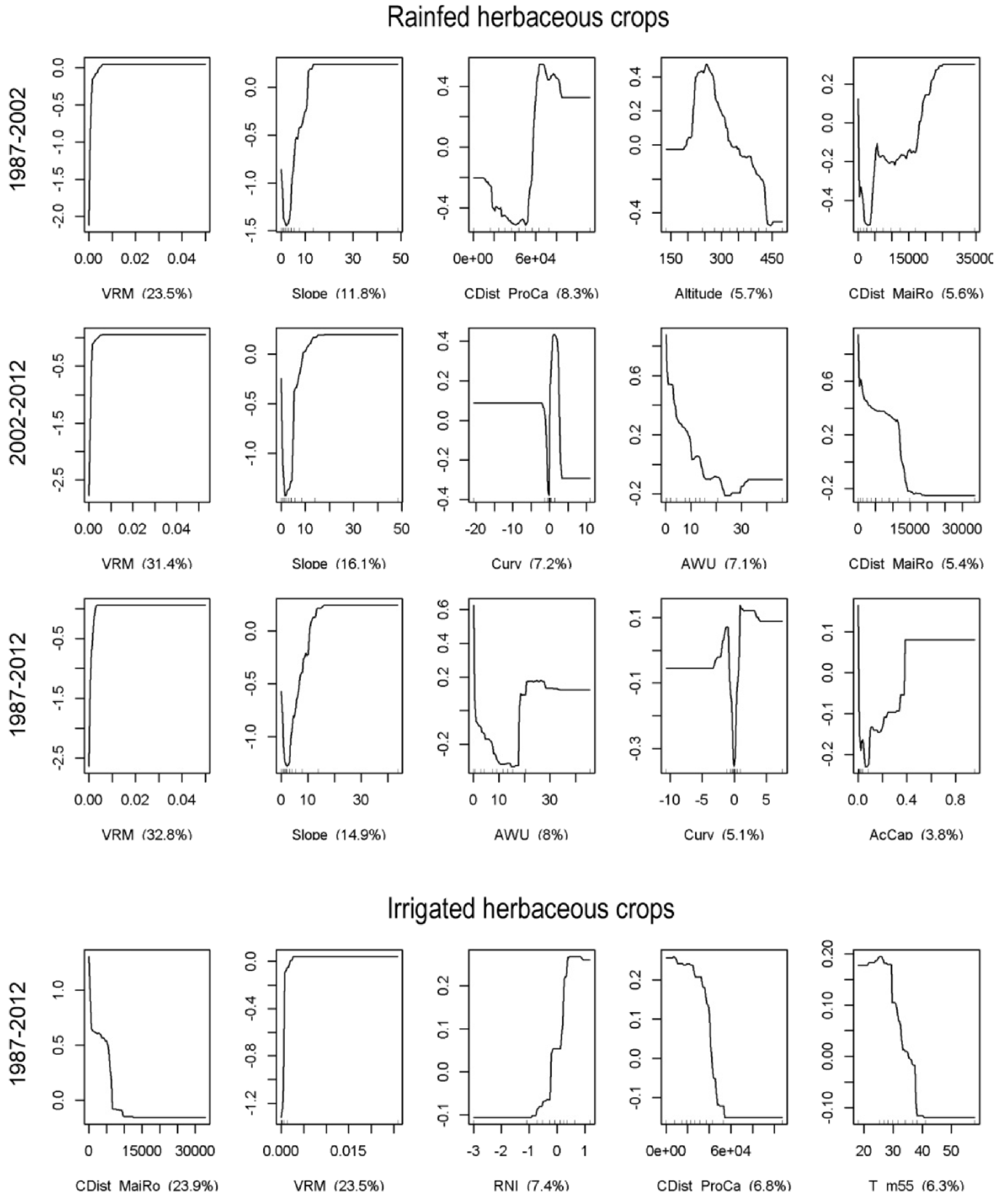

Fig. A2. Dependence plots and relative importance for the five most important variables in models that include Slope and VRM. Central Ebro Basin.

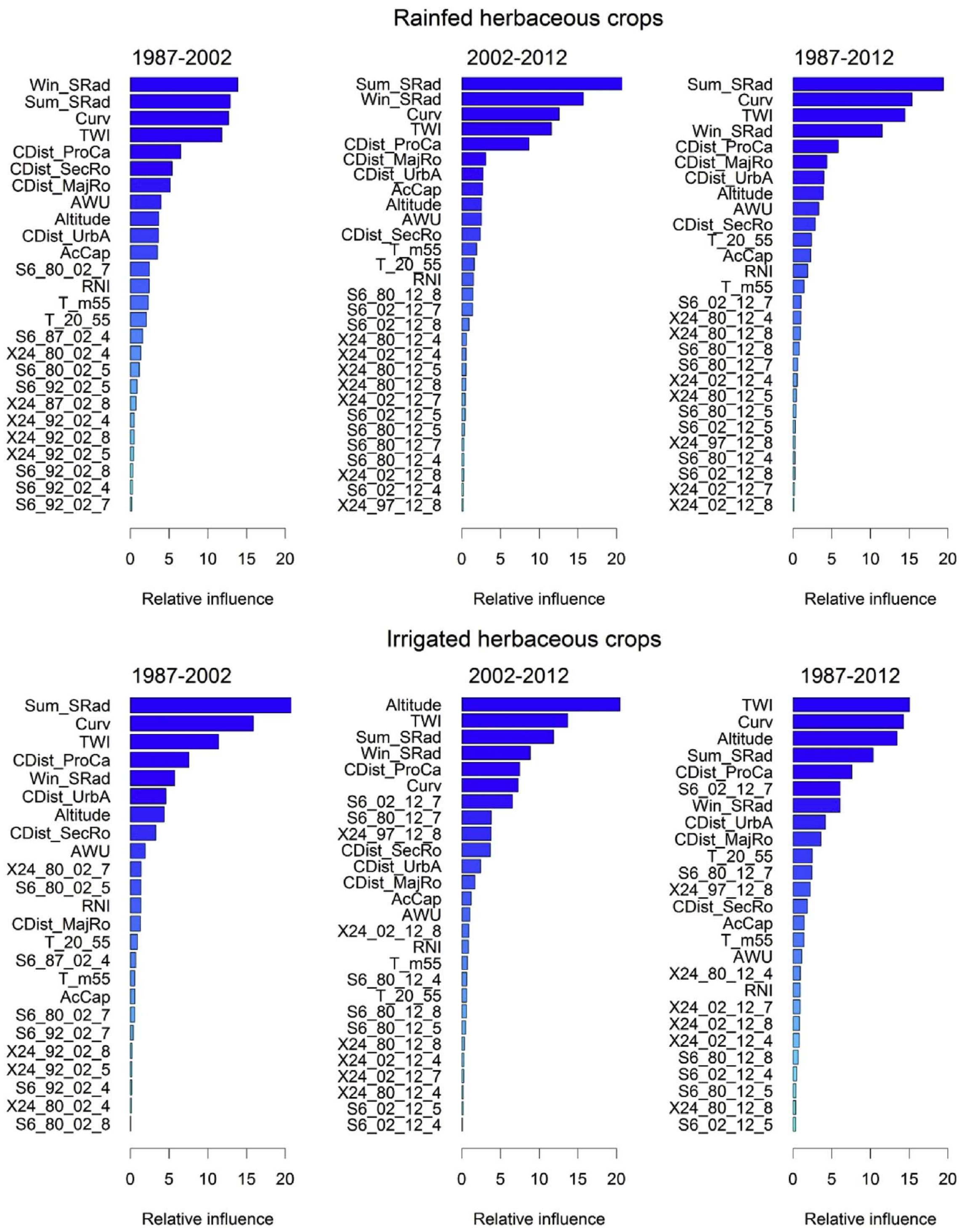

Fig. A3. Relative importance of variables in models that do not include Slope and VRM. Central Spanish Pyrenees.

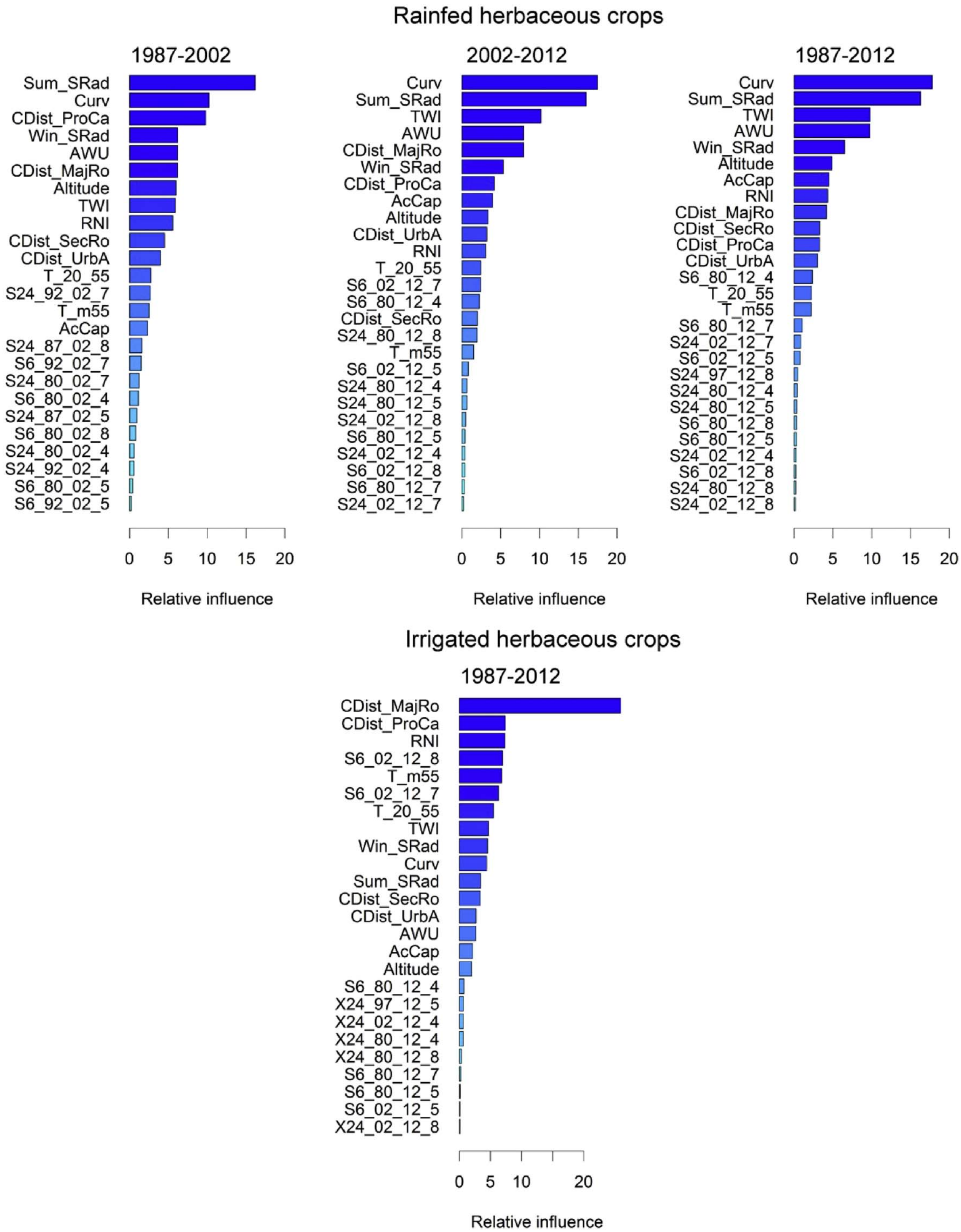

Fig. A4. Relative importance of variables in models that do not include Slope and VRM. Central Ebro Basin.

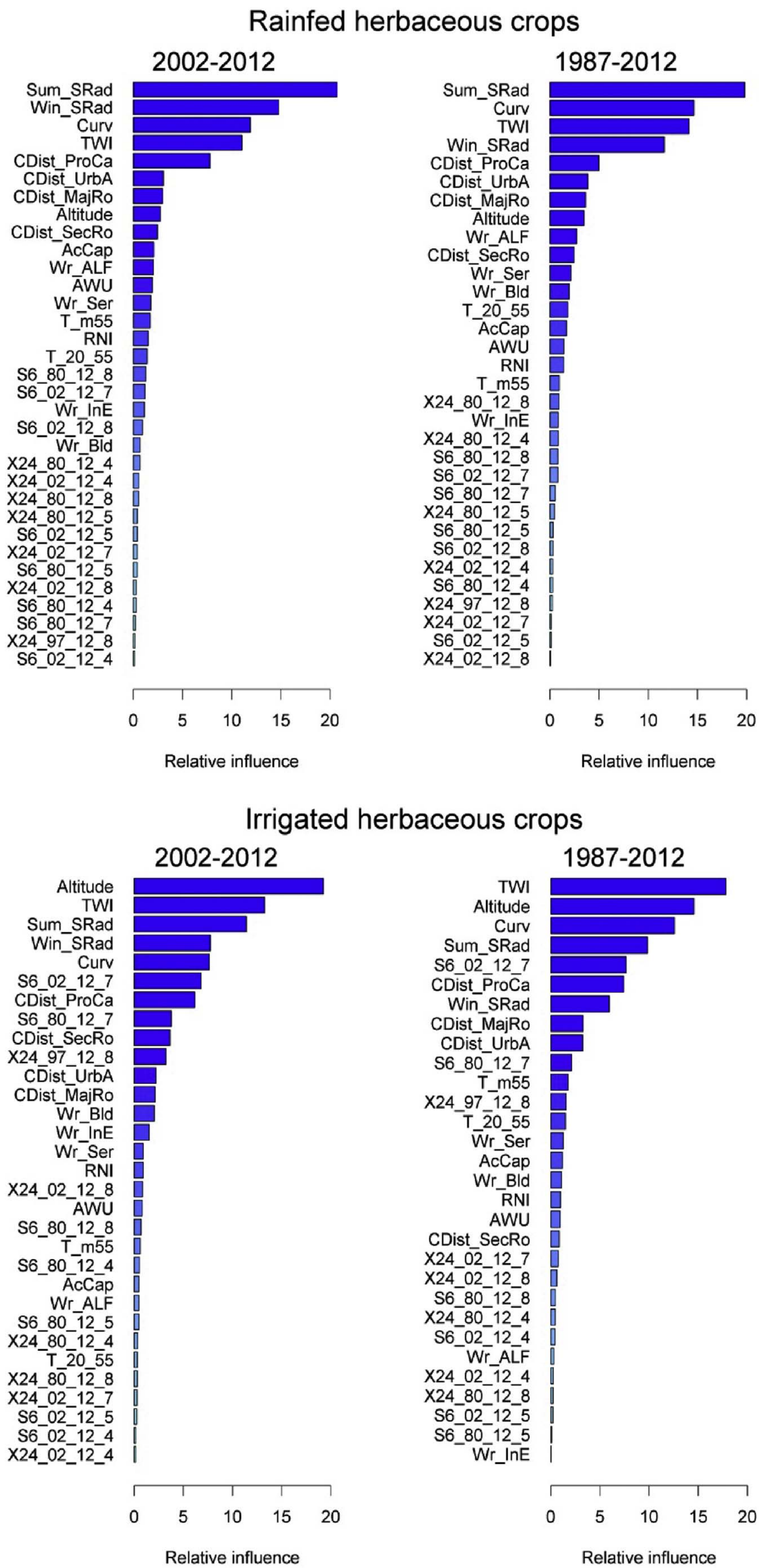

Fig. A5. Relative importance of variables in models that include the variables *Wr_ALF*, *Wr_InE*, *Wr_Bld* and *Wr_Ser*. Central Spanish Pyrenees.

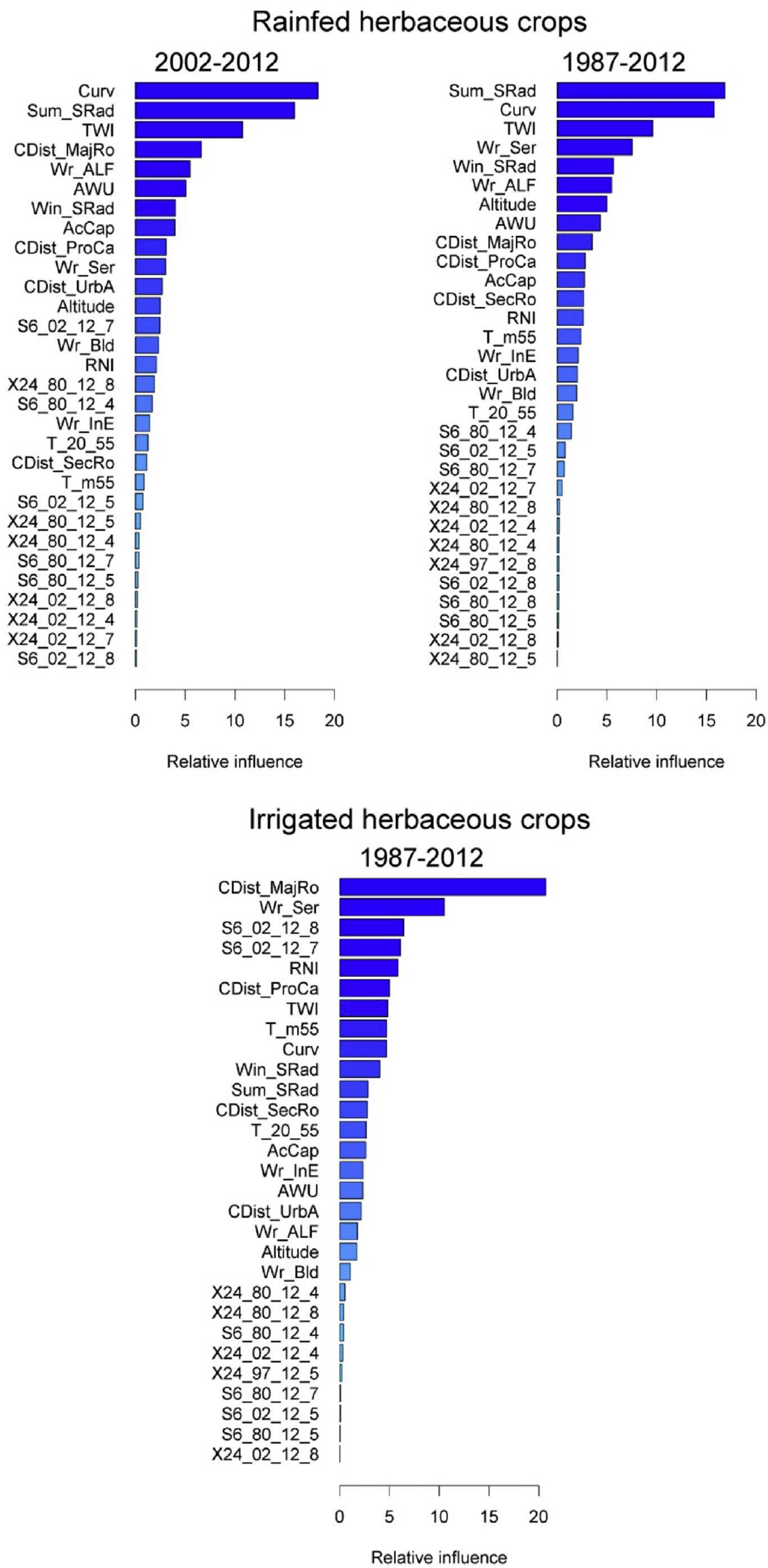

Fig. A6. Relative importance of variables in models that include the variables *Wr_ALF*, *Wr_InE*, *Wr_Bld* and *Wr_Ser*. Central Ebro Basin.

References

Álvarez-Martínez, J. M., Stoorvogel, J. J., Suárez-Seoane, S., & de Luis Calabuig, E. (2010). Uncertainty analysis as a tool for refining land dynamics modelling on changing landscapes: A case study in a Spanish natural Park. *Landscape Ecology, 25*(9), 1385–1404.

Baylis, K., Peplow, S., Rausser, G., & Simon, L. (2008). Agri-environmental policies in the EU and United States: A comparison. *Ecological Economics, 65*(4), 753–764.

Beilin, R., Lindborg, R., Stenseke, M., Pereira, H. M., Llausàs, A., Slätmo, E., et al. (2014). Analysing how drivers of agricultural land abandonment affect biodiversity and cultural landscapes using case studies from Scandinavia, Iberia and Oceania. *Land Use Policy, 36*, 60–72.

Benayas, J. R., Martins, A., Nicolau, J. M., & Schulz, J. J. (2007). Abandonment of agricultural land: An overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2*(57), 1–14.

Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. *Hydrological Sciences Journal, 24*(1), 43–69.

Bezák, P., & Halada, L. (2010). Sustainable management recommendations to reduce the loss of agricultural biodiversity in the mountain regions of NE Slovakia. *Mountain Research and Development, 30*(3), 192–204.

Bielsa, I., Pons, X., & Bunce, B. (2005). Agricultural abandonment in the north Eastern Iberian Peninsula: The use of basic landscape metrics to support planning. *Journal of Environmental Planning and Management, 48*(1), 85–102.

Breiman, L. (2001). Statistical modeling: The two cultures (with comments and a rejoinder by the author. *Statistical Science, 16*(3), 199–231.

Breiman, L., Friedman, J., Stone, C. J., & Olshen, R. A. (1984). *Classification and regression trees.* Monterey: Wadsworth & Brooks.

Burrough, P. A., van Gaans, P. F., & MacMillan, R. A. (2000). High-resolution landform classification using fuzzy k-means. *Fuzzy Sets and Systems, 113*(1), 37–52.

Cánoves, G., Villarino, M., Priestley, G. K., & Blanco, A. (2004). Rural tourism in Spain: An analysis of recent evolution. *Geoforum, 35*(6), 755–769.

Cohen, M., Varga, D., Vila, J., & Barrassaud, E. (2011). A multi-scale and multi-disciplinary approach to monitor landscape dynamics: A case study in the catalan pre-Pyrenees (Spain). *The Geographical Journal, 177*(1), 79–91.

Collantes, F., & Pinilla, V. (2004). Extreme depopulation in the Spanish rural mountain areas: A case study of Aragon in the nineteenth and twentieth centuries. *Rural History, 15*(2), 149–166.

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., et al. (2015). System for Automated geoscientific analyses (SAGA) v. 2.1.4. *Geoscientific Model Development*.

Craft, K. E., Mahmood, R., King, S. A., Goodrich, G., & Yan, J. (2013). Drought and corn in Kentucky. *Applied Geography, 45*, 353–362.

Crase, B., Liedloff, A. C., & Wintle, B. A. (2012). A new method for dealing with residual spatial autocorrelation in species distribution models. *Ecography, 35*(10), 879–888.

Dax, T. (1998). *Mountain farming and the environment: Towards integration; perspectives for mountain policies in central and eastern alps* Bundesanst. für Bergbauernfragen.

Dax, T., Loibl, E., & Oedl-Wieser, T. (1995). *Pluriactivity and rural development*, *35* Theoretical Framework. Forschungsbericht.

Del Río, S. D., Herrero, L., Fraile, R., & Penas, A. (2011). Spatial distribution of recent rainfall trends in Spain (1961–2006). *International Journal of Climatology, 31*(5), 656–667.

Del Río, S., Cano-Ortiz, A., Herrero, L., & Penas, A. (2012). Recent trends in mean maximum and minimum air temperatures over Spain (1961–2006). *Theoretical and Applied Climatology, 109*(3-4), 605–626.

Domingo-Marimon, C. (2016). *Contributions to the knowledge of the multitemporal spatial patterns of the Iberian Peninsula droughts from a Geographic Information Science perspective*Ph.D. thesis. Universitat Autònoma de Barcelona.

Duarte, R., Pinilla, V., & Serrano, A. (2014). The water footprint of the Spanish agricultural sector: 1860–2010. *Ecological Economics, 108*, 200–207.

Elith, J., Graham, C. H., Anderson, R. P., Dudík, M., Ferrier, S., Guisan, A., et al. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography, 29*, 129–151.

Elith, J., Leathwick, J. R., & Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology, 77*(4), 802–813.

Environmental Systems Research Institute (ESRI) (2012). *ArcGIS release 10.1.* (Redlands).

Farina, A. (2008). *Principles and methods in landscape ecology: Towards a science of the landscape*, *Vol. 3*. Springer Science & Business Media.

Fawcett, T. (2004). ROC graphs: Notes and practical considerations for researchers. *Machine Learning, 31*(1), 1–38.

Fernández-Comuñas, J., & Arrojo, P. (2000). *Biscarrués-Mallos de Riglos. Inundación o modernización.* Zaragoza: Egido editorial.

Fielding, A. J. (1989). Migration and urbanization in western Europe since 1950. *The Geographical Journal, 155*(1), 60–69.

Freund, Y., & Schapire, R. E. (1996). *Experiments with a new boosting algorithm. International conference of machine learning.* New Jersey, 22 January 1996.

Friedman, J. H. (2001). Greedy function approximation: A gradient boosting machine. *Annals of Statistics,* 1189–1232.

Friedman, J. H. (2002). Stochastic gradient boosting. *Computational Statistics & Data Analysis, 38*(4), 367–378.

Friedman, J. H., & Meulman, J. J. (2003). Multiple additive regression trees with application in epidemiology. *Statistics in Medicine, 22*(9), 1365–1381.

Gallart, F., & Llorens, P. (2004). Observations on land cover changes and water resources in the headwaters of the Ebro catchment, Iberian Peninsula. *Physics and Chemistry of the Earth, Parts A/B/C, 29*(11), 769–773.

García-Ruiz, J. M. (1990). *Geoecología de las Áreas de Montaña.* Logroño: Geoforma Ediciones.

García-Ruiz, J. M. (2010). The effects of land uses on soil erosion in Spain: A review. *Catena, 81*(1), 1–11.

García-Ruiz, J. M., & Lasanta, T. (1993). Land-use conflicts as a result of land-use change in the central Spanish Pyrenees: A review. *Mountain Research and Development,* 295–304.

Garcia-Ruiz, J. M., Lasanta, T., Ruiz-Flano, P., Ortigosa, L., White, S., González, C., et al. (1996). Land-use changes and sustainable development in mountain areas: A case study in the Spanish Pyrenees. *Landscape Ecology, 11*(5), 267–277.

García-Ruiz, J. M., López-Moreno, J. I., Vicente-Serrano, S. M., Lasanta, T., & Beguería, S. (2011). Mediterranean water resources in a global change scenario. *Earth-Science Reviews, 105*(3), 121–139.

Gellrich, M., Baur, P., Koch, B., & Zimmermann, N. E. (2007). Agricultural land abandonment and natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis. *Agriculture, Ecosystems & Environment, 118*(1), 93–108.

Gellrich, M., & Zimmermann, N. E. (2007). Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning, 79*(1), 65–76.

Gerard, F., Petit, S., Smith, G., Thomson, A., Brown, N., Manchester, S., & Boltiziar, M. (2010). Land cover change in Europe between 1950 and 2000 determined employing aerial photography. *Progress in Physical Geography, 34*(2), 183–205.

Halada, L., Evans, D., Romão, C., & Petersen, J. E. (2011). Which habitats of European importance depend on agricultural practices? *Biodiversity and Conservation, 20*(11), 2365–2378.

Hanley, J. A., & McNeil, B. J. (1982). The meaning and use of the area under a receiver operating characteristic (ROC curve). *Radiology, 143*(1), 29–36.

Hastie, T., & Tibshirani, R. I. (2009). *The elements of statistical learning: Data mining, inference and prediction.* Berlin: Springer.

Hatna, E., & Bakker, M. M. (2011). Abandonment and expansion of arable land in Europe. *Ecosystems, 14*(5), 720–731.

Herrero, J., & Snyder, R. L. (1997). Aridity and irrigation in Aragon, Spain. *Journal of Arid Environments, 35*(3), 535–547.

IAEST (2017). *Instituto Aragonés de Estadística.* Censos Agrarioshttp://www.aragon.es/iaest.

IDESCAT (2017). *Institut d'Estadística de Catalunya.* Censos Agrarishttps://www.idescat.cat/.

IPCC (2007). *Climate change 2007: The physical science basis. Contribution of working group I to the forth assessment report of the intergovernmental panel on climate change*Cambridge: Cambridge University Press.

IPCC (2013). Climate change 2013: The physical science basis. *Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge and New York: Cambridge University Press.

James, G., Witten, D., Hastie, T., & Tibshirani, R. (2013). *An introduction to statistical learning.* New York: Springer.

Jiang, L., Deng, X., & Seto, K. C. (2012). Multi-level modeling of urban expansion and cultivated land conversion for urban hotspot counties in China. *Landscape and Urban Planning, 108*(2), 131–139.

Kawakita, M., Minami, M., Eguchi, S., & Lennert-Cody, C. E. (2005). An introduction to the predictive technique AdaBoost with a comparison to generalized additive models. *Fisheries Research, 76*(3), 328–343.

Keenleyside, C., Tucker, G., & McConville, A. (2010). *Farmland abandonment in the EU: An assessment of trends and prospects.* London: Institute for European Environmental Policy.

Kopecký, M., & Čížková, Š. (2010). Using topographic wetness index in vegetation ecology: Does the algorithm matter? *Applied Vegetation Science, 13*(4), 450–459.

Kosmas, C., Kairis, O., Karavitis, C., Acikalin, S., Alcalá, M., Alfama, P., & Brito, J. (2015). An exploratory analysis of land abandonment drivers in areas prone to desertification. *Catena, 128*, 252–261.

Lasanta, T., Arnáez, J., Pascual, N., Ruiz-Flaño, P., Errea, M. P., & Lana-Renault, N. (2017). Space–time process and drivers of land abandonment in Europe. *Catena, 149*, 810–823.

Lasanta, T., Vicente-Serrano, S. M., & Cuadrat-Prats, J. M. (2005). Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: A study of the Spanish central Pyrenees. *Applied Geography, 25*(1), 47–65.

Leathwick, J. R., Elith, J., Francis, M. P., Hastie, T., & Taylor, P. (2006). Variation in demersal fish species richness in the oceans surrounding New Zealand: An analysis using boosted regression trees. *Marine Ecology Progress Series, 321*, 267–281.

Lewis, H. G., Brown, M., & Tatnall, A. R. L. (2000). Incorporating uncertainty in land cover classification from remote sensing imagery. *Advances in Space Research, 26*(7), 1123–1126.

Lieskovský, J., Kenderessy, P., Špulerová, J., Lieskovský, T., Koleda, P., Kienast, F., et al. (2014). Factors affecting the persistence of traditional agricultural landscapes in Slovakia during the collectivization of agriculture. *Landscape Ecology, 29*(5), 867–877.

Liu, X., Wang, Y., Li, Y., Liu, F., Shen, J., Wang, J., et al. (2017). Changes in arable land in response to township urbanization in a Chinese low hilly region: Scale effects and spatial interactions. *Applied Geography, 88*, 24–37.

Lloret, F., Calvo, E., Pons, X., & Díaz-Delgado, R. (2002). Wildfires and landscape patterns in the Eastern Iberian Peninsula. *Landscape Ecology, 17*(8), 745–759.

López-Moreno, J. I., Beguería, S., & García-Ruiz, J. M. (2006). Trends in high flows in the central Spanish Pyrenees: Response to climatic factors or to land-use change? *Hydrological Sciences Journal, 51*(6), 1039–1050.

López-Moreno, J. I., & García-Ruiz, J. M. (2007). In P. Robinson, J. A. A. Jones, & M. K. Woo (Eds.). *Hydrological effects of reservoirs in the central Spanish Pyrenees* (pp. 103–114). .
López-Moreno, J. I., Vicente-Serrano, S. M., Moran-Tejeda, E., Zabalza, J., Lorenzo-Lacruz, J., & García-Ruiz, J. M. (2011). Impact of climate evolution and land use changes on water yield in the Ebro basin. *Hydrology and Earth System Sciences, 15*(1), 311.
López-Moreno, J. I., Vicente-Serrano, S. M., Zabalza, J., Beguería, S., Lorenzo-Lacruz, J., Azorin-Molina, C., et al. (2013). Hydrological response to climate variability at different time scales: A study in the Ebro Basin. *Journal of Hydrology, 477*, 175–188.
MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., et al. (2000). Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management, 59*(1), 47–69.
Marín-Yaseli, M. L., & Lasanta, T. (2003). Competing for meadows: A case study on tourism and livestock farming in the Spanish Pyrenees. *Mountain Research and Development, 23*(2), 169–176.
Melendez-Pastor, I., Hernández, E. I., Navarro-Pedreño, J., & Gómez, I. (2014). Socioeconomic factors influencing land cover changes in rural areas: The case of the Sierra de Albarracín (Spain). *Applied Geography, 52*, 34–45.
Metternicht, G., & Zinck, A. (2008). *Remote sensing of soil salinization: Impact on land management.* CRC Press.
Meza, L., & Albisu, L. M. (1996). *Aspectos economicos de la retirada de tierras en Aragon.* Zaragoza: CSIC239–240 1995, por Sebastian Llompart. Agricultura y Sociedad.
Molinillo, M., Lasanta, T., & García-Ruiz, J. M. (1997). Managing mountainous degraded landscapes after farmland abandonment in the Central Spanish Pyrenees. *Environmental Management, 21*(4), 587–598.
Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., & Mouillot, F. (2011). Landscape–wildfire interactions in southern Europe: Implications for landscape management. *Journal of Environmental Management, 92*(10), 2389–2402.
Nainggolan, D., de Vente, J., Boix-Fayos, C., Termansen, M., Hubacek, K., & Reed, M. S. (2012). Afforestation, agricultural abandonment and intensification: Competing trajectories in semi-arid Mediterranean agro-ecosystems. *Agriculture, Ecosystems & Environment, 159*, 90–104.
Navarro, L. M., & Pereira, H. M. (2015). Rewilding abandoned landscapes in Europe. *Rewilding European Landscapes* (pp. 3–23). Springer International Publishing.
Nogués, J., Herrero, J., Rodríguez-Ochoa, R., & Boixadera, J. (2000). Land evaluation in a salt-affected irrigated district using an index of productive potential. *Environmental Management, 25*(2), 143–152.
Noun Project (2017). *Icons for everything.* https://thenounproject.com/.
Osawa, T., Kohyama, K., & Mitsuhashi, H. (2016). Multiple factors drive regional agricultural abandonment. *The Science of the Total Environment, 542*, 478–483.
O'brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality and Quantity, 41*(5), 673–690.
Pazúr, R., Lieskovský, J., Feranec, J., & Oťaheľ, J. (2014). Spatial determinants of abandonment of large-scale arable lands and managed grasslands in Slovakia during the periods of post-socialist transition and European Union accession. *Applied Geography, 54*, 118–128.
Petrou, A., Pantziou, E. F., Dimara, E., & Skuras, D. (2007). Resources and activities complementarities: The role of business networks in the provision of integrated rural tourism. *Tourism Geographies, 9*(4), 421–440.
Pinilla, V. (2006). The development of irrigated agriculture in twentieth-century Spain: A case study of the Ebro Basin. *Agricultural History Review, 54*(1), 122–141.
Pointereau, P. (2008). Analysis of farmland abandonment and the extent and location of agricultural areas that are actually abandoned or are in risk to be abandoned. *EUR-OP*.
Pons, X. (2006). *MiraMon. Geographical information system and remote sensing software.* Bellaterra: CREAF Research Center.
Pons, X., & Ninyerola, M. (2008). Mapping a topographic global solar radiation model implemented in a GIS and refined with ground data. *International Journal of Climatology, 28*(13), 1821–1834.
Pons, X., Serra, P., & Saurí, D. (2003). *A rigorous protocol for post-classification land cover and land use change detection. Geoinformation for European-wide integration.* Rotterdam: Millpress Science.
Pontius, R. G., & Parmentier, B. (2014). Recommendations for using the relative operating characteristic (ROC). *Landscape Ecology, 29*(3), 367–382.
Ramankutty, N., & Foley, J. A. (1999). Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles, 13*(4), 997–1027.
Ridgeway, G. (2007). Generalized boosted models: A guide to the gbm package. *Update, 1*(1), 2007.
Ridgeway, G., & Ridgeway, M. G. (2004). The gbm package. *R Foundation for Statistical Computing, Vienna, Austria, 5*(3).
Roura-Pascual, N., Pons, P., Etienne, M., & Lambert, B. (2005). Transformation of a rural landscape in the Eastern Pyrenees between 1953 and 2000. *Mountain Research and Development, 25*(3), 252–261.
Sang, N., Dramstad, W. E., & Bryn, A. (2014). Regionality in Norwegian farmland abandonment: Inferences from production data. *Applied Geography, 55*, 238–247.
Sappington, J. M., Longshore, K. M., & Thompson, D. B. (2007). Quantifying landscape ruggedness for animal habitat analysis: A case study using bighorn sheep in the Mojave desert. *Journal of Wildlife Management, 71*(5), 1419–1426.
Schröter, D., Cramer, W., Leemans, R., Prentice, I. C., Araújo, M. B., Arnell, N. W., et al. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science, 310*(5752), 1333–1337.
Serra, P., Pons, X., & Saurí, D. (2003). Post-classification change detection with data from different sensors: Some accuracy considerations. *International Journal of Remote Sensing, 24*(16), 3311–3340.
Serra, P., Pons, X., & Saurí, D. (2008). Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography, 28*(3), 189–209.
Serra, P., Vera, A., Tulla, A. F., & Salvati, L. (2014). Beyond urban–rural dichotomy: Exploring socioeconomic and land-use processes of change in Spain (1991–2011). *Applied Geography, 55*, 71–81.
Sörensen, R., Zinko, U., & Seibert, J. (2006). On the calculation of the topographic wetness index: Evaluation of different methods based on field observations. *Hydrology and Earth System Sciences Discussions, 10*(1), 101–112.
Stoebner, T. J., & Lant, C. L. (2014). Geographic determinants of rural land covers and the agricultural margin in the Central United States. *Applied Geography, 55*, 138–154.
Strijker, D. (2005). Marginal lands in Europe—causes of decline. *Basic and Applied Ecology, 6*(2), 99–106.
Tapia, R., Stein, A., & Bijker, W. (2005). Optimization of sampling schemes for vegetation mapping using fuzzy classification. *Remote Sensing of Environment, 99*(4), 425–433.
Tenerelli, P., & Carver, S. (2012). Multi-criteria, multi-objective and uncertainty analysis for agro-energy spatial modelling. *Applied Geography, 32*(2), 724–736.
Tiessen, H., Salcedo, I. H., & Sampaio, E. V. S. B. (1992). Nutrient and soil organic matter dynamics under shifting cultivation in semi-arid northeastern Brazil. *Agriculture, Ecosystems & Environment, 38*(3), 139–151.
Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate, 23*(7), 1696–1718.
Vicente-Serrano, S. M., Lopez-Moreno, J. I., Beguería, S., Lorenzo-Lacruz, J., Sanchez-Lorenzo, A., García-Ruiz, J. M., et al. (2014). Evidence of increasing drought severity caused by temperature rise in southern Europe. *Environmental Research Letters, 9*(4), 044001.
Vidal-Macua, J. J., Zabala, A., Ninyerola, M., & Pons, X. (2017). Developing spatially and thematically detailed backdated maps for land cover studies. *International Journal of Digital Earth, 10*(2), 175–206.
Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). *Mixed effects models and extensions in ecology with R.* New York: Spring Science and Business Media.