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Selection of Environmental Parameters for *Pinus halepensis* in Castilla y León (Spain) through Geostatistical Techniques

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ABSTRACT

Planning and management of biomass (including resources, biofuels and composting processes) require knowledge of the areas of tree species distribution. Geographic information systems (GIS) and geostatistical techniques have proved to be very useful tools to develop models of climate estimation, habitat determinations, biomass quality, changes in soil organic carbon storage, potential areas and connectivities. In this study, *(i)* several physiographic, climatic, edaphic and forestry parameters have been elaborated from the sampling data; *(ii)* a space-correlation analysis has been prepared by means of a digital elevation model (DEM); and *(iii)* a trend analysis has been carried out for each environmental variable under study. In Castilla y Leon (central Spain), semivariograms for climate and physiographic variables are unimodal, quasi-symmetrical, continuous and show a gradual evolution. In the plains of Castilla, with presence of forest masses of *carrasco* pine (*Pinus halepensis*), the distributions are more continuous and present totally homogenous distribution surfaces. In order to study on a parametrical autoecology model the ecological aptitude of our territory to establishing stable *carrasco* pine stands, we have developed a habitat classification system for *P. halepensis* in Castilla y Leon based on multiple regression analysis. The optimal areas are located in the provinces of Palencia and Valladolid, in the Duero Cenozoic Basin and the species that shows the best quality is located in one unit known as the "*Facies Cuestas"* which has a clear lacustrine character. A connectivity network for our species is presented with the aim of promoting a Regional Forest Rearrangement Plan.

Keywords: biomass quality, geographic information systems (GIS), habitat determinations, parametrical autoecology

Abbreviations: DEM, digital elevation model; **DW**, Statistical Durbin-Watson; **ET**, potential evapotranspiration; **GIS**, Geographic Information System; **HI**, hydric index; **LL**, lower limit; **LT**, lower threshold; **UL**, upper limit; **UT** upper threshold

INTRODUCTION

The use of multivariate statistical models to predict the distribution of species has increased recently. Distribution models on a great scale have become essential tools for the management and conservation of an ecosystem. Most strategies for the development of such models are based on the characterization of bio-climatic data. The models assume that the best indicators of the climatic requirements of species are those that present a uniform distribution. The areas with similar climatic distributions consider potential areas of natural distribution for a given species.

According to Pearson and Dawson (2003), it is essential to construct distribution models that consider biotic interactions and changes in the populations of the species or their dispersive capacity, considering climatic variables. In Sarmiento's (2005) opinion, it is necessary to carry out systematic studies of the ecological reality of the forest stations of a certain species. In order to determine the potential distribution of the species, first of all, it is required to know the handling of the plant, its morphology, genetic factors, physiology and quality (Grossnickle 2000; South 2000; Griffis *et al.* 2001; Dale 2002).

The analysis of the distributions or patterns requires numerous methods, including geo-statistical analyses and Geographic Information Systems (GIS) (Hidalgo *et al.* 2008), multiple-criteria analysis (MCA) (Briceño-Elizondo *et al.* 2008) and teledetection (Rodríguez *et al.* 2006; Viña *et al.* 2008). The description of the distributions depends on the object of analysis: uses of the ground (Romanyaá *et al.* 2000), integrated handling of a culture and evaluation of damages (Moral *et al.* 2004), quality of afforestation (Navarro *et al.* 2004), studies of environmental variables such as forest evapotranspiration (Tanaka *et al.* 2008), evaluation of polluting agents (Wu *et al.* 2008), habitat definition (Iverson *et al.* 2008), simulation of fire frequencies (Syphard *et al.* 2007), etc.

The consideration of space patterns of organisms and abiotic factors has important implications for the construction and validation of models (Tilman and Kareiva 1997; Stewart *et al.* 2000; Dennis *et al.* 2002; Legendre *et al.* 2002; Perry *et al.* 2002; Escudero *et al.* 2003; Torres *et al.* 2003; Legendre *et al.* 2004; Fortín *et al.* 2005; Maestre 2006) and for contamination minimization (Stenger *et al.* 2002).

The potential distribution models can predict the distribution of the vegetation through landscape studies (Guisan and Zimmermann 2000; Anderson *et al.* 2003). It is noteworthy to indicate that in order to use potential distribution models in the arrangement of the territory, it is necessary to consider certain variables to define the zones in which to intervene (Felicísimo *et al.* 2002). Space modeling in the context of GIS and the application of geostatistical techniques have become the driving force behind the analysis of the space distribution of plant species, facilitating the simultaneous consideration of manifold variables and their interactions, the understanding of the territory operation and its evaluation and planning (Romero *et al.* 2001). The interpolation with geostatistics analysis is essentially based on the theory of the regionalized variables and on their dependency and autocorrelation, within a framework of space variability (Bertsch *et al.* 2002).

In this study, we conduct a space modeling of the variables that determine the potential distribution of *Pinus hale-*

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pensis Mill. in Castilla y Leon, in order to decide which areas are the most important for territory conservation and management. Therefore, a precise knowledge of the locations and space distribution of the habitats of key species is required. The most usual approach for the mapification of habitats using climate data is the generation of environmental variables that represent the species with more exactitude and their combination with digital elevation models (DEM) of the land. In order to implement experiences focused on species conservation, it is necessary to introduce landscape arrangement techniques, by means of a study of connectivities and the knowledge of key areas, to make the reintroduction of species and the promotion of environmental runners possible.

The main intention of this study was to examine the physiographic-climatic data in order to determine the potential distribution of *Pinus halepensis* Mill in Castilla y Leon and to promote the planning and arrangement of forest resources. Nowadays, the arrangement of agricultural and forest remainders coming from biomass can contribute to the expansion of new resources or biomass energy by means of an increase in the composting processes or the creation of biorefineries to develop new biofuels.

The specific aims of this manuscript were to:

- Elaborate a database of environmental variables of Castilla y Leon to explain the space behavior of those variables on the basis of the model of regression of environmental variables (Sánchez-Palomares *et al.* 1999).
- Present an analysis of semivariograms, from a database and by means of the use of geostatistics techniques in order to offer the space location of the environmental variables.
- Establish a definition of the physiographic and edaphoclimatic habitat of *P. halepensis* (*carrasco* pine) in the region of Castilla y Leon.
- Define the potential areas of the masses of *P. halepensis* from the creation of an aptitude index and to develop a quality model by means of a variance and regression analysis (aimed at extending the traditional space scales or connectivities for the arrangement of forest resources).
- Consider the ground organic carbon kidnapping under masses of *P. halepensis* Mill in Castilla y Leon, applying the Rothamsted model.

MATERIALS AND METHODS

Elaboration of a database of environmental variables in Castilla

The elaboration of a database of environmental variables of Castilla y Leon is necessary to explain the space behavior of those variables on the basis of the model of regression of environmental variables by Sánchez-Palomares, and to have a physiographic-climatic cartography of Castilla y León.

The elaboration stage of an alphanumeric database is essential to obtain a digital cartography by means of a Geographic Information System (GIS). A GIS is a system of management of databases for the capture, storage, recovery, analysis and visualization of spatial data. The process of elaboration of databases of environmental variables of Castilla y Leon requires the following steps:

(i) Selection of municipalities or points for the creation of a digital cover

In this stage, data from 6235 population entities in Castilla y Leon were analyzed by means of the software Arcview® 3.3, corresponding to 2248 municipalities and their coordinates *Xutm*, *Yutm* and *Z* parameter (altitude), in order to generate a single layer in vector format. The data come from Spanish National Geographic Institute (*Instituto Geográfico Nacional*, IGN) and are analyzed on a subriver-basin classification. Castilla y Leon has four river basins: North (subriver basin N1 and N2), Duero (subriver basins D1 and D2), Tajo (subriver basins T2, T3, T4) and Ebro (E1 and E4).

(ii) Creation of an alphanumeric database from the thermopluviometric climatic model

A thermopluviometric model climatic database is essentially an information storage which uses algorithms. It is based on multiple linear regression models, where the dependent variable is the climatic value and the independent variables are the altitude and the values that determine the geographic position of each meteorological station (in coordinates *Xutm-Yutm* and referred to zone 30). The construction of the alphanumeric database is conducted in two MS Excel® spreadsheets, where one spreadsheet refers to the variable 'temperature' and another spreadsheet is referred to 'precipitation', with 6235 rows or registries for each population entity.

The main data variables in the temperature spreadsheet are: monthly temperatures, annual average temperatures, maximum temperatures, minimum temperatures, thermal oscillation, insolation, alpha (α), the potential evapotranspiration (ET) with and without correction for each month, and the total potential evapotranspiration.

The potential evapotranspiration in mm/month (ET) has been calculated by means of the Thornthwaite equation (1948), from the monthly average of the air daily average temperatures in centigrade degrees (°C). The annual index is calculated using the following expression:

$$ET = 16 \cdot f \cdot (10 \cdot T / I)^{\alpha}$$

where *f* refers to the maximum number of hours of sun, depending on the month and the latitude (Doreenbos and Pruitt 1977), *I* is the insolation, *t* is the daily average temperature of the month in °C, and *α* is expressed in hours per day.

$$\mathrm{I} = \quad I = \sum (t/5)^{1.514}$$

$$\alpha = 675 \cdot 10^{-9} \cdot I^{3} - 771 \cdot 10^{-7} \cdot I^{2} + 1972 \cdot 10^{-5} \cdot I + 0.49239$$

For the precipitation spreadsheet, it is required to include monthly and total evapotranspiration, duration of drought, monthly and total surplus/deficit sums, and monthly hydric index (HI). The last can be calculated by means of the following Thornthwaite and Matter formula (1957):

$$HI = (100 \cdot surplus\_sum - 60 \cdot deficit\_sum) / ET$$

The thermopluviometric estimation model follows the equation in **Appendix 1**.

The coefficients *a*, *b*, *c*, *d*, *e*, *f*, and *g* vary depending on the river basin. For the aims mentioned above, we have used the information available from the models developed by Sánchez-Palomares *et al.* (1999), corresponding to the period 1940-1990, and considering the meteorological data from publications by the Spanish Ministry of Agriculture, Fishing and Food.

(iii) Physiographic-climatic cartography

For the construction of the physiographic-climatic cartography of each environmental variable, it is necessary to order, classify, relate by means of regression techniques and interpolate the "files" or "lists", so that they present an homogenous structure, avoiding information duplicity, assuring the maintenance of the database internal structure and confirming that all the data layers have the same dimensions and coordinates system. The database, which contains the entities of each municipality of Castilla y Leon, is interpolated with the alphanumeric database of the environmental variables, in order to attribute space coordinates to the parameters. Later on, a vector model in the GIS is defined for its space representation (because the data are located in points, lines and polygons).

Thematic maps of each of the above described environmental variables have been elaborated: maps of precipitations and temperatures for each season, annual temperature average, minimum and maximum average temperatures, thermal oscillation, evapotranspiration, potential insolation, hydric index, slope and altitude.

Geostatistical techniques for the creation of a surface (*kriging*)

In reference to Krige (1951), the methods for geostatistics estimation are known as *kriging*. Burrough *et al.* (1998) and Lam *et al.* (1983) describe different interpolation methods, which use semivariograms or covariances to consider both the distance and the geometry of the samples location in order to diminish the variance of the expected error and to allow a great flexibility for the interpolation. All these methods generate an estimation of the variance in all the points, which cannot be made with other methods of interpolation. The geostatistical techniques quantify the space autocorrelation among the measured points, and reflect the space configuration of the sample points around the space location.

The histograms and statistical summaries for the analyzed variables data, involving both precipitation and temperature, reflect the minimum and maximum values, average and standard deviation, symmetry (*skewness*), *kurtosis*, median, *1st* and *3rd quartil*. The relative proportion or data density within each type is represented by the height of each bar in the histogram. The most important characteristics of the distribution are the central value, the bandwidth and its symmetry.

Definition of the physiographic-climatic habitat for *P. halepensis* in Castilla y Leon

For the definition of the physiographic-climatic habitat, only the values of the environmental variables where the vegetal species is located are considered. In the case of *P. halepensis* in Castilla y Leon, the methodology by Gandullo and Sánchez (1994) has been applied. It defines three zones for each parameter or environmental variable used in Sánchez-Palomares' analysis model (1999): an optimal or *central* habitat, a *marginal upper* habitat, a *lower* one, and the *extramarginal* habitat.

The *lower limit* (LL) represents the registered minimum value in our database for each environmental variable for our species under study. The *upper limit* (UL) represents the registered maximum value for each environmental variable for the species subject to study. The *central* habitat is defined between percentile 10 (denominated *lower threshold*, LT) and percentile 90 (*upper threshold*, UT). The *lower marginal* habitat is the one delimited by the absolute lower value (*lower limit*, LL) and the *lower threshold* (LT). Similarly, the *upper marginal* habitat is delimited by the *upper threshold* (UT) and the absolute upper value (*upper limit*, UL). Those biotopes in which any of the parameters are located in the marginal sections are considered *marginal* habitats. If any of the parameters is located outside the predetermined limits (fixed by the values of interval LL – UL), it will correspond to *extramarginal* habitats.

Definition of potential areas and creation of a quality model of the forest masses of *carrasco* pine

(i) Determination of the potential distribution of a species

In order to establish the contribution of each environmental parameter to the species' aptitude degree in a territory, it is necessary to establish a potentiality index, which shows if the species occupies a central or a marginal habitat (Gandullo 1972, 1994; Sánchez-Palomares *et al.* 2001a, 2001b).

As a variant of the Sánchez (2001) methodology, we propose the introduction of a maximum index of aptitude for each climatic parameter, based both on the value that each parameter's average (x_i) reaches and on the standard deviations from that average value. The values that define the habitats are: *lower limit* (LL_i), *lower threshold* (LT_i), *average* (A_i), *upper threshold* (UT_i), *upper limit* (UL_i); where the subscript *i* represents the variable under study. These indicators of potentiality for each variable of the *P. halepensis* in Castilla y Leon are divided into the classes and intervals shown in **Table 1** and **Fig. 1**.

Table 1 Classes of potentiality for each variable of the *Pinus halepensis* in Castilla y León (lower limit (LL), average ($\bar{x}$), upper limit (UL), standard deviation (σ)).

Classes	Potentiality	Index of potentiality
1	Extramarginal	$\bar{x}_i < LL_i$; $\bar{x}_i > UL_i$
2	Low	$[LL_i, \bar{x}_i - 3\sigma]$; $[\bar{x}_i + 3\sigma, UL_i]$
3	Average	$[\bar{x}_i - 3\sigma, \bar{x}_i - 2\sigma]$; $[\bar{x}_i + 2\sigma, \bar{x}_i + 3\sigma]$
4	High	$[\bar{x}_i - 2\sigma, \bar{x}_i - \sigma]$; $[\bar{x}_i + \sigma, \bar{x}_i + 2\sigma]$
5	Optimal	$[\bar{x}_i \pm \sigma]$

(ii) Determination of forest masses quality

In order to develop a Quality Predictive Model for the forest masses of *P. halepensis*, only those provinces in which this species predominates have been considered (Palencia and Valladolid). The multiple regression analysis has been conducted with the aid of Statgraphics Plus® 5.1 software.

Data from the Spanish Third National Forest Inventory (IFN 3) for Palencia and Valladolid provinces (1997-2006) about health conditions, quality levels and pine-forest age have been compared, for each species, with the best specimen found in that zone. According to Gandullo (1994), the appropriate approach is a multiple regression treatment in which the dependent variable is a biokenosis parameter, generally the mass quality, and the independent variables are the available ecological parameters.

(iii) Connectivity and forest planning of the masses of carrasco pine in Castilla y Leon

In connection with *Red Natura 2000*, software *Conefor Sensinode®* 2.2 (Saura and Castro 2007) integrated in ArcGis® 9.1 has allowed us to establish the mosaics and most representative topological networks of the masses of *carrasco* pine for the Cerrato-Astudillo, Esgueva-Duero, Pisuerga-*Tierra de Campos* and *Tierra de Campos* regions (**Fig. 2**).

Determination of ground organic carbon kidnapping under masses of *P. halepensis* in Castilla y Leon, applying the Rothamsted model

We have applied the Rothamsted model (RothC-26.3®) to predict the percentage of carbon in the ground of forest masses of *P. halepensis*, to learn how much ground organic carbon will be available in the long term.

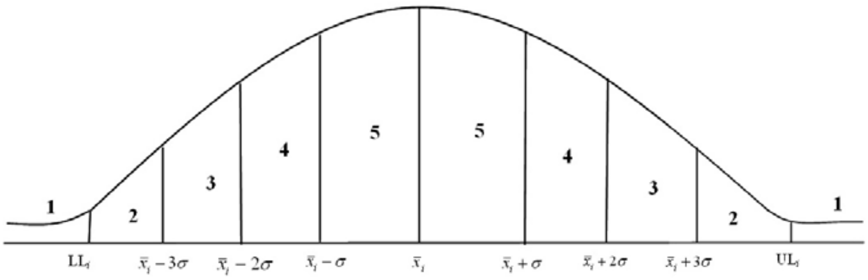


Fig. 1 Definition of the potentiality classes and intervals of *Pinus halepensis* in Castilla y Leon (*lower limit* (LL), *average* ($\bar{x}$), *upper limit* (UL), *standard deviation* (σ)). Classes of potentiality (1 extramarginality, 2 low, 3 average, 4 high, 5 optimal).

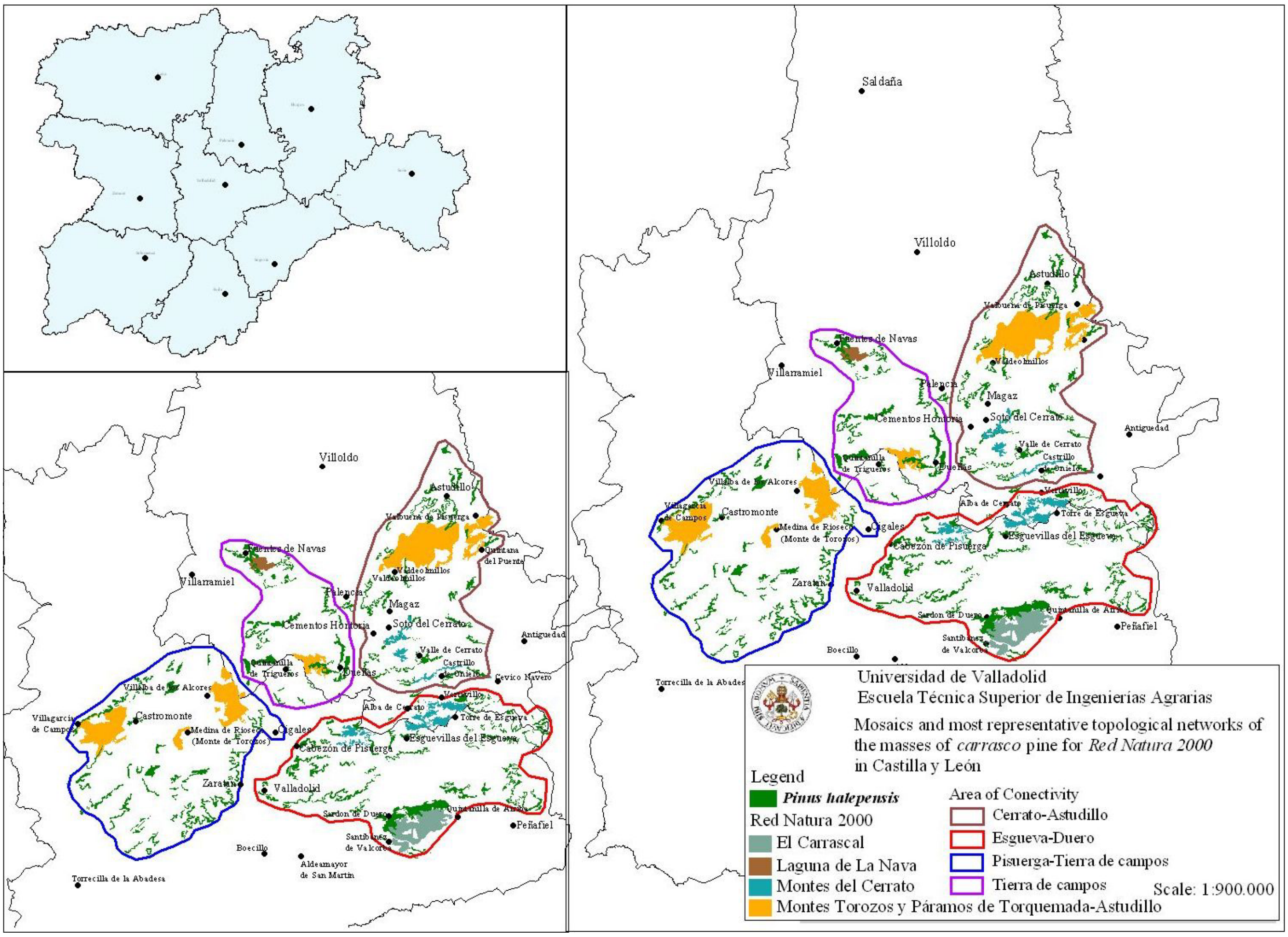


Fig. 2 Mosaics and most representative topological networks of the masses of *carrasco* pine for *Red Natura 2000* in Castilla y León.

RESULTS AND DISCUSSION

Geostatistical techniques for the creation of a surface (*kriging*)

The distribution of the attribute "Total Annual Precipitation" in Castilla y Leon (**Fig**. **3-A**) is unimodal and quite symmetrical; note that the mean (714 mm) and the median (632 mm) nearly agree. The *kurtosis* shows that the distribution is leptocurtical. For the "Total Annual Precipitation", the form of the density distribution has been symmetrical and positive, displaying a long tail to the right that extends from the West to the East of the geographical region (**Fig. 3B**). If we remark the highest bar of the total annual precipitation histogram (**Fig. 3C**), and we represent for that interval the symmetry coefficient, a displacement of the points towards the right is also observed (**Fig. 3D**). In (**Fig. 3E**) we reproduce, for that variable, the small deviations of the standard normal distribution, *versus* the straight line of the QQPLOT curve. If we select the lowest points that do not fall on the straight line of the normal q-q plot curve, it is possible to appreciate the illuminated points in a shape oriented towards the right (**Fig. 3F**).

In the semivariogram-covariance cloud (**Fig. 3G**), each red central point represents a pair of locations. The "Y" axis is the value of the empirical semivariogram and the "X" axis is the distance of the *bin* centre to the semivariogram surface centre ("*binning*" refers to the process of grouping the pairs of locations). The value of the empirical semivariogram for each *bin* is reflected according to a colour code, and the *bines* collection is denominated "surface of the semivariogram". In the lower part of **Fig. 3G**, the surface of semivariogram neither presents increases in the size of "*bines*" as we move from the centre of semivariogram to the surface, nor allows to appreciate a slight separation of colours (cold colour "*bines*" in the outer part and warm colour ones in the interior), since for this variable disparity does not occur between a pair of locations.

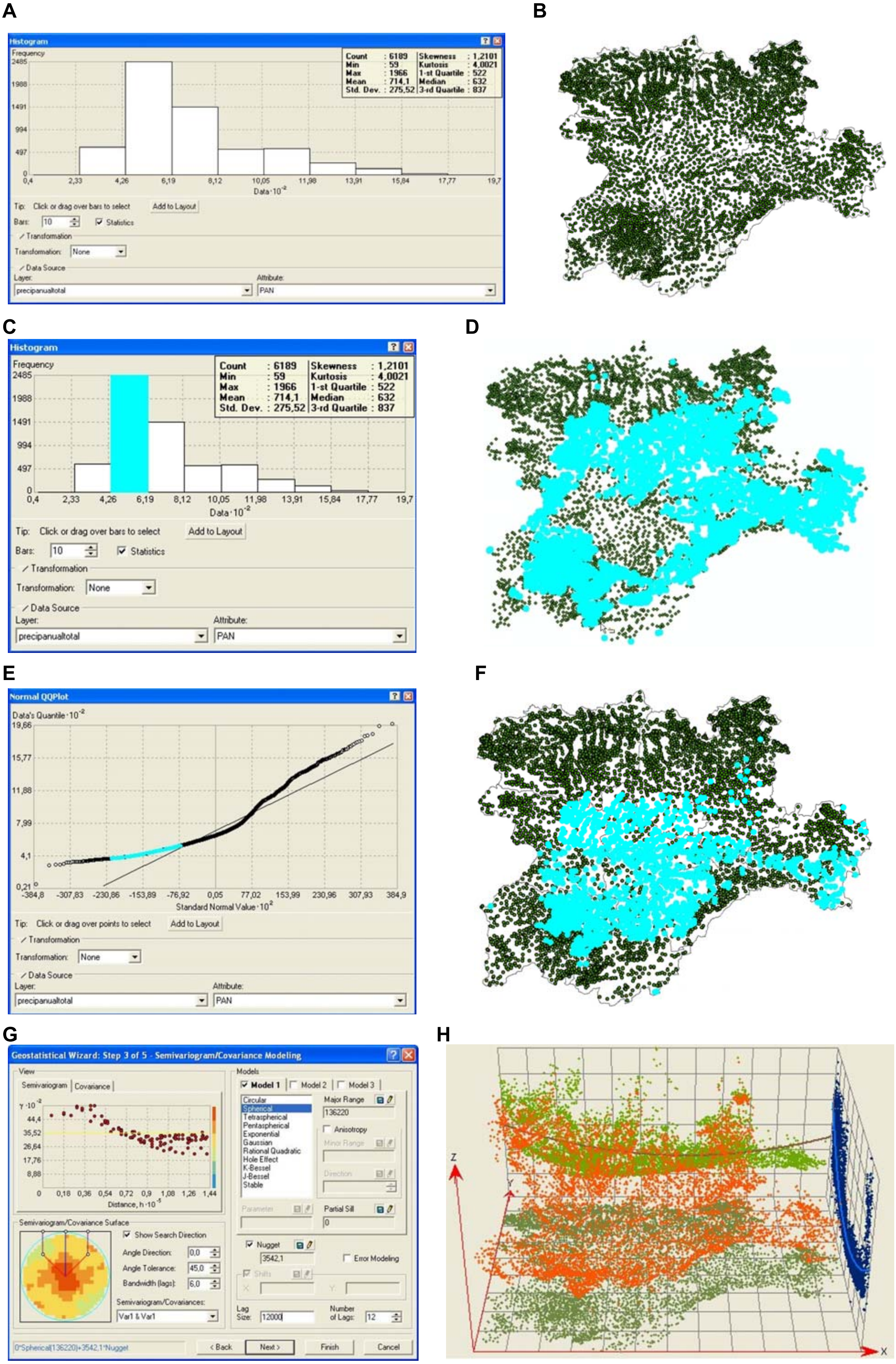
In **Fig. 3H**, in the frontal and right panels, it is shown that the tendency analysis for the Total Annual Precipitation is linear and gradual, and that it is oriented from West to East.

The distributions of the other precipitation variables are also unimodal, quite symmetrical and with *kurtosis* > 3. Likewise, the distributions have a long tail to the right which extends from West to East.

The previous histograms and semivariograms for the variables analyzed in Castilla y Leon were unimodal, quite symmetrical and of gradual continuous evolution. Only for some variables and long distances, separation between the "*binning*" and the average of the clouds values with the semivariogram can be observed. If instead of referring to all Castilla y Leon, we study the evolution of the histograms and semivariograms just for the regions in which forest masses of *carrasco* pine are present, we obtain much more continuous distributions and totally homogenous distribution surfaces, since they are located in the centre of Castilla y Leon (Palencia and Valladolid provinces).

Definition of the physiographic-climatic habitat for *P. halepensis* in Castilla y Leon

Fig. 4 shows the physiographic-climatic habitat of *P. halepensis* in Castilla y Leon, the values that define the central and marginal climatic habitat, and the upper and lower values of the central interval for the different parameters.



Count	: 6189	Skewness	: 1,2101
Min	: 59	Kurtosis	: 4,0021
Max	: 1966	1-st Quartile	: 522
Mean	: 714,1	Median	: 632
Std. Dev.	: 275,52	3-rd Quartile	: 837

Bars: 10 ☑ Statistics
Transformation: None
Layer: precipanualtotal
Attribute: PAN

☑ Model 1 ☐ Model 2 ☐ Model 3
Major Range: 136220
☐ Anisotropy
Partial Sill: 0
☑ Nugget: 3542,1
☐ Error Modeling
☑ Show Search Direction
Angle Direction: 0,0
Angle Tolerance: 45,0
Bandwidth (lags): 6,0
Semivariogram/Covariances: Var1 & Var1
Lag Size: 12000
Number of Lags: 12
0*Spherical(136220)+3542,1*Nugget

Fig. 3 Distribution of *Total Annual Precipitation* attribute in Castilla y Leon. (**A**) histogram; (**B**) symmetry coefficient for the entire histogram; (**C**) selection of the highest bar of the histogram; (**D**) symmetry coefficient for the highest bar of the histogram; (**E**) interval selection in normal *QQPLOT*; (**F**) symmetry coefficient for the selected interval from normal *QPLOTT*; (**G**) semivariogram-covariance cloud, H) trends analysis.

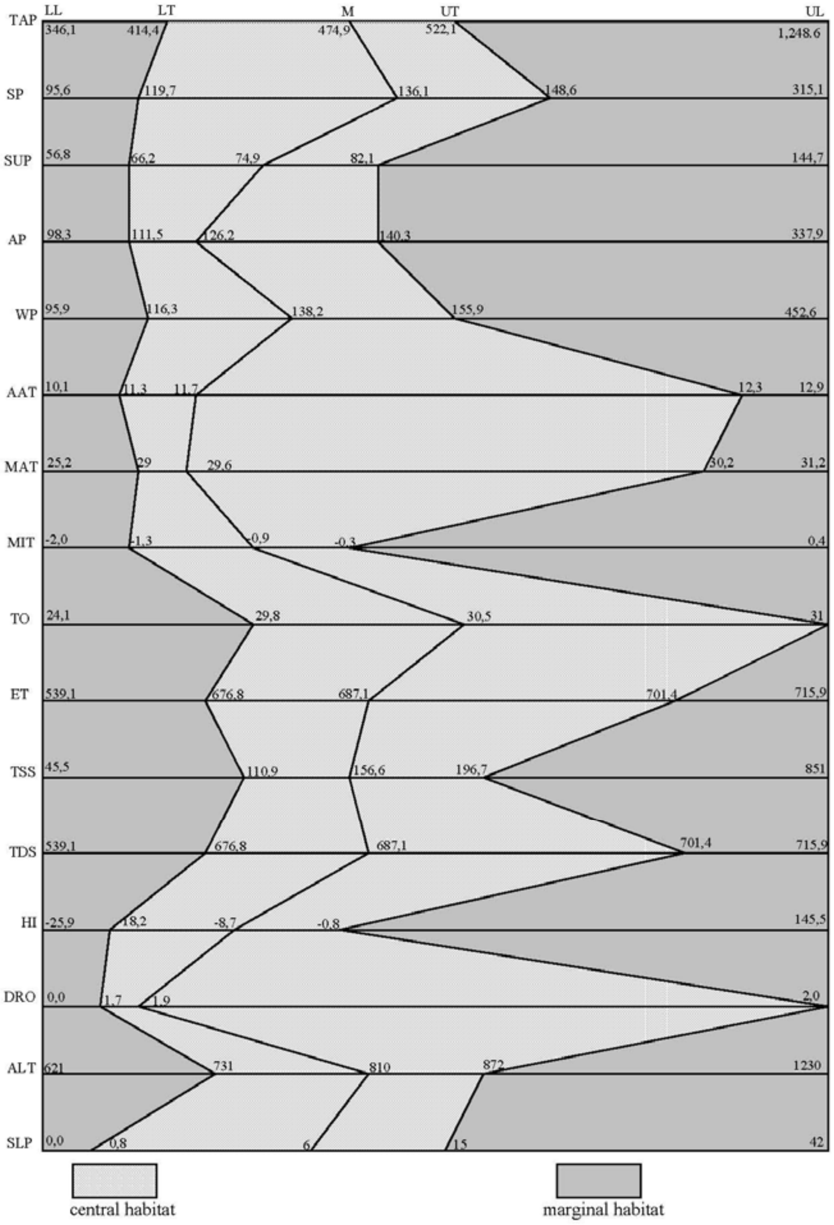


Fig. 4 Physiographic-climatic habitat of *Pinus halepensis* Mill. in Castilla y Leon. Values that define the central and marginal climatic habitat: *lower limit* (LL), *upper limit* (UL), *lower threshold* (LT), *upper threshold* (UT), *mean* (M). Parameters: *Total annual precipitation* (TAP), *spring precipitation* (SP), *summer precipitation* (SUP), *autumn precipitation* (AP), *winter precipitation* (WP), in millimeters (mm). *Annual average temperature* (AAT), *maximum temperature* (MAT), *minimum temperature* (MIT), *thermal oscillation* (TO), in degrees centigrade (°C); *potential evapotranspiration* (ET), *total surplus sums* (TSS), *total deficit sums* (TDS) in mm/month*; hydric index* (HI), adimensional; *drought duration* (DRO), in months; *altitude* (ALT), in meters (m); and *slope* (SLP), in percentage (%).

Particularities that derive from the definition of the habitat of P. halepensis

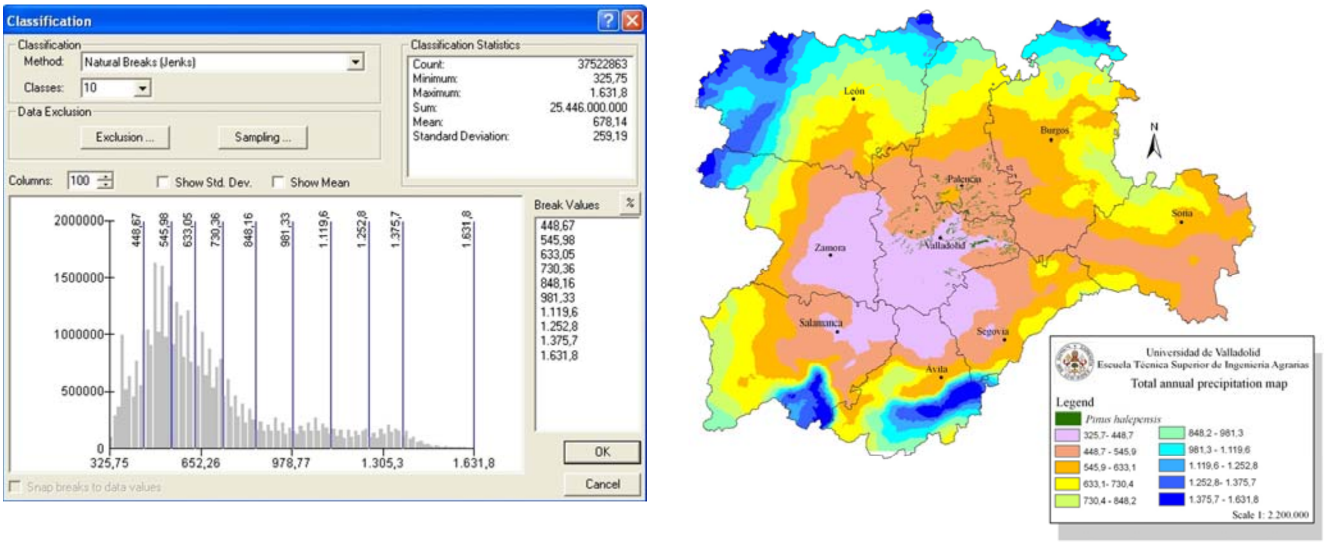
The characteristics that can be derived from the marginal and central habitats of the *carrasco* pine and their variation ranks, for the different variables, are summarized below.

The pluviometric regime in Castilla y Leon, according to **Fig. 5**, presents annual precipitations for the plain or central region between 351 and 500 mm, and between 414 and 522 mm for the optimal habitat for *carrasco* pine. The water requirements for *carrasco* pine in summer are in the range of 56.8 mm (minimum) to 144.8 mm (maximum), the optimal level being between 66.2 and 82.1 mm. For the rest of the year, the minimum value varies from 95.6 to 98.3 mm, and the maximum is 315 mm in spring, 337 mm in autumn and 452 in winter. According to Gil *et al.* (1996), in spring *carrasco* pine requires rain. From the dendrogram by Gandullo and Sánchez-Palomares (1994) regarding this parameter, we can infer the existence of four sets for Spanish pine groves. The smaller rainfall one corresponds to *P. canariensis* and *P. halepensis*, with average values ranging between 110 and 130 mm, upper thresholds close to 190 mm, and little ecological valence.

In the summer, *carrasco* pine can withstand long droughts. Its capacity for growing in poor and naked grounds, as well as its resistance to conditions of little hydric availability and thermal contrasts, makes this species very suitable to be used as a colonizer and generator of the arboreal cover in dry areas or regions with problems of erosion. The shortage in precipitations not only is marked during the whole year, but also presents a great uniformity in space terms.

The winter period in the plains of Castilla can be defined as rigorous and long. The average minimum temperature of the month of January in the province of Palencia is -0.3°C and, in the case of Valladolid, it is -0.6°C (García Fernández 1986). The most influential factor for the distribution of *carrasco* pine, according to Gil *et al.* (1996), is the winter minimum temperatures. Falusi *et al.* (1984) establish that, as it is a precocious species with regard to recommencing its vegetative activity in spring, it is therefore a sensible species to late low temperatures and, as a result, it presents a tendency to occupy areas with mild winters, generally free of frosts. The summer period in Castilla y Leon is short, relatively mild and has strong thermal oscillations.

The thermal regime in Castilla y Leon is Mediterranean with a high component of continental climate, due to the altitude and to the mountains location. The *carrasco* pine has a stenoic behavior: the maximum and minimum temperature parameters display a pointed distribution shifted away from the normal one, with values below the average.

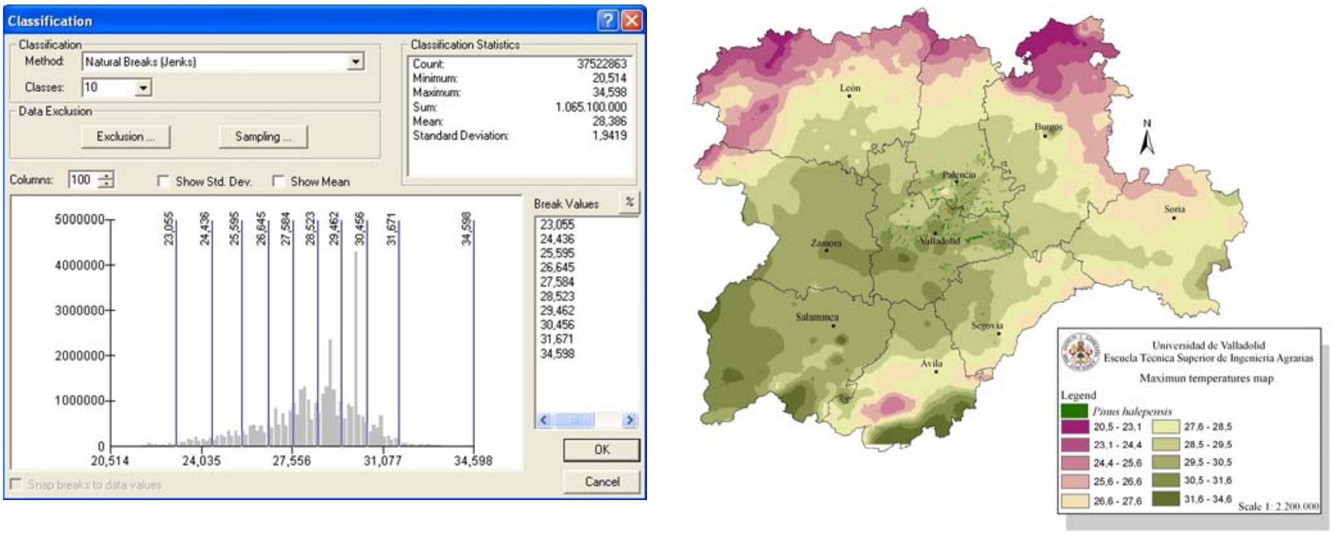


Classification
Method: Natural Breaks (Jenks)
Classes: 10
Columns: 100

Classification Statistics
Count: 37522863
Minimum: 325,75
Maximum: 1.631,8
Sum: 25.446.000.000
Mean: 678,14
Standard Deviation: 259,19

Break Values
448,67
545,98
633,05
730,36
848,16
981,33
1.119,6
1.252,8
1.375,7
1.631,8

Fig. 5 Total annual precipitation map and histogram in Castilla y León.



Classification
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Columns: 100

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Standard Deviation: 1,9419

Break Values
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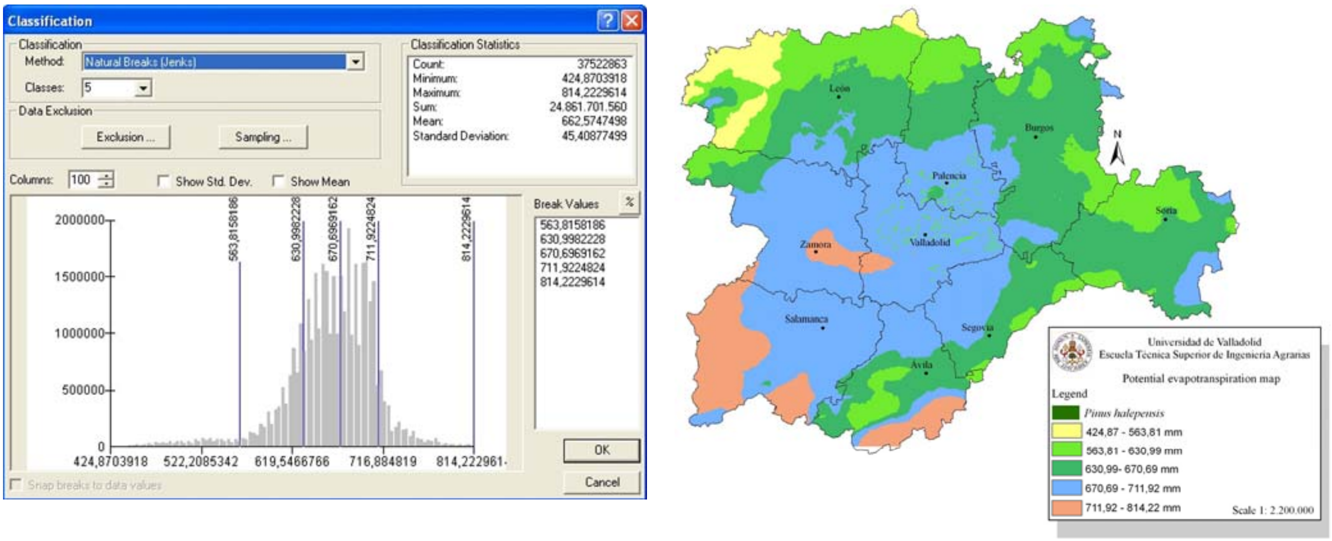
24,436
25,595
26,645
27,584
28,523
29,462
30,456
31,671
34,598

Fig. 6 Maximum temperatures map and histogram.



Classification
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Classes: 5
Columns: 100

Classification Statistics
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Maximum: 814,2229614
Sum: 24.861.701.560
Mean: 662,5747498
Standard Deviation: 45,40877499

Break Values
563,8158186
630,9982228
670,6969162
711,9224824
814,2229614

Fig. 7 Potential evapotranspiration map and histogram in Castilla y León.

Nonetheless, the average maximum temperatures of the hottest month (**Fig. 6**) show greater variation than the average minimum temperatures of the coldest month. The optimal values for the annual average temperatures of our study oscillate between the 11.7 and 12.3°C, which is in agreement with the ranges of average temperatures for Castilla y Leon in autumn, according to García Fernandez (1986).

The masses of *P. halepensis* are classified as thermo- and xerophile (Gil *et al.* 1996). The drought and deficit parameters display a pointed distribution habitat shifted away from the normal one, with values higher than the average (drought: 1.9 months, deficit: 687.1 mm). The hydric

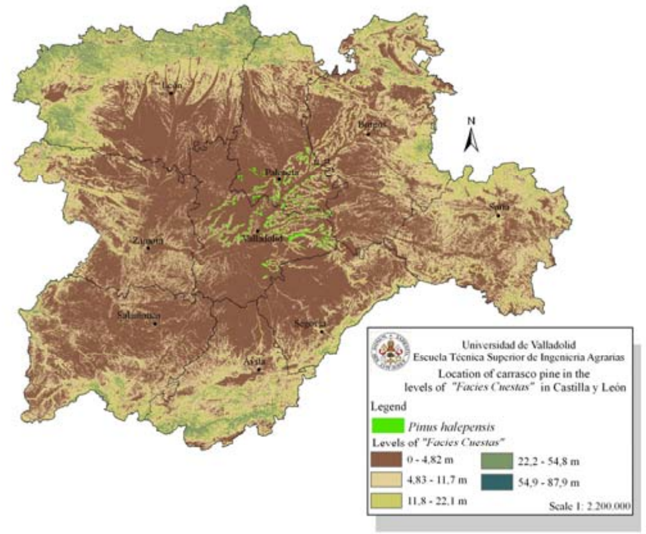

Fig. 8 Location of *carrasco* pine in the levels of *Facies Cuestas* in Castilla y León.

index (HI) for the habitat of the *carrasco* pine in Castilla y Leon is within the adimensional rank (-18.2 and -0.8).

Gandullo and Sánchez (1994) present, with regard to Spanish pine groves, habitats of very high primary potential productivity, when real evapotranspiration maximum is higher than 550 mm and its average is higher than 625 mm. Evapotranspiration of the *P. halepensis* in Castilla y Leon in our study ranges from 539 mm to 715 mm, and therefore the factor of primary potential productivity of this species is high (**Fig. 7**).

On the basis of the study conducted for the altitude parameter, from dendrograms of Spanish Pines habitats by Gandullo and Sánchez (1994), the existence of four quite diverse sets is deduced: the first for the lowest levels, which includes the habitats of *P. radiata*, *P. pinaster* ssp. *atlantic* and *P. pinea*; the second defines the one of *P. halepensis*; the third (always in increasing altitude) contains those of *P. nigra* var. *pyrenaica* and *P. pinaster* ssp. *mediterranean*; and the fourth one comprises those of *P. nigra* var. *hispanic*, *P. sylvestris and P. canariensis.*

In our study, it is observed that the parameter altitude in Castilla y Leon varies from 621 to 1230 m, but for the optimal habitat of *P. halepensis* located in centre of the region (and primarily in the *facies cuestas*), the altitude fluctuates from 731 to 872 ms, with an average value of 810 m (**Fig. 8**). Masses of *P. pinea* do not exist in areas in which the slope is higher than 30%. The presence of masses of *P. halepensis* is compatible with masses of *P. pinea* and, additionally, it can reach slopes of 42.9% (although the average values are 6.9%).

Definition of potential areas and creation of a quality model of the forest masses of *carrasco* pine

(i) Determination of the potential distribution of a species

The above potentiality classes are mapped, for total annual precipitation and the other most significant variables, in **Fig. 9**. The summer precipitation variable is not included due to its similarity to the other precipitations. In all the cases, it is observed that the optimal potentiality for the *carrasco* pine adopts the shape of concentric, flattened aureoles, which are oriented towards the East (Soria province). The forest masses of *P. halepensis* appear in the central aureoles (**Figs. 9A-F**). The integration of the seven variables that better define the areas of potentiality of the *carrasco* pine in Castilla and Leon, using software ArcGis$^{®}$ 9.0, has allowed us to obtain a map of global potentiality (shown in **Fig. 10**). This map is a powerful tool in order to know the surface percentage that each class of habitat occupies in each of provinces of Castilla y Leon.

(ii) Determination of forest masses quality

A multiple regression analysis for pine *carrasco* in the province of Palencia is carried out, using Statgraphics Plus$^{®}$ 5.1. The equation of the fit model is described in **Appendix 2**.

The determination coefficient R-square (69.9%) suggests that part of the answer's variability is explained by the fit model. The adjusted R^2 is 65.9%.

The multiple regression analysis for the province of Valladolid is shown in **Table 2**.

Statistical Durbin-Watson (DW), which examines the autocorrelation among residuals, is 1.3, an evidence of positive correlation.

In Palencia and Valladolid provinces, the independent variable that shows the highest error probability is the altitude.

Fig. 11 shows the quality levels of masses of *carrasco* pine in Palencia and Valladolid provinces. The worst quality masses of *carrasco* pine are located at the south of Peñafiel (Valladolid), in the Southeast of the Palencia province and in the *Tierra de Pinares* (in Olmedo, Valladolid). This decrease in quality is due not only to edapho-climatic conditions, but also to the health conditions and pine-forest age.

(iii) Connectivity and forest planning of the masses of carrasco pine in Castilla y Leon

We have carried out preliminary studies on global connectivity of the forest landscape, making use of nodes and tessera analysis of the woodland, for forest masses in the locality of Astudillo (Palencia). For example, **Fig. 12** shows that the node or tessera where a mass of *carrasco* pine is located, near the old Torre-Marte villa (**Fig. 13**), connects in the South with *Red Natura 2000* (Cerrato-Astudillo) and in the Northeast with the forest masses of Melgar de Yuso. The connection of the masses of *carrasco* pine of Astudillo with *Red Natura 2000* has been possible thanks to a governmental investment of 191,761 euros from Junta de Castilla y León (March 2006). The aim of this investment has been the development of forestry treatments in 199 ha of Astudillo and Cevico de la Torre municipal terms. For a more detailed study, it is necessary to use the methodology of graphs or mathematical structures, so as to determine probability and adjacency matrices (Saura and Carballal 2004), which will constitute a part of our future work.

Fig. 13, relative to the Pisuerga-*Tierra de Campos* region, shows a classification of tesseras: the key and connected tesseras 3 and 4 correspond to the masses of pine of the Northwest of Simancas (Valladolid), number 4 being more important than number 3 with regard to connectivity. We observed that tessera 2 is isolated while that tessera 1, although connected to tessera 4, is not a key one. These connectivity models can be complemented with measures such as CO_2 kidnapping capacity by *P. halepensis*. According to Figueroa and Redondo (2007), *P. halepensis* capture power is of 48,000 kg CO_2/year, whereas for *Pinus pinea* it is of 27,000 kg CO_2/year and for *quercus suber* it is only of 4500 kg CO_2/year.

Determination of ground organic carbon kidnapping under masses of *P. halepensis* in Castilla y Leon, applying the Rothamsted model

In our study, we have been able to predict the percentage increase of ground organic carbon in five masses of *carrasco* pine in the period 2005-2105 (Charro 2007) (**Fig. 14**). These results are extremely important for developing territory arrangement plans and for forest biomass management, aimed at obtaining new resources or composting processes from the forest remainders and new biofuels

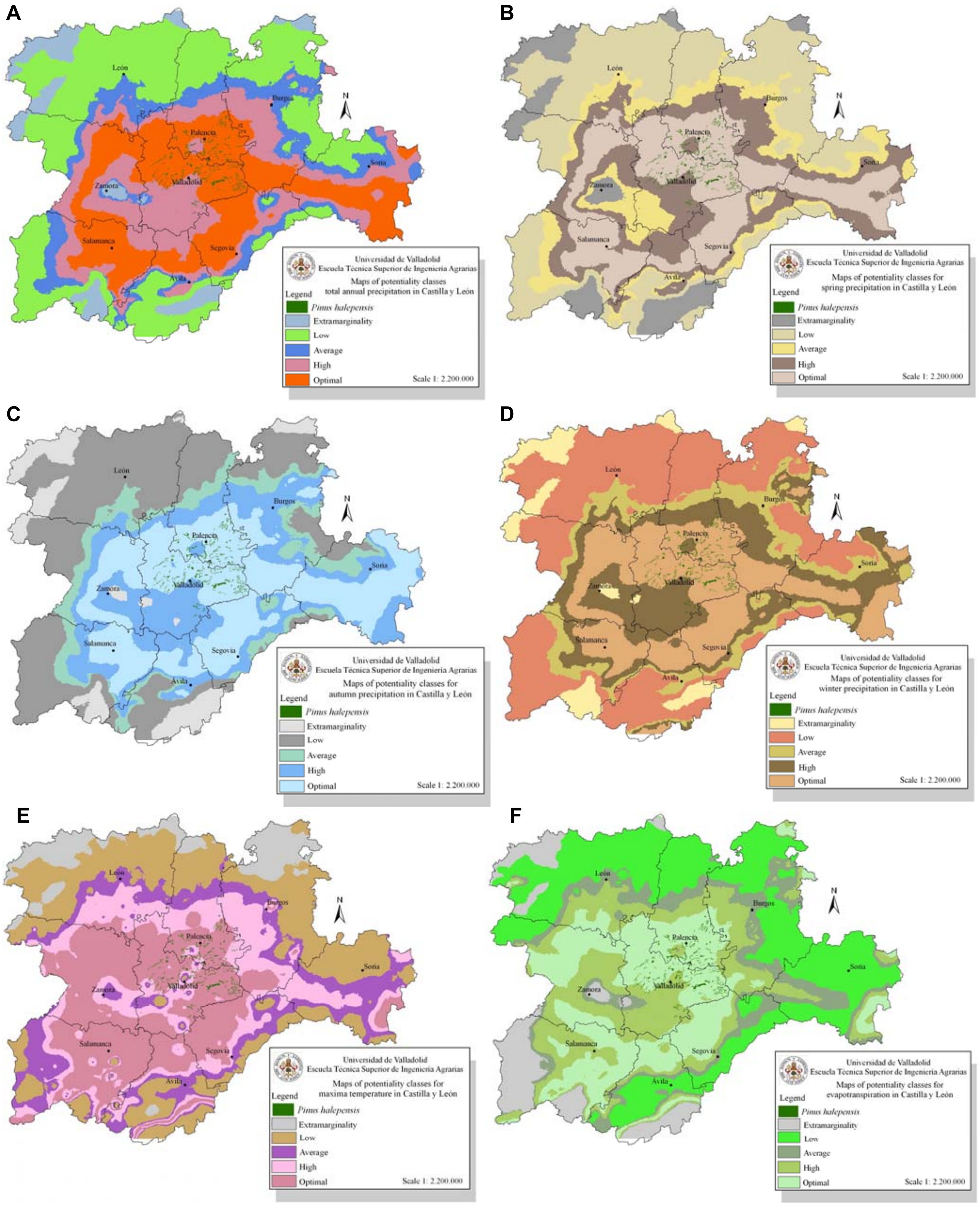

Fig. 9 Maps of potentiality classes in Castilla y León for (**A**) *total annual precipitation* (TAP); (**B**) *spring precipitation* (SP); (**C**) *autumn precipitation* (AP); (**D**) *winter precipitation* (WP); (**E**) *maximum temperature*; and (**F**) *evapotranspiration*, for *Pinus halepensis* Mill.

(Rey 1993).

CONCLUDING REMARKS

First of all, thematic maps of Castilla y León (Spain) for each of the environmental variables (seasonal precipitation and precipitation; annual average, minimum and maximum temperatures; thermal oscillation; evapotranspiration; potential insolation; hydric index; slope and altitude) have been generated using a digital elevation model.

The distributions obtained for the analyzed variables have been unimodal, quite symmetrical and show gradual continuous evolution. In the semivariograms, for some variables and long distances, separation between the "*binning*" and the average of the clouds values has been observed. If instead of referring to all Castilla y Leon we study the evolution of distributions in the regions in which forest masses of *carrasco* pine are present (Palencia and Valladolid pro-

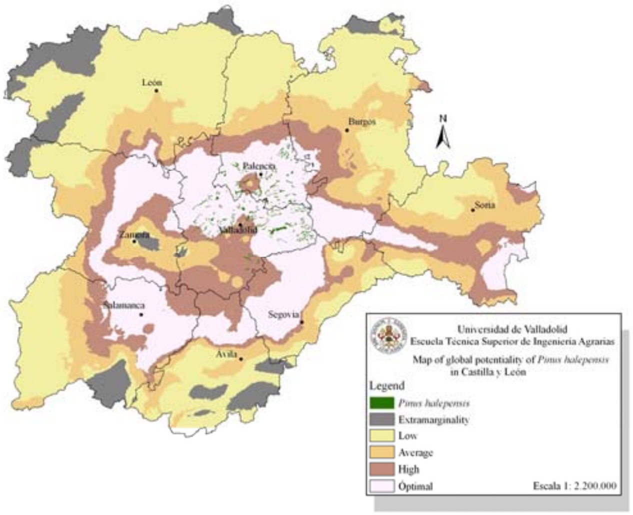

Fig. 10 Map of global potentiality of *Pinus halepensis* Mill in Castilla y León.

vinces), much more continuous and totally homogenous distribution surfaces are achieved.

In addition, for the definition of potential areas and the creation of a quality model of the forest masses of *carrasco* pine, a potentiality index has been established. *Central*, *marginal* and *extramarginal* habitats for the different environmental variables under study have been defined.

Moreover, potentiality classes have been mapped for total annual and seasonal precipitation, maximum temperature and evapotranspiration. The optimal potentiality for the *carrasco* pine adopts the shape of concentric, flattened aureoles, which are oriented towards the East (Soria province), and the forest masses of *Pinus halepensis* appear in the central aureoles. Using software ArcGis® 9.0, a map of global potentiality has been obtained in order to determine the surface percentage occupied by each class of habitat for each of the Castilla y Leon provinces.

The worst quality masses of *carrasco* pine (in terms of edaphoclimatic conditions, health and pine forest age) are located at the south of Peñafiel (Valladolid), in the South-east of the Palencia province and in *Tierra de Pinares* (Olmedo, Valladolid).

Finally, preliminary studies on global connectivity have been conducted for forest masses in the locality of Astudillo (Palencia), using nodes and tessera analysis of the woodland. The percentage of organic carbon in the ground of forest masses in the long term has been predicted by means of the Rothamsted model application.

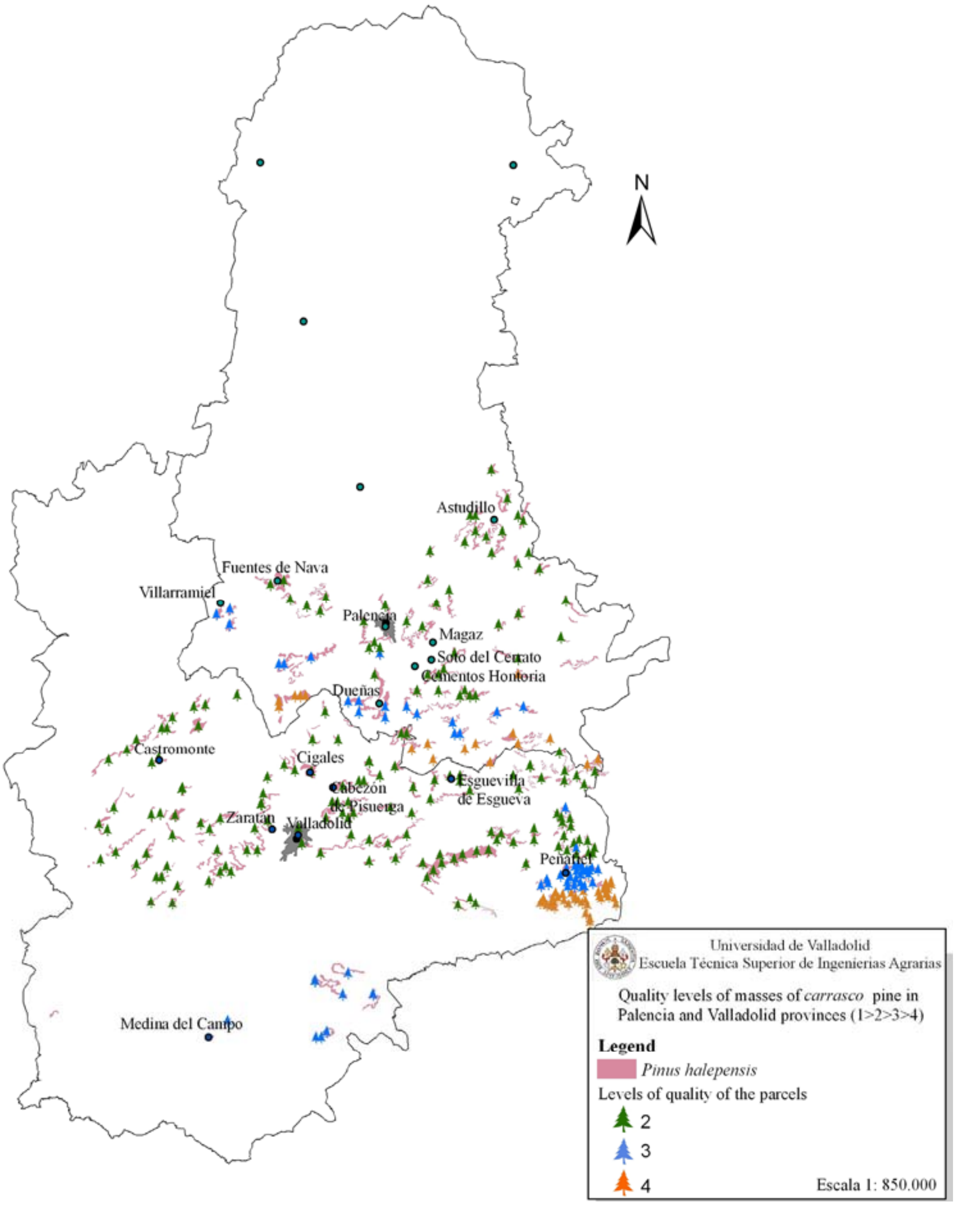

Fig. 11 Quality levels of masses of *carrasco* pine in Palencia and Valladolid provinces (1>2>3>4).

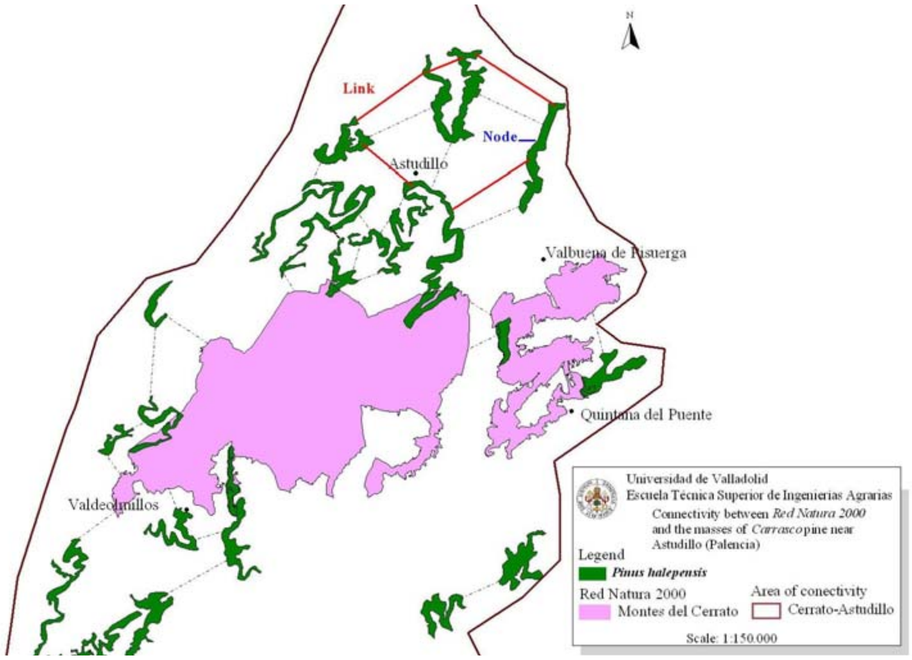

Fig. 12 Connectivity between *Red Natura 2000* and the masses of *carrasco* pine near Astudillo (Palencia).

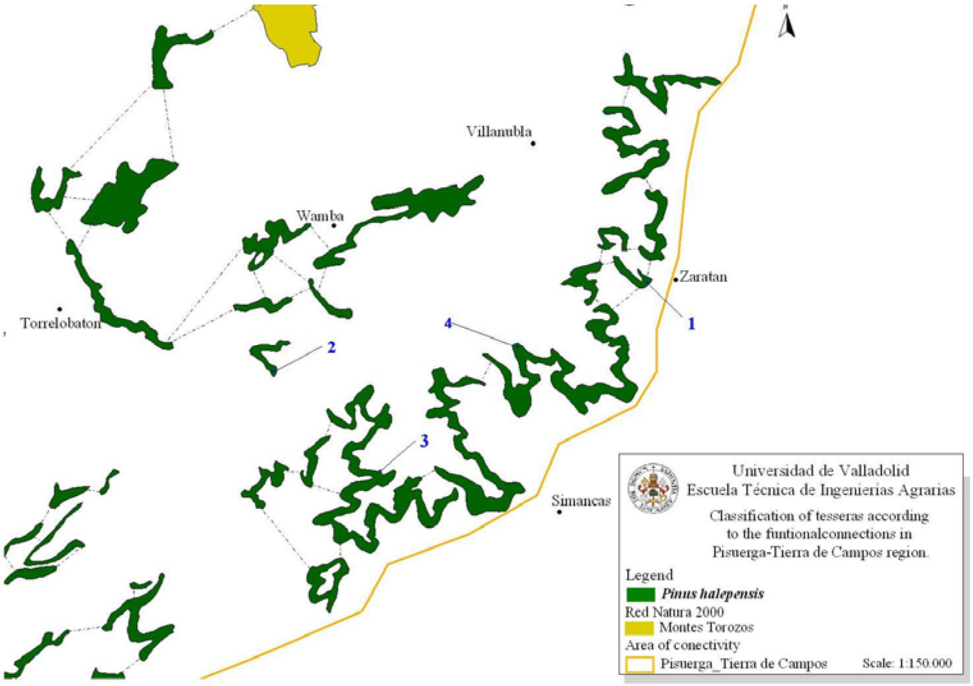

Fig. 13 Classification of tesseras according to the functional connections in *Pisuerga-Tierra de Campos* region.

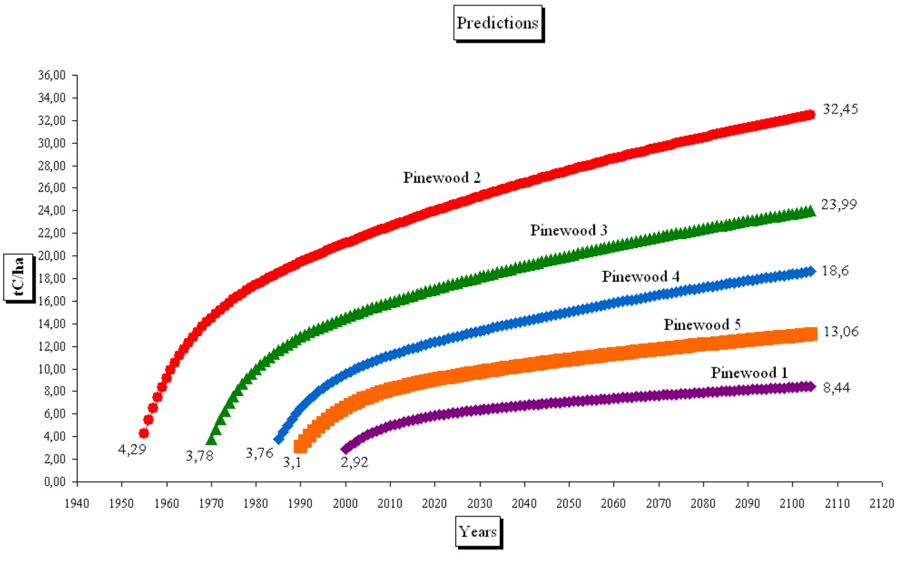

Fig. 14 Predictions of carbon to 100 years in the ground of forest masses of *Pinus halepensis* in Castilla y León.

Table 2 Multiple regression analysis for Valladolid province.

Dependent variable: Quality

Parameter	**Estimate**	**Standard error**	***t*-statistics**	**P**
Quality	253.434	23.2026	10.9226	0.0000
Altitude	-0.00006	0.0008	-0.7070	0.9387
Evapotranspiration	-0.28824	0.0279	-10.3067	0.0000
Total annual precipitation	-0.15357	0.0205	-7.4664	0.0000
Slope	-0.00761	0.0054	-1.3902	0.1660
pH	-0.83292	0.3023	-2.7544	0.0064
Autumn precipitation	0.38578	0.0833	4.6270	0.0000
Summer transpiration	-0.02873	0.0164	-1.7457	0.0824
Maximum temperature	-0.02873	0.2895	6.4929	0.0000
Annual average temperature	-6.14329	1.9398	-3.1668	0.0018
Minimum temperature	3.48191	1.3849	2.5141	0.0127

Analysis of Variance

Source	**Sum of squares**	**Degrees of freedom**	**Average sum of squares**	***F***	**P**
Regression	91.5432	10	9.15432	47.47	0.0000
Residual	38.1793	198	0.192825		
Total	129.722				

R-square = 70.57 %, adjusted R-square = 69.08 %

Standard error est. = 0.439, Average absolute error = 0.343, Durbin-Watson statistics = 1.3 (p = 0.000),

Residual Lag 1 autocorrelation = 0.313

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Appendix 1

$$\text{Climatic value} = a + b \cdot \frac{altitude}{10^3} + c \cdot \frac{Xutm}{10^5} + d \cdot \frac{Yutm}{10^5} + e \cdot \left(\frac{altitude}{10^3}\right)^2 + f \cdot \left(\frac{Xutm}{10^5}\right)^2 + g \cdot \left(\frac{Yutm}{10^5}\right)^2$$

Appendix 2

$$Quality = 170.172 - 0.00041 \cdot altitude - 0.18587 \cdot evapotranspiration + 0.02680 \cdot total\_annual\_precipitation -$$
$$- 0.0103 \cdot slope - 0.87509 \cdot pH - 0.23790 \cdot autumn\_precipitation - 0.07319 \cdot summer\_precipitation -$$
$$- 0.18297 \cdot T_{\max} - 0.24977 \cdot T_{aver} + 0.42036 \cdot T_{\min}$$