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Predictive Models and the Evolution of Tree Vegetation during the Final Pleistocene-Holocene Transition A Case Study from the Asón River Valley (Cantabria, Spain)

Abstract: This paper proposes two predictive models, created with GIS technology and developed to evaluate the evolution and spatial distribution of arboreal vegetation during the Final Pleistocene – Early Holocene transition. Weighted values and logistic regression methods have been used, based on the ecological preferences of the tree species identified in certain pollen diagrams from the Cantabrian region. Using GIS, zones in the study area that fit with these ecological preferences and to thereby model the areas where specific vegetation types would have been more likely to develop were marked out for both the Younger Dryas and the Early Holocene periods.

Introduction and Context

Studies concerning mobility patterns and territorial exploitation by hunter-gatherer societies, such as those from the end of the Upper Palaeolithic, require knowledge regarding their environment. Some methods may infer the composition of the vegetation (basically palynology and anthracology), although they do not offer any information regarding its spatial distribution. This is of great importance given that the location of forest accumulations, areas of great resource diversity, probably had a great influence on the way in which Palaeolithic human groups understood and exploited their environment, such as, for example, in their choice of areas for habitation (Spikins 1997). In the case of Cantabrian hunter-gatherer groups, a gradual diversification of the resources exploited has been observed throughout the end of the Late Glacial (González Morales et al. 2004; González Sainz 1989), coinciding with general improving climatic conditions and reforestation. Access to new forestal resources may have triggered an economic reorientation if compared to the specialization that took place during earlier periods. Tooth wear analyses from specimens found at El Rascaño site show an important vegetarian component in the diet of Cantabrian hunter-gatherers, which shows the importance of forestal resources in this group's economies.

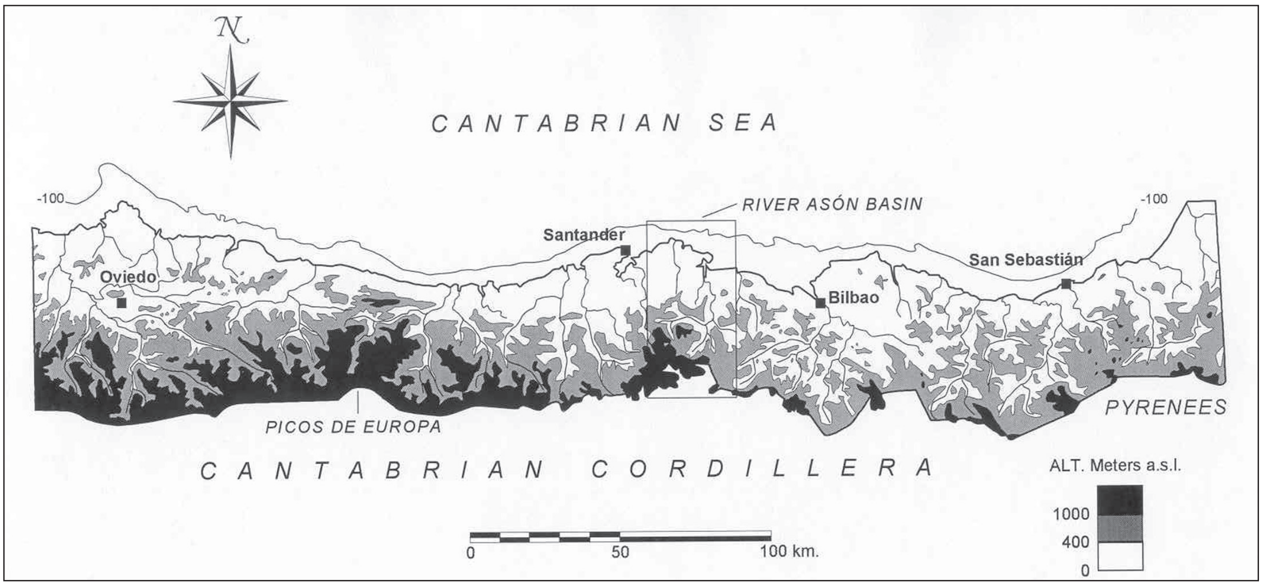

Fig. 1. Location of the study area.

In the case of the Asón river valley (Cantabria, Spain) *(Fig. 1)* from the Upper-Final Magdalenian (Magdaleniense Superior-Final: MSF in Spanish) and the Azilian (16 ka cal BP – 10 ka cal BP) a change in territorial settlement patterns has been observed; the main Lower Magdalenian site, El Mirón cave, located in a prominent position half way up a hillside, goes on to be sporadically occupied, whereas the main inhabitation areas are concentrated at other sites located in more sheltered areas at the ends of the valley – El Horno, El Valle, Cullalvera, La Chora or El Otero caves – or near the coast – La Fragua and El Perro (Straus et al. 2004).

The sites' new positions could be related to the appearance of new masses of deciduous forests, confirmed by several regional palynological and anthracological analyses (López García / López Sáez / Uzquiano 1996; Uzquiano Ollero 2000). The results have shown that, throughout the end of the Late Glacial, the dominant species Pinus was substituted by others associated with more temperate climates, such as Quercus, Alnus, Corylus etc. The ecologic needs of these latter species imply a change in the location of forest masses, which could, in turn, be related to the choice of new occupation sites.

In order to identify the position and evolution of the main forest formations at the end of the Late Glacial in the Asón valley, a predictive model based on the weighted values method has been developed, basing it on the ecologic requirements of the tree species. To verify its reliability, the information also has been contrasted with the current location of these types of forests in the Cantabrian region. In order to do this, the importance of each variable in relation to current forest dispersal has been analysed using logistic regression analysis, applying the coefficients obtained in our study area. The similarity between the models obtained with both methods allows us to accept its validity, given that all of the method's limitations are taken into account.

Tree Vegetation Evolution and its Ecologic Demands

The study of several pollen diagrams of the central-eastern area of the Cantabrian Region allowed for the identification of the main tree species present during the end of the Late Glacial (Boyer-Klein 1981; Leroi-Gourhan 1966; López García 1981; Peñalba 1994). The dominant genus during the cold periods of the Glaciation is Pinus (sylvestris), however, closer to the Holocene, with milder climatic conditions, it begins to be substituted by termophile species, such as Quercus (petraea / robur), Corylus, Alnus, etc., resulting in a reforestation of the landscape, through the appearance of bigger and more thicker forests than in the Cantabrian Late Glacial coniferous woodlands.

Once the species were identified, the ecologic conditions under which they appear at present in the Cantabrian area and the Pyrenees were analysed in order to define the medium under which they appear, and thus define their ecologic needs. Thanks to current botanical studies (Felicísimo Pérez et al. 2002; Gómez Manzaneque 1997), it was possible to establish how much influence a set of environmental variables has in the development of

PINUS			
ALTITUDE= 4			
Variable Value	Range	Range Value	TOTAL VALUE
4	0-550 m.	1	4
4	550-1.5500 m.	3	12
4	> 1.550 m.	2	8
SUMMER INSOLATION= 3			
Variable Value	Range	Range Value	TOTAL VALUE
3	0-3 h.	1	3
3	3-9 h.	2	6
3	> 9 h.	4	12
WINTER INSOLATION= 2			
Variable Value	Range	Range Value	TOTAL VALUE
2	0-3 h.	1	2
2	3-9 h.	2	4
2	> 9 h.	4	8
SLOPE= 1			
Variable Value	Range	Range Value	TOTAL VALUE
1	0-15%	2	2
1	15-45%	2	2
1	> 45%	1	1

QUERCUS			
ALTITUDE= 4			
Variable Value	Range	Range Value	TOTAL VALUE
4	-	0	0
4	0-1.150 m.	3	12
4	> 1.150 m.	2	8
SUMMER INSOLATION= 3			
Variable Value	Range	Range Value	TOTAL VALUE
3	0-3 h.	2	6
3	3-9 h.	2	6
3	> 9 h.	3	9
WINTER INSOLATION= 2			
Variable Value	Range	Range Value	TOTAL VALUE
2	0-3 h.	2	4
2	3-9 h.	2	4
2	> 9 h.	3	6
SLOPE= 1			
Variable Value	Range	Range Value	TOTAL VALUE
1	0-15%	2	2
1	15-45%	2	2
1	> 45%	1	1

MIXED FOREST			
ALTITUDE= 4			
Variable Value	Range	Range Value	TOTAL VALUE
4	> 150 m.	1	4
4	0-150 m.	3	12
4	-	0	0
SUMMER INSOLATION= 3			
Variable Value	Range	Range Value	TOTAL VALUE
3	0-3 h.	2	6
3	3-9 h.	2	6
3	> 9 h.	3	9
IWINTER INSOLATION= 2			
Variable Value	Range	Range Value	TOTAL VALUE
2	0-3 h.	2	4
2	3-9 h.	2	4
2	> 9 h.	3	6
SLOPE= 1			
Variable Value	Range	Range Value	TOTAL VALUE
1	0-15%	2	2
1	15-45%	1	1
1	> 45%	1	1

Tab. 1. Variables, ranges and values for each tree species identified in the palynograms, for -3 ºC with regard to present average temperature.

vegetation. Variables from which it was possible to obtain information regarding our period of study were selected, to create a thematic model, in raster format, for each one of them: altitude (altitudinal range where vegetation appears), summer insolation, winter insolation, and slope. However, some important variables, such as relative humidity or precipitation pattern, were not included in the predictive model given the lack of data. This lack of data can be alleviated by using insolation, since hydrophilic trees usually are situated in more shaded areas. In any case, a preliminary predictive model can be done with the available data, giving us some interesting information, while always taking into consideration those methodological limitations (Spikins 1997, 5).

For each of the variables taken into account three different ranges were established which indicated the suitable development conditions for each species. For example, in the case of Pinus the optimal range for the altitude variable would between 1000–2000 m above sea level (main range for the present appearance of Pinus sylvestris); above 2000 m it was considered a positive range, whereas below 1000 m it would be a negative range. This classification was carried out for the three species identified in the palynograms *(Tab. 1)*.

Tree Vegetation Predictive Model: the Weighted Values Method

The weighted values method is based on the assignation of a specific value (weight) to each of the variables included in the model, depending on their importance in the prediction (Dalla Bona 2000; Ebert 2004). In this way, the variables with most influence will have higher values, and vice versa. In the case of arboreal vegetation, the variables that condition their development are weighted in relation to their influence; the sum of all the variables allows for the calculation of the suitability of each area for the development of vegetation. Those areas with the highest total values will be those that meet the ecologic criteria for each species, and are thus the most appropriate for their appearance. These areas are termed potential areas for the distribution of vegetation (Felicísimo Pérez et al. 2002).

Once these species are identified and their ecologic requirements defined, the considered variables were classified according to their importance. Altitude was considered the most important because it reflects the distribution of vegetation in altitudinal floors (Frenzel 1993), therefore it was classified with a weight=4. In order to simulate the several climatic conditions of the Glaciation, four different altitudinal ranges were considered for each species, corresponding with an evolution of average temperatures from 4 °C below those at present to -1 °C. In order to do this, the current optimal altitudinal range was decreased, applying a thermal gradient of 100 m/0.65 °C (that is to say, given a temperature of -4 °C, a correction of -615 metres to the current optimal altitudinal range for each species was applied), and an altitude model for each degree centigrade interval was generated. The calculation of the average temperatures at the end of the Late Glacial was based on the evolution of the equilibrium lines of various glacial ensembles on the Cantabrian mountains and the Pyrenees (Chueca Cia 1992; Serrano Cañadas / Gutierrez Morillo 2001).

Next, summer insolation was classified with a weight=3 given that this is the period when vegetation growth takes place, whereas winter insolation had a weight=2. Finally, slope was classified with a weight=1 given that it is a factor that conditions vegetation growth slightly, but does not prevent it. Ground geology was also taken into consideration, although this variable was not included in the model given the homogeneity of our study area (basically composed of basic soils well-disposed for the growth of the tree formations). However, other important variables, such as relative humidity, were not taken into account because it was not possible to calculate them for our study period.

Meanwhile, the ranges were also classified according to the needs of each species. The optimal ranges obtained the highest values (value=3 or 4), positive ranges were classified with value=2, and lastly negative ranges were assigned a value=1.

Finally, the ranges' values were multiplied by the weight of their variables, thus obtaining the value corresponding to each of the cells for the different thematic models (for example, in the case of altitude for Pinus, the areas found between 1000–2000 m scored a total value of 12: 4(variable weight) *3 (rank value) = 12).

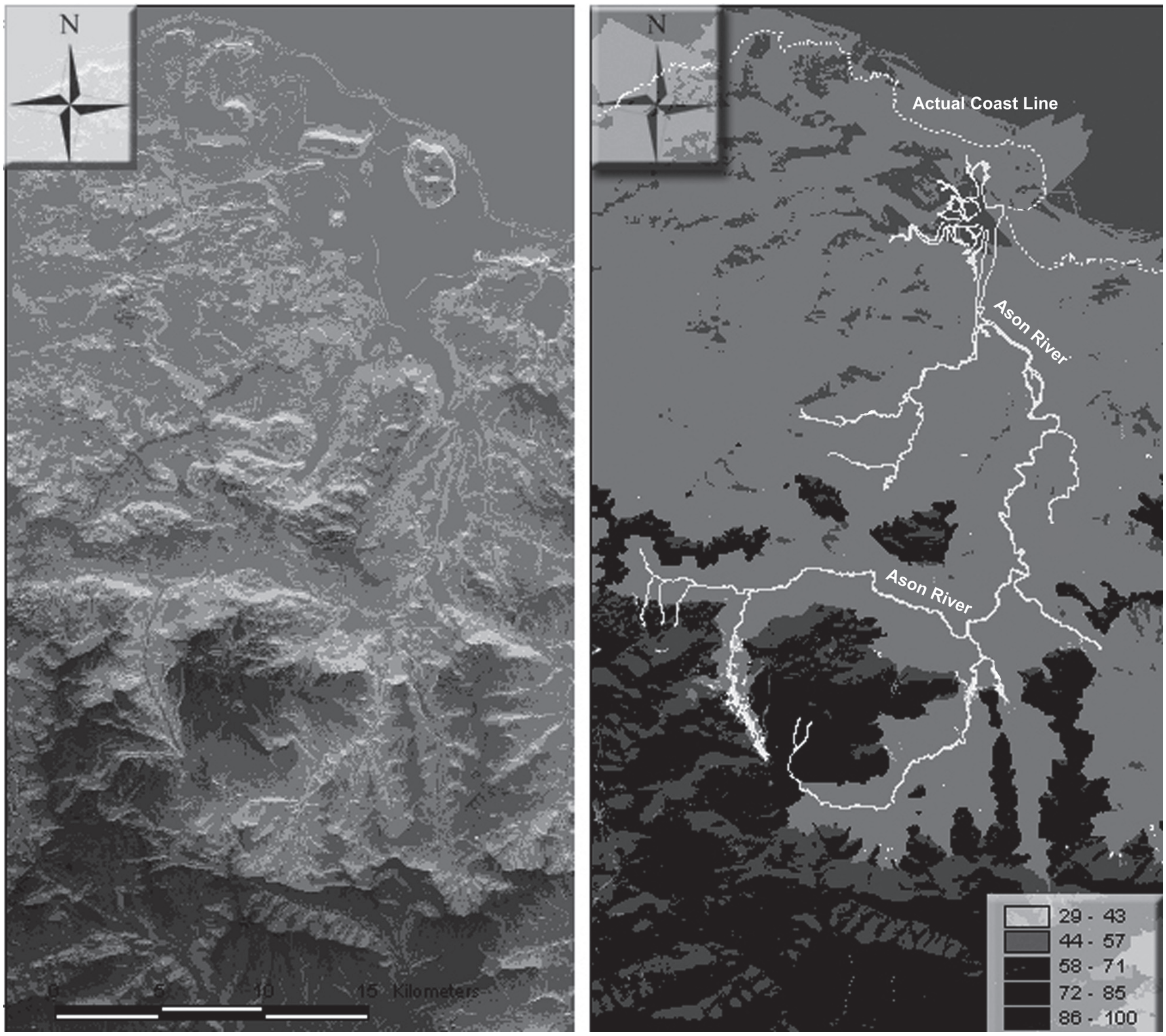

Fig. 2. Comparison between the weighted values method and the logistic regression analysis method. Darkest areas represent the most suitable areas for forest development, in this case, pine forest. Both methods assign similar values to each model (that means, most suitable areas are similar in both predictive models).

From these total values, the different thematic models were reclassified, assigning to each cell the corresponding value. In order to calculate the predictive models, the values of the four reclassified thematic models for each species were added (Predictive Model for Pinus -4 °C = Altitude -4 °C reclass. Of Pinus + Summer Insolation of Pinus + Winter Insolation of Pinus + Slope of Pinus; etc.) A total of twelve predictive models were obtained (four for each species, one for each temperature interval) *(Fig. 3)*. These models show the evolution undertaken by arboreal vegetation at the end of the Glaciation, and its spatial distribution at each point in time.

Model Evaluation: Logistic Regression Analysis

The logistic regression method is based on the statistical calculation of the influence of specific variables on population distribution. From this population, the conditions under which it appears are defined, as well as those when it does not appear. By statistically comparing both groups it is possible to extract a coefficient for each of the variables, which indicates the influence this variable has on the appearance of the population. This coefficient can be extrapolated to similar populations in order to obtain a prediction (Warren / Asch 2000).

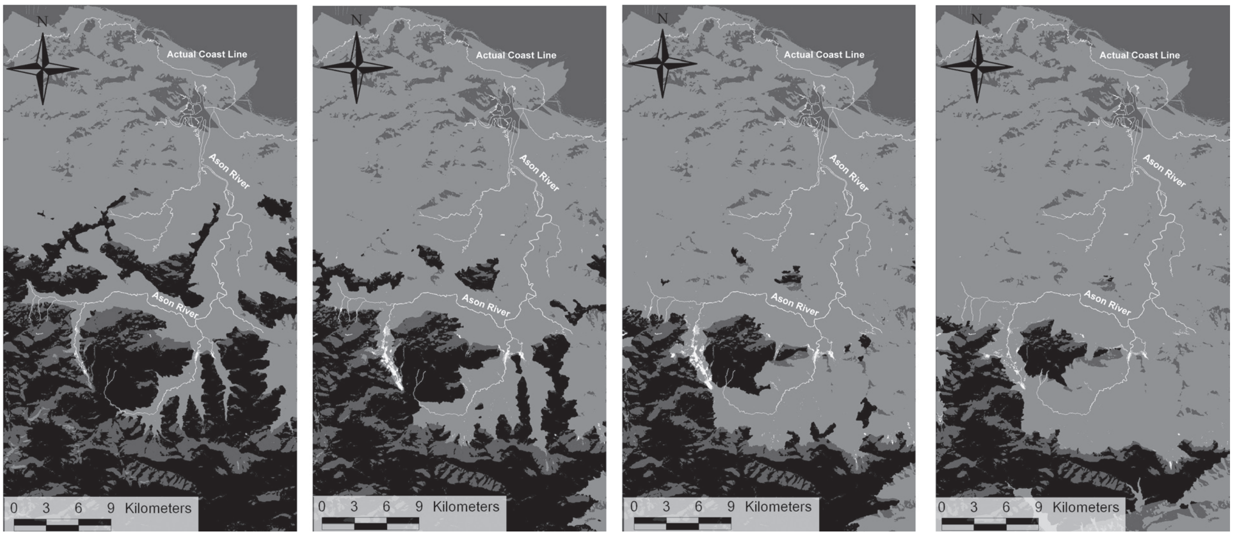

Fig. 3a. Predicted vegetation models showing the evolution of pine forest from -4 ºC (left) to -1 ºC (right). Darkest areas correspond to the most suitable areas for pine development.

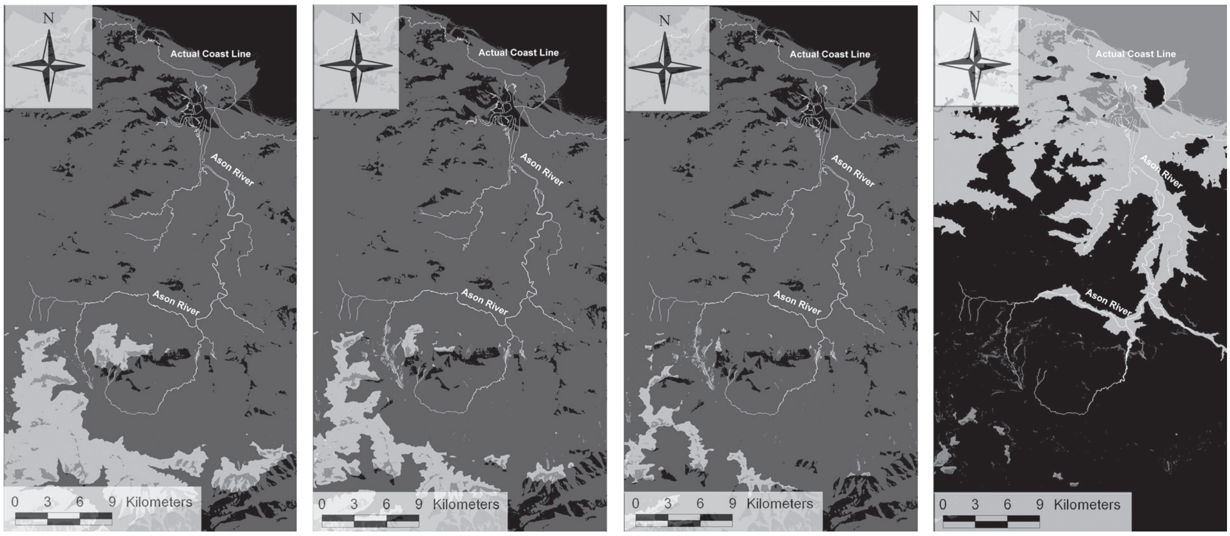

Fig. 3b. Predicted evolution for oak forest, from -4 ºC (left) to -1 ºC (right).

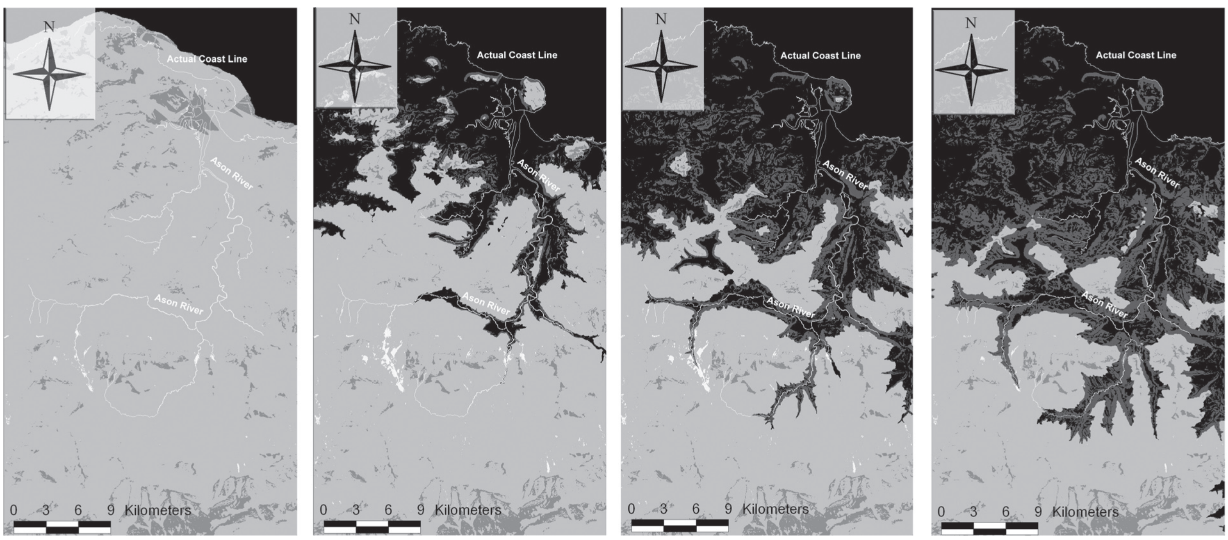

Fig. 3c. Predicted models for mixed forest (deciduous forest) from -4 ºC (left) to -1 ºC (right).

In our case, as a sample population, a distribution of Pinus, Quercus and Mixed Forest was taken from a natural reserve in Gorbea (Basque Country), a well-preserved environment with similar ecologic characteristics to those of the Asón river valley.

Initially, a coefficient was calculated for each variable. In order to do this, 300 points were distributed randomly inside the areas currently covered by each type of formation, and 300 additional points in zones where the species was not present. Afterwards, the values of the four variables included in the model generated using weighted values for each of the points was extracted. Using the SPSS program, both populations (areas with vegetation vs. areas without vegetation) were compared using logistic regression analysis. The result obtained from the analysis showed the influence that each variable had on the development of the different species in the natural reserve of Gorbea.

From these results, a new predictive model for the vegetation in our area was created. In order to do this, the value of the cells for each of the thematic models was multiplied by the coefficient obtained from the logistic regression analysis. Finally, the values from the four models reclassified according to these coefficients were added, thus obtaining the definitive predictive models. As was the case with the weighted values method, the areas with the highest values were those that possessed the best conditions for vegetation development.

When comparing the ensemble of models obtained with both methods *(Fig. 2)*, their similarity can be noted. This partly allows us to verify the validity of the methodology used in the creation of the vegetation predictive model (weighing of the environmental variables according to the ecologic needs of the arboreal species), despite obvious limitations, which will be discussed below.

Discussion

The predictive models *(Fig. 3)* show a general recession of Pinus with increasing temperatures. Pine forests, predominant throughout the Late Glacial and present in the middle zone of the valley, recede towards the mountainous areas, and are finally relegated to the highest area in the valley. Meanwhile, Quercus and Mixed Forest expand across the coastal platform and into the lowlands, colonizing the bottom parts of the interior valleys. Thus, a change in the location of the main tree accumulations can be observed, from the mid-top part of the valley to the lower lands and the bottom of the valley.

A similar process can be observed in territorial settlement patterns at the end of the Palaeolithic in Cantabria. The new sites can be found in the lowlands, and are thus related to the deciduous formations. Although economic changes taking place in these societies are due to a process more complex than simply the appearance of new forests, it is likely that the choice of new habitation areas was related to a large extent to forest environments, and the quest for better access to new resources that began to be exploited more intensely during the Cantabrian Upper-Final Magdalenian.

Conclusions

The predictive model for vegetation obtained by using the weighted values method contains some clear methodological limitations. To start with, it is based on a subjective evaluation of the influence of the variables that intervene in vegetation development. Although this assignation is based on botanical studies regarding the species' ecologic needs, a different evaluation may result in a different predictive model (Ebert 2004). This problem is partly solved through a comparison with the model obtained using logistic regression analysis, although the classification of each variable needs to be discussed adequately. Also the method proposed here does not take into account some important environmental variables, such as humidity, due to a lack of information on the matter. However, even if the introduction of new variables could complement the model obtained, we do not believe that the end result would be significantly different.

Despite these limitations, these types of models can offer interesting information regarding prehistoric environments. As Spikins (1997) states: "A model of past dominant vegetation types describes, at best, a general picture of the types of changes taking place, rather than an 'on the spot' specific prediction of dominant tree types, and cannot hope to describe the complexity of local vegetation histories. Nevertheless, although limited in resolution, an understanding of large-scale changes in vegetation proves essential to understanding changing human adaptations…". In this way, the predictive models obtained in our study allow for the observation of possible patterns of tree vegetation evolution at the end of the Tardiglacial, as well as to establish the relationship between changes in the spatial distribution of forest masses and new territorial settlement patterns.

Acknowledgements

This research project was possible thanks to a predoctoral grant awarded by the Universidad de Cantabria (Spain).

References

Boyer-Klein 1981
A. Boyer-Klein, Análisis palinológico del Rascaño. In: J. González-Echegaray / I. Barandiaran Maestu (eds.), El Paleolítico Superior de la Cueva del Rascaño (Santander 1981) 216–220.

Dalla Bona 2000
L. Dalla Bona, Protecting Cultural Resources through Forest Management Planning in Ontario Using Archaeological Predictive Modeling. In: K. Wescott / J. Brandon (eds.), Practical Applications of GIS for Archaeologists: A Predictive Modeling Kit (London 2000) 73–100.

Ebert 2004
D. Ebert, Predictive Modelling and the Ecology of Hunter-Gatherers of the Boreal Forest of Manitoba. BAR International Series 1221 (Oxford 2004).

Felicísimo Pérez et al. 2002
A. Felicísimo Pérez / E. Francés / J. Fernández / A. González Díez / J. Varas, Modelling the potencial distribution of forest with a GIS. Photogrammetric Engineering & Remote Sensing 68:5, 2002, 455–461.

Gómez Manzaneque 1997
F. Gómez Manzaneque (ed.), Los bosques ibericos (Barcelona 1997).

González Morales et al. 2004
M. González Morales / L. Straus / A. Díez Castillo / J. Ruiz Cobo, Postglacial Coast & Inland: the Epipaleolithic - Mesolithic - Neolithic transitions in the Vasco-Cantabrian Region. Munibe 56, 2004, 61–78.

González Sainz 1989
C. González Sainz, El Magdaleniense Superior-Final de la región cantábrica (Santander 1989).

Leroi-Gourhan 1966
A. Leroi-Gourhan, Análisis polínico de la Cueva en El Otero. In: J. González Echegaray (ed.), Excavaciones en la Cueva del Otero. Excavaciones Arqueológicas en España 53 (Santander 1966) 83–85.

López García 1981
P. López Garcia, Los pólenes de la Cueva de El Salitre. Trabajos de Prehistoria 38:1, 1981, 93–96.

López García / López Sáez / Uzquiano 1996
P. López García / J. López Sáez / P. Uzquiano, Paleoambiente y hábitat en las Marismas de Cantabria en los inicios del Holoceno: el caso del Abrigo de la Peña del Perro. In: P. Ramil-Rego / C. Fernández Rodríguez / M. Rodríguez Guitián (eds.), Biogeografía Pleistocena-Holocena de la Península Ibérica (Santiago de Compostela 1996) 333–348.

Peñalba 1994
M. Peñalba, The History of the Holocene Vegetation in Northern Spain from Pollen Analysis. Journal of Ecology 82:4, 1994, 815–832.

Spikins 1997
P. Spikins, Population Increase in the Mesolithic: a GIS Perspective. In: I. Johnson / M. North (eds.), Archaeological Applications of GIS. Proceedings of Colloquium II, UISPP XIIIth Congress, Forli, Italy, September 1996 (Sydney 1997).

Uzquiano Ollero 2000
P. Uzquiano Ollero, El aprovechamiento del bosque durante el Tardiglaciar y el Holoceno en la cuenca de Arudy (Pirineos Occidentales, Francia). Complutum 11, 2000, 143–156.

Warren / Asch 2000
R. Warren / D. Asch, A Predictive Model of Archaeological Site Location in the Eastern Prairie Peninsula. In: K. Wescott / J. Brandon (eds.), Practical Applications of GIS for Archaeologists: A predictive Modeling Kit (London 2000) 5–32.

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