Predictive models and the evolution of tree vegetation during the Final Pleistocene – Holocene transition. A case study from the Asón River Valley (Cantabria, Spain).

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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 was marked out, during both the Younger Dryas and the Early Holocene.

Key words: landscape, Final Pleistocene-Early Holocene transition, settlement, Cantabrian Region, predictive models.

1 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 Lateglacial (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 these groups' economies.

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).
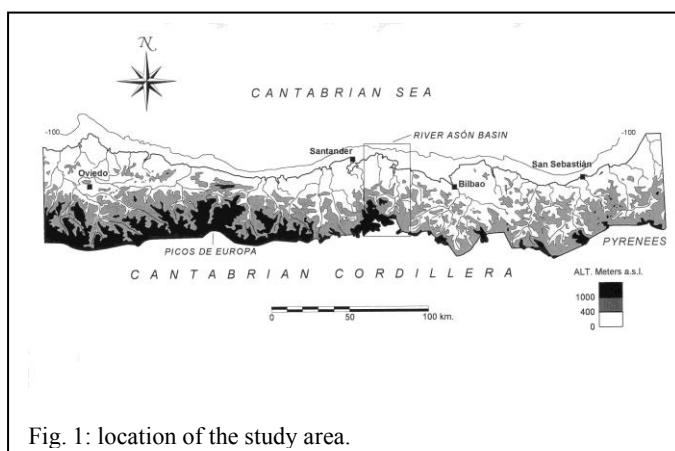

Fig. 1: location of the study area.

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, *et al.* 1996; Uzquiano Ollero 2000). The results have shown that, throughout the end of the Lateglacial, 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 know the position and evolution of the main forest formations at the end of the Lateglacial 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. On the other hand, in order to verify its reliability, the information 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.

2 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 Lateglacial (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, with the appearance of bigger and more thicket forests than Cantabrian Lateglacial 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 number of environmental variables have in the development of vegetation. Variables from which it was possible to obtain information regarding our period of study were selected, creating 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 somehow solve using *insolation*, since hidrophilic trees usually are situated in more shading areas. In any case, a preliminary predictive model can be done with the available data, giving us some interesting information, and always taking into consideration those methodological limitations (Spikins 1997, 5).

On the other hand, 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 1,000 – 2,000 m/sl (main range for the present appearance of *Pinus sylvestris*); above 2,000 m/sl it was considered a *positive range*, whereas below 1,000 m/sl it would be a *negative range*. This classification was carried out for the three species identified in the palynograms (Table 1).

PINUS

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

QUERCUS

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

MIXED FOREST

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

Table 1: variables, ranges and values for each tree specie identified in the palynograms, for -3°C with regard to present average temperature.

3 Tree vegetation predictive model: the weightd 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 weighed 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 100m/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 Lateglacial 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).

Secondly, *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.

On the other hand, the *ranges* were also reclassified 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*.

Lastly, 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 1,000 – 2,000 m/sl scored a *total value* of 12: *4(variable weight) *3(rank value) = 12).*

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.

4 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).

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.

Firstly, 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 more 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 were extracted. Using the *SPSS* programme, 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 the 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.
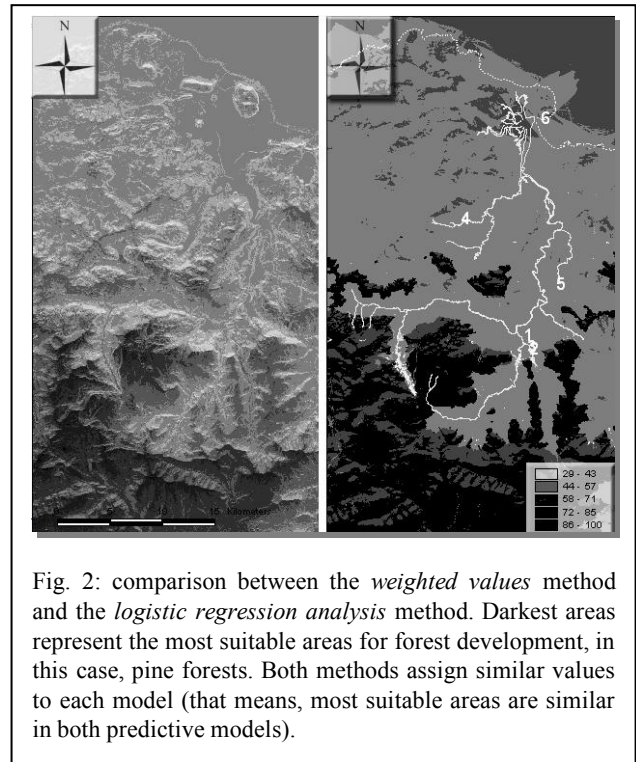

Fig. 2: comparison between the *weighted values* method and the *logistic regression analysis* method. Darkest areas represent the most suitable areas for forest development, in this case, pine forests. Both methods assign similar values to each model (that means, most suitable areas are similar in both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

5 Discussion

The predictive models (Fig.3) show a general recession of *Pinus* with increasing temperatures. Pine forests, predominant throughout the Lateglacial and present in the middle zone of the valley, recede towards the mountainous areas, finally relegating to the highest area in the valley. On the other hand, *Quercus* and *Mixed Forest* expand across the coastal platform and in 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 greater link 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.

6 Conclusions

The predictive model for vegetation obtained by using the *weighted values* method contains some clear methodological limitations. Firstly, 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. On the other hand, the method here proposed 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 a 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.

7 Acknowledgements

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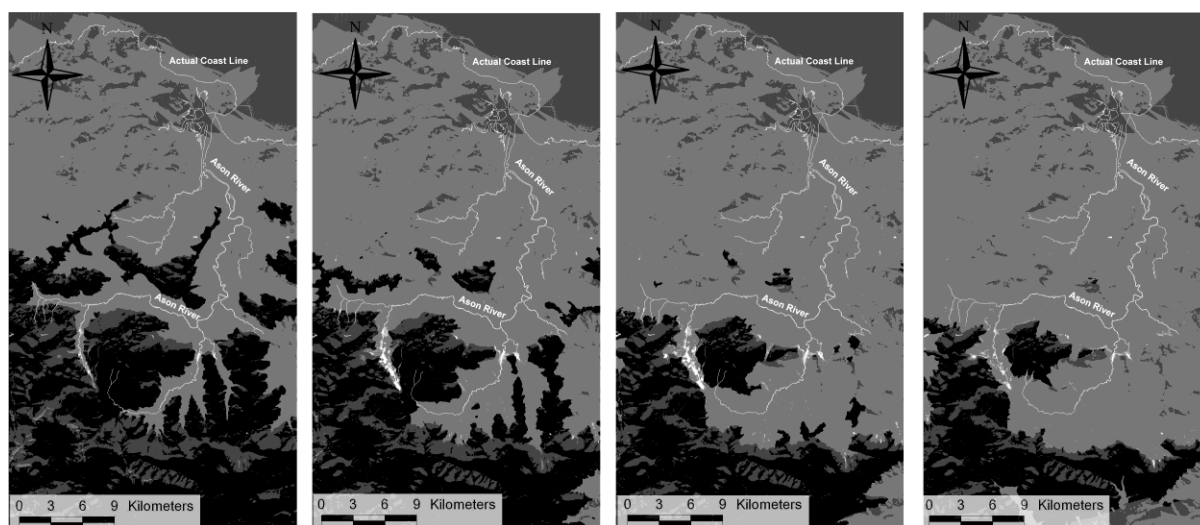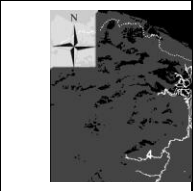

Fig. 3a: *predictive vegetation models* showing the evolution of pine forest from -4ºC (left) to -1ºC (right). Darkest areas correspond to the most suitable areas for pine development.
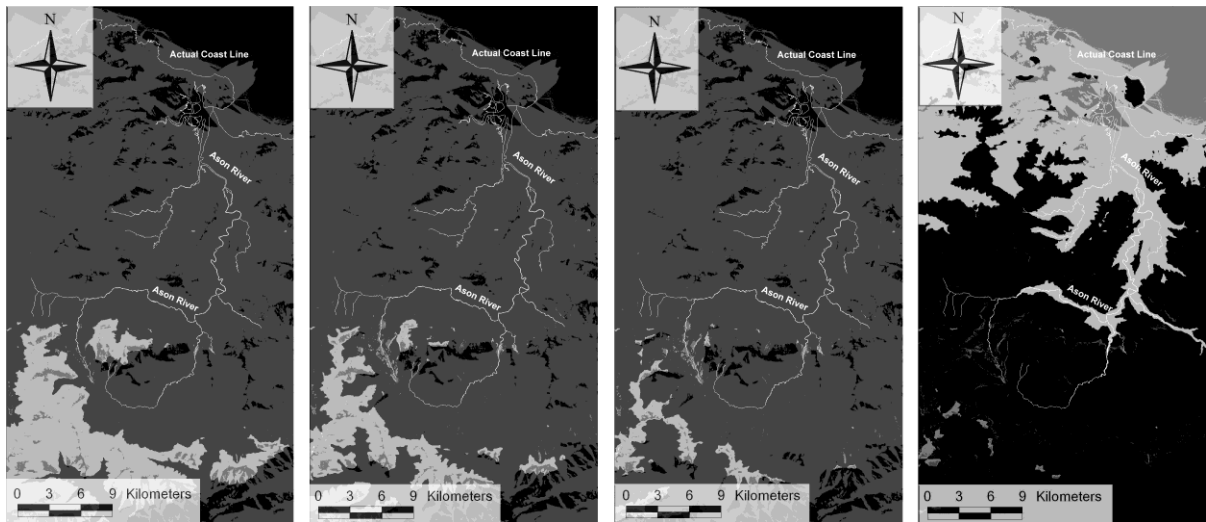
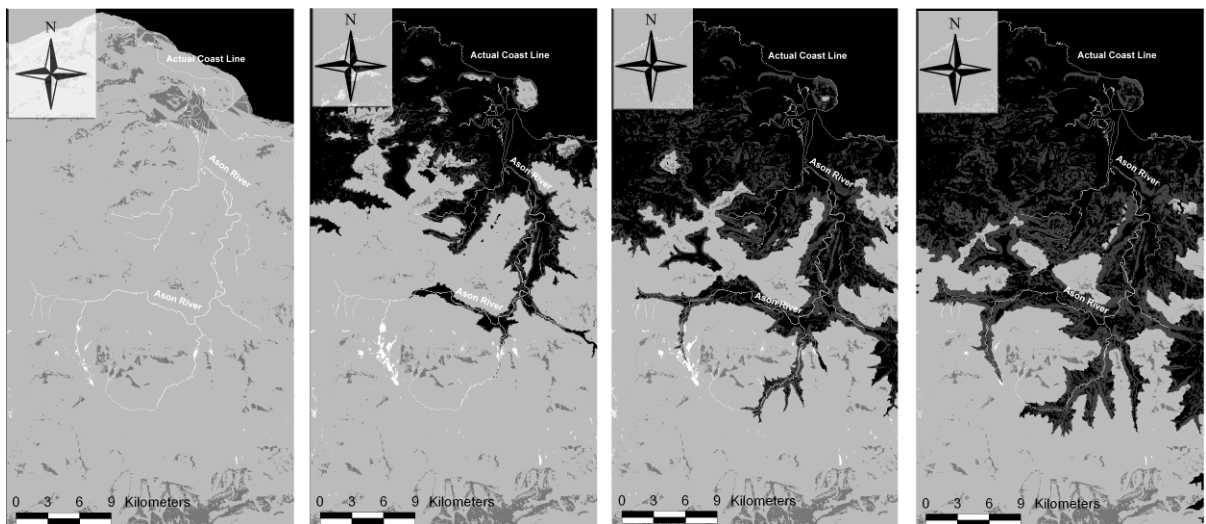Fig. 3b: predicted evolution for oak forest, from -4ºC (left) to -1ºC (right).

Fig. 3c: *predictive models* for mixed forest (deciduous forest) from -4ºC (left) to -º1C (right).