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RESOURCE COMMUNICATION

A state-and-transition model of Iberian dehesas based on spatial patterns

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Abstract

Aim of study: In this study a process based on a Geographic Information System (GIS) is proposed as a tool for analyzing the spatial structure of the Mediterranean dehesa ecosystem.

Area of study: Western Peninsular Spain.

Material and methods: The method allows a semi-quantitative "state and transitions" (S&T) net that provides original information derived from spatial patterns that cannot be obtained by other means.

Main results: This GIS analysis also supplies a spatial basis which complements the conceptual framework of vegetation series successional proposals. Moreover, the proposed method can be a useful tool for understanding landscape changes.

Research highlights: Our work proposes not only a descriptive model but also a methodology based on spatial metrics and topological relationships.

Keywords: Geographic information systems; successional net; landscape management.

Abbreviations used: S&T: State and Transition; RFP: Regional Forest Plan.

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Introduction

Dehesas cover more than 3 million hectares of the South-West of the Iberian Peninsula (Díaz *et al.*, 1997). Although there are different definitions for the term "dehesa", it generally refers to managed wooded pastureland (Joffre *et al.*, 1988, Pinto-Correia, 1993, Campos *et al*. 2013). They are of considerable importance from a socio-economic, environmental and cultural point of view (Campos Palacín, 1993, Díaz *et al.*, 1997, Rensburg, 2001). In terms of sustainability, it is especially remarkable the compatibility between economic profitability and the conservational interest of the high biodiversity values (Pinto-Correia, 2000).

The dehesa landscape is characterized by a two-layered structure consisting of seasonal grassland and scattered trees dominated mainly by *Quercus ilex* subsp. *ballota* (Desf.) Samp. and in a lesser extent, *Quercu*s *suber* L. and *Quercus pyrenaica* Willd.

While over the past they been quite stable, landscape changes have taken place in the last decades, mainly due to the mechanization of agriculture and the increase of irrigated land and reforestation with fast-growing tree species (Elena Rosselló *et al.*, 1987, Bermejo, 1994). The remaining dehesas are reported to suffer from land degradation due to several causes: lack of trees' regeneration (Montero *et al.*, 1998); shrub encroachment in abandoned areas (Marañón, 1988); decrease of tree biomass due to excessive pruning for firewood production (Regato-Pajares *et al.*, 2004); and, soil degradation because of excessive stocking rates (Schnabel, 1997). It is important to note that abandonment leads to a regeneration in the direction of what is thought to be the original vegetation cover; however, this is considered as a degradation because the dehesa is considered the suitable stage.

Most of the land use changes in the dehesa landscape take place without specific management plans, and their repercussions for the spatial patterns and the landscape are not well known. The influence of historical factors has been dealt with by (Pinto-Correia & Mascarenhas, 1999).

The correct management of the landscape involves understanding the successional patterns over medium to longer term. Spatial patterns can be a useful tool for understanding dynamic or temporal changes.

The aim of the present study is to propose a descriptive model and a methodology based on spatial metrics and topological relationships to describe a "state and transitions" net as a model of dehesa dynamics. The S&T models are nets describing changes between states: recognizable, resistant and resilient complex of soil base and vegetation structure. The above definition and a review are in (Stringham *et al*., 2003) and (Briske *et al*., 2005).

Materials and methods

The study area

The study was performed in Extremadura, a region of the Iberian Peninsula with a Mediterranean climate. The dominant tree species are mainly *Quercus ilex* subsp. *ballota*, while *Quercus suber* and *Quercus pyrenaica* have also a significant presence (Figure 1).

Data sets

The analysis was carried out using two sets of digital maps reproducing the spatial distribution of the current vegetation. The first set was obtained from the Spanish Forestry Map (SFM). It was used in order to identify the main vegetation classes and their current spatial distribution over the study area.

The second set of maps was the suitability maps (Figure 2). The use of those maps was one of the essential points of this study. A suitability map is a raster model in which each pixel value represents the suitability for a given use (e.g. forest presence). The basis of the suitability models is to establish relationships between the environmental variables and the spatial distribution of vegetation. Commonly, each vegetation type will respond to a different model as a consequence of their different environmental requirements. The suitability is expressed on a scale of 0–1 (incompatible–ideal). A complete explanation of our suitability models can be found in (Muñoz & Felicísimo, 2004, Mateo *et al.*, 2011) Among all techniques for generating suitability maps, multiple adaptive regression splines method (Friedman, 1991) was the selected method.

Spatial analysis

A Geographic Information System (GIS) analysed both the metric and topologic relationships between vegetation patches of each *Quercus* species.

The most suitable values, obtained from the suitability models, defined the potential area for each *Quercus*

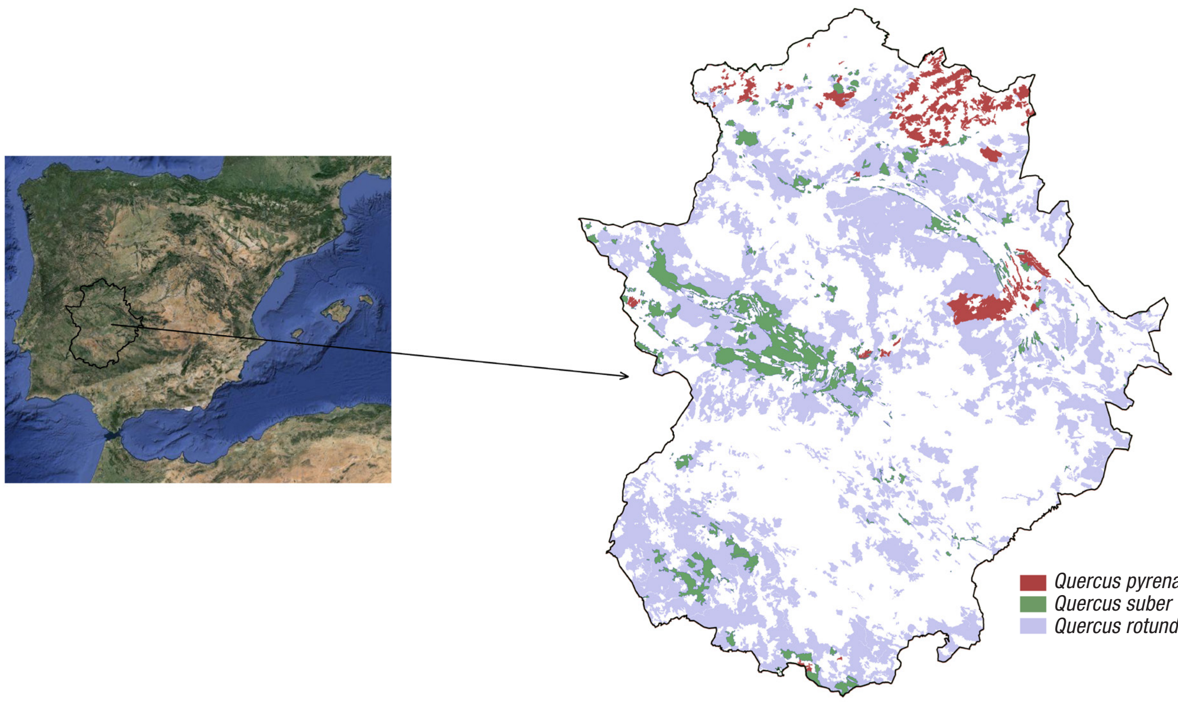

Figure 1. Current distribution of *Quercus* species in the study area

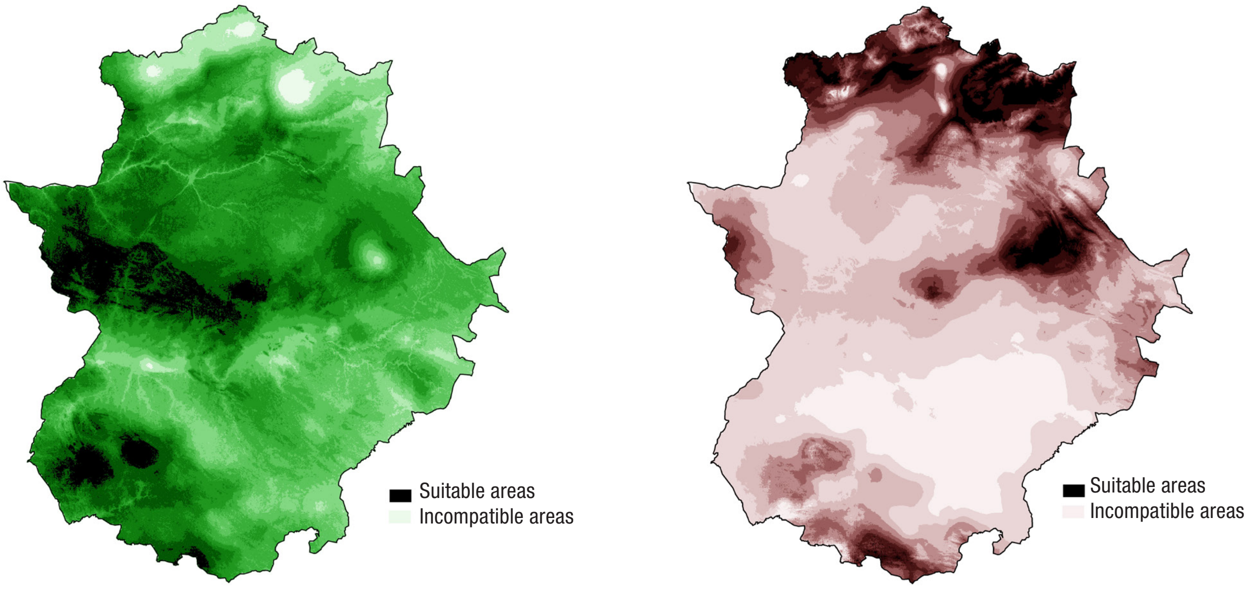

Figure 2. Example of *Quercus pyrenaica* (left) and *Quercus suber* (right) suitability models.

species as a set of patches (polygons). These polygons were intersected with the SFM in order to determine the vegetation classes actually occupying the potential areas. The surfaces were classified according to vegetation categories. The selection of the patches and their area were the basis for the design of the nets for the current vegetation states and their spatial (not temporal) transitions.

Three state and transition (S&T) nets were constructed, one for each species of *Quercus*, which included all the vegetation classes that have spatial relations with the tree formations. These nets were the result of the actual knowledge of the successional stages, but adapted to the observed spatial relations. Both states and transitions were evaluated by means of the statistics derived from the spatial analysis.

Results and discussion

State and transition nets

The S&T nets do not constitute a copy of the common succession models since they include several states that can be outside the natural succession; according to (Pivello & Coutinho, 1996), the model reflects that the succession in the study area is a multiple pathway process, which contrasts with the idea of a linear succession.

Figure 3 shows the S&T nets corresponding to the three considered species. Two types of states were considered: stationary (rectangles with round corners) and non-stationary (rectangles). The first may be possible due to natural (e.g. bedrock) or artificial (e.g. dams, irrigated lands) causes, making the change to another state difficult.

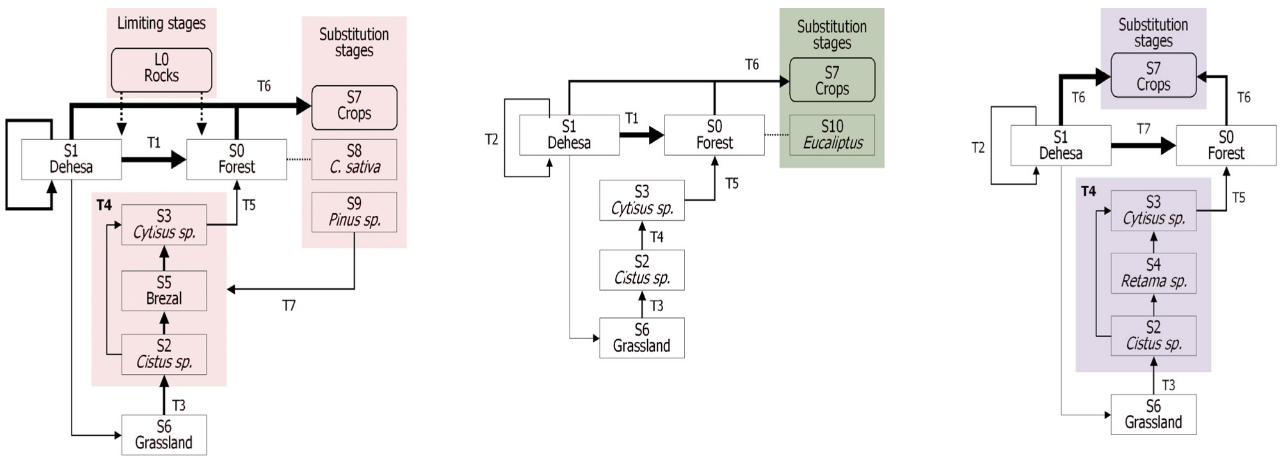

Figure 3. State and transition net for the three *Quercus* species.

Arrows represent the spatial structure derived from GIS analysis of the potential/neighbouring areas. The arrow thicknesses show the importance of transitions between states derived from the actual surface of the patches and they assign a semi-quantitative significance to net elements. Finally, dotted lines represent states without transitions, namely, rocky terrains (a limiting stage) close to *Quercus pyrenaica*.

Descriptions of stages

The following Successional stages were obtained.

S0 **Forests**: with a moderate degree of human intervention, equilibrated strata and a dominance of trees and shrubs.
S1 **Dehesas**: resulting from forest clearance and shrub elimination, with scattered trees over a continuous grass layer.
S2 **Jarales**: shrub formation with dominance of *Cistus ladanifer* L.
S3 **Escobonales**: shrub formation with dominance of *Cytisus striatus* (Hill) Rothm. and *C.scoparius* (L.) Link.
S4 **Retamares**: shrub formation with dominance of *Retama sphaerocarpa* (L.) Boiss.
S5 **Brezales**: heath with dominance of *Erica australis* L., *E. arborea* L., *E. umbellata* Loefl. ex L. and *Calluna vulgaris* (L.) Hull.
S6 **Grasslands**: these herbaceous formations can only be considered a natural stage in some mountainous areas, where there are *Nardus stricta* L. domains; the floristic composition is strongly dependent on the climatic and edaphic conditions.
On the other side, the obtained Substitution stages were the following:
S7 **Crops**: tillage on irrigated lands. This stage can be interpreted as a stationary state in the S&T net.
S8 **Chestnut**: in Extremadura only, appearing in the most humid parts of the mountainous areas.
S9 ***Pinus pinaster*** Aiton and ***Pinus pinea*** L.: the most abundant species of the *Pinaceae* family; they are exotic in the study area.
S10 ***Eucalyptus***: mainly restricted in Extremadura to the humid areas, near to the rivers; *E. camaldulensis* Dehnh. and *E. globulus* Labill. are the most abundant species.

The Limiting stage (**L0**) can be interpreted as stationary in the S&T net. In the highest areas, the ridges of bare rock constitute the physical limit to the growth of vegetation.

Description of transitions

Progressive transitions in the model were the following:

T1 **Dehesa to forest**: This transition could be considered as "natural" due to the successional instability of the dehesas. Inverse transitions, from forest to dehesa, probably do not exist nowadays.
T2 **Dehesa to dehesa loops**: The control of shrub encroachment has been traditionally carried out by direct interventions. Abandonment of these cultural practices decreases the global weight of T2 in favor of T1.
T3 **Grassland to *jaral***: This transition is present on the three *Quercus* nets. *Cistus* is commonly interpreted as a pioneer shrub species which quickly colonizes areas of degraded soils after some natural or human induced perturbations.
T4 ***Jaral* to other shrub formation**. The *Cistus* roots break the ground and their litter contributes by increasing the content of organic matter and improving the soil texture.
T5 **Dense shrubbery to early forest**. This implies the development of a tree layer. This process is possible only if trees exist close to the space of the shrub formation, and it is unlikely to occur in other places.

On the other hand, the obtained regressive transitions were:

T6 **Dehesas or forests to other timber species or croplands**: Croplands, mainly on the irrigated lands, are quasi-stationary stages since their reversion to any other natural state is actually impossible. This is not the case for timberlands, because the reduction of the human interventions can contribute to colonization by Mediterranean shrub species.
T7 ***Pinus* to shrub formation**. The mosaic of patches of *Pinus* suggests a facilitated transition to *escobonales* (*Cytisus* sp.) which could be originated by timber production activities. It seems probable that succession of these areas leads to a dense shrub stratum.

Conclusions

We propose S&T models as a tool for analyzing the spatial structure of the Mediterranean dehesa ecosystem. The S&T models provide original information derived from spatial patterns and complement the conceptual framework of successional proposals for vegetation series. Moreover the S&T models are relatively simple compared to predictive or biologically-based models (Rogers & Johnson, 1998, Lambin *et al.*, 2000).

The interest of the proposed models lies in their ability to provide objective data about the spatial and topological relationships between vegetation patches and establish a conceptual framework for the dynamic of vegetation categories.

Obviously, the S&T models should be discussed carefully in each case since the model assumptions can be appropriated only under some circumstances. The dehesa ecosystem has evolved influenced by natural and anthropogenic factors under common goals and constraints: the optimization of the land uses under strong climate conditions and avoiding expensive inputs as irrigation or artificial fertilization. This forces to optimally exploit the natural resources of the land and conditioned the potential stages and transitions. We believe that in other circumstances (friendly climate and intensive artificial inputs) the S&T models can be less significant.

With these limitations, the advantages of the S&T models are their objectivity and repeatability. Nevertheless, any statistical or GIS model is heavily dependent on data and it would have been very advantageous to have historical data to analyze the sequence with some intermediate states.

It is necessary to emphasize that the actual patterns are only a trace of the history but we believe that this work shows the potential of the S&T nets as a simple but objective technical to help address some management actions.

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