VOL IV

Estudos em Ciências Agrárias e Ambientais

Eduardo Spers
(Organizador)

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APRESENTAÇÃO

É com grande satisfação que apresentamos o volume IV da coletânea **Estudos em Ciências Agrárias e Ambientais**, resultado do esforço colaborativo de pesquisadores de diferentes regiões e instituições, que compartilham aqui reflexões, dados e contribuições relevantes para o avanço do conhecimento técnico-científico em suas áreas de atuação.

Este volume reúne 13 trabalhos organizados em cinco eixos temáticos que refletem a diversidade e complexidade do campo agrário e ambiental contemporâneo: Sistemas de Produção Aquático e Animal; Sustentabilidade Ambiental e Conservação de Recursos Naturais; Sistemas de Produção Vegetal e Agricultura de Precisão e Educação e Inovação no Meio Agrário.

Os temas abordados vão desde o manejo sustentável de recursos naturais, passando por inovações tecnológicas na agricultura e aquicultura, até discussões sobre formação profissional e segurança sanitária nas cadeias produtivas. Essa pluralidade é o reflexo da crescente interdisciplinaridade que caracteriza os estudos agrários e ambientais hoje – exigindo diálogos entre a ciência, a tecnologia, a educação, a economia e a sociedade.

Além da qualidade dos estudos apresentados, destacamos o compromisso dos autores com a pesquisa aplicada, a sustentabilidade e a busca por soluções adaptadas às realidades locais, muitas vezes desafiadoras. A presença de autores da América Latina e Europa também fortalece o caráter internacional da obra, fomentando o intercâmbio de experiências e metodologias.

Agradecemos a todos os autores pela confiança em compartilhar seus trabalhos conosco. Que esta publicação possa inspirar novas pesquisas, colaborações e, acima de tudo, práticas que contribuam com a construção de sistemas agrários e ambientais mais resilientes, justos e inovadores.

Desejamos a todos uma excelente leitura!
Eduardo Eugênio Spers

SUMÁRIO

CAPÍTULO 6

PHYTOCLIMATIC DYNAMICS IN NATURAL OROMEDITERRANEAN FORESTS OF *Pinus sylvestris L.* IN THE CENTRAL SPANISH IBERIAN PENINSULA. SUITABILITY AND VERSATILITY UNDER CLIMATE CHANGE

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ABSTRACT: The effects of phytoclimatic dynamics in Mediterranean high mountains on the current and future phytoclimatic suitability of natural oromediterranean Scots pine forests (*Pinus sylvestris* L.) are analysed at a specific location, "Puerto de Navacerrada" (Guadarrama mountains, Central Spain, 1893 m), between 1951 and 2024. The use of phytoclimatic models applied to the temporal dynamics of the values of 12 climatic variables in 30-year mobile averages allows quantifying the changes of increasing thermoxericity in the site suitability indices for 24 physiognomies and 20 forest types. The results suggest that for the time being the dominant forest will continue to be those dominated by *Pinus sylvestris*, but with evolution from oroborealoid towards nemoromediterranean phytoclimatic positions, which will decrease the current exclusivity of pine, allowing the gradual entry of the decidous broad-leaved species *Quercus pyrenaica* from lower altitudes. This suggests an increase of their phytoclimatic versatility and a decrease in their vulnerability, although it augurs changes in composition, physiognomy and interspecific competition relations, which will force us to rethink adaptive management planning and actions.
KEYWORDS: phytoclimatology; climate change; suitability; versatility; Pinus sylvestris; vulnerability; adaptive management.

1. INTRODUCTION

The adaptation of forest ecosystems to the new challenges posed by climate change so that they can continue to provide vital services to man and the planet must be a priority objective of forest managers, especially when the long life-span of trees does not allow for rapid adaptation to environmental changes (Davis et al., 2005; Kremer, 2007). Forests ecosystems can respond to climate change by shifting distribution, by remaining in isolated pockets of suitable environment (refugia), becoming extinct or by adapting its composition, internal competitive relationships or structure to changing conditions (Holt, 1990; García López & Allué Camacho, 2013).

Phytoclimatic temporal dynamics should be adequately taken into account when planning and implementing preventive active management and conservation policies sufficiently in advance and based on scientific evidence. The development of models to assess and predict possible changes that have occurred or may occur in the future in forest ecosystems, as a consequence of shifts in the suitability of the environment is currently one of the main challenges at present (Condit et al., 2005, Guisan & Thuiller, 2005).

Mediterranean forest ecosystems are generally highly vulnerable to climate change (Lindner et al., 2010; García López & Allué Camacho, 2012), specially forests located close to their altitudinal or latitudinal limit may show more complex and heterogeneous responses to climate change (Malanson, 2001).

Scots pine (*Pinus sylvestris* L.) is a naturally-occurring species in taiga forests in northern Europe and Asia, being its northern area of distribution more or less continuous on plains, whereas in the south, in the Mediterranean region, it is becoming increasingly fragmented and confined to mountain areas. The oromediterranean *Pinus sylvestris* pine forests of the central Iberian Peninsula, such as those of the Guadarrama mountains (Spain), are therefore of special interest because they are located near the southern limit of their global distribution, at the altitudinal limit of tree vegetation and due to their incompatibility with high values of thermoxericity.

In the present work we study the phytoclimatic dynamics in a representative location of this type of forest ecosystems, the weather station "Puerto de Navacerrada", located at 1893 m altitude in the National Park 'Sierra de Guadarrama' (Figure 1), in order to evaluate the possible consequences of climate change in these ecosystems and on their future management.

The natural altitudinal cliserie of the study area is composed of evergreen holm oak forests of *Quercus ilex* ssp. *ballota* in the lower zones, deciduous oak forests of *Quercus pyrenaica* in the middle zones, and pine forests of *Pinus sylvestris* in the higher zones, which constitute the treeline. Above them, there are woodlands dominated by *Cytisus oromediterraneus* and *Juniperus communis* ssp. *alpina* and, in the culminating zones, grasslands of *Festuca indigesta* ssp. *lagascae*.

Figure 1. Natural pine forests of *Pinus sylvestris* in Spain and the situation of the study area.

Figure 2. Oromediterranean natural *Pinus sylvestris* forests in the study location (Puerto de Navacerrada, 1893 m). In the foreground *Cytisus oromediterraneus* and *Juniperus communis* ssp. *alpina* woodlands.

Figure 3. Broad-leaved deciduous *Quercus pyrenaica* forests in middle altitudinal areas of Guadarrama mountains.

2. MATERIALS AND METHODS

Two phytoclimatic models were used: The original Allué-Andrade (1990) updated model, which provides the season suitability for a set of 24 previously established phytoclimatic subtypes corresponding to large physiognomies or life strategies of dominant canopies (FVN model), and the CAF model (García López & Allué Camacho, 2011), which provides the site suitability index for a set of 20 tree species with the capacity to form dominant forest canopies. An updated version of both models, their conceptual bases and guidelines for results interpretation can be found in Allué Camacho & García López (2024). The temporal dynamics component was introduced in both models by calculating the values of 12 phytoclimatic variables (Table 1) in 30-year mobile averages between 1951 and 2024.

Table 1: Phytoclimatic variables used.

	Variable	**Unit**
K	Intensity of aridity. Calculated on the basis of the quotient As/Ah, where Ah is the humid area of the climodiagram (Pi curve above the Ti curve, *i.e.*, 2Ti < Pi) and As is the dry area of the climodiagram (Pi curve below the Ti curve, *i.e.*, 2Ti > Pi). Ti and Pi are the mean temperature and precipitation of the month i	
A	Duration of aridity in the sense of GAUSSEN, that is the number of months in which the Ti curve is above the Pi curve, *i.e.*, 2Ti > Pi	months
P	Total annual precipitation	Mm
PE	Minimum summer precipitation (June, July, August or September)	Mm
TMF	Lowest monthly mean temperature	˚C
T	Mean annual temperature	˚C
TMC	Highest monthly mean temperature	˚C
TMMF	Average of the minima of the month with the lowest mean temperature	˚C
TMMC	Average of the maxima of the month with the highest mean temperature	˚C
HS	Certainty of frost. Calculated as the number of months in which Ti <= 4˚C	months
PV	Period of free plant activity, calculated as the number of months in which Ti >= 7.5˚C, not counting periods where A > 0	months
OSC	Thermal oscillation. Calculated as TMC-TMF	˚C

The phytoclimatic habitat suitability niche-based CAF model assesses simultaneously non-linear, nonstatistical and dual measurements of proximity/potentiality of a target site concerning climatic ranges of 20 natural phytologies (forest arboreous types).

The traditional environmental space is founded in classic ecological niche theory and is defined by climatic variables regarding temperature and precipitation. Through a specific transfer function, this climatic space is replaced by a suitability space. A set of phytoclimatic distances evaluates the climatic suitability of a site for a forest type.

The model considers a 12-dimensional climatic hyper-space corresponding to the n=12 climatic variables. Thus, within the geographical scope of the model the respective forest types ranges or realised niches can be explicitly defined by calculating convex hulls. Although many shapes could be used to enclose the points, the convex hull is defined as the smallest convex set enclosing them and therefore reduces the amount of empty space com-pared with other volumes like parallelepipeds. Therefore, each range takes the form of a convex hyperpolyhedron which can be explicitly defined by a set of vertices and linking edges.

Regarding the complexity of explicitly determining the hyperpolyhedron for n > 2, it is best calculated by means of projections onto m climatic planes with no ViVj repetition formed by climatic variables Vi and Vj, where

$$m = \binom{n}{2} = \frac{n(n-1)}{2}$$

Each variable appears in n−1 ViVj projections. The number of possible combinations is less than a factorial to avoid redundancies, as projections ViVj and VjVi give the same information. For the n = 12 climatic variables used m = 66 polyhedrons are fitted for the 20 forest types.

A target point P whose coordinates are (Vi_p; Vj_p) in the plane ViVj is suitable for a specific woodland type if it occurs inside the polyhedron that represents the projection of the plane of the full range of the type, i.e. the entire hyperpolyhedron in the climatic 12-dimensional hyperspace. The target point’s position with respect to the projected polyhedron is related to its degree of compatibility or suitability by a transfer function (Allué Camacho & García López, 2024):

$$\varphi_P^{Vi} = K_{Vi_p}\left[\frac{2Vi_p - Vi_{\max} - Vi_{\min}}{Vi_{\max} - Vi_{\min}}\right]^{2\partial}$$

Between the two bounds of a variable Vi (Vi_{max} and Vi_{min}), the maximum of the curve is not a peak but a plateau or large central zone of maximum compatibility where the function takes the value 1 for a target point P. Then there is a sharp decline outwards the edges, where it takes the value 0, and outside this range the values are negative. K_{Vip} assesses the capacity to predict species occurrences that the value Vi_p of a climatic variable Vi acquires at a site P and can be estimated as the inverse of the number of species considered in the model with which Vi_p is compatible.

We assume that the degree of suitability for a wood-land type will be greater in occurrence sites situated far from the bounds of their 66 convex climatic ranges (0), and the average of its m values in the m climatic planes can be used as a Phytoclimatic Suitability Index (PSI). Unlike statistical models, the concept of suitability in CAF is not related to the frequency of species occurrence within their geographical ranges.

3. RESULTS

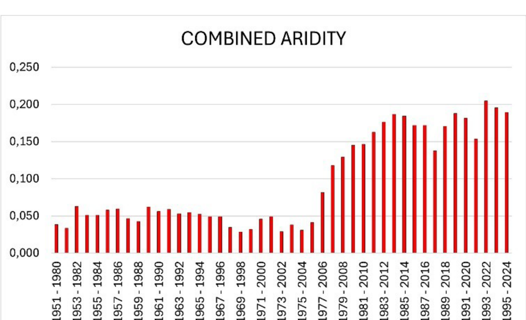
3.1. CLIMATIC VARIABLES DYNAMICS

Figure 4 shows the variables time evolution in 30-year mobile averages. A clear upward evolution of temperatures is observed throughout the period studied, both for maximum and minimum temperatures. The mean annual temperature (T) rises from 5.8º C in the first period analysed (1951-1980) to 7.6º C in the last (1995-2024), showing the most homogeneous trend, followed by that of the maxima. Precipitation, although with a less homogeneous behaviour than temperatures, shows a general downward trend, especially the minimum monthly precipitation from the period 1975-2004. All this causes increasing values of the combined factors of a thermo-pluviometric nature related to thermoxericity, like the intensity and duration of aridity (K and A), with K showing higher relative increases than those of A. The global warming also causes a slight increase in the length of the growing season (PV).

Figure 4. Phytoclimatic factorial dynamics in three-year mobile averages between 1951 and 2024.

The Combined Aridity (CA), which jointly integrates the concepts of intensity (K) and duration (A) (CA=K.A), specially shows a clear trend change from the period 1975-2004, from mean values of 0.046 (with a maximum of 0.063 and Stdv=0.010) to mean values of 0.163, with a maximum of over 0.200 (Stdv= 0.030), values never before recorded in the time period analysed (Figure 5).

Figure 5. Evolution of Combined Aridity (CA) values in 30-year mobile averages at “Puerto de Navacerrada” between 1951 and 2024.



3.2. FVN MODEL

In the FVN model of physiognomies, the site suitability to a phytoclimatic subtype is expressed through the corresponding suitability index (PSI), which can be a maximum of 1, followed by a letter that indicates in each case if the point is Genuine (G) for being inside the factorial scope of existence of the subtype defined by a parallelepiped in the 12-dimensional factorial hyperspace, if it is Analogous (A) for being external but very close to the domain or if on the contrary it is Disparate (D) for being external and further away from the domain at least in relation to some factor, being able to be disparate close depending on this distance. Table 2 shows a simple dichotomous factorial key of separation between the 24 physiognomic types that make up the model.

Table 2. Qualitative numerical key to the physiognomic types used in the FVN model.

<table>
<tr><td rowspan="20">TMMF > -5</td><td colspan="5">A > 11,44</td><td>III(IV)</td><td>Sub-tropical sub-mediterranean deserts</td></tr>
<tr><td rowspan="7">3 ≤ A < 11,44</td><td rowspan="5">TMMF > 0</td><td rowspan="2">K ≥ 7</td><td colspan="2">TMC ≥ 26,5</td><td>IV(III)</td><td>Mediterranean infra-arboreous sub-tropical sub-desert</td></tr>
<tr><td colspan="2">TMC < 26,5</td><td>IV_1</td><td>Mediterranean infra-arboreous stepic</td></tr>
<tr><td rowspan="3">K < 7</td><td colspan="2">TMF ≥ 9,5</td><td>IV_2</td><td>Mediterranean arboreous ilicic or non-ilicic</td></tr>
<tr><td rowspan="2">TMF < 9,5</td><td>P ≤ 500</td><td>IV_3</td><td>Mediterranean true ilicic drier</td></tr>
<tr><td>P > 500</td><td>IV_4</td><td>Mediterranean typical true ilicic less dry</td></tr>
<tr><td rowspan="2">TMMF ≤ 0</td><td colspan="3">TMF > 2</td><td>$IV(VI)_1$</td><td>Mediterranean transitional towards decidous broad-leaved trees</td></tr>
<tr><td colspan="3">TMF ≤ 2</td><td>IV(VII)</td><td>Mediterranean transitional towards cold steppe</td></tr>
<tr><td rowspan="6">1,25 ≤ A < 3</td><td rowspan="2">TMF ≥ 7,5</td><td colspan="3">P ≤ 850</td><td>$IV(VI)_2$</td><td>Mediterranean transitional towards decidous broad-leaved trees thetyc</td></tr>
<tr><td colspan="3">P > 850</td><td>$VI(IV)_3$</td><td>Nemoro-lauroid oceanic tending towards mediterranean</td></tr>
<tr><td rowspan="4">TMF < 7,5</td><td rowspan="3">HS < 5</td><td rowspan="2">TMF < 5</td><td>P ≤ 725</td><td>$VI(IV)_1$</td><td>Dry nemoromediterranean sub-sclerophyll with marcescent broad-leaved trees</td></tr>
<tr><td>P > 725</td><td>$VI(IV)_2$</td><td>Humid Nemoromediterranean sub-sclerophyll with marcescent broad-leaved trees</td></tr>
<tr><td colspan="2">TMF ≥ 5</td><td>$IV(VI)_3$</td><td>Mediterranean atlantic transitional towards decidous broad-leaved trees thetyc</td></tr>
<tr><td colspan="3">HS ≥ 5</td><td>VIII(VII)</td><td>Oroborealoid sub-stepic</td></tr>
<tr><td rowspan="6">0 ≤ A < 1,25</td><td rowspan="3">P ≤ 950</td><td colspan="3">HS = 0</td><td>$VI(IV)_4$</td><td>Nemoromediterranean with broad-leaved evergreen trees</td></tr>
<tr><td rowspan="2">HS ≥ 0</td><td colspan="2">TMF ≥ 7,5</td><td>VI(VII)</td><td>Nemoro-stepic with marcescent broad-leaved trees</td></tr>
<tr><td colspan="2">TMF < 7,5</td><td>$VIII(VI)_1$</td><td>Oroborealoid tending towards nemoro-stepic</td></tr>
<tr><td rowspan="3">P > 950</td><td colspan="3">TMF > 4</td><td>VI(V)</td><td>Typical oceanic nemoro-lauroid deciduous broad-leaved trees</td></tr>
<tr><td rowspan="2">TMF ≤ 4</td><td colspan="2">HS < 5</td><td>VI</td><td>Typical Nemoral deciduous broad-leaved trees</td></tr>
<tr><td colspan="2">HS ≥ 5</td><td>$VIII(VI)_2$</td><td>Oroborealoid tending towards deciduous broad-leaved trees</td></tr>
<tr><td rowspan="4">TMMF ≤ -5</td><td rowspan="2">A > 0</td><td colspan="4">A ≥ 1,24</td><td>X(VII)</td><td>Sub-stepic oroarticoid</td></tr>
<tr><td colspan="4">A < 1,25</td><td>$X(IX)_2$</td><td>Oroarticoid non arboreus with xerothermia</td></tr>
<tr><td rowspan="2">A = 0</td><td colspan="4">TMC > 12</td><td>X(VIII)</td><td>Typical oroborealoid</td></tr>
<tr><td colspan="4">TMC ≤ 12</td><td>$X(IX)_1$</td><td>Oroarticoid non arboreous without xerothermia</td></tr>
</table>

The temporal evolution of the PSI to the 24 phytoclimatic types of physiognomic significance (Table 3) shows three stages: The first, up to the period 1976-2005 corresponds to humid subnemoral oroborealoid physiognomies ($VIII(VI)_2$). The second, up to the period 1994-2023, corresponds to a shift towards sub-steppe oroborealoid positions of type VIII(VII), mainly caused by an increase in the duration of aridity (A), but without sufficient warming to enter into phytoclimatic positions typical of deciduous broad-leaved forests. It is in the last period analysed (1995-2024) that a change in trend towards deciduous broad-leaved physiognomies ($VI(IV)_2$) seems to have begun, whose establishment have to be confirmed in the coming years.

Table 3. Evolution of the phytoclimatic suitability scalars of the FVN model. In green the Genuine positions (G), in orange the Analogous (A), in yellow the Positive Disparate (D) and in white the Negative Disparate (D).

PERIODO	IV_4	$VI(IV)_2$	VI	VIII(VII)	$VIII(VI)_2$	$X(IX)_2$
1951-1980	-10,70D	-0,03D	0,21D	0,59A	0,59G	0,48D
1952-1981	-10,18D	0,01D	0,23D	0,57A	0,59G	0,44D
1953-1982	-9,81D	0,06D	0,19D	0,65A	0,55G	0,40D

1954-1983	-9,83D	0,03D	0,20D	0,62A	0,55G	0,37D
1955-1984	-9,88D	0,03D	0,19D	0,63A	0,56G	0,39D
1956-1985	-9,64D	0,07D	0,19D	0,65A	0,55G	0,34D
1957-1986	-9,32D	0,10A	0,19D	0,64A	0,54G	0,25D
1958-1987	-9,41D	0,10A	0,22D	0,61A	0,56G	0,27D
1959-1988	-9,63D	0,09A	0,24D	0,60A	0,58G	0,33D
1960-1989	-9,34D	0,11A	0,20D	0,65A	0,54G	0,29D
1961-1990	-9,04D	0,14A	0,21D	0,63A	0,53G	0,24D
1962-1991	-9,29D	0,13A	0,19D	0,64A	0,53G	0,32D
1963-1992	-9,11D	0,15A	0,21D	0,62A	0,54G	0,25D
1964-1993	-8,95D	0,17A	0,20D	0,63A	0,53G	0,20D
1965-1994	-8,92D	0,19A	0,21D	0,63A	0,53G	0,24D
1966-1995	-8,51D	0,23A	0,23D	0,62A	0,52G	0,14D
1967-1996	-8,65D	0,22A	0,23D	0,62A	0,53G	0,19D
1968-1997	-8,66D	0,21A	0,30D	0,57A	0,56G	0,18D
1969-1998	-9,06D	0,16A	0,32D	0,48A	0,58G	0,15D
1970-1999	-9,27D	0,13A	0,34D	0,44A	0,59G	0,16D
1971-2000	-8,60D	0,22A	0,29D	0,57A	0,54G	0,12D
1972-2001	-8,35D	0,25A	0,29D	0,58A	0,53G	0,11D
1973-2002	-8,23D	0,24A	0,35D	0,48A	0,56G	0,03D
1974-2003	-7,86D	0,30A	0,32D	0,55A	0,54G	0,06D
1975-2004	-7,88D	0,32A	0,34D	0,51A	0,54G	0,06D
1976-2005	-7,66D	0,35A	0,32D	0,54A	0,52G	0,04D
1977-2006	-7,04D	0,41A	0,24D	0,64G	0,42A	0,05D
1978-2007	-6,57D	0,45A	0,16D	0,67G	0,31D	-0,18D
1979-2008	-6,33D	0,48A	0,14D	0,68G	0,25D	-0,36D
1980-2009	-6,22D	0,50A	0,11D	0,70G	0,08D	-0,62D
1981-2010	-6,19D	0,51A	0,09D	0,69G	0,06D	-0,67D
1982-2011	-6,10D	0,52A	-0,01D	0,70G	-0,23D	-1,16D
1983-2012	-5,96D	0,55A	-0,15D	0,72G	-0,52D	-1,67D
1984-2013	-5,84D	0,56A	-0,70D	0,74G	-1,91D	-4,13D
1985-2014	-5,88D	0,54A	-0,22D	0,71G	-0,70D	-1,98D
1986-2015	-5,71D	0,56A	-0,07D	0,70G	-0,42D	-1,51D
1987-2016	-5,58D	0,58A	-0,06D	0,69G	-0,41D	-1,46D
1988-2017	-5,75D	0,55A	-0,18D	0,65G	-0,17D	-0,43D
1989-2018	-5,39D	0,60A	-0,07D	0,70G	-0,35D	-1,36D
1990-2019	-5,15D	0,60A	-0,24D	0,70G	-0,75D	-2,07D
1991-2020	-4,83D	0,62A	-0,12D	0,66G	-0,67D	-1,98D
1992-2021	-5,09D	0,60A	-0,14D	0,64G	-0,10D	-0,96D

1993-2022	-4,52D	0,65A	-0,41D	0,67G	-1,35D	-3,21D
1994-2023	-4,50D	0,65A	-0,27D	0,64G	-1,06D	-2,60D
1995-2024	-4,39D	0,66G	-0,18D	0,60A	-1,05D	-2,67D

Substeppic type VIII(VII) would imply physiognomies more typical of clear forests of *Pinus sylvestris* on undergrowth of cushiony thorny scrub, as occurs in the few relict forests of this species in the absolute southern limit of Spain, the Baza and Sierra Nevada Betic mountain ranges, due to a combination of cold and dryness. However, the increasing warming seems to determine the rupture of the steppic cold/dryness binomial and therefore the advance towards deciduous broad-leaved types, more adapted to milder temperatures, so that type VIII(VII) ends up being transitory.

This evolution can be seen in the column corresponding to physiognomic type $VI(IV)_2$, which shows its gradual approach from negative disparity positions to positive disparity, analogy and finally genuineness, with increasing values of adequacy.

3.3. CAF MODEL

The application of the CAF Model to the 'Puerto de Navacerrada' location makes it possible to obtain the suitability indices for the 20 forest types, representative of the main wooded forest covers in Spain: *Pinus uncinata* (Pun), *Pinus sylvestris* (Psy), *Abies alba* (Aal), *Fagus sylvatica* (Fsy); *Quercus petraea* (Qpe); *Quercus robur* (Qro); *Abies pinsapo* (Api), *Pinus nigra* (Pni), *Quercus humilis* (Qhu), *Quercus pyrenaica* (Qpy); *Quercus faginea* (Qfa), *Juniperus thurifera* (Jth), *Quercus canariensis* (Qca), *Quercus suber* (Qsu), *Quercus ilex* (Qil), *Pinus pinea* (Ppi), *Pinus halepensis* (Pha), *Pinus pinaster* (Ppr), *Castanea sativa* (Csa) y *Olea europaea* (Oeu).

The suitability indices of five of these forest types are presented in Table 4, which shows how *Pinus sylvestris* forests are the most suitable and therefore the most compatible throughout the whole period analysed. The forest types dominated by the deciduous broad-leaved *Quercus pyrenaica* species continuously increase their phytoclimatic proximity to our study station. The deciduous species *Quercus petraea*, which is more nemoral than the previous one, and which is scarcely present in the Sierra de Guadarrama, also increases its suitability, although in a more discreet way. The broad-leaved evergreen forests of *Quercus ilex* ssp. *ballota*, also increase their suitability, from positions of certain remoteness (negative disparity) to analogies of low suitability, going through intermediate positions of positive disparity. *Pinus nigra* pine forests, more mediterranean and xerophytic than *Pinus sylvestris*, also increase their proximity but remain in negative disparities during the whole period analysed.

Table 4. Evolution of the phytoclimatic suitability indices of the 5 closest forest species of the CAF model with respect to the “Puerto de Navacerrada” meteorological station. In green the Genuine positions (G), in orange the Analogous ones and in yellow the positive Disparate ones (D) and in white the negative Disparate ones (D).

PERIODO	Psy	Qpe	Qpy	Qil	Pni
1951-1980	0,56G	0,33A	0,12A	-0,11D	-1,63D
1952-1981	0,57G	0,36A	0,15A	-0,08D	-1,52D
1953-1982	0,56G	0,28A	0,14A	-0,09D	-1,51D
1954-1983	0,58G	0,29A	0,13A	-0,09D	-1,50D
1955-1984	0,55G	0,27A	0,12A	-0,10D	-1,56D
1956-1985	0,55G	0,27A	0,14A	-0,09D	-1,51D
1957-1986	0,56G	0,27A	0,15A	-0,09D	-1,46D
1958-1987	0,58G	0,33A	0,18A	-0,07D	-1,43D
1959-1988	0,59G	0,36A	0,18A	-0,07D	-1,42D
1960-1989	0,57G	0,29A	0,17A	-0,07D	-1,43D
1961-1990	0,56G	0,31A	0,19A	-0,05D	-1,29D
1962-1991	0,57G	0,29A	0,16A	-0,06D	-1,30D
1963-1992	0,57G	0,34A	0,19A	-0,05D	-1,24D
1964-1993	0,57G	0,31A	0,19A	-0,05D	-1,21D
1965-1994	0,58G	0,33A	0,21A	-0,04D	-1,15D
1966-1995	0,59G	0,36A	0,25A	-0,01D	-1,05D
1967-1996	0,60G	0,35A	0,24A	-0,01D	-1,07D
1968-1997	0,62G	0,45A	0,28A	0,01D	-1,04D
1969-1998	0,63G	0,47A	0,29A	0,01D	-1,02D
1970-1999	0,64G	0,49A	0,30A	0,01D	-0,97D
1971-2000	0,62G	0,43A	0,28A	0,01D	-0,99D
1972-2001	0,63G	0,43A	0,30A	0,02D	-0,92D
1973-2002	0,65G	0,51A	0,35A	0,06D	-0,79D
1974-2003	0,64G	0,49A	0,34A	0,06D	-0,77D
1975-2004	0,67G	0,53A	0,38A	0,09D	-0,70D
1976-2005	0,65G	0,52A	0,37A	0,08D	-0,67D
1977-2006	0,64G	0,42A	0,37A	0,10D	-0,63D
1978-2007	0,63G	0,39A	0,37A	0,11D	-0,55D
1979-2008	0,65G	0,40A	0,40A	0,12D	-0,52D
1980-2009	0,68G	0,41A	0,42A	0,14A	-0,48D
1981-2010	0,67G	0,41A	0,42A	0,14A	-0,43D
1982-2011	0,68G	0,41A	0,42A	0,15A	-0,40D
1983-2012	0,67G	0,38A	0,42A	0,15A	-0,42D
1984-2013	0,68G	0,30A	0,41A	0,15A	-0,41D
1985-2014	0,68G	0,35A	0,42A	0,15A	-0,38D
1986-2015	0,69G	0,43A	0,47A	0,19A	-0,31D

1987-2016	0,70G	0,46A	0,49A	0,20A	-0,27D
1988-2017	0,68G	0,47A	0,49A	0,20A	-0,25D
1989-2018	0,68G	0,42A	0,48A	0,20A	-0,27D
1990-2019	0,67G	0,38A	0,49A	0,21A	-0,25D
1991-2020	0,68G	0,46A	0,52A	0,24A	-0,17D
1992-2021	0,68G	0,48A	0,53A	0,25A	-0,17D
1993-2022	0,68G	0,38A	0,52A	0,24A	-0,15D
1994-2023	0,68G	0,43A	0,54A	0,27A	-0,08D
1995-2024	0,67G	0,45A	0,57A	0,29A	-0,03D

4. PHYTOCLIMATE VERSATILITY

A location with high phytoclimatic versatility, i.e. with a wide range of compatible forest types with high PSI, is more likely to be less vulnerable, more resilient and more adaptive to disturbances derived from climate change, to the extent that these compatibilities are reflected in the composition of its forests, either naturally or assisted by enrichment or afforestation.

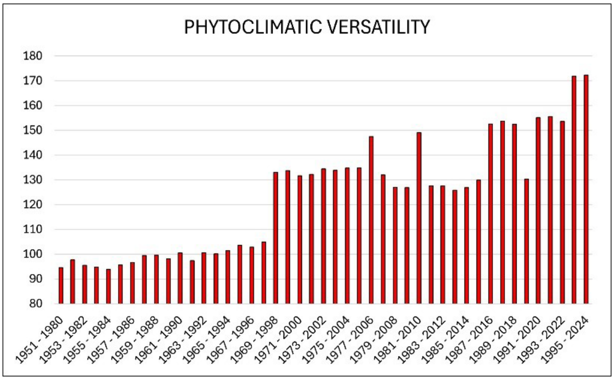
The phytoclimatic versatility of a station can be assessed through the following formula (Allué Camacho & García López, 2024), derived from the well-known Shannon Entropy Index (1948) to suitability indices instead of the numerical number of species for which it was originally devised, and for which it functions as an evaluator of biological diversity (Magurran, 1988; Keylock, 2005; Jost, 2006):

$$\upsilon_P = -10.\sum_{i=1}^{k}\left[\breve{e}_P^{Ai}.Ln\left(\frac{\breve{e}_P^{Ai}}{\sum_{i=1}^{k}\breve{e}_P^{Ai}}\right)\right]$$

Where $\breve{e}_P^{Ai}$ is the normalised scalar or suitability index of the target point P with respect to forest tree cover i of the set of k canopies comprising the CAF model.

Applying this index to the set of positive PSI, a location will have high phytoclimatic versatility when not only the number of compatible main forest types with that station is high (richness), but also when all these compatible covers have a similar degree of suitability between them (proportionality) without there being an excessive dominance of the suitability to the factorial scope of a given forest type over the others, and the PSI are high (quantity). In summary, phytoclimatic versatility simultaneously assesses three concepts: richness, quantity and proportionality.

Figure 6. Evolution of Phytoclimatic Versatility values in 30-year mobile averages in Puerto de Navacerrada between 1951 and 2024.



After a long period of relative stability, the phytoclimatic entropy or versatility index shows an upward trend from the mean 1969-1998, according to the phytoclimatic approach of *Pinus sylvestris* monospecific forests to positions of greater compatibility with broad-leaved species at lower altitudinal levels (Figure 6).

5. CONCLUSIONS AND DISCUSSION

The joint and complementary application of the FVN and CAF phytoclimatic models makes it possible to translate, by means of appropriate transfer functions, shifts from environmental o suitability spaces. Integrating both models allows us to translate the dynamics of climate change into a biological language. This methodology allows to interpret estimations of future changes in temperature and precipitation more efficiently and translate them into vegetation language, by quantifications of the hosting capacities of environment and of the competitive relationships between the principal species in the forest. All this will also allow to improve the tools used to make assessments and make preventive and adaptative decisions in future scenarios of phytoclimatic uncertainty.

Our results suggest that for the moment there is no risk that the current oromediterranean forests of *Pinus sylvestris* will no longer be compatible with the climatic conditions of the study area, so dominant physiognomy would remain similar to the current.

However, the increase in thermoxericity seems to be move towards a gradual rupture of the exclusive *Pinus sylvestris* status. The continuous approach towards sub-nemoral phytoclimatic positions, typical of transitional broad-leaved deciduous forests between the Mediterranean and Eurosiberian biogeographic regions, suggests an altitudinal migration from the *Quercus pyrenaica* forests typical of medium altitudes in these mountains. The dominant evergreen broad-leaved forests in the basal zones are also approaching, although still timidly, and only if the upward trend in thermoxericity continues could they become compatible and even compete with *Quercus pyrenaica*.

The gradual approach, although still timid, to various forest types other than those of Scots pine, points to a trend in recent decades towards an increase in the phytoclimatic entropy or versatility of the study site, which, together with the notable wide-ranging phytoclimatic potential of Scots pine, means that the vulnerability of its high mountain forest stands in the Sistema Central, and specifically in the Sierra de Guadarrama National Park, is not particularly high at the moment, although this situation could change.

The high mountain Scots pine forests of the Sierra de Guadarrama are not endangered in terms of their existence in the near future, although their structure and composition, and therefore their physiognomy, could be modified by the irruption of *Quercus pyrenaica* as a secondary species, which would modify the composition, physiognomy and interspecific competition relations of these forests. This process, whereby several mountain coniferous forests would be enriched by the migratory contribution of broadleaved trees from lower altitudes, has been widely reported by several authors (i.e. Thuiller et al., 2006; Hotmeier & Broll, 2007; García López & Allué Camacho, 2010).

Field observations also point to this trend, as the altitudinal limit of the pure natural Scots pine forest is rising, and this, apart from considerations relating to change of use, possibly related to the climatic dynamics in the Central System, may corroborate the abundant natural regeneration of Scots pine at altitudes where it did not exist barely a century ago. Any case, these predictions should be handled with caution, as the climatic causes of the migration and altitudinal enrichment of tree species may overlap with other causes such as the abandonment of certain high mountain livestock farming practices (Gehring-Fasel et al, 2007).

Favouring broadleaved trees where they appear, initially in places with some kind of compensation (shelter and humidity, etc.) or even their introduction through enrichment planting could become an adaptive management practice that would favour the stability and viability of future stands in case that climate change accelerates, as well as the modification of forest planning instruments in terms of management objectives and the treatment to be given to accompanying species.

One of the limitations of this kind of models is that of their calibration, since the tree species considered in the CAF model have natural distribution areas that far exceed the Iberian Peninsula, which means that the climatic envelopes constructed do not encompass the whole species range. This limitation has already been pointed out in other works (Petit et al., 2005; Guisan et al., 2024). Another issue to be taken into account is the intrinsic genetic or epigenetic adaptive capacity at the individual, community or species level, which may lead to changes in the shape of the initially calculated envelopes (Kremer, 2007; Lindner et al., 2010).

Ecosystems linked to oroarticoid phytoclimates above the level of pine forests will reduce their surface area, which may lead to the loss of protected species associated with them. Given that this process cannot be fought against, it will be necessary to increase efforts to detect these species and their survival mechanisms in order to monitor and minimise the consequences of climate change.

REFERENCES

Allué Andrade, J.L. (1990). Atlas fitoclimático de España. Taxonomías. Ministerio de Agricultura, Pesca y Alimentación. Instituto Nacional de Investigaciones Agrarias. 221 pp. Madrid.

Allué Camacho, C. & García López, J.M. (2024). Los bosques naturales de castilla y león. Caracterización y potencialidades fitoclimáticas en un contexto de cambio climático. Ed. LIFE19/CCA/ES001181. 388 pp. Burgos. Descarga libre desde: https://soriaforestadapt.es/fitoclim/

Condit, R., Aguilar, S., Hernández, A., Pérez, R., Lao, S. & Pyke, C. (2005). Spatial changes in tree composition of high-diversity forests: how much is predictable? 271-294 in E. Bermingham, C.W. Dick and C. Moritz (eds.), Tropical Forests: past, present and future. Univ. of Chicago Press.

Davis, M.E., Shaw, R.G. & Etterson, J.R. (2005). Evolutionary responses to climate change. *Ecology*, 86: 1704-1714.

García López, J.M. & Allué Camacho, C. (2010). Effects of climate change on the distribution of *Pinus sylvestris* L. stands in Spain. A phytoclimatic approach to defining management alternatives. *Forest Systems*, 19 (3): 329-339.

García López, J.M. & Allué Camacho, C. (2011). Modelling phytoclimatic versatility as a large-scale indicator of adaptive capacity to climate change in forest ecosystems. *Ecological Modelling*, 222 (8), 1436-1447.

García López, J.M. & Allué Camacho, C. (2012). A phytoclimatic-based indicator for assessing the inherent responsitivity of the European forests to climate change. *Ecological Indicators*, 18: 73-81.

García López, J.M. & Allué Camacho, C. (2013). Phytoclimatic Dynamics of Mediterranean Forests under Climate Change. A Case Study in a Southern European *Pinus sylvestris* L. Stand. *American Journal of Plant Sciences*, 4: 655-662.

Gehring-Fasel J., Guisan, A. & Zimmermann, N.E. (2007). Tree line shifts in the Swiss Alps: Climate change or land abandonment. *J. Veg. Sci.*, 18: 571-582.

Guisan, A. & Thuiller, W. (2005). Predicting species distribution: Offering more than simple habitat models. *Ecology Letters*, 8: 993-1009.

Guisan, A., Chevalier, M., Adde, A., Zarzo-Arias, A., Goicolea, T., Broennimann, O., Petitpierre, B., Scherrer, D., Rey, P.L., Collart, F., Riva, F., Steen, B. & Mateo, R.G. (2024). Spatially nested species distribution models (N-SDM): An effective tool to overcome niche truncation for more robust inference and projections. *Journal of Ecology*, 1-18.

Holt, R.D. (1990). The microevolutionary consequences of climate change *Trends in Ecology and Evolution*, 5(9): 311-315.

Holtmeier F.-K. & Broll G. (2007). Treeline advance-driving processes and adverse factors. *Landscape Online*, 1: 1-33.

Jost, L. (2006). Entropy and diversity. Oikos, 113 (2): 363-375.

Keylock, C. (2005). Simpson diversity and Shannon-Wiener index as spetial cases of a generalized entropy. *Oikos*, 109: 203-207

Kremer, A. (2007). How well can existing forests withstand climate change? In: Koskela, J., Buck, A. & Teissier du Cros, E., editors. Climate change and forest genetic diversity: Implications for sustainable forest management in Europe. Bioversity International, Rome, Italy. 3-17.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., García-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J. & Marchetti, M. (2010). Climate change impacts, adaptive capacity and vulnerability of European forest ecosystems. *Forest Ecology and Management*, 259 (4): 698-709.

Magurran, A., 1988. Ecologigal diversity and its measurement. Princeton University Press. New Jersey.

Malanson, G. P.; 2001. Complex responses to global change at alpine treeline. *Physical Geography*, 22: 333-342.

Petit, R.J., Hampe, A., Cheddadi, R.; 2005. Climate changes and tree phytogeography in the Mediterranean. *Taxon*, 54: 877-885.

Shannon, C.; 1948. A mathematical theory of communication. *Bell System Tech. Journ.*, 27: 379-423, 623-656.

Thuiller, W., Lavoral, S., Sykes, M.T., Araújo, M.B.; 2006. Using niche-based modelling to assess the impact of climate change on tree functional diversity in Europe. *Diversity and Distributions,* 12: 49-60.

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