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Sweet chestnut silviculture in an ecological extreme of its range in the west of Spain (Extremadura)

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Summary – Forest management has been conducted in many, sometimes opposing, directions, without any relevant environmental restriction. Thus, sweet chestnut stands have been bidirectionally transformed, alternating high forest and coppice structures, with many different management aims in mind: increasing economic benefits, favouring biodiversity conservation, improving landscape protection, etc. To test whether this type of multidirectional management can be extended to the ecological edges of a typical European forest tree, a study was conducted in central-western Iberian Peninsula. There, chestnut forests have been exploited under traditional regimes during recent centuries. Thirty forest stands were chosen after a clustered sampling process. In each of these stands, 53 variables were measured or estimated and assigned to five different data sets: silvicultural, climatic, edaphic, physiographic and floristic. The silvicultural matrix was compared with the other four by canonical correlation analysis. Almost all the data sets presented significant correlations with the silvicultural regime. Thus, it was easy to conclude that the environment is constraining chestnut forest management. Coppice has historically been confined to the highest ranges of the territory, which are exposed to the moist winds from the southwest. On the other hand, high forests have been located in drier sites. There, the forest needs to be intensively managed to avoid inter- and intra-specific competition. Under these conditions, coppice stands do not prosper. The relationships between chestnut silviculture and environment were also established for each data set. Finally, we conclude that the management of the chestnut forest has historically and interactively led to the development of coppice and high forest, on account of environmental constraints and human interests, to obtain benefits from this tree species.

forest management / ecological edge / sweet chestnut stands / coppice / high forest

Resumé – **Sylviculture du châtaignier en limite écologique dans l'ouest de l'Espagne (Extramadure)**. La gestion de la forêt a été menée dans plusieurs directions, parfois opposées, notamment dans les zones sans restrictions environnementales significatives. Ainsi les peuplements de châtaignier

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ont été bidirectionnellement transformés, alternant des structures en futaie avec des structures en taillis, dans des buts différents : augmenter les gains économiques, favoriser la conservation de la biodiversité, améliorer la protection du paysage, etc. Afin de vérifier si cette hypothèse peut être appliquée aux limites écologiques d'un arbre typique de la forêt européenne, nous avons mené une étude dans l'ouest de la Péninsule ibérique où, au cours des derniers siècles, les châtaigneraies ont été exploitées sous des systèmes traditionnels. Après un échantillonage stratifié, nous avons retenu trente châtaigneraies. Dans chacune d'elles on a mesuré ou estimé 53 variables, de type sylvicole, climatiques, édaphiques, physiologiques et floristiques. Afin d'analyser les relations pouvant exister entre ces données, la matrice des données sylvicoles a été comparée aux autres par une analyse de corrélation canonique. Presque tous les paramètres ont montré des corrélations significatives avec le régime sylvicole. Ainsi, il est facile de conclure que les conditions environnementales influent sur la gestion des châtaigneraies. Le taillis a été historiquement confiné aux points les plus hauts du territoire, qui sont exposés aux vents humides du sud-ouest, alors que la futaie est localisée surtout aux endroits les plus xériques et nécessite une gestion intensive afin d'éviter inter- et intraconcurrence. Dans ces conditions, les taillis ne se développeraient pas. Avec chaque groupe de données, ont été également mises au jour les relations fonctionnelles entre sylviculture du châtaignier et conditions environnementales. Finalement, nous arrivons à la conclusion que la gestion en taillis et futaie a été historiquement et interactivement menée en intégrant les besoins humains et les contraintes de l'environnement afin de tirer le meilleur parti de cet arbre.

gestion de la forêt / limite écologique / châtaigneraie / taillis / futaie

INTRODUCTION

Forest management and utilization have a considerable influence on the stability and sustainability of forest ecosystems (Swanson and Franklin, 1992; Larsen, 1995). In this sense, forests of sweet chestnut (*Castanea sativa* Miller), a typical multipurpose tree (Boggia, 1988), have been intensively managed both for production (timber and edible nuts) and for encouraging natural regeneration of mixed broad-leaved species (Cucchi, 1990; Everard and Christie, 1995). In the wide ecological and geographical range where sweet chestnut has been used, many different silvicultural treatments have been proposed and developed in order to improve its profitability. It is believed that the most profitable management of chestnut coppice (COP) is conversion to high forests (HF) in the long-term, with a gradual improvement in the short- and medium-term economical benefits (Ciancio and Eccher, 1983; Bédéneau, 1988). Transformations have also been proposed with conservation and landscape protection aims (Gillins, 1990), such as conversion of COP to HF to reduce fire risk, or conversion of HF to COP on steep slopes to improve the hydrological balance and soil protection (Cucchi, 1990). It seems that there are no serious environmental constraints to the management of these stands; thus, only the final objective must determine and drive any silvicultural treatment. Following the above comments, silvicultural treatments and not environmental factors should be mainly controlling the structure of forest stands.

With these considerations in mind we have developed a study based on the sweet chestnut stands of the region of Extremadura (central-western Spain). This region constitutes one of the boundaries for sweet chestnut distribution in Europe because of its dry Mediterranean macroclimate (Rubio, 1993a). Our hypothesis deals with the fact that forest management in the ecological extremes of tree niches (under severe physical stresses) must be severely constrained by the environment (see Gaines and Denny, 1993). Under these conditions forest availability to absorb very different silvicultural treatments must suffer an intensive narrowing. Therefore management must be driven in these areas not only according to silvicultural criteria but also to environmental restrictions.

The relationships between sweet chestnut forestry, as with any other heavily utilized forests, and the environment can be expressed as the relationship between several sets of data, including silvicultural information. Thus, silvicultural features could be interpreted, if possible, as a function of isolated environmental factors, such as climate, physiography, soil, or even understorey composition. If the silvicultural traits can be explained by some of these factors, we could assert that the historical treatment of the forest had been constrained by some ecological factors in addition to technical and management considerations, and then, forests stands (both HF and COP) could not be easily managed to change their structure.

MATERIALS AND METHODS

Chestnut stands in Extremadura

These forests have been traditionally exploited for timber (1 167 ha for COP), and even more so for edible fruits (10595 ha for HF) (fig 1), following the general trend in Spain (83291 ha for HF and 43267 ha for COP; ICONA, 1976) and in Portugal (65000 ha for HF and 5000 ha for COP; Fernandes, 1954), where HF stands are dominant. This type of forestry is clearly different from that of central and western Europe where, by far, the largest proportion of chestnut is classified as COP (Champs, 1972; Rollinson and Evans, 1987).

Sampling

Sample-plots were located after performing a clustered sampling of the chestnut area in Extremadura through TWINSPAN (Hill et al, 1975; Hill, 1979) by using a 1 km square grid (Daget and Godron, 1982). These grid-cells with a proportion of at least 10% of chestnut forests were included in the analysis. For each grid-cell (the total number was 581) variables were arranged according to average altitude (four types), range of altitude within the grid-cell to estimate the slope (four types), topographic complexity (four types), aspect (four types), annual precipitation (four types), annual mean temperature (three types), date of the last frost (four types), and lithology (ten types) (see Rubio, 1993a for details). The classification process stopped at the five-cluster level. The total number of sample-plots was 30 (fig 1). The number of sample-plots within each of the five geographical clusters was proportional to their size (number of grid-cells) and randomly located. The sample-plots were all chestnut-dominated stands (15 HF and 15 COP) with no recent human disturbance, a prerequisite for long-term traditional silviculture. We found no traces of cutting, burning or fertilizing in the study sites in 15 years. The plot size was 100 m^2 for COP stands and 400 m^2 for HF stands.

Variables

In every sample-plot, 53 variables were evaluated and measured (see Rubio, 1993a). The variable sets were both biotic (silvicultural and floristic) and abiotic (physiographic, climatic and edaphic).

First data set: silvicultural variables

The structure and silvicultural treatment of this forest was described by the following data: (1) sprout density, (2) stool density, (3) stool/sprout ratio, (4) basal area, (5) Hart's index (which estimates the relative distribution of trees in relation to height of dominant trees) (Hart, 1928; Schütz, 1990), (6) maximum height of vegetation and (7) crown coverage.

Second data set: physiographic variables

The physiography of the site was described by the following variables: (8) slope, (9) altitude, (10) surface stoniness (five-step scale, ranging between < 5 and > 75%), (11) surface drainage (classified as defective if the slope surface was concave, normal if it was flat and excessive if it was convex), (12) erosion (3 classes: insignifi-

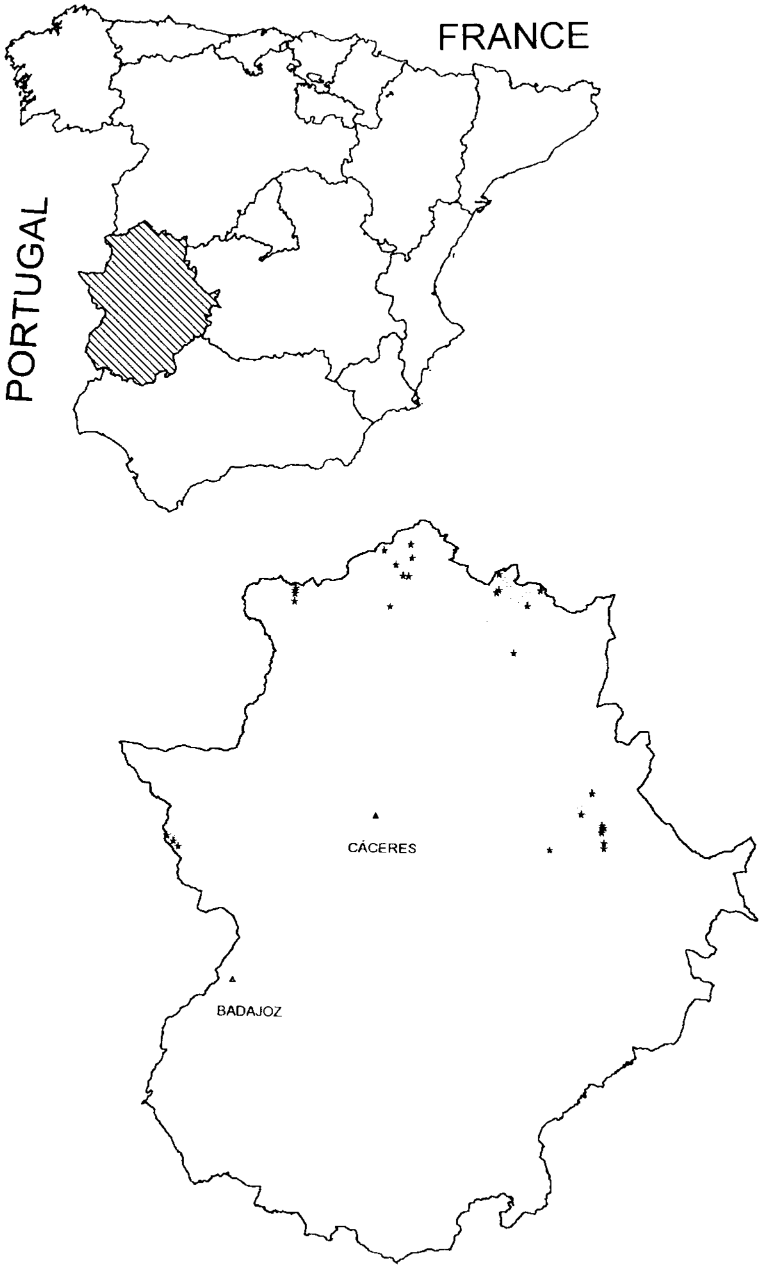

Fig 1. Location of the studied plots. The striped area on the map of Spain corresponds to the Extremadura Region and the shaded area on the second map to thechestnut stands in Extremadura. Sample-plot: ★; capital city: ▲.

cant, slight and severe), (13) insolation (indicating the amount of solar radiation on the ground as determined by the slope, the aspect and the latitude of the plot; Gandullo, 1974), (14) complexity of the surroundings (indicating the degree of simplicity of the orography of the surrounding area; Blanco et al, 1989), (15) wind protection coefficient (according to the fluid mechanics; Blanco et al, 1989), and (16) exposure of the surrounding area where the plot is located (it summarizes the degree of exposure to humid and warm southwesterly winds).

Third data set: climatic variables

The climate was described by the following parameters: (17) annual precipitation, (18) spring precipitation, (19) summer precipitation, (20) autumn precipitation, (21) winter precipitation, (22) annual mean temperature, (23) average daily maximum temperature for the warmest month, (24) average daily minimum temperature for the coldest month, (25) last frost date, (26) annual potential evapotranspiration (Thornthwaite, 1945), (27) sum of the potential evapotranspiration of the six warmest months, (28) sum of the potential evapotranspirations of the six coldest months, (29) Vernet's bioclimatic index (Vernet and Vernet, 1966; Sánchez et al, 1990; Retuerto and Carballeira, 1990), (30) annual sum of the positive P-PE differences, (31) annual sum of the negative P-PE differences (Thornthwaite and Mather, 1955, 1957), (32) Thornthwaite's moisture index (Thornthwaite, 1945), (33) drought duration and (34) drought intensity (Walter and Lieth, 1960).

Fourth data set: edaphic variables

Soil characteristics were described by the following variables: (35) fine earth fraction (for the total natural soil), (36) sand, (37) silt and (38) clay (according to the limits of Soil Survey Staff, USDA, 1975), (39) cementing capacity coefficient (Gandullo, 1994), (40) impermeability coefficient due to silt (Nicolás and Gandullo, 1966), (41) equivalent moisture (Sánchez and Blanco, 1985), (42) permeability (Gandullo, 1994) (the values for each of these last eight variables were obtained by averaging the values for each soil layer, giving each soil layer a weight according to its thickness in the upper 125 cm of the soil profile), (43) soil moisture storage (Gandullo, 1994), as the sum of the values of each layer of the soil profile, (44) organic matter (Walkley, 1946), (45) soil pH value in H_2O (1:2.5), (46) soil pH value in KCl (1:2.5), (47) total nitrogen (Bremner, 1965), (48) carbon/nitrogen ratio, (49) phosphorus (Burriel and Hernando, 1950), (50) potassium adsorbed to colloid (US Salinity Laboratory Staff, USDA, 1954) (these last seven variables were evaluated by calculating the average of the data of each soil layer, giving each soil layer a weight according to its thickness and to its depth, following Russell and Moore, 1968), (51) annual actual evapotranspiration, (52) annual moisture deficit and (53) annual moisture surplus (Thornthwaite and Mather, 1957).

Fifth data set: floristic variables

A complete understorey composition survey was carried out and cover percentage was visually estimated in each plot.

Numerical analysis

One of the most widely-used methods to estimate correlation between two sets of data from the same localities is canonical correlation analysis (COR) (ter Braak, 1994). It is useful as a technique to discover the relationships between two matrices of simultaneously evaluated data (Gauch and Wentworth, 1976). This technique produces a set of ordination axes (canonical variates: CV) for each data matrix in such a way that they are maximally correlated. Many papers have used COR to explore vegetation–environment relationships in a forest context (Kabzems and Klinka, 1987; Courtin et al, 1988; Basnet, 1992). During recent years, canonical correspondence analysis (CCA) and related techniques have been widely used with similar aims in mind; techniques such as these select the linear combination of environmental variables that maximizes the dispersion of species scores (ter Braak, 1987), but they are also likely to detect random effects when both sets of data are not correlated (Oksanen and Huttunen, 1989). Since we wanted to establish a relationship only when it was effective the COR was prefered for data analysis.

The floristic matrix has previously been summarized in orthogonal components by an ordination method (see Escudero et al, 1994), since one of the limitations of COR lies in the number of variables in each of the two data sets, which must be smaller than the number of objects under study (Gittins, 1985; ter Braak, 1987). In our case a principal component analysis (PCA) has been carried out to summarize the vegetation data. Biplot of species × stands has been interpreted following Gabriel (1982) and ter Braak (1994). As the focus of the biplot scaling was on stands the relationships among stands are based on euclidean distance interpretation, whereas among species and stands the relationships are based on abundances (see ter Braak, 1994).

For abiotic variables, we have divided the environmental matrix into three thematic sets of variables: climatic, edaphic and physiographic. Following this procedure, the silvicultural matrix was successively correlated (COR) with the climatic, edaphic, physiographic and finally floristic matrices.

RESULTS

Some descriptive statistics for the most relevant of the 53 variables that have been stud-

Table I. Descriptive statistics for the most relevant ecological variables.

	Average	*SD*	*Min*	*Max*
Altitude (m)	782.50	186.6	500.0	1200.0
Slope (%)	29.47	15.8	3.0	64.0
Insolation	0.91	0.2	0.5	1.2
Exposure of the surrounding area (°)	79.10	51.2	0.0	164.0
Spring precipitation (mm)	329.60	99.8	191.9	521.4
Summer precipitation (mm)	57.44	16.1	31.8	95.4
Autumn precipitation (mm)	334.84	91.6	201.7	561.1
Annual mean temperature (°C)	13.18	1.2	10.9	14.9
Average daily maximum temperature (°C)	31.47	2.6	26.8	36.1
Last frost date (No days from 1st January)	120.10	22.1	76.0	153.0
Potential evapotranspiration (mm)	738.71	40.9	665.6	816.1
Potential evapotranspiration warmest (mm)	602.93	35.4	538.3	692.2
Vernet's index (°C mm^{-1})	–19.47	7.2	–33.1	–8.3
Drought intensity	0.11	0.05	0.05	0.20
Fine earth fraction (%)	41.33	25.9	5.7	83.7
Sand (%)	40.31	16.5	17.2	70.5
Silt (%)	42.85	13.6	20.0	66.1
Clay (%)	16.88	5.2	7.5	28.6
Permeability	3.88	0.8	2.6	5.0
Moisture storage (mm m^{-1})	116.13	80.9	17.4	291.9
Organic matter (%)	2.93	1.5	0.9	6.2
pH_W	4.64	0.4	4.0	5.3
N (%)	0.15	0.1	0.02	0.4
C/N	14.80	8.8	3.2	46.5
P (mg Kg^{-1})	1.54	1.6	0.1	8.0
K (mg Kg^{-1})	115.73	84.9	18.9	455.2
Annual moisture deficit (mm)	264.35	77.0	91.1	409.0
Annual moisture surplus (mm)	701.31	300.8	179.4	1 291.7

SD: standard deviation; Max: maximum; Min: minimum; variables without units are adimensionals.

ied are shown in table I. COP stands are situated on the slopes of the highest ranges of Extremadura, basically Gredos (altitudinal range between 500 and 2 400 m) and Villuercas (400–1 500 m), climbing up as high as the bioclimatological limit of the species (about 1 200 m, table I), which is only surpassed (1 600 m) by the chestnut stands of Sierra Nevada (SE Spain) (Rocha, 1990). The soils are basically acid, with moderate organic matter content and clearly enriched in nitrogen (forestal mull or moder humus, in spite of high acidity values; Rubio, 1993b). The texture is mainly loamy, so that the soils are notably more permeable than other typical chestnut forest soils from the Eurosiberian region (Rubio and Gandullo, 1994). The climate of these chestnut forests can be characterized by a significant autumn and spring rainfall regime (334 and 329 mm, respectively), warm mean annual temperatures (13 °C), last frost date 28th of April

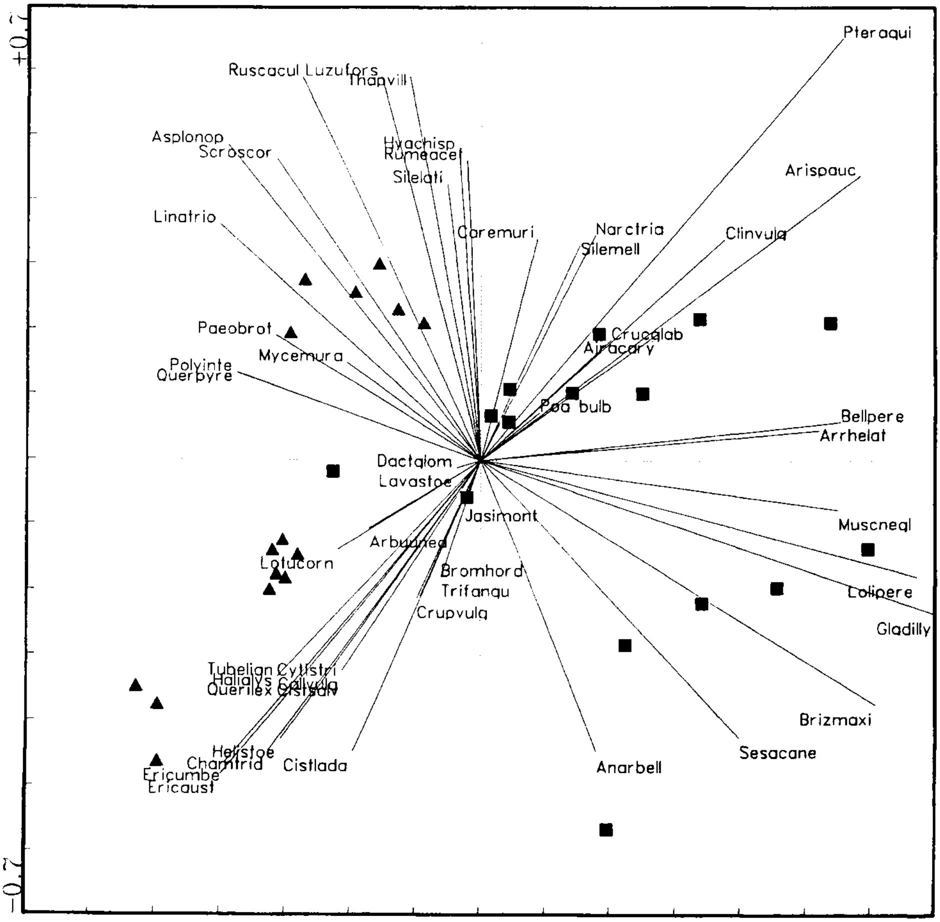

Fig 2. PCA biplot (first two axes) for understorey composition and studied stands. Codes of plants are explained in *Appendix*. High forest stands: ■; coppice stands ▲. Direction and length of floristic vectors indicate the imaginary axis and the intensity of performance of each species on this plane.

Table II. Eigenvalues (Eigenv), percentage of variance (%), canonical correlation (Ca Cor), Wilks' Lambda (λ), degrees of freedom (DF) and significance of F (Sig F) for the first canonical variates (CV1, CV2, CV3) in the canonical correlation analysis between the silvicultural variables and the other four data sets.

	Eigenv	*%*	*Ca Cor*	*Wilks λ*	*DF*	*Sig F*
$CV1_{climatic}$	36.05	54.8	0.99	0.00000	126	0.009
$CV2_{climatic}$	13.25	20.2	0.96	0.00016	102	0.084
$CV3_{climatic}$	7.81	11.9	0.94	0.00230	80	0.267
$CV1_{physiographic}$	3.28	41.3	0.87	0.01320	63	0.028
$CV2_{physiographic}$	2.26	28.4	0.83	0.05652	48	0.160
$CV1_{edaphic}$	16.53	43.9	0.97	0.00006	133	0.615
$CV2_{edaphic}$	11.59	30.8	0.96	0.00101	108	0.843
$CV1_{floristic}$	5.54	72.9	0.92	0.03661	28	0.002
$CV2_{floristic}$	1.29	17.0	0.75	0.23950	18	0.156

(= 120) (table I). Understorey composition was summarized by the two first axes of the PCA, because they account for around 30% of variance (19.7 for axis I and 11.2 for axis II). Furthermore, the sample-plots, HF versus COP, are represented on the PCA plane (fig 2).

The most significant correlations of the silvicultural data set were found first with understorey composition ($CV1_{floristic}$ $P < 0.005$) and second with climatic data set ($CV1_{climatic}$ and $CV2_{climatic}$ $P < 0.1$) (table II). $CV1_{floristic}$ explains more than 70% of the variance, while $CV1_{climatic}$ and $CV2_{climatic}$ account together for 75% of the variance, the information being much greater in the latter case (the inertia, calculated as the sum of all eigenvalues, surpasses that of the other sets of variables). For the physiography, only $CV1_{physiographic}$ was slightly significant, but it explains only ca 40% of the variance. Only for the soil data set, COR has not been able to extract significant canonical variables (table II: $CV1_{edaphic}$ and $CV2_{edaphic}$ ns) although soil is usually considered as one of the main factors controlling forest features (Otto, 1995).

Correlation between individual silvicultural variables and significant canonical variates (from climatic, physiographic and floristic matrices) are shown in table III. In table IV we can see the correlation of physiographic, climatic and floristic variables with their canonical variates. The $CV1_{physiographic}$ value is positively correlated with crown coverage, stool and sprout density (table III), and also with altitude and slope and negatively correlated with insolation and exposure of the surrounding area (table IV). The $CV1_{climatic}$ value is positively correlated with the stool density and sprout density (table III) and with the summer rainfall and Vernet's index, and negatively correlated with drought intensity (table IV). COR also extracted a significant $CV2_{climatic}$, which could be explained by sprout density and stool/sprout ratio (table III) and by average daily maximum temperature for the warmest month and the last frost date (table IV). The first extracted PCA axis can be almost perfectly correlated with $CV_{floristic}$ (table IV) and appears highly correlated with all the silvicultural variables (table III). Furthermore, it can be noted that stool and

Table III. Correlation between silvicultural variables and the significant canonical variates (CV) for each set of variables.

	Climatic		*Physiographic*	*Floristic*
	CV1	*CV2*	*CV1*	*CV1*
Sprout density (No ha^{-1})	0.429	0.567	0.444	–0.518
Stool density (No ha^{-1})	0.589	0.065	0.425	–0.670
Stool/sprout ratio	–0.184	–0.415	–0.140	0.442
Basal area (m^2 ha^{-1})	–0.337	0.069	0.067	0.567
Hart index	–0.196	–0.116	–0.249	0.568
Height of vegetation (m)	0.230	0.037	0.171	–0.431
Crown coverage (%)	0.360	0.094	0.604	–0.408

Table IV. Highest correlation values between physiographic (A), climatic (B) and floristic variables (C) and the significant canonical variates (CV).

A)		*B)*			*C)*	
	$CV1_{physiographic}$		$CV1_{climatic}$	$CV2_{climatic}$		$CV1_{floristical}$
Slope	0.432	Summer precipitation	0.401	—	Axis 1	0.952
Altitude	0.474	Vernet's index	0.553	—		
Insolation	–0.535	Drougth intensity	–0.550	—		
Exposure of the surrounding area	–0.586	Average daily maximum temperature	—	–0.304		
		Last frost date	—	–0.334		

sprout density are always highly correlated with all canonical variates.

DISCUSSION

Two facts make the interpretation of the natural biogeographical and ecological boundaries of sweet chestnut very intricate. First, chestnut is a straightforward tree to manage and it has been used and intensively grown in almost all of Europe and in the Mediterranean Basin during recent millenia (Chassagne, 1956; Font Quer, 1962; Paiva, 1990); second, the long-term dynamics of old-growth forests depends on size and frequency of disturbances (Pickett and White, 1985). Anyway, it seems that in Extremadura this species is at one of its ecological extremes, both for natural, but also managed, stands and for historically planted ones. We are not discussing here the importance of environmental factors in the driving of the structure and growth of trees and forests because it is unquestionable (see Carter and Klinka, 1990), but rather whether forests can be subjected to and respond to very different silvicultural treatments within their ecological boundaries.

Probably the soil data set presents no relationship with the silvicultural data set because these soils are built on very similar lithological substrata (quartzites, sandstones, schists, granites, slates). In this sense, these

Table V. Significant ($P < 0.05$) linear regression (model: $y = b_0 + b_1 \cdot x$) between edaphic and silvicultural variables [and level of significance]. The number corresponds to the slope of each regression line.

	Sprout density	*Stool density*	*Stool/sprout ratio*	*Hart index*	*Crown coverage*
Fine earth fraction	1.44 [0.045]	1.66 [0.010]	–1.29 (0.088)	–1.13 (0.079)	—
PH_W	—	–1.08 [0.072]	—	—	—
K	0.68 [0.081]	0.86 [0.016]	—	—	—
Annual moisture surplus	—	—	—	0.77 (0.059)	–0.66 (0.047)

variables (lithology) were considered during the clustering process, TWINSPAN, for sampling, but they were not relevant (Rubio, 1993a). However, a slight relationship can be recognized because several edaphic variables appear linearly related to individual silvicultural variables, such as K and fine earth fraction with stool and sprout density (table V). This relationship must be working inversely: silvicultural treatments can modify some edaphic parameters, eg, COP stands (high stool and sprout density) can facilitate K balance due to the intense turnover induced by litter fall (Rubio and Gandullo, 1993) as a reflection of higher primary production in this type of COP stands (Weber, 1987; Bellot et al, 1992). In the same way, Pages and Cabanettes (1993) suggest that sprout density depends on soil fertility.

High summer evapotranspiration rates characterize the macroclimate of the Mediterranean Basin. With this in mind, the presence of COP stands for timber production seems to be dependent on the amount and distribution of precipitation, mainly during the summer, as $CV1_{climatic}$ correlation indicates (table IV). For this reason COP seems to have been restricted to the most climatically favoured zones. The threshold value (COP versus HF) might be located around 63.0 mm for the summer (Rubio, 1993a). Correlation with Vernet's index, a bioclimatological ratio used to reflect the water regime for most of the European plant communities, seems to encourage this climatic exclusion. HF appear always to be located on very extreme ecological sites (from an autoecological point of view) and then the silvicultural management must be more intensive: thinning, understorey suppression, basically brooms and Mediterranean heaths, and even irrigation, in order to minimize intraspecific and interspecific competition (Tilman, 1982) and physical stresses. The negative correlation with drought intensity again indicates the relevance of the summer drought in a typical Mediterranean macroclimate. Correlation results for $CV2_{climatic}$ agree with those from $CV1_{physiographic}$ in the way that COP stands are confined to the mountain slopes. On these slopes, COP stands are favoured by higher precipitation (high correlation with slope and altitude). The altitudinal edge for these stands is interactively controlled by a rainfall increase (favourable) on the one hand and by a cooling process (unfavourable) on the other. On these lines, Malato-Beliz (1987) and Pardiñas (1987) indicated related factors, such as late frost and summer heat amount, among the most restrictive ones for chestnut distribution in the Iberian Peninsula. The negative correlation with exposure of the surrounding area outlines a clear preference of COP stands to be southwesterly exposed, which corresponds to the direction of a very moist local wind from the Atlantic Ocean. However, HF stands are correlated with insolation because they are always restricted to more xeric sites, far from the highest ranges or restricted to their piedmonts.

There is a clear difference in understorey composition between HF and COP stands, as the ordination result demonstrates (fig 2). Silvicultural prescriptions to sustain HF in Extremadura may result in the long-term in a loss of diversity, in spite of a high and temporally short peak of species richness following management activities based on ruderal and non-forest herbs, most of them short-life and early-successional plants (Halpern and Spies, 1995).

Most of the plants present in HF area of the ordination plane are annuals or even weeds, such as *Briza maxima*, *Rumex angiocarpus*, *Ornithopus perpusillus*, *Clinopodium vulgare*, etc (fig 2). A more or less opened canopy avoiding chestnut intraspecific competition (floristic component negatively correlated with crown cover) in combination with forestry activities would prevent growth of post-successional and forest plants (Rubio and Sánchez, 1995). In the COP stands (left area of the ordination plane) we can basically find shrubs, such as *Calluna vulgaris*, *Cistus psilosepalus*, *Cistus crispus*, *Lithodora diffusa*, *Cytisus striatus*, *Halimiun ocymoides*, short trees, such as *Arbutus unedo*, *Malus sylvestris*, *Prunus avium*, *Ilex aquifolium*, significant chestnut regeneration (many seedlings and saplings) and even forest herbs, such as the very scarce *Leuzea rhaponticoides* and *Paeonia broteroi*, *Linaria triornithophora*, *Astragalus glycyphyllos* or *Melittis melissophyllum*. These functional groups are sorted along a successional gradient (axis II). The differences among the COP stands are related to the type of harvest, clear-cutting or complete canopy removal and the time since the last action (Berg and Clement, 1992). The effect of forest management on plant species diversity in the Extremadurean COP stands of sweet chestnut are not well understood, because of the paucity of community-level studies in managed stands. Anyway, most of the typical understorey forest species are able to recover their original frequency levels prior to canopy closure, even for strictly shade-tolerant plants. This recovery will be faster after clear-cutting management (Gilliam and Roberts, 1995) and even more so, with a retention of large canopy trees (McComb et al, 1993; Hansen et al, 1995) not always represented in Extremadura by *Castanea sativa* but sometimes by *Quercus pyrenaica*. Therefore, understorey composition and biodiversity maintenance are always a multidirectional response to forest management.

Chestnut forests in Extremadura reach one of their geographical and ecological extremes owing to a typical Mediterranean macroclimate. Under these conditions, COP stands for timber production have been traditionally confined to the most humid areas of the slopes of Gredos and Villuercas ranges. The productivity of these stands are far from that of the typical Eurosiberian chestnut forests (Rubio and Gandullo, 1994) because the rainfall increase is associated with late frosts and a generalized cooling as a consequence of higher altitude. On the other hand, HF stands are located on drier areas, cataloged as man-dependent forest, where inter- and intra-competition induced by environmental stresses can be controlled; thus, the canopy may be not completely closed and understorey removal may be very frequent. In any case, with these ecological constraints HF stands are not transformable to COP stands and they must be basically considered as orchards or even crops, whereas COP stands could be submitted to silvicultural transformation but are seriously affected by the environmental restrictions. In conclusion, it appears that the management of sweet chestnut forest has historically and interactively led to the development of COP and HF stands, on account of environmental constraints and human interest, in order to obtain benefits from this tree species.

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APPENDIX: LIST OF PLANTS INCLUDED IN THE PCA PLANE (FIG 2)

Airacary: *Aira caryophyllea;* Arnabell: *Anarrhinum bellidifolium;* Arbuuned: *Arbutus unedo;* Arispauc: *Aristolochia paucinervis;* Arrhelat: *Arrhenatherum elatius;* Asplonop: *Asplenium onopteris;* Bellpere: *Bellis perennis;* Brizmaxi: *Briza maxima;* Bromhord: *Bromus hordeaceus;* Callvulg: *Calluna vulgaris;* Caremuri: *Carex muricata;* Cistlada: *Cistus ladanifer;* Cistsalv: *Cistus salviifolius;* Clinvulg: *Clinopodium vulgare;* Crucglab: *Cruciata glabra;* Crupvulg: *Crupina vulgaris;* Cytistri: *Cytisus striatus;* Chamtrid: *Genista tridentata;* Dactglom: *Dactylis hispanica;* Ericaust: *Erica australis;* Ericumbe: *Erica umbellata;* Gladilly: *Gladiolus illyricus;* Halialys: *Halimium ocymoides;* Helistoe: *Helichrysum stoechas;* Hyachisp: *Hyacinthoides hispanica;* Jasimont: *Jasione montana;* Lavastoe: *Lavandula stoechas* subsp *pedunculata;* Linatrio: *Linaria triornithophora;* Lolipere: *Lolium perenne;* Lotucorn: *Lotus glareosus;* Luzufors: *Luzula forsteri;* Muscnegl: *Muscari neglectum;* Mycemura: *Mycelis muralis;* Narctria: *Narcissus triandus;* Paeobrot: *Paeonia broteroi;* Poa bulb: *Poa bulbosa;* Polyinte: *Polypodium interjectum;* Pteraqui: *Pteridium aquilinum;* Querilex: *Quercus rotundifolia;* Querpyre: *Quercus pyrenaica;* Rumeacet: *Rumex acetosella;* Ruscacul: *Ruscus aculeatus;* Scroscor: *Scrophularia scorodonia;* Sesacane: *Sesamoides canescens;* Silelati: *Silene latifolia;* Silemell: *Silene mellifera;* Thapvill: *Thapsia villosa;* Trifangu: *Trifolium angustifolium;* Tubelign: *Tuberaria lignosa.*