

SILVICULTURE AND DYNAMICS OF *Pinus sylvestris* L. STANDS IN SPAIN

I. CAÑELLAS¹, F. MARTÍNEZ GARCÍA, G. MONTERO

Dpto. Silvicultura, CIFOR-INIA, Apdo. 8.111. 28080 Madrid, Spain
canellas@inia.es

SUMMARY

This study presents information about the ecology, typology, silviculture, production, dynamics and biodiversity of Scots pinewoods in Spain. The distribution and types of Scots pine stand are described, together with their most important climatic and edaphic aspects. Silvicultural aspects are considered including management objectives. Information is provided on the production potential of the stands, and a production table for the five site qualities defined is presented. The different stages of natural succession of the stands are described. Finally, there is brief mention of the effects of the silviculture on the biodiversity of these pinewoods.

KEY WORDS: Scots pine
Silviculture
Dynamics
Biodiversity
Spain

INTRODUCTION

Pinus sylvestris is an ecologically wide-ranging species (Ceballos and Ruiz de la Torre, 1979; López, 1982; Costa *et al.*, 1997) as it is able to survive on a range of substrates, on well-developed or poor soils, in cool wet climates, or in very cold to extremely cold continental climates. According to Gutiérrez (1990) its ecological amplitude is even wider as it can also thrive in mild climates with very varied precipitation patterns, in Atlantic climates with abundant year-round rainfall, and in Mediterranean climates with winter rains and severe summer drought. Its heliophilous character is summed up in Gruber (1979) who states the species is: «a light demanding taxon, able to withstand very intense cold as well as relatively dry conditions».

This hardiness and ecological adaptiveness has enabled the species to attain the widest distribution of any of its genus (Szafer, 1975 in Gutiérrez, 1990), and in Europe to be the widest ranging of all tree species. It is found in most countries throughout Europe, reaching its southwesterly limits (37° in the Sierra Nevada, Spain) and westerly limits (in

the Sierra de Gêrez, Portugal) in the Iberian Peninsula. Northwards it reaches 70° 20' in Norway, where it forms the northernmost limit of tree growth, and eastwards it reaches 141° near the Sea of Okhotsk, in Russia.

DISTRIBUTION AND ECOLOGY

Area occupied by Scots pine in Spain

The area covered by Scots pine in Spain is 1,280,000 ha (Fig. 1). Here it either forms pure stands (74 %) or is the dominant species in stands mixed with other species (26 %) (Fig. 2). About 605,200 ha are natural stands and 674,800 ha planted (Fig. 1) (Ceballos *et al.*, 1966). Scots pine grows well with other species to the extent that, whilst there are 678,700 ha of uniform stands, the rest are admixed with *Pinus uncinata* Mill. ex Mirb., *Pinus nigra* Arn., *Abies alba* Mill., *Fagus sylvatica* L., *Quercus pyrenaica* Wild. and *Quercus petraea* (Matts.) Liebl. Table I shows the percentages of mixtures with other species in relation to altitude. Where mixtures with broad-leaved trees are concerned (column 4), below 1500 m nearly all mixtures are with *Quercus pyrenaica* in the Sistema Central and *Q. petraea* and *Q. humilis* Miller in the Pyrenees, whilst above 1500 m they are with *Fagus sylvatica* in the Sistema Ibérico.



Fig. 1.—Distribution of *Pinus sylvestris* stands in Spain
Distribución de pino silvestre en España

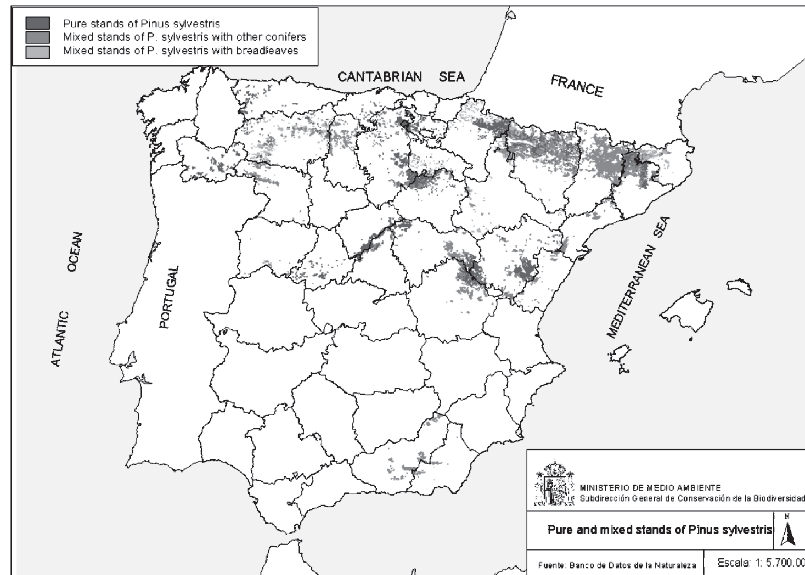


Fig. 2.—Pure and mixed stands of *Pinus sylvestris* in Spain
*Masas puras y mixtas de *Pinus sylvestris* en España*

In the Pyrenees Scots pines are mainly in mixture with *Pinus uncinata* and *Abies alba* at high altitudes, and with *Q. ilex* L. and *Q. pubescens* and, less often, with *Quercus petraea* in lower humid areas. The continental climate appears to be the reason for this pattern, whereby the pines form a band of vegetation between the oakwoods below and the *P. uncinata* forest higher up. This particular altitude band is common to beech and silver fir, species with which Scots pine competes successfully on sunny slopes, at altitudes up to 1700 m, whilst in shade it is only at an advantage where there is insufficient humidity for competing species. In the northern Sistema Ibérico Scots pine is found in mixture with *Fagus sylvatica* at mid to high altitudes, and with *Quercus pyrenaica* and *P. pinaster* Ait. lower down. Over wide areas in the southern Sistema Ibérico mixtures with *Pinus nigra* Arn. subsp. *salzmannii* (Dunal) Franco occur; nearly all the area of *P. nigra* in the mountain ranges of Teruel and Cuenca is mixed to a greater or lesser extent with *P. sylvestris*, at least in low-lying, dry, warmer areas best suited to Scots pine. In moister areas there are mixtures with *Q. pyrenaica* and *Q. faginea* Lamk. subsp. *faginea*. Mixtures with *P. pinaster* are found mainly in the Sistema Central and Sistema Ibérico. Mixtures with other species such as *Abies alba*, *Populus tremula* L., *Betula pendula* Roth. can be found, but these are small in area and are not included in the calculations.

In order to give a better idea of the topography of the sites occupied by *P. sylvestris*, we provide information about the gradients where it grows, whether as a dominant species or in mixed stands (Table 2). Over 70 % of the area occupied by *P. sylvestris* is above the 1000 m contour and at a gradient of over 35 %. This fact is important for the management and application of silvicultural systems.

TABLE 1

AREA (IN PERCENTAGES) AT DIFFERENT ALTITUDINAL LEVELS OF SCOTS PINE, BOTH IN UNIFORM STANDS AND IN THOSE MIXED WITH OTHER SPECIES

Superficie (en porcentaje) a diferentes altitudes de pino silvestre, tanto en masas puras como en mezcla con otras especies

Altitude (m)	Uniform dominant stands	Stands mixed with other species			
		with <i>P. uncinata</i> (1)	with <i>P. nigra</i> (2)	with <i>P. pinaster</i> (3)	with broadleaf (4)
< 400	0.3	0	0.5	0.2	3.2
400-600	1.8	0.2	6.7	0.5	4.2
600-800	10.6	1.6	17.4	4.1	12.6
800-1000	14.4	5.8	19.7	21.6	22.6
1000-1200	17.2	10.3	22.8	44.3	28.0
1200-1400	18.1	16.4	16.2	16.3	18.6
1400-1600	21.4	24.1	11.2	7.3	9.3
1600-1800	14.3	25.4	4.6	5.6	4.0
1800-2000	1.7	11.7	2.3	0.1	0.4
> 2000	0.2	5.5	0.6	0	0.1

TABLE 2

DISTRIBUTION OF THE AREA OCCUPIED BY *PINUS SYLVESTRIS* (UNIFORM AND MIXED STANDS) BY SLOPE GRADIENT (IN %)

Distribución de la superficie ocupada por Pinus sylvestris (masas puras y mixtas) según la pendiente (en %)

Gradient %	Uniform or dominant stands	Mixed stands			
		<i>P. uncinata</i>	<i>P. nigra</i>	<i>P. pinaster</i>	broadleaved
< 3	2.5	0.2	4.5	4.8	0.9
3-12	11.0	0.3	10.1	20.9	3.5
12-20	15.5	2.7	11.4	22.6	7.3
20-35	26.1	17.5	23.8	32.0	20.3
> 35	44.9	79.3	50.2	19.7	68.0

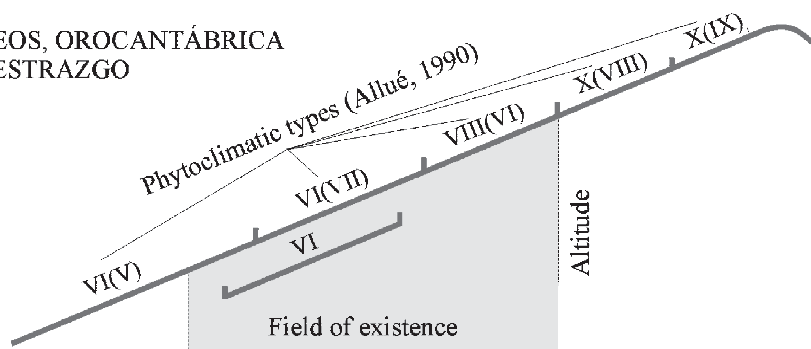
Climate

Fig. 3 shows the phytoclimatic types (Allué, 1990) in which *P. sylvestris* grows in Spain. These are superimposed on the distribution map for the species. Fig. 4 summarises the possible climatic variation of the species in the most important mountain systems in Spain (north, centre and south of the Peninsula). In each mountain systems we have represented the phytoclimatic types in relation to the altitude. In green we have indicated the potential distribution of *Pinus sylvestris* in each mountain system. From this it can concluded that the distribution of the species is primarily oro-borealoid, but also subnemoral -VIII(VI) - where stands of highest quality develop because of the shortness of the drought period.

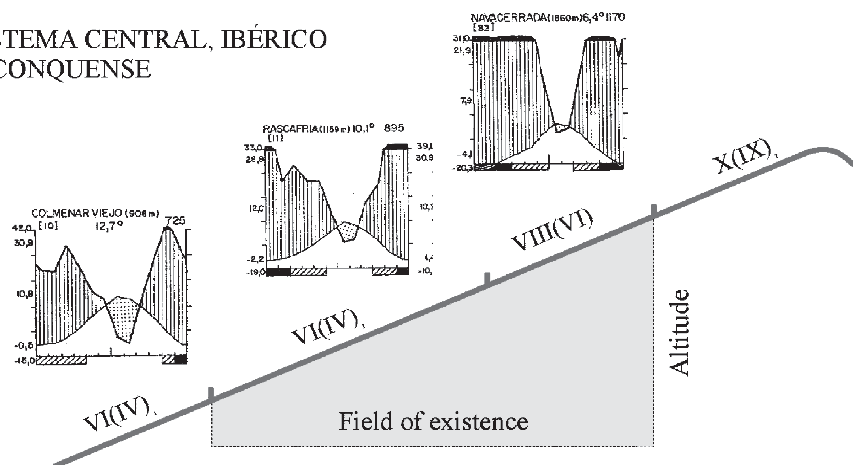


Fig. 3.—Phytoclimatic types of *Pinus sylvestris* stands in Spain
*Tipos fitoclimáticos de las masas de *Pinus sylvestris* en España*

PIRINEOS, OROCANTÁBRICA
Y MAESTRAZGO



SISTEMA CENTRAL, IBÉRICO
Y CONQUENSE



SISTEMA PENIBÉTICO

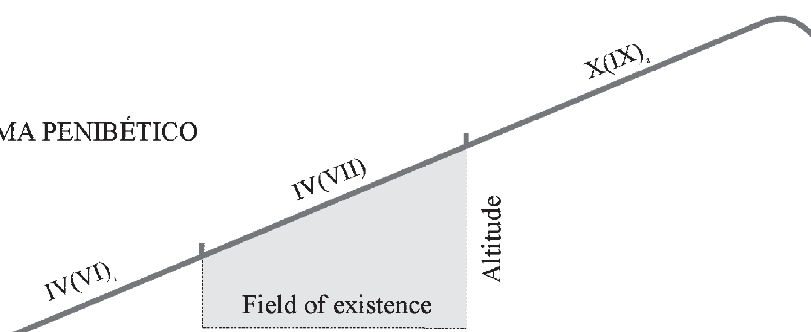


Fig. 4.—Illustration of the phytoclimatic distribution of *Pinus sylvestris* in the three major mountain systems in Spain: most northerly at the top of the page.

*Distribución fitoclimática simplificada de *Pinus sylvestris* en los tres principales sistemas montañosos en España (los más septentrionales en la parte superior de la página)*

Soil types

In Spain Scots pine prefers freely-drained soils rich in organic material, and is relatively indifferent to the pH (Nicolás and Gandullo, 1969). In siliceous areas the soils vary between eutric or distric cambisols and ferric luvisols. These are rather deep, fairly sandy-textured soils, very permeable, with a moderate to highly acidic pH. The alkaline soils where the species grows are mainly calcic cambisols, though there are also calcic luvisols, depending on their stage of development (Fig. 5). In areas of lower precipitation and higher temperature these soils normally contain a high percentage of free lime. Their texture is rather clay-loamy, of low to medium permeability according to the proportion of organic material; they are fairly deep and have moderate to very low pH (Catalán, 1991).

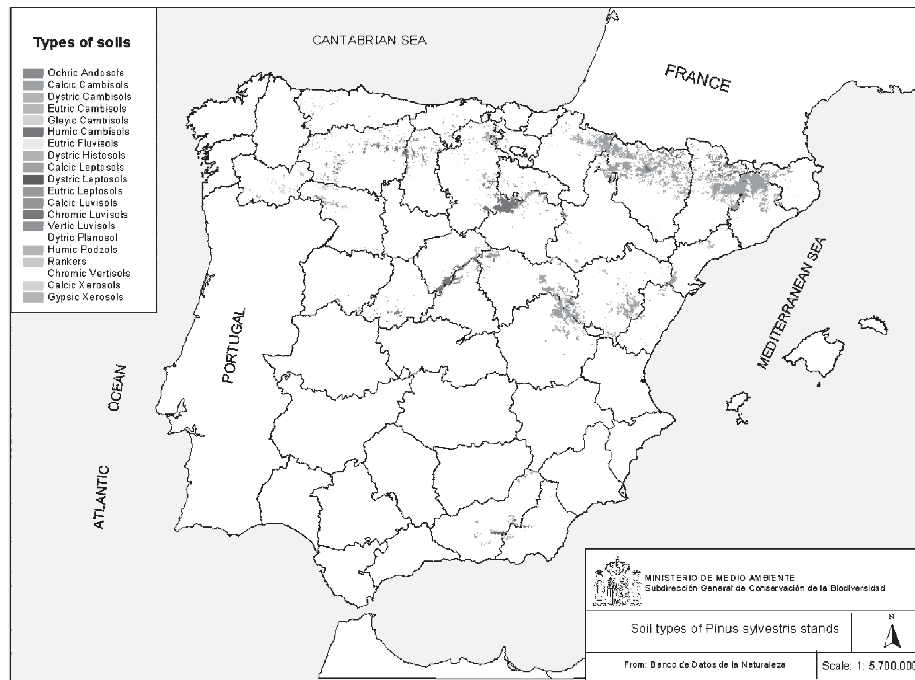


Fig. 5.—Soil types of *Pinus sylvestris* stands in Spain
Tipos de suelos de las masas de pino silvestre en España

Fig. 6 shows a diagram of Scots pine distribution in Spain in relation to landform, climate and soil type with mean, lower threshold and upper threshold values of each main factor. The zone between the two thresholds defines the optimum habitat of *P. sylvestris* in Spain. Beyond these thresholds, the existence of Scots pine stands will be confined to marginal habitats where some compensations between ecological factors may occur.

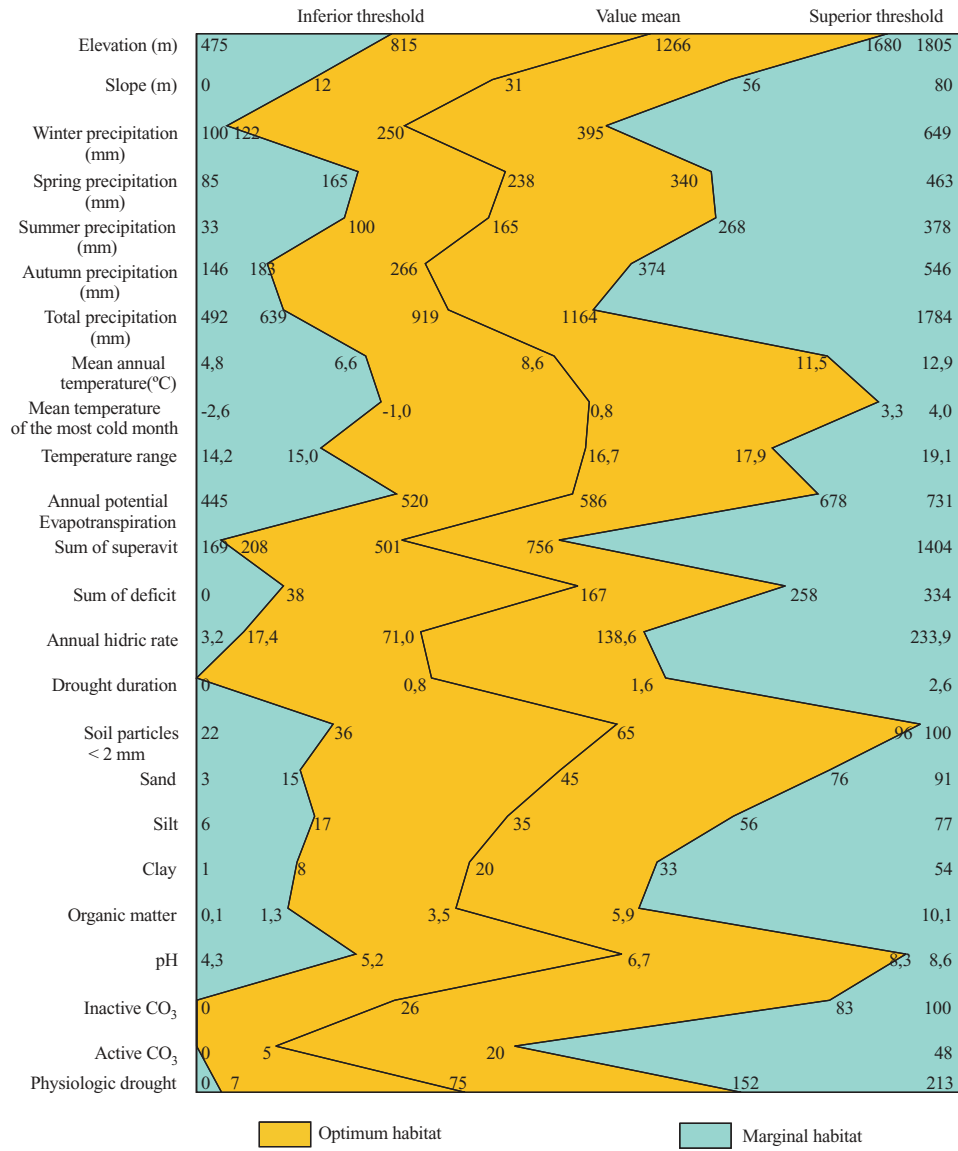


Fig. 6.–Mean, and lower and upper threshold of the main climatic and soil factors of the *Pinus sylvestris* in Spain

Media y umbrales superior e inferior de los principales factores edáficos y climáticos de Pinus sylvestris en España

SCOTS PINE FOREST TYPE

In classifying pinewoods into different types, with their distinctive characteristics, we need to take into account the ecological plasticity and hardiness of this species, which enable it to play a role in many forest communities. We have preferred to use a phytogeographical classification according to Costa *et al.* (1997) instead of a phytosociological classification for two reasons. Firstly, there is no consensus among botanists about the origin of some stands and discussion of the role they play in the communities would be too extensive to be included here. Secondly, a separate paper (Martínez García and Montero, 2000) presents a complete discussion about the phytosociological typology of Scots pine in Spain.

1. Euro-Siberian pinewoods

- *Mesophilic pinewoods*: These are to be found in more humid environments, and are the most hydrophilic type of pinewood. They share the same altitude band as fir and beech stands, which host very similar flora; the three species are also often found mingled in transitional situations. They are mainly dominant in the driest and sunniest valleys. They are widely spread at heights between 1000 and 1700 m. At both the western and eastern ends of the Pyrenean range, where maritime conditions increase, they give way to oak and beech forest. There are at least two subdivisions
 - *calcareous substrate*: where ash (*Fraxinus excelsior* L.), *F. sylvatica* or even *Q. faginea* form part of the tree cover.
 - *acidic substrate*: where pine forest is accompanied by silver fir, phasing into mesophilic fir forest. Elsewhere it is accompanied by beech and *Q. petraea*.
- *Xerophilic pinewoods*: These are found only on southern slopes, in sunny and windy sites, above all in the higher parts of the mountains. The main difference between these and the previous type is in the lack of undergrowth or woodland species and the almost complete absence of moss. The nature of the substrate, together with the geographical situation, influences the floristic composition not only of the forest, but also of the stages of degradation, giving rise to several variants:
 - *eastern variant*: in the eastern part of the Pyrenees. Found only on acidic lithologies and occupying sunny sites with hot dry summers and very cold winters - in other words the areas of more continental influence. These are less dense pine forests than the mesophilic type, with trees less slender, and often more crooked. They are often found together with birches (*Betula pendula*), firs and sessile oak (*Q. petraea*).
 - *central variant*: found on alkaline soils in the central Pyrenees, in dry continental mountain conditions and in sunny, windswept sites; these have similar structure to the above.

2. Sub-Mediterranean pine forest

These are pinewoods sited away from clearly mountainous environments, at lower altitudes where the pine is also found in mixed forest (pre-Pyrenees and Pyrenees range). Here it has a marked tendency to supplant other woodland, spreading in strips into the typical *Q. faginea* and mountain pine stands, and mingling in differing proportions with these species. It forms pure stands where soils are poor. Sometimes these pinewoods are secondary formations, since they easily establish themselves in enclaves where *Q. faginea* are highly degraded. This type of pinewood develops mainly on alkaline, lime-loamy or shaly soils. The disappearance of the original forest leads to some soil erosion, due to loss of vegetation cover which in turn exposes the soil to greater drying by the sun.

3. Mediterranean pine forest

In the Iberian Mediterranean region, *Pinus sylvestris* is the main forest species found at high elevation in the principal mountain ranges. As far as the climatic conditions of these pine forests are concerned, the main feature is that the summer drought, while also very short, is more marked than in the previous types. Summer rainfall can be limiting to Scots pine with minima around 10-55 mm for the driest month so that there is greater development on sheltered northern aspects. Three phytogeographical groups of pine forest can be distinguished:

- *Pine forest in the Sistema Central*: there are extensive climax forests occurring on acidic bedrock at elevations approximately between the 1300 and 2100 m contours. Different forest types can be found depending of the elevation, slopes and aspect of the stand.
- *Pine forest in the Sistema Ibérico*: these form the upper forest limit, from 1500 m upwards to 1900 m., mainly over calcareo-dolomitic lithologies in the south-east and siliceous rock in the north. The Scots pine woods are often interspersed with *Pinus nigra*. At higher elevations, pinewoods are sparse and have a layer of creeping juniper (*Juniperus sabina*). The latter can act as a pioneer in establishing a pine forest, and in such climatic extremes can give shelter to the pines during the first stages of growth. In the north of the Sistema Ibérico there are extensive pine forests of high landscape value and economic importance. Their optimal range is between 1400 and 1700 m, where there is a humid to perhumid bioclimate of cold or very cold variety. The summer drought is very short and the frost-free period limited to the summer months. In these conditions the *Q. pyrenaica* has a very short growing season, not flushing until well into June. Scots pine, on the other hand, has higher growth potential. Higher up there are usually beeches scattered among the pinewoods, which take on a more mixed structure on more northerly slopes, where *Fagus sylvatica* strengthens its hold to form true beechwoods.
- *Remnant pine forest in the Sierras Béticas*: found over both calcareo-dolomitic and metamorphic strata. These pine forests are mainly found in the Sierra Nevada and the Sierra de Baza. The upper zone of the forest land of most of these ranges has been considered as a potential area for Scots pine.

SILVICULTURE OF SCOTS PINE STANDS IN SPAIN

Management objectives for *Pinus sylvestris* in Spain

The objectives pursued in the management of *Pinus sylvestris* are, in general, to guarantee the survival, stability and diversity of the species and to obtain wood production in accordance with good silvicultural practices. These objectives will vary and be in different order of priority according to the location.

Management objectives for *Pinus sylvestris* forest are not very different from those used for managing other montane species. Since the beginning of the nineteenth century general forestry management objectives have not varied much, though particular features of the major objectives have been reformulated to adjust to changing social and environmental circumstances. These objectives are:

- Stand survival and stability. This obliges the manager to conserve forest cover, avoiding the absence of plant cover in order to maximise soil protection. Stability is the aim when applying suitable silvicultural treatments which guarantee the biological structure and function of the forest cover (Montero, 1992).
- Multiple-use. This objective requires the optimisation of the different possible land uses. The term *use* must include both direct benefits (whether economical or not) and non-commercial indirect benefits. The objective of multiple-use is most important in those pinewoods with areas devoted to livestock, wildlife, hunting, recreation, landscape and/or biological value.
- Sustainability. This third objective, currently highly regarded, was formulated in terms basically similar to those of today, though referring almost exclusively to exploitation of timber (sustained yield), by European foresters in the first half of the nineteenth century. Sustainability must refer to forest products and utilities, including the species, the ecological niches and all the other biological and ecological functions of the forest (Montero and Cañellas, 1999). Achieving this objective implies clearly distinguishing between the «capital» and the «income» of the forest, avoiding decapitalisation (Madrigal, 1994). Sustained profit or exploitation should include the concept of integration between the forest and the rural community, guaranteeing a fairly stable labour demand, raw material supply, recreation, landscape value, etc., to satisfy the local needs of industries using forest products and services.

As well as these general objectives, which can be applied to all Scots pine woods, the silviculturist will need to define a series of specific objectives for each pinewood, in accordance with its ecological characteristics and the social needs of the area where the wood is sited. These specific objectives will be different in each case, and their listing and characterisation are not part of this study.

Silviculture of *Pinus sylvestris* stands in Spain

To fulfil the management objectives outlined above it is necessary to apply different silvicultural treatments, depending on the ecological and physiographic conditions of the stand. Given the breadth of the ecological spectrum of *P. sylvestris* in Spain, silviculture

for the species is not easy to summarise. However, in broad terms the stands are to be found in three altitudes zones which strongly influence their silviculture, although climatic differences may be found between the various mountain regions (Pyrenees, Sistema Ibérico, Sistema Central and Sistema Penibético) and hence also silvicultural peculiarities (Montero, 1994).

- In zones over 1800 m, stands have very low tree density and large open areas covered by prostrate snow-adapted shrubs and patches of pasture. The main role of these areas is as protection forests, because the timber production is very low (less than $0.5 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$), natural regeneration is very difficult and management focuses on exploitation of pastures.
- In zones between 1600 and 1800 m stands have low stocking density and uneven surface distribution and have a high protection value. The silvicultural system employed is selection felling for the following reasons: low timber production (0.5 to $1.5 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$), natural regeneration is difficult on south-facing hillsides, the zones are exposed to wind, soils are poor and stands uneven aged.
- In zones at altitudes between 800 and 1600 m where Scots pine predominates, the typical stand is dense, and either monospecific or mixed. The main usage is timber production (high quantity and quality) and the characteristics of these stands are as follows: wood production varies according to altitude and soil fertility (1.5 to $6 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$), natural regeneration is difficult on south-facing hillsides and in very windy and dry zones and stands are even aged. Management is by periodic blocks, designed to assure constant levels of wood production. Normal silviculture is based on shelterwood systems whose essential features are:
 - Fellings separated in time and space. These pursues specific objectives and are performed during the regeneration period in the order: preparatory felling, seedling felling, liberation felling and final felling.
 - The aim is to achieve natural regeneration. Only in exceptional circumstances is artificial regeneration permitted as a supplement or aid.

This silvicultural system, which was intensively applied in Spain from 1890 to 1930, did not always achieve satisfactory natural regeneration, essentially because:

- The intensity of harvesting at each felling was not known precisely.
- Stands were in poor silvicultural condition when the time came to start the regeneration fellings. An entire rotation was required to transform the stands.
- Management methods were over-rigid (periodic blocks). Foresters were told where, when and how much to felling annually, which meant that harvesting could not be linked to natural regeneration, particularly given a species which only produces abundant seed every 2 to 3 years.
- The summers are extremely long, causing many seedlings to perish.
- The method was improperly applied in many cases.
- Grazing took place during the regeneration period.

The difficulty encountered in controlling and synchronising the harvesting sequence caused many foresters to lose faith in the viability of this method for the management of stands of *Pinus sylvestris* and to return to the old system known in Spain as «*La esperilla*», so called because the forester waits until a clump has regenerated before harvesting the parent trees. This method is often used when, after a seeding felling, insuffi-

cient natural regeneration has been attained or where the forester is uncertain whether to undertake the liberation and final fellings. In fact in many stands it is impossible to tell whether regeneration has been achieved through sequential fellings or these have been performed because the stand had already regenerated. The latter is most often the case.

In view of the difficulties encountered in achieving abundant natural regeneration during the regeneration period, many foresters have abandoned the shelterwood system and resorted to the clear felling method, reserving 30 to 40 parent trees per hectare, which are taken out in a second felling after 5-6 years when regeneration is considered satisfactory. After the first massive felling, the soil is prepared in operations of varying intensity (surface harrowing, surface removal and furrowing with rippers, slight terracing, total depth tilling, etc.), then 3-5 kg/ha of seed is sown. The same procedure is followed in the clear felling method when no parent trees are reserved.

Whatever the silvicultural method used, the rotation is between 100 and 120 years, at the end of which diameters range from 35 to 50 cm depending on the fertility of the site and the intensity of silvicultural activity. To obtain wood of higher quality and price, it is advisable to prolong the felling age to 120-140 years. At greater ages, health problems may arise from the fungus *Fomes pini*, which badly deteriorates the wood (Montero *et al.*, 1992).

Post-regeneration care

Young *P. sylvestris* plants are sensitive to competition. In Spain, naturally regenerating stands are weeded and/or cleaned to favour the growth of the *P. sylvestris* seedlings over the regeneration period (approximately 20 years). This clearance is normally followed by light thinning and pruning of the most advanced young trees, and at the same time the residues from felling are gathered up and removed.

In artificially regenerated stands, these operations are not normally required since any shrubs have usually been eliminated in the preliminary soil preparation and young *P. sylvestris* plants achieve rapid growth and are able to compete with any other weeds. After 10 to 15 years, depending on the development of the young trees, thinning is usually carried out removing the weakest and most malformed individuals and any shrubs which may have established themselves. This is followed by pruning up to a height of 1-1.5 m of all the selected individuals or only the best. After thinning, from 5,000 to 10,000 trees/ha are always left.

Pre-commercial thinning

The value of any produce obtained from pre-commercial thinning never meets the costs. For this reason these operations should be considered as an investment in the future stand. Pre-commercial thinning is performed preferentially on highly productive stands, normally accompanied by pruning. In low-productivity stands, it is only performed to improve stand health, to avert fire hazards, to create rural employment, and to make room for recreational areas. This operation is carried out when the stand is between 15 and 25 years old depending on the growth of the individuals and also on financial resources.

Respacing is also a common practice, especially after natural regeneration or seeding. Maintaining too many trees per hectare prevents their development and can lead to growth stagnation. In this situation thinnings usually are systematic at a very early age. This operation is usually followed by pruning of the best individuals and the removal of any residues (Montero, 1994).

Commercial thinning

Commercial thinning regimes are either «low» (felling subdominant trees) or «mixed» (felling subdominant and co-dominant trees). A moderate intensity is used since heavier thinning is only possible at lower altitudes, where up to 40 % of the basal area can be removed with no loss of yield. It is not normally begun until the stand is between 20 and 40 years old, or when dominant height reaches 10-11 m, depending on the quality of the site and the system of stand regeneration. The interval between thinnings should be approximately 10 years. In stands at elevations over 1600 m, thinning should be moderate because of the risk of windthrow and snowbreak (Gómez Loranca and Montero, 1989; Montero, 1992).

Rotation period

Our studies show that the rotation period for *P. sylvestris* using current silvicultural methods is around 135-140 years, in order to achieve maximum timber quality. If a more intensive silviculture is applied, the same quality can be reached in 100-120 years (Montero *et al.*, 1992).

PRODUCTION OF SCOTS PINE STANDS IN SPAIN

In order to indicate stand density and thus to arrive at a better quantification of economic importance, we present the data from by the Second National Forest Census (IFN, 1998).

Table 3 reveals the following:

- The annual volume increment of *P. sylvestris* is 3,691,826 m³/year
- Most plantations established during the last fifty years have not yet reached full production. Depending on their age, the first or second thinnings are being carried out, but none of the stands has reached rotation age. Thus these stands are producing a substantial accumulation of timber which can be extracted in future years as they mature.
- The growth rate of trees of over 22.5 cm diameter is 1,441,427 m³/year. Since the annual harvest of Scots pine timber from trees of over 20 cm diameter is usually around 700,000 m³/year, we can be sure that fellings remove around 50 % of the growth of trees over 20 cm and 20 % of the total growth. This implies that around 80 % of annual growth remains in the forest and mainly in young stands.

TABLE 3

STOCKS OF *PINUS SYLVESTRIS* BY DIAMETER CLASSES APPLIED TO THE ENTIRE NATIONAL TERRITORY (SPAIN)

Existencias de Pinus sylvestris por clase diamétrica, para todo el territorio nacional (España)

Diameter classes (cm)	NATIONAL TOTAL					
	N.º trees (×1000)	G (m ²)	Vb (m ³)	Vwb (m ³)	IAV (m ³ /year)	RI(%)
5	228145	—	—	—	—	—
10	228119	1802431	5580283	3986340	613241	11.0
15	167558	2917176	12365887	9075675	879376	7.1
20	106053	3268505	16038394	12474661	757784	4.7
25	57169	2759985	15134109	12163413	521033	3.4
30	31315	2180342	13099619	10733148	359448	2.7
35	17381	1650539	10781894	8955052	247894	2.3
40	8898	1102691	7640129	6414196	150788	2.0
45	3959	621759	4617680	3918541	78791	1.7
50	1904	369184	2801431	2398768	42757	1.5
55	870	204179	1584781	1369048	21739	1.4
60	371	103791	817198	713057	10158	1.3
65	123	40005	291230	254630	3485	1.2
> 70	161	73458	585660	479843	5332	1.0
Total	852026	17094045	91338295	72936372	3691826	

Where G: basal area; Vb: volume with bark; Vwb: volume without bark; IAV: annual increment of volume with bark; RI: relative increment.

Various yield tables for Scots pine in Spain offer information on real output for different site qualities and silvicultural treatments. Table 4 shows a summary of yield according to quality in a system of moderate thinning (Rojo and Montero, 1996a, 1996b).

Yield potential of *Pinus sylvestris* stands

Potential yield is defined as the maximum timber yield which can be obtained for a site fulfilling the following conditions:

- Stable soil, in equilibrium with the climate, conditioned by its lithology.
- Correct management techniques, including a forest management plan, maintenance of the most suitable stand density, and natural regeneration of the mature trees.
- Good health of the stand.

TABLE 4
GROWTH STOCK IN THE MAIN STAND AFTER THINNING (IN M³/HA) FOR DIFFERENT SITE QUALITY*
AND WITH A MODERATE THINNING REGIME

*Existencias de la masa principal tras la clara (en m³/ha) para distintas calidades de estación
y con un régimen moderado de claras*

Age	Quality 17 *			Quality 20 *			Quality 23 *			Quality 26 *			Quality 29 *		
	V at	VE	CAI	V at	VE	CAI	V at	VE	AC I	V at	VE	CAI	V at	VE	CAI
20	—	—	—	101.8	—	—	107.3	—	—	89.5	25.2	—	92.8	29.8	—
30	116.9	26.4	—	132.4	32.9	6.4	152.8	39.3	8.5	171.3	46.8	12.9	191.1	54.5	15.3
40	164.8	43.9	9.2	195.9	57.8	12.1	230.9	71.5	15.0	267.2	86.8	18.3	305.3	102.7	21.7
50	229.2	44.8	10.9	278.8	58.2	14.1	330.9	72.7	17.3	384.5	88.3	20.6	441.7	102.6	23.9
60	279.8	48.5	9.9	344.2	60.3	12.6	411.0	72.9	15.3	478.4	87.2	18.1	543.5	102.1	20.4
70	334.0	42.6	9.7	405.4	53.3	11.5	478.9	64.5	13.2	557.1	76.4	15.5	632.8	88.6	17.8
80	370.8	41.7	7.8	449.6	50.5	9.5	530.7	59.1	11.1	615.9	68.7	12.8	699.0	77.8	14.4
90	407.5	34.8	7.2	489.9	42.1	8.2	573.3	50.2	9.3	663.7	55.8	10.4	749.9	63.2	11.4
100	431.8	31.0	5.5	518.9	35.7	6.5	607.5	40.3	7.5	694.0	48.1	7.8	785.3	52.1	8.8
110	454.9	25.7	4.9	542.0	29.2	5.2	626.8	35.7	5.6	722.5	36.4	6.5	809.3	43.5	6.8
120	470.1	22.3	3.8	546.4	25.6	4.0	647.2	28.6	4.8	735.2	32.1	4.5	827.4	35.3	5.4
130	482.3	18.9	3.1	565.4	24.5	3.4	657.8	25.0	3.6	746.7	26.4	3.8	838.3	29.0	4.0
140	492.2	15.1	2.5	580.4	17.7	3.3	666.6	20.3	2.9	750.4	26.2	3.0	843.8	25.9	3.2
150	496.0	14.7	1.9	583.0	17.7	2.0	669.9	18.6	2.2	761.6	18.5	3.0	844.6	24.7	2.6
160	500.0	14.2	1.8	590.5	12.7	2.0	675.3	15.3	2.1	761.0	17.2	1.7	851.1	18.1	2.5
170	506.9	10.9	1.8	590.3	13.2	1.3	674.1	15.9	1.5	761.0	15.8	1.6	851.4	16.0	1.6
180	518.7	—	—	603.6	—	—	689.2	—	—	775.9	—	—	862.3	—	—

Where: V at: Volume of main stand after thinning, in m³/ha.

VE: Volume of the take out stand, in m³/ha.

CAI: current annual increment of volume, in m³/ha-year.

* The quality of the stand correspond with the top height (m) at 100 years old (Rojo and Montero, 1996b).

This criterion integrates various factors (ecological and human) which influence the forest ecosystem and give rise to variable yields for different sites and species. In this way it becomes an index suitable for making comparisons between different forest areas (Sánchez Palomares *et al.*, 1999). In order to calculate potential yield, Paterson's (1956) climatic index (I) has been used, modified to take into account the different lithologies which may be capable of generating soils with different characteristics and conditions; these may either encourage or limit high crop yields. Potential yield, in $\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$ of timber, is linked to this index by means of the following logarithmic expression:

$$\text{Potential yield} = 5.3 \cdot \log I - 7.4$$

The classes of climatic yield potential for Scots pine in Spain shown in Fig. 7 are established by means of the values of this index.

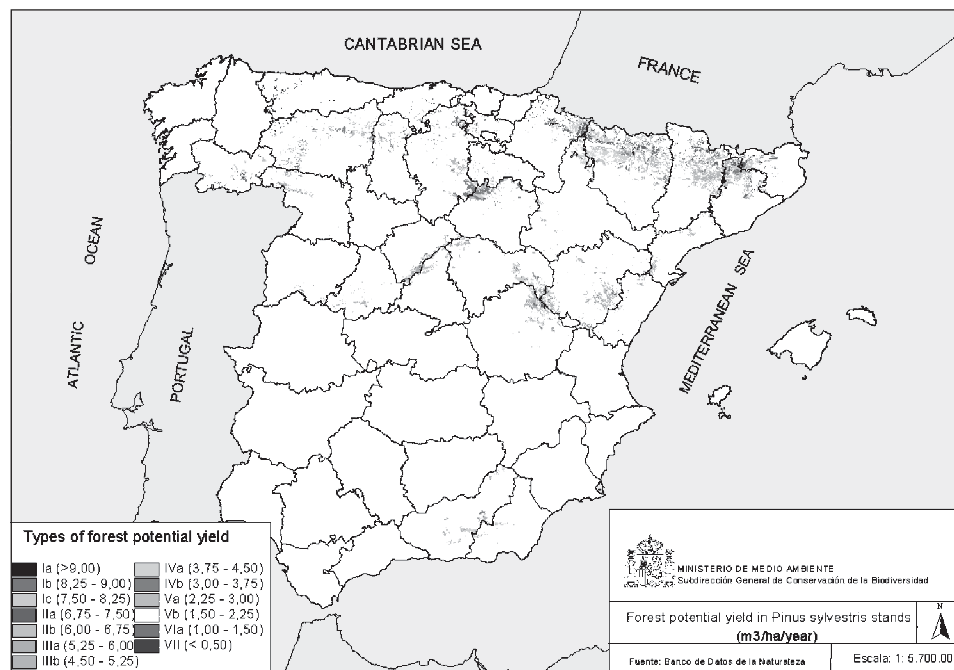


Fig. 7.—Forest potential yield in *Pinus sylvestris* stands in Spain ($\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$)
*Productividad potencial forestal de las masas de *Pinus sylvestris* en España ($\text{m}^3 \text{ha}^{-1} \text{año}^{-1}$)*

THE DYNAMICS OF *PINUS SYLVESTRIS* WOODLAND

The high ecological adaptability of Scots pine, which enables it to exist in a wide variety of monospecific and mixed forest communities as outlined earlier in this paper. The dynamics of these ecosystems vary due to the interaction with other species and direct or indirect human influences. Scots pine is capable of replacing various broadleaf and coniferous species, either because of the active favouring of pine, or because land cleared by erosion, felling or ploughing can be easily colonised by this fast-growing and undemanding species. For these reasons Scots pine, besides forming stable woodland without competition from other species, may also form second-growth forests, in a wide range of situations, largely in place of beech, silver fir, *Q. faginea* and *Q. pyrenaica*.

Natural succession stages in *Pinus sylvestris* stands

We do not have adequate examples to describe the stages of development of untreated stands of Scots pine in Spain. All our information comes from managed stands and we focus on these in the following sections. In order to describe the different stages of succession (Oliver and Larson, 1990) we consider their classification according to altitudinal zones:

- **Zones at altitudes between 1600 and 1800 m**

After a serious disturbance such as a forest fire, the elimination of tree and shrub vegetation in these areas of forest gives rise to a vigorous growth of herbaceous, and, later, low-shrub vegetation. New seedlings have difficulty in becoming established in the presence of domestic livestock (mainly cows and sheep), so that the different phases of evolution towards mature woodland may be interrupted or slowed down. In most cases regeneration would need to be assisted in order to make the stand denser, so that the stages of initiation stand, stem exclusion and understory reinitiation do not exist as such. The old growth stage is much more in evidence (Oliver and Larson 1990).

- **Zones at altitudes between 800 and 1600 m**

In this altitudinal band, where the site is optimal for Scots pine growth, the new seedlings will initially be very abundant and vigorous. If the disturbance has been a fire and all herbaceous and shrubby vegetation has been eliminated, new Scots pine seedlings will have no competition from other vegetation. At lower levels, between 800-1000 m and 1200 m, which is optimal for *Q. pyrenaica*, and where Scots pine has been favoured by human activity, there will be problems of competition, above all from coppice regrowth and root suckers from the broadleaved species.

The stem exclusion stage is characterised by competition between the individuals of a stand leading to natural mortality. This competition takes place if one or more of the resources needed for the tree's development is insufficient for the needs of the stand as a whole. The development of each tree is influenced by the presence of the others, and the

denser the stand the greater the competition. In order to study natural mortality in Scots pine stands, an analysis has been made of unthinned plots in our experimental network. Our results shown the annual mortality rate is not very high, between 1-5 %, but disturbances (strong wind, snowstorm) can produce higher rates.

The third phase, or understory reinitiation stage, is influenced by the intensity of thinnings and cleanings carried out. The development of scrub or undergrowth in the stands is associated with an opening up of the canopy. The presence of certain understory species is related to the success of regeneration of the pine stand, but this presence is usually a consequence of unsuitable human activity rather than a cause of poor regeneration. Nowadays thinnings tend to be moderate and frequent, so that the gaps left by felling can be easily filled by the rest of the trees in the stand. Only in areas of high quality and yield, where the crop is capable of responding rapidly to thinning are intense thinnings carried out. In Spanish stands this phase is usually reached twenty years before the final felling.

The mature phase of the stands is normally interrupted by the final felling (100-120 year rotations). In some areas where silviculture has been flexible, and management plans have not been strictly adhered to, thinned stands with clumps of irregularly distributed new growth, and an abundant regeneration bank in waiting can be found.

Practically all treatments currently performed in Spain in productive Scots pine stands simulate the natural phases of development for stands of this species. These silvicultural treatments attempt to speed up the development process in order to achieve an earlier yield of timber of a given size.

EFFECTS ON BIODIVERSITY OF SILVICULTURAL METHODS APPLIED

For economic reasons, silviculture tends to simplify the structure of forest stands by eliminating less vigorous and technologically inferior trees. Sometimes undergrowth species are removed in order to favour the establishment and development of new growth of the main tree species. This may also lower the risk and limit the intensity of fires, or enable recreational use. Silvicultural interventions such as tree felling, exploitation measures, or removal of residues in order to prevent insect attack or forest fire result in a simplification of the biological complexity of the forest system. There is very little information about the influence of these silvicultural operations on ecosystem diversity, or about the duration of any effects.

In the northern part of the Sistema Central it was found that, at 50-60 years old, *Pinus sylvestris* stands originating either from natural regeneration or from direct seeding were similar in every respect in the floristic composition of their understory (Charle, 1993). Martínez García (1998), in studying the pinewoods of the Sierra de Guadarrama, was unable to demonstrate any floristic differences between the understory of pinewoods subjected to intensive silviculture with clearcutting followed by regeneration seeding, compared with stands growing in similar ecological conditions where regeneration is promoted by moderate felling in uniform shelterwood systems. These results would seem to indicate that, if reforestation takes place in ecological conditions suited to *Pinus sylvestris*, the composition and structure of stands will develop along a common path irre-

spective of silvicultural method. This interpretation is supported by information on variation produced by different felling systems upon the decomposition of organic material, liberation of nutrients and wash (San Miguel, 1982).

In the light of the lack of definitive information on the effect of different silvicultural treatments on the biodiversity of Scots pine stands, and of the even less exact information on their effects on the functioning of the forest, we consider it necessary to set up experiments specifically aimed at clarifying uncertainties in this interesting and complex area, which has such important economic and ecological implications.

ACKNOWLEDGEMENTS

The authors thank R. Vallejo for his helpful in the elaboration of maps of *Pinus sylvestris*, J. de Miguel for the elaboration of some figures and C. Farrell for his work in the paper translation.

RESUMEN

Selvicultura y dinámica de las masas de *Pinus sylvestris* L. en España

En este trabajo se presenta información sobre ecología, tipología, selvicultura, producción, dinámica y biodiversidad de los pinares de Pino silvestre en España. Inicialmente se realiza una descripción de la distribución y tipos de masa de Pino silvestre y de sus aspectos climáticos y edáficos más importantes. En segundo lugar se presenta una tipología de las masas naturales en la Península Ibérica. Posteriormente se tratan los aspectos más importantes de la selvicultura de la especie, incluyendo los objetivos de la ordenación de sus masas en España. En el apartado de producción se aporta información relativa de su producción potencial además de una tabla de producción para las cinco calidades de estación definidas en España. Se tratan las diferentes etapas de sucesión natural de las masas del pinar así como los tratamientos o prácticas selvícolas más comunes en España. Por último se hace una breve referencia de los efectos de la selvicultura aplicada en la biodiversidad de estas masas forestales.

PALABRAS CLAVE: *Pinus sylvestris*
Selvicultura
Dinámica
Biodiversidad
España

REFERENCES

- ALLUÉ J. L., 1990. Atlas Fitoclimático de España. MAPA, Madrid, 221 pp.
CATALÁN G. (ed.) 1991. Regiones de Procedencia de *Pinus sylvestris* L., *Pinus nigra* Arn. subsp. *salmannii* (Dunal) Franco. MAPA, Madrid.
CEBALLOS L., RUIZ DE LA TORRE J., 1979. Árboles y arbustos de la España Peninsular. Escuela Técnica Superior de Ingenieros de Montes. Madrid.
CEBALLOS L., LÓPEZ M., PARDOS J. A., ÚBEDA J., 1966. Mapa Forestal de España, escala 1:400.000. Ministerio de Agricultura, Dirección General de Montes, Caza y Pesca Fluvial. Madrid.
COSTA M., MORLA C., SAINZ OLLERO H., (eds.) 1997. Los bosques ibéricos. Una interpretación geobotánica. Editorial Planeta. Madrid.
CHARLE M. D., 1993. Caracterización ecológica de estaciones forestales de *Pinus sylvestris* L. en el Sistema Ibérico septentrional y su relación con los tratamientos selvícolas. Tesis Doctoral. Universidad de Salamanca, (unpublished).

- GÓMEZ LORANCA J. A., MONTERO G., 1989. Efectos de las claras sobre las masas naturales de *Pinus sylvestris* L. en la vertiente sur del macizo de Urbión. Comunicaciones INIA. Serie Recursos Naturales, n.º 48.
- GRUBER M., 1979. Le pin sylvestre dans les vallées d'Aure et de Louron (Pyrénées Centrales). Bull. Soc. Hist. Nat. Toulouse 115 (1-2): 181-190.
- GUTIÉRREZ E., 1990. Dendrocronología de *Pinus sylvestris* L. en Cataluña. Orsis 5: 23-41.
- IFN, 1998. Segundo Inventario Forestal Nacional. MAPA.
- LÓPEZ G., 1982. La guía de INCAFO de los árboles y arbustos de la Península Ibérica. INCAFO. Madrid.
- MADRIGAL A., 1994. Ordenación de montes arbolados. Colección Técnica. MAPA-ICONA. Madrid, 375 p.
- MARTÍNEZ GARCÍA F., 1998. Los bosques de *Pinus sylvestris* L. del Sistema Central español. Distribución, historia, composición florística y tipología. Tesis Doctoral, Universidad Complutense de Madrid (in press).
- MARTÍNEZ GARCÍA F., MONTERO G., 2000. Typology of *Pinus sylvestris* L. forests in Spain. Investigación Agraria. Sistemas y Recursos Forestales. Fuera de Serie n.º 1 (in press).
- MONTERO G., 1992. Aspectos ecológicos y productivos de la selvicultura. Ecología, 6: 111-121.
- MONTERO G., 1994. Generalities on silviculture of *Pinus sylvestris* L. in Spain. In: Montero G., Elena R. (eds.). Investigación Agraria. Sistemas y Recursos Forestales. Fuera de Serie n.º 3: Mountain Silviculture, INIA-IUFRO: 251-257.
- MONTERO G., CAÑELLAS I., 1999. Gestión sostenible del bosque mediterráneo en España. Unasylva, 50 (197): 29-34.
- MONTERO G., ROJO A., ALIA R., 1992. Determinación del turno de *Pinus sylvestris* L. en el Sistema Central. Montes, 29:42-48.
- NICOLÁS A., GANDULLO J. M., 1969. Ecología de los pinares españoles II. *Pinus sylvestris* L. IFIE, MAPA.
- OLIVER C. D., LARSON B. C., 1990. Forests Stand Dynamics. MacGraw-Hill, Inc.
- PATERSON S. S., 1956. The forest area of the world and its Potential Productivity. Göteborg University. Göteborg.
- ROJO A., MONTERO G., 1996a. Tablas de producción españolas. Montes, 38:35-42.
- ROJO A., MONTERO G., 1996b. El pino silvestre en la Sierra de Guadarrama. Ministerio de Agricultura Pesca y Alimentación. Madrid.
- SAN MIGUEL A., 1982. Procesos biogeoquímicos y selvicultura. Perspectivas de su Estudio. Actas I Asamblea Nacional de Inv. Forestal, Madrid, 40 pp.
- SÁNCHEZ PALOMARES O., SÁNCHEZ F., CARRETERO M. P., 1999. Modelos y cartografía de estimaciones climáticas termopluviométricas para España Peninsular. MAPA.