

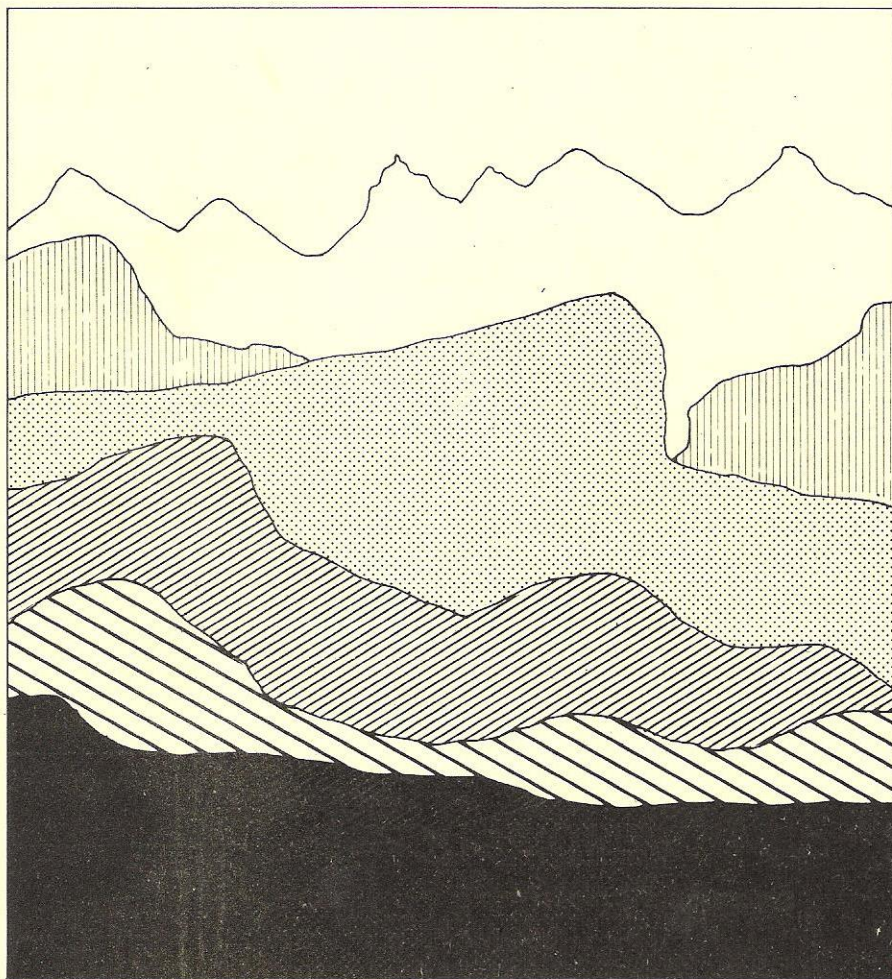


MOUNTAIN SILVICULTURE

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27th September - 1st October 1993

Valsain - Spain



INVESTIGACION AGRARIA
SISTEMAS Y RECURSOS FORESTALES

ISSN: 1131-7965

FUERA DE SERIE Nº 3 - DICIEMBRE 1994

Edita: Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria
Ministerio de Agricultura, Pesca y Alimentación

ISBN: 1131-7965

NIPO: 252-94-004-1

Depósito Legal: M-43776-1991

Diseño: INIA

Imprime: INIA, José Abascal, 56. 28003 MADRID

CONTENTS / INDICE

	Page/Página
FOREWORD/PROLOGO	I
INTRODUCTION/INTRODUCCION	VII
EDITORIAL NOTES/NOTAS EDITORIALES	XII
ORGANIZING COMMITTEE/COMITÉ ORGANIZADOR	XVII
PARTICIPANT FAMILY PICTURE/FOTO DE PARTICIPANTES	XXI
PAPERS	
1./ General topics on silviculture in Mountain Regions.	
MONTERO GONZALEZ G.; ROJO Y ALBORECA A.; HERNANDEZ FERNANDEZ DE ROJAS Ana: Theory and Practice of Silviculture	3
SOLYMOS R.: Forestry and silviculture of Hungary	19
SERRADA HIERRO R.: Reforestation in Arid Mountaineous Areas of Central Spain	29
JEANSSON E. Extent of Naturally and Artificially Regenerated Young Growth Stands according to results from the Swedish National Forest Survey	39
2./ Silviculture of Broadleaved species	
2.1./ Silviculture of Beechwoods (<i>Fagus sylvatica</i>).	
ORLIC S.: Conversion of Beech Coppice Forest by Introduction of Conifers	53
2.2./ Silviculture of Oakwoods (<i>Quercus sp.</i>).	
POPOV G.: Optimizing the Compositions of Forest Stands Growing under Aggravated Environmental Conditions	63
CAÑELLAS Isabel; MONTERO G.; SAN MIGUEL A.; MONTOTO J.L.; BACHILLER A: Transformation of Rebollo Oak Coppice (<i>Quercus</i> <i>pyrenaica</i> Willd.) intoopen Woodlands by Thinning at different intensities: Preliminary Results	71
SERRADA R.; GONZALEZ Inés; LOPEZ C.; MARCHAL B.; SAN MIGUEL A.; TOLOSANA E. Dasometric Classification and Alternative Silvopastoral Uses of Rebollo Oak (<i>Quercus pyrenaica</i> Willd) Stands in Madrid. Design of a Pilot Project	79

3./ Silviculture of Pinewoods (*Pinus* sp.)

3.1./ Silviculture of Scots pine stands (*P. sylvestris*)

MARTINEZ GARCIA F.; COSTA TENORIO M. Phytoecological characterization of the <i>Pinus sylvestris</i> formations in the Spanish Central Range	89
ROJO A.; MONTERO G.; ORTEGA C.: Natural Regeneration in <i>Pinus sylvestris</i> L.	107
KINNUNEN K.: Combination of Natural and Artificial Seeding in Regeneration of Scots Pine	125
ACKZELL L.: Artificial Measures and Natural Forces in Regeneration of <i>Pinus sylvestris</i> L. in Boreal Sweden	133
DONES J.; MONTERO G.; MADRIGAL A.; CABRERA M. Study and Characterization of <i>Pinus sylvestris</i> L. Regeneration in "Pinar de Valsain" Forest	141
OOSTERBAAN A. Results of Trial with Natural Regeneration of <i>Pinus sylvestris</i> in the Netherlands	149
MONTERO G.; ROJO A.; GOMEZ J.A.; ORTEGA C. First Results of a Thinning Experiment on a <i>Pinus sylvestris</i> L. Man-made Forest in the Sistema Central Range	153
GARCIA LOPEZ J.M.: Testing of a Model of Structural Evolution in Stands of <i>Pinus sylvestris</i> L. from the Sistema Central (Spain). Observations on Programming of Thinning and Rotation Selection ..	165
ALIA R.; AGUNDEZ Dolores; DIEZ BARRA R.; MARTIN ALBERTOS Sonia; GIL SANCHEZ L.: Scots Pine (<i>Pinus sylvestris</i> L) Breeding Program in Spain	181
GARCIA ABRIL A.; GRANDE ORTIZ M.Angeles, CIFUENTES VEGA P.: The Transformation on Even-aged Forest in the <i>Pinus sylvestris</i> Public Lands of Cercedilla and Navacerrada	193
GRANDE ORTIZ M. Angeles; ARROYO P.; GARCIA ABRIL A.: Livestock Planning in Forest Lands of Municipalities of Cercedilla and Navacerrada	207

MANUEL VALDES C.M.; ROJO y ALBORECA A.: Valsain Forest in the XVIII Century: An Example of Forest Management in the Pre-Industrial Era	217
SAKSA T.: Natural Regeneration on Prepared Reforestation Areas. Some reasons for the Variation	231
MADDELEIN D.; NEIRYNCK J.; SIOEN G.: Growth and Management of Mixed <i>Pinus sylvestris</i> - <i>Quercus robur</i> stands in Flanders - Belgium	241
MONTERO G.: Generalities on silviculture of <i>Pinus sylvestris</i> L. in Spain.	251
ALLUE Carmen; ALLUE M.: Notes on the managed Development of the "Pinar Viejo" Pine Forest (Coca, Segovia) from 1901 to 1990	259
FERNANDEZ TOIRAN Marina; HERNANDEZ FERNANDEZ DE ROJAS Ana; RIGUEIRO RODRIGUEZ A.; CASTRO CERCEDE Marisa: Effects of forest treatments on macromycete fruit body production in <i>Pinus sylvestris</i> Stands in Soria (Spain).	283
GARCIA LOPEZ J.M.; PRIETO A.; HERNANDO A.: Effects of silvicultural methods upon the structural evolution of a stand of <i>Pinus sylvestris</i> L. in the Sistema Central (1895- 1998). Evaluation of lag.	295
GARCIA LOPEZ J.M.: Short description of the Navafría pine forest and its management history.	309
DONES PASTOR J.; Report on the Valsain forest.	321
 3.2./ Silviculture of other <i>Pinus</i> species stands	
CHATZIPHILIPPIDIS G.; AVTZIS N.: Growth suppression caused on <i>Pinus brutia</i> Ten. by the defoliating Insect <i>Thaumatopoea pityocampa</i> Schiff	333
KONSTANTINIDIS P.; CHATZIPHILIPPIDIS G.: Natural regeneration of a mediterranean aleppo pine ecosystem after fire.	343
KRONFUSS H.: Height growth of <i>Pinus cembra</i> in dependence of air temperature.	349

HERMANN R.K. Regeneration of <i>Pinus ponderosa</i> Douglas ex Laws. in Central Oregon.	363
MERCURIO R.; NOCENTINI Susanna: Silvicultural options for maritime pine (<i>Pinus pinaster</i> ait.) in Tuscany (Italy).	369
CARVALHO OLIVEIRA A.M.: A maritime pine thinning experiment.	275
SALES LUIS J.F.: Seven year results in <i>Pinus pinaster</i> thinning trials in northern Portugal.	393
FRATTEGANI M.; MERCURIO M.; MENCUCCINI M.; PROFILL W.: Quantitative analysis of stone pine (<i>Pinus pinea</i> L.) root systems morphology and its relationship with water table and soil characters.	405
CIANCIO O.; MERCURIO R.: Criteria for the silviculture of stone pine stands.	417
YAGÜE BOSCH S.: Silviculture and production of stone pine (<i>Pinus pinea</i> L.) stands in the province of Avila (Spain)	423
PARTICIPANT LIST/LISTA DE PARTICIPANTES	445

NATURAL REGENERATION IN *Pinus sylvestris* L.

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ABSTRACT

An analysis of *Pinus sylvestris* L. natural regeneration in Spanish forests together with a synthesis of the scarce and scattered information available is presented. The historic confrontation between followers of natural regeneration and those supporting use of artificial methods for regeneration is also commented. Two groups of factors influencing natural regeneration processes, natural or intrinsic (light, soil, topography, moisture, temperature and competition), and antropic or extrinsic (regeneration cutting methods and cattle grazing) are analyzed. Finally, a brief reference to main Spanish research and studies related to forest natural regeneration is made.

KEYWORDS: Natural regeneration, *Pinus sylvestris*, silviculture, regeneration cuttings

1. INTRODUCTION

Scots pine is one of the most important forest trees in Spain, due to area covered by this species (slightly above 922,000 Ha, upon ANUARIO DE ESTADISTICA AGRARIA, 1990), and to the high protective, productive, landscape and recreative values provided by these forests, which occupy mid to high mountain zones and provide sizable amounts of good quality wood resources. For these reasons, a great deal of Spanish forest history is inseparably linked to this species, the object of numerous studies and researches. However, none of them has focused directly on its regeneration.

The goal of our study is to analyze natural regeneration of *Pinus sylvestris* taking in account the few findings available on this very important issue for forest management. A great amount of information comes from decennial revisions of management plans, complemented with general literature and with experience in research and management of several authors.

The scarce experimental research carried out on this issue renders difficult to offer specific data, since most available information refers to opinions, on site impressions or results of actuaciones (several regeneration cutting methods) expressed in management plans revisions by managers on charge. Such information, almost always logically reasoned, and of course

based on silvicultural reality, appears rarely quantified, thus difficulting comparisons between contributions by different authors. Likewise, being a compilation and synthesis study, it is difficult to draw conclusions on some of the points considered.

2. NATURAL AND ARTIFICIAL REGENERATION

Natural regeneration of a forest consists in the ability of present trees to produce seeds and originate new individuals from them, achieving self perpetuation. It represents the main support and the most important problem of silviculture, even though it has not yet been accepted as such (MONTERO, 1992).

On the other hand, although there is always natural regeneration in a forest, only in very limited occasions it occurs in the form and conditions generally intended or required. The search of this optimal forest perpetuation, under the human point of view, has led silviculture to develop two big lines of proceeding, based on the regeneration methods applied. There is a "naturalist" silviculture, almost exclusively based on natural regeneration of forests, and there is other "artificial" that promotes a strong and intensive intervention in the process (MONTERO *et al.*, 1993). There exists a gradation between both extremes, including several intermediate forms of forest treatments. The choice of most suitable treatment in each case represents an essential problem in silviculture (GARCIA DIAZ, 1963), and it has caused a conflict, in every time, between supporters of both lines of actuation. Such controversy has been continuous through history, managing to delimitate different stages according to which of both tendencies prevailed.

First forest treatments applied in Spain which considered regeneration date from the XVI century, throughout the so called "cortas por espesillos" and "cortas a la esperilla" methods (GONZALEZ VAZQUEZ, 1948; MONTERO, 1992), exclusively based on natural regeneration. With the birth of forest science in Central Europe at the end of XVIII and beginning of XIX centuries, and as reaction to the shortage of forest products (MONTERO *et al.*, 1993), methods emerged logically aimed to obtain maximum return from forests, as the clearcutting systems (and resulting area division management methods) proposed and promoted by COTTA. By mid of XIX century this author changed the silvicultural trend, based on his former ideas, to a more naturalistic view, inspired in the shelterwood cutting systems (and its corresponding compartment management methods). This stage culminated at the end of past century and beginning of present with the publication of the works by GAYER and MAYR, in 1880 and 1902 respectively, in which they proposed a "return to nature", aiming to use cutting as imitation of natural regeneration processes. This goal was decisively supported by the scientific development of climatology, edafology, and plant physiology, which allowed a better understanding of natural processes in the forest (MADRIGAL, 1988).

It is at this stage (end of XIX century) when Spanish silviculture appeared on large scale, following the tendencies of the period and adopting a clear position in support of methods that favoured natural regeneration. This is evidenced in the first "Management Instructions" of 1890, almost totally based on shelterwood cutting systems, organized by the method "to manage by transforming" (permanent compartments). These systems were chosen in almost all the numerous management plans devised from the end of past century to the beginning of

present century.

By mid of this century there appeared a tendency contrary to leave nature regenerates itself. This change was given rise due to two reasons: the shortage of forest resources produced by both world wars and the subsequent need of an increase in production by artificially promoting regeneration; the other reason, in our country, was derived from the failures obtained in the application of silvicultural methods used until then (mainly shelterwood systems, until the new "Management Instructions" of 1930 which allowed selection cuttings). This last fact is clearly shown in numerous Management Revisions where, from beginning of the century, several authors were refusing, even though surreptitiously, the shelterwood cutting systems due to the scarce success achieved in natural regeneration of compartments; the former method was replaced by the wrongly named selection cutting, in spite of the fact that failure of shelterwood systems was mainly due to poor application (MARTINEZ DE PISON, 1948).

The II Forest Technical Meeting holded at Madrid in 1962 marked the generalization of intensive silviculture in Spain (ALVAREZ DE MON, 1963; MONTERO, 1992, MONTERO *et al.*, 1993), whereas in Europe such decrease in popularity of natural regeneration occurred after the II World War (LEIKOLA & KOTISAARI, 1989).

Finally, from almost a decade ago and currently, it is possible to observ a new change in the general orientation of European silviculture (LEIKOLA & KOTISAARI, 1989), mainly due to increasing environmental conciousness. This has led to a redefinition of silviculture, trying to identify, in our opinion erroneously, "most natural" methods with enviromentalist positions and most intensive (respect to the cuttings) with productivist positions. Although it is arising, in Spain there is not yet a clear tendency to return "to the natural", due to the delay in environmentalism implantation compared to other European countries. On the other hand, nowadays are occurring many of the conditions that MADRIGAL (1988) considers necessary to result in a "third revision of silviculture", that is, the prevalence of ecology, specially the increasing knowledge of forest ecosystems in two aspects: detailed understanding of its biogeochemical cycles and the study of ecosystem responses to disturbances; these advances will provide realistic data in the future so that silviculture is able to imitate, or at least simulate, the natural patterns in regeneration. For all these reasons, it could be asserted that we are at the beginning of a new "natural revolution" in selviculture, although it is hoped that the valuable discussion between both positions is maintained.

3. FACTORS AFFECTING *Pinus sylvestris* NATURAL REGENERATION

It is possible to tell apart two large groups of factors affecting or conditioning scots pine natural regeneration, and that could be extended to many other species. First, there are those factors that could be designated as "natural" or "intrinsic" to the process, such as climate, topographic and edaphic conditions and both intra and interspecific competition. On the other side, there are factors "extrinsic" to the natural regeneration process, or "antropic", derived from human activities, such as forest harvesting and cattle grazing.

Although every factor is analyzed separately, it is necessary to remark the strong relationships existing among them, in such a way that analysis of their actions would be pointless if they

are not considered jointly.

4. NATURAL OR INTRINSIC FACTORS

Climate is the main natural factor affecting plant regeneration. Throughout temperature, solar radiation and moisture it conditions and restricts development of species in particular environments. Other natural factors involved in regeneration are soil and topography.

Climate derived limitations, even though very important, only preclude regeneration in the case of artificial stands occupying unsuitable areas for the species, or when particular edaphic or topographic conditions are stressing potential climate harshness.

Finally, competition between individuals or species sharing same sites, within plant community succession dynamics, may represent a restraint to scots pine natural regeneration.

Light

Within the Spanish forest range, *Pinus sylvestris* occurs in the Central-Iberian and the Northern or Pyrenean-Iberian regions. In the Central-Iberian region, determinant factors in regeneration are moisture, light and heat, prevailing the first factor; whereas in the second region light prevails over heat and moisture (GONZALEZ VAZQUEZ, 1926). Light represents thus one of the key factors when analyzing natural regeneration processes. Its importance is of such magnitude, expressed by the so called "temperament", that it conditions natural dynamics completely different whether it refers to light-demanding or to shade-bearing species. It becomes clear that the study of such dynamics, being natural regeneration a main component, can provide valuable data to ascertain the processes involved in the species self perpetuation, and thus the influence of silvicultural operations on regeneration.

Scots pine is a light-demanding conifer, heliophile, with strong temperament, or non-tolerant, being its natural development typical of such species. The model of natural succession in a forest, mainly consisting of light-demanding species, sets the origin in a catastrophic episode or in a great disturbance, and in the subsequent colonization of large open areas arisen (MADRIGAL, 1992), with the following stages succeeding:

- *Colonization stage*, during which vigorous light-demanding seedlings establish.
- *Development stage* of the even aged stands installed, characterized by competition between individuals and resulting in a constant decrease of tree number. It includes the following and successive natural age classes:
- *Restocking*, maintained until crowns are tangent, with strong competition between root systems.
- *Thicket*, during which natural pruning of lower, shadowed branches initiates.
- *Pole*, characterized by strong competition resulting in tree differentiation among dominant, codominant, intermediate and overtopped crown classes.
- *Adult*, in which only the dominant layer (dominant and codominant trees) remains, with decreased competition between individuals.
- *Destruction stage*, during which competition between large trees persists, resulting in disappearance of some trees and occurrence of small openings.

If in this last stage only small openings are created, then natural regeneration of light-demanding species is not achieved, and may lead to one of the two following natural situations:

- If there exist nearby shade-bearing tree species, then they begin to installate as a first stage for transformation to mixed stands and eventually to exclusively shade-bearing species stands, thus giving rise to the successional dynamics of shade-bearing species forests.
- If there are not shade-bearing species in the environment, the small openings are colonized by heliophile shrubs and bushes, leading, in successive regressive stages, to understocked forests with bushes, to bushlands, etc.

On the other side, if in this destructive stage, even in the adult stage, strong disturbances resulting in large openings are produced, then the natural cycle of light-demanding species completes, restarting again in the initial colonization stage (MADRIGAL, 1992).

There is, however, an important modification of this scheme, basically expressed by GONZALEZ VAZQUEZ (1945), stating that light or midlight-demanding species in the harsh mediterranean environment behave as if they were delicate species. In effect, it is important to bear in mind the differences in solar radiation existing between Central-Northern European and Spanish latitudes. It is very likely that *Pinus sylvestris* is able to withstand same solar radiation in Spain than and in, for example, Germany (with the expected differences among races and varieties of the species); the problem lies in that both, solar intensity and light period, are greater in the Iberian Peninsula. Although Spanish scots pine forests are located in mountain ranges at high elevation, mediterranean influences are only partially alleviated, and this species must withstand summer harshness with very low rainfall and high temperatures. In this aspect, even though in European silviculture treatises is stated that young scots pine seedlings can not stand shadow (MATTHEWS, 1989), in Spain this species behaves as a mid-light species, being favoured by slight covering during its early years and by northern exposures, two facts widely confirmed by several Spanish authors, among them VILLACAMPA, 1868, GONZALEZ VAZQUEZ, 1926, 1945, 1948; SAINZ MARGARETO, 1953, 1963; RUBIO, 1987; MORILLO, 1987; SANTOS, 1987.

Definitively, it is again demonstrated the prevalence of differential characteristics in the mediterranean environment, and the need of creating a silviculture specifically fitted to our forests, in spite of being formed in many occasions by the same species that cover Central and Northern Europe.

Silviculture attempts to imitate the above scheme, aiming to shorten times, to exploit intermediate products lost by competition, to improve final products and to assure "useful" forest regeneration. For all of these, it is essential the understanding of "light requirements" in every stage, specially in those involved in regeneration. In this sense, CAMPO & PENA (1922) indicated that silviculture could be almost reduced to properly measure the light that tree leaves and forest soil must receive. Light represents, thus, the mean tool used by silviculture to achieve both, suitable quantity and quality of forest products and proper regeneration of forest stands (CAMPO & PENA, 1922; ROJO SAINZ, 1977; MONTERO *et al.*, 1993). Silviculture regulates light by acting on density, a variable much easier to measure and manage.

Despite of its relevance, there are few works that focused on these issues (CAMPO & PENA, 1922; ROUSSEL, 1972; ROJO SAIZ, 1977). However, there are some interesting data available, as for example, that relative radiation nearing 100% (radiation occurring in the open) is optimal for *Pinus sylvestris* growth, whereas relative radiation close to 35% produces maximum germination rates (ROUSSEL, 1972; ROJO SAIZ, 1977). The choice of silvicultural method is based, as shown later, on this reasoning.

Light passage through the forest cover was studied during the first quarter of this century, concluding that light inside a scots pine forest is of same nature as daylight. Besides, it was found that under large crowned *Pinus sylvestris* trees, 80 to 120 years old, light was 70% compared to in the open; and under closed or semi-closed formations of this species, 120 years old and with distorted crowns, light was reduced to a 32% (CAMPO & PENA, 1922). Some studies have even classified the "holes" occurring in the forest cover by its luminosity inside the stand (SMITH, KNAPP & REINERS, 1989). However, in none of these studies light figures were translated to corresponding density, due to the difficulties involved. In this way, the problem, far from being resolved, lies in knowing which crown closures are required to achieve particular radiation values inside the stand. However, although it is not directly involved in the regeneration process, good results have been obtained by managing density (and thus, light) through thinning plans.

On the other side, one of the necessary and essential conditions for natural forest regeneration to proceed, upon GONZALEZ VAZQUEZ (1926), is the occurrence of abundant seed production. Upon this author, Spanish forests commonly fulfil this requirement. Light influence on crown formation, and hence on seed crop, is a fact widely accepted and demonstrated. It has been known since long in our country that yearly seed production of scots pine is very irregular, and it is estimated that two years out of seven are good seed years (alternating between two to five years, often three), another two years are intermediate and the remaining three are bad, being practically null some in which seed is totally lost (VILLACAMPA, 1868; RUIZ DE LA TORRE, 1979).

Soil

Soil conditions are of special importance for germination and survival of young saplings. As indicated by GONZALEZ VAZQUEZ (1926), the second necessary and essential condition for forest regeneration to occur (first condition is abundant seed crop, above discussed), is that soil is in suitable conditions to receive seeds, being a favourable ambience for germination and further seedling development. It is also asserted by this author that such conditions are not generally fulfilled in the Spanish forests, suggesting soil preparation (screefing, bush removing, soil ripping) as solution. At the same time, he considers that the mentioned operations not always lead to good results, due to the generally poor and dry sites involved, estimating that successive sowings are required in not too dry years, thus promoting and assuring appearance of nascent seedlings and restocking.

In the scots pine forests of the Central System range, upon MONTERO (1987), excessive litter accumulation on the surface ("pinocha") over a layer of "black soil", very rich in organic matter compared to the mineral soil, prevents summer survival of seedlings born in spring, due to the following reasons:

- Such soil layer, being very rich in organic matter, presents very low thermal conductivity. Its porosity is high, being air an even worse heat conductor. Besides, specific heat of this type of soil is very low (about 0.2). All these factors determine that during the hottest summer days very high temperatures are reached in these soils at 5-10 cm deep. As such temperatures occurs in dry conditions, they usually result in death of young saplings.
- Being porosity high, dessication is favoured, leading to very little moisture retained during the summer in this soil layer so plants with shallow roots, as in one year old *Pinus sylvestris* seedlings, face great difficulties to survive during the summer.

Definitively, excessive accumulation of pine needles on the forest floor negatively affects natural regeneration. Even though it might be thought that elimination of such layer would favour occurrence of good restocking, such operation should not be carried out in large areas, since this layer induces many beneficial effects, as water retention (even to 2.5 times its weight), decreased evaporation from inner soil layers, diminished soil thermal oscillation, reduced raindrop impact on soil, thus decreasing soil compactation, erosion and water run-off and augmenting infiltration; due to the above reasons, it has been calculated that elimination of "pinocha" layer would decrease forest production by 50% (BRENOSA, 1902), obtaining an undesired effect. In this sense, CAPELLI (1966) suggested prudent ploughing when there exists litter accumulation.

On the other hand, three studies aimed to understand the factors limiting natural regeneration in three different districts of a *Pinus sylvestris* forest in Madrid province (RUBIO, 1987; MORILLO, 1987; SANTOS, 1987) concluded that optimal areas for natural regeneration are those with deep soils and litter layer from 4 to 7 cm deep, indicating that when such layer was above 10 cm regeneration was unacceptable, due precisely to the above discussed effects. In such a way, a limit of 10 cm deep might be established as indicator of good or poor regeneration, regardless other factors. However, litter depth is directly related to the amount of solar radiation reaching the forest floor, since it conditions plant debris mineralization patterns.

Here arises again the enormous influence of light in regeneration and the essential importance of its management in silviculture. On the one hand, if openings large enough are not occurring in the forest, then plant debris are not mineralized at suitable speed and they accumulate excessively on the floor, difficulting regeneration. On the contrary, excessive and non-gradual forest opening produces immediate litter mineralization, decreasing its depth, thus favouring soil dessication (specially in mediterranean climates with coincident dryness and solar radiation maximums) and increasing erosion dangers by fertility losses; these two factors, little moisture and poor soils, prevent that suitable regeneration occurs. Thus, the difficulty lies in finding and managing the forest to a density between both extremes which favours forest regeneration to its maximum.

Experience has evidenced that when forest roads, firebreaks or runs are opened, immediate and vigorous regeneration occurs, due to the total and sudden opening that produces a similar effect to complete pine needle mineralization, as the mineral soil is exposed by these actions. However, it might happen that lateral protection provided by trees in the edges creates mid-light conditions required for scots pine saplings to establish and develop.

Topography

Respect to the optimal topographic conditions favouring *Pinus sylvestris* natural regeneration, it has been already mentioned that northern exposures or those retaining moisture are the best situations. In this sense, areas with presence of abundant mosses, only occurring in moist sites, are identified as specially favourable (RUBIO, 1987; MORILLO, 1987; SANTOS, 1987).

Most suitable altitudinal range is extremely variable with orography, topography and latitude, so is no further commented.

It has been observed in Madrid mountain range that sites with greater scots pine regeneration are those with slopes between 10° and 20° (RUBIO, 1987; MORILLO, 1987, SANTOS, 1987).

Moisture

ROJO SAIZ (1977) estimated that moisture (linked to water retention capacity of soil) is one of the factors (together with light) strongly influencing regeneration.

True limitation to scots pine regeneration, at least in the Central System range, is originated by the usually long summer drought (MONTERO, 1987), worsening edaphic, litter accumulation and competition problems, and other later addressed. In this way, for good regeneration is produced in a particular year. it is necessary the concurrence of both, good seed crop and not too dry summer, with frequent storms during july, august and september. Likelihood of both conditions occurring in a particular year is not very high during the period fixed for scots pine regeneration (twenty years), so it may indicate that such period should vary depending on climate and on the other factors involved in restocking installation and development; this problem can be solved by choosing management methods with flexible regeneration period, as the "movable regeneration compartment" method (MONTERO, 1987).

Temperature

Temperature does not represent any restrain to natural regeneration in the Spanish scots pine forests. Death of young saplings due to extreme temperatures, whether maximum or minimum, is linked to edaphic or water availability problems already examined. In any case, it should not be forgotten the possibility of early and late season frosts, typical in mediterranean climates, that might greatly damage young seedlings.

Competition

Following GONZALEZ VAZQUEZ (1926), it is not possible, without risking failure, to disregard the role of bushes when studying regeneration in the Iberian forests, since they influence and determine the possibility of creation, development and regeneration of forest stands. The occurrence of scrubs or underbrush in the Spanish forests is associated with understocked situations (whatever their origin). Its influence on tree cover depends both, on the type of species forming the underbrush (whether they are "fertilizers" like leguminosae, or "depleters" like cistaceae, labiatae, ericaceae, etc.) and on the forest developmental stage. During the growing season, bushes may prevent or oppose development of young stands; in

the adult tree stage they might be favourable or detrimental to natural regeneration, depending on the species composition of the underbrush, mainly fertilizers or mainly depleters (GONZALEZ VAZQUEZ, 1926).

It has been widely observed that presence of particular species is related to good or poor regeneration in the forest. Thus, areas with abundant brooms (*Sarothamnus scoparius*), genistas (*Genista florida*), blackberries (*Rubus sp.*) or pyrenean oak (*Quercus pyrenaica*) are indicators of poor *Pinus sylvestris* regeneration (RUBIO, 1987, MORILLO, 1987; SANTOS, 1987). Although in many cases the occurrence of these species indicates unsuitable sites for regeneration in the pine forest (for example, blackberries prefer very moist sites, almost swampy, that seem to be rejected by pines), in most cases their presence represent originally more a result of inadequate human activities than a cause of poor regeneration, even though cause and effect are usually complemented and confounded. In this sense, sudden light exposure of forest floor by excessive felling favours invasion of grasses and bushes which compete with pine seedlings. Once again, light appears as an essential factor to, by grading the cuttings, avoid grass and bush installation and favour regeneration.

In the areas with understocked stands, generally in southern exposures, with poor, degraded soil unable to support densities reaching complete crown cover, it occurs a kind of "tangential root systems" (GONZALEZ VAZQUEZ, 1926; ROJO SAIZ, 1977), that occupy the underground space and establish strong and uneven competition between the few existing trees and the scarce saplings able to germinate in such poor soils.

On the other hand, upon MONTERO (1987), grass cover in pine forests produces two different effects, one as a physical barrier, and the other by true interspecific competition: in the meadow areas grass cover prevents fallen seeds from contacting the mineral soil. In this case, germination does not take place, or if it does, the small radicle is unable to contact the soil, so the seedling dies after dessication or freezing. On the other side, if the grass coverage is not so dense and some seedling radicles can pass through it, often they die of summer drought due to water competition by grasses and bushes with more developed root systems. In such meadow areas plowing is the only solution that allows seeds to reach the mineral soil.

5. ANTROPIC OR EXTRINSEC FACTORS

If a forest, whether natural or planted, exists in a particular site with self regeneration, it means that conditions, mainly climatic, are favourable, or at least do not prevent its life and development; thus, it can be asserted that major limitation to natural regeneration comes from certain human activities. Among all of them, there are two greatly affecting perpetuation process: forest harvesting (particularly regeneration cuttings) and cattle grazing.

Silvicultural regeneration cutting methods

Regeneration cutting methods are aimed to imitate population dynamics above discussed, producing "strong disturbances" required by heliophile species to self regenerate. In this sense, at the end of development stage and before destruction stage occurs, the manager must generate openings large enough to achieve installation of seedlings, returning to colonization

stage, shortening and closing the cycle and thus obtaining a dynamic stabilization of it (MADRIGAL, 1992).

Methods producing such effects in *Pinus sylvestris* forests are clearcutting and shelterwood cuttings, in any of their modalities. The choice between both methods has been in many cases influenced by circumstances generally beyond the regeneration problems. In general, shelterwood cuttings have been identified with "naturalist" methods; and clearcutting with "artificial" silviculture, since in the later method "disturbances" are greater and spectacular and it eases any kind of operations to help regeneration after cutting. However, choice between both methods should not be based on such arguments, but must focuss on ecological adequation problems in every particular case, considering forest condition and erosion dangers, always trying to assure forest perpetuation. Economic interest must not prevail over silvicultural interest, but must be considered as an important part of silviculture, specially in management. Finally, landscape limitations should be carefully assessed, even though they should be restrictive only in very special cases.

It is not possible to generalize asserting that one of these methods is more suitable than the other for regeneration of the Spanish scots pine forests, since there are several examples of success achieved using both methods. However, some considerations on both methods could be pointed out.

If artificial operations to help regeneration are not carried out, clearcutting systems produce abundant natural regeneration only when they are applied in not too large areas (strip or small group clearcutting), and this is close to the type of cutting intended by the shelterwood systems. Clearcutting large areas of *Pinus sylvestris* forests has not been experimented in Spain until twenty years ago. From 1960-65 this type of cuttings was applied to scots pine stands in Soria province, within the forests "Pinar grande", "Covaleda", "Santa Inés", etc. (HERNANDEZ & MONTERO, 1993), and in Teruel province ("Grupo ordenado de Bronchales" etc.). Besides, it is currently the most widely used treatment on scots pine forests in Soria province (to save costs and ease machinery operations), together with soil preparation and sowing (HERNANDEZ & MONTERO, 1993).

Clearcutting systems require intensive soil preparation to achieve satisfactory regeneration. Economic silvicultural goals are better attained than in any other method, but from the point of view of ecological silvicultural goals, this method presents serious drawbacks, well described in the European literature (TROUP, 1952; MATTHEWS, 1989; SUSMEL, 1980; and others).

Definitively, "strictly" natural regeneration is not achieved in optimal condition with clearcutting systems. Main reason that seems to explain this fact is the necessity, already discussed, of slight covering for installation and development of scots pine seedlings during their early years, at least in southern, southeastern and southwestern exposures, worst sites for scots pine regeneration in Spain. In the shelterwood systems, adult trees provide suitable protection to young trees recently installed, allowing a later liberation when these reach developmental stage, thus stopping almost completely competition between adult and young trees. The turning point of this method consists in the gradual, non traumatic, succession between destruction and colonization stages, creating the proper "disturbances" required for regeneration. Such circumstances have led to a preference of shelterwood systems for suitable

scots pine natural regeneration in most few Spanish studies on this question (GONZALEZ VAZQUEZ, 1945; MARTINEZ DE PISON, 1948; SAINZ MARGARETO, 1953, 1963).

On the other side, light-demanding species have slow root system growth during germination, so they rarely occur under cover since they are unable to withstand competition during their early years. Bearing this fact in mind, ROJO SAIZ (1977) suggests for *Pinus sylvestris* strip or group systems, since he estimates that such systems provide adequate relative radiation for germination (35%) and at the same time avoid competition among root systems. It is also considered by this author that group diameter should be at least two times the mean height of surrounding stands, whereas width of optimal strips, in any direction, should be similar to stand height.

Strip clearcutting experiments were conducted in the Santa Inés forest (Soria) relying on natural regeneration, but, since it was not satisfactorily achieved for silvicultural purposes, soil preparation, stump removal and sowing had to be carried out (MENENDEZ DE LA VEGA, 1966).

A group clearcutting experiment with 0.25 to 0.5 Ha groups was initiated in "Pinar de Valsain" forest (Segovia) aimed to achieve a more homogeneous regeneration than in gradual cutting systems, and to save exploitation costs by concentrating harvesting in small areas. Results were unsatisfactory (DONES *et al.*, 1993), so this procedure has not been attempted in a bigger scale.

Errors and difficulties in the application of shelterwood cutting systems

Correct application of shelterwood systems implies accomplishment of certain premises, oftenly unobserved. Due to this reason, many of scots pine forest management plans, carried out in our country at the end of past century and beginning of present, that adopted this method failed in their attempt to regenerate first compartments (regeneration compartments). Considered then unsuitable for the species, shelterwood systems were abandoned and replaced in most cases by other type of cuttings, wrongly named "selection cuttings", that merely extracted certain trees and were only aimed to, according to MARTINEZ DE PISON (1948), "not leaving the forest without harvesting, making the cuttings, cleverly scattered, give the impression of not being contributing to reduce stocks". However, following this author, failure of management plans was not due to "failure of the method itself, but to its defective application and in many cases to its complete inapplication"; the same author suggests also several reasons for this apparent failure in regeneration of shelterwood systems.

According to MARTINEZ DE PISON (1948), one of the facts contributing more to shelterwood systems discredit was wrong performance of regeneration cuttings. The reason simply was "fear of cutting arisen at the beginning of management plans", since final stand density for regeneration was unknown. Therefore, less than required was cut for fear of not achieving compartment regeneration, thus excessive density prevented regeneration. Most relevant example of this, mentioned by MARTINEZ DE PISON (1948), is represented by the scots pine forests of Segovia province where "it was doubted that either they did not regenerate because they were not cut or they were not cut because they did not regenerate".

This ignorance of final stand density for regeneration has continued until present. Although

guiding figures can be found in all silvicultural treatises, density that should be achieved in each of the successive stages of shelterwood systems is really unknown. This is one of main difficulties in this method, and it is worsened by the impossibility of generalizing a single figure suitable for all the different micro and macroecological conditions that can be found in the different *Pinus sylvestris* forests, even within a single forest.

Nevertheless, there are some interesting data available. MARTINEZ DE PISON (1948), referring to Navafría (Segovia) *Pinus sylvestris* forest, indicates that this forest is self regenerated only when basal area is lowered down to 12 or 15 m²/Ha. Taking as reference production tables for this species in the Central System range (GARCIA ABEJON & GOMEZ LORANCA, 1984), and considering an intermediate quality (II) at 100 - 120 years age (corresponding to rotation), it can be deduced that a theoretical even aged stand would consist of trees 42 cm in normal diameter (averaging strong and moderate thinnings) and corresponding basal area of 0.1385 m². If we set critical basal area for scots pine regeneration at 13.5 m²/Ha (average between 12 and 15, always referred to Navafría forest), it can be simply calculated by division that such density would be achieved by reducing the stand to 100 trees/Ha of the above characteristics; this value leads to 10 m spacings in a royal frame distribution (trees in the center of a square) or to 10.75 m in a quincunx distribution (trees in the center of a regular hexagon). This brief and rough calculation gives an impression of the density magnitude required, even though a particular stand with such diameter distribution will never be found.

Another problem difficulting application of shelterwood systems is, according to MONTERO (1987), the impossibility of carrying out systematically the different cutting stages of this method in every part of any forest, due to two reasons: first, being the stages of this method successive, they cannot be carried out if stand response to previous stage is not suitable (regeneration); on the other hand, in almost every stand there are areas with complete regeneration achieved, or being achieved, whereas in others regeneration has not been even started, which implies performing different kind of cuttings in each of them (the later areas appear as stands where regeneration cuttings have been carried out, whereas the former areas appear as stands where liberation, or even final, cuttings have proceeded).

Removal of fungus attacked trees requires particular attention in those areas with special ecological characteristics, or in stands with excessive overmature trees. In the case of *Pinus sylvestris*, *Fomes pini* and *Cronartium flaccidum* are the most damaging fungi. These two diseases are relatively frequent in the Spanish scots pine forests, and the only treatment consists in elimination of attacked trees. For this reason, tree marking of more affected stands becomes a true sanitation cutting of the stand, thus limiting shelterwood system method since there is obligation to cut diseased trees, no matter where they occur, resulting occasionally in excessive openings and preventing removal of other trees required for correct procedure (MONTERO, 1987).

ABREU (1959) indicates that little success of shelterwood systems in some scots pine forest in Soria province was owing to two reasons: on the one hand, owners (generally municipalities) refused to cut trees smaller than 30 cm in diameter, thinking they could thrive if bigger trees were eliminated; on the other hand, rigid bureaucracy in the forest administration obstructed correct performance of tree marking.

Besides, windthrown trees are relatively frequent in scots pine forests. Obligate harvesting of these trees leads to deep modification of annual forecasts, postponing cuttings in some stands and changing the timing of cuttings in some others.

Another difficulty of shelterwood systems lies in that time lapses between proposed cuttings are not accurately known and, even though much literature is available on the issue, none definitive conclusion can be drawn.

All the above discussed on shelterwood systems refers to stands with minimum initial density to allow correct application of this method. Precisely, another important mistake in its use consisted in application to stands not reaching such minimum initial density (stands in drier areas or in upper mountain reaches), so they could not respond to liberation cuttings. Since these stands are already understocked (whatever the reasons) and, therefore, they present a density theoretically suitable for regeneration of a light-demanding species, but that did not occurred, it is illogical to suppose that in such areas, with poor, degraded, sometimes grass or bush covered soil, regeneration can be obtained by eliminating of the few existing trees. In these situations shelterwood systems cannot be applied, and, instead, artificial regeneration is necessary to achieve stands that, considering their density and soil fertility, can respond to regeneration cuttings in the future. Several of the first Spanish scots pine management plans assigned the first cutting stage to the least stocked compartments, since they were most needed of silvicultural intervention, resulting in the abovementioned shelterwood system failure. As economic resources for artificial regeneration were not available, these first compartments could not regenerate, leading to the erroneous discredit of this method (MARTINEZ DE PISON, 1948).

Cattle grazing

Cattle grazing, occurring in almost all *Pinus sylvestris* Spanish forests, represents an obstacle to their natural regeneration. In most cases, range count that can be supported by forests is not calculated, nor even regeneration compartments are preserved. Usual practice in these areas consists in leaving cattle (generally bovine and equine) freely grazing in the forest from spring to autumn, so there is none control over it during this period, the most important for occurrence and installation of restocking.

Pressure produced by these animals is exerted on nascent seedlings (generally by stamping on or by indirect grazing when feeding on nearby grasses) and on good size trees which are deprived of buds and sprouts in every reachable branch (whatever their diameter), sometimes almost continuously, impairing growth, vigour and shape. Besides, major incidence occurs during drier years, when pasture grows smaller and dries sooner, increasing pressure on young pines, thus worsening all regeneration problems characteristic of those years.

Above 1,800 m altitude, scots pine forests present low densities, so cattle grazing and pasture growth are favoured, serving these areas as summer sites for cattle. In occasions, planning of these areas has considered pasture production as top priority. In these, to the difficulties of scots pine self regeneration, cattle grazing is added, which, even non intensive nor prolonged (mainly restricted to summer months), contributes to worsen stand regeneration problems.

Lower altitude areas, between 1,800 and 1,400 m approximately, produce woodland pasture

that usually is non intensively grazed during spring and summer, except in resting and drinking places where damage to restocking is acute.

In the lower areas, below 1,400 m, pastures are abundant, mainly in open or very understocked areas. Such places support heavy range count, making very difficult to achieve regeneration without marking out regeneration areas. Dwarf shapes of young saplings with their leaders cut-off by cattle evidence the effects of this important problem for natural regeneration.

Solution of this problem is easy, but generally complicated to put on practice. Calculation of optimal count range, physical marking out of regeneration compartments (the only feasible), and sometimes improvement of pastures out of the forest are solutions enough to cancel out the damaging effect of cattle grazing. However, problems derived from pasturage rights in many forests, from its social relevance in other areas, and from lack of economic resources, prevent implementation of these measures in many occasions, even though their legality.

6. RESEARCH ON NATURAL REGENERATION IN SPAIN

Although most silvicultural studies mention regeneration, and consider its study as essential to proper forest management, few studies carried out in Spain focuss on natural regeneration. Main reasons of this situation are the complexity of such process and the subsequent difficulties to establish representative assays.

According to LEIKOLA & KOTISAARI (1989), there are several difficulties in regeneration research. First, these authors point out that such studies can be soon outfashioned, due to the continous technological improvement in soil preparation and forest management methods. They consider that long time required, advanced or delayed regeneration problems, and necessity to simultaneously study two different structures with different ecology (mother and descendant stands) complicate the analysis of regeneration process. Finally, they estimate that experimentation on the influence of soil preparation methods and different densities requires areas of several hundred hectars that are two times or four times increased by the annual replications. Besides, in mountain areas, where natural regeneration is main procedure followed, these area requirements are impossible to meet.

MONTERO (1992) remarks that change in research goal priorities, imposed by governing institutions of Spanish silvicultural research, have favoured that none of the regeneration studies have concluded, although research on the issue has been initiated at least three times during the last twenty years.

Spanish publications specifically addressed to regeneration are practically reduced to two works by GONZALEZ VAZQUEZ (1926, 1958), so he can be considered the Spanish author most dedicated to this question. In the first work, an study of the Spanish forest environment and of the factors conditioning regeneration in the light-demanding forest of the Iberian Peninsula is presented; in the second, four variables to test development and results of any forest regeneration are established and applied to *Pinus pinaster*, *Quercus suber* and *Eucalyptus globulus* regeneration.

In 1922, CAMPO & PENA studied light absorption under trees and forests of several species (scots pine among them), only measuring such radiation, but obtaining valuable data for regeneration studies.

MARTINEZ DE PISON (1948) analyzed the causes of incorrect regeneration in many Spanish forests, focusing on management and cutting methods.

Of special interest is the study by ROJO SAIZ (1977) attempting to relate solar radiation to forest regeneration and growth, including several references to scots pine.

Later, several studies and graduation projects have been focussed on this issue, but they have not been published. Some of them (RUBIO, 1987; MORILLO, 1987; SANTOS, 1987) studied factors limiting *Pinus sylvestris* natural regeneration in several districts of a forest in Madrid province.

Natural regeneration in cork oak forests has been studied by MONTERO & TORRES (1992), presenting a synthesis of available literature on the question.

Finally, it must be mentioned the study by HERNANDEZ & MONTERO (1993) on evolution of cutting and regeneration methods applied in the *Pinus sylvestris* forests of Soria province.

From all the above discussed, it is straightforward to conclude that there is great need to increase our knowledge on natural regeneration of our forest trees.

Following LEIKOLA & KOTISAARI (1989), ecophysiological research combined with dynamic models might be one of the best approaches to attempt development of optimal natural regeneration methods or to analyze traditional silvicultural methods. Analysis of light influence on the species population dynamics and study of its relation to more manageable silvicultural variables seem to be essential.

Finally, as pointed out by HERNANDEZ & MONTERO (1993), to evaluate economic profit derived from increased growth due to silvicultural treatments, detailed analysis of investments and returns should be done; it would be very interesting, at the experimental level, to apply shelterwood systems (as the most suitable treatment for *Pinus sylvestris* natural regeneration) in areas with different qualities, analyzing their feasibility and economic interest.

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