FRANCISCO MARÍN-PAGEO (*) (°) - ÍGOR RAPP-ARRARÁS (*)

THE APPLICATION OF THE LIOCOURT MODEL TO UNEVEN-AGED CORK OAK STANDS

(*) Departamento de Ciencias Agroforestales de la universidad de Huelva. Spain
(°) Corresponding author; juan@uhu.es

The purpose of this study is to determine the applicability of the Liocourt model to cork oak (Quercus suber *L.) stands in the south-western Iberian Peninsula, and to review the general applicability of the Liocourt method. Seven uneven-aged stands in a densely structured cork oak forest (basal area ≥ 10 m^2/ha) were selected and analysed. The results indicate that the Liocourt expression suffers from theoretical limitations which make it difficult to obtain through regression analysis. Additionally, the paper concludes that the Liocourt model is inapplicable to cork oak stands in conditions similar to those of the study.*

Key words: Liocourt; uneven-aged structure; *Quercus suber* L.; regression; Kolmogorov-Smirnov.
Parole chiave: Liocourt; struttura disetanea; *Quercus suber* L.; regressione; Kolmogorov-Smirnov.

Citation - MARÍN-PAGEO F., RAPP-ARRARÁS Í., 2013 – *The application of the Liocourt model to uneven-aged cork oak stands*. L'Italia Forestale e Montana, 68 (2): 85-93. http://dx.doi.org/10.4129/ifm.2013.2.03

1. INTRODUCTION

1.1. *Historical review of uneven-aged stand management*

There are many different ways within silviculture of categorising uneven-aged stands, but all share the same basic feature of including trees of widely varying ages within small areas (MACKAY, 1949). Determining the age of trees in fieldwork can be difficult in hardwood species, and it is preferable to measure size. Broadly speaking, uneven-aged stands can be loosely defined as those including three or more distinct age classes, either intimately mixed or in small groups (MADRIGAL, 1994; HELMS, 1998 and LOEWENSTEIN *et al.*, 2000), whilst with respect to size, they contain trees of a wide range of diameters (MURPHY and FARRAR, 1981). Where a stand consists of trees of all, or almost all, age classes it can be termed an all-aged stand (HELMS, 1998), although this class is often considered a subset of the uneven-aged category. In contrast, an even-aged stand is a stand comprising trees of a single age class, in which the range of tree ages is usually ± 20 percent of rotation (HELMS, 1998). In this paper we will understand uneven-aged stand to comprise both uneven-aged and all-aged stands.

Managing woodlands as uneven-aged stands represents one of the oldest forms of forest management (GONZÁLEZ VÁZQUEZ, 1948; XIMÉNEZ DE EMBÚN, 1951; BUONGIORNO, 1996). In Spain, applied to oak species, it has been characterised by the traditional methods known as "cortas a la esperilla" and "cortas por espesillos", whereby in the former the forester waits for signs of regeneration before harvesting, and in the latter uses group selection felling (ARTIGAS, 1890).

doi: 10.4129/ifm.2013.2.03

The first reference to uneven-aged stand management as a silvicultural method – "futaie jardinee" in the original French – was by the French authorities in 1730, in reference to the French mountains of Jura (LANIER, 1986; BUONGIORNO, 1996; SHÜTZ, 1997). Later, still in France, a forestry decree of 1883 prescribed the technique in high mountain woodlands, noting its use in Austria in similar conditions (GONZÁLEZ VÁZQUEZ, 1948).

One of the first foresters to research all-aged stand forest management was Gurnaud, who in 1890 proposed the "méthode du contrôle" based on an intensive application of silviculture and detailed dendrometric measurements (GURNAUD, 1890).

LIOCOURT (1898) described the all-aged stand as consisting of trees belonging to all diameter classes, and recommended that the distribution of diameters should first be studied, in what could be considered ideal forest conditions, that is as unmanaged as possible and all-aged. He discovered that the graphical distribution came close to the now well-known reverse-J exponential curve, illustrating that the number of trees tends to decrease in successive diameter classes by a constant ratio, *q*, the "diminution quotient" (LIOCOURT, 1898).

BIOLLEY (1901) developed and modernised the "méthode du contrôle" (BIOLLEY, 1901; CIANCIO and NOCENTINI, 1994; SHÜTZ, 1997; POMMERENING and MURPHY, 2004) on the basis of controlled silvicultural operations towards the gradual achievement of ideal uneven-aged structures.

Uneven-aged stand management systems and their practical application declined throughout the first third of the 20th century, although in Germany they prevailed during the Nazi regime (POMMERENING and MURPHY, 2004), but were consequently thereafter rejected. However, by the end of the 20th century they had regained popularity in forest policy worldwide (Rio de Janeiro conference, 1992; Pro Silva, 2000).

The species for which selection methods have most been used are conifers and shade tolerant species, including *Picea abies* L Karsten (MACKAY, 1949; SHÜTZ, 1997), *Abies alba* Mill (KENK and GUENE, 2001), *Pinus uncinata* Mill. (CANO, 1999), *Pinus taeda* (BUONGIORNO, 1996; O´HARA, 2002); although hardwoods, including *Fagus sylvatica* L (KENK and GUENE, 2001), *Quercus robur*, L (DIAZ-MAROTO and MESEGO, 1999), *Quercus rubra* and *Quercus alba* L (LOWENSTEIN *et al.*, 2000) have also featured.

The movement in favour of uneven-aged stand management according to Liocourt's "biological criterion" has been criticised for its need to impose maximum diameters and cutting cycles (CIANCIO and NOCENTINI, 1994). Additionally, its applicability to small areas has been called into question, and it has even been suggested that it was originally applied to large extensions of forest rather than to stands (O´HARA, 1998), thus undermining its credibility for practical applications. Smith (1994) found that age structure measurements of an uneven-aged Pennsylvanian forest cited by Meyer (1952) were in fact even-aged at stand level. O'HARA (1998) also questioned Liocourt's grouping of trees into age classes at arbitrary intervals. Even before the publication of Liocourt's influential work, GURNAUD (1890) considered the determination of allowance as stationary to be inappropriate, although it is implicit in Liocourt's model (1898).

1.2. Brief introduction to the Liocourt model

The Liocourt distribution is determined by three variables: the maximum tree diameter, the basal area, and the *q* ratio (PENG, 2000), where *q* is the ratio between the number of trees in one diameter class and the next larger class, expressed as

$$q = \frac{N_i}{N_{i+1}}$$

Here, N_{i+1} is the number of trees in the diameter class $i+1$ and N_i the number of trees in the diameter class i, q is considered to be constant throughout the lifetime of the stand. An ideal stand, measured in terms of these variables, is described as exhibiting a reverse-J distribution (LIOCOURT, 1898).

In 1952, Meyer formulated the Liocourt model mathematically in the expression:

$$Y\cdot dX = k\ e^{-a\cdot X}dX \Rightarrow Y = k\cdot e^{-a\cdot X}$$

where:
$Y\cdot dX$ = number of trees in the narrow diameter interval dX
X = breast height diameter.
e = e (mathematical constant)
k, a = constants characterising any particular structure.

The ratio q between consecutive diameter class centres x y $x + \delta$ is as follows:

$$q = \frac{Y_x}{Y_{x+\delta}} = \frac{k\cdot e^{-a\cdot x}}{k\cdot e^{-a\cdot(x+\delta)}} = \frac{1}{e^{-a\cdot\delta}} = e^{a\cdot\delta}$$

Where:
x = centre of the diameter class
δ = age class interval

If the ratio between consecutive diameter classes of a distribution is empirically known, a can be calculated via logarithms, thus:

$$a = \frac{\ln q}{\delta}$$

The coefficient k is calculated from the number of trees N in the resulting diameter distribution when the frequencies of the diameter classes, j, are added together:

$$k = \frac{\sum y_j}{\sum e^{-a\cdot x_j}} = \frac{N}{\sum e^{-a\cdot x_j}}$$

Meyer (1952) states that the number of trees making up successive diameter classes in a diameter distribution of this type represents a geometric series, demonstrating the truth of what he calls Liocourt's law.

The Liocourt model, as formulated by Meyer (1952), does not escape criticism. Specifically, the q ratio shows the weakness of grouping the size of trees into intervals of arbitrary width, to which little ecological or biological value can be attributed (Ciancio and Nocentini, 1994; O'Hara, 1998).

Different types of curves have been put to use in describing uneven-aged stands, among which the most widely known are the Weibull, exponential, truncated exponential, and Pareto distributions, the exponential being the most widespread and developed.

1.3. Description of cork oak stands in the southwest Iberian Peninsula

Cork oak is a typical Mediterranean species. It extends as far as Portugal in the west and Sicily and Calabria in the east (Vieira, 1959). In Spain, pure and dense forests of cork oak cover a surface area of nearly 366,000 hectares, while mixed and sparse forests amount to 122,000 hectares, giving a total extension of close to 488,000 hectares (Montero and Cañellas, 2002). A large part of this total can be found in the south-west of Spain, where there are just over 200,000 hectares, mostly with uneven-aged structures and lacking regulatory controls to assure a sustainable yield and stand regeneration. Many woodlands are located in protected areas, such as the Alcornocales Natural Park (167,767 ha), with private and public landowners.

2. OBJECTIVES

- The analysis of uneven-aged management of dense cork oak forests is motivated by various circumstances, as outlined below:The soil protection benefits are permanent, this being the preferred method for forest protection [Olazábal, 1883; Ministerio de Agricultura (Governmental Forest Management Guidelines currently in force), 1971; Shütz, 1997].Uneven-aged stands represent the spearhead of the "naturally-oriented silviculture" policy (Mayr, 1907; Ciancio and Nocentini, 1994; Buongiorno, 1996; Kenk and Guene, 2001; O´Hara, 2002).
- Single tree selection enables monitoring of thinning in small areas and allows harvesting for economic motives (O´Hara, 2002).
- It can easily be used in mixed hardwood stands (Villarino, 1995, cited in Diaz-Maroto and Mesego, 1999).
- It is compatible with the recreational use of forests (Buongiorno, 1996). The method ensures sustainable yield and the durability of the original distribution of the stand

as long as regeneration is assured (Meyer, 1952).

- Cork oak tolerance is between light-demanding and intermediate, allowing the use of selection systems.
- Uneven-aged structures constitute a guarantee of renewal and sustainability (Vieira, 1950). They even ensure yield regularity (Mackay, 1949), and, moreover, meet the needs for sustainable yields in small properties (Liocourt, 1898, Young. 2003).
- There are some general proposals for the implementation of the Liocourt model to uneven-aged cork oak stand management (Artigas, 1907; Ximénez de Embún, 1963). Pita (1995) proposes this model for stands located in Catalonia. Other authors advise the Liocourt model for forests with similar species, such as evergreen oak (Serrada and San Miguel, 2008).

The above circumstances, in particular the final one, contribute to the need to analyse cork oak management of uneven-aged structures, and to consider the application of the Liocourt model as a forestry standard for large areas.

The main purposes of this study are to:

- Test the null hypothesis that the cork oak stands in Jerez de la Frontera (in the province of Cádiz, Spain) can be described by means of a Liocourt exponential curve.
- Describe the distribution of diameters in the uneven-aged cork oak stands within the Jerez de la Frontera Forest Group, by means of an exponential curve following the Liocourt model.
- Analyse the application of the Liocourt model to the management of cork oak in the Jerez de la Frontera Forest Group.

3. MATERIAL AND METHODS

3.1. Study sites

The area under study is located in the Alcornocales Natural Park (spread across the provinces of Cadiz and Malaga, Spain). The park covers a total area of 124,290 ha (compartments 101, 505, 508) in the Jerez de la Frontera Forest Group. The forest is dominated by dense cork oak stands with an average density (trees/ha) and average basal area (m^2/ha), as shown in Table 1. There is inter-tree competition between cork oak (*Quercus suber* L.) and gall oak (*Quercus canariensis* W.), competing in small copses rather than individual trees, with a significant presence of wild olive (*Olea europaea* var. *Sylvestris* Brot.). The species harvested is cork oak. The cohort includes mastic (*Pistacia lentiscus* L.), strawberry tree (*Arbutus unedo* L.) and tree heath (*Erica arborea* L.), with a varied flora including, amongst other species of laurisilva. The climate is cool Mediterranean type with summer drought. Geologically, the region is situated in the Aljibe Unit, consisting

Table 1 – Species included in the compartments 101, 505 and 508. Basal area (BA).

Compartment	Quercus suber		Quercus canariensia		Olea europaea		Other species		
	No. trees/ha	BA (m^2/ha)	No. trees/ha	BA (m^2/ha)	No. trees/ha	BA (m^2/ha)	No. trees/ha	BA (m^2/ha)	Total BA (m^2/ha)
101	125	11.14	29	2.74	16	0.49	1	0.01	14.38
505	69	4.78	47	4.38	100	3.35	24	0.37	12.78
508	66	4.74	98	8.23	42	1.18	36	0.82	14.97

of sandstones and clays. The main soil types include *leptosols, regosols, cambisols* and *luvisols* depending on the depth, relief and bedrock characteristics. Mean average annual precipitation is 620 mm, with a mean annual temperature of 15.2 ºC. Altitudes range from 150 m to 850 m, with slopes between 5 % and 30 %, and very occasionally up to 40 %.

The stands are managed to produce cork as the main product and cattle as secondary. The study assumed an absence of conflicting interests between natural regeneration and grazing. Over the course of the last century the woodland was managed to maintain, or even increase the number of cork oak trees.

3.2. Data sampling: inventory

The general data come from the inventory of the Jerez de la Frontera Forest Group (MARÍN-PAGEO and CALZADO, 2000). The area was systematically sampled at 2.5 % intensity. The regeneration inventory was carried out in a circular plot with a radius of 5 m and area of 78.54 m^2. The diameter classes were in intervals of 10 cm, starting at 10-19 cm.

The data for this particular study were obtained from an additional inventory (MARÍN-PAGEO *et al*, 2003) which followed a non-systematic, heterogeneous design. This approach, using targeted sampling, selected stands for their apparent irregularity (JUNTA DE CASTILLA Y LEÓN, 1999; SHAEFFER 1930, cited in SHÜTZ. 1997; MADRIGAL, 1994) since, given that uneven stands are less managed, the tendency is to adopt an exponential curve as the distribution model (LEAK, 2002). Plot size was 1 ha, and the sample was taken by counting the total number of trees in each diameter class in each plot. In total seven plots were studied, corresponding to stands 101.1, 101.2, 505.1, 505.2, 505.3, 508.1 and 508.2.

The procedure followed is described in detail below.

3.3. Exponential function fit

Given that diameters below 10 cm were not recorded in the inventory, the minimum diameter of the exponential function, the parameter x_0, is exactly 10 cm.

As recommended by RONDEAUX (1993), the estimation of the parameter a for fitting the exponential function in each sample was not carried out by means of the standard regression techniques. Instead, the exponential function was fitted by means of the maximum likelihood method. The importance of this method resides in the fact that it provides the minimum variance estimators or asymptotically minimum variance estimators (DAGNELIE, 1992). In the case of the exponential function, this estimator is given by the (RONDEUX, 1993):

$$a = \frac{1}{\bar{x} - x_0}$$

$\bar{x}$ = mean

3.4. Goodness of fit test

To compare the goodness of fit of each sample with its corresponding exponential function of fit, the One-Sample Kolmogorov-Smirnov Test was used. This test has two clear advantages compared with the chi-square test. Firstly, it does not call for the observations to be grouped into more or less arbitrary range classes, as is effectively the case with diametrical classes, with the result that all information from the sample is used. Secondly, it does not require a minimum sample size (DANIEL, 1987).

3.5. Fitting a curve to the observed distributions

Despite significant limitations of fit, determining the ideal curve was realised by the maximum likelihood method, via the expression:

$$f(x) = \begin{cases} a \cdot e^{-a\cdot(x-x_0)}, & x \geq x_0 \\ 0, & x < x_0 \end{cases}$$

x_0 is set at 10 cm.

4. RESULTS AND DISCUSSION

Initially, it was assumed that there was adequate regeneration for diameter classes to be replenished, a natural assumption given the imposed condition of sufficient absence of pasture to permit it.

The results obtained from fitting the exponential function to the samples by the method of maximum likelihood and the Kolmogorov-Smirnov test are summarised in Table 2. The degrees of significance in the Kolmogorov-Smirnov test are shown for the exponential distribution, for which the parameter *a* is unknown, i.e., estimated from the sample. As can be seen in the table, the null hypothesis (that the diameter distribution of the trees can be accurately described a negative exponential function) is rejected in all cases, with a significance level of at least 0.01.

The degree to which the null hypothesis is rejected, as reflected in the Table 1, avoids the need for this work to consider the execution of the following basic premises of the Liocourt method: the recruitment period from one diameter class to the next, or the constancy of the *q* ratio.

Indeed, the results give a different curve for each 1 hectare plot studied (moreover, with a minimum degree of significance), so that it is impossible to plot a single curve at stand or compartment level, and still less in terms of the forest group as a whole, which represents a major weakness in the Liocourt method as a management model. Although the literature provides no studies of the method applied to cork oak, there are other works on *Quercus*, specifically *Quercus robur* L. (DIAZ-MAROTO and MESEGO, 1999). In general, studies into the distribution curves of uneven-aged stand have used regression methods (GOODBURN and LORIMER, 1999; SHIMANO, 2000), which were ruled out in this paper. However, one study of note which uses regression is that of SHIMANO (2000), which obtained better fits for *Fagus japonica* Maxim. with potential curves than with exponentials.

It is interesting to compare the sample plot size selected by different authors, in view of the observation that the larger the plot size, the lower the validity of the curve in describing the distribution of the uneven-aged stand, by virtue of having a lower density in terms of mixture of trees (PENG, 2000). LIOCOURT (1898) makes no mention of plot size, whilst the plots in MEYER (1952) range between 5 acres (2.02 ha) and 97.9 acres (39.64 ha), and in MURPHY and FARRAR (1981) between l.01 and 16.2 ha. The work by LOEWENSTEIN *et al.* (2000) in the Ozark Highlands of Missouri with mixed oak stands (*Quercus alba* L. and *Quercus rubra* L.) is especially significant, with plots of 0.4 ha, and a clear tendency towards bi-specific uneven stands in numerous plot.

The study cited above by DIAZ-MAROTO and MESEGO (1999) with *Quercus robur* L., does not give the plot size, but does obtain an exponential curve for distributions based

Table 2 – Results of Kolmogorov-Smirnov test application. Sample size (N), estimated value of parameter a (â), observed values of Kolmgorov-Smirnov statistic (D), critical values of Kolmogorov-Smirnov statistic for a significance level of 0,01 ($d_{0,01}$) according to STEPHENS (1986).

Results of Kolmogorov-Smirnov test				
Observation area/stand	N	â	D	$d_{0.01}$
101.1	89	0.05174	0.228	0.135
101.2	87	0.05741	0.172	0.137
505.1	95	0.05879	0.341	0.131
505.2	83	0.05322	0.215	0.140
505.3	115	0.06800	0.156	0.119
508.1	97	0.05782	0.190	0.130
508.2	121	0.05396	0.149	0.116

on observation of the *q* ratio. An important consideration of this study was that of fixing the plot size at a relatively small area (1 ha) so that the distribution curve really described the structure, ensuring a mixed tree uneven-aged stand.

In terms of mathematical aspects, this study is closest to that carried out by MURPHY and FARRAR (1981) with *Pinus taeda* L. and *Pinus echinata* Mill. In both species, the fit is achieved by the Kolmogorov-Smirnov test, and the paper concludes that the negative exponential curve does not adequately describe the diameter distribution of the species under study in the areas studied. MURPHY and FARRAR (1981) consider larger plot sizes and a greater number of plots, although in this respect, given the independence of the Kolmogorov-Smirnov test from sample size, the validity of the present study is unaffected. In both cases, the negative exponential curve proposed by LIOCOURT (1898) and MEYER (1952) is rejected for describing the areas studied. In the case of the present study the results are even more unequivocal than in MURPHY and FARRAR (1981), rejecting the null hypothesis (that it is possible to describe the stand structure with a negative exponential function) with a degree of significance of predominantly 0.01, compared with the 0.05 by which MURPHY and FARRAR (1981) reject an identical null hypothesis.

The results do not exclude the possibility of achieving a greater degree of significance for other types of curve, and future studies might test others, such as the Pareto and the Weibull.

5. CONCLUSIONS

Regression models are not suitable for obtaining Liocourt distribution curves because these curves are actually frequency distributions and do not include two variables measured on the same individual. Moreover, the curve would depend on the size of the interval from one diameter class to another, and as this is arbitrarily determined it is impossible to correlate with the requirement, demanded by the Liocourt model, for the recruitment period from one class to other to remain constant.

Nor was it not possible to obtain a Liocourt curve at a satisfactory degree of significance using the observed distribution method for the stands studied. And although it was possible to find an exponential curve for each individual stand inventoried, albeit with scant reliability, it was not possible to find a general curve at compartment level, which represents a significant impediment to its application as a forest management model.

The results endorse the Kolmogorov-Smirnov method as suitable for analysing these individual curves and fitting them to the Liocourt negative exponential model, since it avoids the problems associated with fixing the interval of the diameter classes, an important factor in the determination of the ideal distribution curves of uneven-aged stands by single-tree selection. The method can also be applied independently of sample size, which favours its use in uneven-aged stands.

This study was carried out on managed stands; it is possible that in the case of unmanaged stands, the distribution shows itself to be more amenable to Liocourt and gives better results (MEYER, 1952). Whatever the case, the cork oak stands studied in the Jerez Forest Group are characterised by being less managed in terms of silvicultural intervention than other cork oak stands in the Iberian Peninsula.

RIASSUNTO

L'applicazione del modello di Liocourt alle fustaie disetanee di sughera

Lo scopo di questo studio è di determinare l'applicabilità del modello di Liocourt alle fustaie di sughera (*Quercus suber* L.) localizzate nella parte sud occidentale della penisola iberica, e di esaminare l'applicabilità generale del metodo di Liocourt. Sono stati selezionati e analizzati sette popolamenti disetanei in una foresta di sughera ad elevata densità (area basimetrica ≥ 10 m^2/ha). I risultati indicano che l'espressione di Liocourt presenta alcune limitazioni teoriche che la rendono difficile da ottenere attraverso l'analisi della regressione. Si conclude inoltre che il modello di Liocourt è inapplicabile ai popolamenti di sughera in condizioni simili a quelle dello studio.

REFERENCES

Artigas P., 1890 – *Selvicultura ó cria y cultivo de los montes*. Imprenta de Moreno y Rojas, Madrid, Spain, 371 p.

Artigas P., 1907 – *Alcornocales e industria corchere*. Ministerio de Fomento. Madrid, Spain, 374 p.

Biolley H., 1901 – *Le jardinage cultural*. Journal Forestier Suisse, 52 (7-8): 113-131.

Boudru M., 1989 – *Forêt et sylviculture:traitement des forêts*. Presses Agronomiques de Gembloux. Gembloux, Belgium, 356 p.

Buongiorno J., 1996 – *Uneven-aged forest management in Europe and North America: news methods for old concepts*. S.J. Hall lectureship in industrial forestry. Berkeley, 29 p.

Cano F., 1999 – *Quarta revisió de lórdenació de la forest Muntanya d'Aransa*. Spain. Impublished. 171 p.

Ciancio O., Nocentini S., 1994 – *Gurnaud´s control method and silviculture on natural basis: a forest management and silvicultural question*. L'Italia Forestale e Montana, 4: 336-356.

Dagnelie P., 1992 – *Statistique théorique et appliquée*. Les Presses Agronomiques de Gembloux. Gembloux, Belgium, 502 p.

Daniel W.W., 1987 – *Bioestadistica: Base para el análisis de las ciencias de la salud*. Limusa, Ciudad de México, México, 203 p.

Díaz-Maroto I.J., Mesego J.M., 1999 – *Utilización del criterio biológico de Liocourt en masas de* Quercus robur *L. en Galicia: Robledal de la Serra de Candán*. I. In: Actas del Congreso de ordenación y gestión sostenible de montes de Santiago de Compostela, Xunta de Galicia. Santiago de Compostela, Spain, p. 457-466.

González Vázquez E., 1948 – *Selvicultura: Estudio cultural de las masas forestales y los métodos de regeneración*. Residencia de estudiantes. Madrid, Spain, 434 p.

Goodburn J.M., Lorimer C.G., 1999 – *Population structure in old managed Northern hardwoods: an examination of the balanced diameter distribution concept*. Forest Ecology and Management, 118: 11-29. http://dx.doi.org/10.1016/S0378-1127(98)00478-2

Gurnaud A., 1890 – *La méthode du contrôle et la tradition forestière*. Revue des Eaux et Forêts, p. 209-218.

Junta de Castilla y León, 2000 – *Instrucciones Generales para la Ordenación de Montes Arbolados*. B.O.C. y L., 94: 5328-5369.

Kenk G., Guehne S., 2001 – *Management of transformation in central Europe*. Forest Ecology and Management, 151: 107-119. http://dx.doi.org/10.1016/S0378-1127(00)00701-5

Lanier L., 1986 – *Précis de sylviculture*. École Nationale du Génie Rural. Nancy, France, 468 p.

Leak W.B., 2002 – *Origin of sigmoid diameter distributions*. USDA. Research paper NE-718.

Liocourt F. de, 1898 – *De l´amenagement des sapinières*. Bulletin trimestriel, Société forestière de Franche-Comté et Belfort. Juillet, p. 396-409.

Loewenstein E., Johnson P., Garrett H., 2000 – *Age and diameter structure of a managed uneven-aged oak forest*. NRC Canada, 30: 1060-1070. http://dx.doi.org/10.1139/x00-036

Mackay E., 1949 – *Fundamentos y Métodos de la Ordenación de Montes*. Escuela de Ingenieros de Montes. Madrid, Spain, 768 p.

Madrigal A., 1994 – *Ordenación de montes arbolados*. ICONA. Madrid, Spain, 375 p.

Marín-Pageo F., Calzado A., 2000 – *Inventario del Grupo de Montes de Jerez de la Frontera (Cádiz)*, Spain. Impublished.

Marín-Pageo F., Sánchez S., Pérez R., 2003 – *Inventario de los Cuarteles A y E del Grupo de Montes de Jerez de la Frontera (Cádiz)*, Spain. Impublished.

Mayr H., 1907 – *Some fundamental principles of silviculture*. Forestry Quarterly, 5: 174-189.

Meyer H.A., 1952 – *Structure, growth, and drain in balanced uneven-aged forest*. Journal of Forestry, 50 (2): 85-92.

Ministerio de Agricultura 1971 – *Ordenación de Montes Arbolados*. Ministerio de Agricultura. Madrid, Spain, 118 p.

Montero G., Cañellas I., 2002 – *El alcornoque. Manual de reforestación y cultivo*. Ed. Mundi-Prensa and MAPA-INIA. Madrid, Spain, 103 p.

Murphy P.A., Farrar R.M., 1981 – *A test of the exponential distribution for stand structure definition in uneven-aged loblolly-shortleaf pine stands*. USDA Research paper SO-164.

O'Hara K.L., 1998 – *Silviculture for structural diversity: a new look at multiaged system*. Journal of Forestry, 97 (7): 4-10.

O'Hara K.L., 2002 – *The historical development of uneven-aged silviculture in North America*. Forestry, 75 (4): 339-346. http://dx.doi.org/10.1093/forestry/75.4.339

Olazábal L., 1883 – *Manual de valoración y ordenación de montes*. Imprenta Moreno y Rojas. Madrid, Spain, 517 p.

Peng Changhui, 2000 – *Growth and yield models for uneven-aged stands: past, present and future*. Forest Ecology and Management, 132: 259-279. http://dx.doi.org/10.1016/S0378-1127(99)00229-7

Pita P., 1995 – *La planificació dels aprofitaments forestalls*. Ed. Aedos - Mundi-Prensa. Madrid, Spain, 112 p.

Pommerening A., Murphy S.T., 2004 – *A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking*. Forestry, 77 (1): 27-44. http://dx.doi.org/10.1093/forestry/77.1.27

Rondeux J., 1993 – *Le mesure des arbres et des peuplements forestieres*. Les Presses Agronomiques de Gembloux. Gembloux, Belgium, 521 p.

Serrada R, San Miguel A., 2008 – *Selvicultura en dehesas*. In: Compendio de Selvicultura aplicada en España, Ed. Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria. Ministerio de Educación y Ciencia. Madrid. Spain, p. 861-876.

Shimano K., 2000 – *A power function for forest structure and regeneration pattern of pioneer and climax species in patch mosaic*. Plant Ecol., 146: 207-220. http://dx.doi.org/10.1023/A:1009867302660

Shütz J.P., 1997 – *Sylviculture 2. La gestion des forêts irrégulières et melangées*. Presses Polytechniques et Universitaires Romandes. Lausanne, Switzerland, 178 p.

SMITH D.M., 1994 – *Silvicultural perspectives. Have we been here before? What did we learnt?* In: Proceedings of the 1993 Society of American Forester National Convention, Indianapolis, Indiana, USA, November 7-10, 1993, Society of American Forester, p. 216-21.

STEPHENS M.A., 1986 – *Tests based on EDF statistics*. In: R.B. D'Agostino and M.A. Stephens (eds.). Goodness-of-fit techniques. Marcel Dekker. New York, USA, 560 p. (Ch. 4).

VIEIRA NATIVIDADE J., 1950 – *Subericultura.* Direcçao - Geral dos Serviços Florestais e Aquícolas. Ministério da Economia. Lisboa, Portugal, 387 p.

XIMÉNEZ DE EMBÚN J., 1951 – *Los montes, introducción a la selvicultura*. Ministerio de Agricultura. Madrid, Spain, 359 p.

XIMÉNEZ DE EMBÚN J., 1963 – *Diez temas sobre árboles*. Ministerio de Agricultura. Madrid, Spain, 184 p.