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Forest structure and plant diversity in maritime pine (Pinus pinaster Ait.) stands in central Spain

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Abstract

The relationship between forest structure and plant diversity in Mediterranean Maritime pine stands (*Pinus pinaster* Ait.) in the Iberian Range (Spain) was studied. Forty eight stands were sampled. In each, a circular plot (15 m radius) and a transect (25*1 m^2) were established to estimate stand variables and record presence and abundance of vascular species respectively. Canonical correlation analysis (CCA), simple correlations and multiple stepwise linear regressions were used to explore the relationship between plant diversity and forest structure. Correlation between diversity measurements and stand variables is very weak, but significant correlations were found when evaluating each set of variables separately. Presence and cover of some species (for instance, *Veronica arvensis* L. or *Micropyrum tenellum* (L.) Link) is correlated with stand variables; however, determination coefficients found in step-by-step regression are not significant.

Key words: *Pinus pinaster* Ait, Spain, Biodiversity, Stand Structure.

Resumen

Estructura forestal y biodiversidad en rodales de pino negral (*Pinus pinaster* Ait.) en el Sistema Ibérico, España

En el presente trabajo se ha estudiado la relación entre la estructura forestal y la biodiversidad en rodales de pino negral (*Pinus pinaster* Ait.) en el Sistema Ibérico, España. En cada uno de los cuarenta ocho rodales muestreados se estableció una parcela circular de radio 15 m y un transecto de 25 por 1 m para estimar diferentes variables dasométricas y anotar la presencia y abundancia de especies de la flora vascular respectivamente. Se utilizaron técnicas de análisis de correlación canónica, correlación simple y regresión lineal múltiple paso a paso para explorar la relación entre la diversidad vascular y la estructura forestal. La correlación entre las medidas de diversidad y las variables del rodal fue débil pero cuando se analizaron cada conjunto de variables de forma independiente se encontraron correlaciones significativas. La presencia y la cobertura de ciertas especies está correlacionada con variables dasométricas pero los coeficientes de determinación de la regresión resultaron no significativos.

Palabras clave: *Pinus pinaster* Ait, España, Biodiversidad, Estructura del rodal.

Introduction

Sustainability is one of the key concepts in forest management since the Rio conference organized by United Nations. Maintaining biodiversity is one of the main objectives defined to achieve forest sustainability (Gordillo, 2002; Oinandia, 2004). So is not strange that forest criteria and indicators included maintenance and enhancement of biodiversity at different spatial scales as of its objectives. Forest structure drives ecosystem processes and biological diversity (Spies, 1998) and has been proposed as a proxy of biodiversity at stand level

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(Naumburg and Dewald, 1999). Structural complexity can be used as an expression of species richness, because structural complexity generates different ecological conditions that favour different species. Brokaw and Lent (1999) stated that the more vertically diverse a forest is, the more diverse its biota will be. The relationship between forest structure and biodiversity in different ecosystems has been studied over the last decade in different ecosystems (see, for instance, Pitkanen, 1997, Hedman et al., 2000, Miller et al., 2000, Brosofske et al., 2001, Griffis et al., 2001 or Hiroaki et al., 2004). Crown cover, stand basal area and age affect biodiversity in boreal forests (Pitkanen, 1997). Although these stand variables can be affected by management, past land-use can also impact plant composition (Hedman et al, 2000). In Spain, González-Alday et al. (2009) previously studied plant diversity, forest structure and silvicultural treatment in Mediterranean forests. However, there is a lack of this kind of studies focused on Mediterranean forest on a broad scale.

Maritime pine stands (*Pinus pinaster* Ait.) cover a wide area in Southwester Europe, both in plantations and natural stands (Alía et al., 1996). Traditionally, *P. pinaster* in central Spain has been used for resin and wood production and soil protection against mobile continental dunes. Developing ecologically sound silvicultural treatment is important for studying the relationship between forest structure and plant diversity.

The effect of forest structure on plant diversity is complex and it is difficult to generalize underlining the importance of studies, both at local and regional level, on plant diversity responses for different forest types and structure. Moreover, most published studies concern managed forests in North America, whose history and tradition radically differ from Europe (Decocq et al., 2004), and particularly from the Mediterranean region (Scarascia-Mugnozza et al., 2000). Montes et al. (2003) review forest structural indices and their potentiality as a biodiversity indicator extensively.

The aim of this study is to explore the relationships between the structural variables for stands of *Pinus pinaster* in the Southern Iberian Range and understory vegetation. By doing so, we attempt to evaluate to what extent the structure influences the distribution of species in the understory and whether there are direct correlations between structural variables and plant diversity.

Materials and methods

Study area

The area subject to study is located in the Southern Iberian Range, Spain (Figure 1). The study area covers a wide range of ecological situations on 4 different ecoregions (Elena-Roselló, 1997) where Maritime pine stands are situated between 800 and 1200 m.a.s.l. Cli-

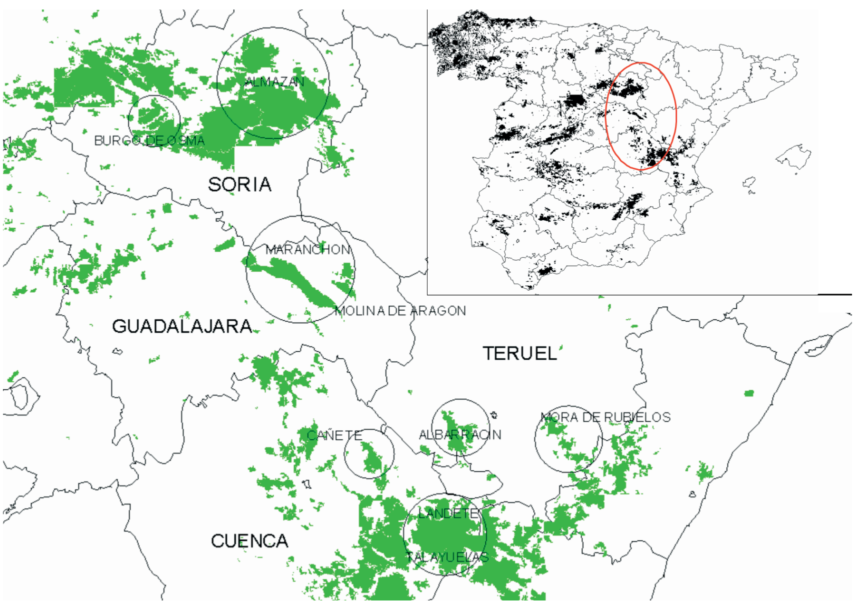

Figure 1. Location of study area (Southern Iberian Range).

mate is typical of Mediterranean mountains. Soils are luviosols and cambisols. The bioclimatological ecoregions studied are Catalonia-Aragon (CA), Litoral-Mediterranean (LM), Manchega (Ma) and Duriense (Du) (Portuguese region). More detailed information about the study area can be found in Bogino and Bravo (2008).

Stand Sampling and structure variables

The structure of the forests was evaluated in natural stands of Maritime pine (*Pinus pinaster* Ait.). Forty-eight circular plots (radius equal to 15 m) were set up from March 2002 to July 2003 in stands that had been without silvicultural practices throughout the last five years. Each of the plots is divided up into three concentric sub-plots with radius equal to 5, 10, and 15 meters. In each subplot, the minimum diameters for the tree inventory are equal to 7.5, 12.5 and 22.5 cm, respectively (Bravo et al., 2002). This sample design is compatible with Spanish National Inventory Design. In each plot, the following data were recollected: aspect, slope (%), rockiness (%), distance to the center of the plot from each tree (m), normal diameter or diameter at breast height (DBH) in cm, total height (HT) in dm, height at crown base (HCB) in dm, height of maximum crown width (HLCW) in dm, maximum crown width or crown diameter (LCW) in dm, growth in the last 5 years (by using Pressler's drill) for all of the trees (mm), age of the four dominant trees in the plot (years), sociological position of each tree, which indicates the location of the trees within the different strata within the stand (dominant, co-dominant and suppressed).

With the data obtained in the field, 10 structural variables were calculated (table 1): Density (trees/ha); basal area (m^2/ha); mean diameter (cm); mean quadratic diameter (cm); Mean total height (m); stand density index (Reineke); Vertical diversity index (VDI); Hart index; cover (%) and age (years). These variables were calculated using the expansion factor (f_i) for plots with a variable radius, to expand the results to hectare (Bravo et al., 2002).

Plant Inventory and diversity indices

A transect (25 by 1 meters) was installed in each of 48 plots, using the contiguous quadrat method (Dale, 1998). These quadrats ordered into a chain or transects are traditionally square, and are small enough that the variation between quadrats may be maximized and variation within each quadrat is minimized. Therefore, the use of rectangular quadrants (quadrats) oriented along the transect direction makes it possible to adjust the radius of the quadrant area (Kenkel et al., 1989). Furthermore, this model makes it possible to study the distribution patterns of the species or estimate their abundance (Naumburg and Dewald, 1999). The quadrats were established in the center of the circular plots and were, in turn, divided into 25 sub-plots measuring 1m^2 in the direction of the greatest slope, if it existed, or if not, in a North – South direction. The species present and the percentage of coverage of each of them were estimated by using a grid with 16 squares, which made it easier to determine the area covered by each individual within the sub-plot (Hedman, 2000; Duque et al., 2001; Dale et al., 2002). Samples of all of the species found in the field were herborized and later identified. The vegetation sampling was also performed from March to July of 2003.

The indices that were used to describe diversity were calculated on the basis of the flora sampling, in which the coverage percentages of each species were estimated, thereby calculating the abundance, richness, maximum diversity, diversity using Shannon's index (Magnussen and Boyle, 1995) and uniformity (Table 2).

Statistical Analysis

In order to establish existing relationships between the ensemble of diversity variables and the ensemble of structural variables and indices for the forest, a canonical correlation analysis (CCA) was performed. This is a direct ordering technique and also represents a special case of multiple regression in which the species are directly related with environmental variables (Ter Braak, 1986, Palmer, 2003). Moreover, simple correlations were used whose objective was to find out the influence of the set of structural variables on the distribution of species. Finally, multiple stepwise linear regressions were carried out to find structural and environmental variables related with the coverage of each of the species selected for this analysis. This method of regression is in widespread use, though its use is only recommended at the exploratory level of data (Peña, 1998). Statistica 5.5 (Statsoft 1999) and SAS (Sas/stat, 1999) were used in the analysis.

Table 1. Structural variables used in the study

Variable	Formula	Mean	Max	Min	SD
Density (trees/ha)	$N=\sum n f_i$	838.1	2450.9	254.7	495.1
Basal area (m^2/ha)	$G=\frac{\pi}{4}\sum n_{ik} d_k^2 f_i$	39.0	56.6	18.4	9.4
Mean arithmetic diameter (cm)	$D_m=\frac{\sum d_i f_i}{N}$	26.9	39.2	10.6	7.0
Mean quadratic diameter (cm)	$Dg=\sqrt{\frac{\sum n_k * d_k^2}{\sum n_k}}$	26.3	38.6	10.5	7.1
Average height (m)	$H_m=\frac{\sum h_i f_i}{N}$	11.7	19.3	5.2	2.9
Stand density index.	$SDI=N\left(\frac{25}{Dg}\right)^{-1,605}$	32.2	64.4	16.1	8.4
Vertical diversity index	$VDI=-\sum_{i=1}^{n} p_i \log_2 p_i$	787.2	1149.0	416.1	185.7
Hart index	$S_{\%}=\frac{1}{H_0}*\frac{10.000}{\sqrt{N*0.866}}$	0.9	1.2	0.5	0.2
Cover(%).	$FCC=\frac{\sum n_i * S_i}{S_t}$	1.1	1.4	0.8	0.1
Age	Mean age of 4 dominant tres	83.3	143	32	29.7

n: number of tree per diameter class; $\mathbf{f_i}$: Expansion factor; $\mathbf{d_k}$: Diameter of class k; $\mathbf{n_{jki}}$: number of tree diameter of class k of the plot $\mathbf{n_i}$: number of tree in each class; $\mathbf{d_i}$: tree diameter *i,* $\mathbf{n_k}$: number of tree de la diameter class *k*; $\mathbf{h_i}$: tree height *i*; **N**: number of tree per hectare, **Dg**, square mean diameter of stand; $\mathbf{p_i}$ proportion of leaf area in each horizontal layer; $\mathbf{H_0}$: dominant height, $\mathbf{S_i}$: Crown Projection tree type *i* of the sample plot. $\mathbf{S_t}$: total area of the sample plot.

Table 2. Variables of diversity

Diversity Index	Formula	Mean	Max	Min	SD
Abundance.	Cover percent of each specie	39.20	116.88	5.04	29.18
Richness.	$RI = n$	15.00	35.00	5.00	6.23
Shannon's index	$H^{'}=-\sum_{i=1}^{s}(\pi_i * Log_2) * \pi_i$	2.40	3.82	0.63	0.71
Maximum diversity	$H_{Max}=-S(\frac{1}{S}\log_2\frac{1}{S})=Log_2 S$	3.80	5.13	2.32	0.58
Uniformity	$J`= H` / H`_{Max}$	0.60	0.85	0.18	0.16

N: number of species. H': is the Shannon information index. (Diversity), π_i = relative abundance for each species. S: number of species the sample plot. H'Max:: is the maximum Shannon index value if all the plant species are equally frequent. S: number of species of the communities. J': uniformity.

Results

Canonical correlation analysis (Table 3) suggests that the relationship between the diversity and structure indices is not very significant, because their canonical determination coefficient for the variables as an ensemble is equal to 0.64, and the correlations between the variables are very weak, because none approaches the condition $p > 0.05$ Significant correlations were found when evaluating each set of variables separately.

Cover species was related to structural and environmental variables by simple correlations and a step-by-step multiple linear regression analysis. The results were significant for some species in the analysis of correlations, while obtaining significant results with some structural variables associated with stand density expressed using the number of trees per hectare, the diameter and indices of stand density, in which these are the figures with the greatest influence on the appearance of species (Table 4) However, determination coefficients found in step-by-step regression were not significant for the species in any of the associated variables in the matrix of correlations.

Table 3. Results of the Canonical Correlation Analysis between Measurements of Structure and Diversity of *Pinus pinaster* in the Southern Iberian Range

Variables	Abundance	Richness	Shannon's index.	Maximum diversity	Uniformity
N	-0.0937 p=0.526	-0.1018 p=0.491	-0.0819 p=0.491	-0.0850 p=0.565	-0.0460 p=0.756
G	-0.0090 p=0.952	-0.1349 p=0.361	-0.2317 p=0.113	-0.1432 p=0.332	-0.1734 p=0.238
G1	0.0009 p=0.995	-0.0450 p=0.761	-0.0248 p=0.867	-0.0437 p=0.768	-0.0120 p=0.936
G2	0.0600 p=0.685	-0.0558 p=0.707	-0.2001 p=0.173	-0.0668 p=0.652	-0.1770 p=0.229
G3	-0.1633 p=0.267	-0.0896 p=0.545	0.0260 p=0.861	-0.0823 p=0.578	0.0756 p=0.609
Dg	0.0687 p=0.642	0.0850 p=0.566	0.0462 p=0.566	0.0827 p=0.755	0.0102 p=0.945
AD	0.0587 p=0.692	0.0824 p=0.578	0.0487 p=0.742	0.0803 p=0.588	0.0167 p=0.910
AH	0.1186 p=0.422	0.1553 p=0.292	0.0566 p=0.702	0.1026 p=0.488	-0.0049 p=0.974
IH	0.0618 p=0.676	0.0313 p=0.832	0.0455 p=0.759	0.0769 p=0.636	0.0116 p=0.938
SDI	-0.0113 p=0.939	-0.1108 p=0.454	-0.2422 p=0.097	-0.1083 p=0.464	-0.2044 p=0.163
FCC	-0.0785 p=0.596	-0.1285 p=0.384	0.0777 p=0.600	-0.1115 p=0.451	0.1714 p=0.244
VDI	0.0985 p=0.505	0.0101 p=0.945	0.0654 p=0.659	-0.0263 p=0.859	0.0822 p=0.578
AGE	-0.0993 p=0.502	-0.0475 p=0.748	0.0541 p=0.715	-0.0158 p=0.915	0.0832 p=0.574

N Density; **G** Basal area; **G1** Basal area (DBH between 0 and 20 cm); **G2** Basal area (DBH over20 and below or equatl to 40 cm); **G3** Basal area (DBH over 40 cm); **Dg** square mean diameter ; **AD** Mean diameter; **AH** Averange height; **IH** Hart index **SDI** Stand density index Reineke; **FCC** Cover; **VDI** Vertical diversity index.

Table 4. Correlation analysis between selected species and stand and environmental variables

Species/variables	N	(G)	G1	dg	Dm	Hm	SDI	IH	Age	Slope
Erica scoparia L.	___	0.29499 p=0.0418	___	___	___	___	0.32694 p=0.02333	___	0.35625 p= 0.024	0.44292 p=0.0016
Thapsia villosa L.	0.40249 p=0.0046	___	0.35279 p=0.0139	___	___	___	___	___	___	___
Thymus vulgaris L.	0.47923 p=0.0006	___	0.53366 p <0.0001	0.34958 p=0.0149	-0.34889 p= 0.0151	___	___	___	___	___
Dorycnium pentaphyllum Scop	0.30448 p= 0.0354	___	0.28357 p= 0.0508	___	___	___	___	___	___	___
Hypochoeris radicata L.	___	___	___	___	-0.30250 p= 0.0366	-0.29142 p= 0.0445	___	___	___	___
Veronica arvensis L.	___	___	___	___	___	___	___	0.57879 p <0.0001	___	___
Micropyrum tenellum (L.) Link	___	___	___	___	___	___	___	0.31290 p= 0.0304	0.44263 p= 0.0016	0.37318 p= 0.0090

N Density**; G** Basal area**; G1** Basal area (Diameter: 0-20 cm)**; dg** Mean quadratic diameter **; Dm:** Mean diameter**; Hm** Mean height**; SDI** Stand density index Reineke**; IH** Hart index

Discussion and Conclusion

Estimation and assessment of biodiversity, in an attempt to establish criteria and indicators of sustainability at various levels is guarantee for the preservation and sustainable management of forest systems (Gordillo, 2002; Oinandia, 2004). In this sense, a lack of significant correlations among the different structure variables and diversity measurements obtained using canonical analysis means that it is not possible to establish indicators which demonstrate the relationship between stand status and plant diversity. Results obtained corroborate the results already found by Neumann and Starlinger, (2001), who found a low relationship between structure indices and biological diversity, while also detecting that structural horizontal diversity indices have the highest correlation with biodiversity. However, structural complexity has been correlated at different scales with biodiversity of a variety of organisms (see MacArthur and MacArthur, 1961; North et al., 1996; or Hiroaki et al., 2004, for instance). Three-dimensional structural attributes has been related with biodiversity in temperate forests (Hiroaki et al, 2004) so this kind of indices should be explored as biodiversity proxy.

In general, it has been observed in the pine groves of *Pinus pinaster* of the Southern Iberian Range that diversity measurements remain constant throughout the different ages of stands. These results are similar to those found in helm groves in Normandy, France (Aubert et al., 2003), where it was found that most species do not display a strong association with a particular status of succession. However, the variables of structure are more influenced by stand age. Nevertheless, in the case studied, we found no conclusive relationships between plant diversity and forest structure.

This fact could be due to environmental variability at different spatial scales in the forests studied. Although the correlation between diversity and stand variables is very weak, the appearance of some species with acceptable levels of significance can be pointed out; this shows how these species are more influenced by structural variables than mainly by density. In this case, the species that have a higher determination coefficient, such as *Erica scoparia, Thapsia villosa, Thymus vulgaris, Dorycnium pentaphyllum* and *Hypochoeris radicata,* are the ones that display the best correlations with certain stand variables such as density and basal area. *Veronica arvensis* stands out because it is a domestic species which predominates in prairies and pathways, and it has practically not been representative of the flora of these ecosystems. However, some of these species are significantly favored by ongoing intervention through different silvicultural treatments (transport of propagule or seeds by machinery or tools, as well as others) (Griffis et al., 2001).

The variable retention harvest system (Franklin et al., 1997) maintains or restores environmental values as biodiversity by retaining part of the crop trees at harvest time. However, in forests where microsite diversity is high (for instance, Mediterranean forests) this strategy might be not necessary. Although foresters can promote biodiversity by enhancing structural diversity, local information both at local and landscape level is needed to shape silvicultural intervention. In Mediterranean maritime pine stands, species richness is controlled by harvest intensity while diversity is not (Gonzalez-Alday et al., 2009). This effect is due mainly to canopy and basal area reduction, because the elimination of tree cover allows the establishment of new species in the forest.

Although the use of indicators based in forest inventory variable is attractive, further research is needed to establish sound indicators related to biodiversity in order to develop forest sustainable management in our targeted forest ecosystem. The use of three-dimensional structural indices in management guidelines can help to promote and maintain biodiversity and ecosystem functions while goods and services are obtained.

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References

ALÍA, R., MARTÍN, R., DE MIGUEL, J., GALERA, R.M., AGÚNDEZ, D., GORDO, J., SALVADOR, L., CATALÁN, G., GIL, L.A., 1996. Regiones de procedencia *Pinus pinaster* Ait. DGCN, Madrid, Spain.

AUBERT M., ALARD D., BUREAU F., 2003. Diversity of plant assemblages in managed temperate forests: a case study in Normandy (France). Forest Ecology and Management. 175, 321-337.

BOGINO, S, BRAVO, F., 2008. Growth response of *Pinus pinaster* Ait. to climatic variables in central Spanish forests Annals of Forest Science 65, 506-518 DOI: 10.1051/forest:2008025.

BRAVO F., PESO C DEL., RÍO M DEL., 2002. El inventario forestal nacional elemento clave para la gestión forestal sostenible. Fundación General de la Universidad de Valladolid. Valladolid, 191 pp.

BROKAW, N. and R. LENT. 1999. Vertical structure. Pp 373–399. *in* Hunter, M. L., editor. Maintaining Biodiversity in Forest Ecosystems. Cambridge University Press. Cambridge, U.K.

BROSOFSKE K. D., CHEN J., CROW T.R., 2001. Understory vegetation and site factors: implications for a managed Wisconsin landscape. Forest Ecology and Management. 146, 75-87.

DALE V. H., BEYELER S.C., JACKSON B., 2002. Understory vegetation indicators of anthropogenic disturbance in longleaf at Fort Benning, Georgia, USA. Ecological Indicators 1, 155-170.

DALE, M., 1998. Spatial pattern analysis in plant ecology. Cambridge university press, Cambridge, 325 pp.

DECOCQ, G., AUBERT, M., DUPONT, F., ALARD, D., SAGUEZ, R., WATTEZ-FRANGER, A., DE FOUCAULT, B., DELELIS-DUSOLLIER, A., BARDAT, J., 2004. Plant diversity in a managed temperate deciduous forest: understorey response to two silvicultural systems. Journal of Applied Ecology 41, 1065–1079.

DUQUE, A., SANCHEZ M., CAVALIER J., DUIVENVOORDEN J., MIRAÑA P., MIRAÑA J., MATAPÍ A., 2001. Relación bosque ambiente en el medio Caquetá, Amazonía colombiana. Evaluación de recursos vegetales no maderables de la amazonía noroccidental. Universities Van Amsterdam. pp. 99-128.

ELENA-ROSELLÓ R., 1997. Clasificación biogeoclimática de España Peninsular y Balear Madrid: Ministerio de Agricultura, Pesca y Alimentación, Madrid, 100 p.

FRANKLIN, J. F., D. R. BERG, D. A. THORNBURGH, and J. C. TAPPEINER 1997. Alternative silvicultural approaches to timber harvesting. In: K. A. Kohm and J. F. Franklin (eds.) Creating a forestry for the 21st century. The science of ecosystem management. Washington, D.C.: Island Press. Pp. 111-139.

GONZALEZ-ALDAY J., MARTINEZ-RUIZ, C., BRAVO, F., 2009. Evaluating different harvest intensities over understory plant diversity and pine seedlings, in a *Pinus pinaster* Ait. natural stand of Spain. Plant Ecology 201, 211-220.

GORDILLO E., (2002). Metodología para la caracterización de la biodiversidad en el inventario forestal nacional. En el inventario Forestal Nacional, elemento clave para la Gestión Forestal Sostenible. Bravo, F.; Del Río, M. y Del Peso, C. (eds). Fundación General de la Universidad de Valladolid, pp. 37-55.

GRIFFIS K.L., CRAWFORD J.A., WAGNER M.R., MOIR W.H., 2001. Understory response to management treatments in northern Arizona ponderosa pine forests. Forest Ecology and Management 146, 239-245.

HEDMAN C.W., GRACE S.L., KING S.E., 2.000. Vegetation composition and structure of southern coastal plain pine forest: an ecological comparison. Forest Ecology and Management 134, 223-247.

HIROAKI, T.I., SHIN-ICHI, T., HIURA, T. 2004 Exploring the relationships among canopy structure, stand productivity, and biodiversity of temperate forest ecosystems. Forest Science 50(3):342-355

KENKEL NC., JUHASZ-NAGY P., PODANI J., 1989. On sampling procedures in population and community ecology. Vegetatio, 83, 195-207.

MACARTHUR, R.H., MACARTHUR, J.W., 1961. On bird species diversity. Ecology 42:594-598

MAGNUSSEN S., BOYLE T.J.B., 1995. Estimating sample size for inference about Shannon-Weaver and Simpson indices of species diversity. Forest Ecology Management. 78, 71-84.

MILLER T.R., BASINGER M.A AND ROBERTSON P.A., 2000. Composition and structure of planted and native *Pinus echinata* Mill. stands in Southwestern Illinois. State Academy of Science. 93 (2), 99-113.

MONTES, F., RIO, M. DEL, CAÑELLAS, I., 2003. Indices de diversidad estructural en masas forestales. Investigación Agraria: Sistemas y Recursos Forestales 12(1): 159-176.

NAUMBURG E., DEWALD L.E., 1999. Relationships between *Pinus ponderosa* forest structure, light characteristics, and understory graminoid species presence and abundance. Forest Ecology and Management 124, 205-215.

NEUMANN M., STARLINGER F., 2001. The significance of different indices for stand structure and diversity in forest. Forest Ecology and Management. 145, 91-106.

NORTH, M., CHEN, J., SMITH, G., KRAKOWIAK, L., FRANKLIN, J.F., 1996. Initial response of understory plant diversity and overstory tree diameter growth to a green tree retention harvest. Northwest Science 70:24-34.

OINANDIA M., DOMINGUEZ I., ALBIZU I., GARBISU C., AMEZAGA I., 2004. Vegetation diversity and vertical structure as indicators of forest disturbance. Forest Ecology and Management. 195, 341-354.

PALMER W.W., 2003. Ordination methods for ecologists. Internet-published, available at hpp/www.carex.osunx.vcc.okstate.edu. [Consulted: 5 December 2004].

PEÑA S.R., 1998. Estadística, modelos y método*s*. Vol 2. Modelos lineales y series temporales. Alianza Editorial, Madrid, 745 pp.

PITKANEN S., 1997. Correlation between stand structure and ground vegetation: an analytical approach. Plant Ecology. 131, 109-126.

SAS. INS. SAS/STAT,(1999). User´s guide. SAS institute Inc., Cary, NC, and 808 pp.

SCARASCIA-MUGNOZZA, G., OSWALD, H., PIUSSI, P., RADOGLOU, K., 2000. Forests of the Mediterranean region: gaps in knowledge and research needs. Forest Ecology and Management 132, 97-109.

SPIES T.A., 1998. Forest structure: a key to the ecosystem. Northwest Science, Vol 72, special issue 2, 34-39.

STATSOFT INC., (1995). Statistic for windows (computer program manual), Statsoft, Inc., Tulsa, Ok, 424 pp.

TER BRAAK C.J.F., 1986. Canonical correspondence analysis*:* a new eigenvector technique for multivariate direct gradient analysis. Ecology 67, 1167-1179.