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PARTE 3: ESTUDIOS ESPECÍFICOS

CRITERIO 1. Mantenimiento y mejora de los recursos forestales y su contribución a los ciclos de carbono

CARBON SEQUESTRATION IN COARSE WOODY DEBRIS IN PINE PLANTATIONS AND OAK STANDS IN NORTHERN SPAIN

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ABSTRACT

Dead wood plays a substantial role in several ecological processes in forest ecosystems. Decaying logs and snags provide habitat for many organisms and participate in biogeochemical element fluxes within the forest ecosystem. Because of their large mass and slow decay rates, they may also play a significant role in the global carbon cycle. For these reasons, it is important to understand the dynamics of coarse woody debris (CWD) during forest succession and estimate the carbon content in snags and logs components

A two-step model for predicting snags and logs in conifer plantations and oak stands in northern Spain is presented joint a carbon sequestration model in order to improve long-term estimation of stand condition. A two-step approach was used, which allow to estimate the probability of CWD occurrence and quantify snags in terms of basal area and logs in term of volume.

Logistic and linear regressions were used. A good performance of the joint model was observed.

Key words: Carbon sequestration, CWD, Snag, log, logistic, *Pinus*, Oak.

RESUMEN

La necromasa desempeña un papel fundamental en los ecosistemas forestales. Tanto los árboles muertos en pie como los caídos son componentes importantes de la dinámica de los bosques, suministrando habitat a muchísimos organismos, contribuyendo a la cantidad de materia orgánica de los suelos forestales, participando en numerosos flujos biogeoquímicos y en el ciclo de nutrientes, entre otras muchas funciones, todas de vital importancia para el mantenimiento de la biodiversidad.

Se presenta un modelo en dos pasos que predice la probabilidad de presencia de necromasa en pinares de repoblación y rebollares del Norte de España y cuantifica el Área basimétrica de los árboles muertos en pie y el volumen los árboles caídos. Por otra parte, se presenta un modelo lineal que cuantifica la fijación de carbono en la necromasa caída en el suelo. Para este proceso se han utilizado regresiones logísticas y lineales que presentan buenos parámetros de ajuste.

Palabras clave: Secuestro de carbono, necromasa, árbol muerto en pie, árbol caído, logística, *Pinus*, *Quercus pyrenaica*.

INTRODUCTION

Dead wood plays an important role in ecological processes in forest ecosystems. Although, decaying logs and snags are recognised as an important component of forest dynamics linked to biodiversity (Harmon et al., 1986, Esseen et al., 1992, McComn et al., 1999), there is a lack of knowledge of dead wood dynamics in Mediterranean forest, where externalities as biodiversity maintenance has a great importance.

Coarse woody debris significantly contributes to the total amount of organic material on the forest floor, thereby affecting carbon storage, energy flow and nutrient cycles (Harmon et al., 1986; Harmon et al., 1991). Brown-rot residues can make up a considerable part of the organic layer in forests ecosystems and increase the water-holding capacity of the soil (Larsen et al., 1980).

In managed forest under sustainable yield paradigm, dead trees have been minimised to avoid pest problems and hazards. Thus, trees killed by insects, diseases and fire are commonly harvested immediately if economics and accessibility permit (DeBell et al., 1997). Also, short-rotation silviculture truncates this development before large-diameter dead trees start to accumulate (Hansen et al., 1991). Currently, the increasing importance of biodiversity and carbon pool lead the manager to maintain and promote dead wood in managed forests. Forest and wildlife managers have suggested 5 to 10 snags per hectare are adequate (Hunter, 1990) to maintain the biodiversity.

Coarse woody debris and their relative contribution to total ecosystem biomass varies greatly in the landscape, depending on forest types, disturbance regimes, topography, and stand characteristics (Spies et al., 1988, Harmon et al., 1991).

In practice forestry, snag and log dynamics are important to define adequate abundance or density, size (both diameter and height), distribution and state of decay, different site conditions and forest types (Hart, 1999, Woldendorp et al., 2004, Christensen et al., 2005, Stephens et al., 2005). Managing this important carbon store, requires knowledge on the amount of CWD as a function of stand conditions and silviculture. Studies focus on modelling snags and logs abundance in Mediterranean type forest ecosystems are scarce (Montes et al., 2006).

Binary events such as presence of structural features in the stands (logs, snags, nest trees,...), ingrowth or natural non-catastrophic mortality show a high stochasticity and are key components in long-term forest forecast systems (Bravo et al., 2006). Two step models method has been used successfully for predict this type of events (probability of mortality stand (Woollons, 1998, Álvarez et al., 2004) or ingrowth stand (Bravo et al., 2006).

The objectives of this study were (1) to develop a snags and logs abundance model for Mediterranean pine plantations composed by *Pinus sylvestris* L., *Pinus pinaster* Ait., *Pinus nigra* Arn., and for Oak stands, *Quercus pyrenaica* Wild. in northern Spain and (2) to estimate a carbon sequestration equation_for coarse woody debris on the ground (logs) in these type of ecosystems. The first model, snags and logs abundance, was developed according to a two-step approach. Finally, a carbon sequestration equation can serve to better understand the process of snags and logs abundance in order to improve long-term estimation of stand condition.

MATERIALS AND METHODS

Study area

The study area, situated in the north of Castile and Leon (Spain), represents a homogeneous transitional with altitudes ranging from 800 to 1000 m asl. This region is located unevenly between the following UTM coordinates 342.000 to 4.685.000, and 398.000 to 4.741.000 (fig. 1), and its area is about 186617.4 hectares. The climate is Mediterranean with a slight Atlantic influence.

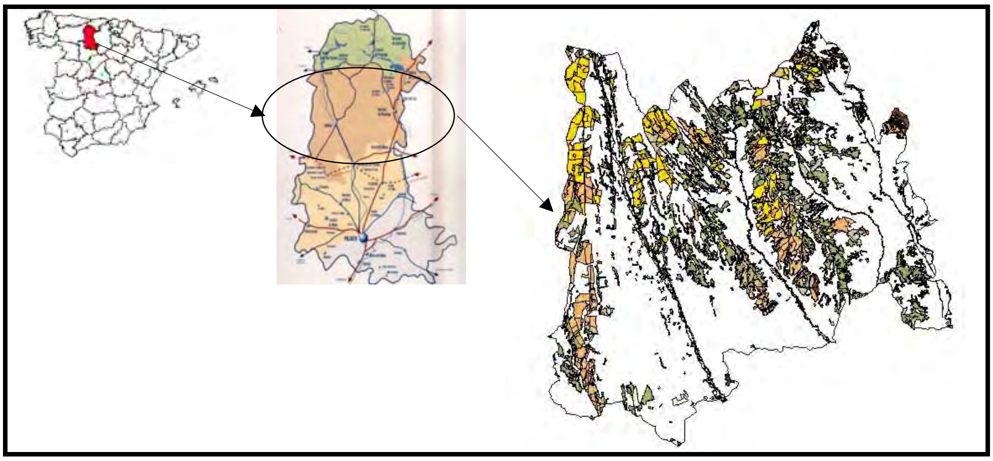

Fig 1. Localization of Study Area

Forests cover is 59471.1 hectares (31.9 % of total area), and is characterised by extensive stands of pyreneen oak (*Quercus pyrenaica* Wild.), joing holm-oak (*Quercus ilex* L.) and scrub oaks (*Quercus faginea* Lam.). As a result of an extensive pine plantation program carried out during the 60's, *Pinus* stands cover 49.4% of the total forest surface of this region. On the other hand, Oak stands cover 38%. The three main species of Pine plantations are *Pinus sylvestris* L. (23%), *Pinus nigra* Arn. (21%) and *Pinus pinaster* Ait. (5%). In the clearings, there are mosaics of heathers (*Erica* sp.) and rock roses (*Cistus* sp.). The soil in this region is mainly acidic, although it is possible to find limestone and neutral soils (Oria de Rueda et al., 1996).

Database

Ninety five study plots were installed in the study area. Database contains 67 plots from *Pinus* spp. planted stands (34 dominated by *Pinus sylvestris* L., 25 dominated by *Pinus nigra* Arn., and 8 by *Pinus pinaster* Ait.) and 28 plots from natural oak (*Quercus pyrenaica* Wild.) stands. Dates are shown in table 1. Measurations were conducted during the year of 2005.

The plots were formed for four subplot joined by two perpendicular transects. The snags inventory was realized in the four subplots and the log inventory was realized in the transects. Snags inventory was carried out sampling in spiral 20 trees. Starting by the trees that were closer to the plot's center, and moving progressively away from it, it was measure if each tree was alive or death. In tally dead trees (diameter at breast height ≥ 7.5 dbh), the variables recorded were species, snag's height, diameter breast height (DBH), decomposition status, presence of excavated cavities, azimuth and distance (taking as a reference the center of the plot). Inventory of logs with diameter greater than 7.5 cm and longitude greater than 1m was carried out in a two perpendicular transects of 50 m of length each one, that joined the four subplots. Intensive inventory of logs with diameter bigger than 1 cm was carried out in 47 plots of the total ninety five study plots. Ten meters nearest of the intersect point of the transects were inventoried. The variables species, diameter on the interception point, length, weight, decomposition status and wildlife characteristics were measured in each log. Dates are shown in table 2. Total carbon contents of samples of woody residues from each plot was measured by instantaneous combustion of fragment samples to 550ºC oven.

Snag basal area (m^2) and log volume (m^3) were calculated for each snag and log tree with diameter bigger than 7.5 cm. Log volume was estimated trough the equation (Lofroth, 1995): $V_i = (\pi^2 d_i^2)/8L$, where V: log volume (m^3/ha), d: diameter of each log (cm), L: transect's length, in our case 50 m. These individual basal area and volumes for each trees were totalled for each plot and plot values, scaled up to give a basal area and volume per hectare.

Mean diameter of logs, mean length, mean weight and mean decomposition status of logs measured in intensive inventory also were calculated.

On the other hand, different tree and stand variables were calculated, including species, total basal area for each species, trees per ha, quadratic mean diameter, dominant height, basal area and number of trees of dominant plot's species, number of small stems (trees with diameter< 7.5cm), site conditions (soil texture, soil organic matter, pH, soil type, altitude, stonyness, slope, exposure and radiation), climate characteristics (rainfall, maximum temperature, mean temperature, minimum temperature, dry months' rainfalls; (obtained using a digital climatic atlas for Iberian Peninsula (Ninyerola et al., 2005), and management forest conditions (harvest and thinning in the past 15 years).

Statistical methods

Firstly, a two step regression approach was used to model the presence of CWD. In the first step, an logistic model to predict the probability of presence of CWD in a specific plot was fitted to Pine and Oak stand, and in a second step, a linear model makes possible to quantify the snags in basal area (m^2/ha) terms and the logs in volume (m^3/ha) terms. Secondly, a linear model to estimate the carbon content for coarse woody debris on the ground (logs) was fitted with data from plots where intensive inventory was carried out.

Before obtaining the best logistic model of CWD and the rest of the linear models, a previous study of the variables was carried out. Correlation process, Principal Component Analysis, Discriminant Analysis, the Score variable selection in logistic regression and the stepwise variable selection in linear regression (probability of 0.05) became to prove the main characteristics of the variables and the main correlations. A similar set of independent variables, transformations and combinations were used for the two stands in the modelling process. Input parameters for this model were the variables that describe the development of the stand, site conditions variables, climate characteristics and management forest conditions. Species, soil texture, soil organic matter, pH, soil type, stonyness, slope and harvest and thinning in the past 15 years were considered categorical variables. The information obtained from applying the score and stepwise variable selection method was combined with an understanding of the biological mean of selected parameters. In the case of the linear model carbon content new variables were introduced. Mean diameter of logs, mean length, mean weight, decomposition classes of logs, species variable and its interactions with stand parameters were also tested.

The logistic model is of the form of Eq. 1, where P is the probability of the event modelled, in this case, the presence of coarse woody debris, that is bound between 1 (presence) and 0 (absence), α the intercept term, $\Sigma b_i X_i$, the linear combination of parameters b_i and independent variables X_i , and *e* is the base of natural logarithm.

$$P = \left(1 + e^{-(\alpha + \sum b_i X_i)}\right)^{-1} \qquad \text{[Eq. 1]}$$

Independent variables in the resulting logistic regression equations were used if significantly different from zero ($P \leq 0.05$). The goodness of fit was studied through the Hosmer and Lemeshow test (Hosmer et al., 1989) and the Akaike information criterion (Zhang et al., 1997). PROC LOGISTIC to SAS 8.1. statistical program was used in the process (SAS Institute Inc. 2001). The ROC curves of each model were used to compare the accuracy of different logistic regression models.

The linear component of this model allows us to quantify snags and logs abundance (in basal area and volume terms respectively) in those stands in which, on the basis of the logistic component, it is determined that there is snags or logs. The linear component tested is as follows (Eq. 2):

$$y = a_0 + \sum a_1 X_i \qquad \text{[Eq. 2]}$$

where y is BA_{snag} (basal area of snags in m^2/ha) or Vol_{logs} (volume of logs in m^3/ha). Tested X_i are QMD, the quadratic mean diameter (m), Ho, dominant height (m), N number of trees of stand (tress/ha), BA, basal area of stand (m^2/ha), BA_msp, basal area of dominant plot's species (m^2/ha), N_msp the number of trees of dominant plot's species (trees/ha), n, number of small stems (trees with diameter< 7.5cm) (trees/ha), S, slope (%), Alt, altitude (m), Exp, exposure, R, rainfall (mm), R_june, R_july, R_august, rainfall of june's, july's, august's month respectively (mm), MaxT, maximum temperature (°C), MeanT, mean temperature, (°C), MinT, minimum temperature, (°C) and Rad, radiation (10 kJ/(m^2*day*µm). a_0 and a_1 are parameters.

The joint model's adequacy two step regression approach was analyzed using the determination coefficient (Eq. 3), through the adjustment of a straight line between real value and predicted values (Eq. 4) and by calculating bias of the model (Eqs. 5 and 6) to determine the accuracy of the joint two-step model (Huang et al., 2003).

$$R^2 = 100 * \left(1 - \frac{S_e^2}{S_{BA_{ing}}^2}\right) \quad \text{[Eq. 3]}$$

Where $\boldsymbol{S_e^2}$ and $S_{BA_{ing}}^2$ are, respectively, the sample's variance of errors committed and the sample's variance in the dependent variable (basal area of snags).

$$actual = c_{10} + c_{11} predicted \quad \text{[Eq. 4]}$$

$$bias = \frac{\sum (actual - predicted)}{n} \quad \text{[Eq. 5]}$$

$$bias\% = 100 * \frac{\sum (actual - predicted)/n}{\sum predicted/n} \quad \text{[Eq. 6]}$$

In which, n is the number of observations, actual is the value of snags (basal area) or logs (volume) abundance observed, predicted is the value obtained by using the abundance linear model of snags (basal area) or logs (volume), while c_{10} and c_{11} are the parameters to adjust which, if equal to 0 and 1, respectively, demonstrate that the model is unbiased.

Again a linear model allows us to quantify carbon content of logs in those stands

$$y = a_0 + \sum a_i X_i \quad \text{[Eq. 2]}$$

where y is C_{logs} (carbon content in logs in %). Tested X_i are Species as dummy variable (1=Pine and 0=Oak), mean diameter of logs, mean length, mean weight and mean decomposition classes of logs, QMD, the quadratic mean diameter (m), Ho, dominant height (m), N number of trees of stand (tress/ha), BA, basal area of stand (m^2/ha), BA_msp, basal area of dominant plot's species (m^2/ha), N_msp the number of trees of dominant plot's species (trees/ha), n, number of small stems (trees with diameter< 7.5cm) (trees/ha), S, slope (%), Alt, altitude (m), Exp, exposure, R, rainfall (mm), R_june, R_july, R_august, rainfall of june's, july's, august's month respectively (mm), MaxT, maximum temperature (ºC), MeanT, mean temperature, (ºC), MinT, minimum temperature, (ºC) and Rad, radiation (10 kJ/(m^2*day*µm). Also, X_i are interaction between Species and main stand variables. a_0 and a_i are parameters.

Carbon model's adequacy was analysed using the determination coefficient and model goodness of fit was assessed using graphic and numeric analysis of the residuals (e_i) to assure assumptions of normality and homogeneity of variance.

RESULTS AND DISCUSSION

Two-step model to predict CWD abundance

A two-step model to predict CWD, snag and log, abundance has been developed. The proposed two-step model allows us to reach a joint model adequacy equal to 27.06% and 63.04% for snag and log in *Pinus* stand, respectively, and to 44.27 % for snag in Oak stands. Logs in Oak stands could not be developed.

Step I. Logistic Component.

In the case of the *Pinus* stands (table 3, Eq. 7), the final model showed a value for the Akaike information criterion equal to 79.832, and the Hosmer and Lemeshow test (Pr >0.5913) shows that there is no lack of fit. On the other hand, for *Quercus* stands (table 3, Eq. 8), the Akaike information criterion value is equal to 28.390 whereas the Hosmer and Lemeshow test also shows that there is no lack of fit (Pr >0.8058). The independent variables tested were the altitude, minimum temperature, soil texture (clay, silt, sandy) and presence of harvest and thinning operations in *Pinus* stands. Soil texture and presence of harvest and thinning operations variables were placed in the model using a variable dummy (clay text=1 if texture soil is clay, 0 otherwise; silt text=1 if texture soil is silt, 0 otherwise; and harvesting=1 if there is presence of harvest and thinning operations in *Pinus* stands, 0 otherwise). Basal area of dominant species was tested in *Quercus* stands. The threshold value, maximum percentage of correctly classified plots, were 0.60 for the two cases, *Pinus* and *Quercus* stands. These threshold values allow us to classify correctly 68.7 % of *Pinus* plots (sensitivity equal to 52.9 % and specificity equal to 84.8%) and 82.1 % of *Quercus* stands (sensitivity equal to 84.6% and specificity equal to 80.0 %). The area under ROC curve in CWD model logistic to *Pinus* stand is 0.7152 and 0.7640 to *Quercus* stands.

$$P = \left(1 + e^{-(-43.9984 + 2.5969 Alt + 0.4001 MinT + 4.6954 ClayText + 2.4785 SiltText + 2.5391 Harvesting}\right)^{-1} \qquad \text{Eq. 7}$$

$$P = \left(1 + e^{-(-3.5843 + 0.0479 BA)}\right)^{-1} \qquad \text{Eq. 8}$$

Step II. Linear Component.

For the two type of stands studied, a linear component that allows us to estimate snag basal area and log volume in the stand was fitted.

For *Pinus* stands, the final model for snags obtained (Eq. 9) shows an adjusted determination coefficient equal to 17.02%, and the final model for logs (Eq. 10), an adjusted determination coefficient equal to 45.09%. In the first case, BA of snags increases with decreases the BA of main species. In the second case, the volume of logs increases with increases the basal area of stand and when decreases the dominant height.

For *Quercus* stands, the snag's model (Eq. 11), shows an adjusted determination coefficient equal to 25.36%. In this case, BA of snag increases when decreases the rainfall in the month less favourable. It was impossible to fit a log model for *Quercus* stand, because our sample size (n=2) was too small to develop it.

Pinus stand

$$BA_{snags} = a_0 - a_1 BA\_msp \qquad \text{[Eq. 9]}$$

$$Vol_{\log s} = a_0 + a_1 BA - a_2 Ho \qquad \text{[Eq. 10]}$$

Quercus stand

$$BA_{snags} = a_0 - a_1 R\_July \qquad \text{[Eq. 11]}$$

In which BA_{snag} is the basal area of snags in m^2/ha and Vol_{logs} is the volume of logs in m^3/ha. BA_msp is the basal area of main species in m^2/ha, BA is the basal area of stand in m^2/ha, Ho is the dominant height in m, and R_july is the rainfall in july's month.

Validation of the Joint Model.

The model for snag in *Pinus* stands shows a joint determination coefficient equal to 27.06%, whereas the case of log in *Pinus* stand is equal to 63.04%. On the other hand, the model for snag in *Quercus* stands shows a joint determination coefficient equal to 44.3%.

The result of the fitted validation straight lines between real and predicted values shown that the independent term is not significatively different from zero, (being C_{10} equal to 0.02973 in *Pinus* Snags, 1.03845*10-15 in *Pinus* logs and -3.7927*10-16 in *Quercus* snags) and the slope is not significatively different from one in the three cases. So, the joint model does not show bias or lack of accuracy. The absolute bias for the snag and log in *Pinus* stand and was very low (-0.024 m^2/ha and 0 m^3/ha respectively) and for *Quercus* stand was 0 m^2/ha. In relative terms the snag and log bias is low (4%) in *Pinus* snag and (0%) in *Pinus* log and *Quercus* snag. However, additional data and validation is needed to help us reach a definitive CWD model for *Pinus* stand and *Quercus* stand.

Carbon content model

The final carbon content model for logs obtained (Table 4, Eq.12) shows a determination coefficient equal to 53.33% and an adjusted determination coefficient equal to 47.50%. Mean diameter of the logs (cm), Basal Area of the stand (m^2/ha) and species interaction with number of small stems (trees with diameter< 7.5cm) (trees/ha) variables were significant in the model. The carbon content for coarse woody debris in logs increases with increases the diameter of the logs, when increase the Basal Area of the stand and when there are small trees of *Pinus* sp. The presence of small trees of *Pinus* sp shows the small development of the stand, where any forest management has been yet carried out.

$$C_{\log s} = a_0 + a_1 m \log diam + a_2 BA - a_3 Sp * n \qquad \text{[Eq. 12]}$$

CONCLUSIONS

The dynamic of ecosystem presents periods with undisturbed natural growth interrupted by disturbances caused by natural hazards (e.g., fires, wind, ...) or human interference (e.g., thinning or pruning). These disturbances, either small scale gap either small scale gap perturbations or stand replacing catastrophic events, continuously replenish and create CWD (Hansen et al., 1991).

Forest management decisions are based on information about current and future forest conditions, so it is often necessary to project the changes of the system over time. Equations obtained modellized the presence of CWD and quantifying snags and logs parameters in northern of Spain. This area presents special characteristics and forest management. *Pinus* plantations are 40-50 years old and are managed to wood production by thinning. In the harvesting, dead trees have been object of cutting, maintaining only an average of 5 to 10 snags per hectare for the biodiversity, by the forest management normative in Castile and Leon region (Government regional of Castile and Leon Instructions, 1999). On the other hand, oak stands are a degraded forest by flogging, fire and low vigour coppice. Firewood harvesting have been carried out to improve the oak stands.

The two step model fitted predict accurately both snags and logs abundance in pine plantations and natural oak stands in Northern Spain. Results show the importance of CWD in Mediterranean forest ecosystems. Furthermore, although CWD of less than 10 cm in diameter accounts for an important fraction of total CWD, there is a notable lack of information on this type of CWD (Currie et al., in press), because most studies tend to focus on the larger pieces of woody debris.

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Table 1. Database characteristics used to develop the snag and log models for *Pinus* plantations and Oak stands in Northern Spain. N: Trees per ha, BA: basal area, QMD: Quadratic mean diameter and BA_{snags}: snags expressed as basal area, V_{logs}: logs expressed as volume

Variable	Mean	Minimum	Maximum	Standard deviation
***Pinus* stand (n = 67 plots)**				
N (trees/ha)	802.8	25.5	1584.5	341.3
BA (m^2/ha)	23.2	5.6	39.3	8.2
QMD (cm)	222.1	131.7	582.7	62.9
BA_{snags} (m^2/ha)	1.7	0.2	14.9	3.6
V_{logs} (m^3/ha)	3.3	1.4	11.8	3.9
***Pinus sylvestris* (n = 34 plots)**				
N (trees/ha)	807.4	1584.5	187.4	351.4
BA (m^2/ha)	24.8	39.3	9.1	7.8
QMD (cm)	219.7	283.5	147.1	31.9
***Pinus nigra* (n = 25 plots)**				
N (trees/ha)	914.9	1400.6	541.1	268.5
BA (m^2/ha)	21.5	36.1	6	8.0
QMD (cm)	195	308	132	42.6
***Pinus pinaster* (n = 8 plots)**				
N (trees/ha)	433.3	817.0	25.5	261.1
BA (m^2/ha)	21.9	32	5.6	10.4
QMD (cm)	317.0	582.7	213.7	115.6
***Quercus pyrenaica* (n = 28 plots)**				
N (trees/ha)	456.9	1479.9	0	501
BA (m^2/ha)	6.6	28.8	0	8.4
QMD (cm)	116.1	243.0	0	81.2
BA_{snags} (m^2/ha)	0.26	0.33	0.97	0.02
V_{logs} (m^3/ha)	0	0	0	0

Table 2. Database characteristics used to develop the carbon content model for logs in *Pinus* plantations and Oak stands in Northern Spain. N: Trees per ha, BA: basal area, QMD: Quadratric mean diameter, mlogDiam: mean diameter logs, mLengthlog: mean length logs, mWeightlog: mean weight logs.

Variable	**Mean**	**Minimum**	**Maximum**	**Standard deviation**
***Intensive inventory* with presence of logs (n = 30 plots)**				
N (trees/ha)	787.2	187.4	1585.0	347.1
BA (m^2/ha)	20.8	5.6	34.8	8.0
QMD (mm)	211.6	131.7	334.2	47.9
mlogDiam (cm)	1.7	1.2	2.8	0.4
mlogLength (m)	0.7	0.2	2.1	0.5
mlogWeight (g)	141.3	11.8	1038	201.4

Table 3. Logistic and lineal components of the snag models for *Pinus* stands and *Quercus pyrenaica* Willd. stands in Northern Spain. Altitude (m als), Minimum temperature (ºC), Clay Soil Texture, Silt Soil Texture, Sandy Soil Texture, Harvest and thinning operations, BA_main species: basal area of dominant species in the plot, m^2/ha, BA: basal area, m^2/ha, Ho: dominant height, m, July rainfall in mm.

Variables	**Estimate**	**Standard error**	**Pr >Chi-squared**
***Pinus* stand**			
	Logistic Component		
Independent term	-43.9984	16.7061	0.0084
Altitude	2.5969	1.0269	0.0114
Minimum temperature	0.4001	0.1696	0.0183
Clay Soil Texture	4.6954	1.9376	0.0154
Silt Soil Texture	2.4785	0.9836	0.0117
Sandy Soil Texture	0	.	.
Harvest and thinning operations	2.5391	0.7768	0.0011
Harvest and thinning operations	0	.	.
	Lineal Component for snag		
Independent term	8.60775	3.41676	0.0199
BA_main species	-0.08549	0.04119	0.0504
	Lineal Component for log		
Independent term	1.52226	2.83827	0.5976
BA	0.40998	0.10137	0.0006
Ho	-0.77458	0.30349	0.0190
Oak stands			
	Logistic Component		
Independent term	-3.5843	1.6198	0.0269
BA	0.0479	0.0187	0.0103
	Lineal Component for snag		
Independent term	1.98078	0.85502	0.0390
July rainfall	-0.00623	0.00308	0.0664

Table 4. Lineal components of the CWD carbon sequestration model for *Pinus* stands and *Quercus pyrenaica* Willd stands in Northern Spain. mlogDiam: mean diameter logs (cm), BA: basal area of stand, m^2/ha, Sp*n: Species interaction with number of small stems (trees with diameter< 7.5cm) (trees/ha).

Variables	**Estimate**	**Standard error**	**Pr >Chi-squared**
Independent term	-54.57405	0.60047	<0.0001
mlogDiam (cm)	0.61940	0.29964	0.0497
BA (m^2/ha)	0.03457	0.01692	0.0522
Sp*n (trees/ha)	-0.00032779	0.00013458	0.0227

Criterio 2: Mantenimiento de la Sanidad y Vitalidad Forestales.

Title:

Monitoring crown condition in poplar plantations

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Abstract

A study was carried out to improve the monitoring of crown condition in poplar stands. Crown transparency and discoloration were visually evaluated in 2857 trees from 34 poplar plantations, which were chosen according to a factorial scheme with three factors, namely tree age, quality site and understorey management. A subset of trees was also assessed using CROCO software, to compare visual and digital crown transparency estimates. Poplar crown transparency and discoloration declined with stand age. Crown conditions improved when the understorey vegetation was harrowed in poor sites but the opposite response was observed in rich sites. The mean values of crown transparency per stand, calculated from one or four plots of 15 m radius, did not differ significantly. Calibration curves of crown transparency estimates obtained with the CROCO software were successfully fitted with observed values for young and old poplar stands. Therefore, the use of CROCO software to estimate the crown transparency in ca. twenty trees is recommended to accurately and objectively survey the sanitary conditions of poplar plantations.

Keywords

Poplar, plantations, monitoring, crown condition, transparency, discoloration, forest health, CROCO.

1. Introduction

Forest health monitoring programs have been carried out in Europe since the 1980s within the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forest, ICP Forest (Level I European network). It comprised more than 6100 plots, on a 16 x 16 km grid, where tree crown conditions were annually assessed, and both crown transparency and crown discoloration were visually estimated on ca. 20 trees per plot.

However, the ability of such a systematic network to describe the real health condition of trees remains questionable, particularly for forests with small and fragmented areas (Ferretti, 1997). This is the case of poplar plantations, which cover about 800.000 ha in Europe and represent 0.39 % of European forests. Spain is the third European country in terms of poplar area after France and Italy (Ball *et al.*, 2005) with 100.000 ha. In Europe there are only 23 plots of *Populus* in the Level I Network, which represent 0.22% of all the plots (Lorenz *et al.*, 2005) Due to the reduced number of plots available, sanitary data are difficult to analyze in poplar plantations, at a time when their growing importance in rural development is acknowledged, and when new rules for sustainable management are required (Ball *et al.*, 2005).

One way to increase the number of monitored plots for the same sampling effort is to try to minimize the number of sampled trees per plot. Because poplar plantations are often monoclonal, protocols developed to assess sanitary conditions in other types of forest may not be relevant. In particular, as the variability of traits between trees is lower, one can assume that tree clones will be similarly damaged (Braganca *et al.*, 1998; Camps, 2001; Sierra, 2001) and that small samples of trees can be representative for the whole stand condition.

Another option to increase the reliability of sanitary assessment while keeping the sampling effort to a minimum is to develop automatic, standardized methods. Considerable effort has been devoted to improve the assessment of tree crown transparency and discoloration, as it is considered as an appropriate indicator of forest health (Ferretti, 1997). In the European Network Level I, these variables are visually estimated by observers from the ground, but due to the subjectivity of human assessment, data quality and comparability across countries have been questioned (Mizoue and Dobbertin, 2003). The sources of error in the quantitative assessment of crown condition are several, including the variation in the expertise of the observers, the weather conditions, crown appearance, tree species, age and social position (Innes *et al.*, 1993; Ghosh *et al.*, 1995; Solberg and Strand, 1999; Wulff, 2002; Redfern and Boswell, 2004). Such sources of error make it difficult to compare patterns between countries, and even across time within the same country. They may also mask the relationship between forest decline and explanatory factors such as pest pressure or site conditions. Researchers have tried to solve these problems; combining field and control team assessments (Ghosh and Innes, 1995), using data from cross-calibration courses to estimate correction factors for between countries differences (Innes *et al.*, 1993), using reference photographs (Solberg and Strand, 1999) or standard sets of two-dimensional silhouettes representing various degrees of foliage density (Frampton *et al.*, 2001).

Nevertheless, these improvements sometimes are not enough and proposals have been made to replace visual by digital assessment from the ground (Mizoue, 2002; Clark *et al.*, 2003; Sang-Mook *et al.*, 2003) or with remote sensing (Stone *et al.*, 2003; Coops *et al.*, 2004; Solberg *et al.*, 2004; Solberg *et al.*, 2005). In particular, Mizoue (2002) developed a semi-automatic image analysis system, called CROCO, to assess crown transparency from digital photographs. In CROCO an automatic thresholding algorithm is used to obtain crown silhouette images, where foliage and branches are transformed to black pixels and background sky to white pixels (Mizoue and Inoue, 2001). Then a fractal dimension (D) is computed, indicating how an object can fill the space, with a value of 0 for a white plane, a value of 1 for a black line and a value of 2 for a black plane, respectively. CROCO calculates two fractal dimensions to estimate the crown transparency of the tree silhouette (Ds) and outline (Do). DSO is calculated as the difference between Ds and Do indicating the index of crown transparency. DSO values decrease with increasing crown transparency.

The main objective of this study was therefore to refine a monitoring method to assess crown condition in poplar stands quantitatively and objectively. To achieve this objective the following questions need to be addressed:

1. Do site conditions and management practices have an effect on crown transparency and discoloration in poplar stands?

2. How far can be reduced the number of sampled trees for crown conditions to detect the same effects of site and management in poplar stands?
3. Can visual crown condition assessment be substituted by digital photo and CROCO estimates to detect the same effects of site and management in poplar stands?

2. Materials and methods

2.1. Site description and experimental design

The present study was carried out in Castile and Leon (Spain) where there are about 45000 ha of poplar plantations, the most common species grown is *Populus x euramericana* hybrid (*P.nigra* x *P.deltoides*).

Several clones are used but the clone I-214 is the most representative covering about 70 % of the total poplar plantation area (Fernández and Hernanz, 2004). The density of clonal poplar plantations is kept constant during the whole rotation, at about 278-400 stems/ha, according to the planting distance of 6x6 or 5x5 metres, respectively. Traditional management of poplar stands is only applied during the first six years of the plantation. Understorey vegetation is controlled with disc harrowing each year until canopy closure. All trees are pruned up to six meters from the ground level during the first six years, and are clear-cut at fourteen years.

The experimental design consisted on a factorial scheme with three factors: stand age (young stands of 3-7 years old or adult stands of 8-14 years old), quality site (rich site (quality 1 and 2) or poor site (quality 3 and 4), according to the quality site abacus developed for the *Populus x euramericana* clone I-214 in the river Duero basin (Bravo *et al.*, 1995) and understorey management (harrowed or not harrowed). Four I-214 clonal plantations as replicates of each factors combination were sampled. Two additional young and harrowed stands in rich site conditions were sampled to account for higher stand structure variability within this combination of factors. A total of 34 poplar stands were therefore sampled in the north of the Palencia province, within the Carrion river basin (from 346.405 to 366.495 and 4.686.275 to 4.712.381, latitude and longitude respectively).

2.2. Assessment of crown condition variables in poplars

In each stand, four circular subplots of 15 meters radius were monitored. These subplots were located 50 metres apart from each other, at the ends of cross located at the centre of the stand. Within each subplot all trees were marked and sampled. A total of 2857 poplar trees were assessed during the summer of 2005 (within the first two weeks of July). Crown transparency and discoloration were visually estimated, according to Level I European network methodology (Eichhorn *et al.*, 2006). Simultaneously, all trees were photographed using a digital photo camera of 8 mega pixels (EOS 350D, Canon), from the same position.

Subsequently, 7 trees with contrasted percentages of crown transparency were selected and photographed. Then the same crown images were analysed by one expert observer from the Spanish field crew of the European Level I network to provide an estimate of crown transparency.

A subset of 204 trees was also used to compare visual and digital crown transparency estimates. A total of 2857 trees from “young and poor”, “young and rich”, “adult and poor” and “adult and rich” stands were sorted according to crown transparency classes. Then one to four trees from each crown transparency class were randomly selected within each stand age and site condition combinations. Values of DSO index of crown transparency were calculated for the 204 trees selected using the CROCO method (Mizoue and Dobbertin, 2003). First, in each crown photograph a rectangular region of interest (ROI) was cut out, including the part of the crown exposed to the sunlight, but excluding the parts overlapping with adjacent trees. At the same time, the overlap rate (OR) was visually categorized into 8 classes (no overlap, 25, 50, 75, 100 % overlap on one side of the crown and 25, 50, 75 % overlap on both sides). Second, and automatic thresholding algorithm was applied to the blue-filtered grey scale image to generate a crown silhouette image. Finally, DSO values were calculated from the crown silhouette images using fractal analysis (Mizoue, 2001). Trees that overlapped have positively biased DSO values (underestimation of crown transparency). This was corrected using the simple linear regression model developed by Mizoue (2002). The corrected DSO provided an estimate of crown transparency, called Digital Crown Transparency (DCT). CROCO uses Scion Image for Windows (available for free at the http://www.scioncorp.com/) and image processing software (in this work was used Adobe Photoshop).

2.3. Statistical analysis

ANOVAs and Tukey's HSD post-hoc test were used after angular transformation (arcsin √(x)) (Peña, 2002) to test factors effects (stand age, quality site and understorey management) on percentage variables of Visual Crown Transparency (VCT), Visual Crown Discoloration (VCD) and Digital Crown Transparency (DCT). Wilcoxon paired tests were carried out to compare dependent variable values in the same stand but calculated from two sample sizes (all trees from 1 subplot vs. all trees from the 4 subplots). Finally, simple regression and ANCOVA were used to fit calibration curves of DCT against VCT and test for slope differences between stand ages and site conditions, respectively. All analyses were performed using Statistica 6.0 package (StafSoft, 2001).

3. Results

3.1. Effect of age, site condition and management on crown conditions of poplar trees

Visual crown transparency and visual crown discoloration values were significantly different between stand age, site quality and understorey management (Table 1). Crown conditions were always of poorer quality (higher VCT and VCD values) in poor than in rich sites (F=3103.39, p<0.0001 and F=2.247.44, p<0.0001 VCT and VCD respectively, Figures 1 and 2). Two double interactions, between site quality and stand age and between site quality and understorey management respectively were also significant, as well as the interaction between the three factors. This indicates that the pattern of crown conditions responded to both stand age and understorey management depending on site quality. Therefore rich and poor sites were considered separately to facilitate the interpretation of the patterns. In both site conditions, Tukey HSD tests revealed that crown conditions were not as good as in adult than in young stands, with an increment of both crown transparency and discoloration with age. By contrast, Tukey HSD tests revealed a different pattern on the effect of understorey management according to site quality. In rich sites, harrowing understorey vegetation resulted in a significant deterioration of crown condition (higher VCT and VCD values) whereas in poor sites the effect was the opposite, with an improvement of crown conditions in harrowed stands.

3.2. Effect of sample size on crown conditions estimation in poplar stands

Comparison of mean VCT and VCD values per stand calculated with data from one versus four subplots per stand did not show any significant differences (Table 2). Analyses of the variances for VCT and VCD mean values per stand (N=34), using the trees of the four subplots or only one subplot to calculate the mean values, showed exactly the same significant effects of the factors on dependent variable (Table 3). This indicates that sampling trees in only one subplot of 15m radius would deliver the same information on crown conditions in a poplar stand than sampling four times more trees (four subplots).

3.3. Ability of CROCO outputs to fit with visual assessment data and to detect driving factors of crown conditions in poplar

Based on a sample of seven trees selected along a linear gradient of crown transparency, ,the calibration curve between visual estimates (VCT values) and DSO values obtained with CROCO showed a good fit with a simple exponential regression ($R^2 = 0.96$, P=0.004) (Figure 3).

Likewise, the linear regression of VCT against DSO values in the sample of 204 trees was positive and highly significant. In the first ANCOVA, the interaction effect between stand age and VCT was significant (Table 4), indicating that the slopes of the regression lines between DSO and VCT differed significantly, i.e. the lines were not parallel. In the second ANCOVA with no interaction, the effect of stand age was significant (Table 5), indicating that the intercept were also different. By contrast the site quality factor had no significant effect alone or in interaction with VCT. It was therefore necessary to fit two regression models for young and adult stands respectively (Figure 4). Both regression models were linear and significant (young stands, $R^2 = 0.65$, $P < 0,0001$; adult stands, $R^2 = 0.59$, $P < 0.0001$).

4. Discussion

Several studies have analysed the effect of different factors, such as tree species, stand age and site condition on crown condition in trees (Innes, 1993; Solberg, 1999; Hendriks *et al.*, 2000; Klap *et al.*, 2000; Bussotti *et al.*, 2002). Stand age has often been considered as a factor affecting crown condition in trees, and particularly crown transparency. Hendriks and collaborators (2000) observed that crown transparency in oak and Scots pine significantly increased with tree age, however Innes (1993) could not confirm this relationship. Likewise, age was not a predictor variable of crown transparency in the Douglas fir (Hendriks *et al.*, 2000). In the present study it was observed a clear trend of increasing crown transparency with increasing age in clonal poplar plantations. Several reasons can explain this relationship, like changes in crown geometry. In particular elongation of branches, may give the feeling that the crown is more transparent (Metzger and Oren, 2001). The susceptibility of trees to biotic agents may be increased with age (Solberg, 1999), as well as stress factors such as drought or nutritional deficiency may cumulate their detrimental effect with age. Likewise, in this study results showed that crown conditions in poplar stands improved with site quality, which is corroborated by several authors (Ferretti, 1998; Solberg, 1999). It is likely that nutritional stress in poor quality sites had a detrimental effect on tree physiology, resulting in a proportional reduction of foliar biomass. The effect of forest management on crown conditions had never been studied in poplars. Our results showed that understorey harrowing, the main management practice in poplar plantations, had an effect on crown conditions and interacted with site quality. Crown transparency in poor sites was lower in the “harrowed” treatment than in the “not harrowed” treatment, whereas the pattern was opposite in rich sites. This fact could be due to the damage caused on secondary roots when the soil is harrowed; since poplar is capable of producing very dense root mats in the first 30 cm of soil (Newman, 1997). Rich sites are usually characterized by a small depth of the water table, and small roots are often superficial. The latter can be damaged by the disc harrow, resulting in a lower capacity to mobilize water and nutrients and therefore in a physiological tree stress. On the contrary, the water table is at a higher depth in poor sites and small tree roots are also often deeper. In this case the disc harrow would cause less injuries to these roots. Furthermore, understorey harrowing may reduce competition with trees for water and nutrient resources. Harrowing may also improve the soil structure and facilitate the incorporation of nutrients into the litter, thus resulting in a gain of stand fertility.

Crown discoloration seems to provide similar information than crown transparency (Table 1 and 3) but with additional limitations. Crown discolouration is known to be more difficult to be assessed objectively (Ferretti, 1998; Wulff, 2002), and more difficult to relate with stress factors (Hendriks *et al.*, 2000).

Different shapes and sizes of sample plot have been used in forest health surveys: four subplots of six trees located 25 m from a fixed point in Europe (Eichhorn *et al.*, 2006), four subplots spaced 36.6 m apart with a fixed radius by the FHM (Forest Health Monitoring) in U.S. (Zarnoch *et al.*, 2004) and one circular plot of 24 trees in Spain (SPCAN-DGCN, 2002). In this study there was no significant difference between the mean values of crown condition variables when calculated from one or four subplots of 15m radius. Moreover, mean values calculated from only one subplot were able to discriminate the same effect of driving factors than those computed from four subplots. Contrary to the results obtained by Innes and Boswell (1990) in Canadian forests, that demonstrated significant variations amongst the 4 subplots of the each plot, the assessment of only one subplot of fixed radius (exactly 15 metres, i.e. approximately 18 trees in plantations with planting distance 6 x 6 meters) seems to be sufficient to qualify forest health in poplar plantation. This discrepancy may be due to the higher homogeneity of the monoclonal plantations.

Once crown transparency was selected as an indicator to assess tree crown condition in poplars, our next aim was to tune up a methodology to assess it objectively. We used the CROCO methodology developed by Mizoue (2002) and with a sample of 7 trees of contrasted crown conditions, we obtained a highly significant correlation between visual crown transparency and DSO estimates (R^2 = 96.18 %). This value was similar to those obtained with a similar approach in other tree species such as Norway spruce (95.4 %), silver fir (97.1 %), Scots pine (95.1 %), larch (92.8 %), beech (99.9 %), pedunculate oak (99.3 %), sycamore (98.8 %) and ash (97.7 %) (Mizoue and Dobbertin, 2004). We could also successfully fit a significant linear model relating visual and digital crown transparency estimate in a larger sample of ca. 200 poplar trees. However, running an analysis of covariance on DSO values, we showed a significant interaction effect between stand age and visual crown transparency. This result demonstrates that the methodology previously proposed by Mizoue and Dobberttin (2003; 2004), which was based on only one calibration curve, may be not enough to assess the crown transparency in poplar plantations. As a consequence we developed two calibration curves of visual against digital crown transparency estimates for young (3-7 years) and adult (8-14 years) poplar stands respectively. With this precaution, the use of the CROCO software is therefore recommended to obtain an objective assessment of the crown transparency in poplar plantation. Problems due to the subjectivity of visual assessment will be solved, thus facilitating the investigation of biotic agents or abiotic factors responsible for changes in crown transparency (Hendriks *et al.*, 2000) and allowing comparison between surveys results across time (Mizoue and Dobbertin, 2003). It is possible that in the future, national forest surveys will have to include different data to document more variables than the traditional dendrometric features, such as soil, biodiversity, and health variables. In this context, the application of the CROCO methodology to assess tree crown transparency in twenty trees seems quite relevant because it is compatible with the sampling strategy in national forest inventories which is based on fixed radius plots and because it can be applied with no special expertise in tree pathology.

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Table 1. Analysis of variance of the crown condition variables to test for the effect of stand age, site quality and understorey management, in the complete sample of 2848 poplar trees.

	VCT			VCD		
Source	d.f.	F	p	d.f.	F	p
A	1	2829,05	0,000	1	1411,833	0,000
Q	1	3103,33	0,000	1	2247,444	0,000
M	1	53,69	0,000	1	12,700	0,000
A x Q	1	1270,46	0,000	1	1090,080	0,000
A x M	1	0,06	0,812	1	3,390	0,065
Q x M	1	336,71	0,000	1	87,258	0,000
A x Q x M	1	6,30	0,012	1	7,662	0,005
Error	2848			2848		

Note: A, stand age; Q, site quality; M, understorey management; VCT, visual crown transparency; VCD, visual crown discoloration

Table 2. Wilcoxon Paired comparison of mean VCT and VCD calculated from 1 vs. 4 subplots per poplar stand

	N	T	Z	p
VCT mean 4 subplot & VCT mean 1 subplot	34	269,0000	0,205480	0,837197
VCD mean 4 subplots & VCD mean 1 subplot	34	163,0000	0,624650	0,532201

Note: VCT, visual crown transparency; VCD, visual crown discoloration

Table 3. Analysis of variance of VCT and VCD mean values calculated with tree data from 4 subplots or 1 subplot to to test for the effect of stand age, site quality and understorey management.

	VCT						VCD					
	4 subplots			1 subplot			4 subplots			1 subplot		
Source	d.f.	F	p	d.f.	F	p	d.f.	F	p	d.f.	F	p
A	1	106,586	0,000	1	57,338	0,000	1	12,736	0,001	1	12,257	0,001
Q	1	121,195	0,000	1	83,210	0,000	1	22,207	0,000	1	23,379	0,000
M	1	2,259	0,144	1	3,634	0,067	1	0,138	0,712	1	0,143	0,708
A x Q	1	50,136	0,000	1	31,532	0,000	1	12,441	0,001	1	9,216	0,005
A x M	1	0,010	0,922	1	0,024	0,879	1	0,053	0,819	1	0,070	0,792
Q x M	1	12,926	0,001	1	6,913	0,014	1	0,912	0,348	1	1,192	0,284
A x Q x M	1	0,370	0,548	1	0,143	0,708	1	0,136	0,714	1	0,196	0,660
Error	26			26			26			26		

Note: A, stand age; Q, site quality; M, understorey management; VCT, visual crown transparency; VCD, visual crown discoloration

Table 4. Result of the analysis of covariance on the DSO values from 204 trees.

	d.f.	F	P
VCT	1	88,160	0,0000
A	1	7,909	0,0054
A x VCT	1	6,068	0,0146
Q	1	0,008	0,9269
Q x VCT	1	0,089	0,7646
Error	197		

Note: Factors: A, stand age; Q, site quality. Covariate: VCT, visual crown transparency

Table 5. Result of the analysis of covariance on the DSO values from 204 trees.

	d.f.	F	P
VCT	1	88,160	0,0000
A	1	7,909	0,0054
Q	1	0,008	0,9269
Error	197		

Note: Factors: A, stand age; Q, site quality. Covariate: VCT, visual crown transparency

Figure 1. Mean Visual Crown Transparency (VCT) values for each understorey management type in (a) rich and (b) poor sites.

Figure 2. Mean Visual Crown Discoloration (VCD) values for each understorey management type in (a) rich and (b) poor sites

Figure 3. Relationship between VCT values and DSO values obtained with CROCO from 7 trees of contrasted crown transparency.

Figure 4. Relationship between VCT values and DSO values obtained with CROCO in 204 adult or young trees.

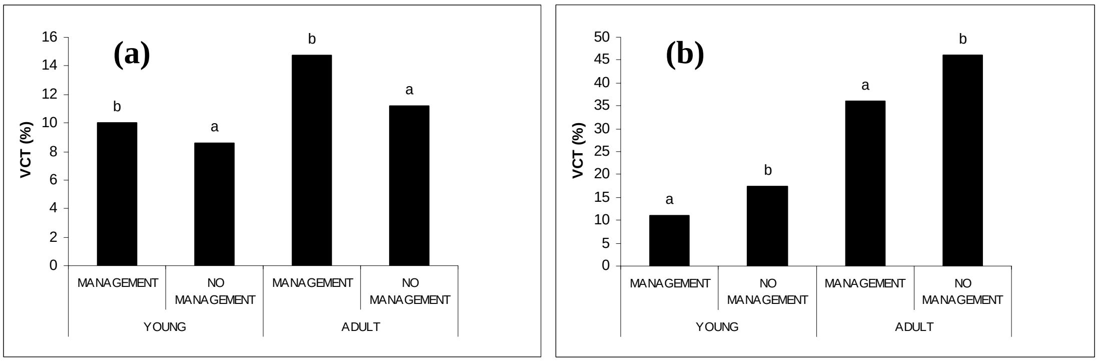
Authors:

J Martín-García*, J Hervé and JJ Diez

Title:

Monitoring crown condition in poplar plantations

Figure 1. Mean Visual Crown Transparency (VCT) values for each understorey management type in (a) rich and (b) poor sites.



Captions:

Within each age class, bars with different letters indicate significantly different means (Tukey’s post-hoc test).

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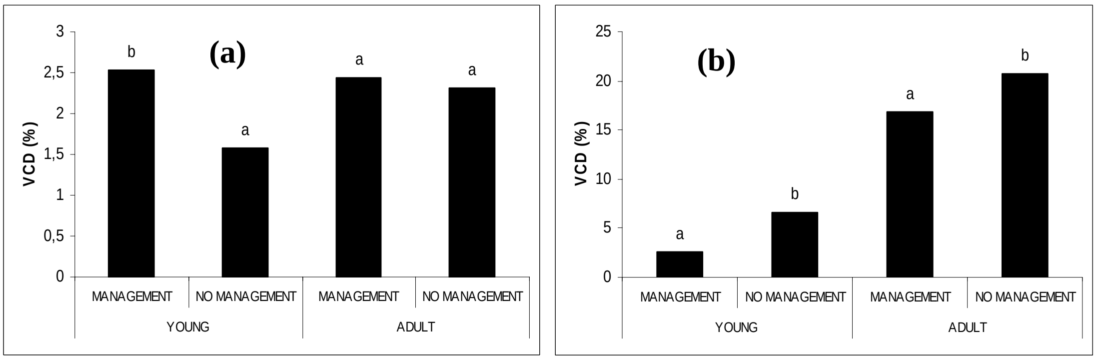

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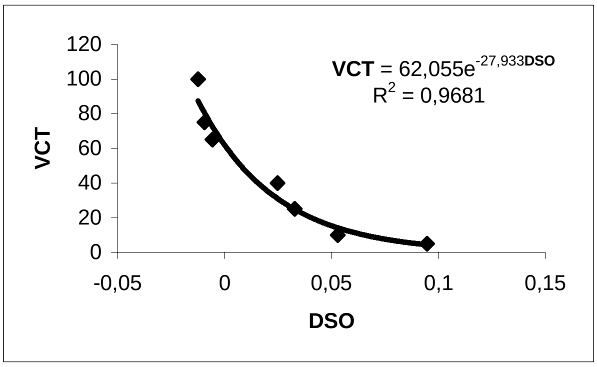


Captions:

VCT: Visual Crown Transparency, DSO: measure of crown transparency based on two fractal dimensions. CROCO: Semi-automatic image analysis system for crown condition assessment in forest health monitoring.

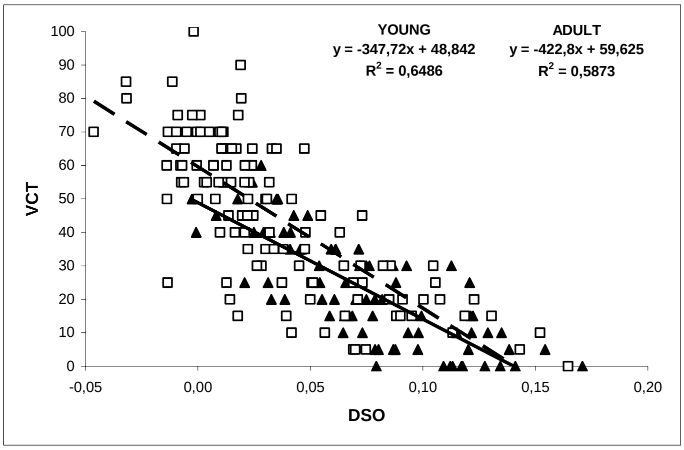
Authors:

J Martín-García*, J Hervé and JJ Diez

Title:

Monitoring crown condition in poplar plantations

Figure 4. Relationship between VCT values and DSO values obtained with CROCO in 204 adult or young trees.



Captions:

Open squares refer to adult trees with their regression fit (discontinuous line), filled triangles to young trees with regression fit (continuous line).

Criterio 4: Mantenimiento e incremento de la diversidad biológica

UTILIZACIÓN DE MÉTRICAS DE PAISAJE COMO SUSTITUTAS DE LOS ESTUDIOS DE AVIFAUNA EN INDICADORES DE BIODIVERSIDAD

1. INTRODUCCIÓN

En las últimas décadas, el concepto de gestión forestal sostenible (GFS) ha cobrado especial importancia entre la sociedad, los políticos y los científicos (Brang et al., 2002). Si bien, la definición y procedimiento para su evaluación fue ampliamente discutido en su origen (Brand, 1997), en la actualidad parece existir un amplio consenso en que la GFS debe ser evaluada mediante criterios e indicadores. De este modo, en la cuarta conferencia interministerial de Viena en 2003 se establecieron seis criterios (C1: mantenimiento e incremento de los recursos forestales y su contribución a los ciclos globales del carbono, C2: mantenimiento de la sanidad y vitalidad de los ecosistemas forestales, C3: mantenimiento e incremento de las funciones productivas de los bosques, C4: mantenimiento, conservación e incremento de la diversidad biológica, C5: mantenimiento e incremento de las funciones protectoras de los bosques y C6: mantenimiento de las funciones socio-económicas) y sus respectivos indicadores. Sin embargo, en ocasiones estos indicadores previamente propuestos no son suficientes para una correcta evaluación del criterio. Por ello el desarrollo de nuevos indicadores es una necesidad que los científicos deben solventar.

Numerosos científicos han trabajado en la búsqueda de nuevos indicadores para el criterio de biodiversidad, encontrando numerosos taxa (aves, carábidos, mariposas, plantas vasculares, etc) que pueden ser utilizados como indicadores (Hilty y Merenlender, 2000). Concretamente, las aves han sido ampliamente utilizadas como bioindicadores debido a que su ecología es bien conocida, sus comunidades se encuentran ligadas a los ecosistemas vegetales, y cubren varios niveles de la pirámide ecológica (Padoa-Schioppa et al., 2006). No obstante, los estudios de avifauna no cumplen algunos de los requisitos indispensables de un buen indicador, como son la obtención de los datos de un modo sencillo y rápido, a un coste efectivo y una interpretación simple e inequívoca (Old et al., 1999).

Los gestores forestales demandan de los científicos herramientas fiables y factibles para la evaluación de la biodiversidad, de modo que puedan obtener sencillas normas de manejo que puedan ser integradas en los instrumentos de ordenación. A este respecto, se conoce que las comunidades de aves (abundancia, riqueza y composición de especies) se encuentran muy ligadas a los cambios del paisaje (Griffis-Kyle y Beier, 2003).

Las nuevas técnicas de GIS han posibilitado el desarrollo de diferentes paquetes informáticos para la evaluación de métricas de paisaje, que permiten su caracterización a través del estudio de la fragmentación, la heterogeneidad y la conectividad. Entre ellos, FRAGSTATS (McGarigal et al., 2002) ha sido ampliamente utilizado por su facilidad de manejo y por calcular una amplia variedad de métricas que permiten categorizar los patrones espaciales de paisaje (Oja et al., 2005).

El principal objetivo de este estudio fue testar la utilidad de las métricas de paisaje como sustitutas de los estudios de avifauna como indicadores de biodiversidad, para lo cual se plantearon una serie de preguntas:

¿Las métricas de paisaje podrían explicar la riqueza real de especies de aves? ¿Cuál sería la escala idónea para el estudio del paisaje si la finalidad fuese determinar la riqueza de especies? ¿La riqueza de especies podría ser utilizada por el gestor forestal como un buen indicador para la conservación de la biodiversidad?

2. MATERIAL Y MÉTODOS

2.1. Área de estudio

El presente estudio ha sido llevado a cabo en las comarcas de Páramos y Valles, situadas en el tercio central de la provincia de Palencia (Castilla y León, España) (Figura 1), las cuales abarcan una extensión total de 186.642 ha, y representan una zona de transición entre tierra de campos y la Cordillera de Campos. El rango de altitud varía entre 800 y 1172 metros, siendo su clima Mediterráneo con cierta influencia Atlántica.

En la actualidad, la zona piloto posee una vocación eminentemente agrícola, con casi el 60 % de la superficie dedicada al cultivo. Por su parte la cobertura forestal es de 55.399,44 ha, la cual se encuentra caracterizada principalmente por repoblaciones de pinar de la década de los 60-70 (*Pinus sylvestris*, *P. nigra* y *P. pinaster*), por grandes rodales de rebollo (*Quercus pyrenaica*) y por plantaciones monoclonales del chopo *Populus x euramericana* (*P.nigra* x *P.deltoides*) que ha pesar de presentar una reducida extensión (3.536 ha), en la comarca constituyen un elevado porcentaje en la comunidad de Castilla y León, cifrada entorno a 45.000 ha, lo cual supone casi la mitad de la superficie dedicada a este cultivo en España (Fernández y Hernanz, 2004). Además, las plantaciones de chopo se encuentran en expansión debido a su gran rentabilidad, a la creciente demanda de madera de calidad de chopo para la industria del desenrollo.

Teniendo en cuenta estos condicionantes y que las plantaciones de chopo se encuentran ubicadas de modo disperso en los terrenos agrícolas más intensificados (como son los terrenos dedicados al regadío) se decidió llevar a cabo el estudio sobre este tipo de formación y concretamente sobre plantaciones del clon I-214 de *P* x *euramericana*, por representar este el 70 % de la superficie total de choperas en la región.

El diseño experimental consistió en un muestreo factorial con cuatro repeticiones y tres factores: edad de la parcela (jóvenes de 3-7 años o adultas de 8-14 años), calidad de estación (pobre; calidad I y II o rica; calidad III y IV), según las curvas de calidad desarrolladas para *P* x *euramericana* en la cuenca del Duero (Bravo et al., 1995), y manejo del sotobosque (parcelas gradeadas o no gradeadas), para tener representados el conjunto de las choperas.

Además, con la finalidad de comparar con otros tipos de hábitat, fueron seleccionadas otras tres formaciones: 4 parcelas de masas de pinar (*Pinus nigra*), 4 parcelas de rebollares (*Quercus pyrenaica*) y 3 parcelas de bosque de ribera autóctono (*Alnus* sp, *Betula* sp., etc)

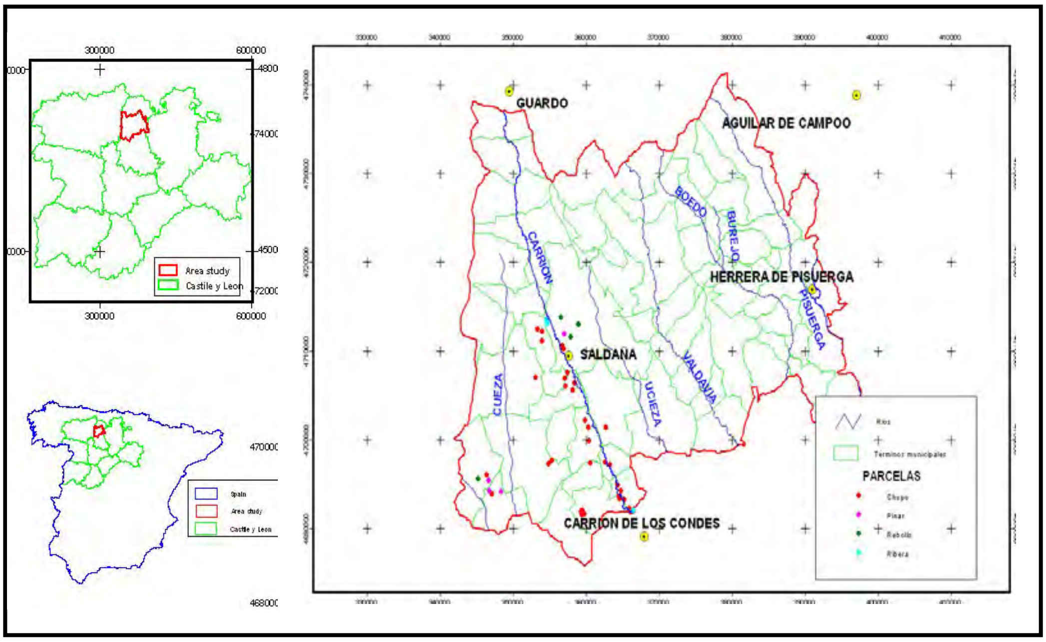


Figure 1: Localización del área de estudio y de las parcelas de muestreo.

2.2. Métodos de muestreo

Los muestreos de avifauna fueron llevados a cabo en verano 2005 y primavera 2006, mediante el método de conteo desde un punto fijo (Blondel et al., 1981). El observador se localizó en el centro de las parcelas y registró todas las aves escuchadas o vistas durante 20 minutos dentro de un periodo de tres horas después del amanecer y en días sin lluvia (Hobson y Bayne, 2000). Se registraron todas las especies identificadas sin límite de distancia, siempre y cuando se encontrasen en el interior del tipo de masa de la parcela. Cada macho cantando o pareja fueron puntuados con 1 y cada individuo avistado no cantando fue registrado con 0,5. Con estas puntuaciones se obtuvo un índice semicuantitativo con un rango de 0-5 (Barbaro et al., 2005). En los análisis estadísticos se excluyeron las especies que aparecieron en menos de tres parcelas y las que se registraron sobrevolando las parcelas.

2.3. Métricas de paisaje

Un mapa de usos del suelo fue desarrollado a partir del teselado de la zona de estudio mediante fotointerpretación de las ortofotos elaboradas en el año 2004, a una escala de 1:2000 y validación en campo. Se caracterizaron diferentes tipos de formaciones (choperas, masas de pinar, rebollares, bosques de ribera, setos lineales, improductivos, infraestructuras lineales, cultivos agrícolas, explotaciones agro-ganaderas (naves, vaquerías, etc) y núcleos urbanos).

El cálculo de las métricas de paisaje fue llevado a cabo utilizando FRAGSTATS 3.3 directamente desde ArcGis 9.1, aplicando el *script* Fragstatsbatch. Las métricas seleccionadas fueron área total de cada clase (CA), densidad de bordes (ED), número de teselas (NP), índice de la tesela más grande (LPI), distancia euclídea al vecino más cercano del mismo tipo de masa (ENN), índice de forma (SHAPE) e índice de Shannon (SHDI). Estas métricas fueron evaluadas a diferentes escalas de paisaje, 100, 200, 300, 500 y 1000 metros de radio alrededor de las parcelas seleccionadas.

2.4. Análisis estadísticos

Con la finalidad de determinar la escala o tamaño muestral óptimo de muestreo se llevaron a cabo en cada una de las escalas estudiadas (buffer 100, 200, 300, 500 y 1000 metros) regresiones múltiples mediante “stepwise” con un procedimiento de selección “forward” (F de entrada = 4.0 y F de salida =2.0; Díaz et al., 1998) desde el módulo GRM del paquete Statistica 6.0 (StatSoft, Inc., 2001), con el objetivo de buscar una combinación de métricas de paisaje, que lograsen explicar el mayor porcentaje de variabilidad de la riqueza de especies.

Una vez establecida la escala de paisaje óptima para el análisis, se desarrollaron dos modelos utilizando el mismo procedimiento de regresiones múltiples mediante “stepwise”. El primero de ellos con la totalidad de parcelas (representados los cuatro tipos de hábitats) y un segundo modelo desarrollado únicamente a partir de las parcelas localizadas en las plantaciones de chopo.

Un análisis canónico de correspondencias (CCA) fue utilizado para estudiar el efecto de las métricas de paisaje sobre las asociaciones de especies. La significación estadística de las variables ambientales, en este caso las métricas del paisaje, fue testada mediante un test de Monte-Carlo con 499 permutaciones. Para ello, se utilizó el software CANOCO 4.5 (ter Braak y Smilauer, 2002) aplicando la opción de infravaloración de las especies raras (“*Downweighting of rare species*”)

3. RESULTADOS Y DISCUSIÓN

Un total de 72 especies de aves fueron registradas durante los dos censos en el conjunto de parcelas, de las cuales solamente 53 fueron utilizadas en los análisis estadísticos (Tabla 1). Las especies más abundantes fueron pinzón vulgar (*Fringilla coelebs*), mosquitero común (*Phylloscopus collybita*), mirlo común (*Turdus merula*), paloma torcaz (*Columba palumbus*), corneja negra (*Corvus corone*), mosquitero papialbo (*Phylloscopus bonelli*), bisbita arboreo (*Anthus trivialis*) y cuco común (*Cuculus canorus*). La mayoría de las especies fueron generalistas, siendo muy frecuentes en hábitats de lo más diverso, desde las extensas masas de pino marítimo de las landas de aquitania, Francia (Barbaro et al., 2005) hasta paisajes agrícolas del Reino Unido (Paquet et al., 2006).

Tabla 2: Listado de especies censadas en los dos muestreos (primavera-verano)

Nombre científico	Nombre común	Nombre científico	Nombre común
Accipiter Gentilis	Azor	*Luscinia magarhynchos**	Ruiseñor común
Acrocephalus scirpaceus	Carricero común	*Miliaria calandra**	Triguero
*Aegithalos caudatus**	Mito	*Milvus migrans**	Milano negro
*Alauda arvensis**	Alondra común	*Motacilla alba*	Lavandera blanca
*Anthus campestris**	Bisbita campestre	*Motacilla flava*	Lavandera boyera
*Anthus trivialis**	Bisbita arbóreo	*Muscicapa striata**	Papamoscas gris
Apus apus	Vencejo común	*Oriolus oriolus**	Oropéndola
*Buteo buteo**	Ratonero común	*Parus ater**	Carbonero garrapinos
*Carduelis cannabina**	Pardillo común	*Parus caeruleus**	Herrerillo común
*Carduelis carduelis**	Jilguero	*Parus cristatus**	Herrerillo capuchino
*Carduelis chloris**	Verderón común	*Parus major**	Carbonero común
*Certhia brachydactyla**	Agateador común	*Passer domesticus**	Gorrión doméstico
*Cettia cetti**	Ruiseñor bastardo	*Passer montanus**	Gorrión molinero
*Coccothraustes coccothraustes**	Picogordo	*Phylloscopus bonelli**	Mosquitero papialbo
*Columba palumbus**	Paloma torcaz	*Phylloscopus collybita**	Mosquitero común
Corvus corax	Cuervo	*Phylloscopus trochilus*	Mosquitero musical
*Corvus corone**	Corneja negra	*Pica pica**	Urraca
*Coturnix coturnix**	Codorniz	*Picus viridis**	Pito real
*Cuculus canorus**	Cuco	*Prunella modularis*	Acentor común
Galerida cristata	Cogujada común	*Regulus ignicapillus**	Reyezuelo listado
*Dendrocopus major**	Pico picapinos	*Remiz pendulinus*	Pájaro moscón
*Emberiza cia**	Escribano montesino	*Saxicola torquata**	Tarabilla común
*Emberiza cirlus**	Escribano soteño	*Serinus serinus**	Verdecillo
*Emberiza citrinella**	Escribano cerillo	*Streptopelia turtur**	Tórtola común
Emberiza hortulana	Escribano hortelano	*Sylvia atricapila**	Curruca capirotada
*Erithacus rubecula**	Petirrojo	*Sylvia borin**	Curruca mosquitera
Falco tinnunculus	Cernícalo vulgar	*Sylvia cantillans*	Curruca carrasqueña
*Ficedula hypoleuca**	Papamoscas cerrojillo	*Sylvia communis**	Curruca zarcera
*Fringilla coelebs**	Pinzón vulgar	*Sylvia hortensis*	Curruca mirlona
*Garrulus glandarius**	Arrendajo	*Sylvia melanocephala*	Curruca cabecinegra
*Hippolais polyglotta**	Zarzero común	*Sylvia undata**	Curruca rabilarga
Jynx torquilla	Torcecuello	*Troglodytes troglodytes**	Chochín
Lanius collurio	Alcaudón dorsirrojo	*Turdus merula**	Mirlo común
*Lanius senator**	Alcaudón común	*Turdus philomelos**	Zorzal común
Loxia curvirostra	Piquituerco	*Turdus viscivorus**	Zorzal charlo
*Lullula arborea**	Totovía	*Upupa epops**	Abubilla

* Especies utilizadas en los análisis estadísticos

La capacidad de dispersión entre taxa fue muy variada (Atauri et al., 2001), por ello fue necesario fijar una escala o tamaño muestral óptimo de análisis (Oja et al., 2005). En el área de estudio, el paisaje presente en un buffer de 200 metros fue el más influyente en la riqueza de especies de aves, ya que las métricas de paisaje de este buffer fueron las que explicaron un mayor porcentaje de variabilidad de la riqueza de especies (Figura 2). Por otro lado, los modelos obtenidos para cada uno de los tamaños de buffer analizados presentaron prácticamente las mismas métricas de paisaje como variables predictoras, lo cual indica que la obtención de un modelo mixto mezclando métricas de distintas escalas de paisaje no permitiría mejorar el modelo, por lo que el análisis del paisaje de un buffer de 200 metros podría considerarse suficiente.

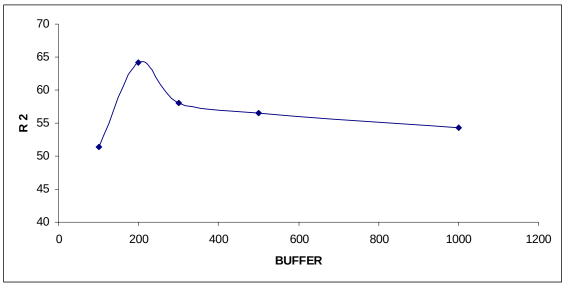


Figura 2: Variabilidad explicada por las métricas de paisaje en los distintos buffers.

El modelo obtenido a partir de métricas de paisaje para el conjunto de parcelas, es decir para los cuatro tipos de hábitats, consiguió explicar casi un 65 % de la variabilidad de la riqueza de especies utilizando cinco variables predictoras (número de explotaciones agroganaderas, superficie ocupada por *Quercus* sp, superficie de bosques riparios, número de setos y densidad de bordes de los setos) (Tabla 2). El porcentaje de variabilidad explicado es similar al obtenido en otros estudios (Parish et al., 1994; Barbaro et al., 2005). Sin embargo, en estos trabajos los modelos obtenidos presentaban mayor número de variables predictoras y mezclaban variables de paisaje con variables de estructura de masa, lo cual está demostrado que incrementa notablemente la variabilidad explicada (Heikkinen et al., 2004).

Tabla 3: Modelo de regresión para el conjunto de parcelas.

	Parámetro estimado	**Coeficiente estandarizado**	**P valor**
Constante	**14,192**	**0**	**< 0,0001**
Nº explotaciones agro-ganaderas	**5,586**	**0,339**	**0,0016**
Área de Quercus	**0,721**	**0,416**	**0,0002**
Área bosques riparios	**1,161**	**0,597**	**< 0,0001**
Nº de setos	**- 0,534**	**-0,331**	**0,0321**
Densidad de bordes de setos	**0,091**	**0,761**	**< 0,0001**
	R2 = 63,65 % (p < 0,0001)		

Por otro lado el modelo obtenido, además de presentar un buen ajuste, tiene sentido ecológico (problema que se le suele achacar a la utilización de procedimientos de selección basados en regresiones por “stepwise” (Heikkinen et al., 2004)), ya que las métricas de paisaje seleccionadas se encuentran asociadas a bosques de *Quercus* sp. y de ribera, setos y áreas con influencia humana. Si bien, el modelo no recoge métricas asociadas a dos tipos de formaciones, como son los pinares y las choperas. Las razones pueden ser bastante diferentes, mientras que en los pinares podría deberse a que su baja riqueza de especies (una media de 15 especies) se encuentre explicada por la constante del modelo (cuyo valor es 14). En las choperas la razón podría ser que el tamaño de la chopera no influyera en la riqueza de especies, sino únicamente su presencia. Así, Griffis-kyle y Beier (2003) demostraron que la presencia de rodales de *Populus tremuloides* en el interior de masas de pinar incrementaban la riqueza de especies, pero al testar diferentes tamaños (rango de 0,1 a 128 ha) observaron que el tamaño de los mismos no tenía ningún efecto. Sin embargo, en nuestro estudio esto no puede ser corroborado al no tener parcelas de muestreo sobre terrenos agrícolas sin presencia de choperas.

El modelo obtenido a partir de métricas de paisaje utilizando únicamente las parcelas de chopo, explicó el 56 % de la variabilidad de la riqueza de especies. Esta cifra es algo inferior a la obtenida para el conjunto de las parcelas, pero debe destacarse que este modelo únicamente introduce tres variables predictoras (número de explotaciones agroganaderas, número de setos y densidad de bordes de los setos) (Tabla 3). Dos de ellas referentes a los setos (número de setos y densidad de bordes), lo cual demuestra la importancia de este tipo de formación respecto a la riqueza de especies de aves en los paisajes agrarios (Parish et al., 1994; Hinsley et al., 1995; Sparks et al., 1996; Fuller et al., 2001).

Tabla 4: Modelo de regresión para las parcelas localizadas en las plantaciones de chopo.

	Parámetro estimado	**Coeficiente estandarizado**	**P valor**
Constante	**13,814**	**0**	**< 0,0001**
Nº explotaciones agro-ganaderas	**5,709**	**0,427**	**0,0017**
Nº de setos	**-0,505**	**-0,348**	**0,0479**
Densidad de bordes de setos	**0,094**	**0,861**	**< 0,0001**
	R2 = 56,16 % (p < 0,0001)		

La densidad de bordes fue la variable más influyente en el modelo (coeficiente estandarizado 0,861, respecto a 0,427 y -0,348 del número de explotaciones agroganaderas y número de setos, respectivamente), presentando una correlación positiva. Sin embargo, la relación densidad de bordes de setos-riqueza de especies no fue lineal, sino que tendió al estancamiento (Figura 3), lo cual parece contradecir la regla general "bigger hedges, more birds" (mayores setos, más aves) (Hinsley y Bellamy, 2000).

Un análisis de la varianza (ANOVA) fue utilizado para detectar diferencias de riqueza de especies en función de la densidad de bordes de setos, para ello se procedió a agrupar las parcelas en tres categorías (0-40, 40-80 y >80 m/ha). El resultado de este análisis mostró que la riqueza de especies se incrementó hasta la densidad de 40-80 m/ha, momento a partir del cual se produjo la estabilización (Figura 4). Este resultado parece indicar que una densidad de bordes de setos de 40-80 m/ha podría ser el óptimo, cifra similar a los 52 m/ha obtenidos por Padoa-Schioppa y colaboradores (2006), y bastante superior a los 16 m/ha apuntados por Fuller y colaboradores (2001) en paisajes agrarios de Italia y Reino Unido, respectivamente. Por otro lado, en este estudio no se percibió una disminución de la riqueza de especies con altos valores de densidad de bordes de setos (O'Connor, 1984; Padoa-Schioppa et al., 2006).

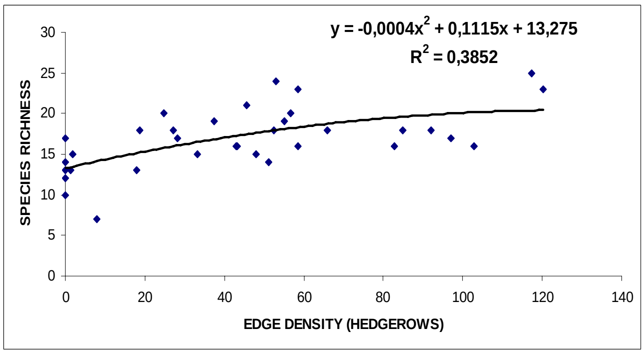


Figure 3: Regresión simple entre la riqueza de especies y la densidad de bordes de setos

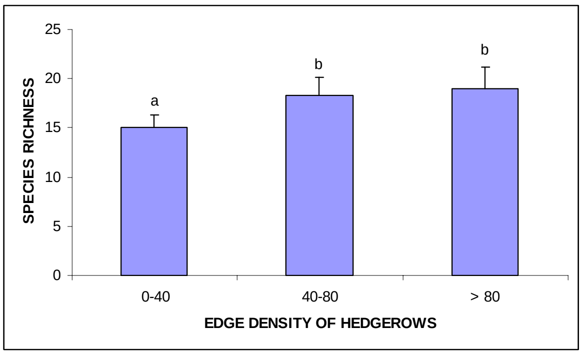


Figure 4: Diferencias en la riqueza de especies en función de la densidad de bordes de setos

El número de setos presentó una correlación negativa con la riqueza de especies (Tabla 3), esto podría deberse a que los setos actúan como corredores de hábitats fragmentados (Bellamy y

Hinsley, 2005) y por lo tanto cuando estos no mantienen su continuidad no presentan los beneficios propios de los corredores (Davies y Pullin, 2006-2007).

Las variables de paisaje en la ordenación por análisis canónico de correspondencias (CCA) explicaron con los dos principales ejes el 51,9 % de la variación en la distribución de las especies de aves (Figura 4), resultado superior a los valores obtenidos en otras investigaciones (Griffis-Kyle y Beier, 2003; Paquet et al., 2006). El primer eje estuvo correlacionado positivamente con la superficie de pino y roble y negativamente con la densidad de bordes de setos y superficie de choperas (test de Monte Carlo, P=0,01). El segundo eje estuvo positivamente correlacionado con la superficie y densidad de bordes de los bosques riparios y negativamente con la superficie de cultivos, número de explotaciones agroganaderas y densidad de bordes de núcleos urbanos (test de Monte Carlo, P=0,01). De este modo, cuatro tipos de asociaciones de especies fueron agrupadas con diferentes métricas de paisaje.

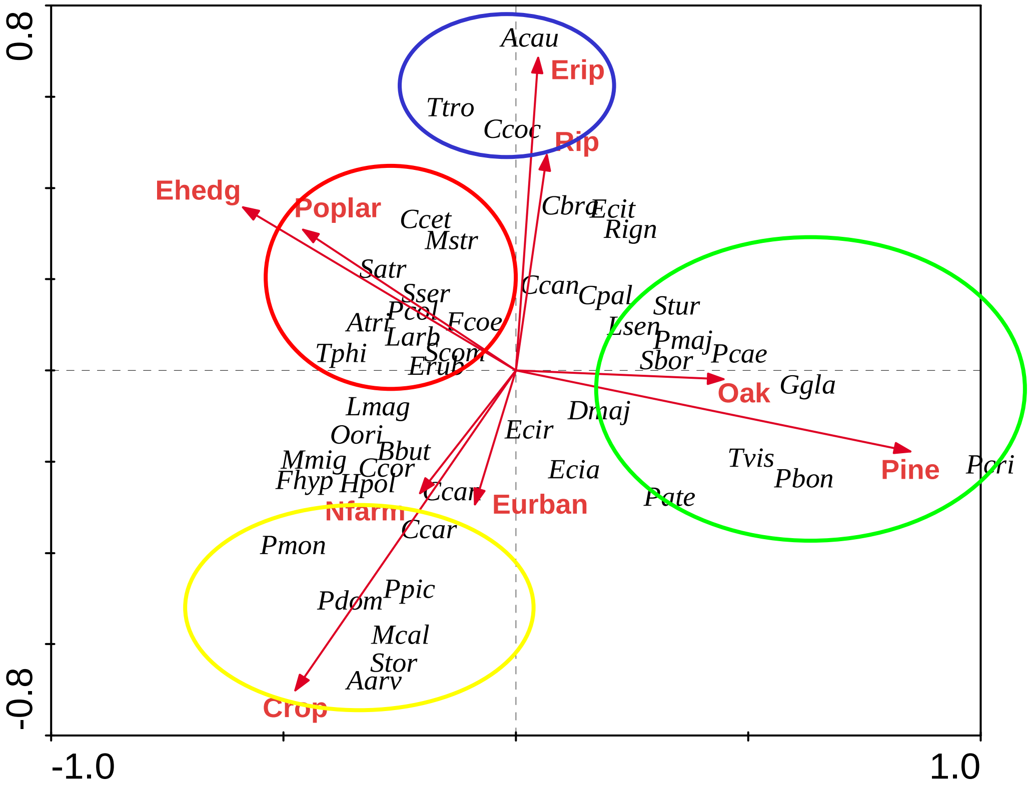


Figure 5: Ordenación de las especies de aves en relación a las métricas de paisaje. Las especies se encuentran codificadas por la primera letra del género y las tres primeras de la especie. Las flechas representan la dirección e importancia de las métricas de paisaje. Erip: densidad de bordes de los bosques riparios, Rip: Superficie de los bosques riparios, Oak: superficie de los robledales, Pine: superficie de los pinares, Eurban: densidad de bordes de las áreas urbanas, Crop: superficie de cultivos agrícolas, Nfarm: número de explotaciones agro-ganaderas, Ehedg: densidad de bordes de setos, Poplar: superficie de plantaciones de chopos.

Por un lado, las especies asociadas a la superficie de pinar y robledal fueron herrerillo capuchino (*Parus cristatus*), mosquitero papialbo (*Phylloscopus bonelli*), arrendajo (*Garrulus glandarius*) y zorzal charlo (*Turdus viscivorus*). Un segundo grupo de especies, alondra (*Alauda arvensis*), triguero (*Miliaria calandra*), gorrión doméstico (*Passer domesticus*), gorrión molinero (*Passer montatus*) y urraca (*Pica pica*), se encontraron asociadas a paisajes agrícolas o áreas de influencia humana. Por otro lado, las especies más generalistas como mosquitero común (*Phylloscopus collybita*), pinzón vulgar (*Fringilla coelebs)*, bisbita arboreo (*Anthus triviales*) o curruca capirotada (*Sylvia atricapilla*), se encontraron ligadas a la superficie de choperas y a la densidad de bordes de los setos. Finalmente, un pequeño grupo de especies como el mito (*Aegithalos caudatus*), chochin (*Troglodytes troglodytes*) y picogordo (*Coccothraustes coccothraustes*) mostraron una gran preferencia por áreas con presencia de bosques riparios (representadas por las métricas de paisaje superficie y densidad de bordes de bosques de ribera).

Si se observa la Figura 5, se puede apreciar que las métricas de paisaje; superficie de choperas y densidad de bordes de setos se encuentran situadas entre las métricas asociadas a los bosques de ribera y las métricas asociadas a paisajes agrícolas o de influencia humana. Esto podría indicar que las choperas y los setos actúan como un paisaje de transición, disminuyendo el efecto borde generado de un brusco cambio entre dos tipos de hábitats tan marcado (Gregory et al., 1991). A su vez estas formaciones proveen alimento a especies especialistas de terrenos agrarios (semillas de malas hierbas, invertebrados, etc), que por encontrarse en un entorno tan intensificado como el paisaje agrícola del área de estudio (escasa diversidad de cultivos, intensificación de las explotaciones, continua aplicación de fertilizantes y productos fitosanitarios, etc), actúan como verdaderas islas.

Finalmente apuntar que los resultados obtenidos en el CCA nos indican que las choperas y setos no deberían ser considerados como alternativas a los otros tipos de hábitats, sino como un complemento, ya que albergan un tipo de especies generalistas (Fuller et al., 2001).

4. CONCLUSIONES

En este estudio se ha demostrado la influencia del paisaje respecto a la riqueza y asociaciones de especies de aves, aconsejando el estudio del paisaje en un buffer de 200 m, considerado como el óptimo de muestreo, como una alternativa a los tediosos y costosos censos de avifauna.

En los paisajes agrarios la presencia y características de los setos es fundamental para la avifauna, así en el área de estudio se propone mantener una densidad mínima de bordes de 60 m/ha, con la mayor continuidad posible.

Sin embargo, los setos deben utilizarse como un complemento a otros tipos de hábitats pero nunca como una alternativa, ya que albergan principalmente especies generalistas. De este modo, el mantenimiento y recuperación de bosques riparios debe ser un objetivo irrenunciable para el gestor forestal.

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