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.

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SECUESTRO DE CARBONO EN NECROMASA EN PLANTACIONES DE PINO Y RODALES DE ENCINOS EN EL NORTE DE ESPAÑA

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 (De Bell *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).

OBJECTIVES

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.

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 masl. This region is located unevenly between the following UTM coordinates 342.000 to 4.685.000, and 398.000 to 4.741.000 (Figure N° 1), and its area is about 186,617.4 hectares. The climate is Mediterranean with a slight Atlantic influence.

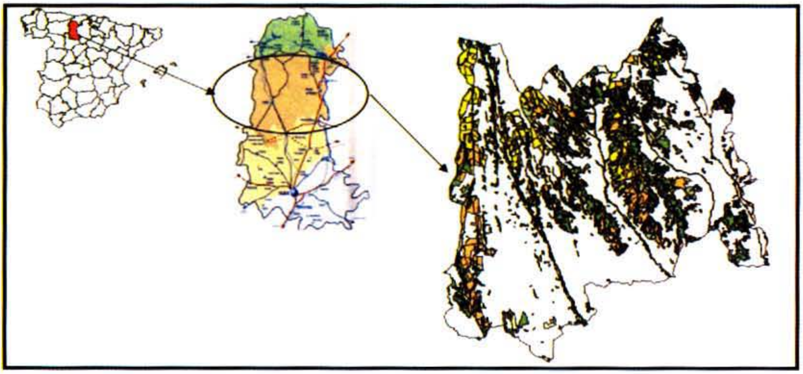

Figure N° 1
LOCALIZATION OF STUDY AREA

Forests cover is 59,471.1 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 cm 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 1 m 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 550 ºC oven.

Table 1
DATABASE CHARACTERISTICS USED TO DEVELOP THE SNAG AND LOG MODELS FOR PINUS PLANTATIONS AND OAK STANDS IN NORTHERN SPAIN

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

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

Table 2
DATABASE CHARACTERISTICS USED TO DEVELOP THE CARBON CONTENT MODEL FOR LOGS *IN PINUS* PLANTATIONS AND OAK STANDS IN NORTHERN SPAIN

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

N: Trees per ha, BA: basal area, QMD: Quadratic mean diameter, mlogDiam: mean diameter logs, mLengthlog: mean length logs, mWeightlog: mean weight logs.

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 tree 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< 7.5 cm), 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 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 : 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 (ºC), MeanT, mean temperature, (ºC), MinT, minimum temperature, (ºC) 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:

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).

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

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

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

Where:

N: number of observations

Actual: 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)

c_{10} and c_{11}: 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: 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 (m²/ha), BA_msp, basal area of dominant plot's species (m²/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/(m²*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 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 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.

Table 3
LOGISTIC AND LINEAL COMPONENTS OF THE SNAG MODELS FOR *PINUS* STANDS AND *Quercus pyrenaica* WILLD. STANDS IN NORTHERN SPAIN

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

Altitude (masl), 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.

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.

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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

Altitude (masl), 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.

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

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

Step II. Linear Component.

For the two type of stands studied, a linear component that allows 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 the sample size (n=2) was too small to develop it.

Pinus stand

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

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

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 numb[illegible] of small stems (trees with diameter< 7.5 cm) (trees/ha) variables were significant in the mod[illegible] The carbon content for coarse woody debris in logs increases with increases the diamete[illegible] the logs, when increase the Basal Area of the stand and when there are small trees of *Pinu[illegible]* The presence of small trees of *Pinus* sp shows the small development of the stand, where a[illegible] forest management has been yet carried out.

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

Table 4
LINEAL COMPONENTS OF THE CWD CARBON SEQUESTRATION MODEL FOR *PINUS* STANDS AND *QUERCUS PYRENAICA* WILLD STANDS IN NORTHERN SPAIN

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

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).

CONSLUSIONS

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 has 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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