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Original article

Aboveground biomass in a beech forest and a Scots pine plantation in the Sierra de la Demanda area of northern Spain

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Summary – The aboveground biomass of a mature beech forest (*Fagus sylvatica* L) and of a Scots pine (*Pinus sylvestris* L) was estimated by cutting and weighing seven trees from each site according to their diameter classes, recording the categories of trunk, branches and leaves. The carbon and nitrogen contents in the different fractions were also analyzed. The results indicate a total biomass of 152.1 mg ha^{-1} in the pine forest and 134.2 mg ha^{-1} in the beech forest, and litter fall was 5 791 kg ha^{-1} in the pine forest and 4 682 kg ha^{-1} in the beech forest. The percentage distribution of biomass weight of the trunk, branches and leaves was similar in both forests, and the carbon/nitrogen (C/N) ratio was greater in the pine forest fractions, particularly in those more lignified. The higher biomass according to diameter classes in the beech forest seems to indicate that it would not be very suitable to reforest land that is apropriate for beech with pine.

aboveground biomass / forest ecosystems / *Fagus sylvatica* / *Pinus sylvestris* / litter fall

Résumé – Biomasse forestière d'une hêtraie et d'une pinède en Sierra de la Demanda au nord de l'Espagne. On a estimé la biomasse forestière dans une hêtraie (*Fagus sylvatica* L) et dans une pinède (*Pinus sylvestris* L) par coupe et pesée de sept arbres dans chaque peuplement selon la distribution des diamètres. Le poids des troncs, branches et feuilles a été mesuré. Le contenu de carbone et d'azote a été analysé dans les différents compartiments. Les résultats indiquent une biomasse totale de 152,1 Mg ha^{-1} dans la pinède et 134,2 Mg ha^{-1} dans la hêtraie, et la chute de litière a été 5 791 kg ha^{-1} dans la pinède et 4 682 kg ha^{-1} dans la hêtraie. Les pourcentages de poids du tronc, branches et feuilles sont similaires dans les deux forêts, et la relation C/N est supérieure dans les compartiments de la pinède, surtout dans les compartiments ligneux. En comparant les biomasses en relation avec les classes de diamètres qui sont beaucoup plus importantes dans la hêtraie, on peut penser qu'il n'est pas opportun de reboiser en pin sylvestre dans l'aire potentielle de la hêtraie.

biomasse forestière / écosystèmes forestiers / *Fagus sylvatica* / *Pinus sylvestris* / chute de litière

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INTRODUCTION

Carbon and energy transfer in forests is basically determined by the primary producers (Lemée, 1974; Margalef, 1980). The increase in biomass coming from primary net productivity (NP) or apparent photosynthesis (Lemée, 1974) is what remains for the different throphic levels.

The primary NP of forest vegetation is subject to external environmental factors such as soil and climate, and to inherent factors such as age and the kind of tree cover (Santa Regina et al, 1991). Plants retain a substantial part of their production in perennial structures (trunks, branches, roots, etc) for which nutritive elements form the mineralomass of the phytocenosis (Duvigneaud, 1967).

Whittaker and Likens (1973) established a general relationship between the aerial biomass of the wood and its primary NP, enabling a comparison among the different productivities of various populations of plants (Stanek and State, 1978). It is also important to study carbon and nitrogen, both as regards the distribution of these elements within (ie, structural) and among (ie, compositional) community types since they affect the development processes and pathways of the ecosystem (Ohmann and Grigal, 1985).

The aim of the present work was to compare certain structural characteristics in a climax beech forest with that of a pine stand planted on a typical beech forest site. To do so, we report on the regression equations employed for estimating trunk, branches, leaves and total aboveground biomass.

MATERIALS AND METHODS

The experimental site is located in the Sierra de la Demanda mountains in the province of Burgos and Logroño in northern Spain. The topography is mountainous and its paleozoic massif is located on the northwest flank of the Central Iberian Range. Its coordinates are 42°20'N, 4°10'E.

The climate in the study area is attenuated meso-Mediterranean and becomes sub-Mediterranean with increasing altitude (1 000 m). Figure 1 shows the ombrothermic diagrams of the site and the plots studied; the summer drought typical of the Mediterranean climates is readily seen.

The beech (*Fagus sylvatica* L) at Tres Aguas is a mature forest, with a density of 526 trees ha^{-1}, comprising 300 young trees (4–20 cm diameter at breast height [DBH]) and the rest adult, the latter of which have diameters greater than 1 m in some cases (fig 2). Mean height ranges from 20 to 22 m. The estimated mean age of the plot is 50 years. The soil varies considerably in depth, clay contents increasing with depth and is classified as Humic Acrisol (FAO, 1973).

The Scots pine (*Pinus sylvestris* L) at La Rasada were planted in a reforestation project initiated 50 years ago on land suitable for beech. Mean tree density at this plot is 581 trees ha^{-1} with a predominance of trees with diameters between 30 and 40 cm (292 trees) (fig 3). Their mean height is approximately 15 m. The soil of this plot varies in depth and has a low clay content, an acid (pH 5.2) and desaturated character and is classified as Humic Cambisol (FAO, 1973).

On comparing the distribution of the trees according to their diameter classes, the Scots pine forest is seen to display a typical Gaussian bell-shaped curve in which most trees are concentrated around the intermediate diameter class (32.5–37.5 cm). The beech forest is distributed in such a way that the smallest trees are the most representative, and their distribution is closer to a negative exponential. This different behavior reflects structural differences such as age, degree of maturity and management.

Fourteen representative trees of different diameter classes were felled to establish their aboveground biomass: seven *Fagus sylvatica* trees and seven *Pinus sylvestris* trees. Each tree thus harvested was divided into trunk, branch and leaves. The trunks were separated into sections, according to their height (0–1.30, 1.30–3, 3–5, 5–7 m, etc) and weight. The wood was separated from the leaves.

Fifteen litter traps were randomly distributed on the two experimental sites. The litter was removed monthly and the material collected subdivided into different respective plant organs (branches, leaves, fruits and flowers).

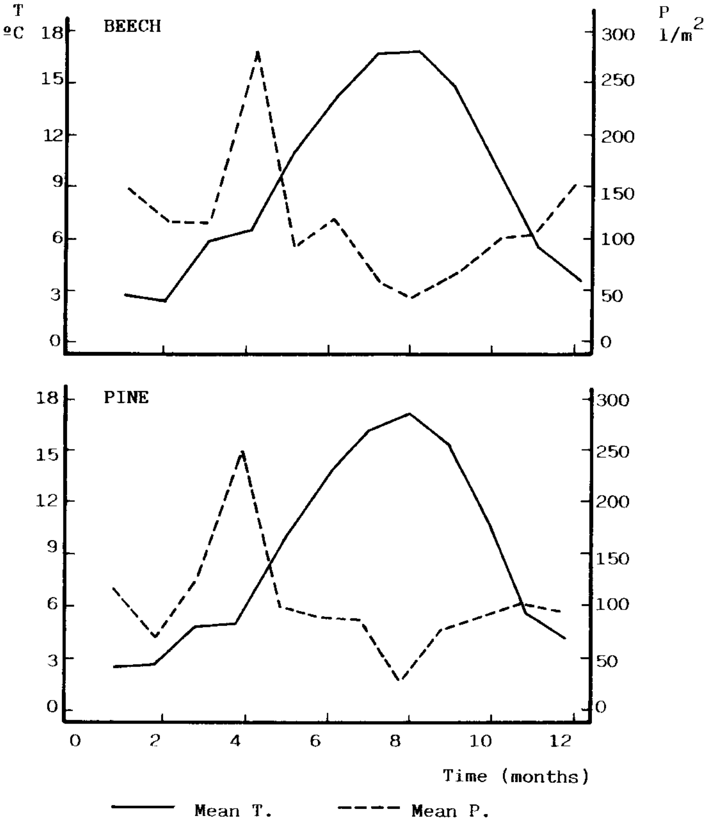

Fig 1. Diagram of monthly average temperature (T) and pluviometry (P) (1986–1988).

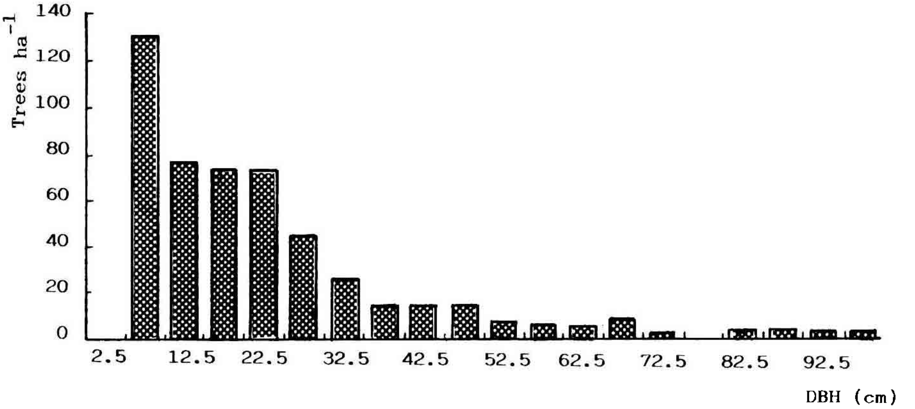

Fig 2. Diameter at breast height (DBH) class distribution in the beech forest.

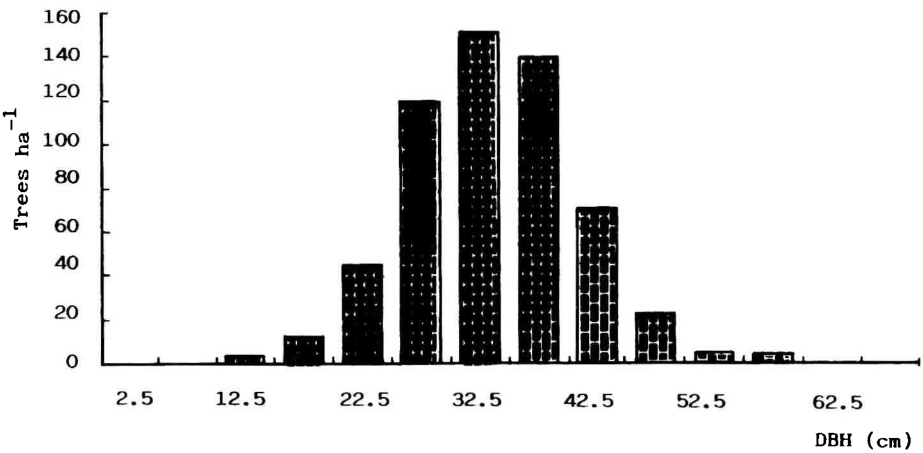

Fig 3. Diameter at breast height (DBH) class distribution in the pine forest.

All subsamples were taken to the laboratory for further analysis, which included moisture content, after drying to constant weight at 80 °C. Representative biomass and litter samples were ground for chemical analysis. After the plant material had been mineralized, total carbon and nitrogen were determined using a Wosthoff carmograph and Macro-N Heraeus analyzer, respectively.

Data were treated with analysis of variance, considering trees belonging to the same diameter class both at the beech and pine stands. The regression curves were also established, according to the best correlation coefficient (r^2).

RESULTS

Table I summarizes the overall set of dendrometric and weight characteristics of the seven trees from each plot studied representative of each population according to diameter classes.

On comparing the values of total aboveground biomass obtained from the felled trees from both sites according to diameter classes (fig 4), a clear divergence may be seen, especially in the mature phases.

The procedure most commonly used to estimate the biomass in forest ecosystems involves destructive techniques in combination with the application of regression equations to manage the data. The best fitted model is the allometric model $Y = ax^b$, where Y is biomass and x tree diameter at a height of 1.30 m. It should be stressed that this model is quite complex and indeed some authors (Baskerville, 1972; Beauchamp, 1973; Sprugel, 1983) have proposed cor-

Table I. Dendrometric and weight characteristics of the felled trees in the each study plot.

	DBH (cm)	*Height (m)*	*Leaves*	*Branches biomass (%)*	*Trunk*	*Trees (ha^{-1})*	*Total biomass (mg ha^{-1})*
Beech forest	17	18	3.1	21.9	75.0	526	134.2
Pine forest	26	15	7.4	19.1	73.5	581	152.1

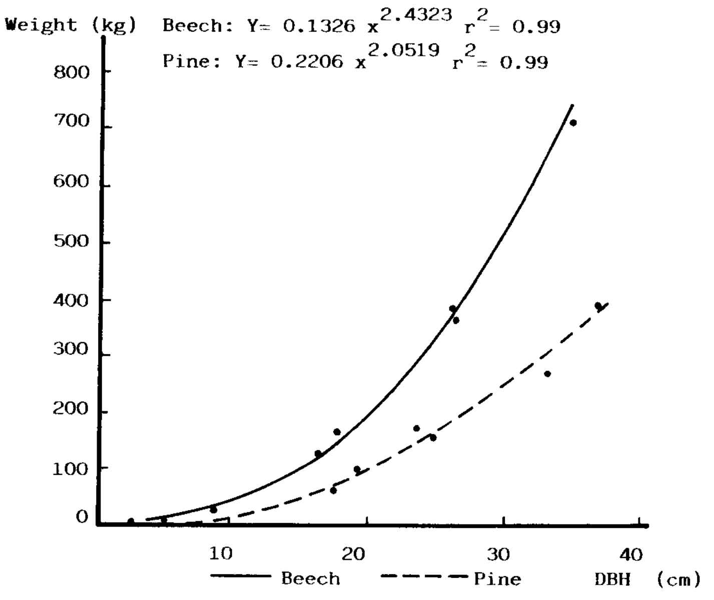

Fig 4. Total biomass in relation to the diameter at breast height (DBH) in individual beech and pine trees.

Table II. DBH–biomass relation in the different compartments of the trees.

		Regression equations	r^2
Beech forest	DBH–total biomass	$y = 1.4160\,x^{0.426}$	0.98
	DBH–trunk biomass	$y = 0.0894\,x^{2.4679}$	0.99
	DBH–branch biomass	$y = 0.0317\,x^{2.3931}$	0.89
	DBH–leaf biomass	$y = 0.0145\,x^{1.9531}$	0.98
	DBH–C	$y = 0.0435\,x^{2.4472}$	0.99
	DBH–N	$y = 0.0004\,x^{2.2946}$	0.98
Pine forest	DBH–total biomass	$y = 1.9410\,x^{0.238}$	0.99
	DBH–trunk biomass	$y = 0.0681\,x^{2.3393}$	0.99
	DBH–branch biomass	$y = 0.5653\,e^{0.1433x}$	0.93
	DBH–leaf biomass	$y = 81.4780\,e^{1.384x}$	0.97
	DBH–C	$y = 72.6630\,e^{2.1267x}$	0.99
	DBH–N	$y = 0.4418\,e^{1.9633x}$	0.98

Table III. Average of carbon (C) and nitrogen (N) content and C/N ratio in different tree fractions of the seven felled trees in each study plot.

		Leaves (%)			*Branches (%)*			*Trunk (%)*		
		C	*N*	*C/N*	*C*	*N*	*C/N*	*C*	*N*	*C/N*
Beech forest	Mean	45.7 ± 1.1	1.90 ± 0.12	24.2 ± 1.9	44.2 ± 1.8	0.32 ± 0.04	142.4 ± 23.5	43.7 ± 1.8	0.21 ± 0.04	214.8 ± 29.1
	Min-Max	43.7 – 47.2	1.76 – 2.13	20.5 – 26.9	42.7 – 46.4	0.25 – 0.38	109.5 – 175.2	41.6 – 46.9	0.18 – 0.30	151.3 – 246.8
Pine forest	Mean	46.0 ± 1.5	1.25 ± 0.12	37.0 ± 3.1	46.5 ± 1.0	0.18 ± 0.06	279.6 ± 64.2	45.9 ± 1.2	0.16 ± 0.01	281.6 ± 30.2
	Min-Max	43.6 – 48.2	1.13 – 1.51	31.3 – 40.4	44.5 – 47.6	0.12 – 0.32	148.8 – 389.2	43.4 – 47.9	0.14 – 0.18	225.3 – 327.1

rections with a view to avoiding underestimations of the true values. This method has been used by several authors (Canadell et al, 1988; Rapp et al, 1992).

Table II shows the DBH–biomass relation in the different compartments of the trees and the regression equations according to the best r^2.

In table III we can see the average of carbon (C) and nitrogen (N) content and C/N ratio in various tree fractions of the seven trees felled in the two study plots. The values were the mean of the seven trees and the maximum and minimum values established.

Table IV. Litter fall and the carbon and nitrogen amounts returning yearly to the soil (k ha^{-1} yr^{-1}).

Litter fraction	*Site*	*Organic matter*	*C*	*N*
Leaves	Tres Aguas	2 897	1 419	12.9
	La Rasada	2 917	1 463	23.3
Total litter	Tres Aguas	4 682	2 294	39.8
	La Rasada	5 791	2 867	46.3

The amounts of yearly litter fall for leaf litter and total litter (leaves + wood + reproductive organs + indeterminate organs) are indicated in table IV.

DISCUSSION

Total biomass

On comparing biomass according to diameter classes, much higher in the beech forest, it may be seen that it would not be very suitable to reforest land appropriate for beech with pine, as confirmed by the contents in N and C, in the different tree fractions. Thus, if the total number of trees in each ecosystem is known, figures of 134.2 mg ha^{-1} and 152.1 mg ha^{-1} for the beech and pine forests, respectively, are obtained; this is because the distribution in the latter sites follows the Gaussian bell-shaped curve, with few trees belonging to the extreme classes, while in the first site many trees were found in the lower classes and only a few in the upper ones.

The references found in the literature report conflicting data, depending on the forest species studied, the age of the wood, the kind of soil and the environmental conditions. In a population of *Fagus sylvatica* Calamini et al (1983) established an aboveground biomass of 319 mg ha^{-1}, Ovington (1963) reported 164 mg ha^{-1} and Reiners (1972) 124 mg h^{-1}; in gymnosperms of 50-year-old communities Green and Grigal (1979) described a range of 92–169 mg ha^{-1} whereas Tappeiner and John (1973) reported 102–136 mg ha^{-1} in groups of 50–90-year-olds.

Biomass compartments

The trunk is the part of the tree that most contributes to the total biomass. This has a value of 75% in the beech forest and 73.5% in the pine forest (table I). Figures of 100.7 mg ha^{-1} are obtained for the deciduous forest and 111.8 mg ha^{-1} for the evergreen forest.

On estimating trunk biomass according to the DBH (table II), greater productivity is seen for the beech, with correlation coefficients of $r^2 = 0.99$ in both cases.

In *Fagus sylvatica* Calamini et al (1993) obtained a trunk biomass of 287 mg ha^{-1}; ie, 90.1% with respect to total biomass.

The branch fractions behave in a manner similar to the trunks; mean percentages of 21.9 and 19.1% were obtained for the beech and pine forests, respectively, obtaining 29.4 mg ha^{-1} for the deciduous species and 29.0 mg ha^{-1} for the evergreen species (table I).

On exploring the biomass of branches with respect to DBH index (table II), the productivity of the beech trees seem to be greater than that of the pines. However, some of the r^2 are poorer than those found for the previous fraction (trunks) $r^2 = 0.89$ for the beech forest and $r^2 = 0.93$ for the pine forest.

In *Fagus sylvatica* Calamini et al (1983) obtained values of 29 mg ha^{-1} or 9.1% with respect to total biomass, whereas Grier et al (1992) reported 65% in *Pinus edulis*.

A clear divergence can be seen in the determination of the biomass of leaf organs. In the beech forest, the contribution of the leaves to total biomass is 3.1% with 4.5 mg ha^{-1} (table I); in the pine forest the values are 7.4% and 10.2 mg ha^{-1}, with $r^2 =$ 0.97 for the beech and 0.88 for the pine (table II). However, on establishing leaf biomass with respect to the DBH parameter (table II), the greatest productivity is also obtained for the beech forest.

The literature reports different values: in *Fagus sylvatica* Calamini et al (1983) calculated 2.7 mg ha^{-1} or 0.8% of leaves, Lemée (1989) reported 3.5 mg ha^{-1} and Lemée and Bichant (1971) 3.1 mg ha^{-1}; in *Juniperus occidentalis*, Gholz (1980) noted a 20% of needles; in *Pinus monophyla*, Meeuwing (1979) calculated 12% of needles and in *Pinus sylvestris*, Rodin and Bazilevich (1967) established values of 9.6% and 5.5% of needle biomass with respect to the total forest biomass.

Total carbon and nitrogen contents

The most substantial total carbon content per diameter class was obtained in the beech forest (table III).

In both cases the $r^2 = 0.99$. Table III shows that the highest carbon content in the beech forest, estimating the mean of each part of the trees, corresponds to the leaf fraction, while in the pine forest, the highest carbon content is generally found in the more lignified fractions.

The differences in the distribution of carbon in the biomass are similar to those reported in other works addressing the differences in biomass as related to the quality of the substratum (Keyes and Grier, 1981).

Greater differences are seen on comparing the total nitrogen content in the biomass of both forests, if the total nitrogen-DBH ratio is considered (table III). In this ratio correlation coefficients of 0.98 were obtained for the pine.

The relative nitrogen contents in the fractions were always higher in the leaves than in the more lignified parts, in both beech and pine. In a comparison of both species, they were higher in the first one (table III).

Litter fall and return of nutrients to the soil

Leaf litter production was very similar in both forests while litter production was more important in the pine forest.

The total of the two nutrients analyzed was higher in the pine forest, most of all in the case of N (table IV).

It is possible to calculate a relationship between the nutrients returning to the soil in the litter fall and nutrients immobilized in the biomass.

$$\frac{\text{litter fall nutrients}\left(\text{kg ha}^{-1}\right)\times 100}{\text{biomass nutrients}\left(\text{kg ha}^{-1}\right)}$$

This relationship can be defined as turnover or rotation coefficient and has the following values for the two forests considered.

	C	N
Beech wood	5.3	13.5
Pine wood	4.6	18.4

Carbon was recycled in the same proportion at both sites, although the total amounts were different. In contrast, nitrogen was recycled twice as fast in the pine wood than in the beech wood.

CONCLUSION

Comparative study of the aboveground biomass, C and N contents in beech and pine forests indicates a larger biomass and litterfall in the latter. Although the productivity according to diameter class was higher in the beech forest, a clear divergence could be seen, especially in the mature phases.

The highest carbon and nitrogen contents in the beech forest corresponded to the leaf fraction while in the pine forest the highest carbon content was generally found in the more lignified fractions and the nitrogen content was higher in the leaves.

On comparing biomass according to diameter classes, much higher in the beech forest, it may be noted that it would not be very suitable to reforest land appropriate for beech with pine, as confirmed by the ion contents N and C in the different tree fractions.

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