GROWING STOCK-BASED ASSESSMENT OF THE CARBON STOCK IN A PILOT ZONE OF NORTHERN SPAIN: COMPARISON OF BIOMASS EQUATIONS AND BIOMASS EXPANSION FACTORS

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Abstract:

Estimation of the biomass and carbon stock of trees has gained importance as a result of the Climate Convention and the Kyoto Protocol. In Northern Spain, forest surface has increased considerably, mainly due to reforestation of former agricultural land. This fact supposes a chance to accumulate C. Anyway, biomass and carbon stock are not easy to estimate.

In this work, differences and uncertainties of alternative methods applicable to estimation of biomass in national forest inventory are evaluated in a representative area of NW Spain. The objectives of this work are: (i) to calculate the total carbon stock in the living tree biomass of three councils of NW Spain in 1987 and after 11 years and (ii) to compare two methods applicable for estimating biomass stock of trees: biomass equations developed in the area applied to tree-level data of a national forest inventory and aggregated stand-level volume estimates multiplied by biomass expansion factors (BEF).

Pilot zone selected covers 48,000 ha and is quite representative of the whole of the region in terms of type of forest and forest productivity. The main types of forest are plantations of *Pinus radiata*, *Eucalyptus globulus*, *Pinus pinaster* and natural stands of oaks (*Quercus robur*). Data from the second and third Spanish forest inventories (1987-1998) were used in the calculations of this study. For most of the species, biomass equation used has been developed in the area.

Biomass equations results showed that total C-stock in the living tree biomass was assessed at around 628,000 Mg C in 1987 and 1,300,000 Mg C in 1998. This increase was mainly due to the increases of surface area distributed to *Eucalyptus globulus* (35.5%), *Pinus pinaster* (27.9%) and *Pinus radiata* (18.3%), which implies an increase of 1.3 Mg C ha^{-1} $year^{-1}$. The use of expansion factors overestimates the C amount by 12 to 17% in relation to the use of predictive equations of biomass for each species.

Keywords: aboveground biomass, allometric equations, biomass expansion factors, Northern Spain.

1. Introduction

The Kyoto protocol has produced in recent years a higher interest in evaluating the role of forest as carbon sinks. The carbon pool in the forest ecosystem is nowadays an objective to be taken into account in Forest Management. The Spanish Forest plan identifies as one of the main targets of forest research the study of the role of forest as carbon and greenhouse gas sink, in a temporal (biomass) or permanent (forest soil) way.

To satisfy the requirements of the Kyoto protocol, it has become necessary to develop methods to estimate changes in carbon stocks and how these pools will change as a result of management [12]. Afforestation and other silvicultural practices can increase the quantities of atmospheric sequestered CO_2 [4]. However, forests may also become a source of atmospheric carbon depending on the management regime or on the risk of destruction by wildfires within a certain period of time [8]

National Forest Inventories are sources of useful information to compare the amount of biomass in a forest area over time, but the information available refers mainly to growing stock rather than to biomass stock, as breast height diameters and total height of the trees contained in plots. The Spanish national Forest Survey provides information of circular plots measured in a net of 1 x 1 km considering the Spanish Forest map as a cartographic base [3]. In the case on north western Spain, the inventories have been done in 1987 and 1998, thus allowing the possibility of make comparisons for a period of 11 years.

In Northern Spain the mild climate and, in last decades, the increased request in wooded raw industrial material for the pulp and fibreboard industries, have favoured the establishment of extensive commercial forest plantations focused on fast-growing species, especially of *Pinus pinaster* (maritime pine), *Pinus radiata* (radiata pine) and *Eucalyptus globulus*. Because of the important surface occupied, these plantations can store large amounts of carbon in the short term and are considered as potential fast carbon sinks. Furthermore, the abandonment of the traditional agricultural activities has produced large areas regenerated by natural broadleaves.

Estimates of forest carbon stock and stock changes are usually obtained by calculations ,based of growing stock and net increment with the aid of simple conversion factors [6,7,9]. Conversion from stem volumes into whole-tree biomass is one of the notable sources of error in forest carbon inventories [15]. Since most of the currently applied BEFs are not based on regionally representative biomass sampling, they are likely to give biased biomass estimates as a result.

This paper derives from the results of the evaluation of indicators of Sustainable Forest management for pilot areas located in a net of European regions. The evaluation of the indicator 1.4. of the criterion 1 (Criterion 1: Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles) requires the estimation of biomass as a first step to calculate the carbon stock and its evolution on time. The objective of this paper is: (i) to calculate the total carbon stock in the living tree biomass of three councils of NW Spain and its evolution from 1987 to 1998 and (ii) to compare two methods applicable for estimating biomass stock of trees: biomass equations developed in the area [2] applied to a single-tree level of detail of a national forest inventory and aggregated stand-level volume estimates multiplied by biomass expansion factors (BEF).

2. Materials and Methods

The pilot area selected has 48,185 ha and is located in the north of Galicia (Fig.1), in an area that expands from the councils of Irixoa and Aranga, in the province of A Coruña, to the council of Guitiriz, located in the west of the province of Lugo. This variation in elevation and maritime influence derives in the presence of several forest types, from the eucalypts and maritime pine plantations to the radiate pine and broadleaves woodland.

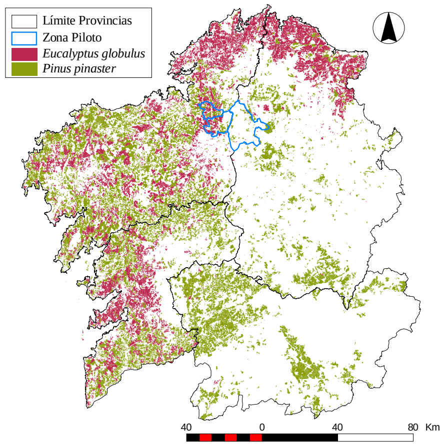

Fig.1. Localization of the pilot zone and main forest species in the whole of the region

2.1. Protocols to evaluate the indicator: Carbon stock

The information on biomass stock is essential to assess the amount of carbon that exists in the woody vegetation. The process of harmonization of the evaluation processes in the European area [5] considers several categories for biomass, as above-ground biomass, below-ground biomass and dead wood biomass. The first one refers of all living biomass including stem, stump, branches, bark, seeds and foliage. Due to the lack of equation to predict below-ground biomass for most of the species we have deal with, the above-ground will be the category to consider in this paper. Furthermore, and as a explanatory note, FRA2005 considers that in cases where forest understorey is a relatively small component it is acceptable to exclude it, provided this is done in a consistent manner throughout the inventory time series. The calculations will be done for the forest land, and then excluding the other wooded lands, covered usually by shrubs, for which only a few equations to determine biomass are available.

The calculation of the biomass stock in forest areas will be performed after the calculations of growing stock. The trees to be considered in the calculations are, after the methodology of the National Spanish Survey, those living trees more than 7.5 cm in diameter, including for the calculation of the wood component the stem from the stump height up to a top diameter of 7 cm.

The components of the above ground biomass considered are the following: wood under bark in the stem (debarked logs with a thin-end diameter of 7 cm), bark in the stem, thick branches (diameter from 2 to 7 cm at the insertion, and no debarked), thin branches (diameter from 0.5 to 2 cm at the insertion), twigs (diameter less than 0.5 cm at the insertion), and needles or leaves.

2.2. The use of expansion factors versus allometric equations

Two methodologies to calculate biomass have been considered: (a) the use of expansion or time factors of over bark volumes to total biomass at a stand level (BEF), and (b) the use of individual tree allometric equations to predict biomass components. These equations were applied to every tree in a net of 140 plots available in the pilot area for the Spanish National Survey. As the plots were of concentric circular design with varying threshold diameters, weighting factors were employed to calculate the biomass per hectare. The calculations of the total amount of biomass in the pilot are were then done considering as the cartographic base the Spanish Forest Plan.

The equations available for Galicia derive from the destructive sample of an average of 80 trees of each of the following species: radiata pine maritime pine, European oak and white eucalypt (*Eucalyptus globulus*). The plots considered to develop these equations are relatively close to the pilot are. The equations have been fitted simultaneously, the observations were weighted to prevent the presence of heterocedasticity, and prediction refers to the oven dry (65ºC) weight of each component [2]). For other species the equations used were developed for other Spanish regions [11, 14]. Tables 1 to 3 show the allometric equations used. Table 4 indicate the expansion factors proposed for Spain [17].

Table 1. Allometric equations for above ground biomass components of Pinus pinaster and Pinus radiata [2].

Pools	Biomass equations	R^2_{adj}	*RMSE*
Pinus pinaster [2]			
Wood	$W = 0.3882 + 0.0115 \cdot d^2 \cdot h$	0.97	51.22
Bark	$W = 2.54 + 0.002 \cdot d^2 \cdot h$	0.94	6.29
Thick branches	$W = 3.2019 - 0.0148 \cdot d^2 - 0.4228 \cdot h + 0.0028 \cdot d^2 \cdot h$	0.81	13.85
Thin branches	$W = 0.0978 \cdot d^{2.2881} \cdot h^{-0.9648}$	0.83	4.74
Twigs	$W = 0.0019 \cdot d^{2.1537}$	0.68	1.42
Needles	$W = 0.00082 \cdot d^{2.8845}$	0.83	5.81
Pinus radiata [2]			
Wood	$W = 0.0123 \cdot d^{1.6042} \cdot h^{1.4131}$	0.96	53.56
Bark	$W = 0.0036 \cdot d^{2.6564}$	0.92	11.14
Thick branches	$W = 1.937699 + 0.001065 \cdot d^2 \cdot h$	0.66	19.95
Thin branches	$W = 0.0363 \cdot d^{2.6091} \cdot h^{-0.9417}$	0.81	6.02
Twigs	$W = 0.0078 \cdot d^{1.9606}$	0.69	1.49
Needles	$W = 0.0423 \cdot d^{1.7141}$	0.79	6.97

where W is the dry weight of the different biomass components of the tree (kg), *d* is the breast height diameter (cm) and *h* is total height (m).

Table 2. Allometric equations for above ground biomass components of broadleaves in Galicia (Eucalyptus globulus, Quercus robur and Betula celtiberica) [2].

Pools	Biomass equations	R^2adj
Eucalyptus globulus [2]		

Wood	$W = -8.9995 + 0.036 \cdot d^2 \cdot h$	*0,927*
Bark	$W = -1.7087 + 0.0059 \cdot d^2 \cdot h$	*0,851*
Thick branches	$W = 44.2207 - 5.0722 \cdot d + 0.1981 \cdot d^2$	*0,704*
Thin branches	$W = 0.0008 \cdot d^{2.8305}$	*0,782*
Twigs	$W = 0.003 \cdot d^{2.8908}$	*0,786*
Leaves	$W = 0.0009 \cdot d^{2.8783}$	*0,674*
Quercus robur [2]		
Wood	$W_{sw} = -7.22736 + 0.01951 \cdot d^2 h$	*0,948*
Bark	$W_{sb} = -0.12820 + 0.00272 \cdot d^2 h$	*0,814*
Thick branches (>7cm)	$W_{b7} = 4.3824 \cdot 10^{-8} \cdot (d^2 h)^{2.09769}$	*0,305*
Thick branches (2-7cm)	$W_{thickb} = 4.6158 + 0.00329 \cdot d^2 h$	*0,858*
Thin branches	$W_{thinb} = 0.04736 \cdot d^{1.70647}$	*0,811*
Twigs	$W_{tw} = 1.36530 + 0.000305 \cdot d^2 h$	*0,579*
Leaves	$W_l = 0.02639 \cdot (d^2 h)^{0.70442}$	*0,843*
Roots	$W_r = 0.085137 \cdot d^{2.15149}$	*0,814*
Betula celtiberica [2]		
Wood	$P_t = 0{,}1488 \cdot d^{2{,}2230}$	
Bark	$P_c = 0{,}0301 \cdot d^{2{,}1860}$	
Thick branches (>7cm)	$P_{r7} = 1{,}515 \cdot e^{0{,}0904 \cdot d}$	
Thick branches (2-7cm)	$P_{rg} = 0{,}1374 \cdot d^{1{,}7596}$	
Thin branches	$P_{rf} = 0{,}0500 \cdot d^{1{,}6184}$	
Twigs	$P_r = 0{,}0372 \cdot d^{1{,}5811}$	
Leaves	$P_h = 0{,}0346 \cdot d^{1.6454}$	
Roots	$P_h = 1{,}0416 \cdot d^{1.2544}$	

Table 3. Allometric equations for above ground biomass components of other species from data coming from other Spanish regions.

Pools	Biomass equations	R^2adj
Pinus sylvestris [11]		
Wood	$W = 0.0215 \cdot d^{2{,}7184}$	0.98
Thick branches	$W = 0.15 \cdot e^{0.1076\, d}$	0.80
Thin branches	$W = 0.0291 \cdot d^2 + 0.2988 \cdot d - 4.22145$	0.88
Twigs and needles	$W = 0.0282 \cdot d^2 + 0.38 \cdot d + 2.1906$	0.86
Total biomass	$W = 0.805 \cdot d^{2.4187}$	0.98
Castanea sativa [14]		
Wood	$P_t = 0{,}066 \cdot d^{2{,}647}$	0.998

Branches	$P_r = 0{,}079 \cdot d^{2{,}541}$	0.996
Leaves	$P_H = 0{,}000467 \cdot d^{3.675}$	0.982
Total	$P_T = 0{,}0000544 \cdot d^{3.943}$	0.860
Other broadleaves [1]		
Wood and branches	$Ln\ B_S = -2.69 + 2.76 \cdot \ln D$	0.97
Twigs	$Ln\ B_t = -4.75 + 2.14 \cdot \ln D$	0.77
Leaves	$Ln\ B_S = -5.40 + 2.14 \cdot \ln D$	0.77
Total	$Ln\ B_S = -2.54 + 2.72 \cdot \ln D$	0.97

Table 4. Biomass expansion factors for the species considered in this study

IFN3 code	Species	BEF
21	*Pinus sylvestris*	0,62
26	*Pinus pinaster*	0,55
28	*Pinus radiata*	0,44
41	*Quercus robur*	0,84
42	*Quercus petrae*	0,84
43	*Quercus pyrenaica*	1,11
54	*Alnus glutinosa*	0,62
55	*Fraxinus spp*	0,83
61	*Eucalyptus globulus*	0,81
63	*Other eucalypts*	0,81
72	*Castanea sativa*	0,75
73	*Betula spp*	0,73
99	*Other broadleaves*	0,80

Several authors have observed differences in C and nutrient concentrations relative to stocking density and other stand conditions [13, 16]. However, as a few data was available for developing the biomass equations, the independence of C concentration in tree components over time and in relation to site quality was assumed in the present study, and so an average concentration of carbon in each component was used, according to the Table 5, for the species *Pinus radiata, Pinus pinaster, Eucalyptus globulus* and *Quercus robur*. For the rest of the species, an average value of 47.35% [11] was used.

Table 5. Average values and Standard deviation of carbon concentrations (mg g^{-1}) in different components of aboveground biomasa for Pinus pinaster, Pinus radiata, Eucalyptus globulus y Quercus robur [2].

	Wood	Bark	Thick branches	Thin branches	Twigs	Needles/ Leaves
Pinus radiata	0.504 (0.029)	0.541 (0.026)	0.513 (0.036)	0.525 (0.039)	0.532 (0.033)	0.527 (0.029)

Pinus pinaster	0.471 (0.027)	0.508 (0.029)	0.479 (0.024)	0.505 (0.030)	0.497 (0.029)	0.497 (0.023)
Eucalyptus globulus	0.452 (0.003)	0.425 (0.031)	0.455 (0.009)	0.451 (0.007)	0.464 (0.008)	0.520 (0.010)
Quercus robur	0.484 (0.004)	0.512 (0.001)	0.484 (0.002)	0.502 (0.000)	0.507 (0.000)	0.503 (0.003)

The calculation of root biomass has not been done due to the lack of information for most of the species.

3. Results and Conclusions

Table 6 shows the results of the inventories comparison in terms of timber stock in the whole pilot area, in terms of volume and basal area of the stands. These changes refer to a period of 11 years, being remarkable the strong increment of timber stock (75%). Table 7 gives the comparison expressed for each species

Table 6. Timber stocking in terms of total volume and basal area compared between inventories

IFN2 (1987)		IFN3 (1998)		Periodic increment		Periodic annual increment	
Vcc (m^3)	AB (m^2)	Vcc (m^3)	AB (m^2)	Vcc (m^3)	AB (m^2)	Vcc (m^3 $año^{-1}$)	AB (m^2 $año^{-1}$)
1785046	295952	3140833	421171	1355787	125218	123253	11383

Vcc: Volume over bark; AB: Basal area

Table 7. Stocking and periodic increment per species.

Species	IFN2 (1987)		IFN3 (1998)		Comparison IFN2 – IFN3	
	Vcc (m^3)	AB (m^2)	Vcc (m^3)	AB (m^2)	Vcc (m^3)	AB (m^2)
Pinus sylvestris	9740.5	2291.1	25602.0	6813.7	15861.5	4522.6
Pinus pinaster	826400.9	133604.4	1205487.3	133996.9	379086.3	392.5
Pinus radiata	196202.4	31559.5	444519.1	71351.1	248316.6	39791.6
Quercus robur	234196.4	46529.8	499560.2	87910.7	265363.8	41380.9
Quercus petrae	50.2	8.8	-	-	-50.2	-8.8
Quercus pyrenaica	1911.0	600.1	3783.4	870.1	1872.4	269.9
Alnus glutinosa	33072.2	6667.2	9423.9	1908.9	-23648.3	-4758.3
Fraxinus excelsior	-	-	24.6	3.7	24.6	3.7
Eucalyptus globulus	207150.2	24606.0	624336.4	60996.8	417186.2	36390.7
Eucalyptus obliqua	14674.8	1688.7	79271.9	10395.7	64597.0	8707.0
Castanea sativa	95697.2	14919.3	123816.7	20319.7	28119.4	5400.4
Betula celtiberica	142298.1	29336.9	115540.1	23834.4	-26758.0	-5502.4

Other broadleaves	990.8	358.7	4393.4	1605.9	3402.6	1247.2
TOTAL	1785046.2	295952.8	3140833.3	421171.3	1355787.1	125218.4

Vcc: Volume over bark; AB: Basal area

If we compare these results to the increment in volume and basal area for the whole territory of the Galician regions we found similar trends for the species having more periodic increment in terms of stocking [18]. This indicates that the selection of the pilot zone as a representative area was a right decision. Maritime pine is the species with more timber volume in the pilot area, having a slight trend to increase. Radiate pine shows a very increasing trend, more than doubling its presence. This is also the situation for the different species of eucalypts. *Eucalyptus globulus* becomes in 1998 the second species in terms of volume, although the further trend to the present may be no so good, due to the serious problems of *Gonipterus* attacks. Common oak shows also an increasing presence, as is the case of other natural broadleaves, except for chestnut. Overall, the coniferous species are still predominant in 1998 in comparison to broadleaves.

Table 8 gives the results of biomass calculations following both methodologies (BEF and allometric equations). A positive trend in biomass amount can be recognized for most of the species, although results are different according to the methodology for calculations.

Table 8. Results of biomass calculations following both methodologies (BEF and allometric equations).

	IFN2		IFN3		Comparison IFN2 – IFN3	
	A.B. (BEF) (Mg)	A.B (allometric equations) (Mg)	A.B (BEF) (Mg)	A.B (allometric equations) (Mg)	A.B. (BEF) (Mg)	A.B. (allometric equations) (Mg)
Pinus sylvestris	6742.3	4845.9	17721.7	12194.3	10979.3	7348.4
Pinus pinaster	485314.1	456657.2	621094.1	526176.4	135779.9	69519.1
Pinus radiata	119778.2	103208.9	265289.0	243714.5	145510.7	140505.6
Quercus robur	200870.5	216902.2	426024.9	488340.4	225154.4	271438.2
Quercus petrae	42.8	54.4	-	-	-42.8	-54.4
Quercus pyrenaica	2132.8	2738.5	3226.5	4315.3	1093.6	1576.7
Alnus glutinosa	22892.6	26471.7	6059.1	7543.1	-16833.4	-18928.5
Fraxinus spp	-	-	20.8	33.5	20.8	33.5
Eucalyptus globulus	171530.7	351367.8	516981.7	1064968.5	345451.0	713600.7
Eucalyptus obliqua	12151.5	28083.3	65641.0	141031.2	53489.5	112947.9
Castanea sativa	74763.4	96055.3	96731.8	146489.4	21968.3	50434.1

Betula celtiberica	109064.4	174975.1	88555.7	143871.6	-20508.7	-31103.4
Other broadleaves	19380.0	24452.	7785.3	12752.5	-11594.6	-11700.0
TOTAL	1224663.8	1485813.4	2115132.1	2791431.4	890468.3	1305617.9

A.B. Aboveground biomass

The amounts of carbon contents calculated for each species are shown in the Table 9. In 1987, the species with more carbon accumulation were *Pinus pinaster, Eucalyptus globulus, Quercus robur* and *Betula celtiberica*. After 11 years, the rank has changed to *Eucalyptus globulus, Pinus pinaster, Quercus robur* and *Pinus radiata.* The higher increment was observed for *Eucalyptus globulus, Quercus robur* and *Pinus radiata.*

Table 9. Amounts of carbon contents calculated for each species and percent of variation for each species according to the methodology of calculation

	IFN2		IFN3		Comparison IFN2 – IFN3		Error (%)
	C (BEF) (Mg)	C (allometric equations) (Mg)	C (BEF) (Mg)	C (allometric equations) (Mg)	C (BEF) (Mg)	C (allometric equations) (Mg)	
Pinus sylvestris	3744.2	2374.4	9841.4	5975.2	6097.1	3600.7	61.2
Pinus pinaster	249986.2	219576.08	288492.8	252633.2	38506.5	33057.2	14.02
Pinus radiata	43353.9	52954.9	86058.9	124985.2	42704.9	72030.3	-24.64
Quercus robur	167544.7	102698.9	352489.7	231229.2	184944.9	128530.2	57.48
Quercus petrae	35.4	25.8	-	-	-35.4	-25.8	57.48
Quercus pyrenaica	2354.6	1713.7	2669.6	2043.3	314.9	329.6	57.48
Alnus glutinosa	12712.9	9252.5	2694.3	1960.9	-10018.6	-7291.5	37.40
Fraxinus spp	-	-	17.0	16.0	17.0	16.0	5.93
E. globulus	135911.2	158224.4	409627.1	479603.5	273715.8	321379.1	-14.92
E. obliqua	9628.1	12664.9	52010.2	63579.7	42382.1	50914.8	-14.92
Castanea sativa	53829.7	45492.6	69646.9	69499.8	15817.2	24007.2	9.27
Betula celtiberica	75830.6	84982.7	61571.3	68123.2	-14259.3	-16859.4	-10.19
Other broadleaves	15108.2	11034.9	6103.3	5442.1	-9004.8	-5592.8	24.53
TOTAL	770040.3	700995.9	1341222.9	1305091.8	571182.5	604095.8	

C: Carbon

The percent of variation for each species according to the methodology of calculation are also shown in this table. The results obtained from the allometric equations should be considered as more exact, since in most cases the trees were sampled in areas very close to the pilot area, and the procedure considers a higher level of detail. The differences are very important for species having no very well developed tools for management, as broadleaves. Differences in the case of Scot pine could be attributed to the young age of most of the stands of the pilot area.

4. Bibliography

1. ALBERTI, G.; CANDIDO, P.; PERESSOTTI, A.; TURCO, S.; PIUSS, P.; ZERBI, G. 2005. An aboveground biomass relationship for mixed ash (Fraxinus excelsior L. and Ulmus glabra Hudson) stands in Eastern Prealps of Friuli Venezia Giulia (Italy). *Ann. For. Sci.* 62 831–836
2. BALBOA, M.A.; 2005. Biomasa arbórea y estabilidad nutricional de los sistemas forestales de *Pinus pinaster* Ait., *Eucalyptus globulus* Labill. y *Quercus robur* L. en Galicia. Doctoral Thesis. Univesidad de Santiago de Compostela. 244 pp.
3. D.G.C.N., 2000. Tercer Inventario Forestal Nacional 1997-2006: Galicia. Ministerio de Medio Ambiente, Dirección General de Conservación de la Naturaleza, Madrid.
4. DIXON, R.K.; BROWN, S.; HOUGHTON, R.A.; SOLOMON, A.M.; TREXLER, M.C.; WISNIEWSKI, J. 1994. Carbon pools and flux of global forest ecosystems. *Science* 263 185-190.
5. FAO. 2004. Global Forest Resoucers Assessment update 2005. Specification of National Reportig Tables for FRA 2005. Food and Agriculture Organization of the United Nations. Forestry Departament. Rome.
6. KAUPPI P.E.; MIELIKÄINEN K.; KUUSELA K.1992. Biomass and carbon budget of European forests, 1971 to 1990. *Science* 256 70–74.
7. KAUPPI P.E.; TOMPPO E.; FERM A. 1995. C and N storage in living trees within Finland since 1950s. *Plant Soil* 168–169 633–638.
8. KIMPHAT, N.; KNORR, W.; KIM, S. 2004. Appropriate measures for conservation of terrestrial carbon stocks Analysis of trends of forest management in Southeast Asia. *For. Ecol. Manage*. 191 283-299.
9. LÖWE, H.; SEUFERT, G.; RAES, F. 2000. Comparison of methods used within member states for estimating CO_2 emissions and sinks according to UNFCCC and EU monitoring mechanism: forest and other wooded land. *Biotechnol. Agron. Soc. Environ.* 4 315–319.
10. MCPFE. 2002. Improved pan-European indicators for Sustainable Forest Management. www.mcpfe.org
11. MONTERO, G.; MUÑOZ, M.; DONÉS, J.; ROJO, A. 2004. Fijación de CO_2 por Pinus sylvestris L. y Quercus pyrenaica Wild. En los montes "Pinar de Balsaín y Matas de Balsaín". *Invest. Agrar. Sist. Rec For* 13 399-415
12. MUND, M.,; KUMMETZ, E.; HEIN, M.; BAUER, G.A.; SCHULZE, E.D. 2002. Growth and carbon stocks of a spruce forest chronosequence in central Europe. *For. Ecol. Manage.* 171 275-296.
13. RANGER J.; MARQUES, R.; BELGRAND, M.C.; FLAMMAG N.; GELHAYE, D. 1995. The dynamics of biomass and nutrient accumulation in a Douglas fir (*Pseudotsuga menziesii* Franco) stand studied using a chronosequence approach. *For. Ecol. Manage.* 72 167-183.
14. SANTA REGINA, I. 2000. Organic matter distribution and nutrient fluxes within a sweet chestnut (*Castanea sativa* Mill.) stand of the Sierra de Gata, Spain. *Ann. For. Sci.* 57 691-700.

15. SCHOENE, D. 2002. Assessing and reporting forest carbon stock changes for FRA, UNFCCC and Kyoto Protocol: a concerted effort?. In: Proceedings of FAO expert consultation on global forest resource assessment, Metsäntutkimuslaitoksen tiedonantoja, 290–297.
16. SHELTON, MG. 1984. Effects of the initial spacing of loblolly pine plantations on production and nutrition during the first 25 years. Diss. from Dep. of Agron., Mississippi State Univ. 161 p.
17. UE. 1999. Inventario de Emisiones de gases de efecto invernadero de España. Años 1990-2002. Comunicación a la Comision Europea (Decisión 1999/296/CE)
18. XUNTA DE GALICIA. 2001. O monte galego en cifras. Consellería de Medio Ambiente, Dirección Xeral de Montes e Medio Ambiente Natural

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