Carbon accumulation by plants in a post-fire *Pinus pinaster* Ait. stand in north-western Spain

Enrique Jiménez[1], José A. Vega, Pedro Pérez-Gorostiaga, Teresa Fonturbel, Cristina Fernández.

Summary

Forest fire is a perturbation playing a very important role in carbon cycles. Post–fire regeneration carbon sequestration can ameliorate carbon losses from the ecosystem due to forest fire. Plant biomass and carbon accumulation were determined in a young *Pinus pinaster* stand regenerated after wildfire. In 2003, seven years after fire occurrence, in a site with high seedling density (about 54,200 seedlings/ha) in Ourense (north–western Spain), 74 2 x 2 m plots were established. Basal diameter, height and crown width were measured for each seedling in all plots. Destructive sampling was carried out to develop allometric equations to calculate seedling biomass content (above- and below–ground) from dendrometric variables. Sub-samples from each seedling biomass fraction were taken to determine carbon concentration. Aboveground shrub biomass from each plot was determined by clipping and oven-drying, and carbon concentration was also determined. Total mean post–fire carbon accumulation was about 12.05 Mg C/ha. Pine seedlings account for the 82.18 percent of total carbon accumulation. Plots with higher shrub biomass showed lower seedling biomass, existing a significant negative relationship between both variables (r^2=0.5176). Future research should analyse, apart from carbon accumulation on vegetation, the carbon content on litter and soil, and carbon losses due to decomposition.

Introduction

Pinus pinaster Ait. is the conifer species most affected in Spain by wildfire, with more than 36000 ha burned from 1996 to 2000 (Ministerio de Medio Ambiente, 2002). It is considered a fire-adapted species, usually showing abundant postfire regeneration (Gil and others, 1990; Vega and others, 2002; Tapias and others, 2004). Forest fires and recovery are important to regional carbon storage because carbon lost in stand – replacing fires is often a significant component of regional carbon budgets (Kashian and others, 2006). Short – term effects of fires are important for predicting carbon balance over this century, because greater fire frequency, extent, or severity will release much carbon through combustion and increase the forested area having negative net ecosystem production (Kashian and others, 2006).

The aim of this study was to determine carbon accumulation in plant biomass in a *Pinus pinaster* stand seven years after fire occurrence.

[1] Centro de Investigación e Información Ambiental-Lourizán, Departamento de Protección Ambiental. Xunta de Galicia. P.O. Box 127, 36080, Pontevedra, Spain.

Materials and methods

Area of study

The study was conducted in a young postfire-regenerated *Pinus pinaster* stand in Laza – Orense, NW Spain – (42º5'43''N; 7º31'9''W). Forest fire took place on September 1996, affecting 575 ha. The site is in a west-facing slope of 20% inclination, at 700 m a.s.l. Climate is Mediterranean, with scarce summer rainfall and slight continental influence (Carballeira and others, 1983). Mean annual precipitation is 1338 mm, and mean annual temperature is 9.6 ºC. Soils are alumi-umbric regosols and leptosols (Macías and Calvo, 2001), about 30 cm depth. Main shrub species were *Pterospartum tridentatum* (L.) Willk., and *Halimium lasianthum* subsp. *alysoides* (Lam.) Greuter.

In February 2003, in an area about 10 ha presenting good pine regeneration (mean density of 54000 seedlings/ha and mean seedling height of 1.6 m) 74 2x2 m plots were radomly stablished (*table 1*). In each plot, total seedlings were counted, and height, crown width, basal diameter and diameter at the base of live crown were measured for all seedlings. Shrub height and cover were also measured for each plot.

Table 1 - *Seedlings mean characteristics before thinning*

Parameters	Mean values
Seedling density (seedlings/ha)	54700 (*4727*)
Basal diameter (cm)	3.09 (*0.11*)
Total height (cm)	160.60 (*5.47*)
Diameter at the base of live crown (cm)	2.39 (*0.08*)
Crown width (cm)	50.87 (*1.69*)
Shrub height (cm)	65.09 (*3.48*)
Shrub cover (%)	24.68 (*2.35*)

Standard error in brackets

Tree selection, sampling and carbon content

In February 2003, in the area of study, 26 seedlings differing in basal diameter (minimum 1.1 cm, maximum 7.6 cm) were selected for destructive sampling. This destructive inventory was made to find equations relating foliage, branches, stem, stump and coarse root biomass of seedlings and dendrometrical variables. For each sample seedling height, crown width, basal diameter and diameter at the base of live crown were measured. For 17 of these 26 seedlings roots were excavated using water pressure. Complete trees were transported to laboratory, where were separated into different biomass fractions: needles, branches, stem, stump and coarse roots (> 2 mm). Dry weight determination of these fractions was based on the fresh/dry weight ratios determined on ovendried (80ºC during 48 h) sub – samples. Representative ovendried sub – samples of all seedling fractions were analysed for carbon content by combustion using LECO analizer. The allometrical equations calculated were used to determine the component biomass of all seedlings in the 74 2x2 plots.

Shrub biomass and carbon content

Whole above – ground shrub biomass was harvested in all 2x2 plots, and transported to the laboratory to estimate its dry weight by species. Carbon content was considered constant for all species (50 per cent of dry weight).

Statistical analysis

Nonlinear regressions were computed using stepwise methodology with SPSS 11.0 for Windows (SPSS Inc. 2004) using untransformed data and a power function of the form:

$$Y = aD^{b}H^{c}CW^{d}$$

where Y is the dependent variables (biomass of each seedling fraction), D seedling diameter (basal or at the base of live crown), H seedling total height, CW seedling crown width, and a, b, c and d are constant. Goodness of fit for all the models was determined by examining the coefficient of determination (r^2) and the standar error of the model. Biomass equations were applied to all seedlings in the 2x2 plots. Total seedling biomass was calculated as the sum of the separately calculated best regression functions of the biomass components.

Results

Seedling biomass allometry and carbon concentration

Best allometric model for needle biomass included diameter at the base of live crown, for branch biomass included diameter at the base of live crown and crown width, for stem biomass included basal diameter, total height and crown width, for stump biomass included included basal diameter, and for coarse root biomass included diameter at the base of live crown (table 2). Coefficients of determination ranged from 0.60 to 0.97.

Table 2 – *Allometric equations, coefficients of determination, standard error and Carbon concentration per biomass fraction. S.E.: Standard Error of the equation*

Fraction	Equation	r^2	S.E.	C pct.
Needles	$5.582\ Dblc^{2.854}$	0.96	81.26	49.50 (*0.03*)
Branches	$0.367\ Dblc^{2.719}\ CW^{0.549}$	0.96	74.35	49.54 (*0.48*)
Stem	$0.002\ Db^{1.369}\ H^{0.457}\ CW^{1.715}$	0.97	90.09	51.47 (*0.24*)
Stump	$10.871\ Db^{1.296}$	0.67	27.54	47.36 (*0.22*)
Coarse roots	$5.081\ Dblc^{1.552}$	0.60	81.26	46.87 (*0.30*)

Standard error in brackets

where *Dblc* is diameter at the base of live crown (cm), *CW* is crown width (cm), *Db* is basal diameter (cm) and *H* is total seedling height (cm).

Carbon concentration was higher in aboveground biomass fractions (from 49.50 percent in needles to 51.47 percent in stem) than in belowground components (46.87 percent in coarse roots and 47.36 percent in stump).

Shrub biomass

Mean shrub biomass observed in 2x2 plots was 3.81 Mg/ha, being *Pterospartum tridentatum*, *Erica umbelata* and *Halimium lasianthum* subsp. *alysoides* the main species, with mean values of 2.32 Mg/ha, 0.70 Mg/ha and 0.53 Mg/ha respectively.

A positive significant linear relationship ($p<0.05$) was observed between total shrub biomass and the product of shrub height and cover for each plot ($r^2=0.68$) (fig. 1).

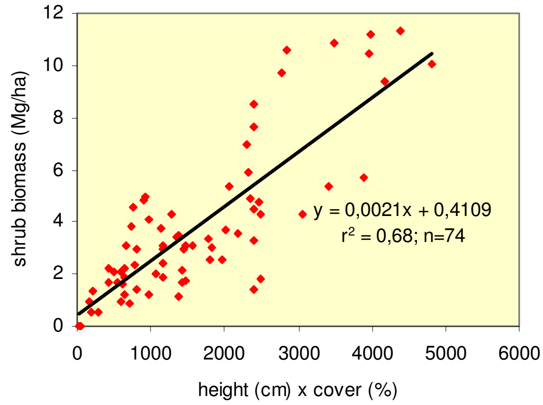


Figure 1 – Relationship between shrub biomass and the product height x cover per plot.

Carbon content

Mean pine seedling biomass was 20.36 Mg/ha (s.e.=0.91). Mean pine seedling carbon content (above- and belowground) was 10.14 Mg/ha (s.e.=0.46) and mean aboveground shrub carbon content was 1.91 Mg/ha (s.e.=0.34), being the mean total (except belowground shrub content) plant carbon conten seven years after fire about 12.05 Mg/ha (s.e.=0.36). Seedling carbon content was negatively related ($p<0.05$) with shrub carbon content in each plot ($r^2=0.52$) (fig. 2).

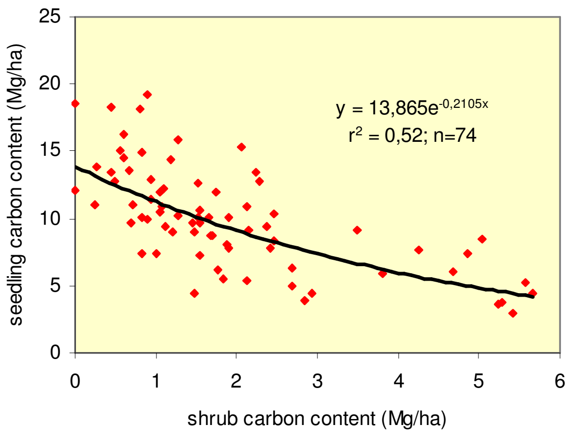
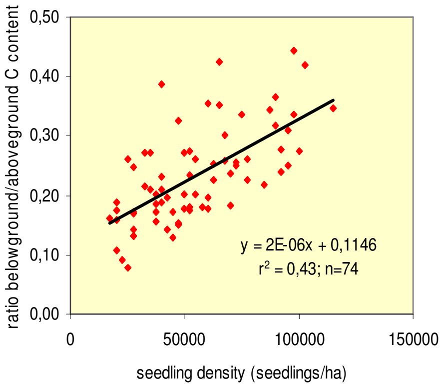


Figure 2 – Relationship between seedling carbon content and shrub carbon content per plot.

The ratio belowground/aboveground (R/S) carbon content was 0.23 (s.e.=0.00002). This ratio was positively related ($p<0.05$) with seedling density, and negatively related with mean seedling diameter at the base of live crown ($p<0.05$) (fig. 3).



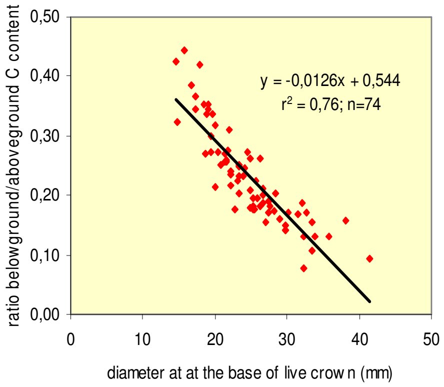


Figure 3 – Relationship between ratio belowground/aboveground carbon content and seedling density (left) and diameter at the base of live crown (right) per plot.

Discussion

High values of coefficients of determination have been found in different studies calculating allometric equations for young pine stands (Oleksyn and others, 1999; Ritson and Sochaki, 2003; Geudens and others, 2004). Lower values of coefficients of determination in root fractions have been observed in other pine studies (Laclau, 2003; Litton and others, 2003) probably due to the difficulty of root extraction resulting in no entire root excavation. Carbon concentration values were of the same range that those reported by Ritson and Sochaki (2003) for the same species, with lowers values for belowground fractions.

High relationship between aboveground shrub biomass and the product of shrub height and cover has been previously reported for other Mediterranean areas (Fernandes and Rego, 1998; Xanthopoulos and Manasi, 2002). Mean shrub biomass was relatively smaller compared with other studies in Mediterranean areas, probably as a consequence of high seedling density.

Mean seedling biomass (and carbon content) was of similar values than those reported in different studies focused in high density young pine stands: 6.66 Mg/ha of biomass in a 8-year-old *Pinus pinaster* stand in Guadalajara – Spain - (Madrigal and others, 2006), 29.7 Mg/ha of biomass in a 10-year-old *Pinus halepensis* stand in France (Montès and others, 2004), 7.92 Mg/ha of biomass in a 4-year-old *Pinus sylvestris* stand in Belgium (Geudens and others, 2004) and between 0.22 and 13.69 Mg/ha of biomass in a 13-year-old *Pinus contorta* stand in USA (Litton and others, 2003). The negative relationship between seedling and shrub carbon content, could reflect the presence of inter – specific competition (Ne'eman and others, 1995).

The R/S value observed in this study was higher than the reported for temperate conifer forests – 0.18 - for Jackson and others (1996). However, juvenile stands generally show higher R/S values than mature forests (Kozlowski and other, 1991). Higher values of this ratio at lower seedling size have been observed in other pine studies (Litton and others, 2003), in which seedlings with greater diameter showed a higher biomass allocation to aboveground tissues. This could explain the positive relationship between this ratio and seedling density, likely due to a greater number of small seedlings in high density plots (Litton and others, 2003).

Conclusions

Stand - replacing fires affect carbon storage, and understanding this process is important for predicting future changes in atmospheric carbon. In this study we observed that shrub competition can negatively affects seedling carbon storage. Seedling allocated more carbon in belowground tissues at higher seedling density and seedling diameters. Allometric equations for juvenile *Pinus pinaster* were developed.

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