Litterfall and growth in three forests in Montseny massif

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ABSTRACT

The nemoral forests of the montane level are especially interesting, because they are on the edge of their distribution. We want to see the influence of some environmental conditions (temperature and rainfall) on the litterfall and growth, in three kinds of these forests. The Montseny massif in the NE part of Iberian Peninsula, with a maximum altitude of 1.706 m, has a strong gradient of climate and vegetation, from the lowlands to the top of the mountains. We analyze three forests in the Montseny massif, two of them are composed by deciduous species not very extensive in the region (beech and sessile oak) and the other is a Mediterranean species, the mountain holm oak. We recollect data since 2007, monthly litterfall was measured and radial growth, and correlated with the climate of the study area. Our results shows that *Fagus sylvatica* recorded the biggest drop in annual litterfall (6.3 Mg / ha), followed by *Q. ilex* (5.3 Mg / ha) and *Q. petraea* (4.6 Mg / ha) all recorded values are similar to those observed in other forests and mountains of the same state of maturity equivalent. The start of the growth took place in the spring and *Quercus* spp. occurred more gradually than in *F. sylvatica*. We found that the accumulated rainfall in late spring has had a positive effect specially on the growth of *Quercus* species while the effect of summer temperature has been especially prominent in beech. Mediterranean species show larger fluctuations growth than Central European ones in response to lower water availability.

Keywords: radial growth, litterfall, *Fagus sylvatica*, *Quercus ilex*, *Quercus petraea*, response to climatic variables

Introduction

Numerous mountain areas in the Iberian Peninsula are susceptible to the effects of climate change and some have been affected by recent summer droughts. In forests, the most serious effects are detected at the southernmost limits of the ranges of trees such as *Fagus sylvatica L*. (Fotelli et al., 2009) and *Quercus petraea* Matt. Lieb (Aranda et al., 2000). The effects of climate change could prompt species to move to higher altitudes (Peñuelas and Boada, 2003) or provoke the replacement of deciduous species by evergreen Mediterranean species – above all, *Quercus ilex* – that are more resistant to prolonged dry summers. On the other hand, the observed increase in the efficiency of water use in populations of beech in the Iberian Peninsula located in low-lying areas (Jump et al, 2006) that have been subject to intense heat in recent last decades (Peñuelas et al., 2008) demonstrates this species' ability to deal with some of the requirements arising from this new climatic situation.

Thus, in the context of climate change, it is important to know how the most vulnerable species that are located on the edge of their distribution respond to climate variation, and to compare their response with that occurring in species such as *Q. ilex* that have mechanisms that allow them to adapt to the increased water stress that are typical of the Mediterranean region. We want to know the response of the three tree species to the meteorological data in Montseny massif as a representative area of mountains of north east of Iberian Peninsula in order to relate with climatic change.

Material and methods

At the end of spring 2006 three experimental beech plots of 400 m^2 were defined at Coll de Te, while in the sessile and holm oak forest at Marmolers in autumn 2006 three circular plots with a radius of 10 m were defined in each forest type. In each experimental plot forest and floristic parameters were evaluated (Table 1). In summer 2006, five litter traps covering an area of 0.25 m^2 were installed in the Coll de Te beech forest and in the sessile and holm oak forest at Marmolers.

To study tree growth, in May 2007 we placed a dendrometer band (Fig. 1) on five trees over 10 cm selected in each plot in the beech forest to monitor monthly the trees' radial growth. The dendrometers were placed on the oak trees following the same guidelines in early June 2007. In 2008 we installed three electronic dendrometers in the

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beech and oak forests in order to record the continuous growth of the different tree types. Data were recorded in every month.

During autumn 2008 at Marmolers forest was cleared for firewood, which meant that all the traps and dendrometers had to be removed. They were subsequently re-installed to conduct a new inventory of the tree layer.

The differences in annual growth were obtained using an analysis of variance (one-way ANOVA) in which the factor considered was the year. This analysis was conducted in order to compare the response of these variables to dry and wet years.

Prior to the statistical analysis the Shapiro-Wilk test was applied to test for normality. Where necessary, the initial data was transformed to reach a normal distribution. In case of significant differences in the ANOVA and/or if the data did not meet the assumption of heteroscedasticity, post-hoc tests (Tukey HSD if data were homoscedastic and Games-Howell if heteroscedastic) were employed in order to determine significant differences between years.

The effect of meteorological variables on the production of total litterfall and leaf growth, and the increase in basal area (BAI) was studied monthly using a Pearson linear correlation. Meteorological data came from the Viladrau meteorological station (451837X, 4632388Y)

Results

Composition of the litterfall

The data obtained show that the annual litterfall production was greatest in *F. sylvatica* (6.3 Mg/ha), followed by *Q. petraea* (5.3 Mg/ha) and *Q. ilex* (4.6 Mg/ha). Holm oak leaves represented 66.52 % ± 6.38% of the total litterfall, while in the deciduous species the leaf litterfall fraction had values of 73% ± 9.81 % in *Q. petraea* and 72.31 % ± 4.74 % in *F. sylvatica*. The observed percentage for fruit in the litterfall in the oak woods was 8% but about 14% in the beech and holm oak forests.

Figure 2 shows the monthly variations in litterfall for the deciduous species. The main peaks are due to leaf fall and usually occur in October or November. Since 2009 maximum leaf fall in *Fagus sylvatica* has occurred just before *Quercus petraea*. There were two other remarkable peaks, one in September 2008 and the other in May 2009

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In the mountain holm oak forest, however, there are two main peaks in the intra-year litterfall curve (Fig. 3). The first takes place in the spring, in May-June, and the second usually in November

The second peak in the intra-year litterfall occurs in large part due to leaf fall in *Q. petraea*.

Although statistically significant correlations with meteorological variables were not always observed, *Q. ilex* litterfall in spring was negatively correlated with rainfall (Table 2)

Radial growth

Figure 4 illustrates the acquired radial growth patterns in the three different species during the study period. The main radial growth period is usually restricted to spring, best seen in *Quercus ilex* and *Fagus sylvatica*. In addition to the spring peak, a second growth peak usually occurs in autumn.

Positive correlations were observed between radial growth and rainfall in June-July in the oak species (that were significant in *Q. petraea*); nevertheless, in the beech the positive correlation occurred in August (Table 3).

In terms of spring and autumn average temperatures, there was a positive but not significant effect on radial growth in *F. sylvatica*. In summer for *Q. petraea*, radial growth correlates negatively with maximum temperature in June-July. In the case of beech, radial growth is negatively and significantly correlated with maximum temperatures in August.

In addition, it is also worth noting that in deciduous species two opposing tendencies were observed in the annual increase of AB (Fig. 5): although the annual increase is getting smaller in *F. sylvatica*, it is getting greater in *Q. petraea* every year. However, this trend was reversed in 2011 and the increase in AB was greater compared to the previous year in both species.

Discussion

Composition and phenology of the litterfall

In almost all cases, the values for litterfall production were similar to those observed in other forests and mountains with similar degrees of maturity; the exception were the beech forests, in which there was a slightly greater drop in annual litterfall, possibly because the studied beech forest is more mature (Rodà et al., 1999; Verdú, 1984). In all cases, leaves compose the bulk of the litterfall fraction, as has been shown by other studies (Carceller et al., 1989 Rapp et al., 1999; Santa Regina, 1987).

In studies of beech forests in different successional states, Lebret et al. (2001) conclude that the total percentage of leaf litterfall in mature beech forests is around 70%, values that match the results of this study and other studies in mature beech forests (Santa Regina et al., 1999).

In a study conducted on 10 different species of trees in very mature woods, Kira and Shide (1967) report that the leaf fraction tends to represent about 50% of the total litterfall. In the *Q. ilex* forest, the fruit percentage was slightly higher than that found by Bellot et al. (1992) (6.3%) in the Prades holm oak forest (NE Spain), probably because of the more northern situation of the Montseny Massif and its more humid and stable climate than Prades. Nevertheless, apart from the influence of weather conditions, we should also take into account the great inter-annual variability in fruit production in the studied species, since years of abundance are often followed by years of low production.

Both *F. sylvatica* and *Q. petraea* (Fig. 2) had a seasonal pattern in their monthly foliar litterfall, which is consistent with the typical pattern of leaf fall in deciduous species (Verdú et al., 1984; Witkamp and Van der Drift, 1961) in cold and temperate regions in the northern hemisphere, where peak leaf fall occurs in autumn. However, the species differ in the month of maximum leaf fall, which occurs normally in November in the *Q. petraea* forests but varies in *F. sylvatica* forests according to the year. This is due to the fact that the beech is more sensitive to climatic conditions.

In the mountain holm oak forest, however, there are two peaks in the intra-year litterfall (Fig. 3). The first takes place in the spring in May and June after the first sprouting and is common in Mediterranean species (Caritat et al., 1996). This leaf fall is interpreted to be an adaptation by *Q. ilex* to the Mediterranean climate and its summer drought, and an attempt by trees to minimize water loss through transpiration during the period of greatest stress (Escudero et al. 1987). The second peak in the intra-year litterfall occurs in large part due to leaf fall in *Q. petraea*. As various authors have observed in other Mediterranean forests (Leonardi et al., 1992; Bussoti et al., 2003; Caritat et al., 2006), a second leaf fall may occur in October and November. This autumn leaf fall in Mediterranean evergreen species is related to a secondary sprouting

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that follows the summer drought and comes before the arrival of the winter frosts if weather conditions are favourable (i.e. rainfall in September and October) Bellot et al. (1992).

In addition, we observed that in relation to the two peaks in leaf fall, evergreen species decline more gradually than deciduous species. The cost of producing evergreen leaves is higher than that of deciduous leaves due to the greater concentration of lignin (Aerts, 1995). Thus, the higher production costs of evergreen leaves ensure that they are preserved for longer than in deciduous trees.

Influence of meteorological variables on litterfall.

For *Quercus* spp., falling *Q. ilex* leaves in spring correlated negatively with rainfall (Table 2) since *a priori* the lack of precipitation favours leaf fall. This is interpreted as an adaptation by this species to water deficit since leaf fall reduces water loss through transpiration during summer drought. Also in El Montseny, in the evergreen *Q. suber* forest at Polell, there was a positive correlation between litterfall and temperature as warmer years had greater litterfall (Caritat et al. 2006).

Furthermore, when there is greater rainfall, more leaf fall occurs in deciduous trees (although values were not statistically significant). Increased rainfall encourages more intense sprouting and an increase in leaf production. In the case of *F. sylvatica*, leaf fall in autumn correlates negatively with temperature, thereby demonstrating this tree's sensitivity to high temperatures. These results are similar to those obtained by Gloaguen and Touffet (1982). To verify these trends a longer-term study of litterfall in these forests in relation to climate variables would be necessary.

Influence of meteorological variables on radial growth.

Radial growth in the Mediterranean is usually restricted to spring and part of autumn, when rainfall is most abundant and temperatures are moderate (Montserrat Martin et al., 2009). The *F. sylvatica* growth pattern was the most consistent during the study period and the maximum growth peak was found to occurs usually in June and July.

As mentioned above, in addition to the spring peak, a second growth peak usually occurs in autumn, which is much less important and shorter than in spring and related to favourable weather conditions (i.e. heavy rainfall and no freezing temperatures). In our case, positive correlations were observed between radial growth and rainfall in June-July in the oak trees, whereas in beech the positive correlation was in August (Table 3). This may explain why *Q. petraea* and *Q. ilex* grow on dry slopes where the soil can retain more moisture in rainy springs. *F. sylvatica*, on the other hand, lives in an area that is regularly wet in spring and so steady growth every year is possible; nevertheless, it does still suffer in August in dry summers. Our results therefore are consistent with those found in temperate forests in Italy (Nola 1991), in which there is also a positive correlation between summer precipitation and radial growth.

In terms of spring and autumn temperatures, there is a positive effect on radial growth in *F. sylvatica* as it grows in relatively wet sites. In northern Spain, Pérez (1993) also found a positive effect for spring temperature in *Q. robur* and *Q. petraea*. In the case of beech, temperature in August is negatively correlated with radial growth since too-high temperatures inhibit tree growth, as reported by Gutierrez (1988).

Conclusions

The drop in annual litterfall in the studied forests is similar to that observed in other studies in the Montseny massif and in other European forests. The litterfall phenology of all three studied species resembles the typical patterns described in the temperate forests of the northern hemisphere.

In *Q. ilex* the observed links between leaf fall and climatic variables was as would be expected in a typical Mediterranean species, in which low rainfall and high temperatures favour leaf fall in spring. In deciduous species, however, the opposite is true, above all in *F. sylvatica.*

The pattern of annual radial growth or basal area was fairly even throughout the study period, especially in the case of *F. sylvatica*, and the largest increases occurred in June and July. The *Quercus* spp. species were highly sensitive to water availability in early summer. The radial growth of *Q. petraea* correlated positively and significantly with rainfall in June and July. Moreover, the special sensitivity of *F. sylvatica* to high temperatures was made evident by the significant negative effect of the average maximum temperature on growth in August.

In *F. sylvatica* there was a reduction in the average annual increase of the basal area for three consecutive years that could be explained by the climatic conditions in specific years of the study period, and which, overall, could be attributed to temperature

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trends at work in El Montseny in recent years. This growth enables us to predict that under current climatic conditions, with an increase in temperature following the tendencies detected in El Montseny, *F. sylvatica* will move to higher levels where thermal conditions are more suitable. In addition, it will probably be replaced at lower levels by Mediterranean species such as *Quercus ilex* that possess more mechanisms for dealing with fluctuations in water availability and have greater resilience to higher temperatures.

Overall, in the context of climate change, differential responses to meteorological conditions in the forest species studied need to be taken into consideration in the conservation and evolution towards maturity of these forest ecosystems.

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Tables and figures

Table 1: Characteristics of the three studied forests

	Fagus sylvatica	***Quercus petraea***	***Quercus ilex***
UTM	456102X,4626901Y	457180X,4627004Y	457206X, 4627098Y
Altitude(ma.m.s.l.)	1000	850	850
Orientation	East	South-east	South-east
Slope	23-29%	18-21%	24-28%
Substratum	Granodiorite	Granodiorite	Granodiorite
Soil depth	>40 cm	24-32cm	22-30cm
Tree level	*F. sylvatica* 100%	*Q. petraea* 93%	*Q. ilex* 75%
		*Castanea sativa*7%	*Q. petraea* 25%
Density n/ha	408±38	2601±32	732±32
Biomass Mg/ha	237±38	217±9	76±25

Table 2: Pearson coefficient between spring weather variables of precipitation and temperature, and the leaves fraction and total litterfall of Q.ilex, Q.petraea and F.sylvatica during Spring or Autum).

Forestry variable	**Sp period data**	**Sp**	**Spring**	
			Temperature	**Precipitation**
Total litterfall	Spring	*Q. ilex*	0,14	-0,959**
	Autum	*F.sylvativa*	-0,442	0,272
		Q.petraea	0,388	0,643
Leaves	Spring	*Q.ilex*	0,348	-0,653
	Autum	*F.sylvativa*	-0,531	0,407
		Q.petraea	0,594	0,675

** p-value < 0,01

Table 3: Pearson correlation between Basal Area Increment (BAI) of F. sylvatica, Q. petraea and Q. ilex, and the variables of average temperature (T), highest average temperature (Tmax) and precipitation (P).

Weather variable	**Year period**	**Basal Area Increment (BAI)**		
		F. sylvatica	*Q. petraea*	*Q. ilex*
T	APR-MAY	0,569	0,135	-0,002
	JUN-JUL	0,073	-0,841	-0,575
	AUG	-0,726	0,32	-0,054
	SEP-NOV	0,511	0,127	0,187
Tmax	APR-MAY	0,798	0,356	0,166
	JUN-JUL	-0,139	-0,747	-0,572
	AUG	-0,832*	0,454	-0,098
	SEP-NOV	0,069	0,534	-0,445
P	APR-MAY	-0,804	-0,357	-0,139
	JUN-JUL	-0,102	0,881*	0,649
	AUG	0,729	-0,233	0,144
	SEP-NOV	0,437	-0,191	0,449

*p-value < 0.05

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Figure 1: Beech tree at Coll de Te with dendrometers

360 Figure 2: Monthly litterfall registered in the Coll de Te beech wood and in the oak forest at Marmolers

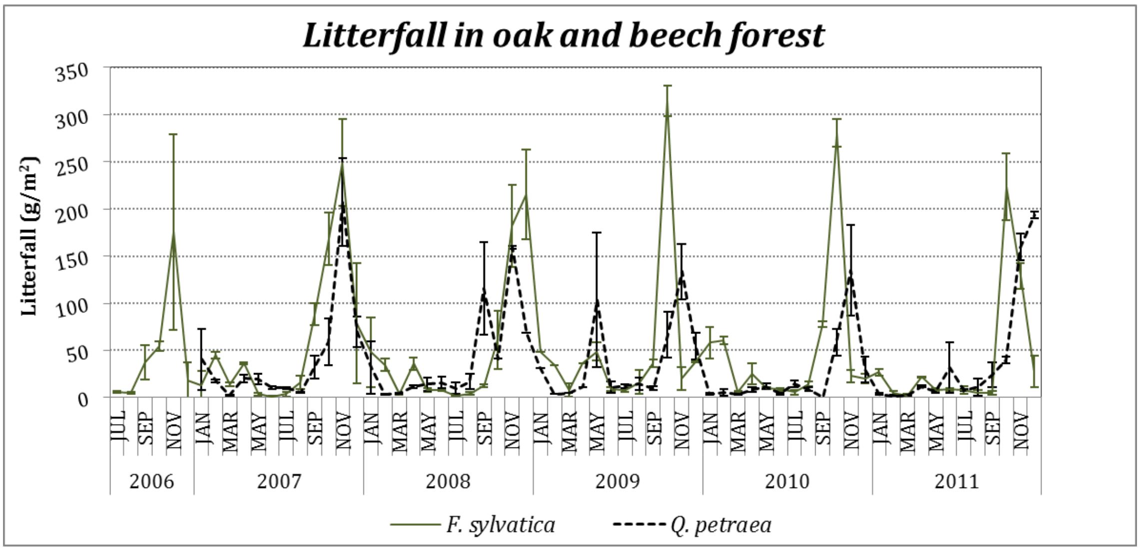

Figure 3: Monthly total litterfall recorded in the holm oak forest at Marmolers. The bars correspond to the standard deviation (SD). There were no data for the second half of 2008.

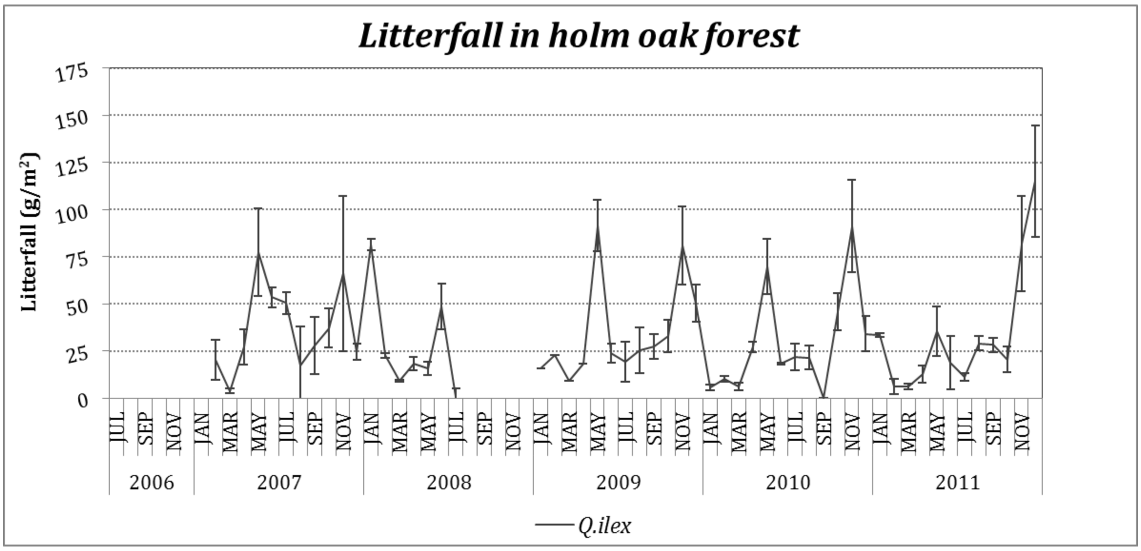

Figure 4: Record of the cumulative radial growth (Basal Area Increment – BAI) at the Marmolers sessile (A) and holm (B) oak forests, and Coll de Te beech forest (C).

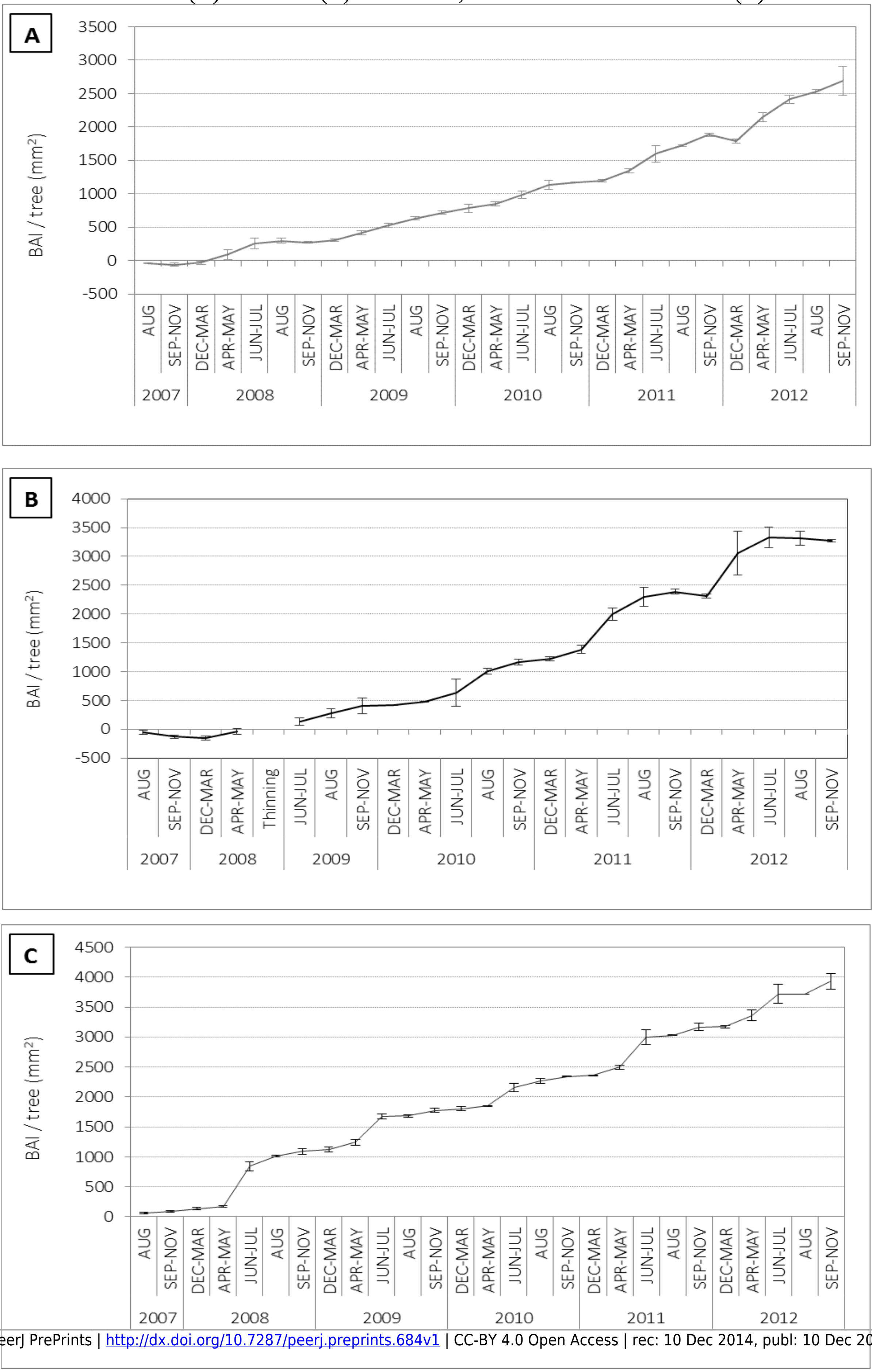

Figure 5: Annual increase in basal area (BAI) expressed in mm2 during the period August-July (of the following year). Bars: standard deviation plots (± SD)