

# Litter decomposition across a post-fire chronosequence in Mediterranean pine forests.

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**Abstract** Litter decomposition is a key component of the global carbon cycle, and a process of great importance for the function of forest ecosystems. The rate of litter decomposition shows significant variation both between different forest types and within forests of different successional stage. Considering that global change is expected to shift (directly) the abiotic conditions experienced by trees in a stand as well as (indirectly) the structure of stands, a sound understanding of how litter decomposition varies within forests of the same dominant species and environmental conditions but of different structure is important. To explore this question, we applied the litterbag method within the permanent forest plot monitoring network established on the island of Lesbos. We selected four *Pinus brutia* dominated plots under similar environmental conditions, across a fire chronosequence ranging from 15 to 90 years. Twenty-four litterbags were buried in each plot and sequentially removed after specific time periods. The percentage of the initial remaining mass was used as a response variable and modeled with a negative exponential and an asymptotic curve. Our findings show that the rate of litter decomposition increases with time since fire and standing biomass of the plot, highlighting the importance of maintaining mature forests in Mediterranean ecoregions.

**Keywords:** decomposition, *Pinus brutia*, C-cycle, stand structure

## 1. Introduction

Litter decomposition refers to the processes of physical and chemical break down of litter mass to its elementary chemical ingredients (Aerts, 1997). Litter decomposition is a key component of the global carbon cycle, and a process of great importance for the function of forest ecosystems (Krisna and Mohan 2017). The global patterns of litter decomposition have been extensively studied and several factors that control its dynamics have been identified, including atmospheric temperature and humidity, soil mechanical and chemical characteristics as well as the organismal synthesis of the soil community (Couteaux et al. 1995). In general litter decomposition increases with temperature (Salinas et al. 2011), nutrient concentration (Ferreira et al. 2015) although interactive effects could arise with air and soil humidity, litter quality and lignin content (Butenschoten 2011). At the global

scale, climate is considered the major factor that controls decomposition rates (Zhang et al. 2008). At smaller scales, other factors such as litter chemistry, soil microorganisms and microenvironmental conditions could be equally or even more important (Herman et al., 2008). Different forest types with different litterfall properties (including litter quantity and quality), could also control the synthesis of soil organisms and consequently the process of decomposition. Even within the same forest type, stands of different structure, could exhibit varying decomposition rates due to variation in litterfall rate and soil microenvironmental conditions.

Forest fires, frequently reset stand-dynamics and thus stand structure, and are expected to increase in frequency and severity because of global change, particularly in Mediterranean ecosystems (Karali et al. 2014). Considering changes in forest vegetation/biomass quantity and quality and soil degradation after fires, it is important to understand how litter decomposition could shift under warmer and more fire prone environmental conditions.

Focusing on Mediterranean pine forests we setup an experimental design to understand how litter decomposition varies in forest ecosystems along a post-fire chronosequence. The primary goal of this study is to explore the magnitude of variation in decomposition rates in stands with the same dominant species and under similar environmental conditions but of different structure. Our research question mainly focusses on potential variation in litter decomposition that could be related to differences in stand structure and soil characteristics and not climate or litter quality.

## 2. Materials and methods

Our study took place within the permanent forest plot monitoring network on the island of Lesbos, maintained by the Biodiversity Conservation Lab of the Department of Environment. Four plots of different post-fire age across the *Pinus brutia* forest ecosystem of the island have been used. Plots (Table 1) are established across a post-fire chronosequence (approximately 15, 40, 70, 90 years), on similar elevation (166 to 306 m above sea level) and soil parental material (Ophiolithic bedrock). All plots are characterized by a mild slope (under 10%) and a

similar Mediterranean climate, with a mean annual temperature of 18 °C and annual precipitation of 645 mm. However due to their discrete post-fire age, the four plots are different in terms of tree density, size-class distribution, total standing biomass, and canopy closure as expressed by their leaf area index (LAI).

**Table 1.** Stand structure characteristics of the plots. Diameter at breast height (dbh, cm), Leaf Area Index (LAI, m<sup>2</sup>m<sup>-2</sup>)

Plot	Plot age	Trees/Plot	Mean dbh	Slope %	LAI (m <sup>2</sup> m <sup>-2</sup> )
AMAL	15	99	1.98	10	0.9
PEV	40	300	7.46	5	1.77
LML	70	62	20.72	10	2.13
ACHL	90	21	43.36	0	1.79

Undecomposed needles from litterfall traps were collected from each plot in July 2019. In the laboratory the collected needles were left to air dry, and a subsample was oven dried to estimate their field humidity as a percentage of their mass. The air-dried needles were subsequently weighted and inserted in 24 (0.5 mm mesh) litterbags of similar weight, for each plot. Every bag was labeled with the initial mass of needles and in September 2019 the litterbags were buried under O<sub>1</sub> horizon, in two different blocks in every plot. Two bags, one from each block, were retrieved at regular time intervals. Retrieved bags were oven dried and the remaining mass of the needles was measured, excluding moisture from the initial weight. Mass difference was then expressed, as the average percentage of remaining weight from the initial litterbag mass, taking the average of the two retrieved litterbags per plot.

To understand different aspects of the litter decomposition process two models were fitted to the dataset using non-linear least squares regression and the Gauss-Newton algorithm (*function: nls*).

The single exponential model (Olson 1963) is a first-order kinetics model assuming a constant decomposition rate  $k_c$ , irrespective of litter mass remaining at any time (Berg and McClaugherty 2008):

$$M_t = M_o \exp(-k_c \cdot t) \quad [1]$$

with  $M_t$  the percentage of the remaining litter mass after time  $t$ .

The asymptotic model, considers that decomposition proceeds progressively slower, and may even not approach zero, as decay progresses (Berg and McClaugherty 2014) and thus expresses  $M_t$  as:

$$M = A + (100 - A) \cdot \exp(-k_o \cdot t) \quad [2]$$

with  $A$  the accumulated mass loss at ( $t = \infty$ ) and  $k_o$  the decomposition rate at the beginning of decay. Variation in the plot specific decomposition rates ( $k_c$  and  $k_o$ ) as well as  $A$ , was subsequently explored in terms of variation in plot level soil properties and stand structure characteristics (Table 1 and 2) using correlation analysis.

All data analysis and graphs were made in R (R Core Development Team, 2021).

**Table 2.** Soil properties of the study plots. Electrical Conductivity (EC, µS/cm), Soil Organic Carbon (SOC, g%), soil nitrogen (N, g%), Carbon and Nitrogen of microorganisms (Cmic, Nmic, µg/g) respectively.

Plot	pH	EC	SOC	N	Cmic	Nmic
ACHL	6.98	131	4.29	21.7	65.7	0.034
AMAL	6.82	188	4.81	25.2	30.9	0.017
LML	6.74	220	12.67	31.8	49.9	0.047
PEV	6.96	150	7.49	26.4	62.5	0.026

### 3. Results and Discussion

At the end of the experiment the percentage of the remaining biomass was lower in the 70 years old stand (LML: 50%) and higher in the 40 years old stand (PEV: 63%), with similar percentages of remaining litter found in the youngest and oldest stand (AMAL: 56% and ACHL: 56%).

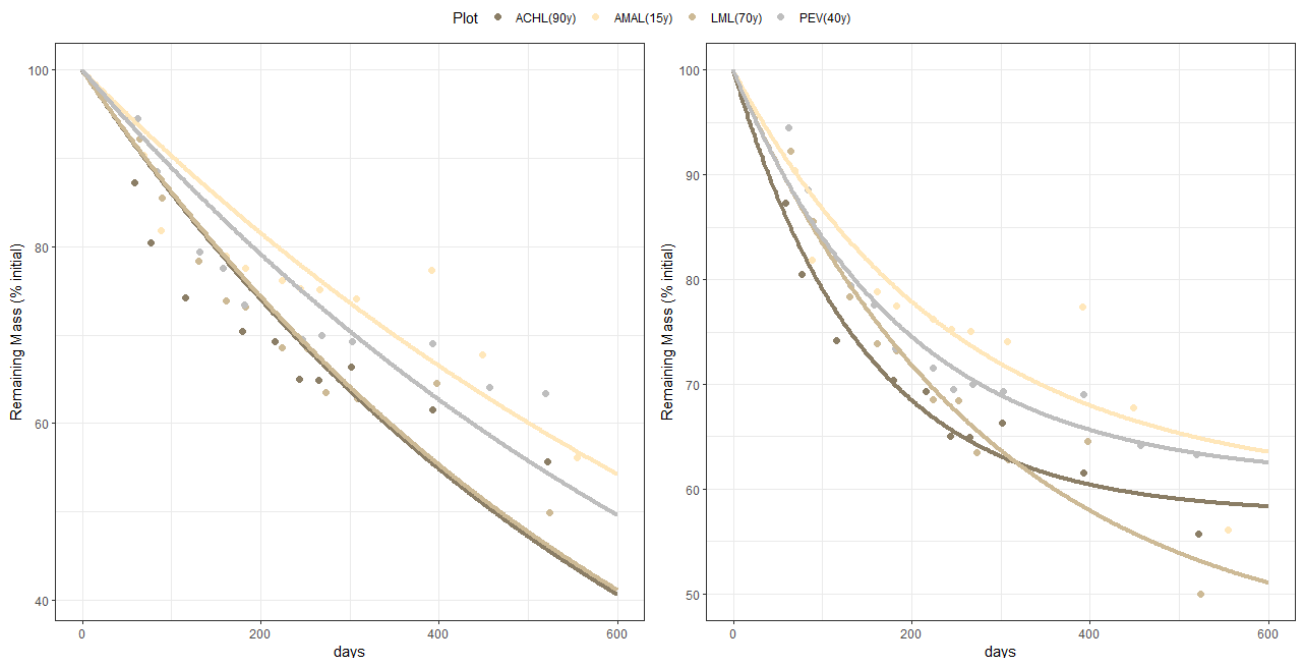
The plot specific litter decomposition rates ( $k_c$ 's) inferred from the negative exponential model were estimated at 0.0010, 0.0012, 0.0015 and 0.0015 (% d<sup>-1</sup>) for the 15, 40, 70 and 90 years old stands respectively (Figure 1 – left panel). These results suggest an increasing “constant” decomposition rate with stand age, although after inspecting the fits an overestimation of the decomposition rates, particularly at the latter stages of the process, was observed.

The asymptotic model seems to better fit the data (Figure 1 - right panel). Litter decomposition rate at the beginning of the process ( $k_o$ ) was estimated at 0.0040, 0.0052, 0.0035 and 0.0068 (% d<sup>-1</sup>) for the 15, 40, 70 and 90 years old stands respectively, indicating no clear trend with stand age, although the older stand indicated the highest  $k_o$ . The accumulated mass loss estimates ( $A$ ) from the second model yielded a value of 59.9, 60.8, 44.3 and 57.6 (%) for the 15, 40, 70 and 90 years old stands respectively, in accordance with the observed remaining litter percentages, with the highest mass loss found in the 70 years old stand.

There are not many studies exploring the impacts of changing stand structure on litter decomposition when the dominant tree species remains the same, i.e., “mimicking” the effects of changing stand structure on decomposition. Most studies explore how changes in species synthesis and thus litter chemical composition can affect decomposition (for example Jacob et al. (2010)). A recent study in *Pinus sylvestris* stands in Turkey, examining the effect of stand structure and exposure on litter decomposition, found that open canopy stands had a higher decomposition rate compared to moderately dense stands (Comez et al. 2021). Our study seems at a first glance to contrast these findings as in our case closer stands indicated higher decomposition rates.

However, both studies need to be considered in terms of the main driving factors of litter decomposition in Mediterranean ecosystems. Incerti et al. (2011) modeled litter decomposition rate primarily as a function of temperature and litter moisture, which should be related with the energy balance at the forest floor. Both responses are approximated with parabolic functions, having optimum rates at intermediate temperature and litter moisture. In relatively cold stands (such as *P. sylvestris*, found at higher elevation), canopy opening should result in greater amounts of radiation reaching the forest floor and thus higher temperature that could accelerate litter decomposition. On the other hand, at relatively drier stands (such as *P. brutia*, found at lower elevation) canopy closure should result in lower amounts of radiative energy reaching the forest floor and thus a higher litter moisture content, which in addition with adequate temperature could accelerate litter decomposition. This suggestion seems to be in accordance with a positive although not significant correlation between  $k_C$  and stand level LAI ( $r=0.83$ ,  $p=0.173$ ) identified in our dataset. Increasing the number of study plots could elucidate whether our hypothesis could be verified.

On the other hand, the initial litter decomposition rates ( $k_0$ ) were strongly correlated with soil characteristics such as pH ( $r=0.92$ ,  $p=0.076$ ), suggesting that at the initial stages of the process soil properties may play a significant role. We note however that variation in pH is rather small within our study plots and thus these relationships might not necessarily reflect causal relationships. The accumulated mass loss was strongly correlated with the ratio of C:N microbial biomass ( $r=0.91$ ,  $p=0.086$ ). Higher N content and thus lower  $C_{mic}:N_{mic}$  seems to accelerate early stage decomposition due to higher microbial nutrient demand (Moorhead and Sinsabaugh 2006), leading for example the LML plot to a lower  $A$  over the time course of our experiment. Variation in  $C_{mic}:N_{mic}$  reflect different soil community synthesis in terms of fungi and bacteria abundance, that control decomposing efficiency of the more recalcitrant litter components. Thus, even within stands of the same dominant species, changes in organic matter controlling both pH and relative C and N availability, could affect both the rate with which the process of decomposition initiates, as well as the non-decomposable litter proportion.



**Figure 1.** Remaining biomass (% of initial) in relation to time. Dots are observed values for the four plots and lines represent the fits from the negative exponential (left) and a symptotic (right panel) models.

#### 4. Conclusions

Our findings show that the rate of litter decomposition increases with time since fire and standing biomass of the plot, highlighting the importance of maintaining mature forests in Mediterranean ecoregions. Interactive effects between abiotic and biotic factors may shift both

the rate and efficiency of the process of litter decomposition.

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