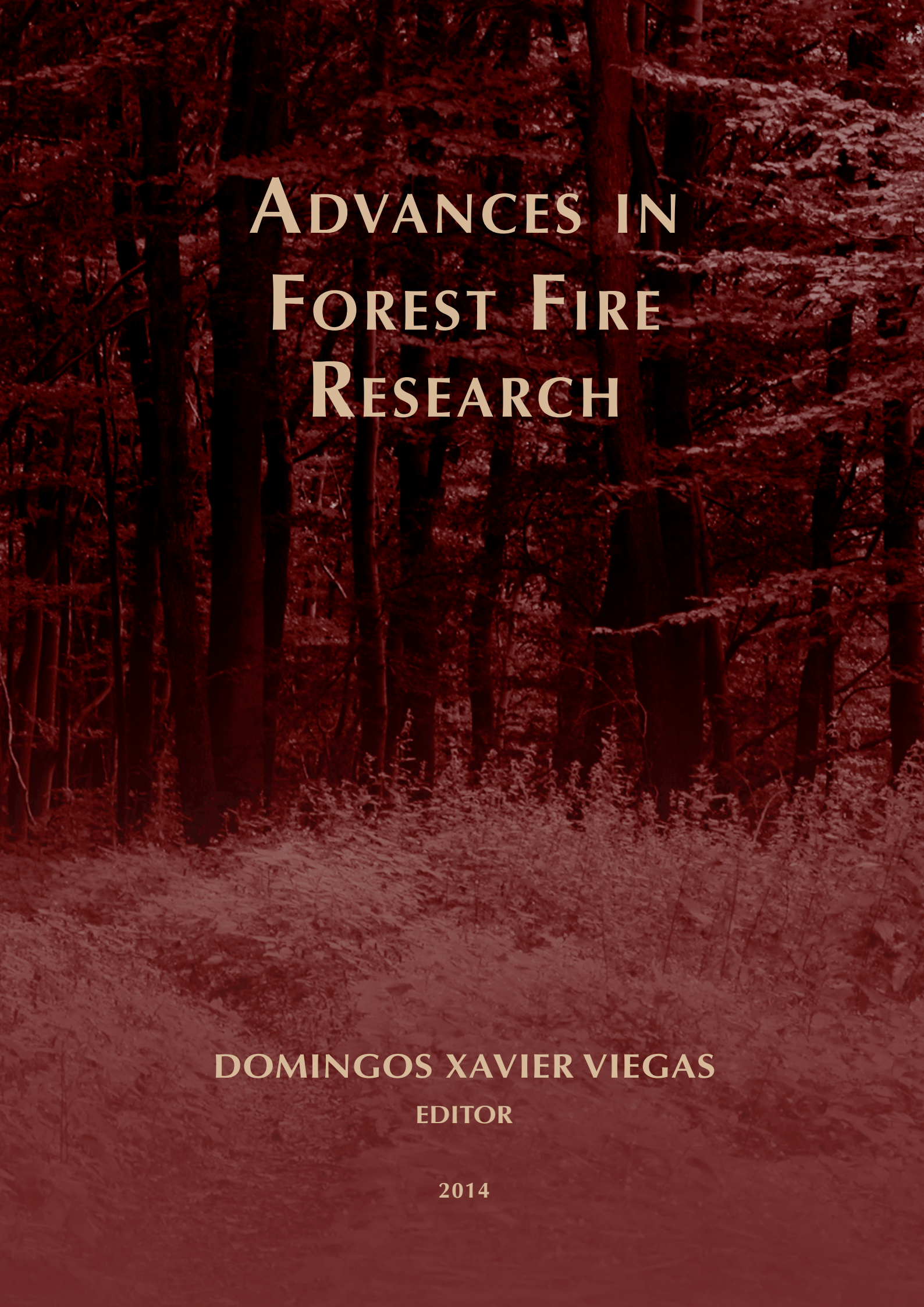

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Monitoring post-fire forest regeneration of *Pinus brutia* in North Lebanon

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Abstract
Forest fires represent a major threat to Lebanon's forests. More precisely, *Pinus brutia* forests, which occupy relatively large areas in Lebanon, are affected by frequent fire events. Lebanon's National Strategy for forest fire management highlighted the need to facilitate natural forest regeneration and undertake reforestation activities in areas where regeneration is not possible. Accordingly, this study aimed at assessing post-fire regeneration of *Pinus brutia* in the Mediterranean region of North Lebanon. A total of 540 samples of 1x1m² were collected on 18 different sites affected by fires throughout the past 20 years. The density of seedling regeneration was calculated for each plot. The highest regeneration density (10.33 seedlings/m²) was observed on plots that were sampled one year after fire. The regeneration density decreased by 68% on plots sampled four years after fire when compared to plots sampled one year after fire. Also, the plots that were sampled five years after fire showed a 93.8% decrease in regeneration density. This continuous could be attributed to a high mortality rate due to prevailing severe weather conditions and human disturbances. The results highlighted the need to implement efficient post-fire management measures within the first four years after a fire event to decrease the mortality rate of young pine seedlings and to assist in the successful recovery of fire affected sites.

Keywords*: forest fires, post-fire natural regeneration, Pinus brutia*

1. Introduction

Lebanon's forest cover is a unique feature in the semi-arid environment of the Mediterranean. Lebanon's forests play an important role in supporting high biodiversity and providing a variety of environmental goods and services. Nevertheless, several biophysical and anthropogenic factors have shaped biodiversity in Lebanon (MOE/UNDP, ECODIT 2011).
Increasingly, fire occurrence risk was observed in association with high maximum temperatures and long dry seasons (Salloum and Mitri, 2014). Forest fires represent a major and continuous threat to Lebanon's forests (Mitri *et al*., 2014). In this context, monitoring post-fire regeneration of *Pinus brutia* is expected to support National efforts in restoring healthy ecological conditions of burned forest lands by providing useful and insightful information about the status of natural regeneration after fire (Mitri and Fiorucci, 2012).
Lebanon's National Strategy for forest fire management clearly indicated the need to facilitate natural forest regeneration and undertake reforestation activities in areas where regeneration is not possible (MOE/AFDC, 2009). Until present, Lebanon lacks comprehensive studies for assessing trends in post-fire forest regeneration. Accordingly, the aim of this study was to assess post-fire regeneration of *Pinus brutia* in North Lebanon.

2. Study area and dataset description

Lebanon is situated on the eastern shores of the Mediterranean. The country is characterized by its Mediterranean climate with warm and dry summer and cool and wet winters. Forests in Lebanon cover around 139,376 ha which accounts for 13.3 % of the Lebanese territory. Coniferous forests occupy 31

% of the total forest cover (MOE/UNDP/ECODIT, 2011). More specifically, pine forests including *Pinus pinea*, *Pinus brutia*, and *Pinus halepensis* are mostly found on the western slopes of the Mount Lebanon chain and they are constantly affected by fire events.
During the year of 2013, sampling of *Pinus brutia* fire affected forests was conducted on 8 different fire sites located between 500 m and 1000 m above sea level in North Lebanon (Table 1). A total of 540 samples of 1x1m² were collected and the number and height of seedlings was recorded for each sample. Historical weather data showed that around 95% of the annual precipitation fall between October and April. The average rainfall in this region has an average 1210 mm per year (MOE/UNDP/ECODIT, 2011).

Table 1. Characteristics of fire affected sites

Year of fire	**Slope percent**	**Elevation (m)**	**Aspect**
1993	30	703	North East
2004	5	710	West
2006	45	722	South
2007	30	794	North west
2007	10	416	South west
2008	15	642	North East
2009	30	670	South east
2012	45	1139	North east

3. Methods

3.1. Field sampling

The field sampling comprised surveying 20x20m plots. Each plot comprised three different locations of sampling across the slope (namely, top, middle, and bottom). A total of 30 samples of 1m² were collected within each plot using the belt transect sampling method. The length of the belt transect was 20 meters and the sampling interval was 5 meters. A quadrat of 1 m x 1 m was placed on each side of the line at the interval level. Accordingly, the number and height of individual seedlings were collected.

3.2. Statistical analysis of field data

The calculation of the regeneration density was developed based on the number of seedlings per square meter (Equation 1), an approach that was also used by Titsoni (1997).

$$\frac{\Sigma \text{ number of seedlings}}{\text{Total number of plots}} \qquad \text{Equation 1}$$

Consequently, the variation in the post-fire regeneration density of *Pinus brutia* based on descriptive statistics, and the average regeneration density was calculated for each year. ANOVA-stepwise analysis was applied to investigate significant changes in regeneration density and height of seedlings throughout the years.

4. Results and discussion

The highest regeneration density (average of 10.33 seedlings/m²) was recorded on plots that were surveyed one year after fire. This could be attributed to seed availability on site and lack of long-term natural stresses and human disturbances (Figure 1).

Sites surveyed three years after fire showed a decreased density by 68% (7.11 seedlings/m²) when compared to the results of sites surveyed one year after fire. Following the same comparison approach, sites sampled five years after fire showed an abrupt decrease in the regeneration rate (0.44 seedlings/m²), while sites sampled six years after fire showed only 0.22 seedlings/m². These gradual decreases in regeneration density could be attributed to both environmental and anthropogenic conditions including severe climatic conditions, human disturbances, and the effect of local environmental characteristics of the sites. Other factors such as fire characteristics (fire severity), could also affect regeneration density of *Pinus brutia* (Pausas *et al*., 2008).
Finally, the results from plots sampled twenty years after fire showed a regeneration density of 1 seedling/m². This could be attributed either to insignificant variation in regeneration density or to a continuous enrichment of young seedlings from the surrounding forested areas (Tsitsoni, 1997).

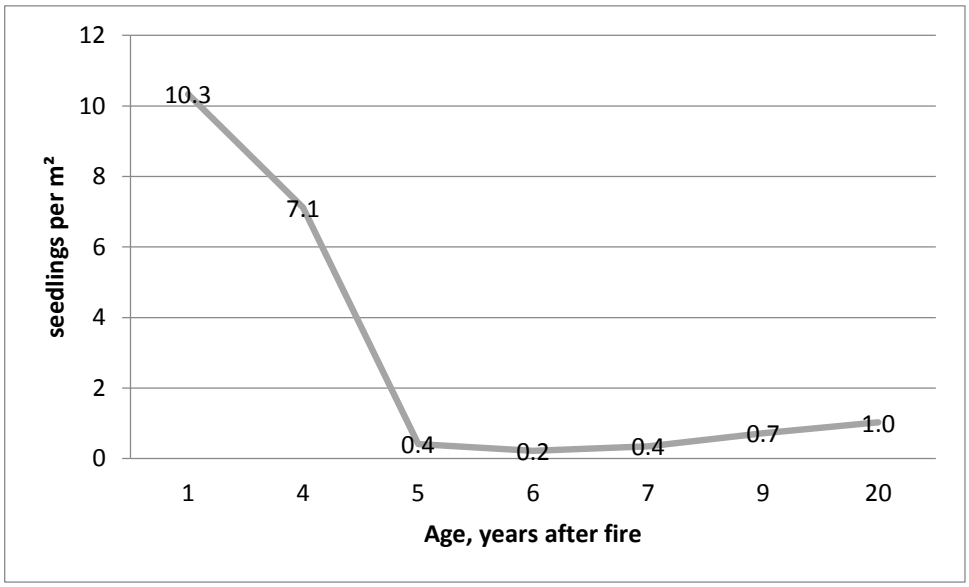

Figure 1. Multi-temporal rate of regeneration density of Pinus brutia

The regression analysis showed post-fire average height increment of 9.26 cm (Figure 2), while other studies in the Mediterranean showed an average growth of 5-20 cm per year (Neyisci, 1989; Thanos *et al*., 1989; Spanos, 1994; Spanos el al., 2000).

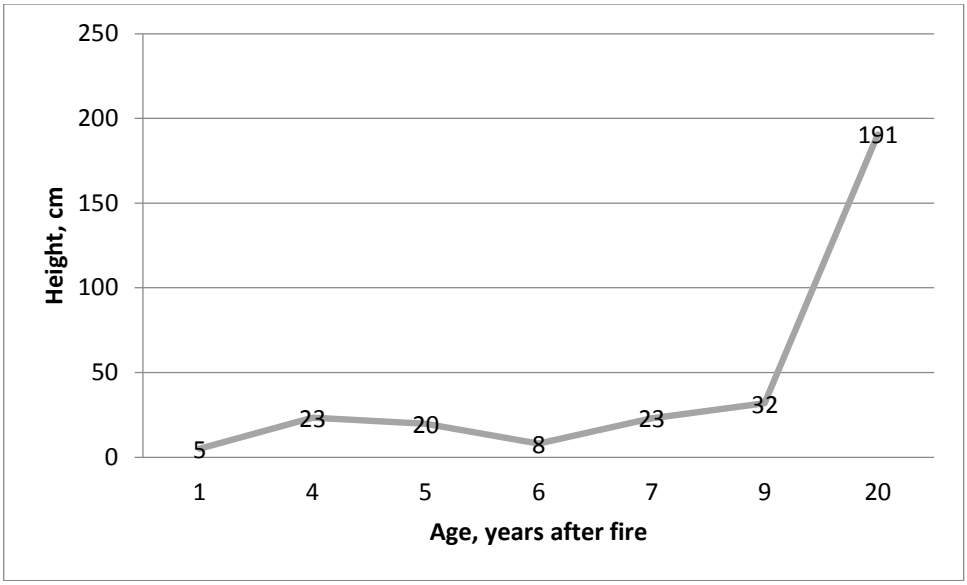

Figure 2 Post-fire variation of average seedling height

5. Conclusions

The highest regeneration density (10.33 seedlings/m²) was observed on plots that were sampled one year after fire. When compared to plots sampled five years after fire, the regeneration density abruptly decreased to 0.44 seedlings/m².

In the light of these findings, it is essentially important to invest more post-fire restoration efforts in assisting natural regeneration in order to promote natural recovery of pine burned forests. The implementation of certain protection measures during the first two years after a fire event is expected to facilitate a higher survival rate of established seedlings. This is expected to be a cost saving initiative in comparison to costly reforestation campaigns.

Future work will involve conducting further studies to understand the different factors that affect the natural regeneration of pine forests in Lebanon as an attempt to come out with improved post-fire management initiatives.

6. Acknowledgments

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