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Early post-fire regeneration of a fire-prone subtropical mixed Yunnan pine forest in Southwest China: Effects of pre-fire vegetation, fire severity and topographic factors ☆

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ABSTRACT

Early stages of post-fire regeneration are sensitive to various factors, and can provide critical information for understanding forest responses to fire disturbance and projecting subsequent forest dynamics. Yunnan pine forests are the most widespread conifer forest type in Southwest China, and are frequently threatened by fire disturbance. Post-fire regeneration of this forest type, however, has not been previously studied. In this study, we investigated the early post-fire regeneration in mixed Yunnan pine forests five months after a severe burn in 2013 on Mt. Qinglongling, Yunnan Province, China. We found very active post-fire regeneration in the burned area likely facilitated by ample summer rainfall, with an average regeneration density of $\sim 10^5$ stems ha^{-1}. Species composition of the post-fire regeneration was highly similar to the pre-fire community–the similarity between the pre- and post-fire communities was 0.530 ± 0.222. Elevation, pre-fire community type, and slope position were the three primary factors in the variations in regeneration density and species composition, while the impact of fire severity was low. The regeneration density of *Pinus* species and evergreen broadleaf species showed contrasting patterns across the environmental gradients, and the results implied that Yunnan forests are generally resilient to fire disturbance. The controlling impacts of the pre-fire community on post-fire regeneration are driven by the efficient regenerating strategies of dominant species, and are a comprehensive reflection of habitat conditions, which are primarily mediated by topographic features. Species regeneration strategies and the high resilience of the community to fire disturbance should be taken into account in fire prevention and management approaches for this forest type.

1. Introduction

Fire is a major disturbance shaping the structure and function of many terrestrial ecosystems (Bond and Keeley, 2005; Bowman et al., 2009). Over the past few decades, there has been an increasing global trend of fire disturbance, mainly caused by climate change and human activity (Bowman et al., 2011; Westerling et al. 2011; Oliveira et al., 2014). Ecosystem response to fire disturbance, especially post-fire vegetation regeneration, is a central issue in fire ecology (Ackerly, 2004; Forrestel et al., 2014), and the post-fire environment provides unique field opportunities to test classical theories of disturbance and community succession (Capitanio and Carcaillet, 2008). Understanding disturbance and regeneration processes and the determinants of post-fire vegetation dynamics can also shed light on the management needs of fire-prone ecosystems (Poirazidis et al., 2012; Hibsher et al., 2013).

Previous studies have revealed four major factors that are critical for post-fire regeneration: fire severity (Maia et al., 2012; Smithwick et al., 2012; Crotteau et al., 2013), topography and edaphic conditions (Turner et al., 2003; Greene et al., 2006; Nuñez and Raffaele, 2007; Hibsher et al., 2013; Ascolia et al., 2013), pre-fire vegetation (Broncano and Retana, 2004; Lee et al., 2014), and species life-history strategies (Cowan and Ackerly, 2010). These factors, however, are not completely independent (Maia et al., 2012; Cai et al., 2013), and their interactions may create difficulty for analyses aiming to disentangle the importance of

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different drivers in post-fire vegetation dynamics. For instance, in a deciduous forest in the southern Alps, higher fire severity and lower post-fire regeneration density were both found on south aspects and steeper slopes (Ascolia et al., 2013). In a Mediterranean mixed pine and oak forest, fire severity was also higher on south slopes, whereas slope aspect had no effect on post-fire regeneration (Broncano and Retana, 2004). Currently, there is no consensus about the relative roles of different environmental factors governing post-fire vegetation dynamics. For example, while most studies found fire severity critical for determining the initial regeneration bank (Maia et al., 2012; Crotteau et al., 2013; Lee et al., 2014), Camac et al. (2013) found little impact of fire severity on the post-fire regeneration of two alpine heathlands in Australia. Empirical observations on various environmental contexts are therefore needed to better understand the processes of post-fire regeneration and their determinants.

Wildfire is a primary disturbance type for forest ecosystems in subtropical China, especially in Southwest China (Zheng et al., 1994). Yunnan pine forests, which normally include *Pinus yunnanensis* Franch and its variety *P. yunnanensis* var. *pygmaea* (Hsueh) Hsueh, are one of the most widespread forest types found in Southwest China. They occur in both monocultural plantations and natural mixed stands, and comprise 52% of forest coverage and 32% of the wood stock in Yunnan province (Guo et al., 1999). Yunnan pine forests play a critical role in the Yunnan forestry, providing 90% of the regional wood products (Tang and Zhou, 2007). Areas dominated by Yunnan pine also have some of the highest frequencies of fire disturbance in China (Tang and Zhou, 2007; Dai et al., 2011). Interestingly, almost all fires with identified causes are of anthropogenic origin, according to monitoring data released annually by the government. Numerous studies have characterized fire behavior and fuel distribution in this forest type (Wang et al., 2011, 2013), and investigated the impacts of fire disturbance on biodiversity (Liu et al., 2012; Zhao, 2013). However, little is known about post-fire regeneration of this plant community, and its adaption to fire disturbance.

In April 2013, a large forest fire occurred on a mountain mostly covered by mixed Yunnan pine forests, only 100 km away from Kunming, the capital of Yunnan Province (Fig. 1). The fire covered an area of about 2000 hm^2, approximately 70% of the entire mountain. We conducted a field study of the early stage post-fire regeneration in the burned area, with a focus on the factors influencing vegetation response to this disturbance. Specifically, we aimed to address the following questions: (1) What was the spatial pattern of early post-fire regeneration across the burned forest? (2) Did the species composition of post-fire regeneration significantly differ from that of the pre-fire communities? (3) How did fire severity, pre-fire canopy composition, and topography contribute to the

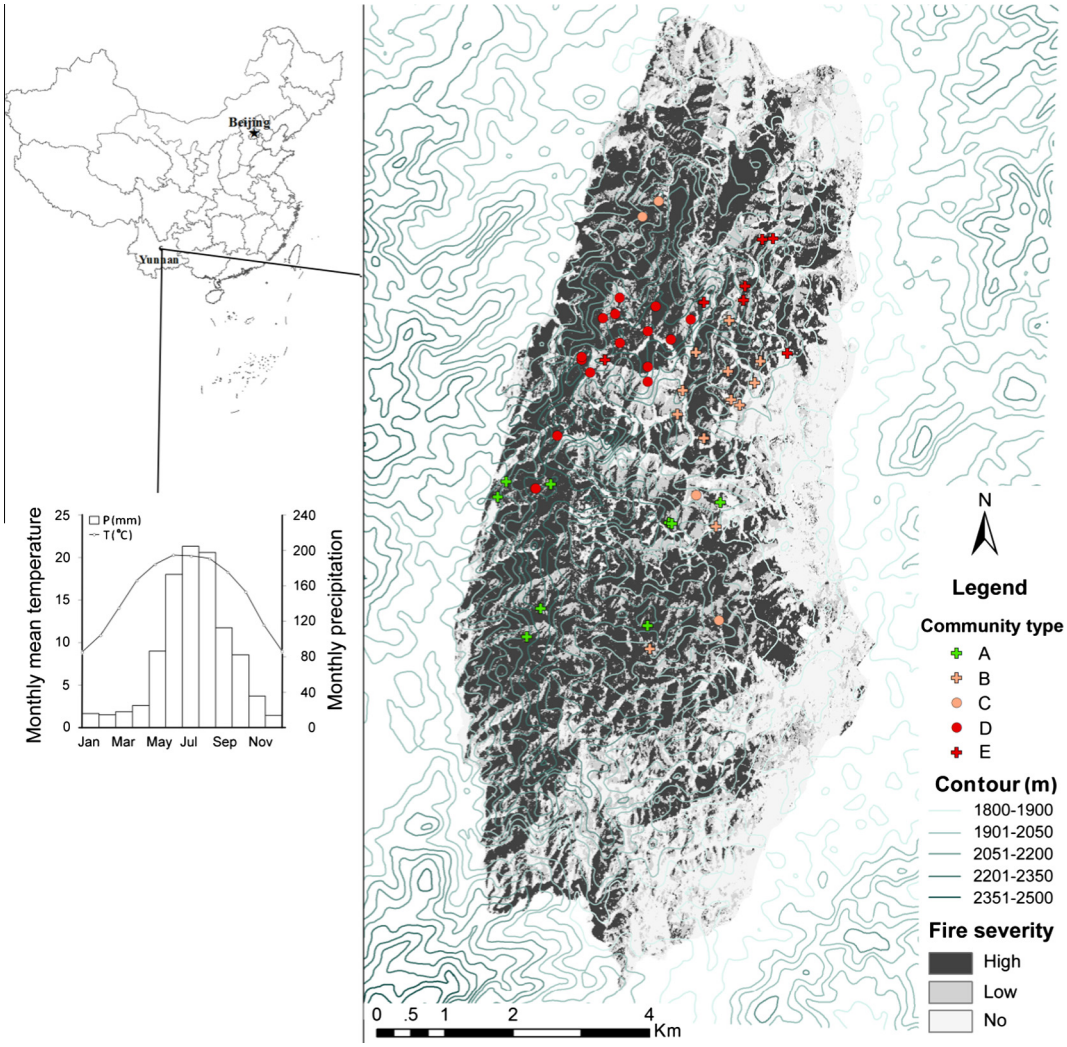

Fig. 1. The geographical location of the study area and sampling sites, as well as a climatic diagram of the region. Community types of pre-fire vegetation follow the results of community classification in Fig. 2.