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The role of fire in the Central Yunnan Plateau ecosystem, southwestern China ☆

Wen-Hua Su *, Zhan Shi, Rui Zhou *, Yuan-Jiao Zhao, Guang-Fei Zhang

Institute of Ecology and Geobotany, Yunnan University, Kunming 650091, China

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ABSTRACT

Fire plays a major role in fire-dependent ecosystems in shaping plant traits, community assemblage, and in maintaining biodiversity and sustaining ecosystems. Excluding fire from fire-dependent ecosystems can substantially alter these ecosystems. This study mainly investigates the how the zonal vegetation evergreen broad-leaved forests as well as widely distributed vegetation *Pinus yunnanensis* forest and shrubland in the Central Yunnan Plateau adapt to fire, and addresses the role of fire in the Central Yunnan Plateau ecosystem to determine whether this ecosystem is fire-dependent. Re-sprouting trees and shrubs composed about 90.6% of the dominant taxa. In re-sprouting species, 41 species (77.4% of all re-sprouting species) were observed re-sprout from underground basal burls after a fire. After a fire, 100% of all trees and tall shrubs, 93.6% of all shrubs and 73.9% of all herbs recovered. Two serotinous tree taxa were found, including two varieties of *P. yunnanensis* (var. *pygmaea* and var. *yunnanensis*) which is a dominant and the most common tree species in this region. All these were identified here as weakly serotinous species. The degree of serotiny was 50.4% for *P. yunnanensis* var. *yunnanensis* and 74.7% for var. *pygmaea*. Heat shock resulted in higher seed germination rates for both varieties of *P. yunnanensis*. Dominant and common taxa in these two typical forest types had typical traits of species known to be adapted to fire; forest fire did not significantly reduce number of species. Based on the above results, the Central Yunnan Plateau ecosystem is a fire-dependent system. Wildfire plays an important role in the community assembly for the semi-humid evergreen broad-leaved forests, *P. yunnanensis* forest and shrub communities. Wildfire should not be viewed as a totally catastrophic event in forests of the Central Yunnan Plateau. In theory this region appropriates to carry out prescribed burning.

1. Introduction

Wildfire is a worldwide phenomenon that appears in the geological record soon after the appearance of terrestrial plants (Scott and Glasspool, 2006; Bowman et al., 2009). For hundreds of millions of years, fire influences global ecosystem patterns and processes, helps to shape global biome distribution and to maintain the structure and function of fire-prone communities (Rundel, 1981; Pausas and Vallejo, 1999; Bond and Keeley, 2005; Bond et al., 2005; Bowman et al., 2009; Pausas and Keeley, 2009). Fire also acts as an evolutionary filter against certain plant traits in fire-prone systems (Pausas et al., 2004; Bradshaw et al., 2011; Pausas, 2015). In view of the special role of fire in the biosphere, Bond and Keeley (2005) consider fire as a global significant consumer that is analogous to herbivory.

Various ecological systems respond differently to fire in their ability to ignite, the intensity and rate-of-spread of fire and their ability to recover after a fire incident (Shlisky et al., 2007; Bowman et al., 2009). Based on natural fire regimes and roles of fire, terrestrial ecosystem can be classified as fire-independent, fire-sensitive and fire-dependent ecosystems (Shlisky et al., 2007). In fire-independent ecosystems such as tundra and deserts, fire is rate, either because of unsuitable climate conditions or lack of biomass to burn (Shlisky et al., 2007; Maezumi et al., 2015). Fire-sensitive ecosystems such as tropical rainforests are damaged by fire, which disrupts ecological processes that have not evolved with fire (Shlisky et al., 2007; Maezumi et al., 2015). Fire-dependent ecosystems are those where most of the species have evolved in the presence of fire, and where fire is an essential

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* Corresponding authors.
E-mail addresses: whsu@ynu.edu.cn (W.-H. Su), 910846340@qq.com (Z. Shi), zhour@ynu.edu.cn (R. Zhou), zyfj@hotmail.com (Y.-J. Zhao), gfzhang@ynu.edu.cn (G.-F. Zhang).

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process for conserving biodiversity, and where fires are natural and plants have the capacity to cope with them (Shlisky et al., 2007).

Obviously, both fire-sensitive and fire-dependent ecosystems can be the fire-prone habitats, especially under human influence. However, the two different systems should execute different management tactics. Generally, fire-sensitive systems rely on fire suppression, and fire-dependent systems rely on the human application of prescribed fire (Mitchell et al., 2014). The introduction of ecologically-inappropriate fire in fire-sensitive systems can have extensive negative impacts on biodiversity and ecological processes. In Amazon, a typical fire-sensitive system, human-ignited wildfires are becoming an increasingly important cause of forest loss (Nepstad et al., 1999; Laurance et al., 2001). It is proved by experiments that anthropogenic understory fires pose a threat to increase tree and liana mortality, reduces biomass and species richness in Amazonian forests (Balch et al., 2008, 2011). Whilst, if fire management policies did not address or even ignore the role of fire in fire-dependent ecosystems, these practices may damage ecological sustainability and lead to ecologically catastrophic fires that burn intensely and may even glassify the soil. In California, one hundred years of fire suppression in a mixed-conifer forest which evolved with frequent natural fires has shifted successional patterns (Parsons and DeBenedetti, 1979). In tall grass prairies fire suppression has led to the loss of as many as 50% of the plant species (Leach and Givnish, 1996; Uys et al., 2004). So it is important to identify the type of the ecosystems with fire regimes.

The key difference between the two ecosystems is if the system evolves with fire. In the typical fire-dependent ecosystems such as temperate coniferous forest and savanas, are fire-adapted, flammable and fire-maintained (Pivello, 2011; Maezumi et al., 2015). In these systems, fires remove fine fuels and improve ecological health; meanwhile, fire creates an evolutionary pressure that shape or filter plant traits. Species often exhibit traits such as re-sprouting, serotiny and germination by heat and smoke. These traits provide species with an ecological fitness and advantage in a fire-prone environment (Bond and Keeley, 2005; Keeley et al., 2011; Pausas, 2015).

Re-sprouting commonly occurs in response to injury from a variety of disturbances, including drought, frost, heat wave, waterlogging, herbivory, storm damage, lightning strikes and excessive salt levels (Bond and Midgley, 2001). Different re-sprouting types may have appeared in different plant lineages in response to different evolutionary pressures. However, Keeley et al. (2011) believed that plants with the ability to re-sprout have a fitness advantage in fire-prone habitats. After a fire, fire-tolerant plant species often re-sprout and grow from protected dormant buds hidden under the bark and in the soil that can survive a fire; second, the re-sprouting plant can rely on material and energy stored in the original plant, so that re-sprouting occurs far more quickly than the growth of newly germinated seedlings.

Serotiny is defined as a condition in which plants retain seeds in the canopy for one to 30 years or more; the high temperature of fire can induce serotinous cones to open and release their seeds after a fire passes through an area (Lamont et al., 1991). Serotinous plants retain a seed bank in the canopy. Compared with seed on the ground, seeds in the canopy are more likely to survive in a forest fire, especially in the case of a ground fire. After a fire, serotinous cones will open and release their seed; these fall to the ground as seed rain. Serotinous cones and canopy seed banks provide serotinous plants with a fitness advantage in fire-prone habitats (Lamont et al., 1991; Lamont and Enright, 2000; Keeley et al., 2011). Serotiny is particularly prominent in Mediterranean-climate ecosystems of southern Australia, South Africa and the coniferous forests of California, North Africa and the Middle East (Tapias et al., 2004), all of which have fire-prone environments.

VerdÚ and Pausas (2007) have suggested that physical dormancy is another trait that reflects a plant's response to fire; physical dormancy also shows phylogenetic clustering in Mediterranean plant communities with fire-prone habitats. Seeds undergoing physical dormancy seldom germinate until exposed to the heat shock of a fire (Keeley and Fotheringham, 1997). Observers have seen an enhancement of seed germination by high temperatures between 40 and 70 °C in several fire-prone ecosystems. Fire-cued seed germination occurs as a widespread trait with clear adaptive significance in ecosystems in which a fire may provide space and conditions that are appropriate for the growth of seedling (Tyler and D' Antonio, 1995; Tyler, 1996; Keeley and Bond, 1997; Keeley and Fotheringham, 1998).

Yunnan located in southwestern China and bordering the Indo-China Peninsula in the south, is connected to the Himalayas and Tibet in the northwest (Fig. 1). The mountainous and terraced topography of Yunnan stretches along one of the greatest elevation gradients on earth from 6740 m a.s.l. in the northwest to 76 m a.s.l. in the southeast. The climate ranges from the icy highland of the northwestern frontier to the tropical lowlands of the southern area, with a centrally located subtropical region. There are highly diverse vegetation types ranging from tropical rainforests at lower altitudes and subtropical forests in the central to montane and sub-alpine temperate forests and alpine meadows at higher altitudes. This is one of the richest areas of biodiversity worldwide.

This is a fire-prone region (Li, 2000; Zhao et al., 2009). Actually, the wildfire histories in this area can be traced back to the Later Permian (Shao et al., 2012). From 1961 to 2000, 656 peoples dead from wildfire, every year over 2000 wildfires were reported and 100,000 ha of forests was burnt. The average economic loss directly related to forest wildfires reached over ten million US dollars annually during the past decade (Huo and Liu, 1987; Li, 2000; Zhao et al., 2009).

The Central Yunnan Plateau lies in the middle part of this fire-prone province (Fig. 1). There are vegetations with a high level of endemicity that is very different from vegetation types typically found in eastern China. The zonal vegetation of Central Yunnan is subtropical semi-humid evergreen broad-leaved forests (henceforth EBLFs) (Wu and Zhu, 1987; Tang and Ohsawa, 2009), while humid EBLFs more typically occur in eastern China. From the global scope, subtropical ecosystem with net primary productivity about 301–600 g C m^{-2} $year^{-1}$, are high fire activity (van der Werf et al., 2008; Bowman et al., 2009). In addition, coniferous *Pinus yunnanensis* forest, an early successional stage in the reestablishment of the EBLFs (Tang, 2010), now dominates a large area (Tang et al., 2010). In the world, most species of the *Pinus* lineage live in fire-prone ecosystems (Pausas, 2015). Yet relatively little is known about the role of fire in subtropical forest ecosystems in China (Shlisky et al., 2007; Krawchuk and Moritz, 2009; Tang et al., 2013). Which type of this region belongs to? Fire-sensitive or fire-dependent? How to manage fire in these endemicity ecosystems?

Although in history fire influences plant evolution, global ecosystem patterns and processes, today fire does not pose a threat to biodiversity or human well-being (Bowman et al., 2009). Therefore, most countries have made fire prevention laws. However, in China, any uncontrolled wildfire that naturally spreads over 100 m^2 is termed a "forest fire disaster" (森林火灾) in documents related to forest fire prevention and management policies. Government and forest management departments must put forth their best efforts to avoid the occurrence of wildfires. Current policies require that once a wildfire occurs it should be extinguished as soon as possible. Are these policies appropriate?

This study mainly aims to investigate the fire-adaptive traits of the zonal vegetation in Yunnan's semi-humid EBLFs and the most widely distributed vegetation type of *P. yunnanensis* forest and