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Understanding fire drivers and relative impacts in different Chinese forest ecosystems

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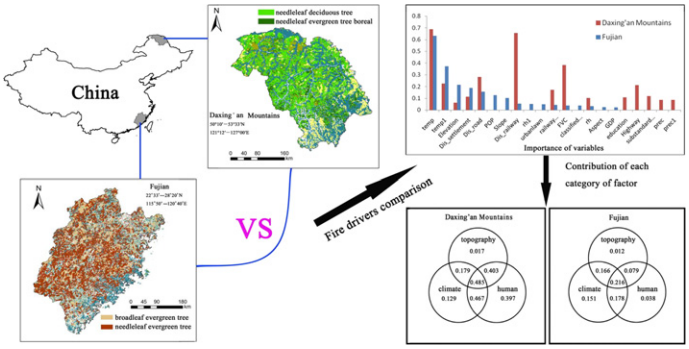
HIGHLIGHTS

- Fire occurrence drivers vary in different forest ecosystems of China.
- Fire occurrence drivers in boreal and subtropical forests were compared.
- Logistic regression model and standardized coefficients method were applied.
- Various fire management strategies are required in Chinese forest ecosystems.
- A strong correlation between socio-economic development and fire regimes was revealed.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, spatial patterns and driving factors of fires were identified from 2000 to 2010 using Ripley's K (d) function and logistic regression (LR) model in two different forest ecosystems of China: the boreal forest (Daxing'an Mountains) and sub-tropical forest (Fujian province). Relative effects of each driving factor on fire occurrence were identified based on standardized coefficients in the LR model. Results revealed that fires were spatially clustered and that fire drivers vary amongst differing forest ecosystems in China. Fires in the Daxing'an Mountains respond primarily to human factors, of which infrastructure is recognized as the most influential. In contrast, climate factors played a critical role in fire occurrence in Fujian, of which the temperature of fire season was found to be of greater importance than other climate factors. Selected factors can predict nearly 80% of the total fire occurrence in the Daxing'an Mountains and 66% in Fujian, wherein human and climate factors contributed the greatest impact in the two study areas, respectively. This study suggests that different fire prevention and management strategies are required in the areas of study, as significant variations of the main fire-driving exist. Rapid socio-economic development has produced similar effects in different forest ecosystems within China, implying a strong correlation between socio-economic development and fire regimes. It can be concluded that the influence of human factors will increase in the future as China's economy continues to grow - an issue of concern that should be further addressed in future national fire management.

1. Introduction

Fire is a critical aspect of ecosystem dynamics, and plays a crucial role in certain forest ecosystems and species evolution (Chandra and

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Bhardwaj, 2015). A better understanding of spatial distribution and drivers of forest fire occurrence is critical for effective fire management, such that fire prevention and suppression resources can be optimally allocated (Hering et al., 2009).

Considerable studies have therefore been carried out to identify the spatial distribution and drivers behind forest fire occurrences in various ecosystems globally (Archibald et al., 2009; Miranda et al., 2012; Oliveira et al., 2012; Guo et al., 2015; Nunes et al., 2016). Previous research has indicated that fire regimes are variable in both space and time (Pereira et al., 2005; Syphard et al., 2008; Parisien et al., 2012; Collins et al., 2015) as a consequence of the interaction of a multitude of factors, which are generally divided into four broad categories, including: climate, vegetation, topography and human activities (Ganteaume et al., 2013; Guo et al., 2016b). Factors such as climate and weather determine the availability and moisture content of fuels, while the fuel load will directly reflect the fuel condition and fire activity - which can be strongly controlled by topography that influences winds, water balance and heat transfer (Rollins et al., 2002; Sharples, 2009). Additionally, human intervention may trigger both fire ignition and suppression, as well as alter the frequency, intensity, severity and distribution of fires (Archibald et al., 2009; Mundo et al., 2013; Penman et al., 2013; Hantson et al., 2015; Guo et al., 2016a, 2016b). Complexity is a prominent feature of forest ecosystems due to diverse internal factors, including climate, terrain, forest composition, human activity and other socio-economic conditions. Interactions amongst influencing factors in an ecosystem have multiple, dynamic effects on forest fires that may change with time due to the inconsistent development of specific factors such as human activity, micro-climate or infrastructure in different ecosystems (Sturtevant and Cleland, 2007; Miranda et al., 2012; Wu et al., 2014). The drivers of fire, therefore, vary amongst different ecosystems, which influence the consistence of future fire prediction and fire management resource allocation.

China's national borders span over a great variation in latitude, and subsequently vegetation can generally be divided into eight vegetation types, including: (1) temperate desert; (2) alpine vegetation of the Tibetan Plateau (very low forest coverage and forest fire are rare to occur); (3) cold temperate needle-leaf forest (boreal forest); (4) temperate coniferous and broad-leaved mixed forest; (5) temperate grassland (low fire frequency but high average burned area); (6) warm temperate broad-leaved forest (low forest coverage, large population, developed industrialization and low forest fire frequency); (7) subtropical broad-leaved forest (occupied nearly one-fourth of China's total area with high forest coverage, high fire frequency but low average burned area); and (8) tropical rainforest (high forest coverage but low fire frequency) (Hu, 2005). Since cold temperate needle-leaf forest and subtropical broad-leaved forest are two typical ecosystems with dominant forest fire regimes, the Daxing'an Mountains and Fujian province were selected as study sites for fire drive and occurrence analysis, as they reside in these two ecosystems respectively. Previous studies regarding fire spatial patterns and drivers in China, however, are unbalanced and primarily focus on Chinese boreal forest with less frequent and less detailed information available regarding fires in sub-tropical forests (Liu et al., 2012; Guo et al., 2016a, 2016b). A comprehensive understanding of the variations of fire drivers in different forest ecosystems in China is the basis for future forest fire risk assessment and the development of regional and national forest fire management policy; however, the lack of comparative analysis limits contributions and implications of the previous studies. Direct comparison of fire drivers in previous studies may lead to uncertainty due to the inconsistency in data extraction, analysis methodology and study span, as studies have been independently conducted in different regions of China.

Taking all aforementioned factors into consideration, two regions - the Daxing'an Mountains and Fujian province - were selected to conduct this study, as they represent Chinese boreal forest and sub-tropical forest ecosystems. The main objectives of this study were: (1) to analyze and compare the spatial patterns of fire ignition in boreal and sub-tropical forest ecosystems; (2) to identify the most influential fire drivers and their relative importance on fire occurrence, and compare differences amongst drivers in different ecosystems; and (3) to discuss the future trend of forest fire occurrence and the corresponding forest management strategies in various forest ecosystems in China. This study aims to provide insight and aid in promoting the implementation of regionally-specific fire management strategies in various forest ecosystems in China, particularly in the given context of a general national forest fire management policy.

2. Materials and methods

2.1. Study area

The Daxing'an Mountains study site is located is northeastern China, while the Fujian Province study site is located in southeastern China. Both study sites have significant differences in forest composition, climate, topographic and socio-economic conditions, while regional fire regimes also vary. In Fujian, dominant forest types include temperature needleaf evergreen and temperate broadleaf deciduous shrub (Fig. 1), as the region is located in a humid subtropical environment (Table 1). In the northeastern Daxing'an Mountain region, needleaf deciduous trees and broadleaf deciduous trees dominant the landscape (Fig. 1) due to its location in a cool temperate zone (Table 1). Fujian has a considerably more mountainous topography than the Daxing'an Mountains, and experiences approximately 3.34–4.77 times more annual average rainfall than the northeastern study site (Table 1). Currently, fire occurrence in Fujian is also considerably higher than that of the Daxing'an Mountains at a frequency of nearly 15,000 forest fires occurring from 2000 to 2010, while the Daxing'an Mountains experienced 4000 fires in the same duration (Table 1). The mean annual density for fires occurring in Fujian, similarly is greater than twice as dense of mean annual forest fire density in the Daxing'an Mountains, which measure $10.9 \times 10^{-3}/km^2$ and $4.31 \times 10^{-3}/km^2$, respectively (Table 1). Detailed information about the two regions of study are shown in Fig. 1 and Table 1 below:

2.2. Data preparation

2.2.1. Fire data extraction and control point generation

Historically, information regarding forest fires events in China (the location, time and burnt area of each fire ignition) was recorded and coordinated by government at various levels in “bottom-up” approach, and was eventually reported to the State Forestry Administration (SFA). Errors and uncertainties gradually increase in the process of “bottom-up” reporting systems, which is adverse for the comparative analysis of wildfire characteristics in different forest ecological zones of China. In order to address the above issues, Moderate Resolution Imaging Spectrometer (MODIS) fire products were consistently used for the two study regions to avoid any inconsistencies and discrepancies in the historical reporting approach. The spatial distribution of fire pixels was recorded by MODIS for the Daxing'an Mountains and Fujian province from 2000 to 2010. Remote sensing data obtained by the MODIS radiometer Terra and Aqua satellites have been identified as a suitable and reliable source for monitoring vegetation fires (Justice et al., 2002; Amraoui et al., 2015). Fire products used in this study include daily timescales with 1 km resolution (MOD14A1), which is also a rapid-response fire product for operational near-real time fire data users (Justice et al., 2002). Although MODIS fire products have many advantages for forest fire-related studies, the disturbances from other fire sources such as refuse burning or fires close to forest urban interfaces occur frequently. In the present study, fire pixels for the 2000–2010 fire seasons in the Daxing'an Mountains (March to November) and in Fujian (September to April) were extracted to conduct the analysis as >95% forest fires occur in fire seasons. Strict fire-ignition source investigation was taken, which will improve the accuracy of forest fire