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Relative effects of climatic and local factors on fire occurrence in boreal forest landscapes of northeastern China

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HIGHLIGHTS

- We explored fire patterns and their influencing factors in Chinese boreal forests.
- Human-caused fires are clustered at areas where human population density is high.
- Lighting fires are clustered at areas where elevations are high and less populated.
- Human activity is secondary to climate as the primary fire occurrence factors.
- Management strategies might benefit from increased monitoring of human activities.

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ABSTRACT

Fire significantly affects species composition, structure, and ecosystem processes in boreal forests. Our study objective was to identify the relative effects of climate, vegetation, topography, and human activity on fire occurrence in Chinese boreal forest landscapes. We used historical fire ignition for 1966–2005 and the statistical method of Kernel Density Estimation to derive fire-occurrence density (number of fires/km^2). The Random Forest models were used to quantify the relative effects of climate, vegetation, topography, and human activity on fire-occurrence density. Our results showed that fire-occurrence density tended to be spatially clustered. Human-caused fire occurrence was highly clustered at the southern part of the region, where human population density is high (comprising about 75% of the area's population). In the north-central areas where elevations are the highest in the region and less densely populated, lightning-caused fires were clustered. Climate factors (e.g., fine fuel and duff moisture content) were important at both regional and landscape scales. Human activity factors (e.g., distance to nearest settlement and road) were secondary to climate as the primary fire occurrence factors. Predictions of fire regimes often assume a strong linkage between climate and fire but usually with less emphasis placed on the effects of local factors such as human activity. We therefore suggest that accurate forecasting of fire regime should include human influences such as those measured by forest proximity to roads and human settlements.

1. Introduction

Fire is a dominant disturbance in boreal forest landscapes, which has significantly affected the species composition, structure, and ecological processes of these forests (Bergeron et al., 2004; Bond-Lamberty et al., 2007; Flannigan et al., 2009; Lynch et al., 2004; Wang and Kemball, 2005). Fire occurrence also is increasing across the boreal forest landscape (Liu et al., 2012; Stocks et al., 1998; Wotton et al., 2010). In Chinese boreal forests, Liu et al. (2012) projected an increase in fire occurrence of 30–230% by the end of 2100. Understanding the underlying causes of fire occurrence in fire-prone boreal forest landscapes in China thus is a key issue for fire managers (Liu et al., 2012).

Among many factors related to fire occurrence, climate is often considered as regional in scale, whereas vegetation, topography, and human activity are considered local (Ali et al., 2009). Studies have reported that climate-dominate effects can be altered by local factors, especially in strongly human-affected landscapes (Ganteaume et al., 2013; Lynch et al., 2004; Niklasson and Granstrom, 2000; Syphard et al., 2007; Wallenius et al., 2004; Zumbrunnen et al., 2012). Human activity can directly affect fire through ignition or suppression (Liu et al., 2012; Zumbrunnen et al., 2011), and can indirectly induce changes in fire occurrence by modifying the spatial pattern of vegetation

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distribution and composition across the landscape (Hawbaker et al., 2013; Zumbrunnen et al., 2011). Signs of human influences on fire regimes have been detected in many forest landscapes. For example, in a European boreal forest landscape, Wallenius et al. (2004) found that between the sixteenth and twentieth centuries, numbers of forest fires greatly increased with the expansion of human settlement and population density. Therefore, the relationship between fire occurrence and its influencing factors needs to be carefully examined, especially in human-affected landscapes.

Chinese boreal forests have been heavily influenced by humans (Duan et al., 2004; Xu, 1998). Human population density in the region (15.2 persons/km^2) is higher than that of the North American boreal forest region of Canada (0.1–0.9 persons/km^2). Most of the people in Chinese boreal forests live at lower elevations near roads. Roads are widely distributed in the region and their density averages 0.24 km/km^2. Human settlement and exploitation of these forests have altered their composition, structure, and consequent fire regime in accordance with their historic variation (Wu et al., 2013; Zhou, 1991). For example, several decades of extensive logging have created a relatively fire-prone landscape by expanding a mosaic of young deciduous forests dominated by species such as birch and aspen. Such forests are widely distributed in hills and lower mountains where fires were frequently ignited by humans. Today the environmental factors influencing fire occurrence remain poorly understood across this heavily human-affected landscape.

In Chinese boreal forests, understanding the relations between fire occurrence and its causation is often focused at regional scales (e.g., the entire Chinese boreal forest (Liu et al., 2012; Tian et al., 2011; Yang et al., 2011). However, the processes determining fire occurrence are scale-dependent, meaning that relations between fire occurrence and causation observed at one spatial scale may not hold at another scale. Evaluating the relative effects of climatic and local factors at different spatial scales is thus essential (Falk et al., 2007, 2011). Accordingly, we conducted our study at two spatial scales: 1) the regional scale, i.e. the entire Great Xing'an Mountains; and 2) the landscape scale represented by each of the three forest bureaus (Xilinji, Huzhong, and Jiagedaqi).

The objective of our study was to identify the relative effect of climate, vegetation, topography, and human activity on fire occurrence in Chinese boreal forest landscapes. We asked the following three questions: (1) What are the spatial patterns of fire occurrence in the Chinese boreal forest landscape? (2) Are fire occurrence patterns predominantly affected by climate and what is the role of human activity in such human-affected forest landscapes? (3) Do the relative effects of climatic and local factors on fire occurrence differ between regional and landscape spatial scales?

2. Material and methods

2.1. Study sites selection

The Great Xing'an Mountains (50°10′N-53°33′N, 121°12′E-127°00′E), located in northeastern China, encompass approximately 8.46 × 10^4 km^2 (Fig. 1). This mountain range divides the plains of northeastern China to the east from the Mongolian Plateau to the west. The area has a cold, continental climate with average annual temperatures that decline from 1 °C at its southern extreme to −6 °C at its northern extreme; precipitation declines from 442 mm in the south to 240 mm in the north. More than 60% of annual precipitation falls in the summer (June to August) (Zhou, 1991).

The vegetation of this area is representative of cool temperate coniferous forests, which here form the southern extension of the eastern Siberian boreal forest. The proportion of conifers declines from north to south, while deciduous tree species increase. The overstory species include larch (*Larix gmelini*), pine (*Pinus sylvestris* var. *mongolica*), spruce (*Picea koraiensis*), birch (*Betula platyphylla*), two species of aspen (*Populus davidiana and Populus suaveolens*), willow (*Chosenia*

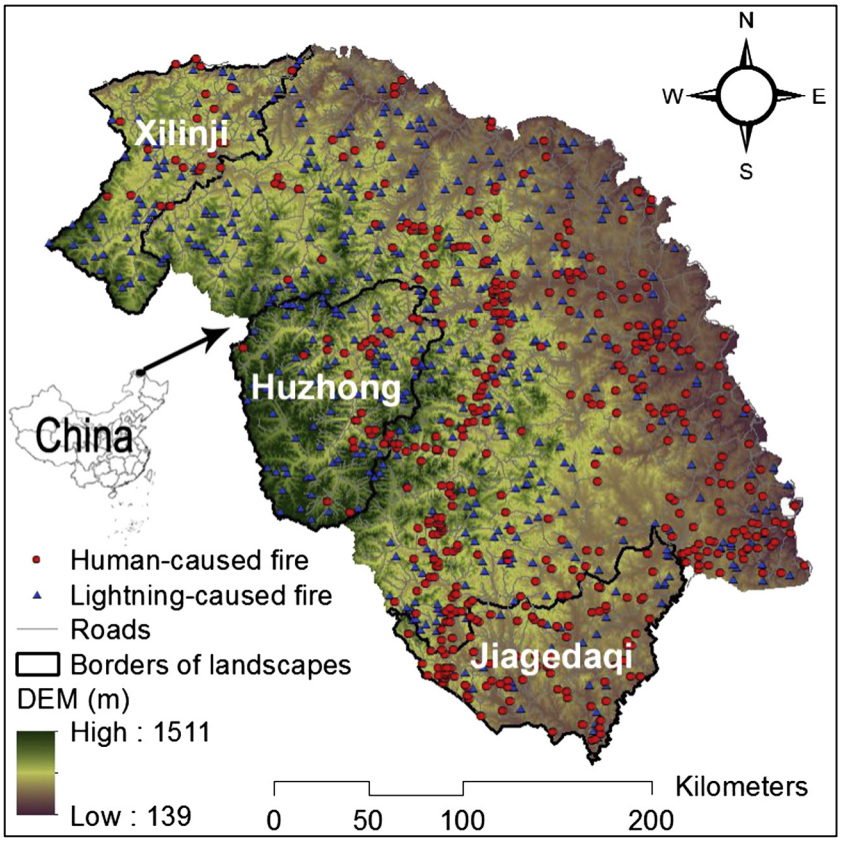

Fig. 1. Study area with historical human-caused and lightning-caused fire locations (1966–2005), roads, and DEM (digital elevation model). The spatial resolution of the DEM was 500 m.