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Modeling the spatial patterns of human wildfire ignition in Yunnan province, China

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ABSTRACT

Despite wildfire being an important regulator of dryland ecosystems, uncontrolled wildfire can be harmful to both forest ecosystems and human society, and wildfire prevention and control continue to raise worldwide concern. Wildfire management depends on knowledge of wildfire ignitions, both for cause and location. The regimes and factors influencing wildfire ignition have been studied at length. Humans have a profound effect on fire regimes and human activity is responsible for igniting the largest number of fires in our study area. Understanding the spatial patterns of ignitions is foremost to achieving efficiency in wildfire prevention. Previous studies mainly concentrate on overall wildfire risk integrating numerous factors simultaneously, yet the importance of human factors on ignition has not received much attention. In this study, we mapped human accessibility to explore the influence of human activity on wildfire ignition in a simple and straightforward way. A Bayesian weights-of-evidence (WofE) method was developed based on fire hotspots in China's Yunnan province extracted from satellite images and verified as known wildfires for the period 2007–2013. We considered a set of factors that impact fire ignition as associated with human accessibility: the locations of settlements, roads, water and farmland susceptible to human wildfire ignition. Known points of likely wildfire ignition were selected as training samples and all suspected thematic maps of the factors were taken as explanatory layers. Next, the weights of each layer in terms of its explanatory power were computed and used to generate evidence based on a threshold to pass a statistical test. The conditional independence (*CI*) of each layer was checked with the Agterberg-Cheng test. Finally, the posterior probability was calculated and its precision validated using samples of both presence and absence by withheld validation data. A comparison of WofE models was made to test the predictability. Results show proximity to villages, roads and farmland are strongly associated with human wildfire ignition and that wildfire more often occurs at an intermediate distance from high-density human activity. The WofE method proved more powerful than logistic regression, improving predictive accuracy by 10% and was more straightforward in presenting the association of dependence and independence. In addition, WofE with 1000 m buffer bands is more robust in predicting human wildfire ignition risk than binary or 100 m buffers for the ecoregion studied. Our results are significant for advising practical wildfire management and resource allocation, evaluation of human ignition control and also provides a foundation for future efforts toward integrated wildfire prediction.

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1. Introduction

Despite wildfire being an important regulator of ecosystems by influencing vegetation succession, shaping biomass distribution and maintaining biological diversity (Bond & Keeley, 2005; Bond, Woodward, & Midgley, 2005; Bowman et al., 2011; Crisp, Burrows, Cook, Thornhill, & Bowman, 2011; Simon et al., 2009), uncontrolled wildfire is usually destructive to both forest ecosystems and to human society by causing natural resource degradation, economic disruption and loss of life, and reduced biodiversity (Cameron et al., 2009; Johnston, 2009; Kwak et al., 2012; Rodrigues, de la Riva, & Fotheringham, 2014). Especially in managed ecosystems, wildfire prevention and control continues to be a worldwide concern. The regimes and factors influencing wildfire ignition have been studied at length (Cardille, Ventura, & Turner, 2001; Harrison, Marlon, & Bartlein, 2010; Maingi & Henry, 2007; Plucinksi, 2011). Wildfire occurrence is attributed to weather and climate, fuel condition and a source of ignitions (Gralewicz, Nelson, & Wulder, 2012a; Malamud, Millington, & Perry, 2005), based on which, wildfire risk or susceptibility can be assessed (Dickson et al., 2006; Guo et al., 2017; Hawbaker et al., 2013; Xu, Zhang, Chen, Wu, & Li, 2016). Although ignition is an integral component of wildfire factors, it is crucial in terms of wildfire occurrence, because the possibility of wildfire is minimal, no matter how dry the weather conditions and how high the forest flammability without ignition. Humans have a profound affect on fire regimes by being a source of ignitions (Fusco, Abatzoglou, Balch, Finn, & Bradley, 2016), and human activity is responsible for igniting a majority of all fires (Benali et al., 2017; FAO, 2007; Prestemon & Butry, 2005; Román-Cuesta, Gracia, & Retana, 2003). According to statistics, the main causes of wildfires in China are related to human activities, with lightning accounting for only 0.38% of the total (Zhong, Fan, Liu, & Li, 2003). Consequently, an improved understanding of wildfire risk should address the patterns of human activity and its relation to fire ignition (Dickson et al., 2006; Narayanaraj & Wimberly, 2012; Prestemon, Pye, Butry, Holmes, & Mercer, 2002). Significant research effort has been undertaken to explore the relationship between wildfire and its causative factors with the goal of building predictive models (Cardille et al., 2001; Chas-Amil, Prestemon, McClean, & Touza, 2015; Maingi & Henry, 2007; Narayanaraj & Wimberly, 2012; Romero-Calcerrada, Barrio-Parra, Millington, & Novillo, 2010; Román-Cuesta et al., 2003; Salis et al., 2013; Syphard et al., 2007; Watts & Hall, 2016; Ye, Wang, Guo, & Li, 2017), and has concluded that wildfire tends to occur in areas near human infrastructure on the human-wildland interface (Zhang, Lim, & Sharples, 2016), and frequently exhibits nonlinear relationships (Hawbaker et al., 2013). However, previous studies mainly concentrate on overall wildfire risk integrating numerous factors simultaneously, yet the importance of human factors on ignition has not received much attention. Most fire literature examines biological and physical wildfire factors, such as topography, wind, humidity and fuel load (Romero-Calcerrada et al., 2010; Yang, He, & Shifley, 2008). With an increasing concern in studies of the anthropogenic impacts on wildfire regime, some researchers have tried to isolate the human variables in a quantitative way to figure out the patterns of human influence that cause wildfire ignition (Catry, Rego, Bação, & Moreira, 2010; Fusco et al., 2016; Romero-Calcerrada et al., 2010). The modeling of human activity and its patterns of influence in a more explicit spatial way offer a new level of explanation for local government decision making in wildfire prevention. This implies wildfire prevention, rather than firefighting and management after ignition.

With the development of remote sensing and Geographic Information Systems, it is feasible to model human variables and their impacts on wildfire ignition spatially. Yet due to the variety of human motivations and behavior, modeling human activity remains a difficult and complicated problem (Song, Wang, Satoh, & Fan, 2006). Nevertheless, there are clearly empirical associations between wildfire ignition points and certain aspects of the human footprint. Humans usually have an extent of mobility and a geographic range, which is largely determined by the infrastructure and settlements. Consequently, previous work associated with human activity has commonly utilized land cover, distance or proximity to roads, settlements or other infrastructure as straight distance for buffer analyses (Fusco et al., 2016; Gralewicz et al., 2012a; Guo et al., 2017; Hawbaker et al., 2013; Kwak et al., 2012; Maingi & Henry, 2007; Romero-Calcerrada et al., 2010; Zhang et al., 2016). However, the effects of different factors on fire occurrence can vary among ecosystems and across spatial scales (Catry et al., 2010). Additionally, numerous approaches have been employed to estimate wildfire ignition probability. Logistic regression is the most extensively used method due to its flexibility and robustness to non-normally distributed variables (Catry et al., 2010; Curt, Fréjaville, & Lahaye, 2016; Guo et al., 2014, 2016b; Legendre & Legendre, 2012; Rodrigues et al., 2014). However, logistic regression generally produces a result based on approximate linear relations between map layers (Agterberg & Cheng, 2002; Guo et al., 2016c). Consequently, an improved spatial prediction model of human activity should lead to a better understanding of the spatial and temporal patterns of human-caused wildfire ignition.

In this study, we applied an objective model using weights-of-evidence (WofE) to identify the extent of human impacts on wildfire ignition. To better investigate the patterns of human influence, we assumed that wildfire occurrence is mainly determined by human variables. Several steps were required. First, known points of historical wildfire ignition locations were selected as the training samples and all suspected thematic maps of human activities were taken as explanatory layers. Next, the weights were computed and evidence generated at different scales and for categories based on statistical significance. Conditional independence was examined with the Agterberg-Cheng test. Accordingly, the posterior probability was calculated and its precision validated for both presence and absence of wildfire ignition. Lastly, we analyzed the predictive power of the model compared with logistic regression and with different variable patterns.

2. Materials and methods

2.1. Study area

Yunnan province is located in the southwestern border of China between 21°09′-29°15′ N and 97°32′-106°12′E (Fig. 1). It is ranked second among the forested regions of China with abundant forest resources. The area has a highly diverse gene pool of plants and animals, and is among the top 25 global biodiversity hotspots (Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000; Yuming, Kun, Jiming, & Shengji, 2004). Yunnan has rugged topography, underdeveloped transportation, is relatively poor, has multi-ethnic inhabitants and is highly populated. Additionally, the northerly winter monsoon in this region is usually obstructed by high mountains, generating a warm, dry winter and moderately hot humid summer monsoon type climate (Li et al., 2017). There is a record of continuous droughts in recent years, which have made Yunan also a region of frequent and severe wildfire occurrence, among the most in China (Xu et al., 2007; Zhong et al., 2003). Wildfires in Yunnan mainly occur in winter and spring from December to May, concentrated in spring from mid-February to mid-May (Cao, Wang, & Liu, 2017; Chen, Fan, Niu, & Zheng, 2014). Wildfire in Yunnan has shown a slight upward trend during recent years (Zhao, Shu, Tiao, & Wang, 2009), mostly caused by human activity (Chen, Pereira, Masiero, & Pirotti, 2017; Tian, Zhao, Shu, & Wang, 2013) including arson, fire misuse, and the tradition of honoring ancestors around Tomb Sweeping Day by burning imitation currency. Additionally, the slash-and-burn farming cultivation and the mosaic of farmland and forest aggravate this situation. State and local governments conduct large scale ground patrols to check the ignitions induced by human activities at the peak of wildfire occurrence season every year.