Forest Ecology and Management 310 (2013) 460–467

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Distribution characteristics and the influence factors of forest fires in China

Xiaorui Tian, Fengjun Zhao, Lifu Shu *, Mingyu Wang

State Forestry Administration's Key Open Laboratory of Forest Protection Research, Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing 100091, PR China

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form 13 August 2013
Accepted 14 August 2013
Available online 21 September 2013

Keywords:
Forest fires
Hotspots
Spatial distribution
Satellite remote sensing

ABSTRACT

Spatial information related to the occurrence of fire is the basis for risk reduction efforts. Satellite data on the occurrence of hotspots and statistical data were used to analyse the distribution characteristics of wildfires for 2008–2012. The results show that most hotspots were caused by prescribed and agricultural burning and forest fires. The size of 99% of forest fires was less than 100 ha, and the average annual burned area was 124,192 ha. Most of the forest fires occurred in the spring (accounting for 83%), with March having the highest rate (60.0%). Forest fires were mainly distributed in the south and southwest regions of China. In total, 72.2% of the forest fires occurred in humid region of the medium temperate zone, and 54% occurred in regions with altitudes lower than 500 m. Forest fires often occurred in sparsely populated areas (<100 people/km^2), and 58% and 44% of the fires were located in areas away from the road (<5 km) and around settlements (<1 km), respectively.

1. Introduction

Forest fires are a recurrent management problem in China. Information on the spatial distribution of fires is needed to improve fire prevention strategies and tactics. The spatial scale of analysis of fire occurrence can provide new information to guide planning and risk reduction efforts (Yang et al., 2007). There have been many studies on fire distribution and impact factors. Liu et al. (2012) used spatial point pattern analysis to model fire occurrence in boreal forests from 1965 to 2009 in northeastern China and concluded that human-caused fires were strongly related to human activities (e.g., landscape accessibility), including the proximity to settlements and roads. Yang et al. (2007) used a spatial point process modelling approach to quantitatively analyse the effects of land cover, topography, roads, municipalities, ownership, and population density on fire occurrence in the Missouri Ozark Highland forest. Díaz-Delgado et al. (2004) analysed the spatial patterns of fire occurrence in Catalonia (NE Spain) from 1975 to 1998 and determined the interactions between fire occurrence and environmental parameters such as altitude, slope, solar radiation, and burned land cover. Some mathematical models have been used to analyse the distribution of fires and quantify the effects of anthropogenic activities on the fire occurrence. Zumbrunnen et al. (2012) investigated the impact of human activities and climate on fire occurrence in a dry continental valley of the Swiss Alps (Valais) by relating the fire occurrence to the population and road density, biomass removal by livestock grazing and wood harvest, temperature, and precipitation in two distinct periods (1904–1955 and 1956–2006) using generalised additive modelling. The relationship between fire frequency and population density satisfies an asymptotic power law with a boundary effect (Song et al., 2005).The nonstationary Poisson process model does not account for all the complexity of the structure of fire occurrence (Corral et al., 2008). The prediction of fire activity was not affected by the spatial resolution of the climate model used (12 vs. 25 km) (Carvalho et al., 2010).

Forest fire regimes are sensitive to changes in climate, fuel load, and ignition sources (Zumbrunnen et al., 2012). Topography, vegetation, and climate act together to determine the spatial patterns of fires at the landscape scale (Rollins et al., 2002). Fuel moisture and vegetation type were the most important controlling factors on the spatial pattern of lightning fires (Liu et al., 2012). Rollins et al. (2002) used long-term data on the fire perimeter (fire atlases) and data for topography, vegetation, and climate to evaluate the relationships between large 20th century fires and landscape characteristics in two contrasting areas. The main structural factors were identified to explain the likelihood of fire occurrence on the European scale (Oliveiraa et al., 2012). Dickson et al. (2006)

---

* Corresponding author. Address: The Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, YiheyuanHou, Beijing 100091, PR China. Tel./fax: +86 1062889519.

E-mail addresses: tianxr@caf.ac.cn (X. Tian), zhaofj@caf.ac.cn (F. Zhao), shulf@caf.ac.cn (L. Shu), fire@caf.ac.cn (M. Wang).

0378-1127/$ - see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.foreco.2013.08.025

examined the contributing landscape factors and patterns related to the occurrence of large (20 ha in extent) fires in the forested region of northern Arizona, and the authors found that seasonal large fire events were a consequence of non-random patterns of occurrence. Given that fires are increasing in number and magnitude in the Mediterranean, Arnan et al. (2013) predict a major change in the landscape structure and composition at the regional scale.

For certain regions, extreme climate events have shown a great impact on forest fire activity. For example, in central and eastern Washington State (USA) inter-annual to decadal climatic variability affected the fire occurrence (Amy et al., 2004), and long-term fire planning using the Pacific Decadal Oscillation (PDO) may be possible in the Pacific Northwest, potentially allowing for decadal-scale management of fire regimes, prescribed fire, and vegetation dynamics (Amy et al., 2004). Schoennage et al. (2005) examined the relationship of El Nino Southern Oscillation (ENSO) and the PDO to drought-induced fires in subalpine forests in three study areas across the Rocky Mountains and determined the sign and strength of the relationships between these climatic anomalies and subalpine fire occurrence along a broad north–south gradient of the Rockies. Extreme weather events impact China's climate with complexity and uncertainty because the climate of China's mainland is affected by many factors (Tian et al., 2003). An El Niño event caused a severe drought in northeastern China from the autumn of 1997 to the spring of 1998, resulting in a severe fire season in the spring of 1998. During an ENSO event, the average summer temperature of the eastern Daxing'anling region decreased by 0.5–1.5 °C (Mo, 1989), and precipitation in May and June decreased by 30–50% compared with an average year (Zhang et al., 2004). There was a significant correlation between the number of fires or the burned area of Heilongjiang province and extreme weather events (El Niño or La Nina) (Wang et al., 2010).

Prediction models for the occurrence of forest fire have been developed and applied in certain regions. Chou et al. (1993) used an ecological database for the San Jacinto Mountains, California, USA, to construct a probability model of wildland fire occurrence. The model incorporates both environmental and human factors, including vegetation, temperature, precipitation, human structures, and transportation. Wotton et al. (2003) built a human-caused fire prediction model and a lightning fire occurrence model (Wotton and Martell, 2005). Renard et al. (2012) used hierarchical partitioning to assess the independent contributions of climate, topography, and vegetation to the goodness-of-fit of the models and built the most parsimonious fire susceptibility model for the Western Ghats of India.

There have been some studies carried out in China on the occurrence and impact factor of forest fires. Most studies have focused on the temporal distribution of fires in specific provinces based on fire statistics (e.g., Jiang et al., 2012; Lu, 2011). Jin and Hu (2002) and Hu and Jin (2002) studied the forest fire regime of Heilongjiang province and conducted an analysis of the factors affecting fire distribution. Li et al. (2005) assessed the forest fire risk for provinces based on the data for forest area and the components of the tree species. Tian et al. (2012) performed an analysis of the conditions for lightning fire occurrence in the Daxing'anling region and found that lightning fires mainly occurred in the day with high fire danger and frequent lightning activity without effective rainfall. However, these studies were limited to one region of the country and lacked spatial information analysis regarding forest fires. Therefore, this study will analyse the spatial distribution characteristics and the factors that influence the occurrence of forest fires in mainland China. The results will provide additional spatial information on fire occurrence in recent years and provide suggestions for fire management.

2. Data and methods

2.1. Data sources

The data on hotspots and forest fire statistics for 2000–2011 were provided by the Forest Fire Monitoring Centre, State Forestry Administration. The satellite sources include FY-1D, FY-1C, FY-3A, HJ-1B, Aqua, Terra, NOAA-12, NOAA-14, NOAA-16, NOAA-17, NOAA-18, and NOAA-19. The satellite remote sensing data were processed using Fire Monitor software, and the hotspots were extracted. All of the hotspots in the wildland were checked by the local fire agencies for ground verification. The hotspot information includes the date, time, location, longitude and latitude, the number of pixels, continuity, land type, and feedback. The forest fire statistics only included the number of forest fires, the burned area, the burned areas covered by forest, casualties, and the fire causes for every province; these data did not include the specific information for each fire.

The basic data for China include a vegetation map (2000), a Digital Elevation Model (DEM), roads (2000), settlements (2000), the population density (2003) at 1-km resolution, and a Chinese ecological geographical area map with a plotting scale of 1:1000,000 (Liao et al. 2007).

2.2. Methods for impact factor analysis

Spatial and temporal analysis was performed based on fire statistics, and the hotspot information, including continuity, land type, and causes, were evaluated using ArcMap10.0 and Excel. For the repeat hotspots detected by satellites, their locations detected at first time were used in next analysis. The hotspot density for 2008–2012 was determined by a point density method with a neighbourhood radius of 100 km. The forest fire occurrence risk was divided into five grades using natural breaks (Jenks) for forest fire density, which were designated as very low, low, medium, high, and very high. The characteristics of the forest fires were summarised based on the impact factors (e.g., vegetation types, eco-geographical districts, DEM, population density, and distance from settlements and roads).The distances from fire occurrences to roads and settlements were the distance to road and settlement respectively. The population density where fire occurred was extracted from the population density map. All of the maps were generated with the Clarke_1866_Lambert_Conformal_Conic projected coordinate system (central meridian 110.0, latitude of origin10.0).

2.3. Detected hotspots by satellite monitoring

Since 1994, meteorological satellites have been used for forest fire monitoring. The satellites used in the current study include FY-3A, FY-3B, the NOAA series (NOAA-16, NOAA-18, and NOAA-19), and the EOS series (TERRA, AQUA). Every day, the satellites scan the same region approximately 10 times. Within 30 min of when the satellites pass over China, suspicious hotspots are extracted through human–computer interaction, and the results are published to the forest fire information system. Local fire agencies will check those hotspots and give feedback to the forest fire information system. If the hotspots are confirmed to be wildfires, the local fire brigade will take the appropriate measures to address the fires.

Fig. 1 shows the hotspots detected by satellites for the period 2001–2012. These data include repeat detections for the same forest fires. Since 2004, the annual detected hotspots remained stable (range from 13,570 to 20,083) and included wildfires, agricultural fires, prescribed burning, and other fires outside of the city. There was no feedback information (checked from the ground) for the