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Relationship between landscape structure and burn severity at the landscape and class levels in Samchuck, South Korea

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ABSTRACT

Fuel treatments for reducing fire risk are necessarily tied to the landscape structure including forest composition and configuration. Thus understanding the relationships between landscape structure and burn severity is important for developing guidelines and management strategies for fire-resilient forests. The goal of this study was to investigate the relationship between landscape structure as described by spatial pattern metrics and burn severity at the landscape and class levels. In 2000, a mostly severe fire burned 16,210 ha of dense forest located in Samchuck on the east coast of the Korean peninsula. Spatial pattern metrics including patch density, largest patch index, mean shape index, area-weighted mean shape index, Euclidean nearest neighborhood distance, and Shannon's diversity index, as well as topographic characteristics of slope and elevation, were correlated with burn severity based on delta Normalized Burn Ratio (dNBR) assessments. Regression tree analysis was also carried out with the same variables to avoid spatial autocorrelation and to reveal the relative importance of variables to burn severity. The results of this study strongly suggest that both composition and configuration of the forest cover patches are closely tied to burn severity. In particular, both the correlation analysis and regression tree analysis indicated that the area of red pine tree forest cover was the most significant factor in explaining the variance of burn severity. Topography and spatial configuration of forest cover patches were also significantly related to burn severity. The heterogeneity of forests also had a significant influence on burn severity. To reduce fire risk and increase the fire resilience of forests, forest managers and agencies need to consider enhancing the heterogeneity of forests when implementing fuel treatment schemes. However, such fuel treatments for landscape structure may only be effective under moderate weather conditions.

1. Introduction

Because fire has a profound influence on forest ecosystems and human lives (Gustafson et al., 2004; Nunes et al., 2005) it has been an important area of study for forest scientists, forest managers, land use planners, and government agencies for decades. Fire has been shown to have significant impacts on forest ecosystems, resulting in alteration of the size, arrangement, and age structure of vegetation (Collins et al., 2007; Delcourt and Delcourt, 1997; Lloret et al., 2002; Turner et al., 1994; Wimberly and Reilly, 2007). Conversely, forest composition and configuration influence fire spread and severity (Collins et al., 2007; Stephens, 2001). Other variables have been shown to influence burn severity including topography, disturbance history (Bigler et al., 2005), and weather conditions (Collins et al., 2007; Pyne et al., 1996; Rothermel, 1972). Despite the intensive investigations of those previous studies, our understanding of the interactive relationship between burn severity and environmental variables is still limited due to the complexity and dynamics of the relevant variables.

Recently, much more attention has been given to the relationship between landscape structure and characteristics of fire including burn severity and spread (e.g., Bajocco and Ricotta, 2008; Kerby et al., 2007; Nunes et al., 2005; Ryu et al., 2007; Wimberly and Reilly, 2007). For example, Ryu et al. (2007) investigated the relationship between the burned area (BA) of the Washburn Ranger District of the Chequamegon National Forest, Wisconsin, United States, and landscape structure described using spatial pattern metrics including largest patch index (LPI), mean patch size (MPS), patch density (PD), patch size standard deviation

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(PSSD), mean shape index (MSI), area-weighted mean shape index (AWMSI), and Shannon's diversity index (SHDI). They reported a strong tie between burned area (BA) and landscape structure and concluded that the forest should be composed of numerous, small, irregularly shaped, and different types of forest to mitigate fire spread. From a landscape ecology perspective, forest structure can be viewed as two-dimensional: (1) the composition and (2) the configuration (McGarigal and Marks, 1995; Turner et al., 2001). Both aspects are strongly tied to many characteristics of fire such as spread, severity, fuel types, and fuel loading (González et al., 2005; Kerby et al., 2007; Lloret et al., 2002; Nunes et al., 2005; Ryu et al., 2007). Indirectly, landscape structure is also closely associated with the composition and configuration of the post-fire forest including plant regeneration and plant mortality (Brown, 2000). Landscape structure is also tied to fuel treatments. Effective fuel treatments must consider the spatial patterns of forests that may interrupt the flow of high-intensity fire across the landscape when the entire landscape is not planned for treatments (Finney, 2001). Thus, understanding the relationship between landscape structure and the characteristics of fire is critical to managing or restoring forests that have resistance to fire ignition and spread, as well as to enhancing the recovery of the ecosystems of burned areas.

This study investigated, on a small scale, the relationship between burn severity and landscape structure and topography in South Korea. Our aim was to provide some basis for managing forests for reduced susceptibility to fire. The rationale of the study is that spatial patterns, including the composition and configuration of forests in a landscape, dictate the fire susceptibility of forests. Burn severity also partly depends on the spatial pattern of forests with high or low fire susceptibility (Cumming, 2001; Krasnow et al., 2009; Pyne et al., 1996). Furthermore, certain aspects of all fuel treatments, forest management practices, and restoration efforts are related to the spatial patterns of forests. Therefore, knowledge of the relationship between the spatial patterns of forests in landscapes and burn severity can be directly applied to fuel treatment, forest management, and restoration practices. Based on the factors and spatial patterns of forests identified as being associated with burn severity, managers and policymakers can reduce fire risks and enhance the resilience of forests to fire. With these issues in mind, our specific study question was as follows: is there a significant relationship between landscape structure described by spatial pattern metrics and burn severity derived from satellite imagery?

In 2000, a catastrophic fire burned 16,210 ha of dense forest in Samchuck on the east coast of the Korean peninsula. Although numerous studies have examined the landscape structure of forests and various fire characteristics in Europe and North America, relatively little information is available on the relationship between spatial patterns of forests and burn severity in East Asia, particularly in Korea. The fire event and subsequent collection of large amounts of data provided an opportunity to examine the complex relationship between landscape structure and burn severity, as well as the ecological consequences of severe fire.

2. Methods and data

2.1. Study site and the Samchuck fire

The study area, located in Samchuck on the eastern coast of Korea (Fig. 1a), has an annual average temperature and precipitation of 12.1 °C and 1342 mm, respectively, with dry, windy conditions in spring. The pre-fire vegetation in the area was dominated by Japanese red pine (*Pinus densiflora*) forest and mixed forest of *P. densiflora* and Mongolian oak (*Quercus mongolica*). At the time of the fire, the forests had an average age of approximately 30 years and represented secondary succession following burning during the Korean War in the early 1950s. Postwar regeneration in the area was delayed due to fuel wood collection by local people. A few rural residential areas are scattered through the lower elevations, although no densely populated areas exist in the study area. Stream systems are found mostly on the eastern and southern sides of the area.

In 2000, a fire, severe in most areas, burned about 16,151 ha of dense forest in the Samchuck area (37°7′42″–37°20′34″N, 129°11′24″–129°22′32″E, Fig. 1(a). The fire spread from a garbage-burning site near a residential area on 7 April and continued to burn for 9 days. During the day, the maximum wind speed was 26.8 m/s, and the minimum humidity was 7%. The dry and windy weather conditions accelerated fire spread and made suppression efforts ineffective. This burned area was designated as a Long-Term Ecological Research (LTER) site and has been monitored by the Korea Forest Research Institute (KFRI) since 2000 to investigate the ecological consequences of the fire and to monitor the natural recovery process.

2.2. Description of spatial layers

The National Forest Classification Map was used to measure the pre-fire landscape structure of the damaged area. This map is paper-based and was digitized into a Geographic Information System (GIS) for analysis. The National Forest Classification Map is derived from satellite imagery and field data. The forest classification is based on three criteria including tree type, age, and sub-layers. In Table 1, the forest covers on the map were initially classified into 50 categories and are now reclassified into 10 categories including mixed coniferous forest, broad-leaved forest, mixed forest, planted Japanese red pine forest, planted Korean white pine forest, planted pitch pine forest, Japanese red pine forest, open forest, and agricultural land. Forests are classified into a forest class when more than 75% of the areas are covered by a single dominant tree type. Mixed forests are covered by multiple tree types without a dominant tree type (i.e., <75% canopy cover). The forest on the eastern side of the study area is relatively homogeneous and dominated by pine trees, whereas the western side shows a variety of forest cover types, as shown in Fig. 1d.

FRAGSTATS was employed to compute landscape structure including composition and configuration before the fire (McGarigal and Marks, 1995). FRAGSTATS is a spatial pattern analysis program designed to quantify landscape patterns at the patch, class, and landscape level. Literally hundreds of spatial metrics are available. Their purpose is to obtain sets of quantitative data that allow a more objective comparison of different landscapes for grouping or differentiation (Antrop, 2000). According to McGarigal and Marks (1995), most spatial patterns can be measured with composition and configuration metrics. Composition refers to features associated with the variety and abundance of forest cover types within the forest without considering spatial character, placement, or location of forest cover patches. However, composition metrics are only applicable at the landscape level because of integration over all forest cover types. Configuration includes the spatial character and arrangement, position, or orientation of forest cover patches within the class or forest. Configuration can be quantified in terms of the spatial relationship of forest cover patches. These aspects of configuration are measures of the placement of forest cover patch types relative to other patches, other patch types, or other features of interest (Turner et al., 2001). Because many of the numerous spatial metrics are intercorrelated (McGarigal and Marks, 1995), spatial metrics selected to describe landscape structure relevant to burn severity must be based on clear study purposes and criteria.

Relevant spatial metrics associated with burn severity, as well as the ecological functions of post-fire forests, can be identified