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Assessing the impacts of topographic and climatic factors on radial growth of major forest forming tree species of South Korea

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A R T I C L E I N F O

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A B S T R A C T

Although the annual diameter growth of trees is vital for assessing site suitability in terms of potential timber yield, the effects of climatic and topographic factors on this variable are poorly understood. The main objective of this study was to develop a tree-level radial growth model incorporating topographic and climatic factors for four major temperate tree species [red pine (*Pinus densiflora*), oak (*Quercus* spp.), Japanese larch (*Larix kaempferi*), and Korean pine (*Pinus koraiensis*)] in South Korea. The model was developed and then validated using increment cores sampled from permanent plots in the Korean National Forest Inventory country wide. The Standard Growth (SG) of each increment core, which eliminated the effect of tree age on radial growth, was derived using a SG model. Spatial autocorrelation was detected for the SGs of every species, but not for the original radial growth data. The results showed that using the SG model to standardize radial growth for age was successful for explaining the impact of topographic and climatic factors on radial growth. The influence of climatic (warmth index and precipitation effectiveness index) and topographic (topographic wetness index) factors on the SG of each species was evaluated by the estimated SG (eSG) model. Results show that for all species each variable was correlated to SG. The mean R^2 of the final radial growth model for red pine, oak, Japanese larch, and Korean pine during 2001–2009 were estimated to be 0.71, 0.73, 0.67, and 0.65, respectively. In addition, for every tree species the time sequence of estimated annual radial growth exhibited similar characteristics to that of the observed annual radial growth on an individual tree scale. Thus, this growth model can contribute to an understanding of the impacts of topographic and climatic factors on tree radial growth and predict the annual growth changes of major tree species in South Korea, given climate change.

1. Introduction

The prediction of tree growth for forest planning and management is typically achieved by considering environmental factors, such as precipitation, temperature, drought, and soil and topographic characteristics (Schweingruber, 1988). This approach has had a long tradition among foresters, particularly when the climatic parameters are considered to be major abiotic influences on the phenological, physiological, and geographical states of the forest ecosystem (Box, 1996). However, climate observations are currently exhibiting a global warming trend; global average temperatures have increased by 0.8 °C since 1900 (Hansen et al., 2006), and the 12 hottest years on record have all occurred between 1990 and 2005. Consequently, the uncertainty of future forest resource estimates has increased. Therefore, to cope with global warming and climate change, proper forest management requires understanding the relationships between forest growth and climatic factors.

Tree ring growth has played a critical role in identifying the growth response of trees to environmental and climatic variation (Fritts, 1976). For example, studies in a wide range of forest environments have shown that variations in tree ring width are correlated with variations in macroclimate (Takahashi et al., 2003). Accordingly, tree ring data have been used extensively in the development of tree growth models. Tree growth models are a fundamental component of forest growth and yield frameworks, and the development of such models is supported by large research bodies (Adame et al., 2008; Sterba et al., 2002; Trasobares et al., 2004); thus, growth models have been constructed for a wide range of forest regions and management scenarios.

Many existing tree growth models incorporate various factors that can affect tree growth, particularly the age and size of individual trees,

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topography, and climate. Some comments can be made about these factors. First, since growth rates can vary according to the age and size of trees, these factors should be incorporated into growth models (Enquist et al., 1999; Enquist, 2002). Furthermore, climatic and topographic factors localize growth models to specific regions (Moore et al., 1993; Sørensen et al., 2006; Zirlewagen et al., 2007). Finally, changes in tree growth over time can be explained by both tree age and climatic factors (Ryan et al., 2008).

Unfortunately, most models do not adequately meet the requirements of the large-scale forestry scenarios applicable to a country, or country wide analyses at the property level. Some models are based on insufficiently representative or only locally relevant data, others are adapted to certain treatments, and still others account for only one or a few specific tree species of interest. Another major limitation of previous research is that most has been quantitative rather than qualitative. Models based on a quantitative analysis of tree growth are essential for forming the sufficiently accurate predictions of forest growth and yield necessary for decision making in forestry.

The main goals of this study were to develop a model to simulate tree-level radial growth in the temperate forests of South Korea and to evaluate the effects of climatic and topographic factors on diameter growth. To achieve these objectives, the permanent sample plots recorded by the Korean National Forest Inventory (NFI), the standard growth model, semi-variogram analysis, and the generalized additive model (GAM) were used. The new model presented in this paper can be used to predict forest growth, taking into account climatic change, for entire forests across South Korea.

2. Materials

2.1. Study area

The study area included all of South Korea's forests (longitude 124°54′–131°06′ and latitude 33°09′–38 °45′; Fig. 1a). The Taebaek Mountain Range rises to over 1500 m on the eastern side of Korea and then drops steeply toward the East Sea with a narrow coastal plain (Fig. 1b). From the Taebaek Mountain Range, the Sobaek Mountain Range runs from the northeast to the southwest. In the central zone, moderately high mountains dominate the landscape. Lowlands are found primarily along the western region of the study area. Approximately 64% (6,368,844 ha) of South Korea is covered by forest.

2.2. Dataset and measurement protocols

The tree ring dataset used in this study was taken from the 5th South Korea NFI, which was conducted from 2006 to 2010 for all South Korea's forests (Fig. 1a). The survey design consisted of a systematic sampling at intervals of 4 km (longitude) × 4 km (latitude) across South Korea. The total inventory is 4200 clusters, and individual clusters consist of four circular sample plots. The Korean NFI system measured a sample representing 20% of Korea's forests every year. Fieldwork under the inventory system began in April 2006 and the enumeration was completed by 2010.

In each plot, increment cores were obtained from approximately six dominant or co-dominant trees. One core per tree was extracted from trees at breast height from a direction parallel to the slope using an increment borer. Cores were mounted, sanded and polished and ring width was then measured using a digital tree ring system, (DTRS)-2000, which can determine annual tree ring width at a high resolution (up to 1/100 mm), by the Korea Forest Research Institute (2013). Tree-ring widths were carefully measured, and cross-dated using several numerical methods (Aniol, 1983; van Deusen, 1990), and tree-ring characteristics were compared visually. In dendrochronological cross-dating, variations in ring widths are first examined and then synchronized with all available samples from a given region.

In this study, we used the 43,532 core samples available for the four main temperate tree species in South Korea (Table 1), which include red pine (*Pinus densiflora*), Japanese larch (*Larix kaempferi*), Korean pine (*Pinus koraiensis*) and oak (*Quercus variabilis*). These tree species form large forests in most of the mountainous areas of South Korea, and occupied approximately 37%, 5%, 4%, and 25%, respectively, of the total forested area in 2010. The available data for each species were divided into two sets: the data obtained between 2006 and 2008 were used to estimate model parameters and the remaining data (2009–2010) were reserved for subsequently validating the models (Table 1).

2.3. Climatic data preparation

Climate data were collected from recent years (1996–2009). The Korean Meteorological Administration (KMA) provided climatic data from 75 weather stations during this period. These data were interpolated with a 0.01° grid size (about 1 km) using the kriging interpolation methods and inverse distance squared weights (IDSW) based on absolute temperature and precipitation lapse rate by altitude (Choi et al., 2011; Yun et al., 2001).

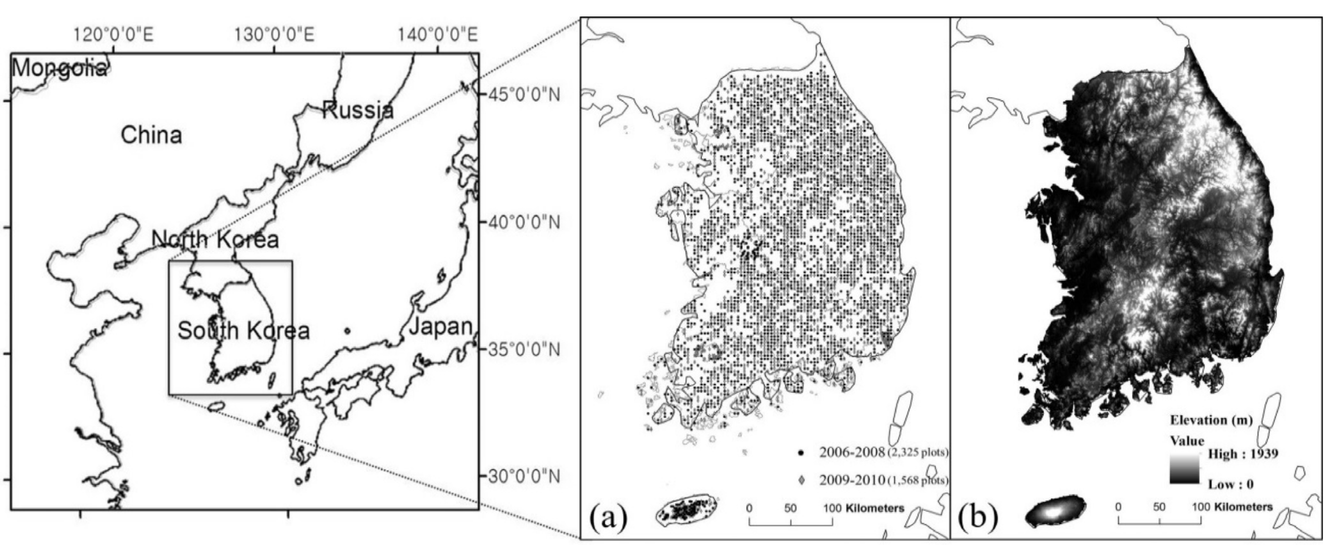

Fig. 1. (a) Locations of National Forest Inventory plots from which data were obtained and (b) a map of the digital elevation model of South Korea.