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Spatial climate-dependent growth response of boreal mixedwood forest in western Canada

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ABSTRACT

The western Canadian mixedwood boreal forests were projected to be significantly affected by regional drought. However, drought degrees were spatially different across elevations, longitudes and latitudes, which might cause different tree growth responses to climate change in different sub-regions within western Canada. In this way, regional classification of western Canadian boreal forests and understanding spatial tree growth responses to climate might be necessary for future forest management and monitoring. In this paper, tree-ring chronologies of two dominant tree species, trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench.) Voss), were obtained from mixed forest stands distributed across western Canada to study spatial tree growth response to climate based on three regional classification schemes (a phytogeographic sub-region classification, a natural sub-region classification and non-classification). Phytogeographic sub-region classification was estimated based on tree ring samples we collected in this study, while natural sub-region classification was previously developed based on analysis of regional differences in vegetation, soil, site and climate conditions. Results showed that air temperature did not significantly increase, while drought stress became more severe between 1985 to 2010. Relationships between trembling aspen growth and temperature differed between north and south parts of the study area, resulting from spatial difference in water supply. Trembling aspen growth was influenced by temperature or moisture variables of the previous years. White spruce growth was influenced primarily by moisture variables (current or previous year), and response coefficients between white spruce and drought conditions (represented by drought code) were negative in all phytogeographic sub-regions, suggesting that white spruce was more sensitive to drought stress under climate change. As a late-successional dominant species, increasingly drought stress on white spruce might cause significant alteration in forest composition of western Canadian boreal forest.

1. Introduction

Climate changes during the past several decades have led to a variety of responses in terrestrial ecosystems, including variations in net primary productivity, forest growth, and species distributions (Zhao and Running, 2010; Liang et al., 2015; Nabeshima et al., 2015). Much progress has been made to quantify the impact of climate changes on forest growth all around the world (Bowman et al., 2014; Zhang et al., 2015). Boreal forest ecosystem contains nearly half of the global forest carbon due to the slow decomposition rate of dead biomass in cold climates, playing an important role in the global carbon cycle, and has been identified as a potential tipping element of the Earth climate system (Lenton et al., 2008). However, inconsistent effects of climate change on the boreal forest ecosystems create a challenge to accurately predict global carbon cycle and forest productivity. A previous study suggests that western Canadian boreal forest seems to be more sensitive to climate change than eastern Canadian boreal forest (Peng et al., 2011); while within vast western Canada, spatially different climate change responses of boreal forest may also be caused by elevations, longitudes, latitudes, site effects (Gewehr et al., 2014) or species composition (Coomes et al., 2014; Chen and Luo, 2015).

Climate changes are spatially different in change rates and trends. For example, the increasing trend of average surface air temperature in Arctic area is higher than those in low latitudinal regions (ACIA, 2004). Climate change can also cause spatially inconsistent effects on tree growth through different mechanisms. In high latitude or altitude, climate warming seems to be able to directly alleviate the limiting effect of cold temperature on tree growth, which is distinct from

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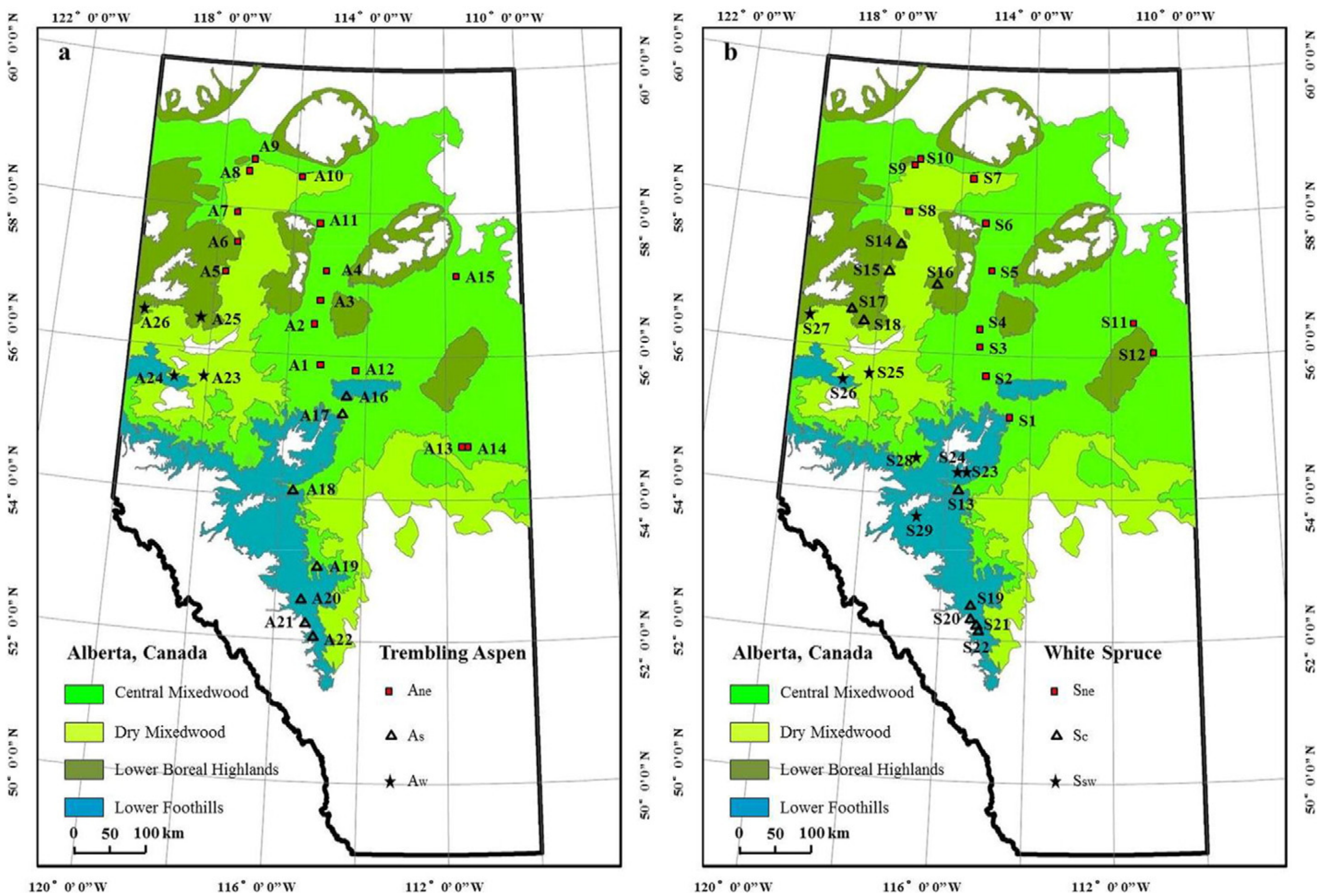

Fig. 1. Natural sub-regions and phytogeographic sub-regions for a) trembling aspen and b) white spruce in our study area. Different colors represent the natural sub-regions, including central mixedwood (green), dry mixedwood (yellow), lower boreal highlands (olive), and lower foothills (light blue). A_{ne} (hollow square), A_s (hollow triangle), and A_w (solid asterisk) represent three phytogeographic sub-regions for trembling aspen; while S_{ne} (hollow square), S_c (hollow triangle), and S_{sw} (solid asterisk) represent phytogeographic sub-regions for white spruce. A_{ne}, A_s, and A_w covered northeast, south, and west of the study area; while S_{ne}, S_c, and S_{sw} covered northeast, central, and southwest of the study area, respectively. Words next to different symbols represent site numbers.

situations in lower latitude or altitude (Reich and Oleksyn, 2008; Zhang et al., 2012). In some regions, such as North America, climate warming may induce regional drought, which reduce biomass carbon of boreal forests (Ma et al., 2012; Chen and Luo, 2015). Even for the same climatic variable, induced effects on tree growth may also vary across large spatial scales. For instance, changes in precipitation can significantly influence tree growth in low latitudes, but have less effect in high latitudes (Helama et al., 2005; Henttonen et al., 2014).

Effects of climate changes on tree growth are also dependent on tree species, especially in the same eco-region with similar spatial climatic change trends (Luo and Chen, 2011; Messaoud and Chen, 2011). Species effect further complicates modeling efforts; therefore, it is necessary to include species specific responses to climate change in tree growth studies. Tree growth is dependent on biomass of neighbors as a result of asymmetric competition (Huang et al., 2013). Unlike shade-intolerant species, shade-tolerant species commonly obtain a net carbon gain to create thicker bark and higher wood densities under species competition or shaded environments because of their lower plant respiration rates (Niinemets and Valladares, 2006); therefore, shade-tolerant species are more resistant to disturbance agents (Poorter et al., 2010). In western Canada, boreal mixedwood forests, dominated by trembling aspen (canopy and shade-intolerant species) and white spruce (understory and shade-tolerant species), distribute across large latitudes and longitudes. This area also covers an elevation range of 210 m in the northeast to 3700 m in the western Rocky Mountains, and has some of the most diverse terrain in North America. Climate change forecasting indicates substantial warming and increased drought stress over the next century in this region (Price et al., 2013; Wang et al., 2014). A previous study has also reported the spatially different mortality response of trembling aspen to environmental stressors in southeastern part of this region (Michaelian et al., 2011).

Given that there may be a heterogeneity in spatial climate dependent tree growth response, it is necessary to achieve regional classification based on spatial difference in tree growth response to climatic variables across a large spatial scale. But how to achieve the regional classification is still a challenge. Some ecological sub-region classification schemes have been developed, for example in western Canada a natural sub-region classification scheme has been developed based on analysis of regional differences in vegetation, soil, site, climate conditions and forest productivity information (Beckingham et al., 1996). This sub-regional classification is thus a logical place to start. However, tree species ecotypes may cross these boundaries; trees that are in geographic proximity but in different natural sub-regions may be more similar than more distant trees of the same species in the same natural sub-region.

In this study, another classification scheme called phytogeographic sub-regions classification will be developed based on tree-ring data collected directly in field. In this way, tree-ring data were collected from different boreal mixedwood forest stands in western Canada to 1) identify the main climatic variables affecting growth in different sub-regions