Forest Ecology and Management 267 (2012) 215–227

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Geographic and temporal patterns in white spruce climate–growth relationships in Yukon, Canada

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ARTICLE INFO

Article history:
Received 3 October 2011
Received in revised form 30 November 2011
Accepted 1 December 2011
Available online 3 January 2012

Keywords:
White spruce
Dendroecology
Yukon
Climate–growth relationships
Tree-rings
Boreal forests

ABSTRACT

A growing body of evidence suggests that climate change will have complex effects on the boreal forests of western Canada. Studies that examine historical species responses over large geographic and climatic distances may provide insights into the temporal and spatial complexities underlying forest vulnerabilities to climate change. We analyzed annual tree-ring data collected from 56 white spruce (*Picea glauca* (Moench) Voss) populations across the species' distribution in Yukon, Canada. Regional growth patterns were identified and correlation and response functions were computed to determine primary climatic influences on growth within each region. The temporal stability of climate–growth relationships was also tested in regions with sufficient climate records. Key results showed that white spruce radial growth shows strong geographic patterns across Yukon, likely reflecting large-scale climatic influences on growth. Drought appears to be a primary limitation to white spruce growth across much of southern Yukon, whereas snowfall and summer temperatures may be more important limitations in other regions. Spruce populations growing at high-elevations in central Yukon may be changing their climatic sensitivity over time and are converging with low-elevation populations in terms of climate–growth relationships. The considerable spatial and temporal complexity of climate–growth responses suggest that climate change will have varying implications for white spruce growth across Yukon.

1. Introduction

As temperature increases at northern latitudes are projected to exceed the global rate (Christensen et al., 2007), the northern boreal forests of western North America may be particularly vulnerable to climate change (Beck et al., 2011). There is evidence that climate change is already causing northward shifts and productivity changes in boreal plant species and communities (Beck et al., 2011; D'Arrigo et al., 2007), which may have substantial implications to global carbon and climate cycles, as well as forest management in these areas. Studies at the stand-scale indicate that interior boreal forests in Alaska are experiencing growth declines possibly associated with increasing temperatures and drought (Barber et al., 2000), while trees growing at the forest-tundra ecotone appear to be responding positively to warmer temperatures (Wilmking and Juday, 2005). However, other studies have found contrasting growth responses to climate change between and within treeline and interior spruce (*Picea* spp.) populations (Wilmking and Juday, 2005; Wilmking et al., 2004), suggesting climate change effects on boreal forests will be complex even within climatically homogenous areas. Further, the historically positive relationship between temperatures and growth in both high-latitude and high-elevation boreal forests appears to be weakening in certain areas, suggesting that temperatures may have increased beyond a physiological threshold (c.f. D'Arrigo et al., 2007), and creating further complexity in understanding future boreal forest responses to climate change. Sampling and analysis differences between smaller studies can confound cross-study comparisons, however (Chen et al., 2010). Regional-scale studies that integrate stand-level observations can provide valuable insight into broad-scale responses but are currently lacking for many areas (Beck et al., 2011).

Dendroecological techniques (i.e., the study of ecological variation in tree-rings, including climate; Fritts, 1976) provide an effective approach to studying historical forest productivity responses to climate. Tree radial growth increments often contain a strong climate signal (Fritts, 1976) and integrate the effects of genetics and environment into an annual measure that can be analyzed across a wide range of taxonomic, spatial, temporal, and ecological scales (Williams et al., 2010). Radial growth may represent adaptive capacity as it embodies information about annual levels of productivity, resilience, and health (Case and Peterson, 2005; Smith, 2008). Dendroecological studies have identified coherent patterns in species-specific tree-ring responses to climate change at large geographic scales (Chen et al., 2010; Griesbauer and Green, 2010a) as well as across climatic and geographic gradients

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doi:10.1016/j.foreco.2011.12.004

(Zhang and Hebda, 2004; Griesbauer et al., 2011). Further, tree-ring studies have detected recent temporal changes in climate–growth relationships, particularly in northern forests (D'Arrigo et al., 2007). These studies support suggestions that climate change effects on forests will be spatially and temporally complex and may reflect in large part strong adaptation to local conditions (Aitken et al., 2008; O'Neill et al., 2008).

In this paper, we use a dendroecological approach to conduct a regional-scale assessment of white spruce (*Picea glauca* (Moench) Voss) radial growth responses to climate across a broad geographic and climatic range in the boreal forests of Yukon, Canada. Spatially restricted studies in this area have shown that at lower elevations, drought or high summer temperatures negatively influence white spruce growth (Hogg and Wein, 2005; Zalatan and Gajewski, 2005; Miyamoto et al., 2010), whereas at higher elevations, radial growth is positively influenced by summer temperatures (Youngblut and Luckman, 2008). D'Arrigo et al., (2004) also found temporally unstable climate–growth relationships in high-elevation white spruce populations in central Yukon. What remains unclear, however, is the spatial extent of white spruce regional growth patterns and the nature of regional climate–growth relationships across its distribution in Yukon (and western North America). The specific objectives of this study were to: (1) use the approach of Griesbauer and Green (2010a) to elucidate regional white spruce growth patterns across a large portion of the species distribution in Yukon, (2) identify key climate variables that influence growth within these geographic patterns, and (3) to test the temporal stability of the climate–growth relationships.

2. Methods

2.1. Field sampling

We collected tree-ring data from 45 mature (older than 60 years) white spruce stands across the southern half of the Yukon Territory from 2008 to 2009 (Fig. 1 and (Table 1). We also analyzed 11 white spruce populations located near the Richardson Mountains of northern Yukon which were collected and prepared by Sweeney (2011). Our study sites were located in six of the eight climatic zones of the Yukon (Smith et al., 2004). Most of our study sites were located within the Boreal Cordillera Ecozone that covers the southern half of the Territory (Smith et al., 2004). The climate in this broad area is predominantly influenced by weather systems moving north and east from the Pacific Ocean, with numerous mountain ranges exerting a strong rain shadow effect. The climate ranges from sub-humid to semi-arid, with long cold winters and short, warm summers modified by elevation and aspect. Mean

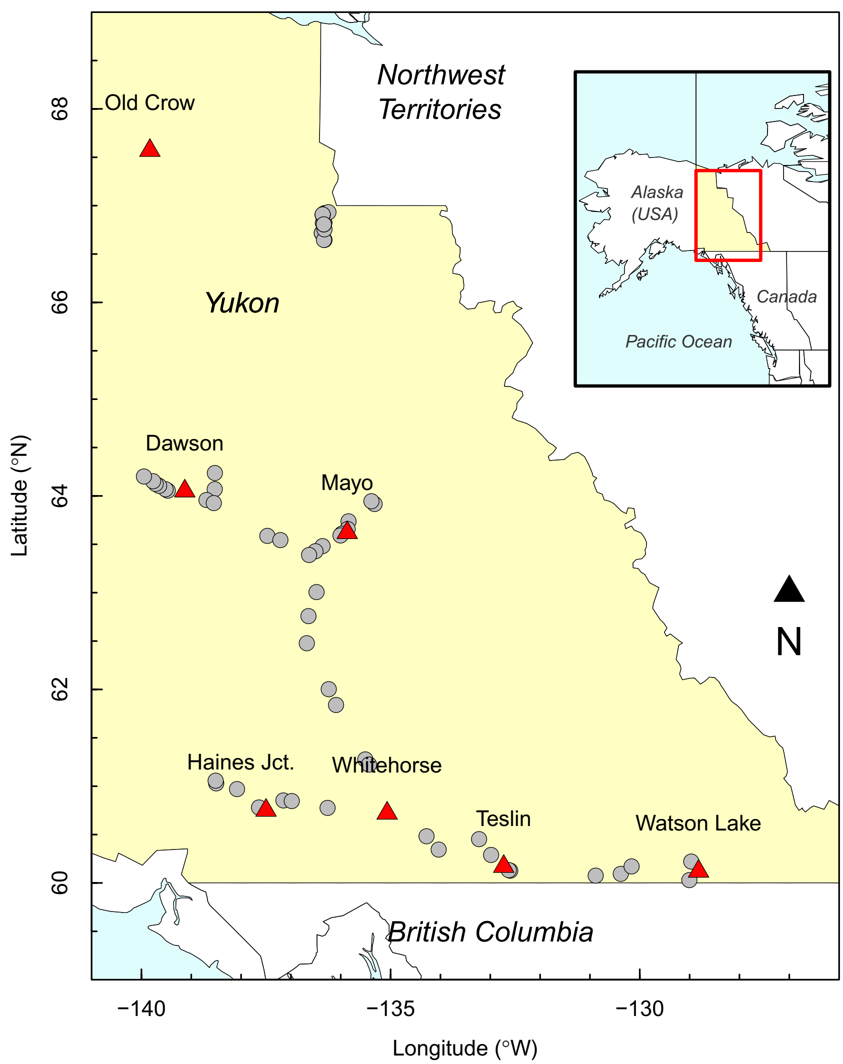

Fig. 1. Locations of white spruce tree-ring chronologies (grey dots) and climate stations (red triangles and labels) in Yukon, Canada. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)