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Relationships between climate and tree radial growth in interior British Columbia, Canada

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ABSTRACT

Climate is a main driving factor of the formation of annual tree-rings, but which climatic variables are the most influential on radial growth may vary among species and sites. To explore these interactions, tree-ring chronologies along a major elevation gradient were examined for three tree species in southern interior British Columbia (Canada): *Pseudotsuga menziesii*, *Pinus contorta*, and *Picea glauca* × *engelmannii*. We used correlations and linear and multiple regressions to explore the relationships between tree-ring radial growth and climate variables in the area from 1922 to 1997. All correlation coefficients between ring chronologies and monthly climatic variables were medium to low (from −0.3 to 0.4); nevertheless, moderate but significant trends could be identified. Multivariate models explained up to 53%, 43% and 32% of radial growth variability for *P. contorta*, *P. menziesii* and *P. glauca* × *engelmannii*, respectively. All three species showed similar radial growth–climate patterns across the elevational gradient, but they had different details that made ring width–climate relationships species-specific. Precipitation-related variables were more related to radial growth at low-elevations, changing into temperature-related variables at high-elevations. Tree-ring width for all three species was primarily and significantly affected by climate variables from the year previous to the growing season and only secondly by current year conditions, but the critical months varied for different species and altitudes. Winter precipitation also affected radial growth, either as a source of water or as a possible agent of physical damage. Although our work showed significant climate influences on breast height tree radial growth, our results also indicated that other site factors such as microclimate or stand dynamics can be as or more important than climate variability.

1. Introduction

Terrestrial vegetation responds to weather and climate through a variety of physiological, demographic, and ecosystem functions, which determine where plant species grow, how well they grow, and how their presence and arrangement within the biotic community change over time (Bonan, 2002). Any changes in weather and climate can therefore be expected to affect terrestrial vegetation. The impact may be direct via interference with plants phenology (e.g. growth rates, bud formation, flowering) or indirect via changes in the stand dynamics (e.g. regime of disturbances) (Loehle and LeBlanc, 1996; Weber and Flannigan, 1997). Tree species sensitivity to climate at continental scales is usually described in terms of biogeographic distribution (Thompson et al., 2000). Climate can also lead to gradual changes in population or community processes, such as differential species growth, turnover, or establishment, which play a role in biogeographical changes by altering community composition over large areas (Littell et al., 2008). Understanding climate-mediated population processes is a key step to better prediction of climate change impacts on forest ecosystems (Beniston, 2002).

Temperature and precipitation in the North American Pacific Northwest have increased more than global averages, a trend likely to continue into the future (Mote, 2003). The changes vary from place to place, but the general trend in the 20th century in south-western British Columbia (Canada) for the climate is to become warmer and wetter. However, not only the annual temperature and precipitation have changed: seasonal temperature, maximum and minimum temperature and snowpack have also changed (MWLAP, 2002). Although there is some uncertainty about the exact changes in precipitation, future summers will likely be warmer and drier, and winters will be warmer and wetter than at present (Mote, 2003). A warmer, wetter winter will cause more precipitation to fall as rain and a longer growing season when compared to current conditions. To model the future response of

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forest vegetation to these expected changes, quantitative relationships derived from long-term climate data and observed population processes at multiple scales can be efficiently extrapolated across mountainous terrain (Littell et al., 2008).

Dendrochronology has been used as a tool to explore the ecosystem response to climate variability in this region (Chhin et al., 2008). Zhang et al. (1999) used different conifer species to identify regional climatic anomalies for the past four centuries in central British Columbia. Zhang and Hebda (2004) explored Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) radial growth in mountainous areas in relation to climate; they found that growing season precipitation influenced growth at both high- and low-elevations, but temperature played different roles at different elevations. Luckman and Wilson (2005) reconstructed past summer temperatures in the Canadian Rockies from tree-ring records. Bower et al. (2005) built a historical response coefficient to drought for Douglas-fir, although the effect of drought was limited to very dry sites. Watson and Luckman (2001a,b) summarized dendroclimatology research in the southern Canadian Rockies. Peterson and others examined the effects of climatic variability during the 20th century on the growth of lodgepole pine (*Pinus contorta* Dougl.) and Douglas-fir along an elevational gradient in the North Cascades National Park (Washington, U.S.A.) (Case and Peterson, 2005, 2007; Holman and Peterson, 2006; Littell et al., 2008; Nakawatase and Peterson, 2006). They reported that high-elevation plots responded positively to annual temperature while mid-elevation plots responded negatively to growing season maximum temperature but positively to growing season precipitation. Chhin et al. (2008) examined the relationships between climate and growth of lodgepole pine in Alberta across elevational sequences of ecoregions, and found that annual growth was generally sensitive to heat and moisture stress in late summer of the previous year, the degree of winter harshness, and the timing of the start of the growing season. Green and Miyamoto (2006) and Green and Griesbauer (2007) used dendrochronology as a proxy to evaluate changes in Douglas-fir growth rates under climate change.

All these studies followed the traditional dendrochronology approach of looking for trees on sites that are under high environmental stress (tree lines or xeric sites – locations where climate clearly acts as the main growth limiting factor; Begon et al., 2006) with the objective of avoiding "complacent" trees (which produce tree-ring series with low sensitivity to climate variability; Fritts, 1976). This technique could be a biased sampling strategy if we want to understand the growth–climate relationship at the local landscape, population and ecosystem levels (Krajina, 1969). The growth response of climate-stressed trees on a relatively arid or exposed site is not representative of the growth response of the whole landscape population (Wilmking et al., 2004). Population-level variability in response of radial growth to climate can be better studied along ecological gradients (Kienast et al., 1987). Consequently, we carried out a dendroclimatological study along a major elevation gradient in southern interior British Columbia (western Canada) to quantify the relationships between key climate variables and tree radial growth that are truly representative of the responses of tree populations, and to determine whether the responses varied between different tree species and along an altitudinal gradient. We used the classic dendroclimatology techniques but with a different site selection strategy for three different tree species: Douglas-fir, lodgepole pine, and hybrid white spruce (*Picea glauca* × *engelmannii*).

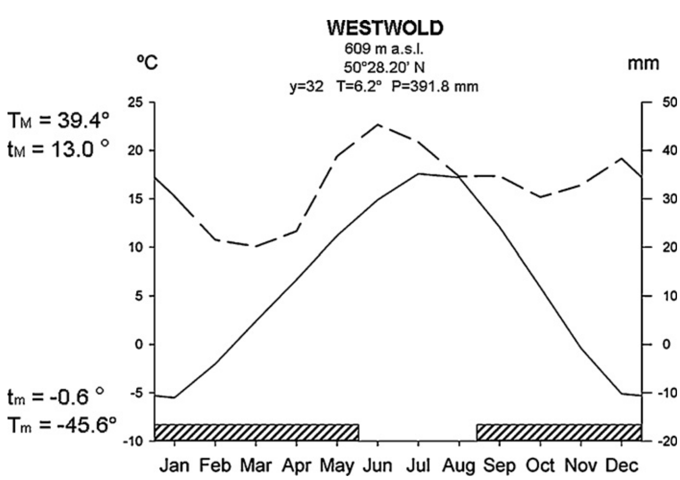

Fig. 1. Climatic diagrams of Westwold (1971–2002). Dashed line: mean monthly precipitation including snow; Solid line: mean monthly temperature; *y*: number of years considered; *T*: mean annual temperature (°C); *P*: mean annual amount of precipitation (mm); T_M: absolute maximum temperature (°C); t_M: mean daily maximum temperature (°C); t_m: mean daily minimum temperature (°C); T_m: absolute minimum temperature (°C). Oblique striped area shows months with an absolute minimum temperature below 0 °C (frost period). Data from Environment Canada (2009).

2. Materials and methods

2.1. Sampling sites

Study sites were located on Tolko Industries Ltd.'s Tree Farm License 49 (TFL 49) in the Okanagan Valley, near Kelowna, British Columbia, Canada (50°28′N, 119°45′W, 609 m.a.s.l.). Mean annual precipitation in the area is 391.8 mm, and mean annual temperature is 6.2 °C, with mean July temperature 19.1 °C and mean December temperature −2.9 °C (see ombroclimatic diagram in Fig. 1). The study area contains five forested biogeoclimatic (BEC) zones: the Ponderosa Pine (PP), Interior Douglas-fir (IDF), Montane Spruce (MS), Engelmann Spruce-Subalpine Fir (ESSF) and Interior Cedar Hemlock (ICH) zones (Pojar et al., 1987, Lloyd et al., 1990). The three most abundant tree species, which were selected for our study, are lodgepole pine (*P. contorta* Dougl. var. *latifolia*), Douglas-fir (*P. menziensii* (Mirb.) Franco var. *glauca*) and hybrid white spruce (*P. glauca* × *engelmannii*) (Nitschke, 2006).

2.2. Sample collection and process

Based on the TFL49 BEC zone maps of species distribution, availability of stands of the target species and accessibility of the stands, two study transect lines that passed through three of these zones (ESSF, MS and IDF) were sampled, representing a gradient of elevation-induced climates from a low-elevation sub-continental warm dry summer and cool winter (IDF), to high-elevation sub-continental subalpine with cold snowy winters and cool summers (ESSF) (Table 1). The MS zone represents the local mid-elevation environment with an intermediate climate (Lloyd et al., 1990). Access to elevation sequences in the area was limited to those roads that ascend the steep slopes from the Okanagan Valley floor and bypass cliffs, which act as physical barriers to field sampling. Sampling was limited to stands that could be reached and sampled within a work day from an access road. Sample plots were deliberately located on zonal or mesic sites (sensu Krajina, 1969), in which soil moisture experienced by trees is dominated by local precipitation and climate-induced water balance. This strategy was adopted in order to characterize the response of the majority of the tree populations within the BEC zones, and not just trees on the extreme dry end of the soil moisture gradient.

TFL 49 has been severely attacked by mountain pine beetle (*Dendroctonus ponderosae* Hopkins) with widespread mortality in lodgepole pine stands. We therefore sampled mixed stands that had surviving pines and provided a growth signal reflecting