Dendrochronologia 37 (2016) 69–78

Contents lists available at ScienceDirect

Dendrochronologia

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

Original article

Species and site differences influence climate-shrub growth responses in West Greenland

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ARTICLE INFO

Article history:
Received 19 January 2015
Received in revised form 8 November 2015
Accepted 11 December 2015
Available online 24 December 2015

Keywords:
Arctic shrubs
Vegetation dynamics
Climate change
Dendroclimatology
Dendroecology
Clonal plants

ABSTRACT

We examined the suitability of two deciduous arctic shrubs (*Salix glauca* L. and *Betula nana* L., hereafter *Salix* and *Betula*, respectively) for dendroclimatological analysis at two sites in West Greenland. Chronologies were successfully cross-dated, and the oldest covered the period 1954–2010 (Expressed Population Signal [EPS] > 0.85, 1977–2010). Distinctive pointer years, also called micro-rings, including those from a known outbreak of the irruptive moth *Eurois occulta* L. (Lepidoptera: Noctuidae) that peaked in 2005, assisted in the dating process. Climate-growth analyses were performed in two ways: first, using correlation analysis between residual site-level chronologies and monthly and seasonal climate data, and second, using linear mixed effects models (LMM) with seasonal climate data and standardized chronologies for each individual. We used climate data for the current and previous years for a given growth ring for both analyses. Both analyses revealed differences in climate-growth response among species and among sites of contrasting topography. *Salix* ring widths from south facing slopes correlated positively with current year's summer temperatures, while those on gentle slopes associated negatively with current year's spring precipitation. *Betula* was only sampled at one site (flat), and displayed associations with temperature and precipitation in spring. Results from the LMM largely corroborated the correlations for *Betula* and *Salix* on south facing slopes. *Salix* at the flat site displayed significant associations with a large number of climate variables, most strongly previous year's summer and autumn temperatures, though precipitation in multiple seasons of the current and prior year did a better job of accounting for the variation in the data. Many dendrochronological studies in the Arctic illustrate clear summer temperature responses, but the majority were conducted on a single topographic position. Due to the heterogeneity of West Greenland's landscapes, it is important to examine individuals from varying topographies. We found that samples collected from south facing slopes do appear to respond positively to summer temperatures, while those on shallow slopes respond to a wider array of seasonal temperature and precipitation parameters. Accounting for these species and topographic differences, when sampling, is imperative for improving our understanding of how plant communities in the Arctic will respond to ongoing and expected warming.

1. Introduction

Understanding how ecosystems have and will continue to respond to climate variability requires spatially explicit time series of temperature and precipitation data (Bradley, 2011). Time series of climate data from relatively dense networks of climate stations in more populated regions of the world have provided important insights into climatic variability and how the magnitude of recent climate change varies among regions (Hijmans et al., 2005). Recent temperature increases in the Arctic illustrate how the magnitude of warming varies regionally. Over the last several decades, the Arctic has warmed roughly twice as much as the global average (Trenberth et al., 2007), and this has led to pronounced localized changes in vegetation (Walker et al., 2006) that vary among Arctic climates (Post et al., 2009).

The Arctic as a whole has few spatially explicit time series of climate data compared to temperate regions (Hijmans et al., 2005). One approach for expanding knowledge of the spatial and temporal variation in historical climate in areas lacking highly-spatially resolved temperature data is to develop proxies to supplement the instrumental record (Mann et al., 1998). Past climatic variability has been reconstructed for parts of Greenland using climate proxies

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http://dx.doi.org/10.1016/j.dendro.2015.12.007
1125-7865/

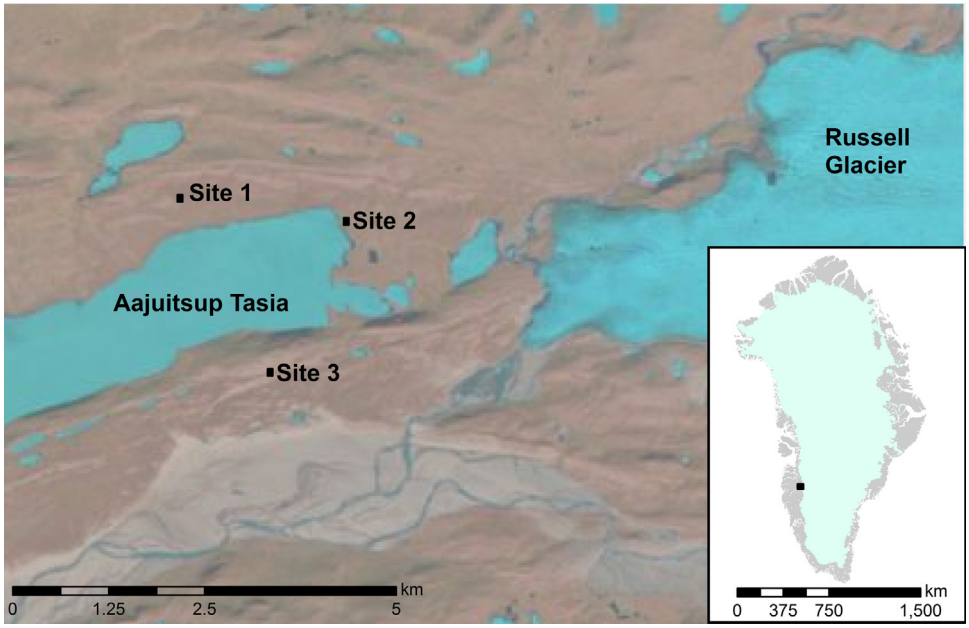

Fig. 1. Map of sites located on the eastern end of Long Lake (Aajuitsup Tasia), roughly 2–5 km from Russell Glacier, West Greenland. Data Source: Landsat 5 (NASA), Cryosphere Atlas (National Snow and Ice Data Center).

preserved in ice cores, which extend back to 100 ka (Andersen et al., 2004). The climate data preserved in ice cores has sub-annual (seasonal) resolution for some climate proxies and climate-associated parameters (e.g., snow accumulation, $\delta^{18}O$, CH_4, and NO_2 (Alley, 2000; Blunier et al., 2002; Flückiger et al., 2004; Andersen et al., 2004)) and decadal to multidecadal resolution for others such as sea surface temperature and the Atlantic Multidecadal Oscillation (Dowdeswell and White, 1995; Chylek et al., 2012). However, the spatial resolution of ice core climate data is limited. Ice core-based climate data are derived from the Greenland ice sheet, often hundreds of kilometers from Greenland's terrestrial ecosystems, and are therefore unlikely to represent climate variability in heterogeneous local environments.

Tree ring widths are sensitive to climatic variability, and tree rings are commonly used as a climate proxy. However, with the exception of *Betula pubescens* Ehrh. in sheltered valleys in southwest Greenland (western coast between 60 and 63°N), trees are not present in most of ice-free Greenland (Böcher, 1979; Kuivinen and Lawson, 1982; Fredskild and Ødum, 1990). The most abundant woody plants in much of inland Greenland are deciduous shrubs. Many shrub species form annual rings, and have the potential to be used as climate proxies (Myers-Smith et al., 2015a). In spite of this, little research on shrub growth has been conducted in arctic ecosystems to evaluate their potential as climate proxies compared with the abundant research on tree growth in temperate regions. Shrub species in both temperate and arctic ecosystems are known to produce annual rings, and have been used to reconstruct past precipitation and temperatures (Schweingruber and Poschlod, 2005; Schweingruber et al., 2013). For example, arctic shrubs provide a record of past climate variability in Siberia (Blok et al., 2011), Canada (Rayback and Henry, 2006), Svalbard (Weijers et al., 2012), mainland Scandinavia (Bär et al., 2006; Meinardus et al., 2011; Weijers et al., 2012), and High-Arctic Greenland (Forchhammer et al., 2008). Nonetheless, the Arctic remains understudied for dendrochronological climate reconstructions given the size of the region.

Greenland's terrestrial ecosystem represents a particularly infrequently studied part of the Arctic. In Zackenberg, NE Greenland, an approximately 50–75 year long shrub ring width chronology has been developed for *Salix arctica* Pall. (Wilson, 1964; Schmidt et al., 2006, 2010; Forchhammer et al., 2008). We are aware of only two studies, both recent, on secondary growth responses to climate in shrubs in the West Greenland region. Jørgensen et al. (2014) developed approximately 60 and 75 year long records of *Alnus viridis* (Chaix.) D.C. and *Salix glauca* L., respectively, and Hollesen et al. (2015) developed a nearly 90 year record of *Betula nana* L.; both studies demonstrate arctic shrub growth responses to maritime climates. *B. nana* L. and *S. glauca* L., hereafter *Betula* and *Salix*, are two of the dominant shrubs in our study area (Post and Pedersen, 2008). Both species have been successfully used for dendroecological and dendroclimatological investigations elsewhere (Blok et al., 2011; Meinardus et al., 2011; Buras et al., 2012).

The objectives of this study were to (1) determine if these two shrub species form annual growth rings that are amenable to reliable cross-dating in a continental climate in West Greenland and (2) conduct a climate-shrub growth analysis to determine how species and site differences mediate climate-shrub growth associations. We hypothesized that growth in both *Salix* and *Betula* would be associated with temperature and precipitation, especially on the well-drained sites on steep south-facing slopes.

2. Materials and methods

2.1. Study site

The study area is located in West Greenland ca. 20 km northeast of Kangerlussuaq near Long Lake (Aajuitsup Tasia, 67.1 N, 50.29 W; Fig. 1). The climate has frigid winters, cool summers, and low annual precipitation. Five months (May–September) have mean monthly temperatures above freezing (Fig. 2; Klein Tank et al., 2002 [KNMI]). Most precipitation falls during the summer and estimates of total annual precipitation range from 131 to 338 mm, with a mean of 149 mm (Fig. 2). Daily temperature measurements have been collected at the Kangerlussuaq airport (67.02 N, 50.70 W) since 1949 but missing values are common before 1973. Consequently, only data for the 1973–2010 period were used in our analysis. Missing monthly values from the data set (January–July in 1999) were interpolated using mean monthly temperatures for that month in the prior and subsequent 2 years. There were no missing values in