Divergent tree growth response to recent climatic warming, Lake Clark National Park and Preserve, Alaska

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[1] Many dendroclimatic studies have been conducted in Alaska to understand recent climate changes, identify past and current warming trends, and determine how climate change may influence ecosystems. Four new white spruce (*Picea glauca* [Moench] Voss) ring-width chronologies from four sites along a 30 kilometer north-south transect in the Lake Clark National Park and Preserve on the Alaskan Peninsula span a common interval from AD 1769 to 2003. Two sites show an internally consistent positive growth response to increasing April–July temperatures after 1950. The two other sites each contain two subpopulations showing varying growth responses. One subpopulation diverges from historical temperature data after 1950 and one shows increased growth consistent with warming or exceeds expected growth increases. The growth decline may be due to temperature-induced drought stress that acts on some trees. Unprecedented climatic changes are triggering diverse growth responses between and within study sites that may greatly complicate dendroclimatic reconstructions of past climate conditions. **Citation:** Driscoll, W. W., G. C. Wiles, R. D. D'Arrigo, and M. Wilmking (2005), Divergent tree growth response to recent climatic warming, Lake Clark National Park and Preserve, Alaska, *Geophys. Res. Lett.*, *32*, L20703, doi:10.1029/2005GL024258.

1. Introduction

[2] *Barber et al.* [2000] showed that some white spruce sites from interior Alaska experienced a consistent decrease in growth over the past 90 years, based on comparisons with a climate index comprised of temperature and precipitation. They suggested that a continuing decrease in ring widths is largely a function of warmer mean summer temperatures and a simultaneous drop in precipitation. *Wilmking et al.* [2004] have shown that the response to warming at tree-line sites in the Brooks and Alaskan Ranges was both positive and negative within a site. The phenomenon of divergent response to increasing temperatures within a single population could dampen population-level climate response if undetected [*Wilmking et al.*, 2004]. *D'Arrigo et al.* [2004] and *Wilmking et al.* [2004] have suggested that temperatures beyond a certain threshold may negatively influence growth, largely due to decreasing net photosynthetic gains and temperature-induced drought stress.

[3] Here, we report on the climate response of four new ring-width chronologies sampled at four sites in Lake Clark National Park and Preserve, Alaska. The Park and Preserve covers over 4 million acres in southwestern Alaska and is located in the headwaters of the Bristol Bay fisheries (Figure 1). The elevational tree-line sampling sites are located between 400–580 meters above sea level along the western flank of the Chigmit Mountains, in the transitional climatic zone between coastal and interior climate regimes. The climate of the region is strongly influenced by the Aleutian Low during the winter and spring months. The North Pacific High dominates the remainder of the year with average monthly temperatures from nearby King Salmon range from −10°C in January and 13°C in July, and precipitation ranges from 81.7 cm in August to 22.4 cm in February [*Vose et al.*, 1992].

2. Data and Chronology Development

[4] Tree cores were taken from living white spruce (*Picea glauca* [Moench] Voss) and subfossil wood during June of 2004. Sites were located on alluvium at tree-line and trees were generally well spaced. At first, four ring-width chronologies were developed using standard dendrochronological techniques [*Cook and Kairiukstis*, 1990; *Stokes and Smiley*, 1968]. The raw ring-width data was conservatively standardized using negative exponential growth curves with the ARSTAN program [*Cook*, 1985].

[5] Ring-width chronologies were compared with monthly temperature and precipitation records from the closest meteorological station, King Salmon, Alaska ((Global Climate Historical Network) GHCN), approximately 130 kilometers southwest of the tree ring sites, at an elevation of approximately 18 meters (Figure 1). Annual average temperature has increased 2°C over the 53-year period (1947–2000), with no significant increase since 1980 and mean annual precipitation has decreased 5 cm from 1942–2000.

[6] During standardization, it became clear that the chronologies from Fish Trap Lake (FT) and Portage Lake (PO) contained two subpopulations within each site and hence they were separated into four chronologies, two of which responded positively to increased temperatures in the latter half of the 20th century and two of which appeared to experience an overall decline after the 1950s (Figure 2). The positive-responding subchronologies (FTp and POp) correlated with one another more strongly ($r = 0.89$, $p < 0.0001$ for the years 1673–2003) than the two subchronologies within a single site ($r = 0.37$ and 0.58, $p < 0.0001$ for FT for the years 1673–2003 and PO for the years 1672–2003, respectively). Negative-responding components (FTn and POn) also correlated well between sites ($r = 0.67$, $p <$

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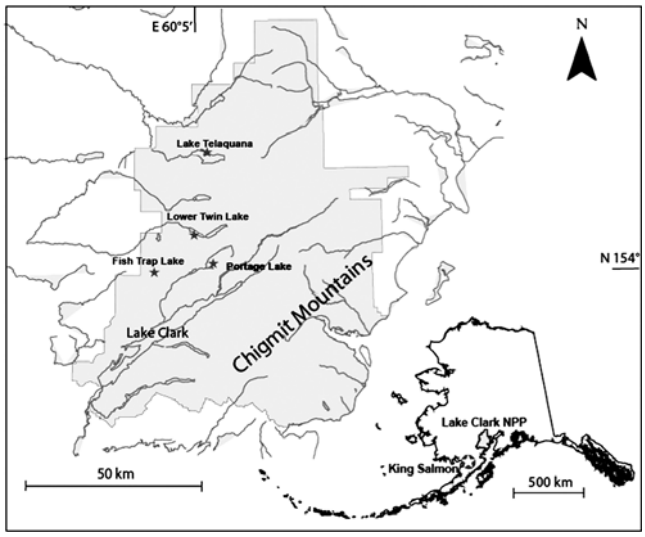

Figure 1. Map of the study site at Lake Clark National Park and Preserve, Alaska. The Lake Telaquana (MT), Lower Twin Lake (TW), Fish Trap Lake (FT) and Portage Lake (PO) sites are shown as stars and the shaded area is the Park and Preserve. The inset shows the Park and Preserve in relation to the King Salmon climate station, shown as a star within a circle. See color version of this figure in the HTML.

0.0001 for the years 1627–2003), suggesting that common influences were limiting growth at both sites.

3. Tree-Ring Climate Response

[7] Four chronologies (Middle Lake Telaquana (MT), Lower Twin Lake (TW), FTp and POp) correlate positively with temperatures for the months of April–July (Figures 3a–3d). Both negative responding chronologies (FTn and POn) displayed strongly positive responses to August precipitation (Figures 3e and 3f), whereas correlations between positive responders from the same sites and August precipitation were considerably weaker (Figures 3c and 3d), but not insignificant. Both FTn and POn also showed strong correlations with temperatures from December to March, (Figures 3e and 3f), whereas FTp and POp displayed no such relationship (Figures 3c and 3d). These data suggest that warming winter temperatures are partially responsible for the growth deceleration at both sites.

[8] Principal component analysis was used to combine the four positive-responding chronologies (MT, TW, FTp, POp) into one principle component (PC1). The two negative-responding chronologies (FTn, POn) were similarly combined (PC2) and these principle components were then compared with temperature and precipitation data (Figure 4). Both principle components were highly corre-

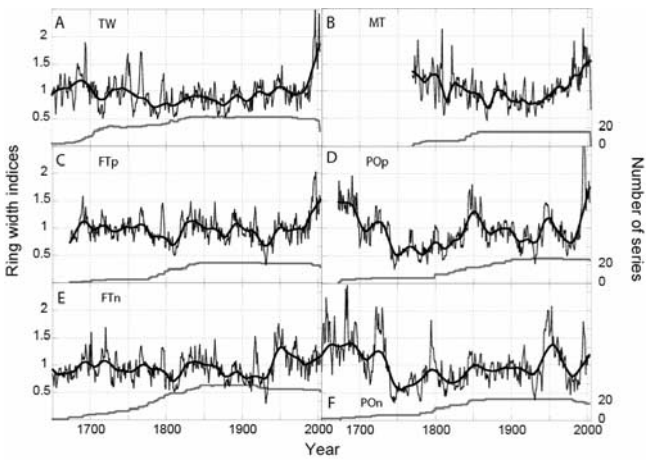

Figure 2. Lake Clark ring-width chronologies. Thin black lines represent the ring-width chronologies; thick black lines represent decadally smoothed values. Sample size is also shown. A–B. These chronologies show 20th century warming and did not appear to contain a significant population of negative responders. C–D. FTp and POp showed an apparent growth deceleration in the decades following 1950, with accelerated growth after the 1970s. E–F. These chronologies experienced growth acceleration prior to 1950 and then reduced growth with some recovery after the 1970s. Note that POp (D) and PON (F) show similar growth patterns, and differ in that POp shows less vigorous growth during the 1950s and a stronger recovery after the 1970s relative to PON. See color version of this figure in the HTML.

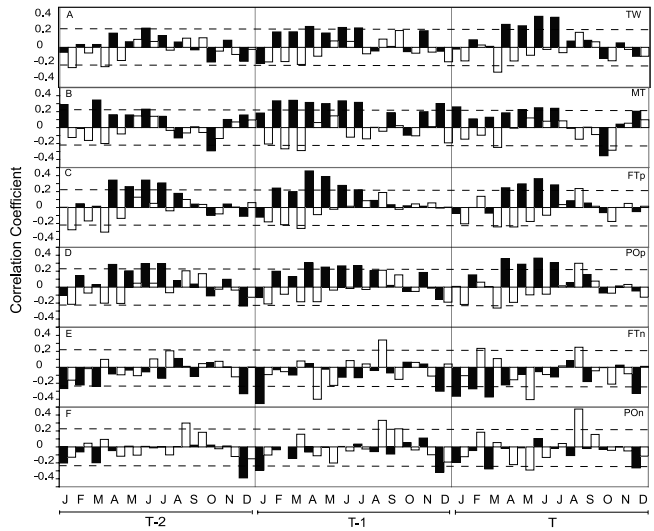

Figure 3. Comparison of the six ring-width series with monthly data (58 years for precipitation (white), 53 years for temperature (black)) from King Salmon, AK during the growing season for year of growth and two prior years. Dashed lines at r = 0.23 represent significance levels (p = 0.05) for precipitation and temperature. A. TW responded to growing season temperatures in the year of growth, less the in year prior, and was not significant two years prior to growth. B–D. MT, FTp, and POp correlated positively with April–July temperatures in the two years prior to growth and the year of growth. E–F. FTn and POn responded positively to August precipitation during the year of growth and the two years prior; winter and early spring temperatures negatively influenced growth to varying degrees at both sites.

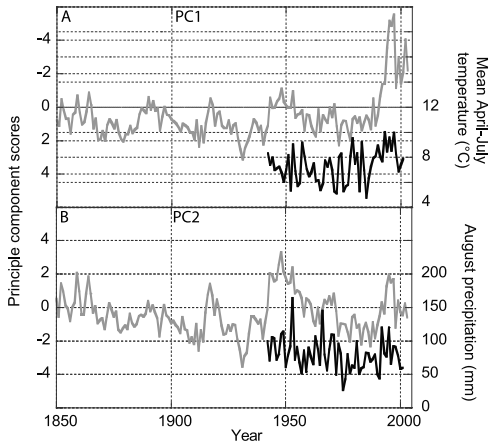

Figure 4. Principal component scores from 1850–2003 from the six chronologies compared with historic climate data. A. Positive-responding principal component (PC1) derived from four chronologies and average April–July temperatures. Note acceleration of growth during the 1990s coinciding with increasing summer temperatures and August precipitation. B. PC2 compared with August precipitation, showing poor growth during the 1970s corresponding with low precipitation levels and recovery thereafter. Note close correspondence between PC1 and PC2 prior to historical times and divergence thereafter.

lated until the middle of the 20th century, after which the relationship deteriorates (Table 1).

4. Discussion

[9] Whereas all of the study sites contained a population of trees that were sensitive to April–July temperatures and responded positively to recent warming, two sites also contained populations of negative responders. Negative responders between sites correlated strongly with one another ($r = 0.67$, $p < 0.0001$), suggesting that a common climatic factor was influencing growth of these populations at both sites. Late growing season temperature-induced drought stress, which may be partially relieved by higher rates of August precipitation, is one likely factor affecting growth deceleration in FTn and POn. Increasing winter temperatures also appear to be negatively influencing growth at both sites, although August precipitation was a more powerful influence on PC2 ($r = 0.42$, $p = 0.0007$) than December–April temperatures ($r = -0.21$, $p = 0.05$).

[10] Previous tree ring studies have shown growth decreases midway through the 20th century with varying degrees of recovery after 1970 [*D'Arrigo et al.*, 2004; *Jacoby and D'Arrigo*, 1995; *Wiles et al.*, 1998] in general agreement with PC2. These negative-responding Lake Clark chronologies correlate well with August precipitation, which decreases during historic times (after 1942) until the 1970s, at which point it begins to increase. Recent growth increases at these and other locations may therefore be largely a function of precipitation increases and might not accurately represent growing season temperatures during recent decades (Figure 4). Winter temperatures follow a similar, yet inverted trend: temperatures rise until sometime near the mid-1970s, at which point they stabilize and drop slightly. Thus the recovery during this period may be attributable to both August precipitation and cooler winter temperatures.

[11] Positive-responding chronologies (e.g. TW, POp) experienced unprecedented growth surges with late 20th century warming, suggesting possible nonlinear growth response to contemporary warming. However, other factors (e.g. increasing late growing season precipitation after the mid-1970s) likely enhanced positive response to increasing growing season temperatures. *Wilmking et al.* [2005] have recognized diverging growth trends at circumpolar tree-line sites since the 1960s. The diverging chronologies exhibit recent increased temperature sensitivity, possibly due to the effect of physiological thresholds, which are crossed more often under the current warming temperatures [*D'Arrigo et al.*, 2004; *Wilmking et al.*, 2004]. Microsite differences, controlling local drought conditions [*Wilmking and Juday*, 2005] might be one explanation for the enhanced growth of some but not all trees at latitudinal as well as our elevational tree-line sites.

[12] The emergence of separate, coherent climate signals within a single tree-line site suggests that the assumption of population-wide climate response may be flawed. Real climate signals may be muted when otherwise careful dendroclimatic analyses ignore the possibility of within-population variability. Furthermore, as precipitation may be a powerful influence on growth response of temperature-stressed trees, it is important to consider this possibility when sampling sites and to include analysis of precipitation response in dendroclimatic studies for northern areas.

5. Conclusions

[13] Two populations, one responding positively to growing season temperatures and the other responding primarily to August precipitation, were identified within two tree-line sites in Lake Clark National Park and Preserve, Alaska. Growth of the divergent subpopulations correlate well prior to 1950 and diverge thereafter, supporting the idea that contemporary warming has introduced unprecedented stresses on some trees and thus impeded growth. Furthermore, strong positive correlations with August precipitation among negative responders suggest that temperature-induced drought stress may be relieved in these populations by higher levels of precipitation late in the growing season.

[14] The interplay between climate variables (e.g. temperature, precipitation), highly localized non-climate variables (e.g. competition, depth to permafrost) and individual tree growth rates and allometry is not well understood in the context of recent warming at high latitude tree-line sites. It appears that unprecedented climatic stresses are triggering diverse growth responses between and within study sites that may greatly complicate dendroclimatic reconstructions

Table 1. Correlations Between PC1 and PC2 for 49-Year Intervals From 1801–2000[a]

Interval	r	p
1801–1850	0.946	<.0001
1851–1900	0.805	<.0001
1901–1950	0.952	<.0001
1951–2000	0.628	<.0001

[a]Note divergence after 1950.

of past climate conditions. Such intervening variables, if undetected, may seriously threaten the accuracy and validity of dendroclimatic reconstructions of past climate conditions. More research is needed to better understand the complex interplay between climatic variables and highly localized environmental and biological factors governing growth on both individual and population-wide levels, and old assumptions about the coherence of climate response within a tree line site must be revisited in the face of shifting climatic stresses.

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