STAND DYNAMICS OF RELICT RED SPRUCE IN THE ALARKA CREEK HEADWATERS, NORTH CAROLINA

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Abstract.—Disjunct red spruce (*Picea rubens* Sarg.) forests in the southern Appalachians can serve as models for understanding past and future impacts of climate change and other perturbations for larger areas of high-elevation forests throughout the Appalachians. We conducted a vegetation and dendrochronological survey to determine the age, size class, and condition of extant red spruce and composition of co-occurring woody and herbaceous vegetation in the Alarka Creek headwaters basin on the Nantahala National Forest in Swain County, NC. Using 10-m-wide belt transects, we measured the diameter of overstory red spruce and nearby saplings and seedlings, cored them, and mapped their location. We also examined red spruce for evidence of insect infestation. We noted the presence of all other woody species and recorded the diameter of other overstory trees. At 20-m intervals, we cored an overstory tree (other than red spruce) and quantified the herbaceous vegetation using 5-m x 10-m plots. Large red spruce, which averaged 755 cm^2 in basal area per tree, made up 18 percent of canopy trees. Serviceberry and sweet birch dominated the remainder of the overstory at 36 percent and 18 percent, respectively. Overall tree density averaged 450 stems/ha with 242 cm^2 basal area per tree, or 10.89 m^2/ha basal area. Great rhododendron and mountain laurel dominated the shrub layer, with red maple and sweet birch seedlings present throughout. Red spruce has been continuously recruited for the past century and new seedlings are still being established. Dendrochronological analysis indicates growth decline in the 1930s, followed by persistent recovery to near expected levels until a decade ago. Recent growth declines coincided with a heavy regional outbreak of southern pine beetles (*Dendroctonus frontalis* Zimm.), which may or may not have caused the decline. Red spruce growth was insensitive to precipitation, but improved with warm fall (previous year October, current year September, October) temperatures. Our assessment indicates that the Alarka Creek headwaters harbor a second-growth red spruce component still capable of self-replacement and partially buffered by site characteristics from climatic perturbations despite its relatively low elevation and southern latitude.

INTRODUCTION

Disjunct forests at the southern range of red spruce (*Picea rubens* Sarg.) can help reveal impacts of climate change and other perturbations, thereby serving as models for understanding other red spruce forests throughout the Appalachians. One such relict forest occurs in the headwaters basin of Alarka Creek in Swain County, NC. Situated at roughly 1,220 m, this site is among the southernmost and lowest-elevation forests with red spruce in the southern Appalachians (White and Cogbill 1992). Canopy red spruce trees occur along the periphery and are scattered throughout the basin. The basin itself is a forested wetland with gullied topography created by a network of small streams.

Previous research (Webb et al. 1993) has shown that red spruce in small, disjunct bog populations in New Jersey were longer-lived and more productive than those in adjacent upland populations. Although tree ring chronologies showed growth declines beginning in about 1975, the bog populations showed no climate sensitivity. In contrast, two

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upland populations appeared sensitive to spring and summer drought, with better growth in years with a wet March, wet June, or warm January. The authors suggest bogs offer a refugium from drought in the central Appalachians. At the southern distribution of red spruce, low-elevation bogs and other wetlands also might provide protection from drought or cloud- and fog-borne pollution, but perhaps only in sites where cold air drainage alleviates potential warm temperature stress. Red spruce is adapted to cool, shaded conditions (e.g., Alexander et al. 1995, Dumais and Prevost 2007). For example, understory red spruce exhibited maximum net photosynthesis rates between 15 and 20 °C; higher temperatures reduced photosynthesis rates and increased respiration rates (Alexander et al. 1995). These responses could lead to reduced growth rates or production in southern, low-elevation sites.

We conducted a vegetation survey to examine the size class and condition of extant red spruce and composition of co-occurring woody and herbaceous vegetation in the Alarka Creek headwaters basin. In addition, we used dendrochronology methods to determine age and history of red spruce in the basin. We asked: Is there evidence of a recent (post-1960) spruce decline or sensitivity to annual variation in temperature and precipitation as shown in high-elevation and more northern populations (e.g., McLaughlin et al. 1987)?

METHODS

The Alarka Creek headwaters basin (35°19'58" N; 83°21'35" W; Fig. 1), in the Big Laurel area of the Nantahala National Forest in Swain Co., NC, was acquired as part of a larger tract (ca. 900 ha) by the U.S. Forest Service in the 1990s. Monthly mean temperatures range from 1.4 °C in January to 22.1 °C in July; annual precipitation is 123 cm (data for 1971-2000 Swain County from National Climate Data Center, Asheville, NC). Elevation in the area ranges from 1,097 to 1,340 m. The basin encloses braided small stream channels, which have formed a network of gullies. Canopy red spruce and hardwoods are scattered, forming an incomplete cover over a patchy shrub layer of laurel. The surrounding Big Laurel area was logged at least once, and parts may have been logged twice, during the 1900s (Mike Wilkins, U.S. Department of Agriculture, Forest Service, pers. comm.), but there are no known records for the basin.

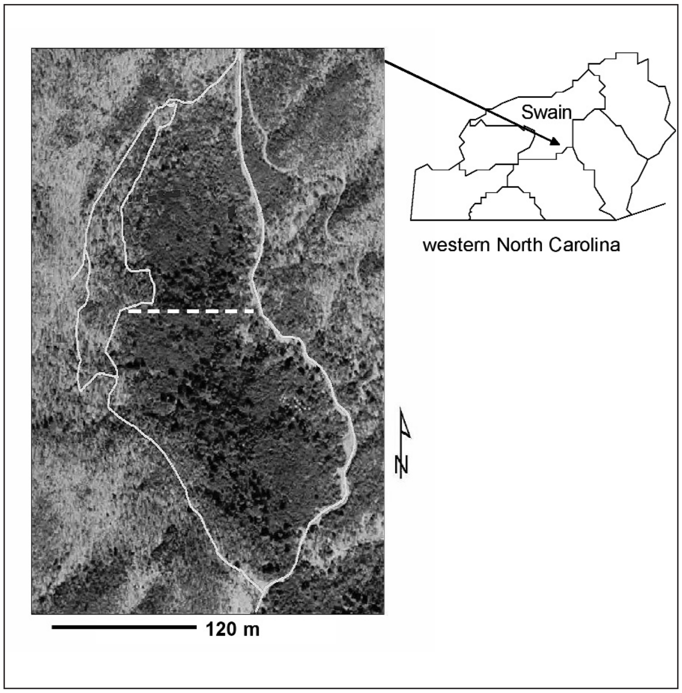

Figure 1.—Location and aerial photo of the Alarka Creek basin, showing trails (gray lines) and a representative sampling transect (dashed white line).

We surveyed the vegetation in the basin in summer 2007, using five 10-m-wide belt transects that were spaced 100 m apart along the long axis and extended across the short axis of the basin (Fig. 1). Transect lengths varied with width of the basin: T1 = 120 m, T2 = 100 m, T3 = 120 m, T4 = 80 m, and T5 = 85 m, for a total of 5,050 m^2, or 0.51 ha sampled. Within each transect, we measured tree diameter at breast height (d.b.h., 1.37 m above ground), cored, and mapped the location of overstory red spruce (>10 cm d.b.h.). Trees were cored at breast height with an increment borer; a single 0.52-mm core was removed from each tree. We also examined red spruce for evidence of insect infestation. We recorded height of spruce saplings and seedlings (<10 cm d.b.h.) and measured distance to the nearest overstory tree. We noted the presence of all other woody species and recorded the diameter of other overstory trees. At 20-m intervals along each transect, we cored an overstory tree (other than red spruce) at breast height and recorded presence of shrub and herbaceous species in a 5-m x 10-m plot for a total of 33 plots (or 1,650 m^2) sampled. We report shrub and herbaceous species occurrence as frequency or percent of the 33 plots.

Standard techniques of dendrochronology were used to process the tree cores (Fritts 1976). We used a Velmex tree-ring measuring system calibrated to 0.01 mm for the physical measurements. The samples were first validated by measuring each core twice and comparing the results graphically for measurement inconsistencies. We attempted to cross-date individual tree ring series using the same methodology. However, some apparent pattern inconsistencies could not be resolved as measurement errors or ring anomalies. We speculate that competitive interactions among individual trees may have weakened the response to climate. We caution the reader to recognize that our inability to positively resolve some annual dates may have degraded our ability to model the long-term growth and climate relationship. The series were analyzed using COFECHA to test the quality of the cross-dating (Holmes 1983). The computer program ARSTAN was used to develop a standardized chronology. ARSTAN uses time-series modeling to produce chronologies with reduced error variance by minimizing the age-trend and small-scale disturbance signals (Cook and Holmes 1986). We used negative exponential or straight line curve fits for most series to preserve the low-frequency variation, such as the potential climate signal and synchronous disturbance signals. We report both the raw and residual ARSTAN chronologies so that readers may better understand the nature of the chronology signal retained from the original unfiltered data. Because of the small sample size for earlier periods of the chronology, results should be interpreted with caution prior to about 1930.

Monthly mean surface air temperature and precipitation data for the western North Carolina region (Division 1) from 1894 through 2006 were obtained from the National Climate Data Center in Asheville, NC. We used Dendroclim2002 (Biondi and Waikul 2004) to examine the relationship between the residual red spruce chronology and climate over time. This program computes response functions, or coefficients of a multivariate Principal Components Analysis. We determined response functions using a forward 30-year "evolutionary window" beginning with the oldest samples and applying increments over time.

RESULTS

Red spruce was distributed over the range of sapling to canopy tree sizes, had greater representation than hardwoods in the larger (>45 cm d.b.h.) size classes, and was the largest (91 cm d.b.h.) tree in the sampled area (Fig. 2A). Red spruce trees averaged 31 cm d.b.h. (755 cm^2 per tree, 451 m^2/ha basal area) and composed 18 percent of canopy trees.

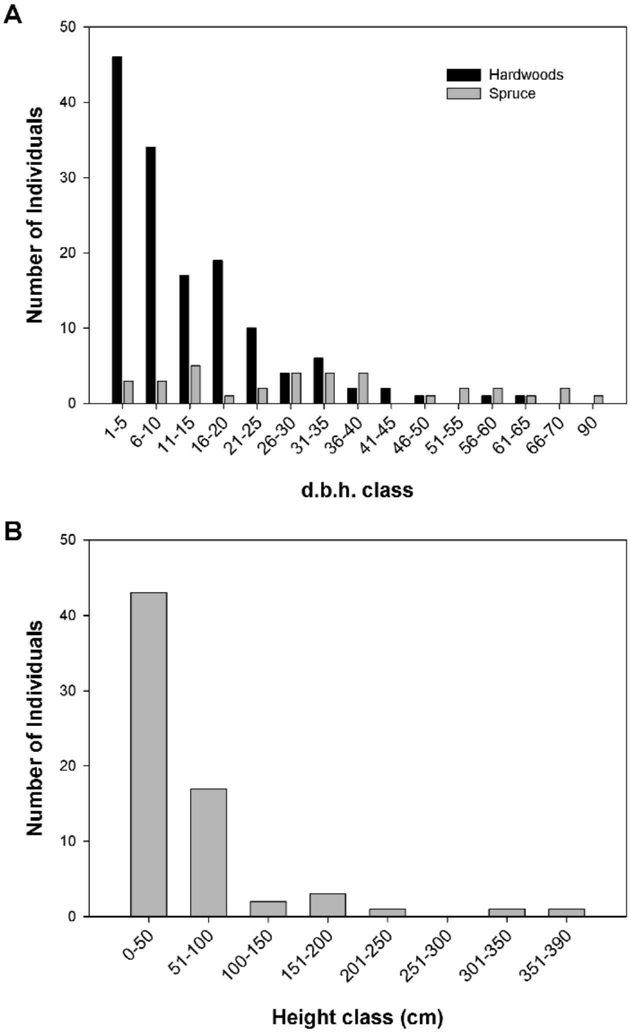

Figure 2.—A: Total number per 0.51 ha (summed over all transects) of hardwoods and red spruce in each of 14 size (d.b.h.) classes. B: Number of red spruce seedlings in each of eight height classes.

American serviceberry (*Amelanchier arborea* Michx.) (52 trees, 36 percent) and sweet birch (*Betula lenta* L.) (25 trees, 18 percent) made up more than 50 percent of the remaining trees in the sampled area; other species included red maple (*Acer rubrum* L.), common winterberry (*Ilex verticillata* [L.]) A. Gray), Fraser's magnolia (*Magnolia* fraser Walt.i) and white oak (*Quercus alba* L.). Many individuals of these species exhibited wetland or resprout growth form, with multiple-stemmed trunks. Overall tree density averaged 450 stems/ha with 242 cm^2 basal area per tree, or 10.89 m^2/ha basal area. Great rhododendron (*Rhododendron maximum* L.) (11 percent) and mountain laurel (*Kalmia latifolia* L.) (3 percent) made up the shrub layer, which was patchy and primarily on gully tops. The ground layer was a mixture of herbs, including *Trillium* species (primarily painted trillium [*T. undulatum* Willd.] and wake-robin [*T. erectum* L.] at 5 and 2 percent, respectively), *Sphagnum* moss (5 percent), wood fern (*Dryopteris marginalis* [L.] A. Gray) (3 percent), and tree seedlings of red maple and sweet birch at 7 and 3 percent, respectively. Red spruce seedlings and saplings (N = 68) in the sampled area averaged 64 cm in height, were distributed over height classes from less than 50 cm to almost 4 m (Fig. 2B), and, on average, were 6.4 m from a red spruce tree.

Tree ring analysis of 32 cores (mean age = 64 years) dated the oldest red spruce core to 1855. Linear population structure suggests nearly steady recruitment over the last 100 years (Fig. 3A). A significant (P = 0.001, r^2 = 0.41) linear relationship exists between tree age and d.b.h. (d.b.h. = 7.444 + 0.378 * age). Individuals present before 1995 likely were below the 10-cm d.b.h. threshold for coring and were included in the seedling survey. No relationship was found between tree age and distance from the edge of the basin (P = 0.92). There was, however, a weak positive (r^2 = 0.08; P = 0.07) relationship between d.b.h. and distance from the edge; the larger trees tended to be in the middle of the basin.

The raw tree chronology shows a sharp drop in growth in the 1930s (Fig. 3B); in the residual chronology, growth in each year between 1930 and 1933 was less than the year before. An apparent age-related decline in the raw chronology is not seen in the residual chronology for 1933 to 1993. Subsequently, an abrupt synchronous decline began in 1994, with recovery after 2003 evident in both the raw and ARSTAN residual chronologies (Fig. 3B). Ring widths showed no significant response to precipitation or the Palmer Drought Severity Index, but there was a significant positive response to previous year October, current year September, and current year October temperatures (Fig. 4).

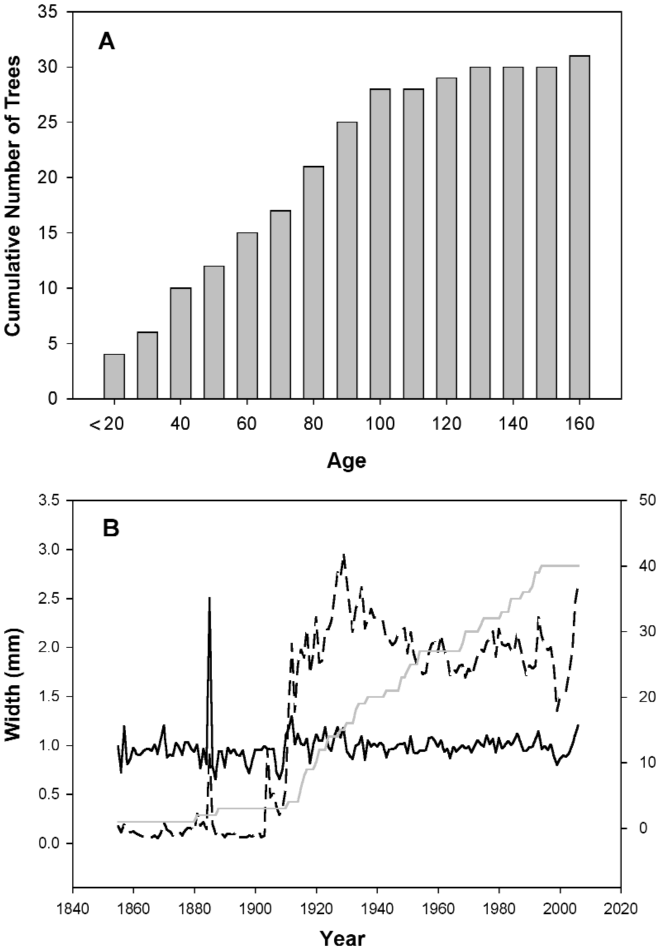

Figure 3.—A: Cumulative age distribution of red spruce cores. B: Raw (dashed line) and ARSTAN residual (solid black line) red spruce chronologies and sample number (solid gray line) over years.

DISCUSSION

Dendroecological studies of high-elevation red spruce in the Southern Appalachians show slower growth periods from 1850-1870 and after 1965, with above-average growth between 1900 and 1950 (Cook and Zedaker 1992). Tree ring chronology for red spruce in the Alarka basin indicates recruitment and growth beginning about 1915. Rather steady recruitment followed, suggesting the relatively low-elevation basin has offered protection from, or been resistant to, changes in atmospheric deposition and regional climate. However, an abrupt drop in red spruce growth in the 1930s correlates well with continental extreme drought conditions (Herweijer et al. 2007), although annual regional precipitation hovered around the average (114 cm) for most years between 1930 and 1940. We did not detect a post-1960 decline linked to climate. The second abrupt drop of spruce growth in the late 1990s coincides with a heavy regional outbreak of southern pine beetles (*Dendroctonus frontalis* Zimm). We cannot be certain whether the beetles were the causative agent, but southern pine beetles have been reported as a "serious pest" of spruce (Murphy 1917), were responsible for widespread destruction of spruce in West Virginia (Murphy 1917), and killed spruce trees in western North Carolina (McNulty 2009). Red spruce growth in the Alarka basin recovered rapidly, and damage possibly due to pine beetles was noted on only 20 percent (7 of 35 trees) during the vegetation sampling in 2007.

In high-elevation forests of the Northeast, above-average temperatures from 1925 (prior November, current July temperatures) or 1945 (prior August, December temperatures) through 1960 appear beneficial to red spruce growth (Cook and Zedaker 1992). In the Alarka basin, warm previous- and current-year fall (October) temperatures appear beneficial to growth, but red spruce growth was insensitive to monthly precipitation.These results suggest the basin provides protection from summer temperature stress and drought, whereas warm fall temperatures prolong the growing season.

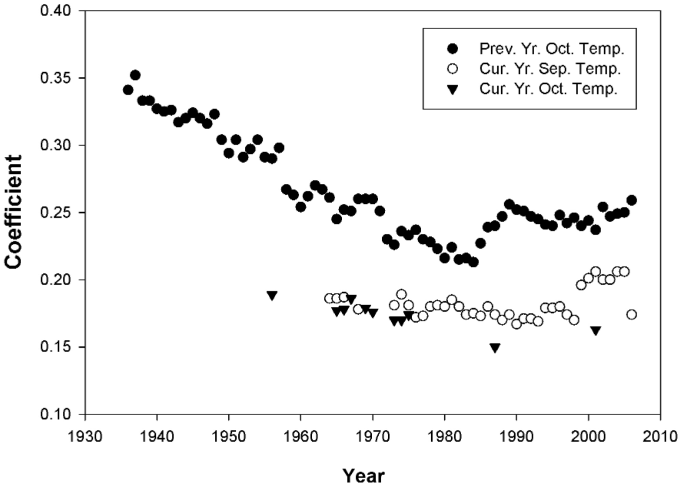

Figure 4.—Significant response values (coefficients) for average monthly temperature effects on residual chronology.

Although red spruce makes up less than 20 percent of the trees, they constitute most of the largest trees in the Alarka basin. Red spruce and hardwoods, including American serviceberry and sweet birch, are scattered throughout the basin, amidst a shrub-layer canopy of great rhododendron and mountain laurel. The presence of red spruce seedlings and saplings distributed over height classes from less than 50 cm to almost 4 m suggests that red spruce is still capable of self-replacement in the basin. In addition, positive growth response to warm September and October temperatures and recovery from the possible pine beetle outbreak indicate that larger, canopy red spruce trees generally have remained robust. The concave basin clearly provides cold air drainage, i.e., a favorable microclimate with protection from summer temperature and drought stress (Murphy 1917).

Persistence of red spruce through past climate fluctuations at the relatively low-elevation Alarka basin suggests higher-elevation populations, especially those in more sheltered landforms, may persist under future climate regimes in the southern and central Appalachians. Our results demonstrate, however, that exogenous disturbances such as insect outbreaks can rapidly alter long-term growth patterns and could lead to community replacement even though conditions are otherwise favorable for growth. Continued monitoring of vulnerable communities, such as the Alarka Creek red spruce community, is a crucial step for developing climate change strategies and deciding when and where to implement them. With continued monitoring, land-use practices that maintain favorable environmental conditions, and avoidance of stochastic stand-altering disturbances such as wind or ice storms, Alarka and similar scattered concave basins should continue to harbor low-elevation red spruce populations in the Southern Appalachians in the near term.

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