

Impact of ground-level ozone on trees in the Great Smoky Mountains National Park

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Abstract

Great Smoky Mountains National Park (GRSM) is the most visited National Park in the United States. The Park encompasses over 206,000 hectares of area in the states of Tennessee and North Carolina. It contains a wide diversity of plants and animals representative of a large region of the eastern US. Therefore, any detrimental effects on vegetation is of major concern. Yellow-poplar and black cherry trees previously cored (1994) and identified regarding ozone sensitivity were re-cored (2001) at three sites within the GRSM. Twenty trees/species (10 sensitive, 10 non-sensitive) site were cored. Black cherry radial growth did not vary by ozone sensitivity groups during any time period analyzed. Some differences existed between the original analysis using cores collected in 1994 compared with those collected in 2001. Growth for both species was different by location, but no location X sensitivity interactions were observed. Yellow-poplar varied by sensitivity group during the period 1990-1994 (ozone-sensitive trees exhibited less radial growth), but no differences in growth were observed from 1997-2001. Yellow-poplar grew better from 1997-2001 compared with the period 1990-1994, but the opposite results were found with black cherry (they grew less).

Introduction

Ozone is considered the most phytotoxic air pollutant in the eastern United States and can be transported long distances from urban sources to rural, forested areas. Concentrations of ozone in the rural southeastern US are as high or higher than any other region in the US, excluding the South Coast Air Basin of California (USEPA 1996).

Visible symptoms of ozone injury have been observed on sensitive plant species in many areas of the eastern US, including GRSM. Correlative studies suggest that visible injury and growth reductions are related in some species (Chappelka and Samuelson, 1998). Based on a study where visible symptoms of ozone injury were characterized on large, mature yellow-poplar and black cherry trees in GRSM, Somers *et al.* (1998) compared radial growth differences among trees classified as sensitive or non-sensitive based on the severity of visible foliar injury observed over a three-year period (1991-1993). Significantly more radial growth for the non-sensitive yellow-poplar compared with the sensitive trees growing in the same area was observed over both a 5 (1990-1994) and 10-year (1985-1994) period. This relationship was not significant for black cherry.

Direct comparisons in growth between those trees with a history of visible injury and those uninjured would reduce the potential confounding of other environmental factors with ozone exposure and reduce the variability of trees in each group, therefore requiring smaller sample sizes to detect differences in growth.

During the 1997-1999 time period, data indicate the Great Smoky Mountains National Park (GRSM) was exposed to levels of ozone that were above the new 8-hour ozone standard established to protect human health (Jim Renfro, personal comm.). In 1998 and 1999 GRSM recorded 44 and 52 days, respectively, when the maximum daily 8-hr ozone average exceeded 85 parts per billion (the level of the new health based standard). In fact, ozone levels in GRSM were significantly higher in the later part of the 1990s (1995-1999) compared with 1990-1994 (Jim Renfro NPS, personal comm.).

Objectives

The overall objective of this investigation was to re-measure mature yellow-poplar and black cherry trees that were previously cored and reported by Somers *et al.* (1998). These new data will prove valuable regarding identification of the overall the health of mature forest trees representative of the eastern US. In addition, useful information (potential AQRVs) will be provided to federal land managers pertaining to ozone effects and forest health in Class I areas. Specific objectives were:

1. Correlate past and present ambient ozone concentrations with radial growth of black cherry and yellow-poplar trees at three sites in GRSM.
2. Determine if black cherry and yellow-poplar trees differing in visible sensitivity to ozone differ in radial growth rates at three sites in GRSM.
3. Relate ozone exposure to growth rates of black cherry and yellow-poplar among three sites in GRSM.



Measuring tree heights of target and competitor trees in GRSM.

Methods

During the week of October 22-24, 2001 yellow-poplar and black cherry trees previously identified regarding ozone sensitivity (Somers *et al.*, 1998) were cored (increment borers, 2 cores/tree, dbh) at three sites within the GRSM in the vicinity (< 2 km) of ambient ozone monitors: Cove Mountain (elev. 1265 m), Look Rock (elev. 823 m) and Twin Creeks (elev. 597 m). A detailed description of the sampling procedures are provided in Somers *et al.* (1998). Twenty trees/species (10 sensitive, 10 non-sensitive) site (60 trees per species, 120 total trees, 240 samples) were cored. Two cores were taken from each tree at breast height (1.4 m) at right angles. In addition, all sample trees were measured for tree height, diameter, crown condition and presence of insect pests and diseases. Potential competitors were measured during June 2002 using a 1.15m²/ha angle gauge to select them in proportion to their diameter and inversely proportional to the distance from each tree (see Somers *et al.* 1998 for more details). The distance from each competitor to the target tree was determined. In addition, the dbh and height of each target and competitor trees were measured.

Tree cores were sent to Appalachian State University for measurement of ring widths. Cores were dried, and mounted, then sanded. Data were cross-dated and measured using dissection scopes and commercial tree-ring software. All cores with unusual data were checked for potential errors. In some instances the cores were discarded, and trees re-cored. Ten percent of the cores were remeasured and checked for accuracy. In addition, growth ring data from the previous study were checked to determine the accuracy between the two collection periods.



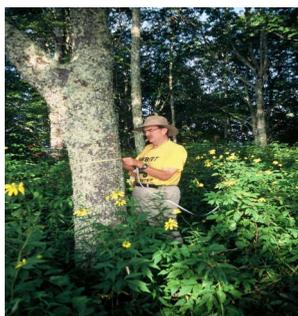
Yellow-poplar located at Cove Mountain being measured for diameter growth. Two cores were removed at approx. 1.5 m in ht on the stem, and analyzed for radial growth.

Results

The results for 5-year radial growth in 1994 (Somers *et al.* 1998) are shown in Table 1. The first test performed was a simple ANOVA looking for differences between locations and tolerance to ozone. On the basis of these results ($p = 0.0014$) for yellow-poplar we then proceeded to add terms trying to remove any differences in the two tolerance (sensitive and non-sensitive) classes due to competition, dbh, height, and age. Since no difference was found in black cherry, 5-year radial growth, no further analysis was conducted with this species.

Table 1. ANOVA of five-year radial growth (1990-1994) using cores collected in 1994 (Somers *et al.*, 1998).

Source	df	Black cherry	Yellow-poplar
Location	2	<0.0001	<0.0001
Sensitivity	1	0.5601	0.0014
Loc X Sens	2	0.6018	0.3778



Measurement of the dbh of competitor trees.

The same analysis for radial growth for the same 5-year period (1990-1994) based on the 2001 cores is shown in Table 2. No significant values were found with black cherry. Yellow-poplar, however, was only significant at the $p=0.10$ level (Table 2). Comparing these results is a little misleading because they are based on slightly different trees sampled.

Table 2. ANOVA of five-year radial growth (1990-1994) using cores collected in 2001.

Source	df	Black cherry	Yellow-poplar
Location	2	0.0020	0.0015
Sensitivity	1	0.7231	0.1022
Loc X Sens	2	0.9872	0.5352

It should be noted that Look Rock, black cherry #2 (sample #) was dropped in the 1994 analysis because the radial growth for 1994 was missing in both cores, but since it was not measured in 2001 it does not affect the analysis either way; Cove Mountain, yellow-poplar #s 13, 15, 20, 21, 25, 26, 28 were dropped in the 1994 analysis due to dbh values over 30 inches; and Look Rock, black cherry #29 was dropped in the 1994 analysis due to a much larger growth rate than the other trees. In the 2001 analysis the only tree not included in the analysis was Cove Mountain, black cherry #5, which was missing radial growth for any year prior to 1992 on the single core measured. There were also some trees measured during one time period but not the other. To produce an analysis on the same trees from sample periods several were removed.



Recording the distance and number of competitor trees from each target tree for potential development of competition indices.

Using the same trees the data were compared using the original data sampled from cores collected in 1994 for the five-year period from 1990-1994 and those that were collected in 2001 and sampled in the same time period (1990-1994). Results from these analyses are shown in Tables 3 and 4.

Table 3. ANOVA of five-year radial growth (1990-1994) using cores collected in 1994 but similar trees to those sampled in 2001.

Source	df	Black cherry	Yellow-poplar
Location	2	0.0016	<0.0001
Sensitivity	1	0.4532	0.0127
Loc X Sens	2	0.7943	0.6011

Table 4. ANOVA of five-year radial growth (1990-1994) using cores collected in 1994 but similar trees to those sampled in 1994.

Source	df	Black cherry	Yellow-poplar
Location	2	0.0021	0.0002
Sensitivity	1	0.9750	0.1159
Loc X Sens	2	0.8791	0.6822

Based on the 1994 cores, significant differences at $p=0.02$ were observed for yellow-poplar regarding differences in sensitivity. These results as expected, were similar to those published in Somers *et al.* 1998. However, using the data from the cores collected in 2001 slightly different results were observed. Significance was observed only at the 88% level. This still indicates a trend between the two sensitivity groups. However, it is not as highly significant as observed in the previous analysis. Reasons for these differences are unknown, but could be due to the following factors: 1) variability due to small sample size, 2) differences in analytical procedures or equipment used between laboratories, and/or 3) differences between individuals reading samples. Original (1994 samples) analyses were conducted at TVA laboratory in Norris, TN. Unfortunately, samples from this collection (1994) were discarded and cannot be directly compared using one equipment operator.



Visible ozone injury on black cherry in GRSM



Visible injury on yellow-poplar in GRSM.

After comparing samples between collection periods the next step was to investigate growth patterns for the past 5 years (1997-2001), 10 years (1992-2001), and 15 years (1987-2001). For this analysis all of the 2001 cores were used. These results are shown in Table 5 and 6. As before, there are significant differences between locations, but none between ozone tolerance groups and no significant interactions.

References

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Table 5. ANOVA of growth over 5, 10 and 15-year time periods for black cherry and yellow-poplar using all 2001 cores collected.

Source	df	Black cherry		
		5-yr	10-yr	15-yr
Loc	2	0.0052	0.0014	0.0017
Sens	1	0.6928	0.9134	0.9865
LocXSens	2	0.8376	0.9084	0.8841
Source	df	Yellow-poplar		
		5-yr	10-yr	15-yr
Loc	2	<0.0001	0.0004	0.0002
Sens	1	0.5087	0.3740	0.2102
LocXSens	2	0.9439	0.8261	0.6781

As illustrated in Table 5, there is a loss in significance in 5-year radial growth between ozone sensitivity groups. However, the differences become closer to significance for the 10 and 15-year growth periods for yellow-poplar. The reason is that although ozone-sensitive yellow-poplar trees maintained a lower average growth than non-sensitive trees (0.41 vs 0.44 cm, respectively for 5-year growth, 1997-2001), it is no longer significant. It is important to note that the 5-year radial growth from 1990-1994 was 0.27 vs 0.34 cm for sensitive and non-sensitive trees, respectively, which is almost half the growth rate recorded from tree rings measured from 1997-2001. This means that all yellow-poplar trees sampled have been growing at a faster rate from 1997-2001 than 1990-1994, and the difference between sensitive and non-sensitive trees has decreased to the point it is no longer significant. These differences could be related to different climatic and site factors occurring among the species.

Next we dealt with the question, were there significant differences in growth rates from 1990-1994 vs 1997-2001? A new variable was created for the differences in these growth rates for each tree providing the following analysis for black cherry and yellow-poplar (Table 8). There were no differences in growth-rates, except location for yellow-poplar ($p=0.0007$).

Table 6. ANOVA of growth rate differences between 1990-1994 compared with 1997-2001 for black cherry and yellow-poplar.

Source	df	Black cherry	Yellow-poplar
Location	2	0.1341	0.0007
Sensitivity	1	0.5035	0.3554
Loc X Sens	2	0.2050	0.8718

Data were pooled across sensitivity groups and locations by species to determine if differences existed among species between the two time periods. Black cherry significantly decreased (t -test) in growth when the two time periods were compared: 0.52 vs 0.44 cm for the periods 1990-1994 compared with 1997-2001, respectively. However, yellow-poplar on average increased in growth during 1997-2001 (0.41 cm) compared with 1990-1994 (0.30 cm). The reasons for these species differences are unknown at present. Since no differences in radial growth patterns were observed, no other analyses (competition, ozone over time, etc.) were conducted. These data are available and will be entered into a data base and used to help determine why the yellow-poplar trees increased, but black cherry decreased in radial growth when the two 5-year time periods were examined. Comparisons of ozone vs. tree growth over time were not made. It would be interesting in the future to pursue these findings in further detail by comparing other periods of "good" and "poor" growth to determine if these growth differences still existed. It is hoped that these contrasts will be made in the future by examining ozone and climatic records in the GRSM over these time periods.

Conclusions

The following conclusions can be made:

1. Black cherry radial growth did not vary by ozone sensitivity groups during any time period analyzed.
2. Some differences existed between the original analysis conducted using cores collected in 1994 compared with those collected in 2001.
3. Growth for both species was different by location, but no location X sensitivity interactions were observed.
4. Yellow-poplar varied by sensitivity group during the period 1990-1994, but no differences in growth were observed from 1997-2001.
5. Yellow-poplar grew better from 1997-2001 compared with the period 1990-1994, but the opposite results were found with black cherry (they grew less).

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