Final Report

An FHM Evaluation Monitoring Project:

INVESTIGATION OF FACTORS ASSOCIATED WITH OZONE-INDUCED FOLIAR INJURY WITHIN BIOMONITORING PLOTS IN SOUTHWESTERN PENNSYLVANIA FORESTS

A Cooperative Project between the Penn State Institutes of the Environment, the Pennsylvania Department of Conservation and Natural Resources, and the United States Forest Service Forest Health Monitoring Program


Cooperators: Tom Hall and Don Eggen, PA Department of Conservation and Natural Resources, Bureau of Forestry
James R. Steinman, USDA-Forest Service

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PENN STATE
INSTITUTES OF THE ENVIRONMENT
UNIVERSITY PARK, PA
FINAL REPORT

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FOLIAR INJURY WITHIN BIOMONITORING PLOTS IN SOUTHWESTERN
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A Cooperative Project

The Pennsylvania State University
Institutes of the Environment

and

The Pennsylvania Department of Conservation and Natural Resources
Bureau of Forestry

and

The USDA Forest Service
Forest Health Monitoring Program

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James R. Steinman, USDA-Forest Service

June 23, 2003
INTRODUCTION

Tropospheric ozone is a secondary pollutant formed by a fairly complex series of photochemical reactions involving oxides of nitrogen and hydrocarbons as precursor primary pollutants; ozone is also a natural gaseous component of the troposphere reaching concentrations of 10-40 ppb v/v in the cleanest areas of the Earth's surface (Lefohn, 1990; USEPA, 1996). The primary pollutants that lead to ozone formation are emitted during the burning of fossil fuels with automobiles, industries, and electric power generation as the major anthropogenic sources. This pollutant is of regional scale importance in northeastern United States due to long range transport within slow moving and often stagnant high pressure systems (Comrie, 1990; Simini et al. 1992; USEPA, 1996; Douglass, 1998). Rural sites tend to have higher long-term ozone exposures as polluted air masses are transported downwind of urban/industrial centers with little scavenging of ozone precursors (Meagher et al., 1987; Gilliam et al., 1989; Winner et al., 1989; Comrie, 1994). Thus, forests within the remote and mountainous terrain of eastern United States have been exposed to elevated ambient ozone concentrations on a seasonal basis with short periods of more severe ozone exposure episodes associated with stagnant high pressure systems (Hayes and Skelly, 1977; Simini et al., 1989; Skelly et al., 1994; Gilliam and Turrill, 1995, Hildebrand et al., 1996). Reviews regarding tropospheric ozone pollution and effects to forests and native plants of eastern United States have recently been published (Chappelka and Samuelson, 1997; Skelly et al., 1997).

Considerable differences in ambient ozone exposures have been demonstrated on a year-to-year (growing season) basis in the more remote forested areas of West Virginia (Gilliam and Turrill, 1995) and in the forested areas of north central Pennsylvania (Simini et al., 1992; Skelly et al., 1992). Within regional areas, topography has been demonstrated to play a significant role in determining ozone exposures with higher ozone exposures occurring at higher elevation sites (Pinkerton and Lefohn, 1987; Hayes and Skelly, 1977; Winner et al., 1989; Hildebrand et al., 1996).

Ozone monitoring

In recent years, passive sampling devices (PSDs) have been widely utilized to determine cumulative concentrations of air pollutants (Koutrakis et al., 1993; Manning et al., 1996). The benefits of passive sampling devices to detect ozone concentrations include low operational costs, high correlation results as compared to continuous ozone monitors, ease of use, and deployment in areas where no electricity is available (Krupa and Legge, 2000). In addition, research has shown that when using passive samplers to determine ozone concentrations, measurements are not affected by temperature and humidity, and under ambient conditions, co-pollutant interference is negligible (Koutrakis et al., 1993). Average cumulative ozone concentration across a sampling period (such as hourly average parts per billion (ppb)/week) may be determined (Manning et al., 1996). The successful use of passive ozone monitoring techniques has been demonstrated within recent studies in north central Pennsylvania (Jagodzinski, 2000; Skelly et al., 2001, Yuska, 2002; and Yuska et al., 2003).
Bioindicator plants

Bioindicator plant species for ozone detection exhibit typical foliar injury patterns associated with injurious concentrations of ozone following either short-term high or long-term moderate ozone exposures (Manning and Feder, 1980; Skelly et al., 1987; Manning, 1990; Brantley et al., 1994). Due to accumulative responses to season long ozone exposures, foliar symptoms typically appear at mid-summer season and increase through the late summer and early fall seasons. Sensitive species are most useful for determination of the cumulative season long exposures and foliar symptom responses of tropospheric ozone air pollution. (Skelly et al., 1987).

Ozone causes several general symptoms on broadleaf species in the field, the most common of which is stipple, or pigmentation on adaxial (upper) leaf surfaces. Indeed, upper leaf surface stipple has been described as the classic symptom of ozone injury on broadleaf species. The upper leaf surface of plants may exhibit minute tan, red, brown, purple, or black coloration that appears uniformly over the leaf surface. Stipple is restricted to certain areas of the leaf and veins and small veinlets are usually not involved; veinlets often bound the injured areas producing angular appearances of the affected tissues. Very fine or newly developing stipple is best observed with a 10 X hand lens. The coloration of stippling is usually characteristic for a species but can vary with environmental or physiological conditions. The entire surface of older leaves may exhibit symptoms when exposed to ozone periodically during the entire growing season. A more general upper surface pigmentation has also been described due to season long ozone exposures. Adaxial leaf reddening and purple tinges may be in evidence with older leaves appearing most symptomatic due to longer term (growing season) exposures to ozone pollution.

OBJECTIVES

A key product of the Forest Health Monitoring (FHM) Program of the USDA Forest Service is a National Technical Report of forest health conditions across the U.S. A recent regional assessment report for 1994-99 shows the highest levels of ozone injury to forest plant indicators to be in western Pennsylvania and northeastern West Virginia. (Figure 1A, inside cover) (Coulston et al., 2002, 2003). Given that this geographic area has traditionally drawn attention as a sink for air pollutants, it is of interest to further investigate the results reported within their report especially in reference to the influence of the local environment on the incidence and severity of foliar symptoms occurring on ozone-sensitive species.

We speculate that observed variations in foliar injury depicted in the report are partially a response to several factors in addition to ozone exposure. Spatial and temporal variations in plant species, weather and soil-site conditions across the geographic area most likely contribute to the range of observed amounts of foliar injury. These factors should be evaluated to determine how they might have influenced results for plant injury used in the National Technical Report. A quantification of these factors would help us create a standardized index for plant injury data so that only a response to ozone exposure could be depicted in future reports.
Determination of ozone induced foliar injuries on sensitive species at or near the FHM plots has become a major consideration within the Forest Health Monitoring protocols. Intensive surveys of ozone bioindicator species take place during August across all states involved within the FHM program, yet few linkages to actual season-long ambient ozone exposures at the FHM plots and observed foliar injuries to the bioindicator species have been made.

**Specific objectives:**

1. Within a selected number of FHM ozone-biomonitoring plots (minimum, 10 plots) in southwestern Pennsylvania, utilize the Ogawa passive ozone monitoring devices along with local measures of rainfall and soil moisture to show season-long relationships between ozone injury and individual factors of ozone exposure, weather and soil-site conditions. (FHM biomonitoring plots within this area of southwestern PA have been identified with ozone-sensitive plants that have been overtly symptomatic of ozone exposures over a several year period.) These methods will also involve accessing databases from other agencies such as NOAA and the NRCS. Data would include but not be limited to AIRS and PA DEP, Bureau of Air Quality certified ambient ozone data, soil moisture, elevation, aspect, temperature and precipitation.

2. In consultation with the appropriate USDA-FHM program representatives, participate within discussions as to how a standardized index would be useful in relating ozone-induced foliar injury to other measures of forest health. In addition we will work with the cooperators on this project, to establish a prioritized listing of those factors that appear to control symptom expression to varying exposures to ozone under natural conditions; an index model showing the relative contribution of the various factors will be developed using differing statistical techniques.

**METHODS**

Ten sites that were adjacent to previously assessed Forest Health Monitoring (FHM) plots were identified and evaluated for ozone exposures and ozone-induced symptoms on bioindicator species throughout southwestern Pennsylvania (Table 1; Figure 1).

**Table 1:** Site descriptions and ozone-sensitive bioindicator species present on verification monitoring plots established in southwestern Pennsylvania, June 3 to September 10, 2002.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Site Name</th>
<th>Nearest FHM Site</th>
<th>Elevation(m)</th>
<th>Lat</th>
<th>Long</th>
<th>County</th>
<th>BC</th>
<th>MW</th>
<th>BB</th>
<th>WA</th>
<th>YP</th>
<th>Sass</th>
<th>DB</th>
</tr>
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<tr>
<td>1</td>
<td>Somerset</td>
<td>3907981</td>
<td>660</td>
<td>39 57.28</td>
<td>79 02.48</td>
<td>Somerset</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>2</td>
<td>Grantsville</td>
<td>3907962</td>
<td>650</td>
<td>39 43.45</td>
<td>79 12.57</td>
<td>Somerset</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>3</td>
<td>Hopwood</td>
<td>3907966</td>
<td>235</td>
<td>39 53.72</td>
<td>79 41.99</td>
<td>Fayette</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>4</td>
<td>Forbes SF</td>
<td>4007922</td>
<td>735</td>
<td>40 07.04</td>
<td>79 12.20</td>
<td>Westmoreland</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>5</td>
<td>Paint Twp</td>
<td>4007828</td>
<td>560</td>
<td>40 10.25</td>
<td>78 53.45</td>
<td>Somerset</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>6</td>
<td>Old Cranberry</td>
<td>4007934</td>
<td>305</td>
<td>40 29.94</td>
<td>79 27.44</td>
<td>Westmoreland</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
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<td>7</td>
<td>Homer City</td>
<td>4007953</td>
<td>295</td>
<td>40 33.05</td>
<td>79 17.41</td>
<td>Indiana</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
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<td>y</td>
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<td>Conemaugh</td>
<td>4007941</td>
<td>370</td>
<td>40 25.06</td>
<td>79 04.65</td>
<td>Indiana</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
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<td>y</td>
</tr>
<tr>
<td>9</td>
<td>Carrolltown</td>
<td>4007866</td>
<td>485</td>
<td>40 36.21</td>
<td>78 43.77</td>
<td>Cambria</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>10</td>
<td>S. Altoona</td>
<td>4007844</td>
<td>225</td>
<td>40 27.2</td>
<td>78 26.22</td>
<td>Blair</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
</tbody>
</table>
Figure 1. The location of the ten passive ozone and bioindicator plots established June 3 and 4 and visited weekly through to September 9 and 10, 2002. The locations of the nearest Pennsylvania Department of Environmental Protection, Bureau Air Quality air quality monitoring stations have also been indicated.

- Passive monitoring sites and bioindicator plots
- PA DEP, BAQ air quality monitoring stations
No less than 10 plants per species were flagged for season-long observations of foliar symptoms. From June 3 to September 10, 2002, weekly foliar observations were recorded for each bioindicator that represented the amount and severity of foliage injured. Bioindicator species observed included black cherry, blackberry, common milkweed, white ash, yellow poplar, dogbane, and sassafras (Table 1). All sites were represented with 4 to 6 bioindicator species except for the Forbes State Forest site (Westmoreland county), at which only 2 bioindicator species could be located. A species index (SI) was calculated for each site according to FHM guidelines at the end of the monitoring period:

For each plant
AMT = injury amount
SEV = injury severity

For each species

\[ \begin{align*}
N_1 &= \text{the number of injured plants} \\
N_2 &= \text{the number of evaluated plants} \\
A &= \frac{N_1}{N_2} \\
B &= \varphi \left( \frac{\text{AMT} \times \text{SEV}}{N_1} \right)
\end{align*} \]

Species index = \( A \times B \)

For each biomonitoring site

\[ \text{Plot Index} = \varphi \left( \frac{\text{Species Index}}{N_3} \right) \]

In the field, the percent injury to the plant was estimated and then assigned to nominal values that reflected 5 broad classes of injury with 0 = no injury; 1 = 1-6 % injury; 2 = 7-25 % injury; 3 = 26-50 % injury; 4 = 51-75 % injury; and 5 = > 75 % injury.

In the laboratory, the nominal codes were converted to percentage values representing the midpoint of each injury class with 0 = 0; 1 = 3.5 %; 2 = 16 %; 3 = 38 %; 4 = 63 %; and 5 = 88 %.

**Ozone monitoring**

Ozone was monitored weekly at each site for a 14-week period beginning June 3 and ending September 10, 2002. The Ogawa passive ozone samplers and associated analytical techniques were selected for use within this investigation (Koutrakis et al., 1993). The filter assemblies of the PSDs for the ten sites plus two control blanks were prepared in the laboratory each week on Sunday evening and kept frozen until being transferred to an insulated ice chest the next morning for field travel on Monday and Tuesday of each week. The deployment of passive sampling devices was within a 24-hour window of the previous week's replacement time, most within a 1-hour window. Upon arrival at each site, the previous week's PSD was removed and replaced with a new PSD. Removed PSDs were stored in the ice chest until they were returned to the
laboratory where they were placed back into a freezer. The control blanks were kept in the ice chest for the entire period of field travel and placed back into the laboratory freezer with the collected PSDs. Filters were removed from the collected PSDs and corresponding control blanks on Wednesday mornings, placed in labeled vials, and sent to the Water Quality Laboratory within the Penn State Institutes for the Environment for analysis. Analysis for nitrate concentration was performed by ion chromatography (Koutrakis et al., 1993). For each week, mean nitrate concentration obtained from the blank was averaged and subtracted from the exposed PSDs values to calculate net nitrate concentration. Using these methods, average weekly ozone concentrations (ppb) were obtained.

Hourly ozone data acquired from nearby API-400 (Advanced Pollution Instruments) continuous monitors (as operated by the PA Department of Environmental Protection, Bureau of Air Quality) were adjusted to correspond to the exposure periods of the PSDs. The locations of seven BAQ Air Quality Stations that monitored ozone were selected from within or immediately peripheral to the research area to provide a reasonable representation of local and regional ozone trends (Table 2). The acquired hourly ozone data from the API monitors was used to determine weekly (hourly) ozone averages; this data was subsequently tested for agreement (correlation) with weekly (hourly) averages for ozone as obtained via the Ogawa passive samplers.

In addition, gravimetric soil moisture measurements were taken at each site during the last four weeks of the monitoring period and a Palmer Drought Index graph for each county where sites were located was retrieved and analyzed for the entire monitoring period.

RESULTS AND DISCUSSION:

Topographic maps of the locations of each of the ten sites as described in Table 1 may be found in Appendix Figures 1-10. The geographic relationships of the sites to one another and the seven PA DEP air quality-monitoring sites have been presented within Figure 1. The overall area of the investigation spanned portions of just five counties; elevations ranged from 225 m msl (S Altoona, Blair County) to 735 m msl (Forbes State Park, Westmoreland Co.) (Table 1; Figure 1).

Characterizing O$_3$ exposures:

The Ogawa passive samplers as located at each of the 10 sites were successfully maintained with filters exchanged on a weekly basis during the 14-week investigation; secure sites had been selected at study initiation with no obvious disturbance of the passive filter assemblies. Likewise, the analysis of the filters via ion chromatography was successfully performed for all weekly samples within our Penn State University facilities.

Ozone exposures were high during the early part of the summer (week 1 one-hour peak 108 ppb O$_3$) with several peak episodes occurring during weeks 3, 4, 7, 9, 11, and 14; these higher ozone episodes were intermixed with weeks of much lower ozone exposures (Table 2.). The highest hourly peak occurred at the Washington Co. air quality monitoring station during an episode spanning August 11 with a 126 ppb O$_3$ one-hour average.

The hourly average ozone concentrations as determined for each week with the Ogawa passive samplers positioned at each of the ten FHM sites were closely correlated ($r = 0.759$) with the hourly averages for each respective week that were obtained via the nearest PA DEP, BAQ Air Quality Monitoring Stations (Figures 1,2). On a seasonal average basis, the ozone
concentrations as monitored by the Ogawa passive samplers was consistently higher than the PA DEP, BAQ monitors for the four closest co-located sites \((r = 0.815)\); the greatest differences in seasonal averages appeared for the passive monitors located at Old Crabtree, (305 m msl) and the Greensburg BAQ Air Quality monitor (360 m msl)(Figure 3).

Considerable differences were notable on a week-to-week basis for hourly \(O_3\) concentrations that were recorded and averaged for all ten sites combined during the 14-week investigation (Figure 4). In contrast, with very few exceptions all sites appeared to conform to very similar patterns of increasing and decreasing \(O_3\) on a week-to-week basis (Figure 5). For three sites there were several weekly periods of higher \(O_3\) exposures with weekly averages near 60 ppb \(O_3\) (Crabtree, Somerset, and Paint) and one site approached an hourly average exposure of 70 ppb \(O_3\) (Forbes) during week 7 (July15-21). The lowest \(O_3\) exposures occurred at most of the ten sites during week 13 (August 26-September 2) with another peak week of \(O_3\) exposures following during week 14 (September 3-10) (Figure 4, 5).

Table 2. Location, date, and peak one-hour ozone concentrations as monitored at PA DEP Air Quality Monitoring Stations proximal to the area of investigation during the period June 3 through September 10, 2002.

<table>
<thead>
<tr>
<th>WEEK</th>
<th>WEEK DATE</th>
<th>PADEP, BAQ Station</th>
<th>1-hr PEAK (O_3) (ppb)</th>
<th>DATE of 1-hr peak (O_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6/3-10</td>
<td>Murrysville</td>
<td>108</td>
<td>6/10/2002</td>
</tr>
<tr>
<td>4</td>
<td>6/24-7/1</td>
<td>Kittanning</td>
<td>122</td>
<td>6/25/2002</td>
</tr>
<tr>
<td>5</td>
<td>7/1-8</td>
<td>Greensburg</td>
<td>102</td>
<td>7/3/2002</td>
</tr>
<tr>
<td>6</td>
<td>7/8-15</td>
<td>Greensburg</td>
<td>119</td>
<td>7/15/2002</td>
</tr>
<tr>
<td>7</td>
<td>7/15-22</td>
<td>Pittsburgh</td>
<td>107</td>
<td>7/17/2002</td>
</tr>
<tr>
<td>8</td>
<td>7/22-29</td>
<td>Pittsburgh</td>
<td>101</td>
<td>7/22/2002</td>
</tr>
<tr>
<td>9</td>
<td>7/29-8/5</td>
<td>Pittsburgh</td>
<td>110</td>
<td>8/2/2002</td>
</tr>
<tr>
<td>10</td>
<td>8/5-12</td>
<td>Washington Co.</td>
<td>126</td>
<td>8/11/2002</td>
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<tr>
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<td>8/12-19</td>
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<td>108</td>
<td>8/13/2002</td>
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<tr>
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<td>93</td>
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<tr>
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<td>8/26-9/2</td>
<td>Altoona</td>
<td>72</td>
<td>9/2/2002</td>
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</tbody>
</table>

1 Passive filters were changed on Monday (Plots 1-5) and Tuesday (Plots 6-10) of each respective week to within one hour of the previous week sample time; the continuous ozone data from proximal PA DEP, BAQ air quality monitoring stations was adjusted to the exact hour of passive sample collections for each respective site.
Figure 2. Correlation of the weekly average hourly O\textsubscript{3} concentrations (ppb) with Ogawa passive O\textsubscript{3} devices at ten sites in comparison to the four nearest continuous O\textsubscript{3} monitors operated by the PA DEP, BAQ within southwestern Pennsylvania for a 14-week period June 3 to September 10, 2002.

Figure 3. A comparison of hourly average O\textsubscript{3} concentrations (ppb) monitored with Ogawa passive O\textsubscript{3} devices at four sites in comparison to the nearest continuous O\textsubscript{3} monitors operated by the PA DEP, BAQ within southwestern Pennsylvania for a 14-week period June 3 to September 10, 2002.
Figure 4. Hourly average O₃ concentrations (ppb) for each of 14 weeks; presented as an averaged O₃ concentration for ten monitored sites combined using Ogawa passive samplers for the period June 3 to September 10, 2002.
Figure 5. Hourly average O₃ concentrations (ppb) for 14 weeks; presented as O₃ concentration for each of ten individual sites using Ogawa passive samplers for the period June 3 to September 10, 2002.
Ozone increased with increasing elevation \((r = 0.689)\) amongst the 10 sites with Forbes (735 m msl) having the highest elevation and seasonal O3 exposures; two of the three lowest elevation sites (Hopwood, 235 m msl and Homer City 295 m msl) experienced the lowest average seasonal O3 exposures (Table 1, Figure 6 A, B). The ozone distribution within the area of investigation has been depicted in Figure 7 (using interpolation techniques) with the intensity of the blue coloration depicting increasing ozone concentrations; the most intense ozone exposures occurred in the Forbes State Park area of Westmoreland and Somerset Counties.

**O3-induced foliar symptoms**

Once initiated, typical ozone-induced foliar symptoms inclusive of adaxial leaf surface stipple and reddening were recorded at weekly intervals at each site over the 14-week period. Symptoms were initially observed in late June (black cherry) with injury to most species (5 of 7) expressed by late July (Table 3). Of the 7 bioindicator species, blackberry expressed foliar symptoms at the majority of sites (9 of 10) followed by black cherry (8 of 10), common milkweed (6 of 10), white ash (2 of 10), and yellow poplar (1 of 10). Injury was not observed on dogbane or sassafras at any site.

Table 3: Date of initial O3-induced foliar symptoms being observed on bioindicator species at 10 monitoring sites in southwestern Pennsylvania during the period June 3–September 10, 2002.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Nearest FHM Site</th>
<th>Site Name</th>
<th>BC</th>
<th>MW</th>
<th>WA</th>
<th>YP</th>
<th>BB</th>
<th>DB</th>
<th>Sass</th>
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<tbody>
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<td>1</td>
<td>3907981</td>
<td>Somerset</td>
<td>15-Jul-02</td>
<td>NA</td>
<td>12-Aug-02</td>
<td>No Inj</td>
<td>29-Jul-02</td>
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<td>NA</td>
</tr>
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<td>2</td>
<td>3907962</td>
<td>Grantsville</td>
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<td>No Inj</td>
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<td>3</td>
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<td>NA</td>
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<td>4007953</td>
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<td>No Inj</td>
<td>NA</td>
<td>6-Aug-02</td>
<td>No Inj</td>
<td>NA</td>
</tr>
<tr>
<td>9</td>
<td>4007866</td>
<td>Carrolltown</td>
<td>30-Jul-02</td>
<td>No Inj</td>
<td>No Inj</td>
<td>NA</td>
<td>6-Aug-02</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>4007844</td>
<td>S. Altoona</td>
<td>No Inj</td>
<td>NA</td>
<td>No Inj</td>
<td>NA</td>
<td>No Inj</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Injury by Site

All sites showed ozone-induced injury except for the South Altoona site (Blair County) (Table 4). The greatest injury was observed at Hopwood (Fayette county) with a cumulative species injury (Plot Index) value of 2.68. Species that were symptomatic at Hopwood included black cherry, blackberry, and common milkweed with blackberry and milkweed showing the greatest amount of injury with Species Index values of 8.48 and 4.87, respectively. The Forbes State Forest site (Westmoreland county) ranked second behind Hopwood for greatest cumulative foliar injury with a Plot Index value of 1.89 calculated from black cherry and blackberry. The sites with the least amount of injury, aside from the non-symptomatic South Altoona, were Grantsville (Somerset county) and Old Crabtree (Westmoreland county) with Plot Index values of 0.11 and 0.33 respectively. At Grantsville, the injury primarily developed on blackberry \((SI = 0.63)\) while at Old Crabtree injury was mainly contained to black cherry \((SI = 1.83)\). The remaining five sites showed cumulative Plot Index values in the range of 0.42 to 1.10.
Figure 6. A comparison of seasonal average \( \text{O}_3 \) concentrations (ppb) and elevation(A), and the regression (B) for each of ten individual sites using Ogawa passive samplers for the period June 3 to September 10, 2002.
Figure 7. Seasonal $O_3$ concentrations (ppb) within a multi-county area of southwestern Pennsylvania as interpolated from ten sites using Ogawa passive samplers and hourly averages for each of 14 weeks (June 3-September 10, 2002). Darker blue colors indicate increasing ozone exposures.
Injury by Species

Blackberry (represented at all sites) was the most heavily injured species of bioindicator at all symptomatic sites. Among the sites, blackberry injury was greatest at Hopwood (SI = 8.48) and lowest at Armaugh (0.08); no injury was noted on blackberry at the South Altoona site (Figure 8 A, B). Black cherry was flagged and observed at all sites but only found to be symptomatic at 8 of 10 sites (Figure 9 A, B). The highest amount of black cherry injury was observed at the Forbes State Forest site (SI = 3.22) while lowest values were found at the Homer City site (Indiana county) (SI = 0.12)(Figure 10). Milkweed was located at 6 of 10 sites with greatest symptoms at the Hopwood site (Indiana county) (SI = 3.3); no symptoms were found at the south Altoona (Blair Co.) or Grantsville (Somerset Co.) sites. White ash was injured at 2 of 10 sites, Somerset (Somerset county) and Carrolltown, having SI values 0.06 and 0.03, respectively. Ozone injury to yellow-poplar was only found on one tree at the Grantsville site (SI = 0.1).

Table 4. Species Injury Index and Total Plot Injury Index for each of 10 monitoring sites in south western Pennsylvania for symptoms as they developed during the period June 3 to September 10; Plot index was calculated from the individual plant and species scores recorded during the final week of observations.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Blackberry</th>
<th>Black Cherry</th>
<th>Milkweed</th>
<th>Dogbane</th>
<th>White ash</th>
<th>Yellow poplar</th>
<th>Sassafras</th>
<th>Plot Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somerset</td>
<td>4.2278</td>
<td>0.1572</td>
<td>NA</td>
<td>0.0</td>
<td>0.00000</td>
<td>0.00000</td>
<td>NA</td>
<td>.8882</td>
</tr>
<tr>
<td>Grantsville</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
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<tr>
<td>Hopwood</td>
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<td>.0683</td>
<td>4.8720</td>
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<td>0.00000</td>
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<tr>
<td>Forbes SF</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Paint Twp.</td>
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<td>.1582</td>
<td>.4363</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>.4523</td>
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<tr>
<td>Old Crabtree</td>
<td>.1243</td>
<td>1.8298</td>
<td>NA</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
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<td>1.216</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>NA</td>
<td>.4132</td>
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<tr>
<td>Armaugh</td>
<td>.0805</td>
<td>.1330</td>
<td>2.3045</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>NA</td>
<td>.4197</td>
</tr>
<tr>
<td>Carrolltown</td>
<td>.1610</td>
<td>3.5160</td>
<td>.6885</td>
<td>NA</td>
<td>.0000000</td>
<td>NA</td>
<td>NA</td>
<td>1.0975</td>
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<tr>
<td>S. Altoona</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>NA</td>
<td>0.00000</td>
<td>0.00000</td>
<td>NA</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

NA', Plant not available at the site
0.000, 0.0 no injury observed at this site

Soil moisture observations:

Soil moisture was measured by the gravimetric method weekly at each site over the last month (Week 11 through 14), August 19 to September 10, 2002, of the south central Pennsylvania monitoring project. Two soil samples were extracted at each site from 0 to 12 cm, placed in tins, and stored in a cooler until returned to the lab where the tins were dried in an oven for a 48-hour period then weighed.

Over the four-week period, soil moisture was consistently lower than 40% for all sites with most averaging less than 20% soil moisture on a weekly basis (Figures 11-14).
Figure 8. A comparison of seasonal $O_3$ concentrations (ppb) and symptoms (A), and the regression (B) observed for blackberry at ten biomonitoring sites in southwestern Pennsylvania; symptoms scores were those as observed on September 9 and 10 at each of the respective sites.
Figure 9. A comparison of seasonal O₃ concentrations (ppb) and symptoms (A), and the regression (B) observed for blackcherry at ten biomonitoring sites in southwestern Pennsylvania; symptoms scores were those as observed on September 9 and 10 at each of the respective sites.
Figure 10: End of season O₃ induced foliar injury on black cherry within a multi-county area of southwestern Pennsylvania as interpolated from symptoms observed on plants at each of ten biomonitoring sites. Seasonal average O₃ concentrations were determined using Ogawa passive samplers with hourly averages calculated at each site for each of 14 weeks (June 3-September 10, 2002). Darker blue colors indicate increasing O₃ exposures.
Figure 11. Average soil moisture at each south central Pennsylvania monitoring site at the end of Week 11 and recorded on August 19 & 20, 2002.

Figure 12. Average soil moisture at each south central Pennsylvania monitoring site at the end of Week 12 and recorded on August 26 & 27, 2002.

Figure 13. Average soil moisture at each south central Pennsylvania monitoring site at the end of Week 13 and recorded on September 2 & 3, 2002.
The average available soil moisture among all sites over the entire period was approximately 17%. At the end of the growing season, the site with the highest 4-week average was Forbes State Forest with a value of 27% as opposed to the driest site, South Altoona, which had average soil moisture content of only 9% (Figure 15).

For the last four weeks of the investigation, and across all ten sites, the wettest soil moistures occurred during Week 12 with a combined site average of 21% (Figure 16). Conversely, the driest week was Week 14, with an average of 13% soil moisture.
Palmer Drought Index

The Palmer Drought Index was utilized to represent soil moisture conditions over the entire monitoring period. The index represents drought conditions based on actual and 30-year average precipitation for each of the 6 counties where sites were located over the entire monitoring period. Based on the precipitation totals the index assigns drought classes where "Normal" is within 25% above or below the 30 year precipitation average, "Watch" is within 25 to 35% below the 30 year precipitation average, "Warning" is within 35 to 45% below the 30 year precipitation average, and "Emergency" is greater than 45% below the 30 year precipitation average. Over the monitoring period from June 3 to September 10, 2002, two counties, Fayette and Westmoreland, remained in the "Normal" class of precipitation, one county, Indiana, ended in the "Watch class, two counties, Cambria and Somerset reached the "Warning" class, and Blair county reached the "Emergency" class.

Early in the growing season (March, April, May) there were no major difference in precipitation between the five counties but it is apparent that the northern (Indiana, Cambria, and Blair) and Somerset to the east in the lower tier counties) entered more sharply and directly into the drought conditions of the 2002 season with decreasing rains occurring for the remainder of the summer season (Table 5; Figures 17-22). Apparently rainfalls in Westmoreland and Fayette counties provided more adequate soil moisture for a longer period of time in the central weeks of the summer season. Following along the moving 90 day total precipitation line for the 2002 summer season in comparison to the 30 year averages shown by the 1961-1990 line it is evident that the more northern and eastern counties of Indiana, Cambria, Blair and Somerset entered into the 25 percent below average precipitation values as early as the end of July (Blair and Somerset Counties). Drier conditions were more common during early to mid-August (Indiana and Cambria Counties) in comparison to Westmoreland and Fayette Counties; these latter two counties benefited from a two to three week delay before falling under the 30-yr.below normal precipitation line.
Table 5. Rainfall inches by month (A) and the accumulative total rainfall (B) recorded at weather stations within the five county area of investigation for the summer season, 2002.

<table>
<thead>
<tr>
<th>COUNTY</th>
<th>CITY</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOMERSET</td>
<td>SOMERSET</td>
<td>4.97</td>
<td>7.39</td>
<td>4.87</td>
<td>2.23</td>
<td>4.92</td>
<td>3.89</td>
<td>28.27</td>
</tr>
<tr>
<td>FYETTE</td>
<td>HOPWOOD(CONNELSVILLE)</td>
<td>3.51</td>
<td>6.87</td>
<td>4.87</td>
<td>3.47</td>
<td>4.09</td>
<td>3.54</td>
<td>26.35</td>
</tr>
<tr>
<td>SOMERSET</td>
<td>PAINT TWP(JEROME)</td>
<td>5.77</td>
<td>5.12</td>
<td>5.00</td>
<td>1.62</td>
<td>2.56</td>
<td>4.06</td>
<td>24.13</td>
</tr>
<tr>
<td>WESTMORELAND</td>
<td>OLD CRABTREE(DERRY)</td>
<td>2.87</td>
<td>5.21</td>
<td>5.22</td>
<td>2.84</td>
<td>3.09</td>
<td>3.19</td>
<td>22.42</td>
</tr>
<tr>
<td>CAMBRIA</td>
<td>CAMBRIA</td>
<td>3.19</td>
<td>6.33</td>
<td>4.31</td>
<td>1.88</td>
<td>3.57</td>
<td>3.91</td>
<td>23.19</td>
</tr>
<tr>
<td>BLAIR</td>
<td>S. ALTOONA(ALTOONA 132)</td>
<td>3.11</td>
<td>6.18</td>
<td>5.87</td>
<td>1.18</td>
<td>3.00</td>
<td>3.12</td>
<td>22.46</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>COUNTY</th>
<th>CITY</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>TOTAL</th>
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</thead>
<tbody>
<tr>
<td>SOMERSET</td>
<td>SOMERSET</td>
<td>4.97</td>
<td>12.36</td>
<td>17.23</td>
<td>19.46</td>
<td>24.38</td>
<td>28.27</td>
<td></td>
</tr>
<tr>
<td>FYETTE</td>
<td>HOPWOOD(CONNELSVILLE)</td>
<td>3.51</td>
<td>10.38</td>
<td>15.28</td>
<td>18.72</td>
<td>22.81</td>
<td>26.35</td>
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<tr>
<td>SOMERSET</td>
<td>PAINT TWP(JEROME)</td>
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<td>17.51</td>
<td>20.07</td>
<td>24.13</td>
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<tr>
<td>WESTMORELAND</td>
<td>OLD CRABTREE(DERRY)</td>
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<td>19.23</td>
<td>22.42</td>
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</tr>
<tr>
<td>CAMBRIA</td>
<td>MMOX(RINCE GALLITZIN S.P.)</td>
<td>3.19</td>
<td>9.52</td>
<td>13.83</td>
<td>15.71</td>
<td>19.28</td>
<td>23.19</td>
<td></td>
</tr>
<tr>
<td>BLAIR</td>
<td>S. ALTOONA(ALTOONA 132)</td>
<td>3.11</td>
<td>9.29</td>
<td>15.16</td>
<td>18.34</td>
<td>19.34</td>
<td>22.46</td>
<td></td>
</tr>
</tbody>
</table>
Figure 17: Palmer Drought Index for Blair Co., Pennsylvania through mid-September, 2002. The South Altoona site was located in Blair Co. The moving 90-day precipitation total in mid-June showed above normal conditions, however, by late June and through the end of the monitoring period the moving 90-day total precipitation total continued to decrease to greater than 45% below the normal average.
Figure 18: Palmer Drought Index for Cambria Co., Pennsylvania through mid-September, 2002. The Carrolltown site was located in Cambria Co. The moving 90-day precipitation total was above average by late June then sharply decreased the consecutive months until the end of the monitoring period where precipitation values were 35 to 45% below the normal average.
Figure 19: Palmer Drought Index for Fayette Co., Pennsylvania through mid-September, 2002. The Hopwood site was located in Fayette Co. The moving 90-day precipitation total was above normal for the first half of the monitoring period until late July, then declined to less than 25% below the normal average.
Figure 20: Palmer Drought Index for Indiana Co., Pennsylvania through mid-September, 2002. The Homer City and Conemaugh sites were located in Indiana Co. Similar to Blair and Cambria counties, the moving 90-day precipitation total declined in late June to 25 to 30% below the normal average by the end of the monitoring period.
Figure 21: Palmer Drought Index for Somerset Co., Pennsylvania through mid-September, 2002. Three sites, Somerset, Grantsville, and Paint Township were located in Somerset Co. Throughout the monitoring period, the moving 90-day precipitation total started to decline by early June to a value of 35 to 45% below the normal average by September.
Figure 22: Palmer Drought Index for Westmoreland Co., Pennsylvania through mid-September, 2002. The Forbes State Forest and Old Crabtree sites were located in Westmoreland Co. Westmoreland Co. appeared to be the wettest county out of the six. The moving 90-day precipitation total remained within the range of 25% above and 25% below the normal average until the last two weeks of the monitoring period.
A comparison of evaluators of ozone-sensitive biomonitor species:

Ten sites were assessed under the Forest Health Monitoring Program (FHMP) within and immediately peripheral to the ten passive ozone monitoring sites in southwestern Pennsylvania during the period late July to mid-August 2002. For the ten co-located FHM and passive ozone monitoring plots, the Species Index and an overall Plot Index were calculated (Table 6). The greatest injury was located at Forbes State Forest (PI = 4.035) and Carrolltown (PI = 3.492) while no injury was observed at the Johnstown, Altoona, and Murrysville locations.

Table 6. Species Injury Index and Total Plot Injury Index for each of 10 monitoring sites in southwestern Pennsylvania for symptoms as they developed during the period June 3 to September 10; the plot index was calculated from the individual plant and species scores recorded during the final week of observations.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Blackberry</th>
<th>Black Cherry</th>
<th>Milkweed</th>
<th>Dogbane</th>
<th>White ash</th>
<th>Yellow poplar</th>
<th>Sassafras</th>
<th>Plot Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somerset</td>
<td>4.720</td>
<td>.407</td>
<td>0.0^2</td>
<td>.378</td>
<td>0.0</td>
<td>NA^1</td>
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<td>.918</td>
</tr>
<tr>
<td>Grantsville</td>
<td>4.074</td>
<td>.194</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>.023</td>
<td>0.0</td>
<td>.612</td>
</tr>
<tr>
<td>Hopwood</td>
<td>4.252</td>
<td>.566</td>
<td>.1338</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>NA</td>
<td>.990</td>
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<tr>
<td>Forbes SF</td>
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<td>3.737</td>
<td>1.1097</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
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<td>NA</td>
<td>NA</td>
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</tr>
<tr>
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<td>1.501</td>
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<td>0.0</td>
<td>0.0</td>
<td>.430</td>
</tr>
<tr>
<td>Homer City</td>
<td>NA</td>
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<td>0.0</td>
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<td>NA</td>
<td>0.0</td>
<td>0.0</td>
<td>.013</td>
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<tr>
<td>Armaugh</td>
<td>NA</td>
<td>.8021</td>
<td>1.9738</td>
<td>0.0</td>
<td>0.0</td>
<td>.221</td>
<td>0.0</td>
<td>.500</td>
</tr>
<tr>
<td>Carrolltown</td>
<td>13.684</td>
<td>3.317</td>
<td>.1483</td>
<td>0.0</td>
<td>.3108</td>
<td>NA</td>
<td>NA</td>
<td>3.492</td>
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<tr>
<td>S. Altoona</td>
<td>2.235</td>
<td>.135</td>
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<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>NA</td>
<td>.474</td>
</tr>
</tbody>
</table>

NA^1, Plant not available at the site
0.0^2, 0.0 no injury observed at this site

Comparisons of injury scores and classes leading to the overall plot index as recorded by two independent observers produced very interesting results. The season-long and final week evaluations of the bioindicators located at the passive ozone monitoring plots were made by D. Yuska while the end-of-the season evaluations of the bioindicators at the FHM biomonitoring plots were made by J. Savage. When the plot indices for all species were considered within and between all plots, there was no apparent agreement between the two observers with a non-significant correlation relationship being developed (r = 0.50 p = 0.142). However, by removing blackberry from both sets of observations, a very significant correlation was obtained (r = 0.85, p = .001) (Figures 23, 24). These observations further confirm the difficulties encountered when evaluating blackberry for ozone induced foliar symptoms during periods of significant drought and/or due to the presence of common leaf rust ...both of which were in evidence at most plots during the final week of observations.
Figure 23. Correlation and regression of overall plot index values using the symptom indices for all O₃-sensitive bioindicator species found at 10 co-located (passive and FHM) biomonitoring plots established in southwestern Pennsylvania.

Figure 24. Correlation and regression of overall plot index values using the symptom indices for O₃-sensitive bioindicator species but with the absence of blackberry evaluations as recorded at 10 co-located (passive and FHM) biomonitoring plots established in southwestern Pennsylvania.
CONCLUSIONS:

A network of ten natural field sites were successfully identified and monitored in southwestern Pennsylvania on a weekly basis for ambient ozone exposures with Ogawa passive sampling devices and weekly observations were made for ozone-induced foliar symptoms on ozone-sensitive bioindicator species at each of the ten locations.

The multi-county area of southwestern Pennsylvania identified within the report of Coulston et al. (2002, 2003) as having higher than the norm incidence and severity of ozone-induced foliar symptoms on the FHM bioindicator plots was confirmed via these investigations. Symptoms that are considered typical of ozone-induced injury were prominent on black cherry, milkweed, and several other bioindicator species.

Significant relationships were notable between weekly hourly average ozone concentrations as monitored with the Ogawa passive samplers in comparison to nearby continuous ozone monitors as operated by the Pennsylvania Department of Environmental Protection, Bureau of Air Quality.

The ozone exposures at the ten sites essentially “tracked” together suggesting that ozone occurrences were common to the entire area due to mesoscale influences of larger weather patterns as they occurred throughout the summer season, 2003. Sites with higher elevations tracked similar to one another with higher ozone exposures while those at lower elevation consistently tracked with lower ozone exposures.

Foliar symptoms as due to ozone exposures were initiated in earnest during early to mid-July with earliest symptoms noted on black cherry in late June at one site. Milkweeds also became symptomatic in mid-July with increasing incidence and severity of typical adaxial stippling observed on both species.

Foliar symptoms were initially observed and then subsequently found to be increasing in incidence and severity on the wetter sites at the higher elevations within the study area. A severe drought occurred during the latter portion of the 2003-growing season as shown via the Palmer Drought Indices developed for each respective County. At the drier sites, the severity and duration of the drought played a significant role in reducing the advance of the early season ozone-induced foliar symptoms; reduced soil moisture and reductions in stomatal conductance have been consistently shown to greatly reduce ozone uptake.

Significant foliar injury was observed on blackberry during the late season but led to confusion within the data sets when comparisons of two independent observers were made at the termination of the study. The severe drought and infections by a rust fungus clearly led to the expression of many black berry with mimicking symptoms thus seriously confounding the diagnostic process for ozone-induced symptoms.
Acknowledgements

This research was completed under USDA-Forest Service, Federal Lands Forest Health Monitoring Program, Northeastern Area State and Private Forestry Cooperative Agreement No. 02-DG-11244225-258. Appreciation is expressed to Dr. Jim Steinman for the guidance offered in the project initiation through to the interpretation of the results and the review of the review of the final report. The additional participation and reviews provided by Dr. Tom Hall and Dr. Don Eggen of the Division of Forest Pest management, PA Bureau of Forestry, PA Department of Conservation and Natural Resources, Harrisburg is also acknowledged with appreciation.

The cooperation of Mr. Shawn Nolan of the Bureau of Air Quality, PA Department of Environmental Protection, Harrisburg in providing hourly ozone data from the air quality monitoring stations within the study area provided a significant contribution to the project.

The cooperation of several private landowners, hunt clubs, and managers of the designated State Parks and State Forests where plots had been established is likewise acknowledged with sincere appreciation.
Citations:


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APPENDIX

Figures 1-10. The location of the ten passive ozone samplers and associated bioindicator plots established within a five county area in southwestern Pennsylvania. Plots established June 3 and 4 and visited weekly throughout the summer until September 9 and 10, 2002.

± = Passive monitoring sites and bioindicator plots

FHM = Assigned number of nearest FHM plot as established during previous surveys. When numbers appear together, the FHM biomonitoring plots and the passive ozone samplers and biomonitoring plots were essentially co-located.

1 Somerset
2 Grantsville
3 Hopwood
4 Forbes State Forest
5 Paint Township
6 Old Crabtree
7 Homer City
8 Armaugh
9 Carrolltown
10 South Altoona