

NATCHEZ TRACE NATIONAL SCENIC TRAIL (NATR)

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION AT SITES ALONG THE NATCHEZ TRACE NATIONAL SCENIC TRAIL

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers to better understand the risk of ozone injury to vegetation and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used, and how they were applied and modified to meet the requirements of producing an assessment for the 444-mile long Natchez Trace Trail. It also provides a summary of the results of risk assessments for sites along the Trail.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Due to its linear configuration and length, the Natchez Trace Trail is represented by nine sub-sites with a risk assessment for each. The sub-sites consist of US National Park sites on and near the Natchez Trace Trail and EPA AIRS ozone monitoring sites located near

the Trail. Plant species and ozone exposure data are not complete for each site, and therefore the quality of the risk assessment varies among sites.

Natchez Trace National Scenic Trail Assessment Sites and Data Availability

State	Location	County	AIRS ID #	Sum06 yrs	W126 yrs	N-value yrs
MS	Natchez	Adams	280010004	95-99	95-99	95-99
	Vicksburg NMP		NPS	95-99	95-99	95-99
	Jackson	Hinds	280890002	95-99	95-99	95-99
	Ackerman	Choctaw	280190001	97	97	97
	Tupelo	Lee	280810005	98-99	99	99
TN	Shiloh NMP		NPS	95-99	95-99	94-99
	Busby	Lawrence	470990002	97-99	97-99	97-99
	Fairview	Williamson	471870103	95-96	95-96	95-96
	Stones River NB		NPS	95-99	95-99	95-99

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone.

Ozone-sensitive and bioindicator plant species at each National Park Service site along the Natchez Trace Trail were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop. Since there are no floral lists for the EPA AIRS monitoring sites used in the assessment, another approach had to be adopted for them. The database maintained by the US Forest Service for the Forest Inventory/Forest Health Monitoring program (FIA/FHM) was consulted. Data on all FIA/FHM assessment plots within 25 miles of the AIRS monitoring site were evaluated to identify ozone-sensitive tree species occurring there. Since the FIA/FHM assessments currently examine only trees, it was not possible to identify ozone-sensitive herbaceous or understory species associated with the AIRS sites.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 were obtained either from on-site monitoring or by kriging, a statistical interpolation process. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the

assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Ozone exposure values for the sites along the Natchez Trace Trail were provided by the Air Resources Division of the National Park Service using hourly data either from their own or from the EPA AIRS database. Exposure values for the National Park Service sites were produced using hourly data either from on-site monitoring or estimated by kriging. Hourly monitoring data from EPA AIRS were used to generate exposure values for the non-Park Service sites in the assessment.

Although the assessment period is five years, 1995 through 1999, not all sites have the complete suite of data for the exposure indices. This limits the understanding of the exposure regimes at some sites and constrains their risk assessments. Sites with limited ozone data were included in the Natchez Trace Trail assessment to both identify them for use future evaluation and to provide an initial look at their ozone environments.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not

available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

The collection of nine National Park Service and AIRS sites provides a reasonable spatial distribution of assessment points from Mississippi to Tennessee along the Natchez Trace Trail. However, there are several factors that need to be considered when relating the risk assessments for the sites to that of the Trail. Except where the Trail passes through a national park, the species lists represent those found in the vicinity of the assessment site and not those actually on the Trail. A second consideration is that since the Park Service and AIRS monitoring sites are generally at elevations different from those of the Trail in that area, the ozone regimes at the monitoring sites may not be representative of those on the Trail. The magnitudes of the differences between the sites cannot be accurately assessed except to note that ozone exposures generally increase with increasing elevation. Lastly, the Palmer Z data used for the monitoring sites may not accurately represent soil

moisture conditions on the Trail due to differences in soil type, physiography, and precipitation that occur with elevation. As a consequence of these factors, the assessments should be viewed as providing insight to the levels of risk that exist at selected points along the Natchez Trace Trail, and used as guidance in determining either whether a field injury survey is appropriate, or whether additional ozone exposure and species information should be collected and evaluated before a decision about risk can be made.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

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**SUMMARY OF RISK ASSESSMENTS FOR SITES ALONG THE NATCHEZ
TRACE NATIONAL SCENIC TRAIL**

Site / Park		State	Risk
Natchez		MS	low
Vicksburg NMP	VICK	MS	low
Jackson		MS	low
Ackerman		MS	low
Tupelo		MS	high
Shiloh NMP	SHIL	TN	high
Busby		TN	moderate
Fairview		TN	low
Stones River NB	STRI	TN	high

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Natchez, Adams County

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Natchez, Adams County					
	1995	1996	1997	1998	1999
Sum06	12	21	20	22	28
W126	19.2	26.1	30.8	35.5	37.3
N60	356	499	609	631	688
N80	24	45	34	107	105
N100	2	0	3	2	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Natchez					
	1995	1996	1997	1998	1999
Month 1	-0.12	-1.63	-1.34	-0.06	-2.45
Month 2	-1.48	2.05	0.16	-2.44	0.39
Month 3	-0.11	-0.83	-1.29	0.98	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Natchez					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a significant number of hours in some years. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are unlikely to injure vegetation.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Soil moisture levels show one or two months of mild to moderate drought stress each year, and no relationship between levels of ozone exposure and soil moisture conditions can be established. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The years with the highest and second highest exposure levels, 1999 and 1998, experienced three and four months,

respectively, of mild to severe drought stress. The two mid-level ozone years, 1997 and 1996, experienced two and one month of mild drought, while the lowest exposure year had normal soil moisture throughout.

The low levels of ozone exposure at Natchez, Adams County make the risk of foliar ozone injury to plants low. While the Sum06 index exceeds the threshold for injury, the W126 does not since the N100 criterion is not satisfied. Hourly concentrations of ozone exceed 80 ppb for a significant number of hours in some years, but the number of hours above 100 ppb in these years is low. Soil moisture conditions of several months of drought constrain the uptake of ozone in the years with higher exposures and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Vicksburg National Military Park (VICK)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VICK					
	1995	1996	1997	1998	1999
Sum06	18	15	17	13	16
W126	27.5	22.7	25.5	28.5	31.4
N60	521	411	490	525	600
N80	46	34	31	68	59
N100	1	1	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to

foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VICK					
	1995	1996	1997	1998	1999
Month 1	-1.48	2.05	-1.34	-0.06	-2.45
Month 2	-0.11	-0.83	0.16	-2.44	0.39
Month 3	-0.95	2.11	-1.29	0.98	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VICK					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
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Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Ozone exposures were similar over the five-year period, and no relationship is apparent between the 90-day Sum06 levels of ozone and soil moisture. Four of the five years experienced one or more months of drought, and only 1996 had favorable conditions. The years with the highest and lowest ozone exposures, 1995 and 1998, experienced one month of mild and moderate drought, respectively. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposure in producing foliar injury. The highest ozone year, 1999, had three months of mild to moderate drought stress. The next two highest ozone years, 1998 and 1995, had similar levels of ozone, but experienced four months of mild to severe drought and one month of mild drought, respectively. The two years with the lowest ozone, 1996 and 1997, had one and two months of mild drought respectively.

The low levels of ozone exposure and the frequent low soil moisture conditions at Vicksburg National Monument Park make the risk of foliar ozone injury to plants low. While the Sum06 index exceeds the threshold levels for injury, the W126 does not since the N100 criterion is generally not satisfied. There are occasional exposures to concentrations of ozone above 80 ppb, and rare exposure to 100 ppb. Soil moisture conditions of moderate to severe drought reduce the effectiveness of the higher concentration exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, and American elder.

Jackson, Hinds County

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

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Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Jackson, Hinds County					
	1995	1996	1997	1998	1999
Sum06	18	21	19	20	26
W126	25.7	26.7	25.6	34.2	35.6
N60	512	495	495	617	671
N80	22	33	18	83	56
N100	0	0	1	7	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Jackson					
	1995	1996	1997	1998	1999
Month 1	-1.48	-1.63	-1.34	-2.44	-2.45
Month 2	-0.11	2.05	0.16	0.98	0.39
Month 3	-0.95	-0.83	-1.29	-1.40	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Jackson					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone satisfies the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had seven hours in which the concentration exceeded 100 ppb, but two years had no hours at this level. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Soil moisture levels show one or two months of mild to moderate drought stress each year, and no relationship between levels of ozone exposure and soil moisture conditions can be established. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The years with the highest and second

highest exposure levels, 1999 and 1998, experienced three and four months, respectively, of mild to severe drought stress. The remaining three years had lower and similar levels of ozone and each had one or two months of mild drought.

The low ozone exposure at Jackson, Hinds County makes the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Since soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures in the higher ozone years, and hourly concentrations of ozone seldom exceeded 80 ppb, foliar injury on plants is unlikely.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Ackerman, Choctaw County

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Ackerman, Choctaw County					
	1995	1996	1997	1998	1999
Sum06	-	-	13	-	-
W126	-	-	24.3	-	-
N60	-	-	440	-	-
N80	-	-	6	-	-
N100	-	-	0	-	-

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Ackerman					
	1995	1996	1997	1998	1999
Month 1	-	-	-1.89	-	-
Month 2	-	-	1.82	-	-
Month 3	-	-	1.69	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Ackerman					
	1995	1996	1997	1998	1999
April	2.19	0.97	1.82	-0.05	-1.69
May	-0.15	-2.20	1.69	-1.79	-0.07
June	0.61	-0.49	3.50	-1.37	1.07
July	-0.21	-0.09	-0.79	0.36	-0.54
August	1.22	1.54	1.58	-0.68	-1.36
September	-0.34	0.73	0.10	-1.64	0.72
October	1.08	-0.60	2.04	-1.61	-0.58

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- Since only one year of ozone monitoring data is available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. In the single year of data, the Sum06 threshold is satisfied while the W126 is not.
- The N-values show only six hours in which concentrations exceeded 80 ppb and no hours at 100 ppb. These levels of exposure are not likely to injure vegetation.

- No assessment of the relationship between the levels of ozone exposure and soil moisture can be conducted since only one year of ozone data is available.

From the single year of ozone data, the risk of foliar ozone injury to plants at Ackerman, Choctaw County appears to be low. Hourly concentrations of ozone rarely exceed 80 ppb and do not reach 100 ppb. Additional ozone data should be examined to assess whether the single year of data is representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Tupelo, Lee County

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less

weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Tupelo, Lee County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	28	38
W126	-	-	-	-	52.7
N60	-	-	-	-	928
N80	-	-	-	-	198
N100	-	-	-	-	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Tupelo					
	1995	1996	1997	1998	1999
Month 1	-	-	-	1.81	-2.72
Month 2	-	-	-	1.93	-2.73
Month 3	-	-	-	-2.15	-1.31

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Tupelo					
	1995	1996	1997	1998	1999
April	0.68	0.78	-0.42	1.56	0.07
May	-1.16	-1.73	3.32	-0.82	-0.38
June	0.65	1.29	6.49	-2.13	2.68
July	0.86	1.57	0.13	1.81	-0.83
August	2.67	1.26	1.25	1.93	-2.72
September	-0.86	2.28	0.17	-2.15	-2.73
October	0.46	0.96	1.18	-0.67	-1.31

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- Since limited ozone monitoring data are available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. Two years of data are available for the Sum06 index, and the threshold is exceeded in both years. One year of data is available for the Sum06 index, and both the cumulative and N100 criteria are exceeded.

- The N-values for the year show concentrations of 60, 80, and 100 ppb are all elevated and there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- No assessment of the relationship between the levels of ozone exposure and soil moisture can be conducted since only one year of ozone data is available. In that year, there were two months of mild drought.

From the single year of ozone data, the risk of foliar injury to plants at Tupelo, Lee County appears to be high. Hourly concentrations of ozone frequently exceed 80 ppb, and there are a significant number of hours above 100 ppb. Additional ozone data should be examined to assess whether the data are representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

TENNESSEE

SHILOH NATIONAL MILITARY PARK (SHIL)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SHIL					
	1995	1996	1997	1998	1999
Sum06	6	6	7	8	14
W126	34.7	36.1	32.7	48.8	62.2
N60	619	648	604	887	1103
N80	94	81	69	158	262
N100	9	6	4	19	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SHIL					
	1995	1996	1997	1998	1999
Month 1	-2.06	0.49	-1.50	-0.93	-1.23
Month 2	-0.95	3.03	0.61	-2.50	-2.01
Month 3	-0.25	-0.02	1.74	-0.88	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SHIL					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation; in one year it just met the threshold and in another it was slightly above. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and the W126 criteria were satisfied in two the five years of data presented.
- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because ozone exposure was relatively similar in all five years. Soil moisture levels during the year with the highest exposure, 1999, show three months of mild to moderate drought. There were only three months of drought in the remaining four years and no associations between the Sum06 index of exposure and soil moisture were apparent. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five and one month, respectively. In the remaining three years, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997, the lowest exposure year.

The risk of foliar ozone injury at Shiloh National Military Park is high. The Sum06 and

W126 thresholds for injury are satisfied intermittently. The N-values indicate that exposures to 80 to 100 ppb vary considerably among years, and in some years exposure to 100 ppb is significant. In the highest exposure years, low soil moisture levels reduce the uptake of ozone, however exposure thresholds are also satisfied in years with more normal soil moisture conditions. It is anticipated that the risk of foliar injury developing may be greatest during years such as 1995, 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

Busby, Lawrence County

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Busby, Lawrence County					
	1995	1996	1997	1998	1999
Sum06	-	-	22	30	52
W126	-	-	28.5	41.6	77.8
N60	-	-	526	769	1350
N80	-	-	35	118	404
N100	-	-	0	9	36

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Busby					
	1995	1996	1997	1998	1999
Month 1	-	-	-1.50	-0.93	-1.23
Month 2	-	-	0.61	-2.50	-2.01
Month 3	-	-	1.74	-0.88	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Busby					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- Since only three years of ozone monitoring data are available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative values exceed the threshold each year, the N100 count shows that the required number of hours is met in two of the three years. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the three years show concentrations of 60, 80, and 100 ppb are elevated in two years, and significantly lower in the remaining year. The high levels of exposure may injure vegetation.
- Although data are limited, soil moisture levels during the 90-day Sum06 accumulation periods and the seasonal W126 accumulation period appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest ozone exposure value, 1999, had the four months of mild and moderate drought, while the remaining two years had lower levels of exposure and one month of drought each.

From the ozone data available, the risk of foliar injury to plants at Busby, Lawrence County appears to be moderate. In two years, hourly concentrations of ozone frequently exceed 80 ppb, and there are a significant number of hours above 100 ppb. Low levels of soil moisture constrain the uptake of ozone in the highest exposure year, 1999, and reduce the likelihood of foliar injury occurring, but the level of exposure and soil moisture conditions are favorable for injury in 1998, the second highest year. Exposures in the remaining year are significantly lower. Additional ozone data should be examined to assess whether these data are representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Fairview, Williamson County

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Aesculus octandra</i>	Yellow buckeye	Hippocastanaceae
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Fairview, Williamson County					
	1995	1996	1997	1998	1999
Sum06	18	7	-	-	-
W126	31.3	26.5	-	-	-
N60	568	480	-	-	-
N80	60	33	-	-	-
N100	3	2	-	-	-

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Fairview					
	1995	1996	1997	1998	1999
Month 1	0.98	1.09	-	-	-
Month 2	0.14	2.72	-	-	-
Month 3	0.59	1.59	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Fairview					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- Since only two years of ozone monitoring data are available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. The Sum06 index exceeds the threshold for injury to vegetation in one of the two years. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- No assessment of the relationship between the levels of ozone exposure and soil moisture can be conducted since only two years of ozone data are available. However, there were no months of drought stress in the two years examined.

From the ozone data available, the risk of foliar injury to plants at Fairview, Williamson County appears to be low. Hourly concentrations of ozone frequently exceed 60 ppb, but exceed 80 ppb only occasionally. Exposures exceed 100 ppb no more than three hours in any year. Additional ozone data should be examined to assess whether these data are representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Stones River National Battlefield (STRI)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for STRI					
	1995	1996	1997	1998	1999
Sum06	24	25	21	25	27
W126	31.9	34.8	36.7	41.0	54.2
N60	590	650	680	744	969
N80	92	101	118	128	211
N100	12	11	14	17	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at STRI					
	1995	1996	1997	1998	1999
Month 1	0.98	0.49	-1.50	3.31	1.61
Month 2	0.14	3.03	0.61	-0.93	-1.23
Month 3	0.59	-0.02	1.74	-2.50	-2.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at STRI					
	1995	1996	1997	1998	1999
April	0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because ozone exposure was relatively similar in all five years. However, soil moisture levels associated with the Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture levels during the year with the highest Sum06 value, 1999, show three months of mild to moderate levels of drought. There were only two months of drought in the remaining four years. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five months and one month, respectively. In the three years when ozone exposures were lower, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997.

The risk of foliar ozone injury to plants at Stones River National Battlefield is high. While the levels of ozone exposure consistently create the potential for injury, dry soil

conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995, 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, American sycamore, black cherry and American elder.