

NORTHEAST COASTAL AND BARRIER ISLAND NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHEAST COASTAL AND BARRIER ISLAND NETWORK

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 at each park to better understand the risk of ozone injury to vegetation within their park 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. It also provides a summary of the results of risk assessments for sites within the network.

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.

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 site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. 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. Most of the sites in the risk assessment have kriged data. 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.

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.

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.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

**SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHEAST
COAST AND BARRIER ISLAND NETWORK**

Park	Code	State	Risk	O3 Data
Assateague Island NS	ASIS	MD	high	kriged
Cape Cod NS	CACO	MA	high	monitored
Colonial NHP	COLO	VA	high	kriged
Fire Island NS	FIIS	NY	high	kriged
Gateway NRA	GATE	NY	high	kriged
Geo Washington Birthplace NM	GEWA	VA	high	kriged
Sagamore Hill NHS	SAHI	NY	high	kriged
Thomas Stone NHS	THST	MD	high	kriged

ASSATEAGUE ISLAND NATIONAL SEASHORE (ASIS)

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>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<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>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae

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 ASIS					
	1995	1996	1997	1998	1999
Sum06	31	31	38	36	38
W126	37.5	33.8	48.9	52.9	50.1
N60	632	595	790	868	802
N80	149	109	222	241	236
N100	28	9	38	45	42

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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 ASIS					
	1995	1996	1997	1998	1999
Month 1	0.38	1.63	-0.88	0.91	-2.09
Month 2	-2.75	4.18	0.35	2.10	-1.61
Month 3	-3.87	0.37	-1.77	-2.07	-1.00

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

Palmer Z Index data for the 7-month W126 period at ASIS					
	1995	1996	1997	1998	1999
April	-0.11	1.17	0.21	-0.52	-0.23
May	0.78	1.46	-0.78	0.91	-2.20
June	0.38	1.63	-0.88	2.10	-2.09
July	-2.75	4.18	0.35	-2.07	-1.61
August	-3.87	0.37	-1.77	-2.03	-1.00
September	-1.21	3.26	-2.74	-3.06	4.64
October	0.69	1.59	0.38	-2.86	1.90

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. 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 N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In the two years with the highest exposures, there were three months of mild and moderate drought in 1999

and one month of mild drought in 1997. In the mid-level exposure year 1998 there was one month of moderate drought. In the two years with the same, lowest exposure, there were two months of moderate and severe drought in 1995 and normal soil moisture conditions in 1996. 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. The two highest ozone years, 1998 and 1999, each had four months of drought ranging from mild to severe. The mid-level exposure year 1997 had two months of mild and moderate drought. In the second lowest ozone year, 1996, there were three months of mild to severe drought, and soil moisture conditions were favorable during 1996, the lowest exposure year.

The risk of foliar ozone injury at Assateague Island National Seashore is high. The Sum06 and W126 threshold criteria are both satisfied, and the hours of exposure to 80 and 100 ppb ozone are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone 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 1996 when ozone levels are reduced but still exceed the thresholds and soil moisture levels are normal, or in years such as 1997 when exposures are high and periods of drought occur late in the growing season.

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, yellow-poplar, American sycamore, black cherry, skunkbush, American elder and crownbeard.

CAPE COD NATIONAL SEASHORE (CACO)

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>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster umbellatus</i>	Flat-topped aster	Asteraceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

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. The 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 monitored on-site were analyzed to generate annual exposure values. The 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 CACO					
	1995	1996	1997	1998	1999
Sum06	20	17	25	17	23
W126	34.8	33.6	40.4	34.8	34.5
N60	518	510	638	586	480
N80	142	105	193	77	168
N100	52	30	47	6	42

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 months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. 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 CACO					
	1995	1996	1997	1998	1999
Month 1	-0.41	-0.43	-1.75	6.79	0.13
Month 2	-0.70	-1.56	-1.04	-0.18	-3.30
Month 3	-2.61	2.18	0.19	0.48	-0.73

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

Palmer Z Index data for the 7-month W126 period at CACO					
	1995	1996	1997	1998	1999
April	-1.80	1.88	2.21	0.31	-3.25
May	-0.46	-0.43	-0.23	0.90	0.13
June	-0.41	-1.56	-1.75	6.79	-3.30
July	-0.70	2.18	-1.04	-0.18	-0.73
August	-2.61	-0.20	0.19	0.48	-1.85
September	-0.80	5.52	-2.36	-1.29	2.54
October	1.54	8.00	-2.07	1.39	2.55

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 significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods 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 exposure in producing foliar injury. The year with the highest Sum06 exposure, 1997, had two months of mild drought. The two mid-level exposure years 1999 and 1995 had one month of severe and one month of moderate drought, respectively. The two lowest exposure years had one month of mild drought

between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but the pattern is again inconsistent. In the highest ozone year, 1997, there were four months of mild and moderate drought. The three mid-ozone years, 1995, 1998 and 1999, had two, one and three months, respectively, of mild to severe drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Cape Cod National Seashore is high. Exposure criteria for both the Sum06 and W126 are satisfied, and there are a significant number of hours of exposure to 80 and 100 ppb. 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 1996 and 1998 in which ozone levels exceed the thresholds, and soil moisture levels are normal or under mild or short-term 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, spreading dogbane, common milkweed, quaking aspen, black cherry, and northern fox grape.

COLONIAL NATIONAL HISTORICAL PARK (COLO)

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>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>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

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.

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	<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 COLO					
	1995	1996	1997	1998	1999
Sum06	25	23	36	36	34
W126	32.8	28.2	45.4	48.1	42.8
N60	573	498	763	830	699
N80	91	60	184	180	183
N100	8	2	24	23	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, 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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 COLO					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

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

Palmer Z Index data for the 7-month W126 period at COLO					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

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. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods 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. When the Sum06 exposure index was the highest in 1997 and 1998, there were two months and one month of mild and moderate drought, respectively. Mid-ozone years had one and two months of drought stress. Soil moisture was normal in 1996, the year with the lowest index of exposure. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. When the W126 exposure was the highest in 1998, 1997 and 1999, there were, respectively, four, four and two months of mild and moderate drought. In 1996 when exposure was the lowest, soil moisture was normal, and in the second lowest exposure year, 1995, there were three months of mild and severe drought.

The risk of foliar ozone injury to plants at Colonial National Historic Park is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high in most years. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1999 when ozone levels are high, and months of drought do not impose extended constraints on 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, yellow-poplar, American sycamore, quaking aspen, black cherry, American elder, crownbeard and northern fox grape.

FIRE ISLAND NATIONAL SEASHORE (FIIS)

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>Fraxinus americana</i>	White ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus banksiana</i>	Jack pine	Pinaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

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 FIIS					
	1995	1996	1997	1998	1999
Sum06	17	14	21	19	22
W126	24.2	20.7	26.5	29.7	28.4
N60	355	312	379	460	410
N80	108	76	132	127	135
N100	37	15	42	21	39

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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 FIIS					
	1995	1996	1997	1998	1999
Month 1	-0.96	0.69	-0.94	2.97	-3.06
Month 2	-0.06	3.25	1.24	-2.18	-3.96
Month 3	-3.62	-0.39	0.68	-1.97	-0.94

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

Palmer Z Index data for the 7-month W126 period at FIIS					
	1995	1996	1997	1998	1999
April	-1.74	2.18	0.21	1.84	-2.31
May	-0.61	-0.62	-0.40	1.69	-0.26
June	-0.96	0.69	-0.94	2.97	-3.06
July	-0.06	3.25	1.24	-2.18	-3.96
August	-3.62	-0.39	0.68	-1.97	-0.94
September	-0.12	1.71	-1.66	-1.45	2.84
October	1.76	4.81	-1.20	-1.57	0.46

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. The W126 accumulative value and the N100 count are significantly 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 concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods 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 Sum06 exposure index, 1999, had two months of severe drought, however the year with the second highest exposure, 1997, had normal conditions. As exposure decreased in the remaining years, so did the incidence of drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and three months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, each had two months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Fire Island National Seashore is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are high, 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, American sycamore, quaking aspen, black cherry, American elder and northern fox grape.

GATEWAY NATIONAL RECREATION AREA (GATE)

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>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>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

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 GATE					
	1995	1996	1997	1998	1999
Sum06	15	12	17	15	18
W126	26.2	22.1	26.4	28.4	29.8
N60	386	344	390	451	450
N80	136	92	131	135	143
N100	40	15	33	19	46

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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 GATE					
	1995	1996	1997	1998	1999
Month 1	-0.61	0.69	-0.94	2.97	-3.06
Month 2	-0.96	3.25	1.24	-2.18	-3.96
Month 3	-0.06	-0.39	0.68	-1.97	-0.94

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

Palmer Z Index data for the 7-month W126 period at GATE					
	1995	1996	1997	1998	1999
April	-1.74	2.18	0.21	1.84	-2.31
May	-0.61	-0.62	-0.40	1.69	-0.26
June	-0.96	0.69	-0.94	2.97	-3.06
July	-0.06	3.25	1.24	-2.18	-3.96
August	-3.62	-0.39	0.68	-1.97	-0.94
September	-0.12	1.71	-1.66	-1.45	2.84
October	1.76	4.81	-1.20	-1.57	0.46

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. The W126 accumulative value and the N100 count are significantly 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 concentrations of 60, 80, and 100 ppb are elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There does not appear to be any association between the 90-day Sum06 index of

ozone exposure and soil moisture status. The uniform Sum06 indices of exposure and limited distribution of drought over the five-year period make it difficult to assess relationships. A year with the highest Sum06 index, 1999, and a year with a mid-level exposure, 1998, each had two months of mild to severe drought stress. The remaining three years had normal levels of soil moisture. Although the high and uniform levels of ozone also make it difficult to assess relationships for W126 ozone exposures, soil moisture levels 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. In the highest ozone years, 1999 and 1998, there were three and four months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, had the same level of exposure and each had two months of mild and severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Gateway National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels 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, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, American elder, common snowberry and northern fox grape.

GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT (GEWA)

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>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>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

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 GEWA					
	1995	1996	1997	1998	1999
Sum06	24	27	31	38	39
W126	35.9	31.3	41.5	49.6	48.1
N60	622	566	693	821	786
N80	138	92	172	225	237
N100	21	4	24	40	38

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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 GEWA					
	1995	1996	1997	1998	1999
Month 1	0.63	1.68	-1.25	-2.05	-1.18
Month 2	0.65	4.40	0.98	-2.06	-0.87
Month 3	-1.60	1.67	-2.69	-1.42	-0.97

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

Palmer Z Index data for the 7-month W126 period at GEWA					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

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. The W126 accumulative value exceeds the threshold each year while the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in four years. The criteria for injury under the W126 exposure index are generally satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with the 90-day 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. The years with the highest ozone exposure values, 1999 and 1998, had, respectively, one and three months of mild and moderate drought. There were two months of mild and moderate drought in 1997, the year with mid-level ozone exposure. The two lowest ozone years had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The three years with the highest ozone exposures, 1998, 1999 and 1997, experienced four, two, and four months of mild and moderate drought, respectively. The year with the second lowest index, 1995, had three months of mild and severe drought, while the year with the lowest exposure had normal soil moisture conditions.

The risk of foliar ozone injury to plants at George Washington Birthplace National Monument is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high in most years. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1999 when ozone levels are high, and months of drought do not impose extended constraints on 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, yellow-poplar, American sycamore, black cherry, American elder, crownbeard and northern fox grape.

SAGAMORE HILL NATIONAL HISTORIC SITE (SAHI)

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>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae

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 SAHI					
	1995	1996	1997	1998	1999
Sum06	16	13	19	16	20
W126	23.2	19.3	24.3	25.8	26.2
N60	340	296	352	406	386
N80	115	75	120	111	123
N100	33	15	34	17	39

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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 SAHI					
	1995	1996	1997	1998	1999
Month 1	-0.96	0.69	-0.94	2.97	-3.06
Month 2	-0.06	3.25	1.24	-2.18	-3.96
Month 3	-3.62	-0.39	0.68	-1.97	-0.94

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

Palmer Z Index data for the 7-month W126 period at SAHI					
	1995	1996	1997	1998	1999
April	-1.74	2.18	0.21	1.84	-2.31
May	-0.61	-0.62	-0.40	1.69	-0.26
June	-0.96	0.69	-0.94	2.97	-3.06
July	-0.06	3.25	1.24	-2.18	-3.96
August	-3.62	-0.39	0.68	-1.97	-0.94
September	-0.12	1.71	-1.66	-1.45	2.84
October	1.76	4.81	-1.20	-1.57	0.46

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. The W126 accumulative value and the N100 count are significantly 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.
- Soil moisture levels associated with the 90-day 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. The two years with the highest ozone were marked by two months of severe drought in 1999 and normal soil moisture conditions in 1997. The mid-ozone years had one and two months of drought, and soil moisture conditions were favorable in 1996 the year with the lowest ozone

exposure. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations. In the highest ozone years, 1999 and 1998, there were three and four months, respectively, of mild to severe drought. The two mid-ozone years, 1997 and 1995, each had two months of mild and severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Sagamore Hill National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 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, yellow-poplar, black cherry and American elder.

THOMAS STONE NATIONAL HISTORIC SITE (THST)

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>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<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
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

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 THST					
	1995	1996	1997	1998	1999
Sum06	25	26	28	37	38
W126	36.0	30.5	37.6	47.2	46.2
N60	610	549	627	769	751
N80	153	96	154	225	230
N100	29	5	23	44	37

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 associated with 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 site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 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 THST					
	1995	1996	1997	1998	1999
Month 1	-0.49	0.42	0.39	-2.53	-1.66
Month 2	-3.22	2.85	-0.80	-2.62	-2.86
Month 3	-1.37	0.14	0.14	-3.36	1.11

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

Palmer Z Index data for the 7-month W126 period at THST					
	1995	1996	1997	1998	1999
April	-0.63	-1.06	0.02	-0.21	-0.24
May	-0.01	1.35	-1.97	0.06	-3.07
June	0.96	0.42	0.39	3.74	-1.66
July	-0.49	2.85	-0.80	-2.53	-2.86
August	-3.22	0.14	0.14	-2.62	1.11
September	-1.37	0.95	-1.38	-3.36	6.57
October	4.49	2.32	-0.57	-2.56	1.17

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. 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 W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with the 90-day 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. The two years with the highest ozone, 1999 and 1998, experienced two and three months of mild and severe, respectively. Soil moisture conditions for the two intermediate ozone years were favorable. The lowest ozone year, 1995, had two months of mild and severe drought. Soil moisture

levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1998 and 1999, there were four and three months, respectively, of mild to severe drought. The two mid-ozone years, 1997 and 1995, each had two months of mild and severe drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Thomas Stone National Historic Site is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are 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, yellow-poplar, American sycamore, black cherry, American elder, crownbeard and northern fox grape.