

SONORAN DESERT NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SONORAN DESERT 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 SONORAN DESERT NETWORK

Park	Code	State	Risk	O3 Data
Casa Grande Ruins NM	CAGR	AZ	low	kriged
Chiricahua NM	CHIR	AZ	low	monitored
Coronado NMEM	CORO	AZ	low	kriged
Fort Bowie NHS	FOBO	AZ	low	kriged
Gila Cliff Dwellings NM	GICL	NM	low	kriged
Montezuma Castle NM	MOCA	AZ	moderate	kriged
Organ Pipe Cactus NM	ORPI	AZ	moderate	kriged
Saguaro NP	SAGU	AZ	low	monitored
Tonto NM	TONT	AZ	moderate	kriged
Tumacacori NHP	TUMA	AZ	low	kriged
Tuzigoot NM	TUZI	AZ	low	kriged

CASA GRANDE RUINS NATIONAL MONUMENT (CAGR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae

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 CAGR					
	1995	1996	1997	1998	1999
Sum06	29	28	21	28	28
W126	36.9	36.0	31.2	37.0	38.9
N60	650	650	556	669	722
N80	111	104	63	90	79
N100	18	12	4	4	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. 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 CAGR					
	1995	1996	1997	1998	1999
Month 1	1.59	-2.41	-1.07	4.59	-1.93
Month 2	-2.58	-2.39	-2.27	1.33	-1.55
Month 3	0.99	-1.81	-1.59	-0.90	5.49

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

Palmer Z Index data for the 7-month W126 period at CAGR					
	1995	1996	1997	1998	1999
April	1.45	-2.41	-1.07	2.35	1.54
May	1.75	-2.39	-2.27	4.57	-1.93
June	1.59	-1.81	-1.59	4.59	-1.55
July	-2.58	1.09	-2.61	1.33	5.49
August	0.99	-1.27	0.71	-0.90	-0.83
September	0.22	1.51	-0.47	0.08	1.05
October	-2.04	-1.22	-0.99	0.21	-2.28

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in some years. The highest levels of exposure can injure vegetation.
- There is no apparent association between either the 90-day Sum06 or the seasonal W126 index of exposure and soil moisture. Evaluation of the relationships between the Sum06 and W126 indices and soil moisture is difficult because ozone exposure levels were relatively uniform over the five years, and soil moisture conditions showed frequent periods of mild to moderate drought stress. Except for 1998, the annual Sum06 accumulation periods were marked by between one and three months of mild to moderate drought each year. Similarly, except for 1998, the W126 index had two to five months of mild to moderate drought annually.

The risk of foliar ozone injury at Casa Grande Ruins National Monument is low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied. Exposure to 80 and 100 ppb ozone varies considerably among years. The ability of low soil moisture to constrain the uptake of ozone is an important consideration at the site since there are often three or four months of mild and moderate drought in a year. These levels of soil moisture significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. While the year 1998 is characterized by normal soil moisture conditions, it experienced lower levels of ozone that are unlikely to result in foliar injury. The random co-occurrence of higher

levels of ozone exposure and soil moisture conditions that favor the uptake of ozone could increase the likelihood of injury in a particular year.

There are no ozone bioindicator species listed for the site.

CHIRICAHUA NATIONAL MONUMENT (CHIR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae

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 CHIR					
	1995	1996	1997	1998	1999
Sum06	22	30	15	20	23
W126	25.1	33.3	21.2	31.3	29.6
N60	407	659	262	534	469
N80	2	1	0	2	8
N100	0	0	0	0	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 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 CHIR					
	1995	1996	1997	1998	1999
Month 1	1.66	-2.23	-1.06	2.55	0.43
Month 2	3.14	-2.41	-0.84	1.63	-1.96
Month 3	2.46	-0.51	-1.94	2.99	-1.56

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

Palmer Z Index data for the 7-month W126 period at CHIR					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators.
- 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 never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show no concentrations of 100 ppb and only a few greater than 80 ppb. These levels of exposure are unlikely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 exposures, three years, including those with the highest and lowest indices, each had two months of drought stress. The remaining two years had normal soil moisture. There also does not appear to be any association between the W126 index and soil moisture. Soil moisture levels in the years with the three highest levels of exposure, 1996, 1998 and 1999, experienced two, three and three months of mild to severe drought, respectively. The second lowest year, 1995, had two months of drought, and the lowest exposure year, 1997, had three months of mild and severe drought.

The levels of ozone exposure at Chiricahua National Monument make 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. Hourly concentrations of ozone seldom exceed 80 ppb and do not reach 100 ppb. Each year has two or three months of mild to severe drought that constrain the uptake of ozone and reduce the effectiveness of the exposures. It is unlikely that foliar injury will be produced on plants under these exposure and environmental conditions.

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: spreading dogbane, ponderosa pine, black cherry, skunkbush, cut-leaf coneflower and Scouler's willow.

CORONADO NATIONAL MEMORIAL (CORO)

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>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae
<i>Sambucus mexicana</i>	Blue elderberry	Caprifoliaceae

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 CORO					
	1995	1996	1997	1998	1999
Sum06	17	17	12	16	14
W126	27.1	27.0	23.8	29.0	25.8
N60	448	490	376	525	430
N80	40	26	22	27	16
N100	3	1	1	1	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. 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 CORO					
	1995	1996	1997	1998	1999
Month 1	2.46	-2.23	-1.06	2.43	0.43
Month 2	-3.09	-2.41	-0.84	2.07	-1.96
Month 3	-0.43	-0.51	-1.94	-1.71	-1.56

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

Palmer Z Index data for the 7-month W126 period at CORO					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
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September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

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 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.
- Evaluation of the relationships between ozone exposure and soil moisture is difficult since ozone exposure levels for the 90-day Sum06 and the seasonal W126 indices were relatively uniform over the five years, and soil moisture conditions showed frequent months of mild to severe drought stress. There is no apparent association between either the Sum06 or W126 index of ozone exposure and level of soil moisture. The Sum06 index was accompanied by one or two months of mild to severe drought each year. The W126 index was associated with two or three months of mild to severe drought annually.

The risk of foliar ozone injury at Coronado National Memorial is low. The Sum06 index satisfies the threshold for injury, the W126 does not, and the N-values indicate there are only rare exposures to concentrations of ozone greater than 100 ppb. Soil moisture conditions of frequent mild to severe drought significantly reduce the effectiveness of the exposures in most years. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often two or more consecutive months of mild to severe drought. These levels of soil moisture would significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced.

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, black cherry, skunkbush and blue elderberry.

FORT BOWIE NATIONAL HISTORIC SITE (FOBO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

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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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 FOBO					
	1995	1996	1997	1998	1999
Sum06	19	24	13	18	19
W126	25.7	30.3	22.7	30.6	28.4
N60	419	576	318	535	462
N80	19	12	11	14	13
N100	1	1	0	0	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. 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 FOBO					
	1995	1996	1997	1998	1999
Month 1	1.66	-2.23	-1.06	2.55	0.43
Month 2	3.14	-2.41	-0.84	1.63	-1.96
Month 3	2.46	-0.51	-1.94	2.99	-1.56

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

Palmer Z Index data for the 7-month W126 period at FOBO					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are a few 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 few hours each year. No year had more than one hour in which the concentration exceeded 100 ppb, and in three years there were no hours above this level. These levels of exposure are not likely to injure vegetation.
- There were no apparent relationships between either the 90-day Sum06 or the seasonal W126 indices of exposure and soil moisture conditions. Soil moisture in the year with the highest Sum06 ozone exposure, 1996, showed two months of moderate drought, while the year with the lowest exposure, 1997, had two months of mild drought. The remaining three years had levels of ozone exposure that were similar in magnitude, but experienced normal moisture conditions in 1995 and 1998 and two months of mild drought in 1999. Similarly, there is no relationship between the W126 index of ozone and soil moisture with each year having two or three months of mild to severe drought. Soil moisture levels in the highest ozone years, 1996 and 1998, showed two months of moderate drought and three months of mild drought, respectively, while the lowest ozone year, 1997, had three months of mild and severe drought.

The levels of ozone exposure at Fort Bowie National Historic Site make 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 several months of mild to severe drought reduce the effectiveness of the exposures in most years, and hourly concentrations of ozone seldom exceed 80 ppb, it is unlikely that foliar injury will be produced on plants.

If the level of risk increases in the future, a program to assess the presence of ozone injury could employ skunkbush.

GILA CLIFF DWELLINGS NATIONAL MONUMENT (GICL)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	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 GICL					
	1995	1996	1997	1998	1999
Sum06	11	18	12	18	16
W126	21.5	24.1	20.9	28.5	25.9
N60	329	401	300	503	422
N80	25	22	17	22	20
N100	3	2	1	2	1

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 GICL					
	1995	1996	1997	1998	1999
Month 1	0.57	-3.37	0.35	-0.62	-0.73
Month 2	-1.25	0.61	1.78	4.66	-1.31
Month 3	0.30	1.10	-0.77	-0.99	-0.38

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

Palmer Z Index data for the 7-month W126 period at GICL					
	1995	1996	1997	1998	1999
April	0.16	-2.92	0.29	1.15	-0.73
May	0.87	-3.37	1.98	-0.20	-1.31
June	0.57	0.61	0.35	-0.62	-0.38
July	-1.25	1.10	1.78	4.66	3.48
August	0.30	0.76	-0.77	-0.99	3.67
September	0.30	1.78	2.99	-2.52	1.95
October	-2.63	3.22	0.09	3.15	-0.73

Risk Analysis

- There are a few 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 few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Since ozone exposure levels for the 90-day Sum06 index were relatively uniform and there were only three months of drought over the five years, no relationships are apparent between levels of ozone and soil moisture. The W126 index of ozone exposure was also relatively consistent during the five-year period. One or two months of drought occurred in four of the years, and no association between ozone exposure and soil moisture is apparent.

The levels of ozone exposure at Gila Cliff Dwellings National Monument make 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, and hourly concentrations of ozone only occasionally exceed 80 ppb, it is unlikely that foliar injury will be produced on plants.

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: ponderosa pine, skunkbush and cut-leaf coneflower.

MONTEZUMA CASTLE NATIONAL MONUMENT (MOCA)

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>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae

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 MOCA					
	1995	1996	1997	1998	1999
Sum06	5	10	19	31	43
W126	42.5	46.3	43.9	70.9	70.1
N60	743	870	826	1414	1433
N80	131	134	89	164	122
N100	22	13	7	7	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. 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 MOCA					
	1995	1996	1997	1998	1999
Month 1	1.89	-3.39	-1.50	0.19	0.83
Month 2	-2.18	-3.38	-3.65	1.01	-2.16
Month 3	-0.76	-3.14	-0.61	1.01	-1.83

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

Palmer Z Index data for the 7-month W126 period at MOCA					
	1995	1996	1997	1998	1999
April	0.73	-3.39	0.50	1.17	0.83
May	1.87	-3.38	-1.18	1.89	-2.16
June	1.89	-3.14	-1.50	1.68	-1.83
July	-2.18	-0.91	-3.65	3.16	3.41
August	-0.76	-2.47	-0.61	0.19	-2.17
September	1.51	1.55	4.23	1.01	4.95
October	-2.17	-1.39	-1.07	1.01	-2.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally 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 N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two years. These levels of ozone can injure vegetation in high exposure years.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Three years with high, moderate, and low Sum06 exposures, 1999, 1997 and 1996 respectively, had two, two and three months of mild to severe drought, respectively. The remaining two years, with the second highest and the lowest exposures, 1998 and 1995, had normal soil moisture and one month of moderate drought. Soil moisture levels in the two years with the highest seasonal W126 exposures, 1998 and 1999, showed normal soil moisture and four months of mild and moderate drought, respectively. The remaining three years had similar levels of ozone exposure, and each experienced two to five months of mild to severe drought.

The risk of foliar ozone injury to plants at Montezuma Castle National Monument is moderate. The Sum06 and W126 indices exceed the threshold levels for injury and hourly concentrations of ozone occasionally exceed 100 ppb. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often several consecutive months of mild and severe drought. These levels of soil moisture would significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. The year 1998 is an exception to this pattern and is characterized by moderate levels of ozone exposure under normal soil moisture conditions. There are

also relatively few months of drought in 1995 a year of high exposure and one in which the uptake of ozone is not severely restricted. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that generally favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: tree-of-heaven and skunkbush.

ORGAN PIPE CACTUS NATIONAL MONUMENT (ORPI)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

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 ORPI					
	1995	1996	1997	1998	1999
Sum06	11	13	17	21	21
W126	35.8	35.6	30.8	33.7	35.6
N60	639	648	562	619	666
N80	107	105	54	70	67
N100	17	12	2	3	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. 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 ORPI					
	1995	1996	1997	1998	1999
Month 1	2.46	-2.23	-0.84	2.43	0.43
Month 2	-3.09	-2.41	-1.94	2.07	-1.96
Month 3	-0.43	-0.51	-3.88	-1.71	-1.56

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

Palmer Z Index data for the 7-month W126 period at ORPI					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are a few 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 fulfilled the W126 threshold in only two years, 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 and 80 ppb. Most years had four or fewer hours in which the concentration exceeded 100 ppb, but two years had 17 and 12 hours. These levels of ozone may possibly injure vegetation in the high exposure years.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 accumulative index and soil moisture. In the Sum06 assessment, one or two months of mild to severe drought stress occurred each year without any relationship to the level of exposure. The W126 index of ozone was also unrelated to soil moisture. Levels of exposure were similar among the five years and each year experienced periods of two or three months of mild to severe drought.

The risk of foliar ozone injury to plants at Organ Pipe Cactus National Monument is moderate. The Sum06 exposures exceed the threshold levels for injury, while the W126 exposures meet the criteria in two years. Soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures for several months each year. However, in years in which hourly concentrations of ozone often exceed 100 ppb, 1995 and 1996, there are fewer months of drought than in other years. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush.

SAGUARO NATIONAL PARK (SAGU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Oenothera elata</i>	Evening primrose	Onagraceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae
<i>Sambucus mexicana</i>	Blue elderberry	Caprifoliaceae

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 SAGU					
	1995	1996	1997	1998	1999
Sum06	29	21	24	27	20
W126	41.1	28.7	39.2	39.2	27.9
N60	655	452	672	672	455
N80	84	29	45	45	11
N100	7	0	0	0	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 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 SAGU					
	1995	1996	1997	1998	1999
Month 1	2.46	-0.51	-1.06	1.63	0.43
Month 2	-3.09	-0.45	-0.84	2.99	-1.96
Month 3	-0.43	-0.38	-1.94	2.43	-1.56

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

Palmer Z Index data for the 7-month W126 period at SAGU					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

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 fulfilled the W126 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 exceed 60 and 80 ppb, and exceeded 100 ppb in one year. These levels of exposure may possibly injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. In 1995, the year with the highest Sum06 exposure, there was one month of severe drought. In both 1997, a mid-level exposure year, and 1999, the second lowest exposure year, there were two months of mild drought. Soil moisture was normal in 1998 and 1996, the second highest and lowest exposure years respectively. There also does not appear to be any association between the W126 index and soil moisture. In 1995 when ozone exposure was highest, there were two months of mild and severe drought. There were three months of mild and severe drought in 1997 and 1998, both of which had the second highest exposure index, and the years with the two lowest exposures, 1999 and 1998, experienced three and two months of mild and moderate drought, respectively.

The levels of ozone exposure at Saguaro National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 exposures do not since the N100 criterion is not satisfied. There are frequent hours with concentrations of ozone above 80 ppb, but exposure to concentrations greater than 100 ppb occur in only one year. Each year experiences two or three months of mild

to severe drought that constrain the uptake of ozone 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: spreading dogbane, evening primrose, ponderosa pine, quaking aspen, skunkbush, cut-leaf coneflower, Scouler's willow and blue elderberry.

TONTO NATIONAL MONUMENT (TONT)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

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 TONT					
	1995	1996	1997	1998	1999
Sum06	32	32	23	38	45
W126	41.3	41.2	41.2	65.6	62.6
N60	721	742	748	1273	1250
N80	136	133	96	173	135
N100	23	15	7	7	5

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 TONT					
	1995	1996	1997	1998	1999
Month 1	3.23	-1.29	-1.76	0.75	2.17
Month 2	0.18	-2.46	-3.68	0.42	-1.96
Month 3	0.91	-3.05	-1.82	1.00	-3.23

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

Palmer Z Index data for the 7-month W126 period at TONT					
	1995	1996	1997	1998	1999
April	0.09	-2.78	-0.76	0.63	2.17
May	0.97	-3.50	-1.07	0.75	-1.96
June	0.82	-3.29	-1.76	0.42	-3.23
July	-2.53	0.60	-3.68	1.00	4.41
August	-1.22	-3.03	-1.82	-1.24	-0.16
September	-0.31	2.48	-1.63	-0.43	1.28
October	-2.42	-1.37	-0.05	-0.59	-2.66

Risk Analysis

- There are a few 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 the W126 criteria were satisfied in the five years of data.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two of the years. These levels of ozone can possibly injure vegetation in high exposure years.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the year with the highest Sum06 exposure, 1999, showed two months of mild and severe drought, while the second highest exposure year, 1998, had normal soil moisture. Years with mid-level ozone exposure, 1995 and 1996, experienced normal soil moisture and three months of mild to severe drought, respectively. The lowest exposure year, 1997, had three months of mild and moderate drought. Soil moisture levels associated with the seasonal W126 index also appear unrelated to the level of ozone exposure. While the year with the highest W126 exposure, 1998, experienced one month of mild drought, the other four years each had three to five months of mild to severe drought. There was no association between level of exposure and soil moisture conditions.

The risk of foliar ozone injury to plants at Tonto National Monument is moderate. The Sum06 and W126 indices exceed the threshold levels for injury, and hourly concentrations of ozone often exceed 100 ppb. Soil moisture conditions of several months of mild to severe drought each year significantly limit the uptake of ozone and reduce the effectiveness of the exposures. The year 1998 is an exception to this pattern and is characterized by moderate ozone exposure under generally normal soil moisture

conditions. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: skunkbush and blue elderberry.

TUMACACORI NATIONAL HISTORICAL PARK (TUMA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
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No species listed.

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 TUMA					
	1995	1996	1997	1998	1999
Sum06	17	16	11	16	14
W126	26.9	25.4	22.9	26.9	24.1
N60	450	454	371	491	405
N80	43	28	22	25	14
N100	3	1	1	0	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. 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 TUMA					
	1995	1996	1997	1998	1999
Month 1	2.46	-2.23	-1.06	2.43	0.43
Month 2	-3.09	-2.41	-0.84	2.07	-1.96
Month 3	-0.43	-0.51	-1.94	-1.71	-1.56

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

Palmer Z Index data for the 7-month W126 period at TUMA					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- 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 three 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 either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Ozone exposure levels for the Sum06 and the W126 indices were both relatively uniform over the five years. For both indices of exposure, soil moisture conditions showed frequent months of mild to moderate drought throughout the five-year period, and there was no apparent association between either index of exposure and the level of soil moisture. The moderate and severe drought experienced each year would constrain the uptake of ozone and reduce the effectiveness of the exposures.

The levels of ozone exposure and the relatively dry soil moisture conditions at Tumacacori Historical Park make 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 annual soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures for several months each year, and hourly concentrations of ozone only occasionally exceeded 80 ppb, it is unlikely that foliar injury will be produced on plants.

There are no ozone bioindicator species listed for the site.

TUZIGOOT NATIONAL MONUMENT (TUZI)

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>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae

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 TUZI					
	1995	1996	1997	1998	1999
Sum06	5	14	21	30	41
W126	42.4	49.0	45.3	68.1	70.4
N60	739	939	875	1358	1443
N80	125	129	77	142	115
N100	21	11	5	7	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. 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 TUZI					
	1995	1996	1997	1998	1999
Month 1	1.89	-3.39	-1.50	0.19	0.83
Month 2	-2.18	-3.38	-3.65	1.01	-2.16
Month 3	-0.76	-3.14	-0.61	1.01	-1.83

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

Palmer Z Index data for the 7-month W126 period at TUZI					
	1995	1996	1997	1998	1999
April	0.73	-3.39	0.50	1.17	0.83
May	1.87	-3.38	-1.18	1.89	-2.16
June	1.89	-3.14	-1.50	1.68	-1.83
July	-2.18	-0.91	-3.65	3.16	3.41
August	-0.76	-2.47	-0.61	0.19	-2.17
September	1.51	1.55	4.23	1.01	4.95
October	-2.17	-1.39	-1.07	1.01	-2.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are often satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb every year. In two years the N100 values were greater than ten, while they were lower in the other three. These levels of ozone can possibly injure vegetation in the highest exposure years.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the year with the highest Sum06 value, 1999, showed two months of mild and moderate drought, while the second highest exposure year, 1998, had normal soil moisture conditions. The year with mid-level exposure, 1997, had two months of mild and severe drought. There were three months of severe drought in 1996, the year with the second lowest exposure, and the year with the lowest exposure, 1995, had one month of moderate drought. Soil moisture levels associated with the seasonal W126 index are similarly mixed. The two years with the highest exposures, 1999 and 1998, experiencing four months of mild and moderate drought and normal moisture conditions, respectively. The remaining three years had similar and lower levels of exposure, and each experienced between two and five months of moderate to severe drought.

The risk of foliar ozone injury at Tuzigoot National Monument is low. While the Sum06 and W126 indices generally satisfy their thresholds for injury, and the N-values indicate

there are occasional exposures to concentrations of ozone greater than 100 ppb, low soil moisture reduces the potential for foliar injury at the site. Most years experience two to five months of mild to severe drought that can significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. The year 1998 is an exception to this pattern and is characterized by a higher level of ozone exposure under consistently normal soil moisture conditions. The co-occurrence of somewhat higher levels of ozone exposure and soil moisture conditions that favor uptake could increase the likelihood of injury in a given year.

If the level of risk increases in the future, a program to assess the presence of ozone injury could employ tree-of-heaven and skunkbush.