

# **CHIHUAHUAN DESERT NETWORK**

## **ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE CHIHUAHUAN 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 onsite 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  $\geq 60$  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  $\geq 100$  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  $\geq 100$  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  $\geq 100$  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](http://www2.nature.nps.gov/ard/pubs/index.htm))

**SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE CHIHUAHUAN  
DESERT NETWORK**

<b>Park</b>	<b>Code</b>	<b>State</b>	<b>Risk</b>	<b>O3 Data</b>
Amistad NRA	AMIS	TX	moderate	kriged
Big Bend NP	BIBE	TX	low	monitored
Carlsbad Caverns NP	CAVE	NM	low	kriged
Chamizal NM	CHAM	TX	low	monitored
Fort Davis NHS	FODA	TX	low	kriged
Guadalupe Mountains NP	GUMO	TX	low	kriged
White Sands NM	WHSA	NM	low	kriged

## AMISTAD NATIONAL RECREATION AREA (AMIS)

### Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

### 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 AMIS					
	1995	1996	1997	1998	1999
Sum06	11	5	7	15	14
W126	31.1	15.5	16.0	21.9	23.4
N60	497	233	245	372	378
N80	119	40	40	40	73
N100	19	7	3	5	8

## Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at AMIS					
	1995	1996	1997	1998	1999
Month 1	0.33	-0.94	1.64	1.91	-2.41
Month 2	-1.28	-1.15	-1.51	-1.77	-2.94
Month 3	-0.98	-3.47	-2.24	-3.70	-1.22



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

Palmer Z Index data for the 7-month W126 period at AMIS					
	1995	1996	1997	1998	1999
April	0.27	-1.15	2.93	-1.77	-0.71
May	1.74	-3.47	0.74	-3.70	-1.45
June	0.33	-2.73	5.60	-2.31	0.28
July	-1.28	-2.09	1.64	-2.72	-0.80
August	-0.98	2.96	-1.51	6.87	-2.41
September	0.39	1.06	-2.24	-1.81	-2.94
October	-1.98	0.14	-0.54	0.45	-1.22

### Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value exceeds the threshold each year and the N100 count intermittently meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had numbers of hours above 80 and 100 ppb that were significantly greater than those in the other years. Most years had eight or fewer hours in which the concentration exceeded 100 ppb. 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. Three of the Sum06 years, including the highest and lowest years, had two months of mild to severe drought. The remaining two years had one and three months of drought. With the W126 index, the highest ozone year, 1995, had two months of mild drought, and the lowest year, 1996, four months of mild to severe drought. The second highest year, 1999, had four months of mild and moderate drought while the two intermediate years had five and two months of drought. Overall, no associations between ozone exposure and drought are apparent for either index.

The risk of foliar ozone injury at Amistad National Recreation Area is moderate. The threshold levels for the Sum06 and W126 indices are intermittently satisfied. The N-values indicate that exposures to concentrations of ozone greater than 80 and 100 ppb vary widely among years. Since there is no association between levels of ozone and soil moisture, conditions favorable for the uptake of ozone can occur at all levels of exposure. This creates the opportunity for reaching the threshold for injury at both high and more moderate levels of ambient ozone. The risk of injury is greatest in years such as 1995 when the ambient level of ozone is high, and soil moisture conditions favor uptake by plants. No ozone-sensitive species have been identified at the site, and any risk remains

potential until such species are found.

No ozone-sensitive or bioindicator species are identified for the site.

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

Palmer Z Index data for the 7-month W126 period at WHSA					
	1995	1996	1997	1998	1999
April	0.52	-1.99	2.85	2.65	0.26
May	-0.67	-3.01	-0.27	-0.51	-0.16
June	-0.62	4.94	1.48	-0.78	-0.02
July	-2.13	0.20	3.46	6.08	3.60
August	-1.16	0.20	-0.19	-2.03	4.47
September	1.08	2.33	3.14	-3.45	-0.84
October	-2.50	2.01	-1.15	3.01	-1.49

### Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index generally 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 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely 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. The years with the highest and lowest Sum06 exposures, 1998 and 1995, each experienced two months of mild to severe drought. One month of mild drought occurred over the remaining three years. The highest and second highest W126 exposure years, 1998 and 1999, had two months of moderate and severe drought and one month of mild drought, respectively. The lowest and second lowest years, 1997 and 1995, had one month of mild and three months of mild and moderate drought. No association is apparent between the W126 level of ozone exposure and soil moisture.

The low levels of ozone exposure and the frequent dry soil moisture conditions at White Sands National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures generally exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Months of mild to severe drought in most years constrain the uptake of ozone and further reduce the effectiveness of the exposures.

There are no ozone-sensitive or bioindicator species listed for the site.

## BIG BEND NATIONAL PARK (BIBE)

### Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae

### 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 BIBE					
	1995	1996	1997	1998	1999
Sum06	6	10	3	16	4
W126	16.2	17.8	11.7	26.9	14.4
N60	196	235	90	395	132
N80	4	11	0	1	0
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 at the site. The objectives of the assessment were to examine the relationship between 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 a site-specific index. Without site-specific data, ozone/soil moisture relationships can 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  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BIBE					
	1995	1996	1997	1998	1999
Month 1	1.09	-0.51	-0.10	-1.65	-0.14
Month 2	-3.09	-3.37	-0.70	-3.51	-1.49
Month 3	-2.36	1.19	-1.92	-3.00	-0.78

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

Palmer Z Index data for the 7-month W126 period at BIBE					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

## Risk Analysis

- There are a few ozone-sensitive species at the site, both of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. While the W126 index exceeds the accumulative value for injury to vegetation, the N100 count shows that one-hour concentrations of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure conditions are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.
- The N-values for the site show no concentrations of 100 ppb and relatively few greater than 80 ppb. These levels of exposure are unlikely to injure vegetation.
- 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. In 1998 when the Sum06 exposure index was highest, there were three months of low and severe drought. There were two months of moderate and severe drought in 1995, the mid-level exposure year, while the remaining three years each had one month of drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but the pattern is again not consistent. The year with the highest exposure, 1998, had five months of mild and severe drought. The two mid-level exposure years, 1996 and 1995, each experienced three months of mild to severe drought. The second lowest exposure year, 1999, had four months of mild and moderate drought, while the lowest year, 1997, had two months of mild drought.

The levels of ozone exposure and the relatively dry soil moisture conditions at Big Bend National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure thresholds are satisfied. Exposure to concentrations greater than 80 ppb is rare, and concentrations never exceed 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposure levels and further reduces 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 the following bioindicator species: ponderosa pine and skunkbush.

## CARLSBAD CAVERNS NATIONAL PARK (CAVE)

### Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

### 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)
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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 CAVE					
	1995	1996	1997	1998	1999
Sum06	13	16	6	23	14
W126	21.2	21.8	20.6	31.5	24.2
N60	318	331	304	604	402
N80	41	41	29	24	14
N100	8	7	3	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, 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 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 at the site. The objectives of the assessment were to examine the relationship between 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 a site-specific index. Without site-specific data, ozone/soil moisture relationships can be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored 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  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAVE					
	1995	1996	1997	1998	1999
Month 1	0.62	-4.12	-0.02	0.97	1.45
Month 2	-3.05	2.02	-0.15	-0.33	2.22
Month 3	-2.40	-0.15	0.61	-2.83	1.48

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

Palmer Z Index data for the 7-month W126 period at CAVE					
	1995	1996	1997	1998	1999
April	-1.24	-1.24	4.28	-0.33	1.45
May	-0.69	-4.12	1.34	-2.83	2.22
June	0.62	2.02	1.05	-3.04	1.48
July	-3.05	-0.15	-0.02	-1.86	0.02
August	-2.40	3.22	-0.15	-0.48	-1.26
September	2.58	0.26	0.61	-2.85	-1.47
October	-2.08	-1.59	0.83	3.28	-1.74

### Risk Analysis

- There are no ozone-sensitive species listed for the site.
- 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 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 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation in the highest 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. During the Sum06 accumulation periods, four months of drought were distributed over three years without any association with the level of ozone exposure. With the W126 indices, four of the five years experienced three or four months of mild to severe drought. The year with the lowest exposure had normal soil moisture conditions.

The risk of foliar ozone injury to plants at Carlsbad Caverns National Park is 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 occasionally exceeded 80 ppb, but exposure to 100 ppb is rare. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often three or four months of mild to severe drought in a year. These levels of soil moisture significantly constrain the uptake of ozone and reduce the likelihood of foliar injury being produced.

No ozone-sensitive or bioindicator species are identified for the site.



## FORT DAVIS NATIONAL HISTORIC SITE (FODA)

### Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae

### 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 FODA					
	1995	1996	1997	1998	1999
Sum06	7	10	7	18	10
W126	21.0	20.7	18.6	28.8	20.9
N60	308	306	259	500	316
N80	38	37	24	29	20
N100	7	6	3	4	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, 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 site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FODA					
	1995	1996	1997	1998	1999
Month 1	1.09	-1.19	-0.10	-0.76	-1.93
Month 2	-3.09	-0.51	-0.70	-1.65	-2.20
Month 3	-2.36	-3.37	-1.92	-3.51	-2.16

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

Palmer Z Index data for the 7-month W126 period at FODA					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

### Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. 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 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. The highest levels of exposure may injure vegetation.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest ozone year, 1998, had two months of mild and moderate drought. The intermediate exposure years 1996 and 1999 had two and three months of drought, respectively. Two years with the lowest and same ozone exposure, 1995 and 1997, had two months of moderate and severe drought and one month of mild drought, respectively. Soil moisture levels associated with the seasonal W126 index appear inversely related

to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. There were five months of mild and severe drought in the highest ozone year, 1998, and four, three and three months of mild to severe drought in 1999, 1996 and 1995 the next three highest years of exposure. There were two months of mild drought in the lowest year, 1997.

The low levels of ozone exposure and the frequent dry soil moisture conditions at Fort Davis National Historic Site make the risk of foliar ozone injury to plants low. While the Sum06 exposures intermittently exceed the threshold levels for injury, the W126 do not since the N100 criterion is not generally satisfied. Frequent months of mild to severe drought constrain the uptake of ozone and further reduce the effectiveness of the exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use black cherry and skunkbush.

## GUADALUPE MOUNTAINS NATIONAL PARK (GUMO)

### Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

### 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 GUMO					
	1995	1996	1997	1998	1999
Sum06	6	8	8	20	13
W126	21.8	21.8	20.9	30.2	23.5
N60	330	332	312	561	386
N80	44	43	30	31	21
N100	9	7	4	4	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, 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 at the site. The objectives of the assessment were to examine the relationship between 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 a site-specific index. Without site-specific data, ozone/soil moisture relationships can be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the 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  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GUMO					
	1995	1996	1997	1998	1999
Month 1	1.09	-3.37	-0.10	-1.65	-1.49
Month 2	-3.09	1.19	-0.70	-3.51	-0.78
Month 3	-2.36	-1.02	-1.92	-3.00	2.38

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

Palmer Z Index data for the 7-month W126 period at GUMO					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

### Risk Analysis

- There are no ozone-sensitive species listed for the site.

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 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 ppb and occasionally exceeded 80 ppb. No year had more than nine hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest ozone year, 1998, had three months of mild and severe drought and the second highest year, 1999, one month of mild drought. The intermediate years 1997 and 1996 had one and two months of drought each, while the lowest year, 1995, had two months of moderate and severe drought. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. There were five months of mild and severe drought in the highest ozone year, 1998, and four months of mild and moderate drought in 1999, the second highest year. The intermediate ozone years 1995 and 1996 each had three months of drought, and there were two months of mild drought in the lowest year, 1997.

The low levels of ozone exposure and the frequent dry soil moisture conditions at Guadalupe Mountains National 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 generally not satisfied. Frequent months of mild to severe drought constrain the uptake of ozone and further reduce the effectiveness of the exposures.

No ozone-sensitive or bioindicator species are identified for the site.



## WHITE SANDS NATIONAL MONUMENT (WHSA)

### Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

### 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 WHSA					
	1995	1996	1997	1998	1999
Sum06	7	15	10	17	15
W126	20.3	22.2	19.7	27.6	23.8
N60	303	341	272	484	381
N80	34	30	20	27	19
N100	7	4	2	3	1



## Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environment 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 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 at the site. The objectives of the assessment were to examine the relationship between 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 a site-specific index. Without site-specific data, ozone/soil moisture relationships cannot 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. Hence, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored 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  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WHSA					
	1995	1996	1997	1998	1999
Month 1	-0.62	-3.01	1.48	6.08	0.26
Month 2	-2.13	4.94	3.46	-2.03	-0.16
Month 3	-1.16	0.20	-0.19	-3.45	-0.02

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

Palmer Z Index data for the 7-month W126 period at WHSA					
	1995	1996	1997	1998	1999
April	0.52	-1.99	2.85	2.65	0.26
May	-0.67	-3.01	-0.27	-0.51	-0.16
June	-0.62	4.94	1.48	-0.78	-0.02
July	-2.13	0.20	3.46	6.08	3.60
August	-1.16	0.20	-0.19	-2.03	4.47
September	1.08	2.33	3.14	-3.45	-0.84
October	-2.50	2.01	-1.15	3.01	-1.49

### Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index generally 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 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely 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. The years with the highest and lowest Sum06 exposures, 1998 and 1995, each experienced two months of mild to severe drought. One month of mild drought occurred over the remaining three years. The highest and second highest W126 exposure years, 1998 and 1999, had two months of moderate and severe drought and one month of mild drought, respectively. The lowest and second lowest years, 1997 and 1995, had one month of mild and three months of mild and moderate drought. No association is apparent between the W126 level of ozone exposure and soil moisture.

The low levels of ozone exposure and the frequent dry soil moisture conditions at White Sands National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures generally exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Months of mild to severe drought in most years constrain the uptake of ozone and further reduce the effectiveness of the exposures.

There are no ozone-sensitive or bioindicator species listed for the site.

## Sensitive Air Quality Related Values (AQRV) of Chihuahuan Desert Network Parks

Provided by Tonnie Maniero, Air Quality Ecological Effects Coordinator, Northeast Region, National Park Service

December 16, 2005

An air quality related value (AQRV) is a resource that may be adversely affected by a change in air quality. AQRVs include visibility and specific scenic, cultural, physical, biological, ecological, or recreational resources. Research has identified certain AQRVs as sensitive, such as lakes with low acid-buffering capacity and plant species that display injury symptoms at ambient ozone concentrations. An “X” indicates the AQRV is known to be, or likely to be, sensitive to air pollution. “Unknown” indicates there is not enough park-specific information available to determine if the resource is sensitive. The table is based on best available information relative to park resources and pollution sensitivity, and will be updated when more information is available.

**Visibility** is a sensitive AQRV affected by air pollution to some degree in every unit of the National Park System. Air pollution affects how far we can see vistas and landscape features, and how well we can see them. Air pollution and light pollution also affect the dark night sky resource, an integral component of visibility. **Vegetation** may be sensitive to a variety of air pollutants, including nitrogen, sulfur, and ozone. Nitrogen and sulfur may affect plant growth and species composition. Ozone may cause leaf injury and growth and reproduction effects. Ozone-sensitive plant species have been identified in many parks and are listed in [risk assessments](#) that have been conducted to evaluate the risk to vegetation from ozone at park units. **Surface waters** and **soils** are susceptible to acidification, unnatural enrichment, or eutrophication from atmospheric deposition of hydrogen ions, nitrogen and/or sulfur. Water and soils that have evolved under low nutrient conditions, or those with low buffering capacity, are particularly vulnerable. **Fish and wildlife** are all potentially sensitive to air pollutants, including airborne toxics like mercury and dioxins. Air pollutants may have a direct effect to fish and wildlife (e.g., mercury neurotoxicity) or an indirect effect to their habitat (e.g., stream acidification).

<b>Park</b>	<b>Visibility</b>	<b>Vegetation</b>	<b>Surface Waters</b>	<b>Soils</b>	<b>Fish and Wildlife</b>
Amistad NRA	X	X	Unknown	Unknown	X
<u>Big Bend NP</u>	X	X	X	X	X
<u>Carlsbad Caverns NP</u>	X	X	X	X	X
Fort Davis NHS	X	X	No	Unknown	X
<u>Guadalupe Mountains NP</u>	X	X	X	X	X
Rio Grande WSR	X	Unknown	Unknown	Unknown	X*
White Sands NM	X	X	X	X	X

\* The state has issued fish consumption advisories in or near the park due to unsafe levels of one or more toxics.