REASSESSMENT OF THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS EXPERIENCING INCREASES IN LEVELS OF EXPOSURE

Objective

The original assessment of the risk of foliar ozone injury on vegetation for parks in the 32 Vital Signs Networks was conducted in 2004 and used ozone exposure and soil moisture data for 1995 through 1999. This reassessment uses monitoring data for ozone from 2000 through 2004 to update the risk assessments for selected parks. Together the two assessments provide insight to the changes in ozone exposure over a ten-year period, and examine how the changes may have altered the risk of ozone injury to plants.

The reassessment of risk was conducted for Craters of the Moon National Historic Park, Death Valley National Park, Grand Canyon National Park, Great Basin National Park, Mesa Verde National Park, Rocky Mountain National Park, Sequoia and Kings Canyon National Park, and Yellowstone National Park. These parks were selected because it appeared they experienced increased levels of ozone exposure since the initial assessment. This document contains the reassessment for Yellowstone National Park. Other reassessments can be accessed from the appropriate park's AQRV page on ARIS at http://www2.nature.nps.gov/air/Permits/ARIS/index.cfm.

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 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 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 ≥ 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 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

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YELLOWSTONE NATIONAL PARK
(YELL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	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.

	W126	N100
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 YELL					
	1995	1996	1997	1998	1999
Sum06	-	4	3	6	19
W126	12.5	15.1	12.4	19.8	29.8
N60	46	104	52	157	426
N80	0	0	0	0	0
N100	0	0	0	0	0

Ozone air quality data for YELL					
	2000	2001	2002	2003	2004
Sum06	11	12	15	12	2
W126	23.4	25.6	29.5	27.1	15.9
N60	270	269	433	325	59
N80	0	0	0	0	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 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 YELL					
	1995	1996	1997	1998	1999
Month 1	-	-2.09	0.95	-1.52	-3.43
Month 2	-	-1.49	-0.47	-3.06	-0.36
Month 3	-	-2.45	0.05	-3.09	-0.19

Palmer Z Index data for 3-month Sum06 period at YELL					
	2000	2001	2002	2003	2004
Month 1	-1.64	1.59	-0.85	-1.31	5.59
Month 2	-3.91	-2.84	-0.78	-1.05	-1.48
Month 3	-2.74	-1.98	-2.32	-2.14	-1.54

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

Palmer Z Index data for the 7-month W126 period at YELL					
	1995	1996	1997	1998	1999
April	1.43	-0.34	0.95	-3.06	-0.36
May	-0.79	3.26	-0.47	-3.09	-0.19
June	-0.02	-2.09	0.05	4.17	0.10
July	1.31	-1.49	3.33	-1.09	-2.72
August	0.05	-2.45	2.32	-1.94	2.02
September	-0.58	-0.47	1.42	-0.42	-2.00
October	0.52	-1.48	0.60	-2.40	-2.28

Palmer Z Index data for the 7-month W126 period at YELL					
	2000	2001	2002	2003	2004
April	-1.84	1.59	-0.85	-1.31	5.59
May	1.27	-2.84	-0.78	-1.05	-1.48
June	-1.64	-1.98	-2.32	-2.14	-1.54
July	-3.91	-2.85	-3.19	-4.26	-2.67
August	-2.74	-4.69	-2.79	-3.96	0.03
September	-1.03	-2.31	-1.11	-2.37	0.46
October	0.17	-0.55	0.47	-0.63	0.00

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

1995-1999

- The Sum06 index is generally below 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. Both the Som06 and W126 indices are below the levels considered necessary for injury to vegetation.

- The N-values for the site show no concentrations greater than 60 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture status. Four years of Sum06 exposure data are available, and most years show low and similar levels of exposure making it difficult to evaluate associations. Soil moisture levels associated with the Sum06 index show there was one month of severe drought in the highest exposure year, 1999. There were three months of mild to severe drought in both the second highest year, 1998, and a mid-level year, 1996. Moisture conditions were normal in 1997, the lowest exposure year. Soil moisture levels associated with the seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The five years of data show the two highest exposure years, 1999 and 1998, experienced three and five months of mild to severe drought, respectively. The mid-level exposure year1996 had four months of mild and moderate drought. The lowest exposure years, 1995 and 1997 both had normal moisture conditions.

2000-2004

- The Sum06 index generally 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 no concentrations greater than 60 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. The Sum06 indices of exposure were similar in four of the five years with soil moisture ranging from one month of moderate drought in 2002, the highest exposure year,

to three months of mild to severe drought in 2000, the second lowest exposure year. There were two months of mild drought in the lowest exposure year, 2004. The relatively high and uniform levels of ozone exposure make it difficult to assess relationships between the W126 ozone exposure index and soil moisture. In the four years with relatively similar levels of exposure, each year experienced four to six months of mild to severe drought. The year with the lowest level of exposure, 2004, experienced three months of mild and moderate drought. The pattern over the five–year period is somewhat suggestive of an inverse relationship between exposure and drought, when ozone is high soil moisture is low, but the relatively narrow range of four of the exposures make it difficult to confirm such a relationship.

The low levels of ozone exposure and periods of drought at Yellowstone National Park make the risk of foliar ozone injury to plants low. While the Sum06 threshold is generally satisfied, the W126 exposure criteria are not satisfied, and exposures never exceed 60 ppb. However, the levels of exposure as measured by the Sum06 index, the W126 accumulative value, and N60 value all increased over the ten-year period. Months of drought stress were frequent during the second assessment period; this condition constrains the uptake of ozone and reduces the likelihood of injury developing.

The trends of increasing levels of exposure may create concerns in the future. While the interactive effects of low levels of soil moisture serve to constrain the uptake of ozone and reduce the potential for injury, research on the responses of western plant species to long-term exposure to elevated, but still relatively low, levels of ozone under varying degrees of drought is limited. Attention should continue to be paid to the levels of exposure at the park and the soil moisture conditions under which they occur.

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, quaking aspen and Scouler's willow.