

SAN FRANCISCO BAY AREA NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SAN FRANCISCO BAY AREA 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 SAN FRANCISCO BAY NETWORK

| Park | Code | State | Risk | O3 Data |
|-----------------|-------------|--------------|-------------|----------------|
| Golden Gate NRA | GOGA | CA | low | kriged |
| John Muir NHS | JOMU | CA | high | kriged |
| Muir Woods NM | MUWO | CA | moderate | kriged |
| Pinnacles NM | PINN | CA | high | monitored |
| Point Reyes NS | PORE | CA | low | kriged |

GOLDEN GATE NATIONAL RECREATION AREA (GOGA)

Plant Species Sensitive to Ozone

| <i>Latin Name</i> | <i>Common Name</i> | <i>Family</i> |
|----------------------------------|--------------------|---------------|
| <i>Alnus rubra</i> | Red alder | Betulaceae |
| <i>Apocynum androsaemifolium</i> | Spreading dogbane | Apocynaceae |
| <i>Artemisia douglasiana</i> | Mugwort | Asteraceae |
| <i>Oenothera elata</i> | Evening primrose | Onagraceae |
| <i>Physocarpus capitatus</i> | Ninebark | Rosaceae |
| <i>Pinus radiata</i> | Monterey pine | Pinaceae |
| <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. 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 GOGA | | | | | |
|---------------------------------|------|------|------|------|------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 4 | 4 | 2 | 4 | 4 |
| W126 | 6 | 6.2 | 3.4 | 5 | 6.4 |
| N60 | 78 | 84 | 36 | 60 | 82 |
| N80 | 24 | 19 | 7 | 14 | 22 |
| N100 | 7 | 3 | 1 | 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, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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

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

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at GOGA | | | | | |
|--|------|------|-------|------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 1.18 | 1.78 | -0.04 | - | -0.11 |
| Month 2 | 2.33 | 2.83 | 1.36 | - | -1.35 |
| Month 3 | 2.35 | 0.21 | 0.74 | - | -1.07 |

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

| Palmer Z Index data for the 7-month W126 period at GOGA | | | | | |
|---|-------|-------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.37 | 1.78 | -0.30 | 0.26 | -0.16 |
| May | 1.18 | 2.83 | -0.94 | 4.49 | -0.88 |
| June | 2.33 | 0.21 | 0.68 | 0.75 | -0.82 |
| July | 2.35 | 1.15 | -0.04 | 1.36 | -0.57 |
| August | 0.22 | -0.57 | 1.36 | -0.28 | -0.11 |
| September | -0.91 | -0.13 | 0.74 | -1.04 | -1.35 |
| October | -2.66 | -0.28 | 0.31 | -0.78 | -1.07 |

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. The W126 accumulative value exceeds the threshold in some years, and the N100 count meets the threshold requirement in two years. In general, the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. One year had 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. Soil moisture levels during the 90-day Sum06 accumulation periods show only two months of drought stress over the five-year period, and the uptake of ozone is generally fostered. Similarly, soil moisture levels during the W126 periods were generally normal and favored the uptake of ozone. There were four months of drought over the five-year period, with only one month of moderate drought.

The risk of foliar ozone injury to plants at Golden Gate National Recreation Area is low.

Neither the Sum06 nor the W126 injury criteria are satisfied. Although soil moisture conditions favor the uptake of ozone and levels of drought stress are rare and mild, exposures to 80 and 100 ppb levels of ozone are low.

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: red alder, spreading dogbane, mugwort, evening primrose, ninebark and Scouler's willow.

JOHN MUIR NATIONAL HISTORIC SITE (JOMU)

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>Artemisia douglasiana</i> | Mugwort | Asteraceae |
| <i>Philadelphus coronarius</i> | Sweet mock-orange | Hydrangeaceae |
| <i>Robinia pseudoacacia</i> | Black locust | Fabaceae |
| <i>Symphoricarpos albus</i> | Common snowberry | Caprifoliaceae |
| <i>Vitis vinifera</i> | European wine grape | Vitaceae |

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

| Ozone air quality data for JOMU | | | | | |
|---------------------------------|------|------|------|------|------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 9 | 12 | 4 | 11 | 9 |
| W126 | 13.0 | 17.6 | 7.5 | 13.3 | 15.0 |
| N60 | 194 | 276 | 103 | 193 | 221 |
| N80 | 54 | 71 | 17 | 58 | 64 |
| N100 | 12 | 10 | 2 | 12 | 11 |

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at JOMU | | | | | |
|--|------|-------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 2.33 | 0.21 | -0.04 | 1.36 | -0.11 |
| Month 2 | 2.35 | 1.15 | 1.36 | -0.28 | -1.35 |
| Month 3 | 0.22 | -0.57 | 0.74 | -1.04 | -1.07 |

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

| Palmer Z Index data for the 7-month W126 period at JOMU | | | | | |
|---|-------|-------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.37 | 1.78 | -0.30 | 0.26 | -0.16 |
| May | 1.18 | 2.83 | -0.94 | 4.49 | -0.88 |
| June | 2.33 | 0.21 | 0.68 | 0.75 | -0.82 |
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| September | -0.91 | -0.13 | 0.74 | -1.04 | -1.35 |
| October | -2.66 | -0.28 | 0.31 | -0.78 | -1.07 |

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury. While the W126 accumulative value exceeds 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 satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. There were usually ten to twelve hours each year in which the concentration exceeded 100 ppb, but one year had only two hours above 100 ppb. The higher levels of exposure can 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 low and no relationship between ozone exposure and soil moisture levels was evident. Soil moisture levels during the five-year W126 assessment period show three months of mild stress and thus ozone uptake would be fostered. Soil moisture levels were generally normal and favored the uptake of ozone. Months with drought were rare and occurred in three of the five years;

there was only one month of moderate drought in the five-year assessment period.

The risk of foliar ozone injury to plants at John Muir National Historic Site is high. The Sum06 and W126 exposure indices are generally satisfied. Months of drought stress are rare and mild. Soil moisture conditions consistently favor the uptake of ozone and sustain the ability of the exposures to produce foliar injury.

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, mugwort and common snowberry.

MUIR WOODS NATIONAL MONUMENT (MUWO)

Plant Species Sensitive to Ozone

| <i>Latin Name</i> | <i>Common Name</i> | <i>Family</i> |
|------------------------------|--------------------|---------------|
| <i>Alnus rubra</i> | Red alder | Betulaceae |
| <i>Artemisia douglasiana</i> | Mugwort | Asteraceae |
| <i>Pinus radiata</i> | Monterey pine | Pinaceae |

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

Ozone Exposure Data

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

| Ozone air quality data for MUWO | | | | | |
|---------------------------------|------|------|------|------|------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 6 | 6 | 2 | 6 | 5 |
| W126 | 7.9 | 9.4 | 4.5 | 7.6 | 9.1 |
| N60 | 107 | 137 | 53 | 101 | 125 |
| N80 | 33 | 33 | 9 | 28 | 36 |
| N100 | 8 | 5 | 1 | 7 | 7 |

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.

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Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at MUWO | | | | | |
|--|------|------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 2.33 | 1.78 | -0.04 | 0.75 | -0.11 |
| Month 2 | 2.35 | 2.83 | 1.36 | 1.36 | -1.35 |
| Month 3 | 0.22 | 0.21 | 0.74 | -0.28 | -1.07 |

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

| Palmer Z Index data for the 7-month W126 period at MUWO | | | | | |
|---|-------|-------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.37 | 1.78 | -0.30 | 0.26 | -0.16 |
| May | 1.18 | 2.83 | -0.94 | 4.49 | -0.88 |
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| July | 2.35 | 1.15 | -0.04 | 1.36 | -0.57 |
| August | 0.22 | -0.57 | 1.36 | -0.28 | -0.11 |
| September | -0.91 | -0.13 | 0.74 | -1.04 | -1.35 |
| October | -2.66 | -0.28 | 0.31 | -0.78 | -1.07 |

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count marginally satisfies the threshold during three years. The Sum06 index is not satisfied and the W126 criteria are not consistently satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than eight 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. The Sum06 indices of exposure were low and no relationship between ozone exposure and soil moisture levels was evident. Soil moisture levels during the five-year assessment period show two months of mild drought stress and thus ozone uptake would be fostered. Soil moisture levels during the seasonal W126 periods were generally normal and favored the uptake of ozone. Months with drought were rare and occurred in three of the five years; there was only one month of moderate

drought in the five-year assessment period.

The risk of foliar ozone injury to plants at Muir Woods National Monument is moderate. Although the Sum06 threshold is not satisfied, the W126 criteria are often fulfilled. Months of drought stress are rare and mild. Soil moisture conditions consistently favor the uptake of ozone and sustain the ability of the exposures to produce foliar injury.

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: red alder and mugwort.

PINNACLES NATIONAL MONUMENT (PINN)

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>Artemisia douglasiana</i> | Mugwort | Asteraceae |
| <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 PINN | | | | | |
|---------------------------------|------|------|------|------|------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 30 | 41 | 21 | 35 | 29 |
| W126 | 37.9 | 50.9 | 28.9 | 35.5 | 38.2 |
| N60 | 693 | 889 | 524 | 609 | 733 |
| N80 | 113 | 197 | 39 | 93 | 60 |
| N100 | 5 | 22 | 2 | 11 | 3 |

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 PINN | | | | | |
|--|-------|-------|-------|------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 2.32 | 0.70 | -1.63 | 3.23 | 0.76 |
| Month 2 | 0.83 | -0.06 | 0.52 | 1.87 | 0.17 |
| Month 3 | -0.47 | -0.70 | -1.27 | 0.18 | -1.57 |

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

| Palmer Z Index data for the 7-month W126 period at PINN | | | | | |
|---|-------|-------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.59 | -0.22 | -2.08 | 1.43 | 0.90 |
| May | 2.48 | 3.59 | -2.50 | 7.25 | 0.07 |
| June | 3.59 | 1.06 | -1.72 | 2.72 | 1.30 |
| July | 2.32 | 0.70 | -1.63 | 3.23 | 1.09 |
| August | 0.83 | -0.06 | 0.52 | 1.87 | 0.76 |
| September | -0.47 | -0.70 | -1.27 | 0.18 | 0.17 |
| October | -2.08 | 1.09 | -0.82 | -0.42 | -1.57 |

Risk Analysis

- There are a few ozone-sensitive species at the site, all of which are bioindicators for ozone.
- 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. Thus the Sum06 threshold was satisfied each year and the W126 criteria in two of the five years.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and that concentrations exceeded 100 ppb every year. The higher levels of exposure can 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 index, there were two months of drought in 1997, the year with the lowest level of exposure, and one month of drought among the remaining four years. In the year with the lowest W126 exposure index, 1997, there were five months of mild and moderate drought, and only two months of mild and moderate drought occurred among the remaining four years.

The risk of foliar ozone injury to plants at Pinnacles National Monument is high. The threshold for injury is consistently satisfied by the Sum06 index and occasionally by the W126 index. Exposures frequently exceed 80 ppb and in some years there are a significant number of hours of exposure greater than 100 ppb. There is no association between ozone exposure and soil moisture, and during entire years soil moisture appears to either favor or constrain the uptake of ozone. Consequently, the likelihood for the production of foliar injury is greatest in years such as 1996 and 1998 when exposure levels and soil moisture conditions are both favorable.

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, mugwort and blue elderberry.

POINT REYES NATIONAL SEASHORE (PORE)

Plant Species Sensitive to Ozone

| <i>Latin Name</i> | <i>Common Name</i> | <i>Family</i> |
|------------------------------|--------------------|---------------|
| <i>Alnus rubra</i> | Red alder | Betulaceae |
| <i>Artemisia douglasiana</i> | Mugwort | Asteraceae |
| <i>Pinus radiata</i> | Monterey pine | Pinaceae |

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 PORE | | | | | |
|---------------------------------|------|------|------|------|------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 3 | 3 | 2 | 3 | 4 |
| W126 | 4.7 | 6.1 | 3.6 | 5.3 | 7.2 |
| N60 | 66 | 88 | 46 | 72 | 98 |
| N80 | 13 | 13 | 8 | 16 | 24 |
| N100 | 2 | 1 | 1 | 4 | 3 |

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at PORE | | | | | |
|--|------|------|------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 2.33 | 1.78 | 1.36 | 0.75 | -0.11 |
| Month 2 | 2.35 | 2.83 | 0.74 | 1.36 | -1.35 |
| Month 3 | 0.22 | 0.21 | 0.31 | -0.28 | -1.07 |

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

| Palmer Z Index data for the 7-month W126 period at PORE | | | | | |
|---|-------|-------|-------|-------|-------|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.37 | 1.78 | -0.30 | 0.26 | -0.16 |
| May | 1.18 | 2.83 | -0.94 | 4.49 | -0.88 |
| June | 2.33 | 0.21 | 0.68 | 0.75 | -0.82 |
| July | 2.35 | 1.15 | -0.04 | 1.36 | -0.57 |
| August | 0.22 | -0.57 | 1.36 | -0.28 | -0.11 |
| September | -0.91 | -0.13 | 0.74 | -1.04 | -1.35 |
| October | -2.66 | -0.28 | 0.31 | -0.78 | -1.07 |

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. Since the W126 accumulative value is generally below the threshold and the N100 count is below the required number, the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 4 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. The Sum06 indices of exposure were low and no relationship between ozone exposure and soil moisture levels was evident. Soil moisture levels during the five-year assessment period show two months of mild drought stress and thus ozone uptake would be fostered. Soil moisture levels during the seasonal W126 periods were generally normal and favored the uptake of ozone. Months with drought were rare and occurred in three of the five years; there was only one month of moderate

drought in the five-year assessment period.

The risk of foliar ozone injury to plants at Point Reyes National Seashore is low. The Sum06 and W126 exposure indices are not satisfied. Soil moisture conditions generally favor the uptake of ozone and levels of drought stress are rare and mild. If the ambient concentration of ozone increases over time, or the level of exposure increases in a year in which soil moisture conditions favor uptake, the probability of foliar injury to vegetation could increase.

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: red alder and mugwort.