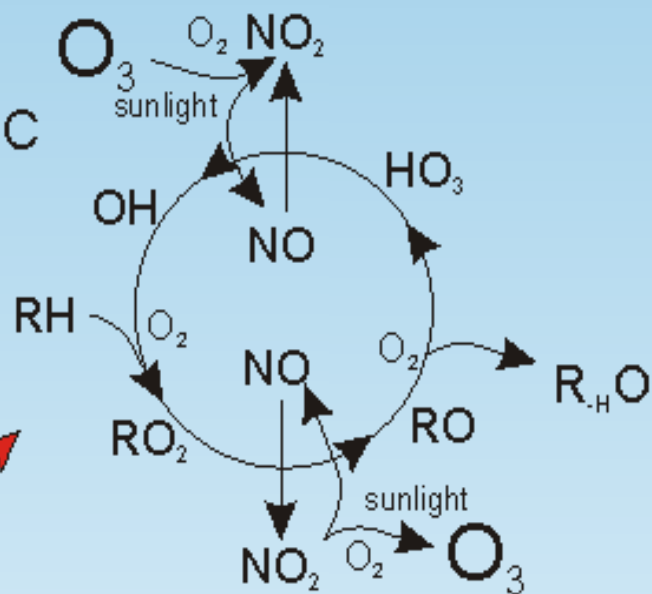


ASSESSING THE RISKS OF
FOLIAR OZONE INJURY ON
VEGETATION AT SITES
WITHIN THE NATIONAL
PARK SYSTEM

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ATMOSPHERIC CHEMISTRY



METEOROLOGY

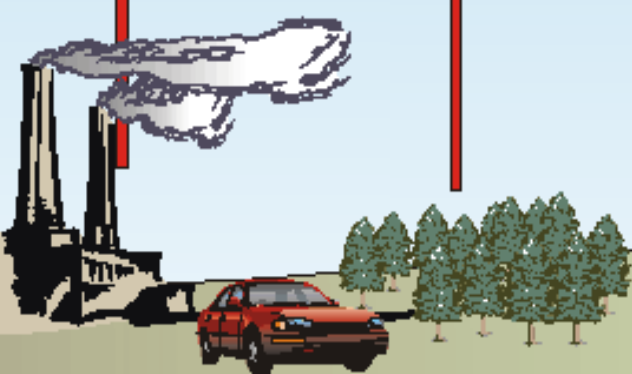


TRANSPORT



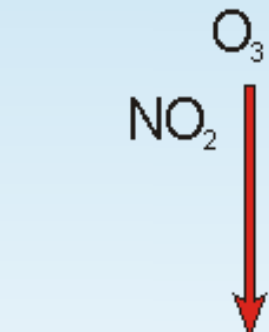
EMISSIONS

VOC
NO_x
VOC



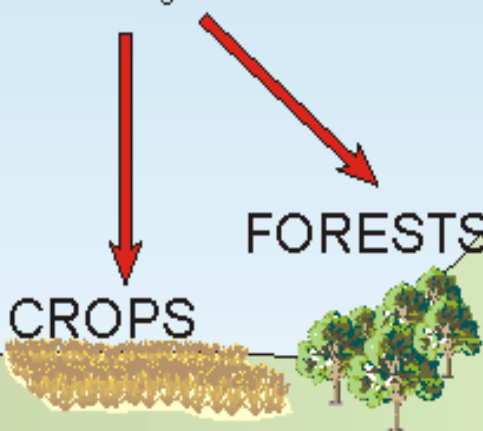
DEPOSITION

O₃
NO₂
HNO₃



EFFECTS

O₃



FORESTS

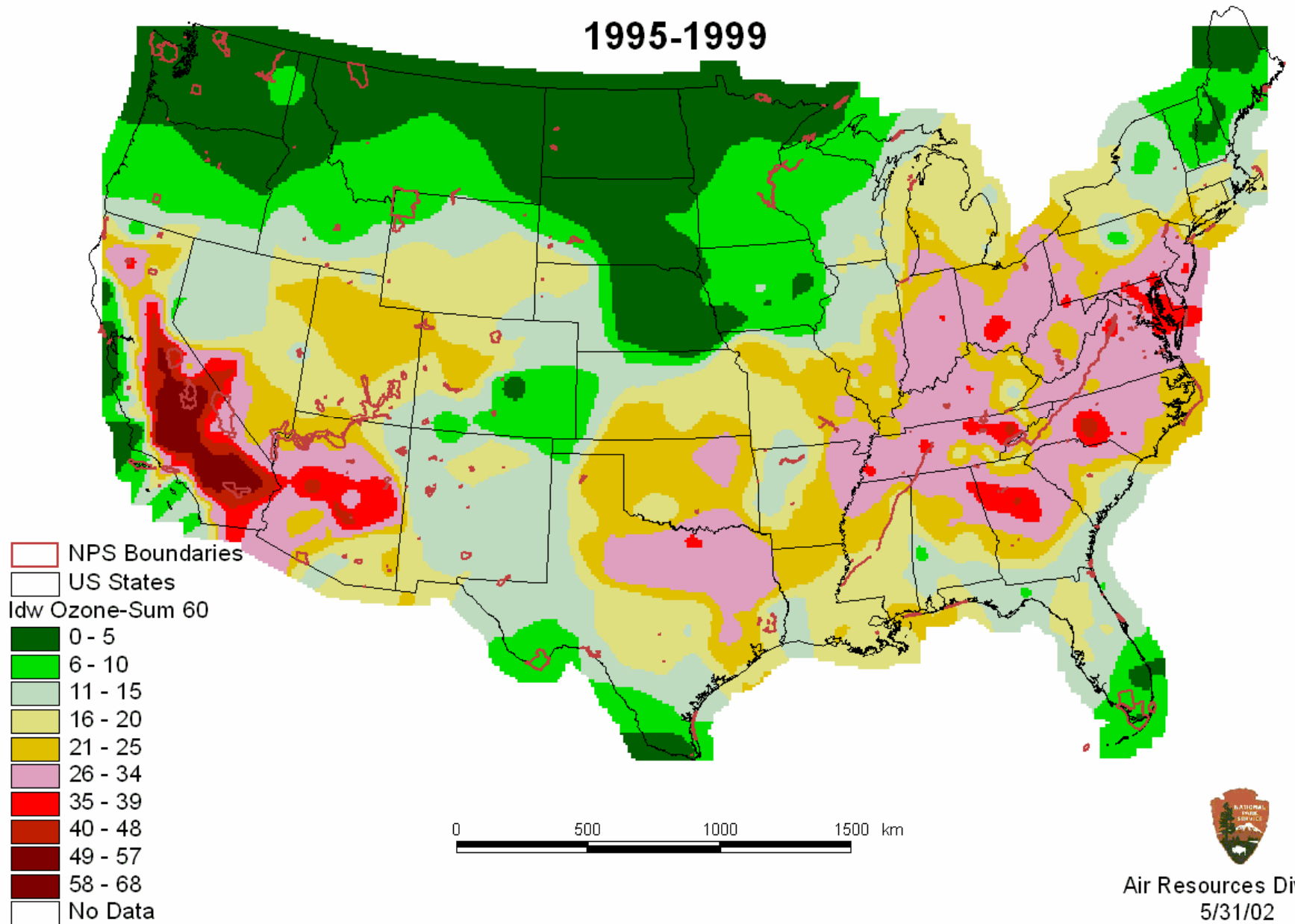
CROPS





OZONE - SUM 60

1995-1999





Ozone Risk Assessment

- Assess risk of foliar ozone injury to plants at 270 NPS sites in 32 Vital Signs Networks
- Provide guidance to resource managers
- Sensitive species, exposure, environment
- Triage the level of risk
 - high
 - medium
 - low

Triad Concept

- The response of a plant to ozone is the result of the interaction of the plant, the level of exposure, and the exposure environment
- Any of the three factors can accentuate or prevent a response
- The response is greatest when all three factors are optimized

Triad Specifics

- The plant must be genetically predisposed to be sensitive to ozone
- Ozone exposure must exceed a threshold level associated with a given effect
- Environmental conditions must foster the uptake of ozone

Site-specific Risk Assessment

- Plants - what ozone-sensitive species are found at the site
- Ozone - what are the levels of exposure at the site; use multiple indices of exposure
- Soil moisture levels - what are the levels of soil moisture and what effects might they have on the uptake of ozone

Sensitive Plant Species

- Lists of species sensitive to ozone are developed from laboratory and field research
- Floral lists for the park sites are compared to the lists of ozone-sensitive species
- Species with the highest potential to be affected by ozone are identified for each park

Ozone Bioindicator

- A species that is particularly sensitive to ozone, and provides an indication that the pollutant is present at injurious levels
- Integrates exposure and environmental variables while optimizing plant sensitivity
- Serves as an early-warning system for the plant community

Ozone Injury Symptoms

- Stipple - accumulations of pigment; often small dots; visible on upper leaf surface
- Chlorosis - bleaching of pigment; yellowing
- Fleck - cell death in palisade layer; visible only on upper surface
- Bi-facial necrosis - cell death in palisade and spongy mesophyll; visible on both surfaces











Ozone Data Sources

- On-site monitoring data - compiled to produce site-specific exposure indices
- Krieged data - no on-site monitoring; indices are statistically estimated using monitoring data from other sites

Ozone Exposures

- Exposure variables
 - concentration
 - duration
 - interval
 - seasonal variation
 - spatial variability
 - cumulative exposure
- Indices seek to synthesize these properties

Ozone Exposure Indices

- Sum06 - running 90-day maximum sum of 0800-1959 ozone concentrations ≥ 60 ppb
- W126 - weighted sum of 24-hour ozone concentrations from April to October; used with count of hours ≥ 100 ppb
- N-values - counts of hours with ozone concentrations $\geq 60, 80,$ and 100 ppb

Ozone Thresholds

- Sum06
 - natural ecosystems 8-12 ppm-hr
 - tree seedlings 10-16 ppm-hr
- W126
 - highly sensitive species 5.9 ppm-hr, N100 = 6
 - moderately sensitive species 23.8 ppm-hr;
N100 = 51

Environment

- Abiotic variables affecting gas exchange and the response of plants to ozone
 - soil moisture
 - temperature
 - relative humidity
 - illumination
 - nutrition

Soil Moisture Conditions

- Represented by the Palmer Z index
- Measures the short-term departure of soil moisture from the average for that period at that site
- Calculated monthly by USDA for each state
- Up to ten regions per state
- Not site specific

O3/Soil Moisture Assessments

- Sum06 index - what were the soil moisture conditions during the 90-day accumulation period each year
- W126 index - what were the soil moisture conditions from April to October each year
- Are there any apparent relationships between the levels of ozone exposure and the levels of drought stress over the 5 years

Drought Effect On O3 Uptake

Palmer Z Index	Drought Level	Uptake Impact
0.0 - 0.9	Normal	Negligible
1.0 - 1.9	Mild	Minor
2.0 - 2.9	Moderate	Significant
3.0 - 3.9	Severe	Major

O₃/Soil Moisture Relationships

- At many sites, the highest levels of ozone exposure are associated with periods of low soil moisture
 - the probability of injury may be highest during periods of more moderate ozone exposure
- At some sites, ozone exposure and soil moisture are unrelated and the risk of injury is a function of their random interaction

Site Risk Assessment Report

- Plant species sensitive to ozone
- Representative ozone injury thresholds
- Ozone exposure data
- Soil moisture data
- Risk assessment
 - Analysis of each assessment variable
 - Level of risk and rationale for the rating
 - Bioindicator species for field monitoring

CAPE COD NATIONAL SEASHORE (CACO)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CACO					
	1995	1996	1997	1998	1999
Sum06	20	17	25	17	23
W126	34.8	33.6	40.4	34.8	34.5
N60	518	510	638	586	480
N80	142	105	193	77	168
N100	52	30	47	6	42

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CACO					
	1995	1996	1997	1998	1999
Month 1	-0.41	-0.43	-1.75	6.79	0.13
Month 2	-0.70	-1.56	-1.04	-0.18	-3.30
Month 3	-2.61	2.18	0.19	0.48	-0.73

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

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

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.
- Soil moisture levels during the 90-day Sum06 accumulation periods with the highest values show levels of mild to severe drought. These conditions would reduce the uptake of ozone and decrease the effectiveness of the exposures during these 90-day periods of peak ozone exposure. 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. However, due to the high levels of exposure in both the Sum06 and W126 indices, it is possible that the threshold for injury may be surpassed even with the reduced uptake. In addition, during the years when ozone exposures are lower, they still exceed the Sum06 and W126 thresholds for injury and occur under soil moisture conditions that foster the uptake of ozone.

The risk of foliar ozone injury to plants at Cape Cod National Seashore is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions may reduce the likelihood of injury developing in any particular year. Due to the high level of exposure, it is possible that even with the reduced uptake the physiological threshold for injury may be surpassed. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, quaking aspen, black cherry, and northern fox grape.

Ozone Injury Field Assessment Handbook

- Serve as standard reference document for NPS assessments of foliar ozone injury
 - the response triad and its significance
 - descriptions of ozone injury; text and photographs
 - bioindicator species
 - field assessment objectives
 - assessment program protocols
 - training personnel
 - quality assurance