Indicator: Ozone Injury to Forest Plants (115)

Air pollution can have a significant cumulative impact on forested ecosystems by affecting regeneration, productivity, and species composition (EPA, 1996). In the U.S., tropospheric ozone is one of the pollutants of primary concern. Ozone injury to forest plants can be diagnosed by examination of plant leaves. Foliar injury is usually the first visible sign of injury to plants from ozone exposure and indicates impaired physiological processes in the leaves (Grulke, 2003).

The U.S. Department of Agriculture Forest Service tracks ozone injury to forest plants as part of the Forest Health Monitoring (FHM) Program (USDA 2004). The FHM Program, which is now known as Phase 3 of the Forest Inventory Analysis, examines forest plant health characteristics at ground monitoring sites across the country. Sites are selected using a systematic sampling grid, which is based on a global sampling design (White et al., 1992; Smith et al., 2003). At each site, FHM looks for damage on the foliage of multiple ozone-sensitive forest plant species. Ozone injury is cumulative over the course of the growing season, and so these examinations are conducted in July and August, when ozone injury is typically highest.

Monitoring of ozone injury to plants in the FHM program has expanded in scope over the last 10 years. In 1994, when the program began, monitoring sites were located in ten states. By 2002, the program included more than 1,000 monitoring sites in 41 states. The data presented in this indicator are based on observations collected between 1994 and 2000. The ozone damage to forest plants is classified using a four-category biosite index: no injury, low injury, moderate injury, and severe injury.

Biosite value	Bioindicator response	Assumption of risk	Possible impact	Relative air quality[2]
0 - < 5	Little or no foliar injury	None	Visible injury to highly sensitive species, e.g. black cherry	Good
5 - < 15	Light to moderate foliar injury	Low	Visible injury to moderately sensitive species, e.g. tulip poplar	Moderate
15 - < 25	Moderate to severe foliar injury	Moderate	Visible and invisible injury. Tree-level response.[3]	Unhealthy for sensitive species
≥ 25	Severe foliar injury	High	Visible and invisible injury. Ecosystem-level response.[3]	Unhealthy

[1]The categorizations of the biosite index are subjective and based solely on expert opinion
[2]Relative ozone air quality from a plant's perspective.
[3]According to the EPA's Proposed Guidelines for Ecological Risk Assessment (Federal Register 61 (175):47552-47631).

What the Data Show

"Severe injury" was not observed at any of the monitoring sites in the Rocky Mountain region, but was observed at 9% of the sites in the South, 8% of the sites in the North, and 1% of the sites in the Pacific Coast (Figure 115-1). On the other hand, monitoring sites classified as having no foliar injury were most

prevalent in the Rocky Mountain region (100% of monitoring sites) and in the Pacific Coast region (97% of sites), as compared to the North region (76% of sites) and South region (77% of sites).

Indicator Limitations

- Field and laboratory studies were reviewed to identify the forest plant species in each region that are highly sensitive to ozone air pollution. Other forest plant species, or even genetic variants of the same species, may not be harmed at ozone levels that cause effects on the selected ozone-sensitive species. The forest plants evaluated differ from one region to the next; these differences might explain part of the spatial variations shown in this indicator.
- Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury (EPA 1996).
- Though the FHM has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury.

Data Sources

The data sources for this indicator were the Forest Health Monitoring (FHM) Program database (http://www.fiaozone.net/tabular.html), National Report on Sustainable Forests - 2003, Final Draft, U.S. Department of Agriculture, Forest Service, 2002, and Coulston et al., 2004. A Preliminary Assessment of the Montreal Process Indicators of Air Pollution for the United States, *Environmental Monitoring and Assessment*, 95: 57-74.

References

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Skelly, J.M., Davis, D.D., Merrill, W., Cameron, E.A., Brown, D.B., Dochinger, L.S. 1987. Diagnosing injury to eastern forest trees - a manual for identifying damage caused by air pollution, pathogens, insects, and abiotic stresses. NAPAP Forest Response Program, National Vegetation Survey, available from: Publications Distribution Center, Pennsylvania State University, 122 pp.

Smith, G., Coulston, J., Jepsen, E. Prichard, T. 2003. A national ozone biomonitoring program - results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). Environ. Monit. Assess. 87:271-291.

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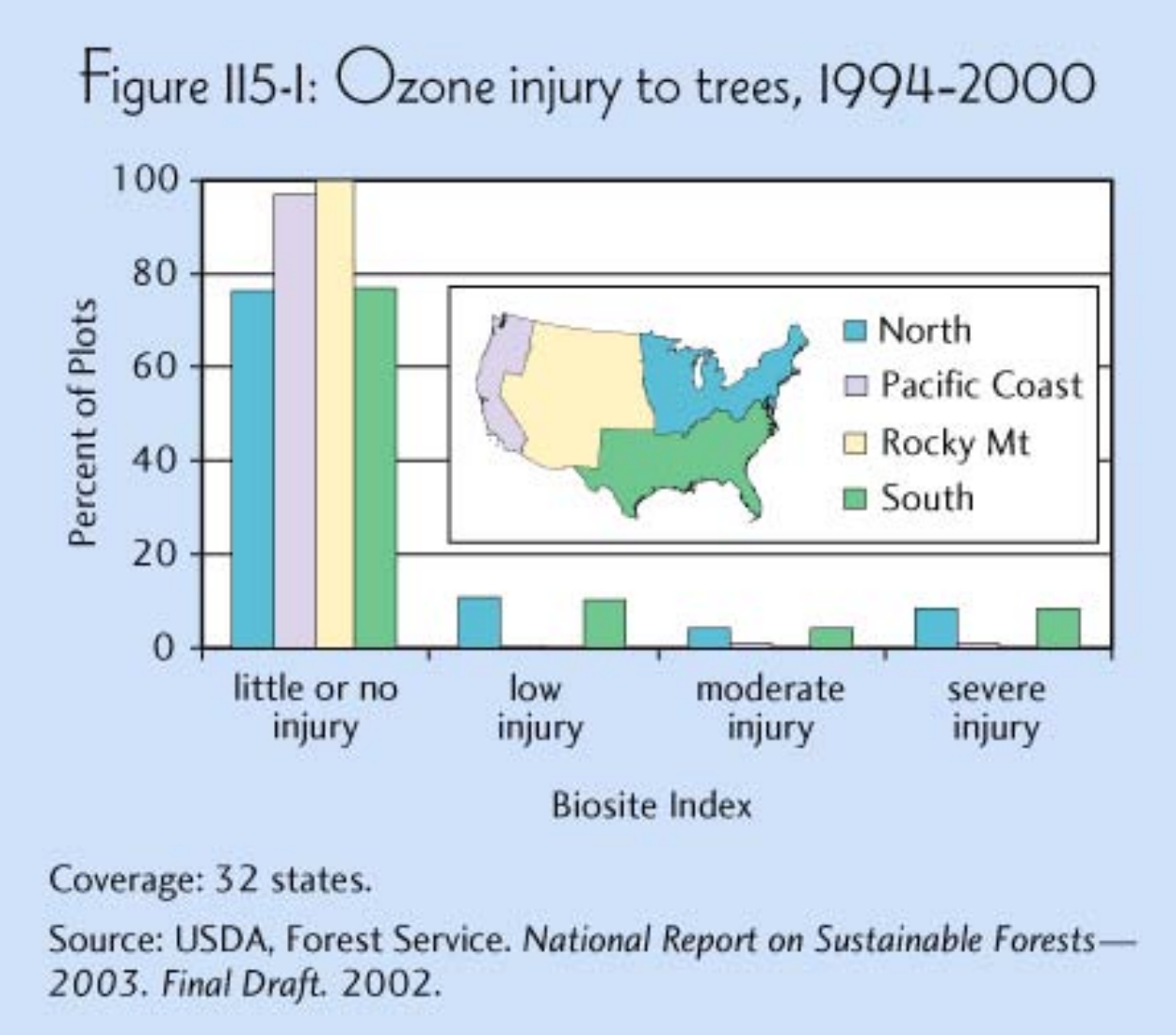
Graphics



R.O.E. Indicator QA/QC

Data Set Name: OZONE INJURY TO FOREST PLANTS
Indicator Number: 115 (89101)
Data Set Source: http://www.fiaozone.net/datadownload.htm
Data Collection Date: 1992 - present
Data Collection Frequency: annually, 1054 biomonitoring plots in 2002
Data Set Description: Ozone injury to plants can be diagnosed by examination of plant leaves (Skelly et al., 1987; Bennett et al., 1994). Foliar injury is the first visible sign of injury to plants from ozone exposure and indicates impairment of physiological processes in the leaves (Grulke, 2003).
Primary ROE Question: What are the trends in outdoor air quality and effects on human health and ecological systems?

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

Field methods for this indicator can be found at: http://www.fiaozone.net/assets/manuals/2003Final%20Distribution%20Copy%20NORTHEAST%20ozone_east_2_0.doc Each predetermined ozone-sensitive plant species with ozone injury is evaluated for the percent of the plant that is injured and the average severity of injury. For each plant located, the percentage of injured area and the severity of injury are both rated on a scale of 0 to 5. Both amount and severity estimates are confined to the exposed portion of the plant. If a plant does not have injury, it is still tallied with zeros for these measurements. The bioindicator species selected for each region are those that have been determined through field and laboratory studies to be highly sensitive to ozone air pollution. However, genetic differences within and between species can introduce uncertainty. For example, within a species, differences in genetics between individuals result in differential sensitivities to ozone. This means that often an individual of a species with severe air pollution injury may be found growing immediately adjacent to another individual of the same species with few or no symptoms.

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

A systematic sampling grid, based on a global sampling design, is used as the basis for determining biomonitoring site locations for ozone plant injury assessment (White et al., 1992). A detailed discussion of the sampling design can be found in Smith et al. (2003).

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

A plot-level foliar injury indicator referred to as a Biosite Index (BI) was formulated from the amount of injury and severity ratings recorded for each plant and the numbers of plants and species evaluated at each site. A complete discussion of the derivation and robustness of the BI can be found in Smith et al. (2003). Ozone uptake by plants is greatly affected by soil moisture. Seventy percent of the variability in BI was explained by ozone concentration (expressed as the SUM06 metric) and the Palmer Drought Severity Index (PDSI) (Smith et al., 2003).

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

The number of ozone biomonitoring sites has increased each year since 1994, as more states implement Forest Health Monitoring, now known as Phase 3 of Forest Inventory and Analysis (FIA). In 2000, there were 918 biomonitoring sites in 32 states. Ozone biomonitoring data for 2002 were downloaded and found to have data from 1054 sites in 41 states. Ozone injury is cumulative over the course of the growing season. Thus, more ozone injury can be observed on plants later in the season, prior to the onset of autumnal senescence. Quantifying ozone injury on the FIA ozone plots is limited to an evaluation window from late-July to mid-August. The evaluation window for crews in the Northern Region (NO) begins 28 July and extends through 22 August. In the Southern Region (SO), the window is open from 21 July through 22 August. The ozone injury evaluations are generally completed over a 5 to 20 day period during the sampling window depending on the size of the State and the number of crews dedicated to the ozone survey. During the evaluation window, all ozone sites on the ozone biomonitoring grid are evaluated for ozone injury. The same sites are evaluated every year.

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

The ozone biomonitoring sites are selected in openings near the FIA plot. Ozone biomonitoring sites are selected purposively to target areas where ozone-sensitive plant species occur. The opening should be greater than three acres (1.2 hectares) with less than 50% crown closure. More than three ozone-sensitive plant species should be found, with at least 30 plants of each of three species; 10-30 plants of additional species. Soil conditions should have low drought potential and good fertility. No recent (1-3 years) disturbance should be evident and no obvious signs of soil compaction.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

In some States with a particular interest in air quality, foliar injury data are also collected from ozone sites on an intensified ozone grid. These supplementary ozone sites are standardized for certain site characteristics that influence ozone uptake by sensitive plants (Heck 1968; Krupa and Manning 1988), and are often co-located with physical air quality monitors. They are intended to improve the regional responsiveness of the ozone indicator. Biosite categories represent a relative measure of plant-level response to ambient ozone exposure. Injury severity is an estimate of the mean severity of symptoms on injured foliage (0 = no injury; 1=1-6%; 2 = 7- 25%; 3 = 26-50%; 4 = 51-75%; 5 >75%). This rating system is applied across all regions. In response to whether the expected baseline for ozone injury is zero, in the absence of any anthropogenic precursors for ozone formation, there is a natural background level for ozone. Most estimates of what that background concentration is fall below the levels that cause visible injury on sensitive plant species that were fumigated in controlled exposure studies. However, that is not to say that there are no physiological effects of background ozone on plants.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

Complete sampling and analytical procedures for this indicator can be found in the USDA Forest Service's FIA field methods guide.
http://www.fiaozone.net/assets/manuals/2003Final%20Distribution%20Copy%20NORTHEAST%20ozone_east_2_0.doc

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

Ozone biomonitoring data sets dating back to 1997 through 2002 are available for download as ASCII text or SAS data set files at the following URL: http://www.fiaozone.net/tabular.html. The contact person for this indicator is the National Ozone Bioindicator Leader: Dr. Gretchen Smith University of Massachusetts Department of Forestry and Wildlife Management Holdsworth Natural Resource Center Amherst, MA 01003-4210 Phone (413) 545-1680 Fax (413) 545-4358 advisor@fiaozone.net

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

Descriptions of the survey design are clear, complete and sufficient to enable the survey to be reproduced, except for the fact that biomonitoring plot locations are confidential. A similar survey could be conducted but not at the same locations as the FIA ozone biomonitoring network.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

Voucher specimens (pressed leaves with symptoms) are collected for each species for proper symptom identification. For each voucher, injury type and location codes are recorded to fully describe the injury observed in the field. Additional quality control measures include field audits and remeasurement of 10% of the biomonitoring sites. Complete quality assurance and quality control measures can be found in the FIA field methods guide at: http://www.fiaozone.net/assets/manuals/2003Final%20Distribution%20Copy%20NORTHEAST%20ozone_east_2_0.doc

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

The biosite index was used along with nine other air pollution indicators in cluster analyses to characterize forest types with respect to air pollution exposure (Coulston et al., 2004). The indicators included the average and coefficient of variation (CV) of the biosite index, ozone exposure index, and nitrate, ammonia, and sulfate deposition levels. Cluster scores showed relative differences between forest types based on the air pollution indicators. Forest types in the eastern U.S. had higher relative air pollution exposure scores than western forest types. The oak-hickory forest type, which covers much of the North and South RPA regions, had the highest relative air pollution exposure score and had a relatively low CV score. Other eastern forest types of high exposure scores and relatively low CV scores were loblolly-shortleaf pine, elm-ash-cottonwood, and oak-pine. Of the western forest types chaparral had the highest exposure score. Additionally, western hardwoods, pinyon-juniper, fir-spruce, ponderosa pine, and lodgepole pine exhibited high exposures scores, but also had high CV scores. High CV scores would indicate that there may pockets of high and/or low exposure across the range of these forest types. The larch, redwood, and western white pine forest types had both low exposure and low CV scores. The larch and western white pine have a small geographic distribution, limited to mostly northeastern Washington, northern Idaho, and northwestern Montana. The redwood forest type is limited to mostly coastal areas of northern California.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

Quality assurance / quality control data are available upon request. Contact Brian Cordova at cordovab@unlv.nevada.edu. Complete quality assurance and quality control measures can be found in the FIA field methods guide at: http://www.fiaozone.net/assets/manuals/2003Final%20Distribution%20Copy%20NORTHEAST%20ozone_east_2_0.doc

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

The recognition of ozone injury symptoms in the field is not an exact science, and many other foliar injury symptoms can be mistaken for ozone injury. Voucher specimens are sent to a national expert for verification of injury.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

The exact coordinates of each ozone biomonitoring plot are confidential. Thus, matching up ozone biomonitoring data with other explanatory or independent variables that would aid in the interpretation of spatiotemporal trends in ozone injury is a challenge.