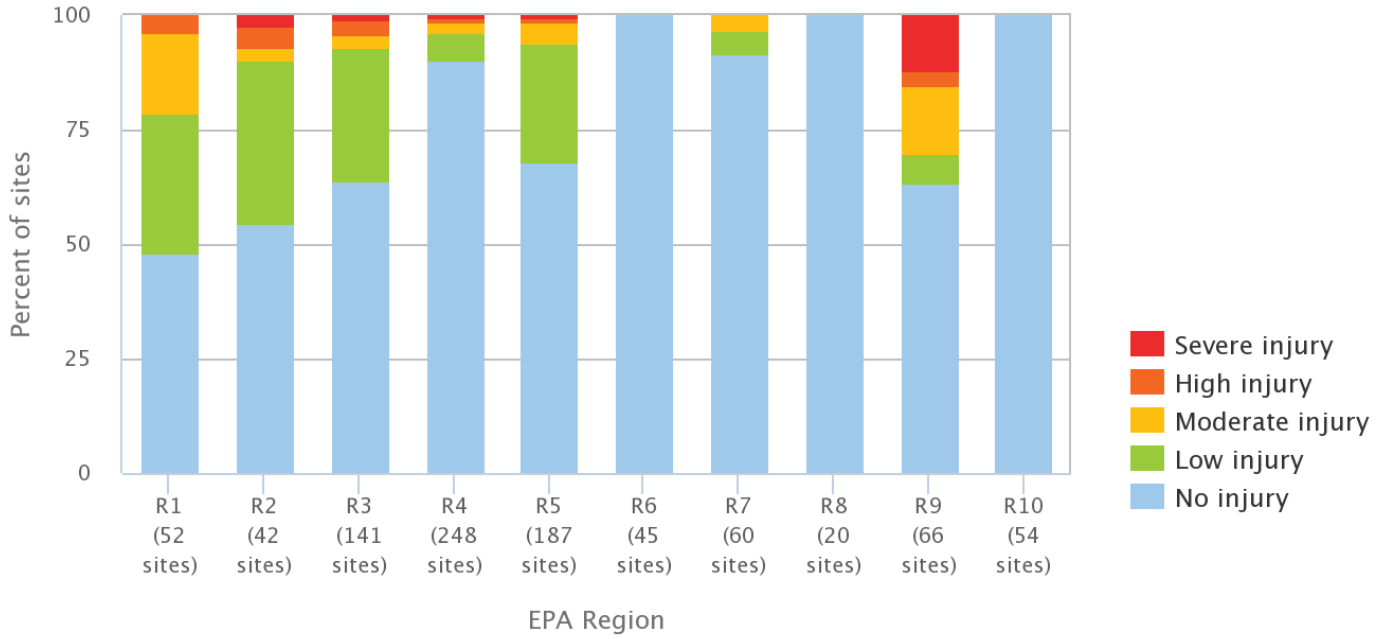
Ozone Injury to Forest Plants

Exhibits

Exhibit 1. Ozone injury to forest plants in the U.S. by EPA Region, 2006



Coverage: 915 monitoring sites, located in 37 states.

Trend analysis has not been conducted because these data represent a single snapshot in time. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: USDA Forest Service, 2009

Introduction

Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition (U.S. EPA, 2013). In the U.S., ozone in the lower atmosphere 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).

This indicator is based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program, which examines foliar injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country. For this indicator, forest land does not include woodlots and urban trees. Sites are selected using a systematic sampling grid, based on a global sampling design (Smith et al., 2008). At each site that has at least 30 individual plants of at least three ozone-sensitive species and enough open space to ensure that sensitive plants are not

protected from exposure by the forest canopy, FIA looks for symptoms attributed to ozone on the foliage of ozone-sensitive forest plant species. Because ozone injury is cumulative over the course of the growing season, examinations are conducted in July and August, when ozone injury is typically highest.

Ozone injury to foliage is classified using a subjective five-category biosite index based on expert opinion, but designed to be equivalent from site to site. Ranges of biosite values translate to no injury, low or moderate foliar injury (visible foliar injury to highly sensitive or moderately sensitive plants, respectively), and high or severe foliar injury, which would be expected to result in tree-level or ecosystem-level responses, respectively (Smith et al., 2008).

The USDA Forest Service began monitoring ozone injury to plants in 10 states in 1994; during the ensuing decade, the program gradually expanded to cover most of the country. This indicator presents averages of all observations collected in 2006, based on 915 monitoring sites in 37 states. The results have been grouped by EPA Region in Exhibit 1. Although some data are available for more recent years, the monitoring program is currently limited to a smaller number of states as a result of funding constraints. Thus, this indicator focuses on data from 2006.

What The Data Show

There is considerable regional variation in ozone injury to sensitive plants (Exhibit 1). The highest percentages of observed high and severe foliar injury, which are most likely to be associated with tree or ecosystem-level responses, are primarily found in the Pacific Southwest, Mid-Atlantic, and Northeast. In EPA Region 9, 15 percent of ozone-sensitive plants showed signs of high or severe foliar injury. In Regions 1, 2 and 3, the proportion of sites with high or severe injury ranged from 4 to 7 percent. The percentage of sites showing no injury was greater than 50 percent in all but EPA Region 1, and no ozone-related foliar injury was observed at any of the 119 biosites in EPA Regions 6, 8, and 10.

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.
- Because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among EPA Regions.
- Ozone injury to foliage is considerably reduced under conditions of low soil moisture (Smith et al., 2003).
- Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury. Conversely, the presence of ozone symptoms or injury does not necessarily mean that sensitive vegetation is suffering from damage such as reduced productivity (U.S. EPA, 2013).
- Though FIA has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury.
- Even though the biosite data have been collected over multiple years, most biosites were not monitored over the entire period. Thus, Exhibit 1 does not show trends over time. The USDA Forest Service has produced multi-year maps to provide an indication of patterns over time and space, but not all states have sufficient data to support a complete national map or to support year-to-year comparisons.

Data Sources

Data were provided by the USDA Forest Service's Ozone Biomonitoring Program, which maintains a database of plant injury statistics by state (USDA Forest Service, 2009) (http://www.nrs.fs.fed.us/fia/topics/ozone/data/). This indicator aggregates the state data by EPA Region.

References

Grulke, N.E. 2003. The physiological basis of ozone injury assessment attributes in Sierran conifers. In: Bytnerowicz, A., M.J. Arbaugh, and R. Alonso, eds. Ozone air pollution in the Sierra Nevada: Distribution and effects on forests. New York, NY: Elsevier Science, Ltd. pp. 55–81.

Smith, G.C., J.W. Coulston, and B.M. O'Connell. 2008. Ozone bioindicators and forest health: A guide to the evaluation, analysis, and interpretation of the ozone injury data in the Forest Inventory and Analysis program. Gen. Tech. Rep. NRS-34. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs34.pdf (PDF) (106 pp, 8.4MB).

Smith, G., J. Coulston, E. Jepsen, and T. Prichard. 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. www.nrs.fs.fed.us/fia/topics/ozone/pubs/pdfs/emas1210.pdf (PDF) (40 pp, 1.5MB).

USDA Forest Service (United States Department of Agriculture Forest Service). 2009. Ozone bioindicator data. Accessed 2009. http://nrs.fs.fed.us/fia/topics/ozone/data/.

U.S. EPA (United States Environmental Protection Agency). 2013. Integrated science assessment for ozone and related photochemical oxidants. EPA 600/R-10/076F. Research Triangle Park, NC. http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=247492#Download.

Technical Documentation

Identification

1. Indicator Title

   Ozone Injury to Forest Plants

2. ROE Question(s) This Indicator Helps to Answer

   What are the trends in outdoor air quality and their effects on human health and the environment?
   What are the trends in biomarkers of exposure to common environmental contaminants in plants and animals?

3. Indicator Abstract

   This indicator describes the extent and severity of ozone injury to forest plants by EPA Region in 2006. Ozone injury can be diagnosed by examining plant leaves, and it indicates impaired physiological processes. This indicator provides some understanding of the extent to which ground-level (tropospheric) ozone is impacting forested ecosystems in the United States.

4. Revision History

May 2008: Original indicator posted
March 2010: Updated metadata to new format
July 2013: Indicator updated

Data Sources

5. Data Sources

This indicator is based on data published by the U.S. Department of Agriculture (USDA) Forest Service's Ozone Biomonitoring Program. These data describe the extent and severity of ozone injury to forest plants in 2006.

6. Data Availability

Data were provided by the USDA Forest Service's Ozone Biomonitoring Program, which maintains a database of plant injury statistics by state (http://nrs.fs.fed.us/fia/topics/ozone/data). This indicator aggregates the state data by EPA Region. The contact person for this indicator is the National Ozone Bioindicator Leader at the University of Massachusetts Department of Forestry and Wildlife Management, Holdsworth Natural Resource Center. This contact person can be reached by phone at 413-545-1680 or by email at advisor@fiaozone.net.

Data were collected from 915 individual plots in 37 states; however, the exact locations of these plots are kept confidential to protect landowners. Although some data are available for more recent years, the monitoring program is currently limited to a smaller number of states as a result of funding constraints. Thus, this indicator focuses on data from 2006.

Methodology

7. Data Collection

This indicator is based on data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program. As part of its Phase 3 program, formerly known as Forest Health Monitoring, the FIA examines visible ozone-induced foliar injury in ozone-sensitive plant species at ground monitoring sites in forest land across the country. FIA observers evaluate an individual plant to identify the percent of the plant that is injured and the average severity of injury, using a standardized numerical scale. The percent and severity estimates are confined to the exposed portion of the plant. If a plant does not have injury, it is tallied with zeros for these measurements. The bioindicator species were selected for each Forest Service region based on field and laboratory studies that identified them as highly sensitive to ozone air pollution. These bioindicator species include several types of trees, woody shrubs, and forbs; for a full listing, see Smith et al. (2008). Although the assessment of ozone injury to forest plants is based on expert opinion, the evaluation is designed to be equivalent from one site to the next (see "Quality Assurance and Quality Control").

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. The number of ozone biomonitoring sites has increased each year since 1994 as more states have implemented Phase 3 of the FIA. This indicator is based on data from 2006, which come from 915 sites in 37 states.

Each monitoring site had to meet various selection criteria. More than three ozone-sensitive plant species should be found at each site, with at least 30 plants of each of the three sensitive species; 10-30 plants of additional

species may also be present. To ensure that signs of "injury" are not enhanced by other environmental factors, soil conditions should have low drought potential and good fertility, no recent (1–3 years) disturbance should be evident, and there should be no obvious signs of soil compaction. The ozone biomonitoring sites are selected in openings near the FIA plot. Sites must have enough open space to ensure that species are not protected from ozone exposure by the forest canopy. The opening should be greater than three acres (1.2 hectares) with less than 50 percent crown closure.

Additionally, to ensure consistency among the data, examinations of forest plants are conducted only from late July to mid-August, when ozone levels (and therefore ozone injury) are expected to be the highest. 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. The evaluation window for crews in the Forest Service Northern Region (NO) begins July 28 and extends through August 22. In the Forest Service Southern Region (SO) the window is open from July 21 through August 22. 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.

For states that have particular interests 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, and are often co-located with physical air quality monitors. They are intended to improve the regional responsiveness of the ozone indicator.

For more details on field methods and sampling design, refer to Smith et al. (2003, 2008) and White et al. (1992). Complete sampling procedures for this indicator can be found in the USDA Forest Service's FIA field methods guide at http://fia.fs.fed.us/library/field-guides-methods-proc and in other publications available from http://nrs.fs.fed.us/fia/topics/ozone/methods/.

8. Indicator Derivation

A plot-level foliar injury indicator, referred to as a Biosite Index, was formulated from the injury and severity ratings recorded for each plant and the number of plants evaluated at each site. A complete discussion of the derivation and robustness of the Biosite Index can be found in Smith et al. (2003, 2008). Field personnel submit their observations (numerical Biosite Index scores) to data reviewers with the USDA Forest Service. Once approved, the data are entered into a centralized database. No models are used to transform the validated Biosite Index values that are entered into the database. Complete analytical procedures for this indicator can be found in the USDA Forest Service's FIA field methods guide at http://fia.fs.fed.us/library/field-guides-methods-proc.

To create this indicator for EPA's Report on the Environment, Biosite Index values were grouped into five categories (see "Reference Points").

No statistical methods were used to generalize or portray data beyond the time and spatial locations where measurements were made. EPA downloaded the validated data from the USDA Forest Service (see http://nrs.fs.fed.us/fia/topics/ozone/data) and aggregated the results by EPA Region for display in Exhibit 1.

9. Quality Assurance and Quality Control

A complete description of the quality assurance and quality control measures can be found in Smith et al. (2008) and the FIA field methods guide at http://fia.fs.fed.us/library/field-guides-methods-proc. A key practice is collecting voucher specimens (pressed leaves with symptoms) from each species to enable proper symptom

identification. Injury type and location codes are recorded on each voucher to fully describe the injury observed in the field, and the vouchers are then sent to a national expert for injury verification.

Numerous quality assurance procedures are in place to ensure that the observational data are of a known and high quality. All field personnel who visit the biomonitoring sites are trained and certified just prior to each sampling window, and the training addresses bioindicator species identification, site selection procedures, ozone injury evaluations, and voucher handling. Additionally, experienced and certified quality assurance crews conduct audits and re-measurement activities, including blind checks on a minimum of 10 biosites in each FIA region. Some of these audits include live observation of field crews in action, to evaluate their performance.

Analysis

10. Reference Points

The numerical Biosite Index score for each site is assigned to one of five categories:

- No injury (biosite score of 0)
- Low injury (biosite score of $>$ 0 to $<$ 5)
- Moderate injury (biosite score of 5 to $<$ 15)
- High injury (biosite score of 15 to $<$ 25)
- Severe injury (biosite score of 25 or higher)

There are no reference points for what represents an "acceptable" amount of ozone injury to forest plants (e.g., what level of injury a plant can sustain without suffering serious physiological impairment).

11. Comparability Over Time and Space

The Biosite Index rating system and the five categories used for this indicator have been applied consistently across all EPA Regions. However, because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among EPA Regions. Although different sites within each state are measured in different years, and some states were not sampled at all in certain years, this indicator addresses these potential concerns by providing a single-year snapshot.

12. Sources of Uncertainty

A detailed quantitative assessment of all sources of uncertainty is not available. However, some quality assurance statistics do provide insights on the reliability of selected measurements, including evaluation of the re-measurement data for at least 10 biosites in each FIA region and the collection of voucher specimens for verification by a national expert. These quality assurance data can be accessed via email request to cordovab@unlv.nevada.edu. Field observations of ozone injury could introduce several potential sources of uncertainty, such as mistaking other foliar injury for ozone injury. This source of error is minimized, however, because ozone typically produces a unique type of foliar injury that observers are trained to recognize.

13. Sources of Variability

Ozone uptake by plants is greatly affected by soil moisture. Of the variability in the Biosite Index, 70 percent has been explained by ozone concentration (expressed as the SUM06 metric) and the Palmer Drought Severity Index (PDSI) (Smith et al., 2003).

Genetic differences within and between species is also a source of variability. For example, within a species, differences in genetics between individuals result in different 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.

14. Statistical/Trend Analysis

No trend analysis has been conducted on this indicator. The USDA Forest Service has produced multi-year maps (not included in EPA's indicator) to provide an indication of patterns over time and space, but not all states have sufficient data to support a complete national comparison.

Limitations

15. Data Limitations

Limitations to this indicator include the following:

1. 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.
2. Because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among EPA Regions.
3. Ozone injury to foliage is considerably reduced under conditions of low soil moisture.
4. Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury. Conversely, the presence of ozone symptoms or injury does not necessarily mean that sensitive vegetation is suffering from damage such as reduced productivity.
5. Though FIA has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury.
6. Even though the biosite data have been collected over multiple years, most biosites have not been monitored over the entire period. Thus, Exhibit 1 does not show trends over time. The USDA Forest Service has produced multi-year maps to provide an indication of patterns over time and space, but not all states have sufficient data to support a complete national map or to support year-to-year comparisons.

References

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