



# Welfare Risk and Exposure Assessment for Ozone

Second External Review Draft

Executive Summary

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## SUMMARY CONCLUSIONS

The goals for this welfare risk and exposure assessment (REA) include (i) characterizing ambient ozone (O<sub>3</sub>) exposure and its relationship to ecological effects, and (ii) estimating the resulting impacts to several ecosystem services. We quantitatively characterize the impact of ambient O<sub>3</sub> exposures on two important ecological effects – biomass loss and visible foliar injury – and quantitatively estimate impacts to the following ecosystem services: regulating services including carbon sequestration and pollution removal; provisioning services including timber production and agricultural harvesting; and cultural services such as recreation. We conduct both national-scale and case study analyses for these two ecological effects, and we also qualitatively assess impacts on additional ecosystem services, including hydrologic cycle, pollination regulation, and fire regulation (regulating services); commercial non-timber forest products and insect damage (provisioning services); and aesthetic and non-use values (cultural services). For each of these analyses, we use a biologically-relevant cumulative, seasonal form for O<sub>3</sub> exposure, the W126 metric, which is measured as ppm-hrs.

For biomass loss, the Clean Air Scientific Advisory Committee (CASAC) recommended that EPA should consider options for W126 standard levels based on factors including a predicted one to two percent biomass loss for trees and a predicted five percent loss of crop yield. Small losses for trees on a yearly basis compound over time and can result in substantial biomass losses over the decades-long lifespan of a tree. For trees, the annual W126 index values leading to a one percent biomass loss range from approximately 4 to 10 ppm-hrs and leading to a two percent biomass loss range from approximately 7 to 14 ppm-hrs. For crops, the annual W126 index values leading to a five percent biomass loss range from approximately 12 to 17 ppm-hrs. The recommended biomass loss benchmark for crops occurs at higher W126 index values than for trees, suggesting that potential alternative standards that are protective of trees will also be protective of crops.

Unlike for biomass, CASAC did not recommend a benchmark for foliar injury. In general, however, the results of several foliar injury analyses demonstrate a similar pattern – the proportion of biosites<sup>1</sup> showing foliar injury increases steeply with W126 index values up to approximately 10 ppm-hrs and is relatively constant at W126 index levels above 10 ppm-hrs. While the proportion of biosites with foliar injury differs, this general pattern of response to W126 is seen in the foliar injury analyses stratified by soil moisture, by year, and by geographic region.

In this REA, we analyzed the changes in risk across several potential alternative standard levels after adjusting air quality to just meet the existing standard<sup>2</sup> and just meet alternative secondary standard levels. Overall, the largest reduction in O<sub>3</sub>-related welfare risk occurs when moving from recent ambient conditions to just meeting the existing standard. Some welfare exposures and risks remain after just meeting the existing standard and in many cases, just meeting potential alternative standard levels results in reductions in those remaining exposures and risks.

## INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a review of the national ambient air quality standards (NAAQS) for O<sub>3</sub> and related photochemical oxidants. This draft welfare REA focuses on assessments to inform consideration of the review of the secondary (welfare-based) NAAQS for O<sub>3</sub>. This draft REA, which is the second draft for this NAAQS review, provides an assessment of exposure and risk associated with recent ambient concentrations of O<sub>3</sub> and potential secondary standards. The REA builds on analyses done for the previous NAAQS review completed in 2008, expands the characterization of risk of ecological effects, and adds consideration of impacts to ecosystem services.

<sup>1</sup> A biosite is a plot of land on which data is collected regarding the incidence and severity of visible foliar injury on a variety of O<sub>3</sub>-sensitive plant species.

<sup>2</sup> The existing secondary standard for O<sub>3</sub> is set identical to the primary standard at a level of 0.075 ppm (75 ppb), based on the annual fourth-highest daily maximum 8-hour average concentration, averaged over three years.

The REA also focuses on improving the characterization of the overall confidence in the risk estimates, including related uncertainties, by improving on the methods and data used in the previous analyses.

## CONCEPTUAL FRAMEWORK

Ecosystem services are distinct from other ecosystem products and functions because there is human demand for these services. In the Millennium Ecosystem Assessment, ecosystem services are classified into four main categories:

- **Provisioning** -- products obtained from ecosystems, such as the production of food and water.
- **Regulating** -- benefits obtained from the regulation of ecosystem processes, such as the control of climate and disease.
- **Cultural** -- the nonmaterial benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.
- **Supporting** -- those services necessary for the production of all other ecosystem services, such as nutrient cycles and crop pollination.

In the previous review of the secondary NAAQS for O<sub>3</sub>, EPA focused the welfare risk assessment on estimating changes in biomass loss in forest tree species and yield loss in agricultural crops, quantifying foliar injury risk, and *qualitatively* considering effects on ecosystem services. In this review, EPA expanded the analysis to consider the broader array of impacts on ecosystem services resulting from known effects of O<sub>3</sub> exposure on ecosystem functions. This expansion includes *quantifying* the risks not just to ecosystems, but also to the aspects of public welfare that depend on those ecosystems, i.e., ecosystem services. Figure ES-1 illustrates the relationships between the ecosystem services and aspects of public welfare that depend on those services.

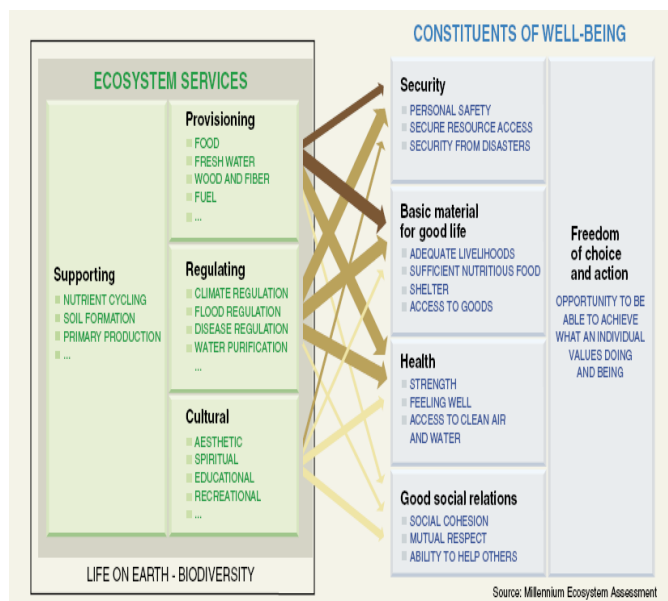


Figure ES-1 Linkages Between Ecosystem Services Categories and Components of Human Well-Being (MEA, 2005)

## AIR QUALITY CONSIDERATIONS

The air quality information and analyses for this review build upon those in prior reviews and include: (1) summaries of recent ambient O<sub>3</sub> data; (2) application of a methodology to extrapolate measured O<sub>3</sub> concentrations to areas without monitors, including natural areas, such as national parks, that are important to a welfare effects assessment; and (3) adjustment of air quality to show the distributions of O<sub>3</sub> when just meeting existing or potential alternative secondary standards. We use estimates of O<sub>3</sub> exposure (measured as W126) (see the text box for a description of the W126 metric) to assess exposures and ecological risks associated with recent ambient conditions and just meeting the existing and alternative standards. While the existing O<sub>3</sub> monitoring network has a largely urban focus, to address ecosystem impacts of O<sub>3</sub>, it is equally important to focus

The **W126 metric** is a seasonal sum of hourly O<sub>3</sub> concentrations, designed to measure the cumulative effects of O<sub>3</sub> exposure on vulnerable plant and tree species. The W126 metric uses a sigmoidal weighting function to place less emphasis on exposure to low concentrations and more emphasis on exposure to high concentrations.

on monitoring in rural areas. The extent of monitoring coverage in non-urban areas has not significantly changed since the previous review. Figure ES-2 shows the current O<sub>3</sub> monitoring coverage in the U.S. – both urban and non-urban sites. To estimate O<sub>3</sub> exposure in areas without monitors, particularly those gaps left by a sparse rural monitoring network in the western U.S., we use a spatial interpolation technique called Voronoi Neighbor Averaging (VNA) to create an air quality surface for the contiguous U.S. for each year from 2006 to 2010 and a surface for a 3-year average of 2006-2008 data.

We also consider the changes in W126 index values after adjusting O<sub>3</sub> concentrations to just meet the existing standard and potential alternative W126 standard levels of 15, 11, and 7 ppm-hrs. After adjusting the monitor values, we generate another 3-year average national-scale VNA surface for just meeting the existing standard. We then further adjust monitor data to just meet potential alternative W126 standard levels of 15, 11, and 7 ppm-hrs. The adjusted surfaces are used as inputs to several assessments, including the geographic analysis to assess the effects of insect damage related to foliar injury, the national- and case study-scale biomass loss assessments, and the national park case studies for foliar injury. For the national-scale and screening-level foliar injury analyses, to better match the air quality data with short-term soil moisture data, we use the surfaces for the individual years from 2006 through 2010.

## RISK TO VEGETATION AND ECOSYSTEMS

**I**n this welfare REA, we quantified the impact of O<sub>3</sub> exposure on two categories of ecological effects: (1) relative biomass loss for trees and crops, and (2) visible foliar injury. The results of these ecological assessments are inputs to ecosystem service assessments, which are described in more detail in the subsequent sections.<sup>3</sup>

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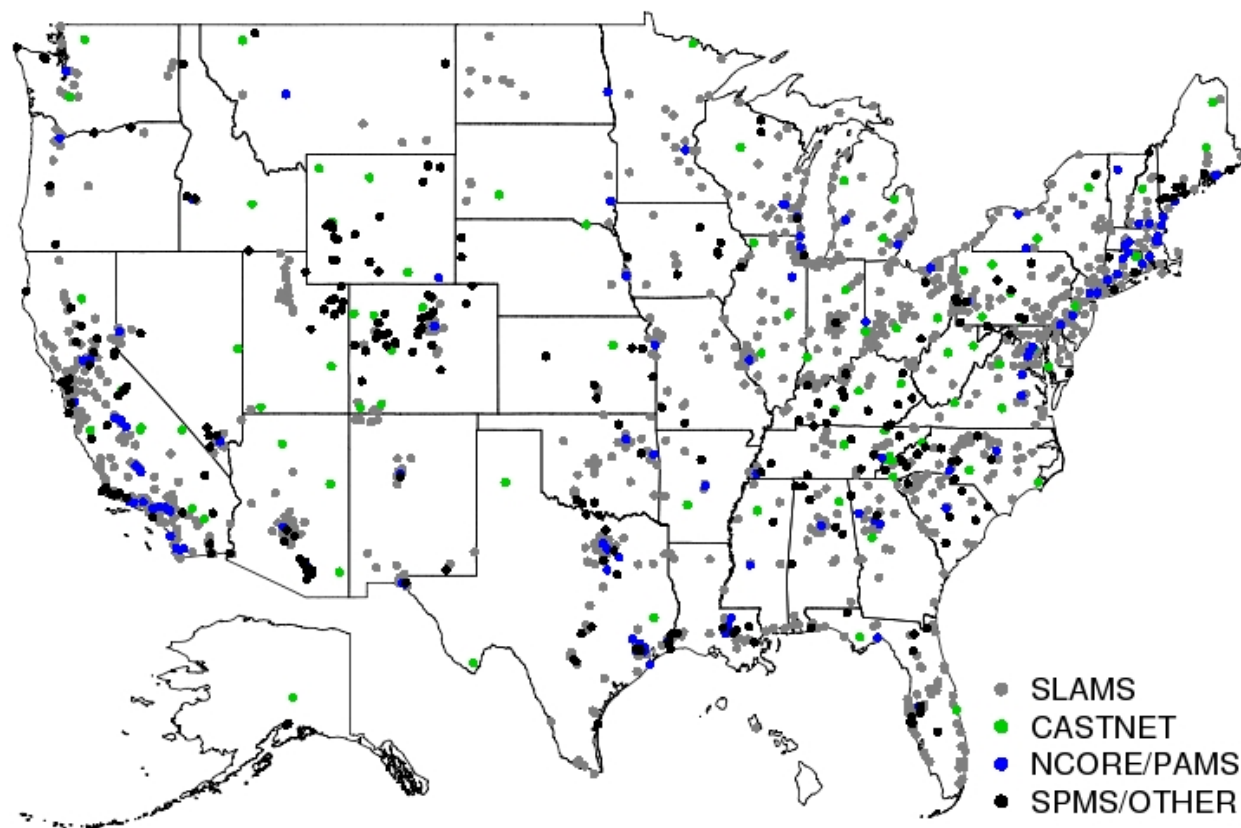
<sup>3</sup> In this welfare REA, we do not quantify insect damage resulting from O<sub>3</sub> exposure. In the next Section, *Risk to Ecosystem Services*, we briefly discuss the ecosystem services associated with insect damage on tree stands and timber production, including the overlap of areas with

The first step in assessing biomass loss for tree seedlings and crops is to identify the range of W126 index values corresponding to benchmarks recommended by CASAC. To compare different levels of biomass loss to different W126 index values, we plot the concentration-response (C-R) functions for 12 tree species and 10 crops as a function of the percent biomass loss against varying index values of W126. For a one percent biomass loss in tree seedlings, the estimated annual W126 index values are between 4 and 10 ppm-hrs; for a two percent biomass loss in tree seedlings the estimated annual W126 index values are between 7 and 14 ppm-hrs; and for a five percent biomass loss for crops the estimated annual W126 index values are between 12 and 17 ppm-hrs. In general, estimates of biomass loss in tree seedlings are comparable to mature trees with a few exceptions. Next, we use these C-R functions to determine the range of biomass loss associated with just meeting the existing and potential alternative W126 standards in analyses of individual species as well as combined analyses of individual species.

To assess foliar injury at a national scale and identify potential benchmarks, we applied a national data set on foliar injury from the U.S. Forest Service's (USFS) Forest Health Monitoring Network, which monitors the potential impacts of O<sub>3</sub> on our nation's forests. Our analyses provide results using both the presence/absence of foliar injury and elevated levels foliar injury. We also conduct analyses across years and different soil moisture categories. Over 81 percent of biosites in USFS's data set showed no visible foliar injury. Generally, the results of all of these foliar injury analyses demonstrate a similar pattern – the proportion of biosites showing foliar injury increases steeply with W126 index values up to approximately 10 ppm-hrs and is relatively constant at W126 index levels above 10 ppm-hrs. We use these results to derive W126 benchmarks for visible foliar injury for six scenarios representing the full range of percentages of biosites showing visible foliar injury (i.e., any injury and elevated injury), including five scenarios considering soil moisture. For the “base scenario”, the benchmark represents the point above which there

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higher W126 concentrations and risk of bark beetle infestation.



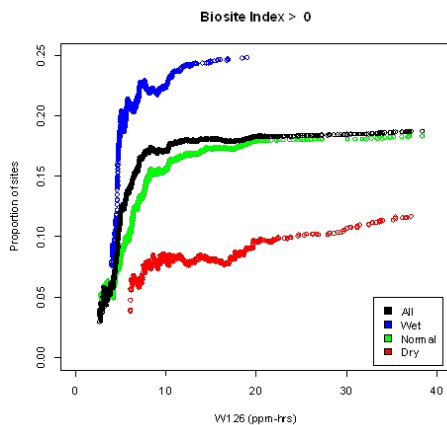
**Figure ES-2 U.S. Ambient O<sub>3</sub> Monitoring Sites in Operation During 2006-2010<sup>4</sup>**

<sup>4</sup> The map shows the location of all U.S. O<sub>3</sub> monitors operating during the 2006-2010 period. The gray dots, which make up over 80 percent of the O<sub>3</sub> monitoring network, are “State and Local Monitoring Stations” (SLAMS) monitors that are largely operated by state and local governments and largely focused on urban areas. The blue dots highlight two important subsets of the SLAMS network: “National Core” (NCORE) multipollutant monitoring sites and the “Photochemical Assessment Monitoring Stations” (PAMS) network. The green dots represent the Clean Air Status and Trends Network (CASTNET) monitors, which are focused on rural areas. In 2010, there were about 80 CASTNET sites operating, with sites in the Eastern U.S. being operated by EPA and sites in the Western U.S. being operated by the National Park Service (NPS). The black dots represent “Special Purpose Monitoring Stations” (SPMS), which include about 20 rural monitors as part of the “Portable O<sub>3</sub> Monitoring System” (POMS) network operated by the NPS.



was a consistent percentage (17.7 percent) of biosites showing foliar injury, regardless of soil moisture. This analysis suggests that reductions in W126 index values at or above this benchmark (W126 > 10.46 ppm-hrs) are unlikely to substantially reduce the prevalence of foliar injury. Similarly, this analysis suggests that reductions in W126 index values below the base scenario benchmark are likely to relatively sharply reduce the prevalence of foliar injury. We also looked at alternative scenarios based on three different categories of soil moisture and the W126 index values associated with four different prevalences (e.g., 5%, 10%, 15% and 20% of biosites) of any foliar injury, and a final scenario based on a 5 percent prevalence of foliar injury index greater than or equal to 5. In total, we evaluated 13 different W126 benchmarks associated with the six foliar injury risk scenarios. The W126 benchmarks across the six scenarios range from 3.05 ppm-hrs (five percent of biosites, normal moisture, any injury) up to 46.87 ppm-hrs (five percent of biosites, dry, elevated injury). These results suggest that soil moisture plays a role in foliar injury, potentially indicating that drought may provide some protection from foliar injury. In addition, we see similar patterns when the foliar injury analysis is stratified by year and geographic region.

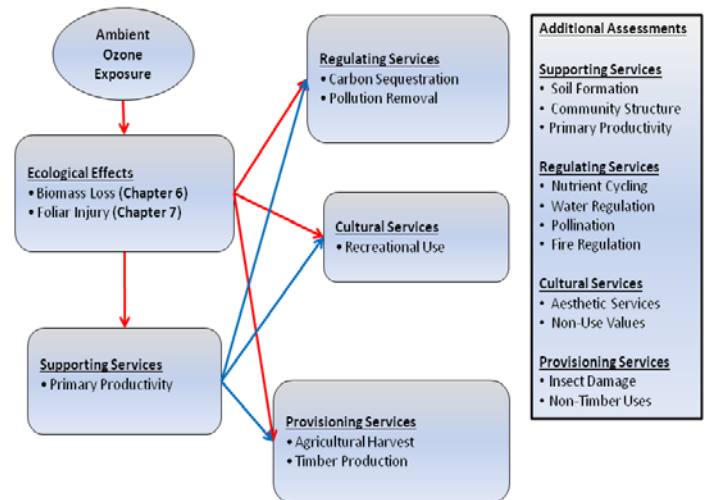
Figure ES-3 shows the pattern seen in the foliar injury analyses stratified by soil moisture category.



**Figure ES-3 Cumulative Proportion of Sites with Any Visible Foliar Injury Present, by Soil Moisture Category**

## RISK TO ECOSYSTEM SERVICES

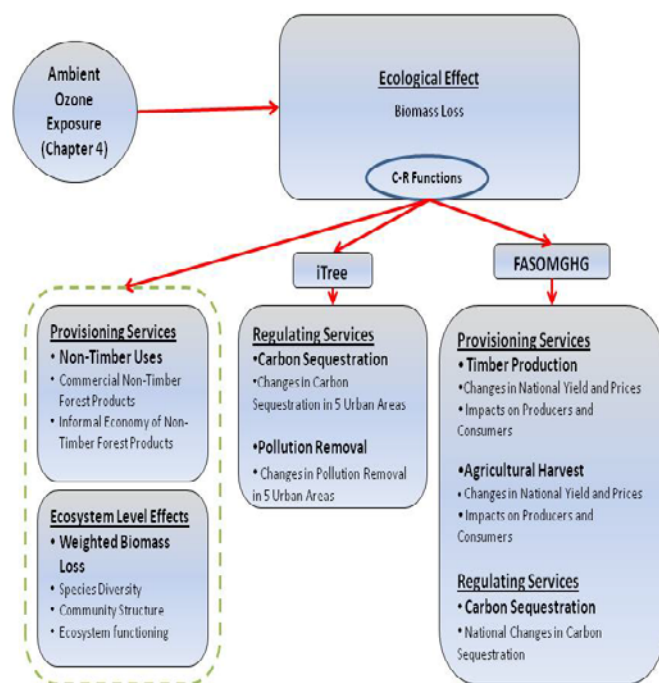
**F**igure ES-4 illustrates the overall relationships between some of the ecological effects of O<sub>3</sub> exposure and the associated ecosystem services impacts. While we estimate the impact of ambient O<sub>3</sub> exposures on biomass loss and foliar injury and the associated ecosystem services, because of a lack of sufficient data, methods, or resources we qualitatively or semi-quantitatively assess additional ecosystem services potentially affected.



**Figure ES-4 Relationship between Ecological Effects of O<sub>3</sub> Exposure and Ecosystem Services**

## Ecosystem Services Affected by Biomass Loss

**E**cosystem services most directly affected by biomass loss include: (1) provision of food and fiber (provisioning), (2) carbon storage (regulating), (3) pollution removal (regulating), and (4) habitat provision for wildlife, particularly habitat for threatened or endangered wildlife (supporting). We conduct national-scale and case-study scale analyses to estimate the ecological effect of biomass loss on several ecosystem services. Figure ES-5 provides a schematic of the relationships between the ecological effect of biomass loss and the analyses conducted to quantify the ecosystem services affected.



**Figure ES-5 Conceptual Diagram of Relationship of Relative Biomass Loss to Ecosystem Services [The dashed box indicates those services for which direct quantification was not possible.]**

Using the Forest and Agricultural Optimization Model with Greenhouse Gases (FASOMGHG), we quantify the effects of biomass loss on timber production, agricultural harvesting, and carbon sequestration in a national-scale analysis.<sup>5</sup> The analysis provided results for nine U.S. climate regions based on National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) regions (see Figure ES-6 below). We consider these regions appropriate for our analyses because geographic patterns of both O<sub>3</sub> and plant species are driven by climatic features such as temperature and

<sup>5</sup> FASOMGHG is a national-scale model that provides a complete representation of the U.S. forest and agricultural sectors' impacts of meeting alternative standards. FASOMGHG simulates the allocation of land over time to competing activities in both the forest and agricultural sectors.

precipitation patterns. We use the O<sub>3</sub> C-R functions for tree seedlings and crops to calculate relative yield loss, which is equivalent to relative biomass loss. Because the forestry and agriculture sectors are related, and trade-offs occur between the sectors, we also calculate the resulting market-based welfare effects of O<sub>3</sub> exposure in the forestry and agriculture sectors.

Because most areas have W126 index values below 15 ppm-hrs after just meeting the existing O<sub>3</sub> standard, yield losses for commercial timber production are below one percent, with the exception of the Southwest, Southeast, Central, and South regions. For agricultural harvest, the largest yield changes occur between recent ambient conditions and just meeting the existing standard. Under recent ambient conditions, the West, Southwest, and Northeast regions generally have the highest yield losses at between 6.5 and 15 percent for winter wheat. Relative yield losses for winter wheat are less than one percent at potential alternative standard levels of 15, 11, and 7 ppm-hrs. For soybeans, yield losses above 1 percent remain after just meeting 15 ppm-hrs in the Southwest and Central regions. Yield losses are below one percent after just meeting 11 and 7 ppm-hrs.

Changes in yield are also associated with changes in consumer and producer/farmer surplus. The overall effect of changes in yield on forest ecosystem productivity depends on the composition of forest stands and the relative sensitivity of trees within those stands. Overall effect on agricultural yields and producer and consumer surplus depends on the (1) ability of producers/farmers

**Welfare economics** focuses on the optimal allocation of resources and goods and how those allocations affect total social welfare. Total welfare is also referred to as economic surplus, which is the overall benefit a society, composed of consumers and producers, receives when a good or service is bought or sold, given a quantity provided and a market price. Economic surplus is divided into two parts: consumer and producer surplus.

to substitute other crops that are less O<sub>3</sub> sensitive, and (2) responsiveness of demand and supply. Economic impacts from just meeting the existing and alternative standards were similar between the forestry and agricultural sectors -- consumer surplus generally increased in both sectors because higher productivity under lower W126 index values increased total yields and reduced market prices. Because the quantity demanded for most forestry and agricultural commodities is not highly responsive to

changes in price, producer surplus often declines. In some cases, lower prices reduce producer profits more than can be offset by higher yields. For example, in 2040, the year with maximum changes in consumer and producer surplus, after just meeting the existing standard, the total producer surplus in the forestry sector is estimated to be \$133 billion and total consumer surplus is estimated to be \$935 billion. When adjusting to meeting alternative standards of 15, 11, and 7 ppm-hrs, consumer surplus **increases** \$597 million, \$712 million, and \$779 million (i.e., 0.06, 0.08, and 0.08 percent), respectively, while producer surplus **decreases** \$839 million, \$858 million, and \$766 million, (i.e., about 0.6 percent), respectively. (All estimates are in 2010\$.)

Biomass loss due to O<sub>3</sub> exposure can reduce carbon sequestration, and shifts between the forestry and agricultural sector can also affect carbon sequestration. Because most areas have W126 index values below 15 ppm-hrs after just meeting the existing O<sub>3</sub> standard, a potential alternative standard of 15 ppm-hrs does not appreciably increase carbon sequestration. The majority of the enhanced carbon sequestration potential is in the forest biomass increases over time under potential alternative standards of 11 and 7 ppm-hrs. On an annual basis, carbon sequestration at 11 ppm-hrs is increased by about 20 million metric tons per year relative to just meeting the existing O<sub>3</sub> standard, which is equivalent to taking about 4 million cars off the road.<sup>6</sup> Carbon sequestration at 7 ppm-hrs is increased by about 53 million metric tons per year relative to just meeting the existing standard, which is the equivalent of taking approximately 11 million cars off the road.

In the case-study scale analyses, we use the iTree model to estimate the impact of biomass loss on tree growth and ecosystem services such as carbon

sequestration and pollution removal provided by urban forests in five urban areas over a 25-year period.<sup>7</sup>

Relative to just meeting the existing standard, three of the urban areas (Atlanta, Chicago, and the urban areas of Tennessee) show gains in carbon sequestration at

**Consumer surplus** is the difference between what a consumer would be willing to pay for a product and the price they have to pay for the product. For example, assume a consumer goes out to buy a CD player and he/she is willing to spend \$250. When the shopper finds that the CD player is on sale for \$150, economists would say that this shopper has a consumer surplus of \$100, e.g., the difference between the \$150 sale price and the \$250 the consumer was willing to spend.

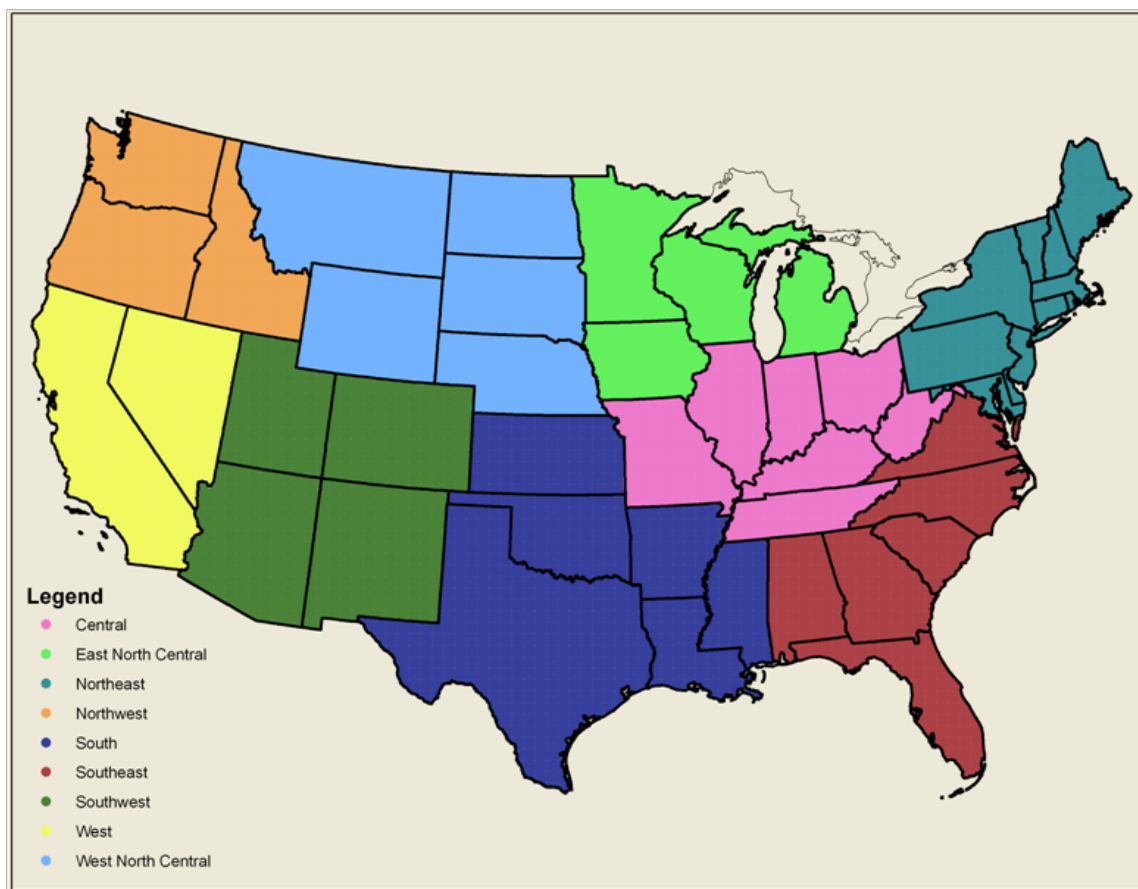
**Producer surplus** refers to the benefit, or profit, a producer receives from providing a good or service at a market price when they would have been willing to sell that good or service at a lower price. For example, if the amount the producer is willing to sell the CD player for is \$75, and the producer sells the CD player for \$150, the producer surplus is \$75, e.g., the \$150 sale price less the \$75 price at which the producer was willing to sell.

potential alternative standard levels of 11 and 7 ppm-hrs. For example, relative to just meeting the existing standard, Chicago gains about 6,400 tons of carbon sequestration per year at 7 ppm-hrs, and the urban areas of Tennessee gain about 8,800 tons of carbon

sequestration per year at 11 ppm-hrs and 20,000 tons of carbon sequestration per year at 7 ppm-hrs. These same three areas show gains in pollution removal (i.e., O<sub>3</sub>, carbon monoxide, nitrogen dioxide, and sulfur dioxide) at potential alternative standard levels of 11 and 7 ppm-hrs compared to meeting the existing standard. For example, relative to just meeting the existing standard, Chicago gains about 2,300 metric tons of pollution removal annually at 11 ppm-hrs and 6,500 metric tons of pollution removal annually at 7 ppm-hrs, and the urban areas of Tennessee gain about 5,300 metric tons of pollution removal annually at 11 ppm-hrs and 11,700 metric tons of pollution removal annually at 7 ppm-hrs.

<sup>6</sup> As calculated by the EPA Greenhouse Gas Equivalencies Calculator, available at <http://www.epa.gov/cleanenergy/energy-resources/calculator.html>.

<sup>7</sup> The iTree model is a peer-reviewed suite of software tools provided by USFS.



**Figure ES-6 Map of the 9 NOAA Climate Regions used in the National-Scale Air Quality Adjustments**



Syracuse and Baltimore do not realize gains in carbon sequestration or pollution removal, because W126 index values almost meet the alternative standards of 15, 11, and 7 ppm-hrs in those areas.

We qualitatively describe the potential effects of O<sub>3</sub> on other (non-timber) forest products that are **harvested for** commercial or subsistence activities, including edible fruits, nuts, berries, and sap; foliage, needles, boughs, and bark; grass, hay, alfalfa, and forage; herbs and medicinals; fuelwood, posts and poles; and Christmas trees. According to the ISA, O<sub>3</sub> exposure causes biomass loss in sensitive woody and herbaceous species, which in turn could affect forest products used for arts, crafts, and florals. For example, Douglas Fir and Red Alder, among others, are used on the Pacific Coast for arts and crafts, particularly holiday crafts and decorations. Foliar injury impacts on O<sub>3</sub>-sensitive plants would potentially affect the harvest of leaves, needles, and flowers from these plants for decorative uses. The visible injury and early senescence caused by O<sub>3</sub> in some evergreens may also reduce the value of a whole tree such as Christmas trees. Likewise, O<sub>3</sub> can reduce the harvest of edible fruits, nuts, berries, and sap in O<sub>3</sub>-sensitive plants. According to the U.S. Census Bureau, the industry sector for forest nurseries and gathering of forest products employed 2,098 people, accounting for an annual payroll of \$71 million (2006\$) with an average annual income of \$34,155).

### Ecosystem Services Affected by Visible Foliar Injury

The ecosystem services most likely to be affected by O<sub>3</sub>-induced visible foliar injury are aesthetic value and outdoor recreation (cultural services), which depend on the perceived scenic beauty of the environment. Studies of Americans' perception of scenic beauty show that people tend to have reliable preferences for forests and vegetation with fewer damaged or dead trees and plants. Many outdoor recreation activities directly depend on the scenic value of the area, in particular scenic viewing, wildlife watching, hiking, and camping. These activities are enjoyed by millions of Americans every year and generate millions of dollars in economic value. According to the National Survey on

Recreation and the Environment, some of the most popular outdoor activities are walking, including day hiking and backpacking; camping; bird watching; wildlife watching; and nature viewing. Total expenditures across wildlife watching



Bags of ponderosa pine (*Pinus ponderosa* C. Lawson var. *ponderosa*) cones gathered in central Oregon for arts, crafts, and floral markets. Courtesy: U.S. Department of Agriculture

activities, trail-based activities, and camp-based activities are approximately \$200 billion dollars annually. Figure ES-7 shows the relationship between foliar injury and the analyses to assess affected ecosystem services.

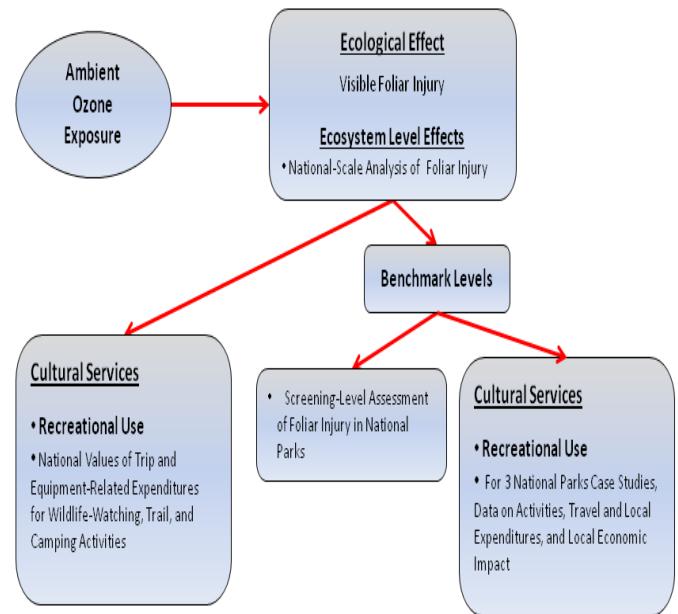


Figure ES-7 Relationship between Visible Foliar Injury and Ecosystem Services

Enjoyment of recreation in national parks can be adversely affected by visible foliar injury, and national parks are designated as special areas in need of protection. In a screening-level assessment at 214 national parks, we apply the benchmarks from the national analysis of foliar

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injury to six scenarios representing a range of percentages of biosites showing visible foliar injury. Based on lists from the National Park Service, 95 percent of the parks in this assessment contain at least one O<sub>3</sub>-sensitive species. Generally, benchmark scenarios corresponding to higher percentages of biosites showing foliar injury show fewer parks that exceed the benchmark criteria for those scenarios. During 2006 to 2010, 58 percent of parks exceeded the benchmark W126 corresponding to the base scenario (W126>10.46 ppm-hrs, 17.7 percent of biosites, without consideration of soil moisture, any injury) for at least three years. The analyses suggest that in order to substantially reduce the risk of foliar injury in these parks, the W126 index values would need to be reduced to be below 10.46 ppm-hrs. In addition, 98 percent, 80 percent, 68 percent and 2 percent of parks would exceed the benchmark criteria corresponding to the 5 percent, 10 percent, 15 percent, and 20 percent prevalence scenarios for at least 3 years within the 2006-2010 period. For the elevated injury scenario, 34 percent of parks would exceed the benchmark criteria (five percent of biosites, multiple moisture categories, elevated foliar injury) for at least three years. Because the screening-level assessment relies on annual estimates of W126 index values and soil moisture, we cannot fully evaluate just meeting the existing and alternative standards because they are based on the 3-year average air quality surfaces. However, we can observe that after adjusting the W126 surfaces to just meet the existing standard (3-year average), all of the 214 parks are below 10.46 ppm-hrs, which corresponds to the annual W126 benchmark criteria for the base scenario.

We also assess foliar injury at a case-study scale. Specifically, we assess O<sub>3</sub>-exposure risk at three national parks – Great Smoky Mountains National Park, Rocky Mountain National Park, and Sequoia/Kings National Parks. For each park, we assess the potential impact of O<sub>3</sub>-related foliar injury on recreation (cultural services) by considering information on visitation patterns, recreational activities and visitor expenditures. We include percent cover of species sensitive to foliar injury and focus on the overlap between recreation areas within the park and alternative W126 standard levels.



Mount Le Conte, Summer  
Great Smoky Mountains National Park  
Courtesy: NPS  
<http://www.nps.gov/grsm/photosmultimedia/index.htm>

In the Great Smoky Mountains National Park, there are 37 sensitive species across vegetative strata, and 2011 visitor spending exceeded \$800 million. Seasonal O<sub>3</sub> concentrations in the park have been among the highest in eastern U.S. -- under recent ambient conditions, 44 percent of the park has W126 index values above 15 ppm-hrs. After adjustments to just meeting the existing standard of 75 ppb, no area in the park exceeds an alternative W126 standard level of 7 ppm-hrs. Rocky Mountain National Park has seven sensitive species, including Quaking Aspen. In 2011, visitor spending at the park was over \$170 million. Under recent ambient conditions, all of the park has W126 index values above 15 ppm-hrs. When adjusted to just meeting the existing standard, 59 percent of the park would have W126 index values between 7 and 11 ppm-hrs. When adjusted to just meeting an alternative W126 standard level of 15 ppm-hrs, no area in the park exceeds an alternative W126 standard level of 7 ppm-hrs. In Sequoia/Kings National Parks, there are 12 sensitive species across vegetative strata, and 2011 visitor spending was over \$97 million. When adjusted to just meet the existing standard, no area in the park exceeds an alternative W126 standard level of 7 ppm-hrs.

### Additional Ecosystem Services Affected

**B**ecause of a lack of data, methods, or resources we qualitatively or semi-quantitatively assess additional ecosystem services potentially affected, including cultural, supporting, regulating, and provisioning services. **Cultural services** include non-use values that can be directly or indirectly impacted by O<sub>3</sub> exposure. When people value a resource even though they may never visit the resource or derive any tangible benefit from it, they perceive an existence value. When the resource is valued as a legacy to future generations, bequest value exists. Additionally, there exists an option value to knowing that you may visit a resource at some point in the future. The National Survey on Recreation and the Environment (NSRE) is an ongoing survey of a random sample of adults over the age of 16 on their interactions with the environment.<sup>8</sup> NSRE data indicate that Americans have very strong preferences for existence, option, and bequest values related to forests – 90 to 97 percent of survey respondents indicated it is moderately, very, or extremely important to them to maintain existence values, to maintain option values, and to maintain bequest values.

Between 90 and 97 percent of NSRE survey respondents stated that maintaining existence, option, or bequest values is moderately, very, or extremely important to them.

The **supporting service** of community composition, or structure, is affected by O<sub>3</sub> exposure because some species are more resistant to the negative effects of O<sub>3</sub> and are able to out-compete more susceptible species. Changes in community composition underlie possible changes in associated services such as herbivore grazing, production of preferred species of timber, and preservation of habitat for unique or endangered communities or species.

Between 93 and 96 percent of NSRE survey respondents stated that provision of habitat for wild plants and animals is moderately, very, or extremely important to them.

The NSRE provides data on the values that survey respondents place on the provision of habitat for wild plants and animals – between 93 and 96 percent of survey respondents indicated it is important to them to preserve wildlife habitat, to preserve unique wild plants and animals, and to protect rare or endangered species.

**Regulating services** include air quality, water quantity and quality, climate, erosion, fire regulation, and pollination regulation. Regulation of the water cycle can be adversely affected by the effects of O<sub>3</sub> on plants. Studies of O<sub>3</sub>-impacted forests in eastern Tennessee in or near the Great Smoky Mountains has shown that ambient O<sub>3</sub> exposures resulted in increased water use in O<sub>3</sub>-sensitive species, which led to decreased modeled late-season stream flow in those watersheds. Ecosystem services potentially affected by such a loss in stream flow could include habitat for species (e.g., trout) that depend on an optimum stream flow or temperature. Additional downstream effects could potentially include a reduction in the quantity and/or quality of water available for irrigation or drinking and for recreational use. Ninety-one percent of NSRE respondents ranked water quality protection as either an extremely or very important benefit of wilderness.

Fire regime regulation is also negatively affected by O<sub>3</sub> exposure. For example, O<sub>3</sub> exposure may contribute to forest susceptibility to wildfires in southern California by increasing leaf turnover rates and litter, increasing fuel loads on the forest floor. In a case-study scale analysis, we develop maps that overlay the mixed conifer forest area of California with (i) areas of moderate or high fire risk and recent W126 index values and (ii) air quality adjusted to just meet existing and alternative standard levels. The highest fire risk and highest W126 levels overlap with each other, as well as with significant portions of mixed conifer forest. Under recent conditions, over 97 percent of mixed conifer forest area has W126 index values over 7 ppm-hrs and fire risk, and 74 percent has W126 index values over 15 ppm-hrs and fire risk. After just meeting the existing standard, almost all of the mixed conifer forest area with fire risk is below 7 ppm-hrs. At the alternative standard level of 15 ppm-hrs, less than one percent of the fire risk area is above 7 ppm-hrs. At alternative standard levels of 11 and 7 ppm-hrs, all of the fire risk area is below 7 ppm-hrs.

<sup>8</sup> The NSRE is conducted by the U.S. Forest Service. Additional information can be located at <http://www.srs.fs.usda.gov/trends/nsre-directory/>.



O<sub>3</sub> exposure results in increased susceptibility to infestation by some chewing insects, including the southern pine beetle and western bark beetle. These infestations can cause economically significant damage to tree stands and the associated timber production

**(provisioning service)**. In the short-term, the immediate increase in timber supply that results from the additional harvesting of



Southern Pine Beetle Damage  
Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

damaged timber depresses prices for timber and benefits consumers. In the longer-term, the decrease in timber available for harvest raises timber prices, potentially benefitting producers. The USFS reports timber producers have incurred losses of about \$1.4 billion (2010\$), and wood-using firms have gained about \$966 million, due to beetle outbreaks between 1977 and 2004. We develop maps that overlay the forest areas at risk of basal area loss from pine beetle infestation with W126 index values. After just meeting the existing standard, most of the pine beetle risk area is below 7 ppm-hrs. At the alternative standard level of 15 ppm-hrs, all of the pine beetle risk area is less than 7 ppm-hrs.

## CONCLUSIONS

his welfare REA provides analyses that further inform the following policy-relevant questions<sup>9</sup>: (1) in considering alternative standards, to what extent do alternative levels reduce estimated exposures and welfare risks attributable to O<sub>3</sub>; (2) what range of alternative standard levels should be considered based on the scientific information evaluated in the ISA, air quality analyses, and the welfare REA; and (3) what are the important uncertainties and limitations in the evidence

and assessments and how might those uncertainties and limitations be taken into consideration in identifying alternative secondary standards for consideration. To develop information to help inform these questions, we quantify ecological effects based on the relationship with the W126 metric and assess the associated impacts on ecosystem services. For some ecosystem services, such as commercial non-timber forest products, recreation, and aesthetic and non-use values, we qualitatively assess potential impacts to services.

For biomass loss, a one to two percent loss for trees corresponds to an annual W126 index value of 4 to 14 ppm-hrs, and a five percent loss for crops corresponds to an annual W126 index value of 12 to 17 ppm-hrs. For visible foliar injury, across all biosites, the proportion of biosites showing injury generally levels off around a W126 index value of 10 ppm-hrs; however, for biosites with greater than normal soil moisture, the proportion of sites with damage can be greater.

We estimate that some exposures and risks remain after just meeting the existing standard and that in many cases, just meeting potential alternative standard levels results in reductions in those exposures and risks. Overall, the largest reduction in O<sub>3</sub> exposure-related welfare risk occurs when moving from recent ambient conditions to just meet the existing secondary standard of 75 ppb. When adjusting for meeting the existing standard, only two of the nine U.S. regions have W126 index values remaining above 15 ppm-hrs (West -- 18.9 ppm-hrs and Southwest -- 17.7 ppm-hrs). Four regions (East North Central, Northeast, Northwest, and South) would meet 7 ppm-hrs, and two regions (Southeast and West North Central) have index values between 9 and 12 ppm-hrs (Southeast -- 11.9 ppm-hrs and West North Central -- 9.3 ppm-hrs). At an alternative standard of 15 ppm-hrs, ambient O<sub>3</sub> exposure and related risk are not appreciably different than they are after just meeting the existing standard. Meeting alternative standard levels of 11 ppm-hrs and 7 ppm-hrs results in smaller risk reductions compared to the decreases in risk from meeting the existing standard relative to recent conditions.

<sup>9</sup> The policy-relevant questions were identified in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards*.



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