United States Environmental Protection Agency

Welfare Risk and Exposure Assessment for Ozone

Final

Executive Summary

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U.S. Environmental Protection Agency
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Office of Air Quality Planning and Standards
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DISCLAIMER

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SUMMARY CONCLUSIONS

The goals for this welfare[1] risk and exposure assessment (REA) include (i) characterizing ambient ozone (O_3) 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_3 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_3 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 protect trees will also protect 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[2] showing foliar injury increases steeply with W126 index values up to approximately 10 ppm-hrs and is relatively constant 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 and by year.

In this REA, we analyzed the changes in O_3 exposure and risk after adjusting air quality to just meet the existing standard[3] and to just meet potential alternative secondary standard levels. Overall, the largest reduction in O_3-related ecological effects and associated ecosystem services occurs when moving from recent ambient conditions to just meeting the existing standard. Exposures and risks remaining after just meeting the existing standard, in many cases, can be reduced when just meeting potential alternative standard levels.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a review of the national ambient air quality standards (NAAQS) for O_3 and related photochemical oxidants. This welfare REA presents assessments to inform consideration of the review of the secondary (welfare-based) NAAQS for O_3. This REA provides an assessment of exposure and risk associated with recent ambient concentrations of O_3 and potential alternative secondary standards. The REA builds on

[1] A secondary, or welfare-based, standard provides public welfare protection, including protection against decreased visibility and against damage to animals, crops, vegetation, and buildings.

[2] A biosite is a plot of land on which data was collected regarding the incidence and severity of visible foliar injury on a variety of O_3-sensitive plant species.

[3] The existing secondary standard for O_3 is set identical to the primary standard at a level of 0.075 ppm (75 ppb), based on the fourth-highest daily maximum 8-hour average concentration, averaged over three years.

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. 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_3, 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_3 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 public welfare.

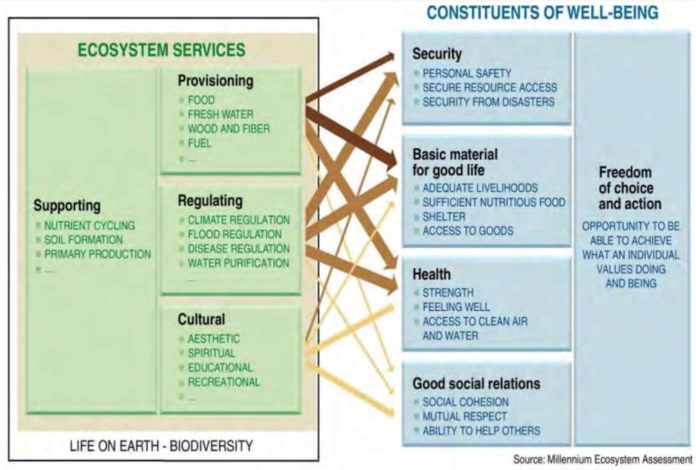

Figure ES-1 Linkages Between Ecosystem Services Categories and Components of Human Well-Being (MEA, 2005)

AIR QUALITY CONSIDERATIONS

The air quality information and analyses in this REA build upon those in prior reviews and include: (1) summaries of recent ambient O_3 monitoring data; (2) an extrapolation of measured O_3 concentrations to areas without monitors, including natural areas that are important to public welfare, such as national parks; and (3) adjustment of air quality to just meet the existing standard and potential alternative secondary standards. We use estimates of O_3 exposure (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_3 monitoring network has a largely urban focus, to address ecosystem impacts of O_3, it is equally important to focus on monitoring in rural areas. The extent of monitoring coverage in non-urban areas has not significantly changed since the previous review. Figure

> The **W126 metric** is a seasonal sum of hourly O_3 concentrations, designed to measure the cumulative effects of O_3 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.

ES-2 shows the current O_3 monitoring coverage in the U.S. – both urban and non-urban sites. To estimate O_3 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_3 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. When adjusting air quality to just meet the existing standard, only two of the nine U.S. regions remain 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) are between 9 and 12 ppm-hrs (Southeast – 11.9 ppm-hrs and West North Central – 9.3 ppm-hrs).

The adjusted surfaces are used as inputs to several assessments, including the geographic analysis to assess the potential overlap between areas with elevated O_3 and areas with elevated risks of fire and insect damage, 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

In this welfare REA, we quantified the impact of O_3 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. We do not quantify fire or insect damage resulting from O_3 exposure. In the *Risk to Ecosystem Services* section, we briefly discuss the ecosystem services associated with fire and insect damage on tree stands and timber production, and show the overlap of areas with higher W126 concentrations and higher risk of bark beetle infestation and fire risk.

The first step in assessing biomass loss for tree seedlings and crops is to identify the range of W126 index values corresponding to annual percent biomass loss benchmarks recommended by CASAC using exposure-response (E-R) functions for 12 tree species and 10 crops, for which sufficient information is available. The estimated annual W126 index values are between 4 and 10 ppm-hrs for a one percent biomass loss in tree seedlings, between 7 and 14 ppm-hrs for a two percent biomass loss in tree seedlings, and between 12 and 17 ppm-hrs for a five percent biomass loss for crops. In general, estimates of annual percent biomass loss in tree seedlings are comparable to mature trees with a few exceptions. Next, we use these E-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 Forest Health Monitoring Network (FHM), which monitors the potential impacts of O_3 on our nation's forests. Our analyses identify the presence/absence of foliar injury. We also conduct analyses across years and different soil moisture categories. Over 81 percent of FHM biosites showed no visible foliar injury. Generally, the results 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 above 10 ppm-hrs. For biosites with greater than normal soil moisture, more biosites showed injury. Figure ES-3 shows the pattern seen in the foliar injury analyses stratified by soil moisture category. In addition, we see similar patterns when the foliar injury analysis is stratified by year.

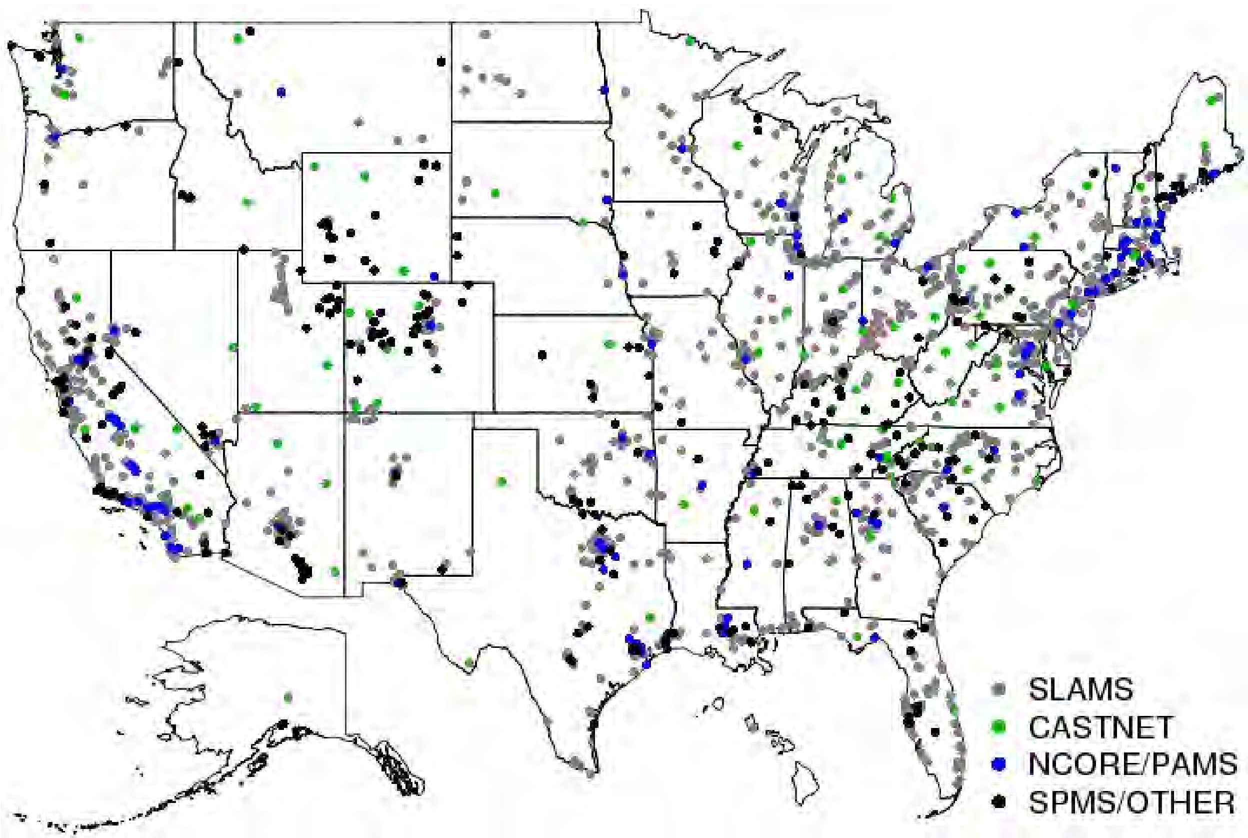

Figure ES-2 U.S. Ambient O_3 Monitoring Sites in Operation During 2006-2010[4]

[4] The map shows the location of all U.S. O_3 monitors operating during the 2006-2010 period. The gray dots, which make up over 80 percent of the O_3 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_3 Monitoring System" (POMS) network operated by the NPS.

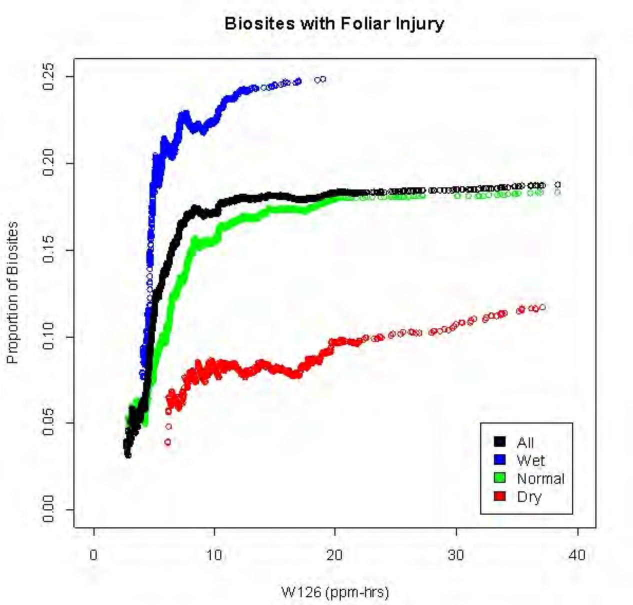

Figure ES-3 Cumulative Proportion of Sites with Any Visible Foliar Injury Present, by Soil Moisture Category

Using the foliar injury benchmarks derived from the national scale analysis, we applied a screening-level approach using O_3 exposure and soil moisture data for 214 parks in the contiguous U.S. All scenarios assessed in the screening-level assessment reflect the special status of parks as areas designated for protection, and thus apply benchmarks corresponding to the presence of any visible foliar injury. We use these results to derive W126 benchmarks for visible foliar injury for five scenarios representing the full range of percentages of biosites showing visible foliar injury, including four scenarios considering soil moisture. For the fifth scenario, or "base scenario", the benchmark is the W126 index value where the slope of exposure-response relationship changes for all FHM biosites in all soil moisture categories. We looked at scenarios based on three different categories of soil moisture (i.e., wet, normal, dry) and the W126 index values associated with four different prevalences of any foliar injury (e.g., 5 percent, 10 percent, 15 percent and 20 percent of biosites). In total, we evaluated ten different W126 benchmarks associated with the five foliar injury risk scenarios. The W126 benchmarks across the scenarios range from 3.05 ppm-hrs (five percent of biosites, normal moisture, any injury) up to 24.61 ppm-hrs (15 percent of biosites, dry, any injury). These results suggest that soil moisture plays a role in foliar injury, potentially indicating that drought may provide some protection from foliar injury.

RISK TO ECOSYSTEM SERVICES

Figure ES-4 illustrates the overall relationships between some of the ecological effects of O_3 exposure and the associated ecosystem services impacts. While we estimate the impact of ambient O_3 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.

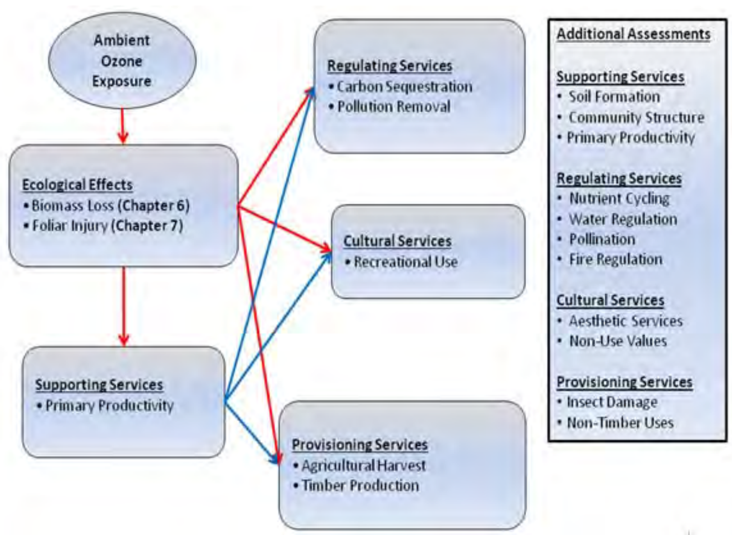

Figure ES-4 Relationship between Ecological Effects of O_3 Exposure and Ecosystem Services

Ecosystem Services Affected by Biomass Loss

Ecosystem 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.

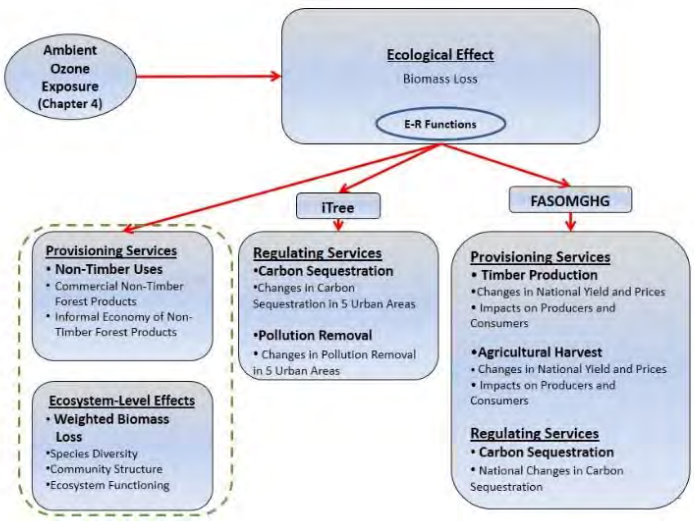

Figure ES-5 Conceptual Diagram of Relationship of Relative Biomass Loss to Ecosystem Services [The dashed box indicates those services for which direct quantification was not possible.]

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.[5] 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_3 and plant species are driven by climatic features such as temperature and precipitation patterns. We use the O_3 E-R functions for tree seedlings and crops to calculate relative yield loss, which equates to relative biomass loss. Because the forestry and agriculture sectors are linked, and trade-offs occur between the sectors, we also calculate the resulting market-based welfare effects of O_3 exposure in the forestry and agriculture sectors.

Because most areas are below 15 ppm-hrs after adjusting O_3 distributions to just meet the existing standard (based on reducing nationwide emissions of NOx), 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 effects on

> **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.

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

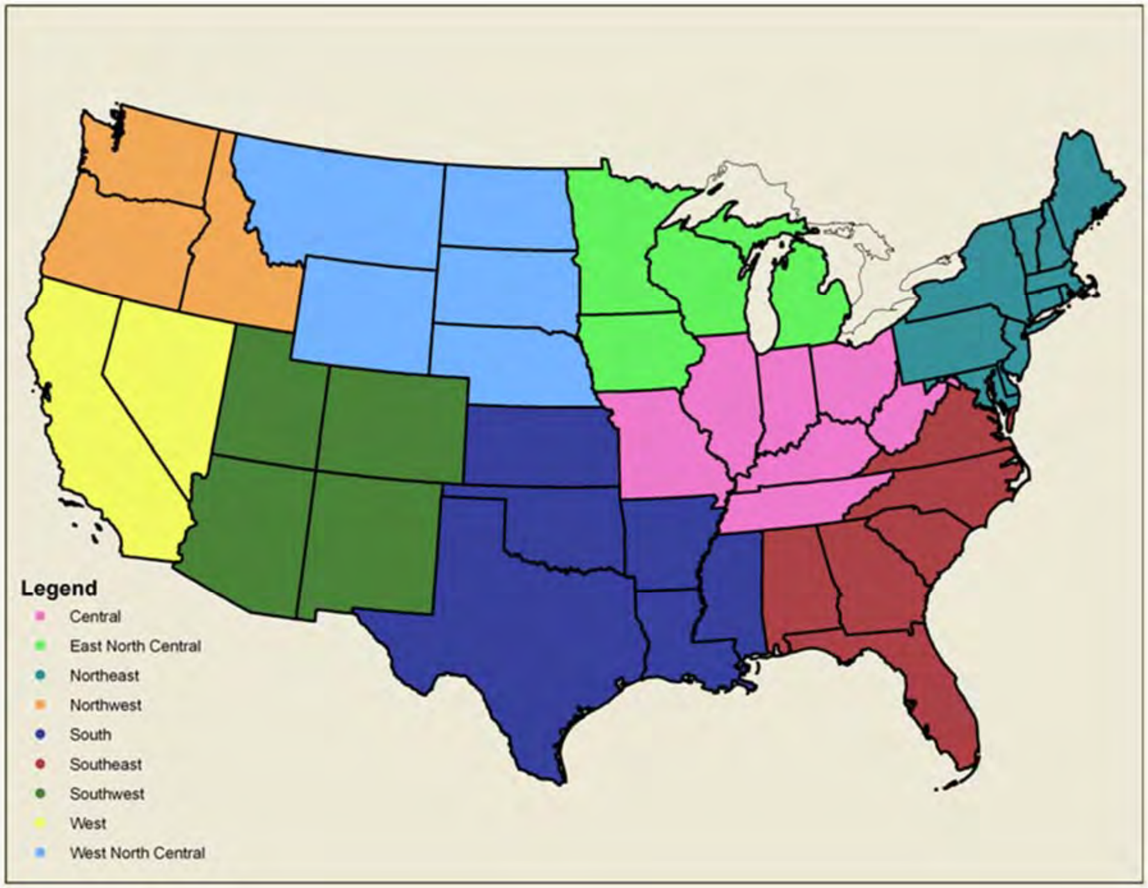

Figure ES-6 Map of the 9 NOAA Climate Regions used in the Welfare Risk and Exposure Assessment

agricultural yields and producer and consumer surplus depends on the (1) ability of producers/farmers to substitute other crops that are less O_3 sensitive, and (2) responsiveness of demand and supply. The overall economic effect of reduced O_3 exposure on the forestry and agricultural sectors from just meeting the existing and alternative standards were similar between the 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 adjusting air quality to 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 air quality to just meet alternative W126 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 $766 million, (i.e., about 0.6 percent), respectively. (All estimates are in 2010$ for the U.S. only.)

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 $70, and the producer sells the CD player for $150, the producer surplus is $80, e.g., the $150 sale price less the $70 price at which the producer was willing to sell.

Biomass loss due to O_3 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_3 standard, a potential alternative standard of 15 ppm-hrs does not appreciably increase carbon sequestration (meeting the existing 8-hour standard of 75 ppb increases carbon sequestration by 2,972 million metric tons per year). 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_3 standard, which is equivalent to taking about 4 million cars off the road.[6] 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 i-Tree 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 study areas over a 25-year period.[7] 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 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

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

[7] The i-Tree model is a peer-reviewed suite of software tools provided by the U.S. Forest Service that provides urban forestry analysis.

carbon sequestration per year at 7 ppm-hrs. These same three areas show gains in pollution removal (i.e., O_3, 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. Syracuse and Baltimore do not realize gains in carbon sequestration or pollution removal because the 2006-2008 W126 index values almost meet the alternative standard levels in those areas.

We qualitatively describe the potential effects of O_3 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. Ozone 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_3-sensitive plants would potentially affect the harvest of leaves, needles, and flowers from these plants for decorative uses. Visible foliar injury and early senescence caused by O_3 in some evergreens may also reduce the value of a whole tree such as Christmas trees. Likewise, O_3 can reduce the harvest of edible fruits, nuts, berries, and sap in O_3-sensitive plants. According to the U.S. Census Bureau, the industry sector for forest nurseries and gathering of forest products employed 2,098 people with an annual payroll of $71 million (2006$).

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

Courtesy: U.S. Department of Agriculture

Ecosystem Services Affected by Visible Foliar Injury

The ecosystem services most likely to be affected by O_3-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,[8] 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 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.

[8] 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. 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/.

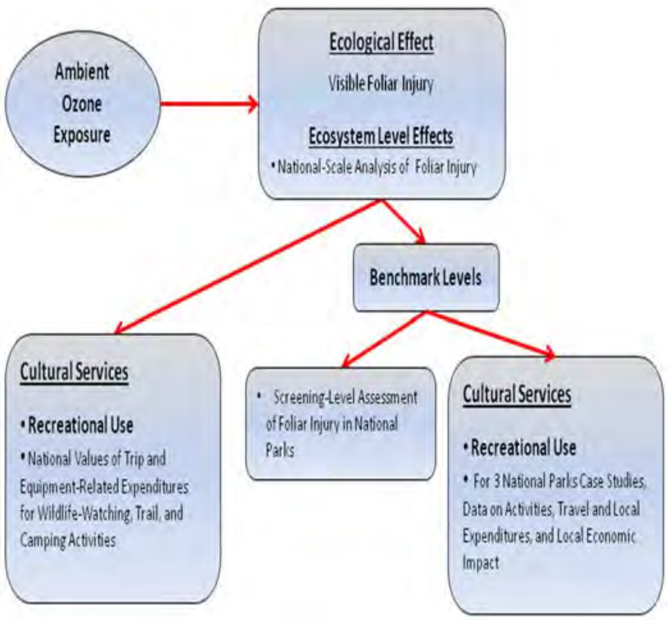

Figure ES-7 Relationship between Visible Foliar Injury and Ecosystem Services

Enjoyment of recreation in national parks can be adversely affected by visible foliar injury, and national parks are areas designated for protection. In a screening-level assessment at 214 national parks, we apply the W126 benchmarks from the national analysis of foliar injury using FHM biosite data to five scenarios (representing the full range of percentages of biosites showing visible foliar injury) in order to provide an indication of the risk of visible foliar injury in each park. Based on lists from the National Park Service, 95 percent of the parks in this assessment contain at least one O_3-sensitive species. Generally, scenarios for higher percentages of FHM biosites showing foliar injury have fewer parks that exceed the benchmarks for those scenarios across multiple years. During 2006 to 2010, 58 percent of parks exceeded the W126 benchmark corresponding to the base scenario (W126>10.46 ppm-hrs, all biosites in all soil moisture categories) for at least three years. In addition, 98 percent, 80 percent, 68 percent and 2 percent of parks would exceed the benchmark criteria corresponding to the prevalence scenarios (i.e., 5 percent, 10 percent, 15 percent, and 20 percent) for at least 3 years within the 2006-2010 period.[9] 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 air quality 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 for the base scenario.

We also assess foliar injury at three national parks – Great Smoky Mountains National Park, Rocky Mountain National Park, and Sequoia/Kings Canyon National Parks. For each park, we assess the potential impact of O_3-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.

In the Great Smoky Mountains National Park, there are 37 sensitive species across vegetative strata, and 2011 visitor spending exceeded $800 million. Seasonal O_3 concentrations in the park have been among the highest in eastern U.S. -- under recent ambient conditions, 44 percent of the park was above 15 ppm-hrs. After adjustments to just meet the existing

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

[9] The prevalence scenarios are also discussion on page ES-5.

standard of 75 ppb, no area in the park exceeds 7 ppm-hrs. Rocky Mountain National Park has seven sensitive species, including Quaking Aspen. In 2011, visitor spending was over $170 million. Under recent ambient conditions, all of the park is above 15 ppm-hrs. When adjusted to just meet the existing standard, 59 percent of the park would be between 7 and 11 ppm-hrs. When adjusted to just meet an alternative standard level of 15 ppm-hrs, no area in the park exceeds 7 ppm-hrs. In Sequoia/Kings Canyon 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 7 ppm-hrs.

Additional Ecosystem Services Affected

Because 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_3 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. Surveys indicate that Americans have very strong preferences for existence, bequest, and option 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.

The **supporting service** of community composition, or structure, is affected by O_3 exposure because some species are more resistant to the negative effects of O_3 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. 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_3 on plants. Studies of O_3-impacted forests in eastern Tennessee in or near the Great Smoky Mountains has shown that ambient O_3 exposures resulted in increased water use in O_3-sensitive species, which decreased late-season stream flow modeled 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 potentially negatively affected by O_3 exposure. For example, O_3 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 areas of moderate or high fire risk and (i) recent W126 index values and (ii) air quality adjusted to just meet existing and alternative standard levels. The areas with 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 with high fire risk had W126 values over 7 ppm-hrs, and 74 percent had W126 values over 15 ppm-hrs. After just meeting the existing standard, almost all of the mixed conifer forest area with high fire risk is below 7 ppm-hrs. At the alternative standard level of 15 ppm-hrs, less than one percent of the high fire risk area is above 7 ppm-hrs. At alternative standard levels of 11 and 7 ppm-hrs, all of the high fire risk area is below 7 ppm-hrs.

O_3 exposure may increase 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 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 U.S. Forest Service 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 high pine beetle risk area is below 7 ppm-hrs. At the alternative standard level of 15 ppm-hrs, all of the high pine beetle risk area is less than 7 ppm-hrs.

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

CONCLUSIONS

This welfare REA provides analyses that further inform the following policy-relevant questions[10]: (1) in considering alternative standards, to what extent do alternative levels reduce estimated exposures and welfare risks attributable to O_3; (2) what range of alternative standard levels should be considered based on the scientific information evaluated in the Integrated Science Assessment, 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.

The analyses in this REA found 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_3 exposure-related welfare risk occurs when moving from recent ambient conditions to just meet the existing standard. This finding should be considered in the context of potential uncertainties in the actual responsiveness of W126 values in all areas to the emissions reductions used in the adjustments to just meet the existing standard. Keeping these potential uncertainties in mind, at an alternative standard level of 15 ppm-hrs, ambient O_3 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.

Despite uncertainties inherent in any complex, quantitative analysis, the overall body of scientific evidence underlying the ecological effects and associated ecosystem services evaluated in this welfare REA is strong, and the methods used to quantify associated risks are scientifically sound.

[10] The policy-relevant questions were identified in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards*.

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