United States Environmental Protection Agency

Welfare Risk and Exposure Assessment for Ozone

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Final

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
Risk and Benefits Group
Research Triangle Park, North Carolina 27711

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Questions on this document should be addressed to Dr. Bryan Hubbell at the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, 109 TW Alexander Drive, C504-02, Research Triangle Park, North Carolina 27711 or email -- hubbell.bryan@epa.gov.

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LIST OF ACRONYMS/ABBREVIATIONS

AGSIM	Agriculture Simulation Model
AQCD	Air Quality Criteria Document
AQS	Air Quality System
BLM	Bureau of Land Management
CAA	Clean Air Act
CAL FIRE	California Department of Forestry and Fire Protection
CASAC	Clean Air Scientific Advisory Committee
CASTNET	Clean Air Status and Trends Network
C.F.R.	Code of Federal Regulations
CH_4	Methane
CMAQ	Community Multi-Scale Air Quality
CO	Carbon Monoxide
C-R	Concentration-Response
CSTR	Continuous Stirred Tank Reactors
EGU	Electric Generating Unit
EPA	Environmental Protection Agency
FACE	Free- Air Carbon Dioxide/Ozone Enrichment
FASOMGHG	Forest and Agriculture Sector Optimization Model with Greenhouse Gases
FHM	Forest Health Monitoring
FHTET	Forest Health Technology Enterprise Team
FIA	Forest Inventory and Analysis
FR	Federal Register
GIS	Geographic Information System
GRSM	Great Smoky Mountains National Park
HDDM	Higher-Order Decoupled Direct Method
HNO_3	Nitric Acid
HO_2	Hydro-Peroxy Radical
IMPLAN®	Impact Analysis for Planning Model
IRP	Integrated Review Plan
ISA	Integrated Science Assessment
i-Tree	Urban Forestry Analysis and Benefits Assessment Tool
MEA	Millennium Ecosystem Assessment
MSA	Metropolitan Statistical Area

NAAQS	National Ambient Air Quality Standards
NCDC	National Climatic Data Center
NCLAN	National Crop Loss Assessment Network
NCore	National Core
NEI	National Emissions Inventory
FHWAR	National Survey of Fishing, Hunting, and Wildlife Associated Recreation
NHEERL-WED	National Health and Environmental Effects Laboratory – Western Ecology Division
NOAA	National Oceanographic and Atmospheric Administration
NOx	Oxides of Nitrogen
NPP	Net Primary Productivity
NPS	National Park Service
NSRE	National Survey on Recreation and the Environment
NTFP	Non-Timber Forest Products
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards
OBP	Ozone Biomonitoring Program
OH	Hydroxl Radical
OIF	Outdoor Industry Foundation
OTC	Open-Top Camber
PA	Policy Assessment
PAMS	Photochemical Assessment Monitoring Stations
ppb	Parts per Billion
ppm-hrs	Parts per Million Hours
POMS	Portable O3 Monitoring System
RBL	Relative Biomass Loss
REA	Risk and Exposure Assessment
ROMO	Rocky Mountains National Park
RYG	Relative Yield Gain
RYL	Relative Yield Loss
SEKI	Sequoia/Kings Canyon National Parks
SLAMS	State and Local Monitoring Stations
SOx	Oxides of Sulfur
SPMS	Special Purpose Monitoring Stations
STE	Stratosphere-Troposphere Exchange
TREGRO	Tree Growth Model

UNESCO	United National Education, Scientific, and Cultural Organization
U.S.	United States
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Society
VegBank	Vegetation Plot Database
VNA	Voronoi Neighbor Averaging
VOC	Volatile Organic Compound
WHO	World Health Organization
W126	Cumulative Integrated Exposure Index with a Sigmoidal Weighting Function
WTP	Willingness-to-Pay
ZELIG	A Forest Succession Simulation Model

1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the national ambient air quality standard (NAAQS) for ozone (O_3) and related photochemical oxidants. The NAAQS review process includes four key phases: planning, science assessment, risk/exposure assessment, and policy assessment/rulemaking.[1] This process and the overall plan for this review of the O_3 NAAQS are presented in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards* (IRP, US EPA, 2011a). The IRP additionally presents the schedule for the review; identifies key policy-relevant issues; and discusses the key scientific, technical, and policy documents. These documents include an Integrated Science Assessment (ISA), Risk and Exposure Assessments (REAs), and a Policy Assessment (PA). This final Welfare REA (WREA) is one of the two quantitative REAs developed for the review by EPA's Office of Air Quality Planning and Standards (OAQPS); the second is a Health REA (HREA). This WREA focuses on assessments to inform consideration of the review of the secondary (welfare-based) NAAQS for O_3.

The existing secondary standard for O_3 is set identical to the primary standard at a level of 0.075 ppm, based on the annual fourth-highest daily maximum 8-hour average concentration, averaged over three years (73 FR 16436). The EPA initiated the current review of the O_3 NAAQS on September 29, 2008 with an announcement of the development of an O_3 ISA and a public workshop to discuss policy-relevant science to inform EPA's integrated plan for the review of the O_3 NAAQS (73 FR 56581). Discussions at the workshop, held on October 29-30, 2008, informed identification of key policy issues and questions to frame the review of the O_3 NAAQS. Drawing from the workshop discussions, EPA developed a draft and then final IRP (U.S. EPA, 2011a).[2] In early 2013, EPA completed the *Integrated Science Assessment for Ozone and Related Photochemical Oxidants* (ISA, U.S. EPA, 2013). The O_3 ISA provides a concise review, synthesis, and evaluation of the most policy-relevant science to serve as a scientific

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[1] For more information on the NAAQS review process, see http://www.epa.gov/ttn/naaqs/review.html.

[2] On March 30, 2009, EPA held a public consultation with the CASAC O_3 Panel on the draft IRP. The final IRP took into consideration comments received from CASAC and the public on the draft plan, as well as input from senior Agency managers.

foundation for the review of the NAAQS. The scientific and technical information in the O_3 ISA, including that newly available since the previous review on the welfare effects of O_3, includes information on exposure, physiological mechanisms by which O_3 might adversely impact vegetation, and an evaluation of the ecological evidence, including information on reported exposure-response (E-R) relationships for O_3-related changes in plant biomass.

The REA is a concise presentation of the conceptual model, scope, methods, key results, observations, and related uncertainties associated with the quantitative analyses performed. This WREA builds upon the welfare effects evidence presented and assessed in the O_3 ISA, as well as CASAC advice (Samet, 2011) and public comments on a scope and methods planning document for the REAs (here after, "Scope and Methods Plan", U.S. EPA, 2011b). Preparation of this WREA draws upon the final O_3 ISA and reflects consideration of CASAC and public comments on the first and second drafts of the WREAs (Frey and Samet, 2012a, Frey, 2014). This WREA is being released, concurrently with the HREA and PA to inform the proposed NAAQS rulemaking.

The PA presents a staff evaluation and conclusions of the policy implications of the key scientific and technical information in the O_3 ISA and final REAs. The PA is intended to help "bridge the gap" between the Agency's scientific assessments presented in the ISA and REAs and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS. The PA integrates and interprets the information from the ISA and REAs to frame policy options for consideration by the Administrator. In so doing, the PA recognizes that the selection of a specific approach to reaching final decisions on primary and secondary NAAQS will reflect the judgments of the Administrator. The development of the various scientific, technical and policy documents and their roles in informing this NAAQS review are described in more detail in the PA.

1.1 HISTORY

As part of the previous O_3 NAAQS review completed in 2008, EPA's OAQPS conducted quantitative risk and exposure assessments to estimate risks to human welfare based on ecological effects associated with exposure to ambient O_3 (U.S. EPA 2007a, U.S. EPA 2007b). The assessment scope and methodology were developed with considerable input from CASAC and the public, with CASAC generally concluding that the exposure assessment reflected generally-accepted modeling approaches, and that the risk assessments were well done, balanced and reasonably communicated (Henderson, 2006a). The final quantitative risk and exposure assessments took into consideration CASAC advice (Henderson, 2006a; Henderson, 2006b) and public comments on two drafts of the risk and exposure assessments.

The assessments conducted as part of the previous review focused on national-level O_3-related impacts to sensitive vegetation and their associated ecosystems. The vegetation exposure assessment was performed using an interpolation approach that included information from ambient monitoring networks and results from air quality modeling. The vegetation risk assessment included both tree and crop analyses. The tree risk analysis included three distinct lines of evidence: (1) observations of visible foliar injury in the field linked to monitored O_3 air quality for the years 2001 – 2004; (2) estimates of seedling growth loss under then-current and alternative O_3 exposure conditions; and (3) simulated mature tree growth reductions using the TREGRO model to simulate the effect of meeting alternative air quality standards on the predicted annual growth of mature trees from three different species. The crop risk analysis included estimates of crop yields under current and alternative O_3 exposure conditions. The assessments also analyzed the associated changes in economic value upon meeting the levels of various alternative standards using an agricultural sector economic model.[3]

Based on the 2006 *Air Quality Criteria for Ozone* (U.S. EPA, 2006), the 2007 Staff Paper (U.S. EPA, 2007) and related technical support documents (including the risk and exposure assessments), EPA published a proposed decision in the Federal Register on July 11, 2007 (72 FR 37818). The EPA proposed to revise the level of the primary standard to a level within the range of 0.075 to 0.070 ppm. Two options were proposed for the secondary standard: (1) replacing the then existing standard with a cumulative, seasonal standard, expressed as an index of the annual sum of weighted hourly concentrations cumulated over 12 daylight hours during the consecutive 3-month period within the O_3 season with the maximum index value (W126), set

[3] We addressed key observations and insights from the O_3 risk assessment, in addition to important caveats and limitations, in Section II.B of the Final Rule notice (73 FR 16440 to 16443, March 27, 2008).

at a level within the range of 7 to 21 ppm-hours[4], and (2) setting the secondary standard identical to the revised primary standard. EPA completed the review with publication of a final decision on March 27, 2008 (73 FR 16436), revising the level of the 8-hour primary O_3 standard from 0.08 ppm to 0.075 ppm, as the 3-year average of the fourth highest daily maximum 8-hour average concentration, and revising the secondary standard to be identical to the revised primary standard.

In May 2008, state, public health, environmental, and industry petitioners filed suit against EPA regarding the 2008 decision. At EPA's request, the consolidated cases were held in abeyance pending EPA's reconsideration of the 2008 decision. The Administrator issued a notice of proposed rulemaking to reconsider the 2008 final decision on January 6, 2010. EPA held three public hearings. The Agency solicited CASAC review of the proposed rule on January 25, 2010 and additional CASAC advice on January 26, 2011. On September 2, 2011, the Office of Management and Budget returned the draft final rule on reconsideration to EPA for further consideration. EPA decided to coordinate further proceedings on its voluntary rulemaking on reconsideration with the ongoing periodic review, by deferring the completion of its voluntary rulemaking on reconsideration until it completes its statutorily-required periodic review. In light of that, the litigation on the 2008 final decision proceeded. On July 23, 2013, the Court ruled on the litigation of the 2008 decision, denying the petitioners suit except with respect to the secondary standard, which was remanded to the Agency for reconsideration. The PA provides additional description of the court ruling with regard to the secondary standard.

1.2 CURRENT RISK AND EXPOSURE ASSESSMENTS: GOALS AND PLANNED APPROACH

This final WREA provides an assessment of exposure and risk associated with recent ambient concentrations of O_3 and O_3 air quality adjusted to just meet the existing secondary O_3 standard and to just meet potential alternative O_3 standards based on recommendations provided in the first and second drafts of the PA. To inform the PA regarding the adequacy of existing standards and the potential for reductions in adverse effects associated with alternative standards

[4] See Chapter 2, Section 2.1 for additional discussion on the W126 metric.

that might be considered, the goals of this quantitative WREA are to (1) provide estimates of the ecological effects of O_3 exposure across a range of environments; (2) provide estimates of ecological effects within selected case study areas; (3) provide estimates of the effects of O_3 exposure on specific urban and non-urban ecosystem services based on the causal ecological effects; and (4) develop a better understanding of the response of ecological systems and ecosystem services to changing O_3 exposure. This quantitative risk and exposure assessment builds on the approach used and lessons learned in the previous O_3 risk assessments and focuses on improving the characterization of the overall confidence in the risk estimates, including related uncertainties, by improving the methods and data used in the analyses; this risk and exposure assessment also incorporates the range of ecosystem effects and expands the characterization of adversity to include consideration of impacts to ecosystem services. This assessment considers a variety of welfare endpoints for which, in our judgment, there is adequate information to develop quantitative risk estimates that can meaningfully inform the review of the secondary O_3 NAAQS.

1.3 ORGANIZATION OF DOCUMENT

The remainder of this document is organized into chapters. Chapter 2 provides a conceptual framework for the risk and exposure assessment, including discussions of O_3 chemistry, sources of O_3 precursors, ecological exposure pathways and uptake into plants, ecological effects, and ecosystem services endpoints associated with O_3. This conceptual framework sets the stage for the scope of the risk and exposure assessments. Chapter 3 provides an overview of the scope of the quantitative risk and exposure assessments, including a summary of the previous risk and exposure assessments and an overview of the current risk and exposure assessments. Chapter 4 discusses air quality considerations relevant to the exposure and risk assessments, including available O_3 monitoring data and important air quality inputs to the risk and exposure assessments. Chapter 5 describes the ecological effects of O_3 exposure and the associated ecosystem services, including the ecosystem services for which data and methods for incremental analysis of direct O_3 are not yet available. Chapter 6 provides quantitative analysis of the biomass loss effects of O_3 and the ecosystem services affected by this loss, such as provision of food and fiber, carbon sequestration and storage, and pollution removal. Chapter 7 provides quantitative assessments of the effects of O_3 on foliar injury and associated ecosystem services, particularly cultural services related to recreation and the three selected National Park case studies. Chapter 8 provides a summary of these analyses and an integrated discussion of the risk estimates generated in these analyses, drawing on the results of the quantitative analyses and incorporating considerations from the qualitative discussion of ecosystem services.

2 FRAMEWORK

In this chapter, we summarize the conceptual framework for assessing exposures of ecosystems to ozone (O_3) and the associated risks to public welfare. This conceptual framework includes elements related to characterizing: (1) O_3 chemistry (Section 2.1); (2) important sources of O_3 precursors, including oxides of nitrogen (NO_x) and volatile organic compounds (VOC) (Section 2.2); (3) O_3-induced effects occurring on O_3-sensitive species and in their associated ecosystems (Section 2.3); and (4) ecosystem services that are likely to be negatively impacted by changes in ecological functions resulting from O_3 exposures (Section 2.4). We conclude the chapter with key observations relevant for developing the scope of the quantitative risk and exposure assessments.

In the previous review of the secondary standards, we focused the ecological risk assessment on estimating changes in biomass loss in forest tree species and yield loss in agricultural crops, as well as 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 expanded scope is addressed in the risk assessment by quantifying the risks not just to ecosystems, but also to the aspects of public welfare dependent on those ecosystems, i.e., services. EPA has started using an ecosystem services framework to help inform determinations of the adversity to public welfare associated with changes in ecosystem functions (Rea et al., 2012). The Risk and Exposure Assessment conducted as part of the Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur (U.S. EPA, 2009) presented detailed discussions of how ecosystem services and public welfare are related and how an ecosystem services framework may be employed to evaluate effects on welfare. In this risk assessment, we identify the ecosystem services associated with the ecological effects caused by O_3 exposure for both the national-scale assessment and the more refined case study areas. These services may be characterized as: supporting services that are necessary for all other services (e.g., primary production); cultural services including existence and bequest values, aesthetic values, and recreation values, among others; provisioning services (e.g., food and timber); and regulating services such as climate regulation or hydrologic cycle (Millenium Ecosystem Assessment, 2005).

2.1 O_3 CHEMISTRY

Ozone occurs naturally in the stratosphere where it provides protection against harmful solar ultraviolet radiation; O_3 is also formed closer to the Earth's surface in the troposphere by both natural and anthropogenic sources. Ozone is not emitted directly into the air, but is created when its two primary precursors, VOC and NO_x, combine in the presence of sunlight. Volatile organic compounds and NO_x are, for the most part, emitted directly into the atmosphere. Carbon monoxide (CO) and methane (CH_4) are also important for O_3 formation (U.S. EPA, 2013, section 3.2.2).

Rather than varying directly with emissions of its precursors, O_3 changes in a nonlinear fashion with the concentrations of its precursors. Nitrogen oxide emissions lead to both the formation and destruction of O_3, depending on the local quantities of NO_x, VOC, and radicals such as the hydroxyl (OH) and hydro-peroxy (HO_2) radicals. In areas dominated by fresh NO_x emissions, these radicals are removed via the production of nitric acid (HNO_3), which lowers the O_3 formation rate. The reduction in, or scavenging of, O_3 by this reaction is called "titration" and is often found in downtown metropolitan areas, especially near busy streets and roads, and in power plant plumes. Titration is usually short-lived and confined to areas close to strong NO_x sources; titration results in localized valleys in which O_3 concentrations are low compared to surrounding areas. Consequently, O_3 response to reductions in NO_x emissions is complex and may include O_3 decreases at some times and locations and O_3 increases to fill in the local valleys of low O_3. In contrast, in areas with low NO_x concentrations, such as remote continental areas and rural and suburban areas downwind of urban centers, the net production of O_3 varies directly with NO_x concentrations and typically increases with increasing NO_x emissions.

In general, the rate of O_3 production is limited by the concentration of VOC or NO_x, and O_3 formation based on these two precursors depends on the relative sources of OH and NO_x. When OH radicals are abundant and are not depleted by reaction with NO_x and/or other species, O_3 production is "NO_x-limited" (U.S. EPA, 2013, section 3.2.4). In this NO_x-limited circumstance, O_3 concentrations are most effectively reduced by lowering NO_x emissions rather than by lowering VOC emissions. When OH and other radicals are not abundant, either through low production or reactions with NO_x and other species, O_3 production is referred to as "VOC-limited", "radical-limited", or "NO_x-saturated" (Jaegle et al., 2001), and O_3 is most effectively reduced by lowering VOC emissions. However, even in NO_x-saturated conditions, very large decreases in NO_x emissions can cause the O_3 formation regime to become NO_x-limited. Consequently, large reductions in NO_x emissions can make further emissions reductions more effective at reducing O_3. Between the NO_x-limited and NO_x-saturated extremes there is a range where O_3 is relatively insensitive to marginal changes in both NO_x and VOC emissions.

In rural areas and downwind of urban areas, O_3 production is generally NO_x-limited. This is particularly true in rural areas such as national parks, national forests, and state parks where VOC emissions from vegetation are high and anthropogenic NO_x emissions are relatively low. Due to lower chemical scavenging in non-urban areas, O_3 tends to persist longer in rural than in urban areas and tends to lead to higher cumulative exposures in rural areas than in urban areas (U.S. EPA, 2013, Section 3.6.2.2).

We focused the analyses in the welfare risk and exposure assessments on the W126 O_3 exposure metric. 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 (see Figure 2-1).

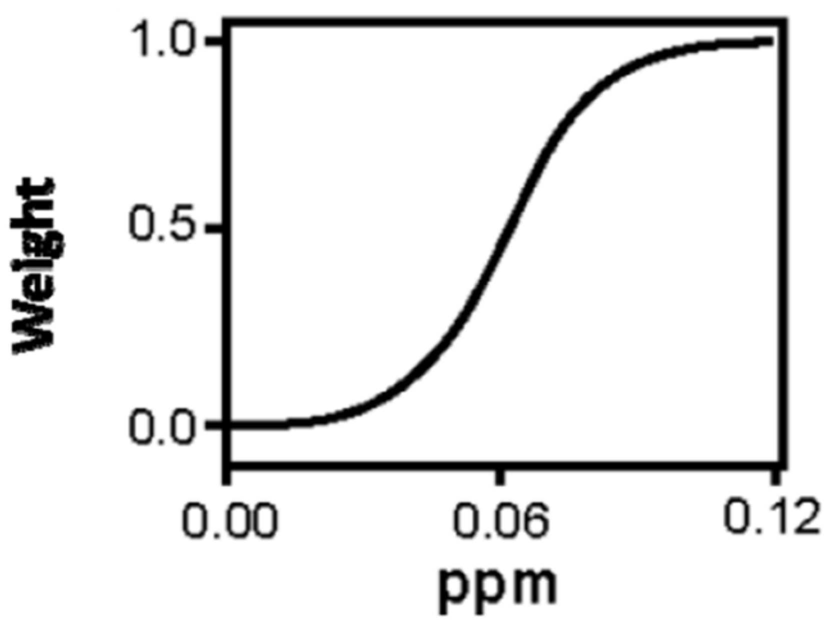

Figure 2-1 W126 Sigmoidal Weighting Function

2.2 SOURCES OF O_3 AND O_3 PRECURSORS

Ozone precursor emissions can be divided into anthropogenic and natural source categories, with natural sources further divided into biogenic emissions (from vegetation, microbes, and animals) and abiotic emissions (from biomass burning, lightning, and geogenic sources). The anthropogenic precursors of O_3 originate from a wide variety of stationary and mobile sources.

In urban areas, both biogenic and anthropogenic VOC emissions are relevant to O_3 formation. Hundreds of VOC are emitted by evaporation and combustion processes from a large number of anthropogenic sources. Based on the 2005 national emissions inventory (NEI), solvent use and highway vehicles are the two main sources of VOC emissions, with roughly equal contributions to total emissions (U.S. EPA, 2013, Figure 3-2). The emissions inventory categories of "miscellaneous" (which includes agriculture and forestry, wildfires, prescribed burns, and structural fires) and off-highway mobile sources are the next two largest contributing emissions categories, with a combined total of over 5.5 million metric tons of VOC emissions a year (MT/year).

In rural areas and at the global scale, VOC emissions from vegetation are much larger than those from anthropogenic sources. In the 2005 NEI, U.S. rural emissions from biogenic sources were 29 MT/year, and emissions of VOC from anthropogenic sources were approximately17 MT/year (wildfires constitute ~1/6 of that total). Vegetation emits substantial quantities of VOC, such as isoprene and other terpenoid and sesqui-terpenoid compounds. Most biogenic emissions occur during the summer because they depend on temperature and incident sunlight. Biogenic emissions are also higher in southern and eastern states than in northern and western states for these reasons and because of species variations.

Anthropogenic NO_x emissions are associated with combustion processes. Based on the 2005 NEI, the three largest sources of NO_x emissions in the U.S. are on-road and off-road mobile sources (e.g., construction and agricultural equipment) and electric power generation plants (electric generating units, or EGUs) (U.S. EPA, 2013, Figure 3-2). Emissions of NO_x are highest in areas with a high density of power plants and in urban regions with high traffic density. However, it is not possible to make an overall statement about their relative impacts on O_3 in all local areas because there are fewer EGUs than mobile sources, particularly in the west and south, and because of the nonlinear chemistry discussed in Section 2.1.

Major natural sources of NO_x in the U.S. include lightning, soils, and wildfires. Biogenic NO_x emissions are generally highest during the summer and occur across the entire country, including areas where anthropogenic emissions are low. It should be noted that uncertainties in estimating natural NO_x emissions are much larger than uncertainties in estimating anthropogenic NO_x emissions.

Ozone concentrations in a region are affected both by local formation and by transport from surrounding areas. Ozone transport occurs on many spatial scales, including local transport between cities, regional transport over large regions of the U.S., and international/long-range transport. In addition, O_3 is also transferred from the stratosphere into the troposphere, which is rich in O_3, through stratosphere-troposphere exchange (STE). These inversions or “foldings” usually occur behind cold fronts, bringing stratospheric air with them (U.S. EPA, 2013, section 3.4.1.1). Contribution to O_3 concentrations in an area from STE are defined as being part of background O_3 (U.S. EPA, 2013, section 3.4).

Rural areas, such as national parks, national forests, and state parks, tend to be less directly affected by anthropogenic pollution sources than urban sites. However, they can be regularly affected by transport of O_3 or O_3 precursors from upwind urban areas. In addition, biogenic VOC emissions tend to be higher in rural areas, and major anthropogenic sources of O_3 precursor emissions such as highways, power plants, biomass combustion, and oil and gas operations are commonly found in rural areas, adding to the O_3 produced in these areas. Areas at higher elevations, such as many of the national parks in the western U.S., can also be affected more significantly by international transport of O_3 or stratospheric intrusions that transport O_3 into the area (U.S. EPA, 2013, section 3.7.3).

2.3 ECOLOGICAL EFFECTS

Recent studies reviewed in the O_3 ISA support and strengthen the findings reported in the 2006 O_3 Air Quality Criteria Document (AQCD) (U.S. EPA, 2006). The most significant new body of evidence since the 2006 O_3 AQCD comes from research on molecular mechanisms of the biochemical and physiological changes observed in many plant species in response to O_3 exposure. These newer molecular studies not only provide very important information regarding the many mechanisms of plant responses to O_3, they also allow for the analysis of interactions between various biochemical pathways that are induced in response to O_3. However, many of these studies have been conducted in artificial conditions with model plants, which are typically exposed to very high, short doses of O_3 and are not quantifiable as part of this risk assessment.

Chapter 9 of the O_3 ISA (U.S. EPA, 2013) provides a detailed review of the effects of O_3 on vegetation including the major pathways of exposure and known ecological and ecosystem effects. In general, O_3 is taken up through the stomata into the leaves. Once inside the leaves, O_3 affects a number of biological and physiological processes, including photosynthesis. This leads, in some cases, to visible foliar injury as well as reduced plant growth, which are the main ecological effects assessed in this review. Visible foliar injury and reduced growth can lead to a reduction in ecosystem services, including crop and timber yield loss, decreased carbon sequestration, alteration in community composition, and loss of recreational or cultural value.

Overall causal determinations are made based on the full range of evidence including controlled exposure studies and field-based ecological studies. Figure 2-2 shows the O_3 welfare effects that have been categorized by strength of evidence for causality in the O_3 ISA (U.S. EPA, 2013, Chapter 2). These determinations support causal or likely causal relationships between exposure to O_3 and ecological and ecosystem-level effects.

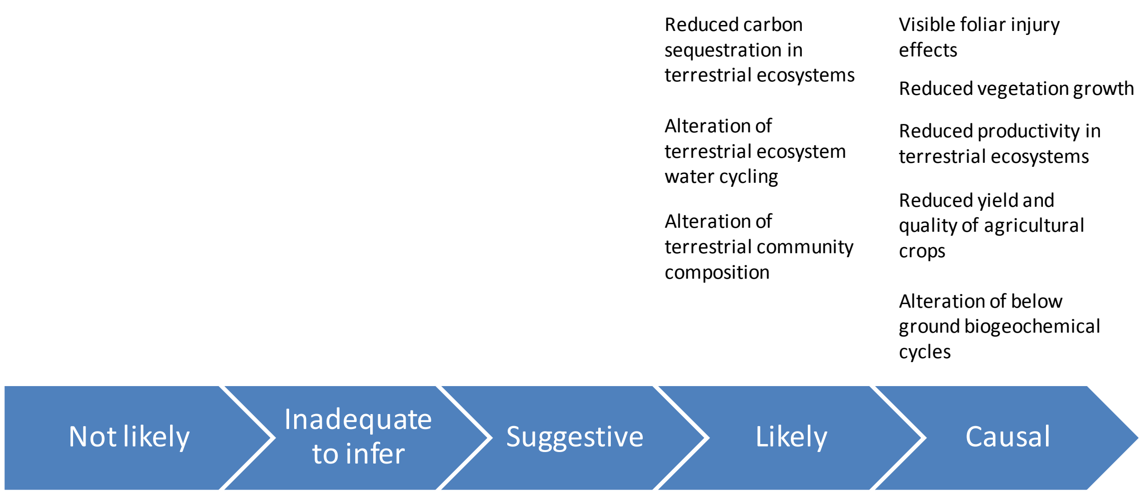

Figure 2-2 Causal Determinations for O_3 Welfare Effects

The adequate characterization of the effects of O_3 on plants for the purpose of setting air quality standards depends not only on the choice of the index used (e.g., W126) to summarize O_3 concentrations (Section 9.5 of the O_3 ISA), but also on quantifying the response of the plant variables of interest at specific values of the selected index. The factors that determine the response of plants to O_3 exposure include species, genotype and other genetic characteristics, biochemical and physiological status, previous and current exposure to other stressors, and characteristics of the exposure.

Quantitative characterization of exposure-response in the 2006 O_3 AQCD was based on experimental data generated for projects conducted by the National Crop Loss Assessment Network (NCLAN) and the EPA's National Health and Environmental Effects Research Laboratory, Western Ecology Division (NHEERL-WED) that used open-top chambers (OTCs) to expose crops and trees seedling to O_3. In recent years, additional yield and growth results for soybean and aspen, respectively, (two of the species that provided extensive exposure-response information in those projects) have become available from studies that used free-air carbon dioxide/ozone enrichment (FACE) technology, which is intended to provide conditions much closer to natural environments (Pregitzer et al., 2008; Morgan et al., 2006; Morgan et al., 2004; Dickson et al., 2000). The results of these FACE studies provided support for the earlier findings reported in the OTC studies.

The quantitative exposure-response relationships described in the 2006 O_3 AQCD have not changed in the O_3 ISA, with the exception of the addition of one new species. The exposure-response models are summarized in the final O_3 ISA (U.S. EPA, 2013) and are computed using the W126 metric, cumulated over 90 days. These response functions provide an adequate basis for quantifying biomass loss damages.

Visible foliar injury resulting from exposure to O_3 has also been well characterized and documented over several decades of research on many tree, shrub, herbaceous, and crop species (U.S. EPA, 2006, 1996a, 1984, 1978). Ozone-induced visible foliar injury symptoms on certain bioindicator plant species are considered diagnostic as they have been verified experimentally in exposure-response studies, using exposure methodologies such as continuous stirred tank reactors (CSTRs), OTCs, and free-air fumigation. Experimental evidence has clearly established a consistent association of visible injury with O_3 exposure, with greater exposure often resulting in greater and more prevalent injury. This welfare risk and exposure assessment assesses the risk of visible foliar injury at differing concentrations of O_3 using U.S. Forest Service biomonitoring data along with soil moisture information.

2.4 ECOSYSTEM SERVICES

The Risk and Exposure Assessment conducted as part of the Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur evaluates the benefits received from the resources and processes that are supplied by ecosystems. Collectively, these benefits are known as ecosystem services and include products or provisions, such as food and fiber; processes that regulate ecosystems, such as carbon sequestration; cultural enrichment; and supportive processes for services, such as nutrient cycling. Ecosystem services are distinct from other ecosystem products and functions because there is human demand for these services. In the Millennium Ecosystem Assessment (MEA), ecosystem services are classified into four main categories:

- Provisioning -- includes products obtained from ecosystems, such as the production of food and water.
- Regulating -- includes benefits obtained from the regulation of ecosystem processes, such as the control of climate and disease.
- Cultural -- includes the nonmaterial benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.
- Supporting -- includes those services necessary for the production of all other ecosystem services, such as nutrient cycles and crop pollination (MEA, 2005).

The concept of ecosystem services can be used to help define adverse effects as they pertain to NAAQS reviews. The most recent secondary NAAQS reviews have characterized known or anticipated adverse effects to public welfare by assessing changes in ecosystem structure or processes using a weight-of-evidence approach that includes both quantitative and qualitative data. For example, the previous O_3 NAAQS review evaluated changes in foliar injury, tree and crop growth loss, and biomass reduction in trees beyond the seedling stage. The presence or absence of foliar damage in counties meeting the existing standard has been used as a way to evaluate the adequacy of the secondary NAAQS. Characterizing a known or anticipated adverse effect to public welfare is an important component of developing any secondary NAAQS. According to the Clean Air Act (CAA), welfare effects include the following:

"Effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effect on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants." (Section 302(h))

In other words, welfare effects are those effects that are important to individuals and/or society in general. Ecosystem services can be generally defined as the benefits that individuals and organizations obtain from ecosystems. The EPA has defined ecological goods and services as the "outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future. Some outputs may be bought and sold, but most are not marketed" (U.S. EPA, 2006). Conceptually, changes in ecosystem services may be used to aid in characterizing a known or anticipated adverse effect to public welfare. In the context of this review, ecosystem services may also aid in assessing the magnitude and significance of a resource and in assessing how O_3 concentrations may impact that resource.

Figure 2-3 provides the World Resources Institute's schematic demonstrating the connections between the categories of ecosystem services and human well-being (MEA, 2005). The interrelatedness of these categories means that any one ecosystem may provide multiple services. Changes in these services can impact human well-being by affecting security, health, social relationships, and access to basic material goods (MEA, 2005). The strength of the linkages, as indicated by arrow width, and the potential for mediation, as indicated by arrow color, differ in different ecosystems and regions.

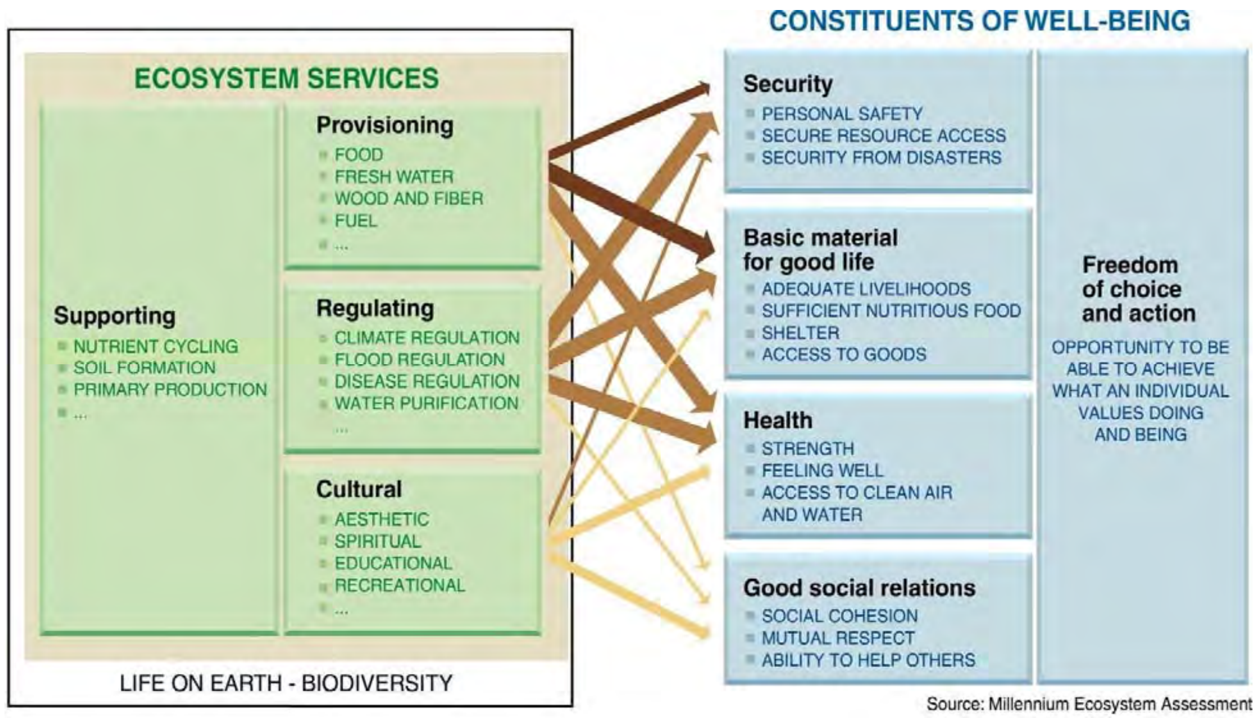

Figure 2-3 Linkages Between Ecosystem Services Categories and Components of Human Well-Being

The ecosystems of interest in this welfare risk and exposure assessment are impacted by the effects of anthropogenic air pollution, which may alter the services provided by the ecosystems in question. For example, changes in forest conditions as a result of O_3 exposure may affect supporting services such as net primary productivity; provisioning services such as timber production; regulating services such as climate regulation; provisioning services such as food; and cultural services such as recreation and ecotourism.

Where possible, we developed linkages to ecosystem services from indicators of each effect identified in the O_3 ISA (U.S. EPA, 2013). These linkages were based on existing literature and models, focus on the services identified in the peer-reviewed literature, and are essential to any attempt to evaluate O_3-induced changes on the quantity and/or quality of ecosystem services provided. According to the EPA's Science Advisory Board Committee on Valuing the Protection of Ecological Systems and Services, these linkages are critical elements for determining the valuation of benefits of EPA-regulated air pollutants (SAB CVPESS, 2009).

We have identified the primary ecosystem service(s) potentially impacted by O_3 for major ecosystem types and components (i.e., terrestrial ecosystems, productivity) under consideration in this risk and exposure assessment. The impacts associated with various ecosystem services for each targeted effect are assessed in Chapters 5, 6, and 7 of this document at a national scale and in the more refined case studies.

3 SCOPE

This chapter provides an overview of the scope and key design elements of the welfare risk and exposure assessment. The design of this assessment began with a review of the risk and exposure assessments completed during the previous review of the National Ambient Air Quality Standard for Ozone (O_3 NAAQS) (U.S. EPA, 2007), with an emphasis on considering key limitations and sources of uncertainty recognized in that analysis.

In October 2008, as an initial step in the current O_3 NAAQS review, the Environmental Protection Agency (EPA) invited outside experts, representing a broad range of expertise, to participate in a workshop with EPA staff to help inform the EPA's plan for the review. The participants discussed key policy-relevant issues that would frame the review, as well as the most relevant new science that would be available to inform our understanding of these issues. One workshop session focused on planning for quantitative risk and exposure assessments, taking into consideration what new research and/or improved methodologies would be available to inform the design of a quantitative welfare risk and exposure risk assessment. Based in part on the workshop discussions, the EPA developed a draft *Integrated Review Plan for the Ozone National Ambient Air Quality Standards* (IRP) (U.S. EPA, 2009) outlining the schedule, process, and key policy-relevant questions that would frame this review. On November 13, 2009, the EPA held a consultation with the Clean Air Scientific Advisory Committee (CASAC) on the draft IRP (74 FR 54562, October 22, 2009), which included opportunity for public comment. The final IRP incorporated comments from CASAC (Samet, 2009) and the public on the draft plan, as well as input from senior Agency managers. The final IRP included initial plans for the quantitative risk and exposure assessments for both human health and welfare (U.S. EPA, 2011a, chapters 5 and 6).

As a next step in the design of these quantitative assessments, the Office of Air Quality Planning and Standards (OAQPS) staff developed more detailed planning documents, including the following: *O_3 National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment* (Health Scope and Methods Plan; U.S. EPA, 2011b) and *O_3 National Ambient Air Quality Standards: Scope and Methods Plan for Welfare Risk and Exposure Assessment* (Welfare Scope and Methods Plan, U.S. EPA, 2011c). These plans were the subject of a May 19-20, 2011, consultation with CASAC (76 FR 23809, April 28, 2011).

Based on consideration of CASAC (Samet, 2011) and public comments on these plans and information in the second draft Integrated Science Assessment (ISA), we modified the scope and design of the risk and exposure assessment and drafted a memo with updates to the information presented in these plans (Wegman, 2012). We further modified the scope in response to comments from CASAC on the first draft assessment (Frey and Samet, 2012a). These plans, together with the update memo and comments from CASAC and the public, provide the basis for the discussion of the scope of the risk and exposure assessment provided in this chapter.

Section 3.1 of this chapter provides a brief overview of the risk and exposure assessment completed for the previous O_3 NAAQS review, including key limitations and uncertainties associated with that analysis. Section 3.2 provides a summary of the design of the current exposure assessment, including the ecosystem services framework, assessments for biomass loss and visible foliar injury. Section 3.3 provides an overview of the uncertainty and variability assessments.

3.1 OVERVIEW OF RISK AND EXPOSURE ASSESSMENTS FROM PREVIOUS REVIEW

The assessments conducted as part of the previous review focused on national-level O_3-related impacts to sensitive vegetation and their associated ecosystems. The vegetation exposure assessment was performed using an interpolation approach that included information from ambient monitoring networks and results from air quality modeling. The vegetation risk assessment included both tree and crop analyses. The tree risk analysis included three distinct lines of evidence: (1) observations of visible foliar injury in the field linked to monitored O_3 air quality for the years 2001 – 2004; (2) estimates of tree seedling growth loss under then current and alternative O_3 exposure conditions; and (3) simulated mature tree growth reductions of meeting alternative air quality standards on the predicted annual growth of mature trees from three different species. The crop risk analysis included estimates of crop yields under current and alternative O_3 exposure conditions. The EPA analyzed the associated changes in economic value upon meeting the levels of various alternative standards using an agricultural sector economic model. Key elements and observations from these risk and exposure assessments are outlined in the following sections.

3.1.1 Exposure Characterization

In many rural and remote areas where sensitive species of vegetation can occur, monitoring coverage is limited. Thus, the 2007 Staff Paper (U.S. EPA, 2007) concluded that it was necessary to use an interpolation method to better characterize O_3 concentrations over broad geographic areas and at the national scale. Based on the significant difference in monitoring network density between the eastern and western U.S., the 2007 Staff Paper further concluded that it was appropriate to use separate interpolation techniques in these two regions. The EPA used monitoring data for the eastern interpolation, and in the western U.S., where rural monitoring is sparser, the EPA used the Community Multi-scale Air Quality (CMAQ) model (http://www.epa.gov/asmdnerl/CMAQ, Byun and Ching, 1999; Byun and Schere, 2006) to develop scaling factors to augment the monitor interpolation.

To evaluate changing vegetation exposures under selected air quality scenarios, the EPA conducted a number of analyses. One analysis adjusted 2001 base year O_3 concentration distributions using a rollback method (Rizzo, 2005, 2006) to reflect meeting the current and alternative secondary standard options. For the "just meet" and alternative 8-hour average standard scenarios, the EPA generated the associated maps of estimated 3-month, 12-hour, W126 exposures.[1]

A second analysis in the 2007 Staff Paper identified the overlap between different alternative forms of the secondary standard. The analysis was designed to evaluate the extent to which county-level O_3 concentrations measured in terms of various concentrations of the then current 8-hour average form overlapped with concentrations measured in terms of the 3-month, 12-hour W126 cumulative, seasonal form. This analysis found that the number of counties meeting either one or both of the standard forms depended greatly on the level of the forms selected as well as the air quality pattern that exists in a particular year or set of years. Thus, the 2007 Staff Paper indicated that it remained uncertain as to the extent to which air quality improvements designed to reduce 8-hour average O_3 concentrations would also reduce O_3 exposures measured by a seasonal, cumulative W126 index. The 2007 Staff Paper stated this was an important consideration because: (1) the biological database stresses the importance of cumulative, seasonal exposures in determining plant response; (2) plants have not been

[1] See Section 4.3.1 for more information regarding the W126 O_3 exposure metric.

specifically tested for the importance of daily maximum 8-hour O_3 concentrations in relation to plant response; and (3) the effects of attainment of an 8-hour standard in upwind urban areas on rural air quality distributions cannot be characterized with confidence because of the lack of monitoring data in rural and remote areas.

3.1.2 Assessment of Risks to Vegetation

The risk assessments in the previous review reflected the availability of several lines of evidence that provided a picture of the scope of O_3-related vegetation risks for seedling, sapling and mature tree species growing in field settings and, indirectly, for forested ecosystems. To assess visible foliar injury, the 2007 Staff Paper presented an assessment that combined U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) biomonitoring site data with the county-level air quality data for those counties containing the FIA biomonitoring sites.

The EPA conducted separate assessments for seedlings and mature trees. To estimate growth reductions in seedlings, the EPA used exposure-response (E-R) functions developed from open- top chamber (OTC) studies for biomass loss for available seedling tree species and from information on tree growing regions derived from the U.S. Department of Agriculture's (USDA) *Atlas of United States Trees*. The E-R functions were then combined with projections of air quality based on 2001 interpolated exposures. To estimate growth reductions in mature trees, the EPA used a tree growth model (TREGRO) to evaluate the effect of changing O_3 concentration scenarios from just meeting alternative O_3 standards on the growth of mature trees. TREGRO is a process-based, individual tree growth simulation model (Weinstein et al, 1991) that is linked with concurrent climate data to account for O_3 and climate/meteorology interactions on tree growth. The model was run for a single western species (ponderosa pine) and two eastern species (red maple and tulip poplar). These three species were chosen based on the availability of species-specific parameterization in the model, their relative abundance in their respective regions, and the importance of their associated ecosystem services.

To estimate yield loss in agricultural commodity, fruit and vegetable crops, the EPA applied information from the National Crop Loss Assessment Network (NCLAN) program and a 1996 California fruit and vegetable analysis to develop E-R functions. The crop risk assessment, like the tree seedling assessment, combined E-R information on nine commodity crops and six fruit and vegetable species with crop growing regions, and interpolated exposures during each crop growing season.

The 2007 Staff Paper also presented estimates of economic valuation for crops associated with the then current and alternative standards. The Agriculture Simulation Model (AGSIM) (Taylor, 1993) was used to calculate annual average changes in total undiscounted economic surplus for commodity crops and fruits and vegetables when then current and alternative standard levels were met. The 2007 Staff Paper recognized that the modeled economic impacts from AGSIM had many associated uncertainties, which limited the usefulness of these estimates.

3.2 OVERVIEW OF CURRENT ASSESSMENT PLAN

Since the 2008 O_3 NAAQS review, new scientific information on the direct and indirect effects of O_3 on vegetation and ecosystems, respectively, has become available. With respect to mature trees and forests, the information regarding O_3 impacts to forest ecosystems has continued to expand, including limited new evidence that implicates O_3 as an indirect contributor to decreases in stream flow resulting from direct impacts on whole tree-level water use. Recently published results from the long-term Free-Air Carbon Dioxide Enrichment (FACE) studies provide additional evidence regarding chronic O_3 exposures in forests, including decreased tree heights, stem volumes (Kubiske et al., 2006), seed weight and seed germination (Darbah et al., 2008, 2007); and changes in tree community structure (Kubiske et al., 2007). In addition, a comparison, presented in the O_3 ISA (Section 9.6.3), using recent data from Aspen FACE found that O_3 effects on biomass accumulation in aspen during the first seven years of the experiment closely agreed with the E-R function based on data from earlier OTC experiments. In addition, recent available data from annual field surveys conducted by the USFS to assess visible foliar injury to selected tree species is available. In light of this more recent information, we are updating the analysis that combines the USFS data with recent air quality data to determine the incidence of visible foliar injury occurring across the U.S. at recent air quality concentrations and have included new assessments that combine foliar injury information with soil moisture data.

One of the objectives of the risk assessment for a secondary NAAQS is to quantify the risks to public welfare, including ecosystem services. For example, the *Risk and Exposure Assessment for Review of the Secondary National Ambient Air Quality Standards for Oxides of*

Nitrogen and Oxides of Sulfur (U.S. EPA, 2009) includes detailed discussions of how ecosystem services and public welfare are related and how an ecosystem services framework may be employed to evaluate effects on welfare. To the extent applicable, we provide qualitative and/or quantitative assessments of ecosystem services impacted by O_3 to inform the current review. In Chapter 5 of this assessment, we identify and describe the ecosystem services associated with the ecological effects for which data and methods for incremental analysis of direct O_3 are not yet available. For example, we overlay data on fire incidence, risk, and expenditures related to fires in California with O_3 data to better characterize areas where O_3 may result in increased risks of fires. Similarly, we also overlay data on bark beetle infestation with O_3 data. In chapters 6 and 7, we identify and describe the ecosystem services associated with the ecological effects for biomass loss and foliar injury, respectively, including national-scale assessments and more refined case study areas.

3.2.1 Air Quality Considerations

Air quality information and analyses are used to inform and support welfare-related assessments. The air quality information and analyses for this review build upon those in the O_3 ISA and include: (1) summaries of recent ambient air quality data; (2) application of a methodology to extrapolate measured O_3 concentrations to areas without monitors, including natural areas important to a welfare effects assessment such as national parks; and (3) adjustments of air quality to just meet the existing standard and potential alternative W126 secondary standards. In this assessment, we use W126 as a shorthand for the maximum consecutive 3-month, 12-hour daylight W126 index value. Consistent with the 2007 Staff Paper (U.S. EPA, 2007) and CASAC recommendation (Henderson et al., 2007), the air quality analyses in this assessment focus on the W126 metric. We provide more information regarding the air quality analyses in Chapter 4.

3.2.1.1 Recent Ambient Data

In addition to updating air quality summaries from the previous review, these air quality analyses include summaries of the recent ambient measurements for 2006 to 2010 for the form of the existing standard (ppb) and a potential alternative form of secondary standard (W126). The ambient measurements are from monitor data from the EPA's Air Quality System (AQS) database (which includes National Park Service monitors) and the EPA's Clean Air Status and

Trends Network (CASTNET) network. Since the previous review, the extent of monitoring coverage in non-urban areas has not significantly changed, and the monitoring network in some locations of the Western U.S. is sparse. We provide more information regarding the air quality analyses for recent ambient data in section 4.3.2.

3.2.1.2 National O_3 Exposure Surfaces for Recent Conditions

National-scale O_3 surfaces are used as inputs to the vegetation exposure and risk assessments described in subsequent sections. 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 used a spatial interpolation technique, called Voronoi Neighbor Averaging (VNA), (Gold, 1997; Chen et al., 2004) to create an air quality surface for the contiguous U.S. at a 12 kilometer grid resolution. We created annual W126 surfaces for each year from 2006 to 2010 and for a 3-year average for 2006-2008. We provide more information regarding the recent W126 exposure surfaces in section 4.3.1.

3.2.1.3 Adjustments to Just Meet Existing and Alternative Standards

The vegetation exposure assessments also rely on recent O_3 concentrations adjusted to just meet the existing standard and potential alternative secondary standards. All adjustments were made to monitored values. New VNA surfaces were then created from the adjusted monitored values. These surfaces are used in several vegetation assessments, including the geographic analysis for fire risk and bark beetle damage, the national- and case-study scale biomass loss assessments, and the national park case studies for foliar injury.

First, we adjusted hourly O_3 concentrations for recent conditions (2006-2008) to just meet the existing standard at 75 ppb. These hourly O_3 concentrations at monitor locations were then aggregated to the 3-year average of the W126 metric and compared against three potential alternative secondary standard levels of 15, 11, and 7 ppm-hrs. We selected these potential alternative standard levels for analysis in this WREA because CASAC recommended and supported a range of potential alternative W126 standard levels from 7 to 15 ppm-hrs during the previous review. In regions of the country for which the 75 ppb adjustment case left some monitors above the secondary standard level being evaluated, hourly O_3 was further adjusted to meet alternative W126 standard levels. In other words, these surfaces assume that the existing standard is met prior to adjustments to meet alternative standards. We describe the adjustment process in detail in section 4.3.2.

3.2.2 Relative Tree Biomass Loss and Crop Yield Loss

3.2.2.1 National-Scale Assessment: Exposure-Response Functions for Tree Seedlings and Crops

In the 2007 Staff Paper, the EPA derived information on tree species growing regions from the USDA Atlas of United States Trees (Little, 1971). In this assessment, we use more recent information (2006-2008) from the USFS Forest Health Technology Enterprise Team (FHTET) to update growing ranges for the 12 tree species studied by National Health and Environmental Effects Research Laboratory, Western Ecology Division (NHEERL-WED). We combine the national O3 surface with seedling E-R functions for each of the tree species and information on each tree species growing region to produce estimates of O3-induced seedling biomass loss for each of the 12 tree species. From this information, we generate GIS maps depicting seedling biomass loss for each species for each air quality scenario. For crops, we estimate yield loss for each of the 10 crop species from NCLAN. This analysis enabled direct evaluation of estimated seedling biomass loss for trees and yield loss for crops expected to occur under air quality exposure scenarios expressed in terms of recent air quality and, after adjusting to just meet the existing standard and potential alternative secondary standards. In addition, this assessment can be used to determine the W126 benchmark values associated with 1 to 2 percent seedling biomass loss for trees and 5 percent yield loss for crops. For biomass loss, CASAC recommended that the EPA should consider options for W126 standard levels based on factors including a predicted 1 to 2 percent biomass loss for trees and a predicted 5 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 (Frey and Samet, 2012b).

3.2.2.2 National-Scale Assessment: National Weighted RBL and Class I Areas

To assess overall ecosystem-level effects from biomass loss, we used FHTET data for modeled predictions of stand density and basal area. The resolution of the FHTET data is 1,000 square meter grids, and we summed these data into the larger CMAQ grid cells (12 km x 12 km). For the individual species analyses, these data were used only as a predictor of presence or absence. In the ecosystem-level analysis, these data were used to scale the biomass loss by the proportion of total basal area for each species. We combined the RBL values for 12 tree species into a weighted RBL rate and considered the weighted value in relation to proportion of basal area covered (as measured by proportion of geographic area with available data on species). A weighted RBL value is a relatively straightforward metric to attempt to understand the potential ecological effect on some ecosystem services. We provide more information regarding the individual species analysis in section 6.2.1.3 and the combined analysis in 6.8.

We also analyzed federally designated Class I areas in relation to the W126 surface and the weighted RBL values in the same manner as the analyses across the entire range of data. Out of 156 Class I areas nation-wide, 145 Class I areas had tree data available for this analysis. This analysis was conducted for air quality exposure scenarios expressed in terms of recent air quality (2006-2008) and after adjusting to just meeting the existing standard and potential alternative secondary standards. We provide more information regarding this analysis in section 6.8.1.1.

3.2.2.3 National-Scale Assessment: Ecosystem Services

The national-level ecosystem services quantified in this review associated with biomass and yield loss include provisioning services (e.g., timber and crops) and regulating services (e.g., carbon sequestration). Where information is available, we describe the impacts on other ecosystem services such as impacts on biodiversity, biological community composition, health of forest ecosystems, aesthetic values of trees and plants, and the nutritive quality of forage crops. We also describe the cultural ecosystem services associated with non-timber forest products. In addition, there is new preliminary evidence that O_3 adversely affects the ability of pollinators to find their targets, which could have broad implications for agriculture, horticulture, and forestry.

We use the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG) model (Adams et al., 2005) to estimate O_3 impacts on the agriculture and forestry sectors and quantify how O_3 exposure to vegetation affects the provision of timber and crops and carbon sequestration. FASOM, including the GHG version, has been used recently in many evaluations of effects of climate change on the timber and agriculture market sectors, in part because it accounts for the tradeoffs between land use for forestry and agriculture.

Specifically, FASOMGHG is a dynamic, non-linear programming model of the U.S. forest and agricultural sectors. The EPA uses this model to evaluate welfare benefits and market effects of O_3-induced biomass loss in trees and of carbon sequestration in trees, understory, forest floor, wood products and landfills that would occur under different agricultural and forestry scenarios. Using this model, we calculate the economic impacts of yield changes between recent ambient O_3 conditions and after adjusting to just meet the existing 75 ppb standard and alternative W126 standards.

3.2.2.4 Case Study Areas: Five Urban Areas

In selecting urban case study areas for more in-depth analysis of the ecosystem services associated with urban tree biomass loss, we relied on several criteria:

- Areas expected to have elevated W126 index values where ecological effects might be expected to occur.
- Occurrence of O_3-sensitive tree species and/or species for which O_3 E-R curves have been generated.
- Availability of vegetation information in the case study area.
- Geographic coverage representing a cross section of the nation, including urban and natural settings.

We use the i-Tree model to assess effects on regulating ecosystem services provided by urban forests, including pollution removal and carbon storage and sequestration for the case study areas. The i-Tree model is a publicly available, peer-reviewed software suite developed by the USFS and its partners to assess the ecosystem service impacts of urban forestry (available here: http://www.itreetools.org/). We collaborated with the USFS to vary the tree growth metric in the model, which allows us to assess the effects of O_3 exposure on the ability of the forests in the selected case study area to provide the services enumerated by the model. Specifically, we estimate impacts on vegetation in Atlanta, Baltimore, Syracuse, the Chicago region, and the urban areas of Tennessee. We present results for model runs representing recent ambient O_3 conditions, just meeting the existing 75 ppb standard, and just meeting alternative W126 standards.

3.2.3 Visible Foliar Injury

3.2.3.1 National Analysis of Visible Foliar Injury

To assess visible foliar injury (hereafter referred to as foliar injury) at a national scale, we compared data from the USFS Forest Health Monitoring Network (USFS, 2011) with O_3 exposure estimates and soil moisture data for 2006-2010. For estimates of short-term soil moisture in the contiguous U.S., we use NOAA's Palmer Z drought index (NCDC, 2012b). Foliar injury sampling data were not available for several western states (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, Oklahoma, and portions of Texas). This analysis provides estimates of the presence and absence of foliar injury for each of the 5 years by soil moisture category, which provides insight into the degree of protection that drought provides from foliar injury. Using this analysis, we derived multiple W126 benchmarks for evaluating foliar injury at national parks in a screening-level assessment and three case studies.

3.2.3.2 National-Scale Screening-level Assessment of Visible Foliar Injury in 214 National Parks

A study by Kohut (2007) assessed the risk of O_3-induced foliar injury on O_3-sensitive vegetation in 244 parks managed by the National Park Service (NPS). We modified this screening-level assessment to use more recent O_3 exposure and soil moisture data and to incorporate benchmarks derived from the national-scale foliar injury analysis (described above in section 3.2.3.1). Specifically, we use O_3 monitoring data to create spatial surfaces of O_3 exposure and short-term soil moisture data (Palmer Z) (NCDC, 2012b) for each year from 2006 to 2010. These data reflect the contiguous U.S. only, which is a key reason why this assessment includes fewer parks than Kohut (2007). Overall, the screening-level assessment includes 42 parks with O_3 monitors and 214 parks with O_3 exposure estimated from the interpolated O_3 surface. We combine these data with lists from the NPS of the parks containing O_3-sensitive vegetation species (NPS, 2003, 2006). Consistent with Kohut (2007), we consider the results for these parks without identified species as *potential* until sensitive species are identified in field surveys at these parks.

Using the results of the national-scale foliar injury analysis, we derived five W126 benchmark scenarios for evaluating foliar injury risk at parks in this screening-level assessment. One scenario reflects O_3 exposure only, and four scenarios reflect O_3 exposure and soil moisture jointly for different percentages of biosites with injury. For each of these scenarios, we identify the number of parks that exceed the benchmark criteria in each year.

3.2.3.3 National-Scale Assessment: Ecosystem Services

We use GIS mapping developed for the ecological effects analysis to illustrate where foliar injury may be occurring, and we cross reference those areas to national statistics for recreational use available through the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. DOI, 2011) and the National Survey on Recreation and the Environment (USDA, 2002). We also scale the resulting estimates of cultural service provision to the current population and values assigned using existing meta-data on willingness-to-pay from the Recreation Values Database.[2] We understand that these estimates are limited to current levels of service provision and provide a snapshot of the overall magnitude of services potentially affected by O_3 exposure. Currently, estimates of service loss from recent O_3 exposure are beyond the available data and resources, as is the calculation of changes in ecosystem services that might result from meeting existing and alternative O_3 standards. However, the current losses in service from O_3 exposure are embedded in estimates of the current level of services.

3.2.3.4 Case Study Analysis: Three National Parks

In selecting case study areas for more in-depth analysis of the ecosystem services associated with foliar injury, we relied on several criteria:

- Areas expected to have elevated W126 index values where ecological effects might be expected to occur.
- Availability of vegetation mapping, including estimates of species cover.
- Geographic coverage representing a cross section of the nation, including urban and natural settings.
- Occurrence of O_3 sensitive species and/or species for which O_3 E-R curves have been generated.

[2] Available at: http://recvaluation.forestry.oregonstate.edu/.

We selected Great Smoky Mountains National Park, Rocky Mountain National Park, and Sequoia/Kings National Park. All three of these park units are in areas with elevated ambient W126 index values, have vegetation maps, and have species that are considered O_3 sensitive. We considered including Acadia National Park, but we determined it did not fit our selection criteria. Specifically, Acadia did not have detailed vegetation mapping comparable to the selected parks, and the W126 index values were all well below 15 ppm-hrs. Using GIS, we compare the NPS vegetation maps to the national O_3 surface to illustrate where foliar injury may be occurring, particularly with respect to park amenities such as trails. Ecological metrics quantified for each park include:

- Percent of vegetation cover affected by foliar injury.
- Percent of trail length affected by foliar injury.

In national parks, foliar injury affects primarily cultural values that include existence, bequest and recreational values. In addition, we describe the other non-use values associated with national parks including existence and bequest values. We also provide park-specific statistics for recreational use available and estimates of service provision values using existing meta-data on willingness-to-pay from Kaval and Loomis (2003). We understand that these estimates are limited to current levels of service provision. Estimates of service loss due to O_3 exposure are beyond the available data and/or resources for many if not all ecosystem services listed above.

3.3 UNCERTAINTY AND VARIABILITY

An important issue associated with any ecological risk assessment is the characterization of uncertainty and variability. *Variability* refers to the heterogeneity in a variable of interest that is inherent and cannot be reduced through further research. For example, there may be variability among E-R functions describing the relationship between O_3 and vegetation injury across selected study areas. This variability may be due to differences in ecosystems (e.g., species diversity, habitat heterogeneity, and rainfall), concentrations and distributions of O_3 and/or co-pollutants, and/or other factors that vary either within or across ecosystems.

Uncertainty refers to the lack of knowledge regarding both the actual values of model input variables (parameter uncertainty) and the physical systems or relationships (model uncertainty – e.g., the shapes of E-R functions). In any risk assessment, uncertainty is, ideally, reduced by the maximum extent practical, through improved measurement of key parameters and ongoing model refinement. However, significant uncertainty often remains, and emphasis is then placed on characterizing the nature of that uncertainty and its impact on risk estimates. The characterization of uncertainty can include both qualitative and quantitative analyses, the latter requiring more detailed information and, often, the application of sophisticated analytical techniques. Sources of variability that are not fully reflected in the risk assessment can consequently introduce uncertainty into the analysis.

The goal in designing a quantitative risk assessment is to reduce uncertainty to the extent practical and to incorporate the sources of variability into the analysis approach to insure that the risk estimates are representative of the actual response of an ecosystem (including the distribution of that adverse response across the ecosystem). An additional aspect of variability that is pertinent to this risk assessment is the degree to which the set of selected case study areas provide coverage for the range of O_3-related ecological risk across the U.S.

Recent guidance from the World Health Organization (WHO, 2008) presents a four-tiered approach for characterizing uncertainty. With this four-tiered approach, the WHO framework provides a means for systematically linking the characterization of uncertainty to the sophistication of the underlying risk assessment, where the decision to proceed to the next tier is based on the outcome of the previous tier's assessment. Ultimately, the decision as to which tier of uncertainty characterization to include in a risk assessment will depend both on the overall sophistication of the risk assessment and the availability of information for characterizing the various sources of uncertainty. We used the WHO guidance as a framework for developing the approach used for characterizing uncertainty in this assessment. The four tiers described in the WHO guidance include:

- Tier 0: recommended for routine screening assessments, uses default uncertainty factors (rather than developing site-specific uncertainty characterizations);
- Tier 1: the lowest level of site-specific uncertainty characterization, involves qualitative characterization of sources of uncertainty (e.g., a qualitative assessment of the general magnitude and direction of the effect on risk results);

- Tier 2: site-specific deterministic quantitative analysis involving sensitivity analysis, interval-based assessment, and possibly probability bounded (high-and low-end) assessment; and

- Tier 3: uses probabilistic methods to characterize the effects on risk estimates of sources of uncertainty, individually and combined.

In this assessment, we applied a variety of quantitative (WHO Tier 2) and qualitative (WHO Tier1) analyses to address uncertainty and variability in this assessment of O_3-related ecological risks. In general, we attempted to quantify uncertainty and variability where we had sufficient data to do so and addressed these aspects qualitatively where we did not have data. Several analyses in this assessment include quantitative assessments of uncertainty and variability. In the air quality analyses, we quantified the standard errors associated with using regressions to relate modeled O_3 responses to O_3 concentrations at various locations and times of day, as well as during different seasons. For the analysis of the alternative percentages of biomass and yield loss, we plotted the E-R relationship for 54 crop studies and 52 tree seedling studies to estimate the differences in within-species variability. We also qualitatively compared the uncertainty in the relationship between E-R functions for tree seedlings and the effects on adult trees. For the screening-level assessment of foliar injury, we conducted several quantitative sensitivity analyses, including five scenarios reflecting consideration of soil moisture, three approaches for estimating O_3 exposure at monitored parks, three durations for soil moisture data, and two time periods evaluating different years of analysis. We provide detailed tables characterizing the uncertainty inherent in the various risk and exposure analyses at the end of Chapters 4, 5, 6, and 7.

4 AIR QUALITY CONSIDERATIONS

4.1 INTRODUCTION

Air quality information is used to assess exposures and ecological risks for national-scale air quality surfaces generated to estimate 2006-2008[1] average concentrations based on the W126 exposure metric, which is defined later in this chapter. These national-scale air quality surfaces are generated for five air quality scenarios by the methodology summarized in Sections 4.3.1 and 4.3.4 below. The five scenarios are for recent air quality, air quality adjusted to just meet the current standard, and air quality further adjusted to just meet three different W126 index values: 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs. Additional national-scale air quality surfaces are generated using observed W126 concentrations for individual years from 2006-2010. This chapter describes the air quality information used in these analyses, providing an overview of monitoring data and air quality (Section 4.2), and an overview of air quality inputs to the welfare risk and exposure assessments (Section 4.3).

4.2 OVERVIEW OF O_3 MONITORING AND AIR QUALITY

To monitor compliance with the NAAQS, state and local environmental agencies operate O_3 monitoring sites at various locations, depending on the population of the area and typical peak O_3 concentrations. In 2010, there were over 1,300 state, local, and tribal O_3 monitors reporting concentrations to EPA. The minimum number of O_3 monitors required in a Metropolitan Statistical Area (MSA) ranges from zero, for areas with a population under 350,000 and with no recent history of an O_3 design value greater than 85 percent of the NAAQS, to four, for areas with a population greater than 10 million and an O_3 design value greater than 85percent of the NAAQS.[2] In areas for which O_3 monitors are required, at least one site must be designed to record the maximum concentration for that particular metropolitan area (US EPA, 2013, Sections 3.5.6.1 and 3.7.4). Since O_3 concentrations are usually significantly lower in the colder months of the year,

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[1] The focus was placed on the years of 2006-2008 based on availability of data during that time period.

[2] The existing monitoring network requirements (40 CFR Part 58, Appendix D) have an urban focus and do not address siting in non-urban (rural) areas. States may operate ozone monitors in non-urban (rural) areas to meet other objectives (e.g., support for research studies of atmospheric chemistry or ecosystem impacts).

O_3 is required to be monitored only during the required O_3 monitoring season, which varies by state (US EPA, 2013, Figure 3-24).[3]

While the existing U.S. O_3 monitoring network has a largely urban focus, to address ecosystem impacts of O_3 such as biomass loss and foliar injury, it is equally important to focus on O_3 monitoring in rural areas. Figure 4-1 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 which are largely operated by state and local governments to meet regulatory requirements and provide air quality information to public health agencies, and thus are 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. There were about 80 CASTNET sites operating in 2010, 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). Finally, 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. Between the CASTNET, NCore, and POMS networks, there were about 120 rural O_3 monitoring sites in the U.S. in 2010.

[3]Some States and Territories are required to operate ozone monitors year-round, including Arizona, California, Hawaii, Louisiana, Nevada, New Mexico, Puerto Rico, Texas, American Samoa, Guam and the Virgin Islands.

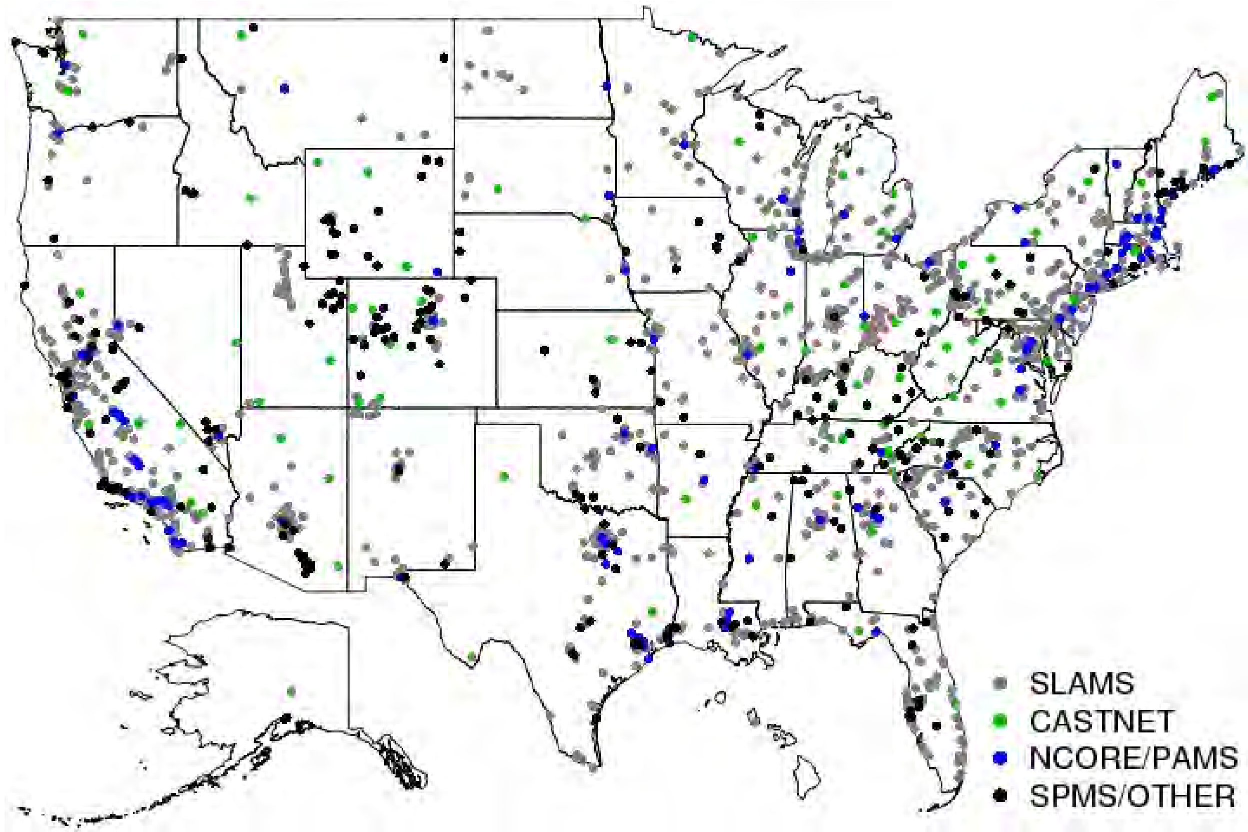

Figure 4-1 Map of U.S. ambient O_3 monitoring sites in operation during 2006-2010

To determine whether or not the NAAQS have been met at an ambient O_3 monitoring site, a statistic commonly referred to as a "design value" must be calculated based on 3 consecutive years of data collected from that site. The form of the existing O_3 NAAQS design value statistic is the 3-year average of the annual 4^{th} highest daily maximum 8-hour average O_3 concentration in parts per billion (ppb), with decimal digits truncated. The existing primary and secondary O_3 NAAQS are met at an ambient monitoring site when the design value is less than or equal to 75 ppb.[4] Figure 4-2 shows the design values for the existing 8-hour O_3 NAAQS for all regulatory monitoring sites in the U.S. for the 2006-2008 period. Monitors shown as red dots had design values above the existing O_3 NAAQS of 75 ppb in 2006-2008.

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[4]For more details on the data handling procedures used to calculate design values for the existing O_3 NAAQS, see 40 CFR Part 50, Appendix P.

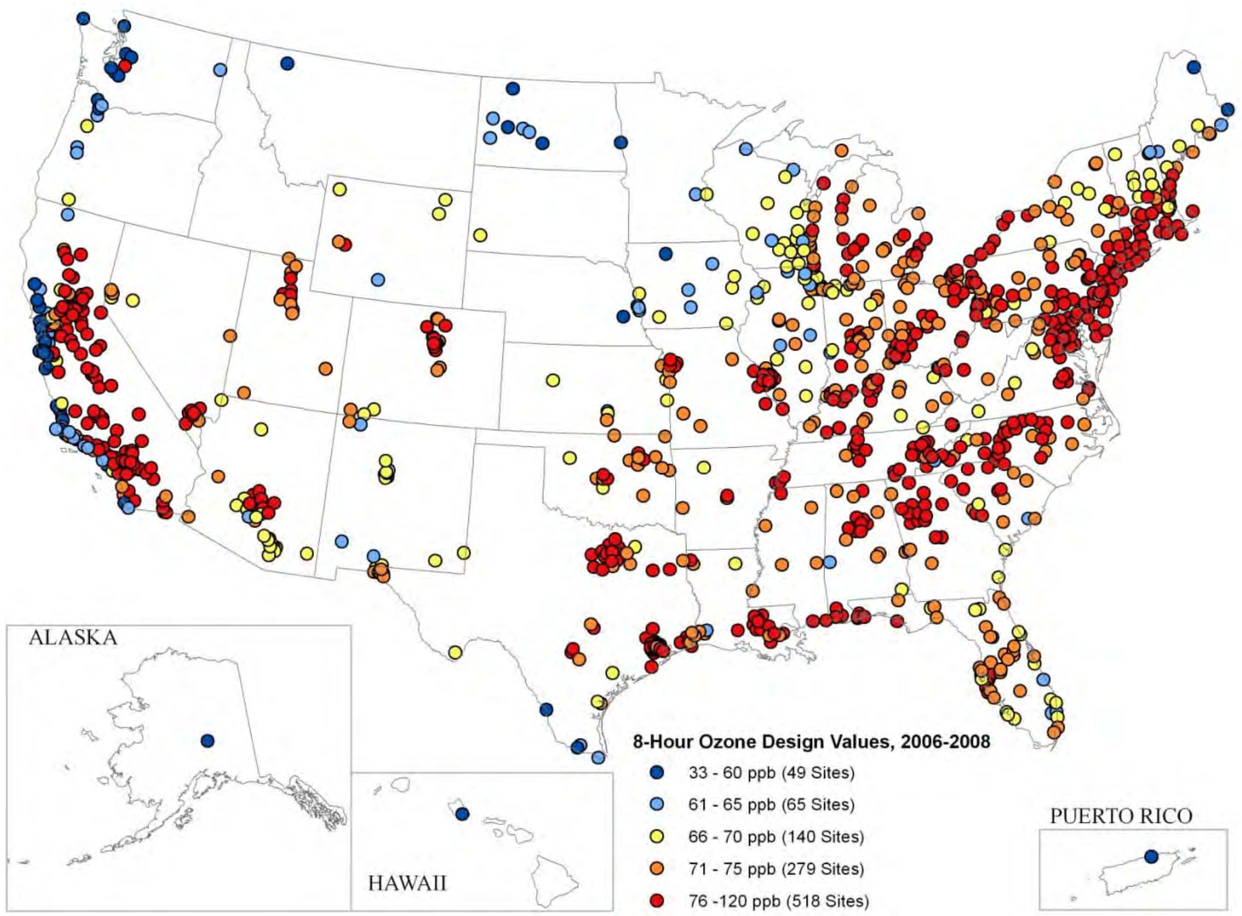

Figure 4-2 Map of monitored 8-hour O_3 design values for the 2006-2008 period

4.3 OVERVIEW OF AIR QUALITY INPUTS TO RISK AND EXPOSURE ASSESSMENTS

In this section, we summarize the air quality inputs for the welfare risk and exposure assessments, and discuss the methodology used to adjust air quality to meet the existing standard and potential alternative standards. These steps are summarized in the flowchart in Figure 4-3 and discussed in more detail in this section.

Section 4.3.1 describes the W126 metric upon which the potential alternative standards are based. Section 4.3.2 describes the ambient air quality monitoring data used in the welfare risk and exposure assessments. Section 4.3.3 describes the procedure used to generate the national-scale air quality surfaces upon which several of the welfare risk and exposure analyses are based, with further details in Appendix 4a. Finally, Section 4.4.4 summarizes the method used to adjust observed air quality concentrations to just meet the existing standard and potential alternative standards, and discusses the resulting distributions of adjusted W126 concentrations.

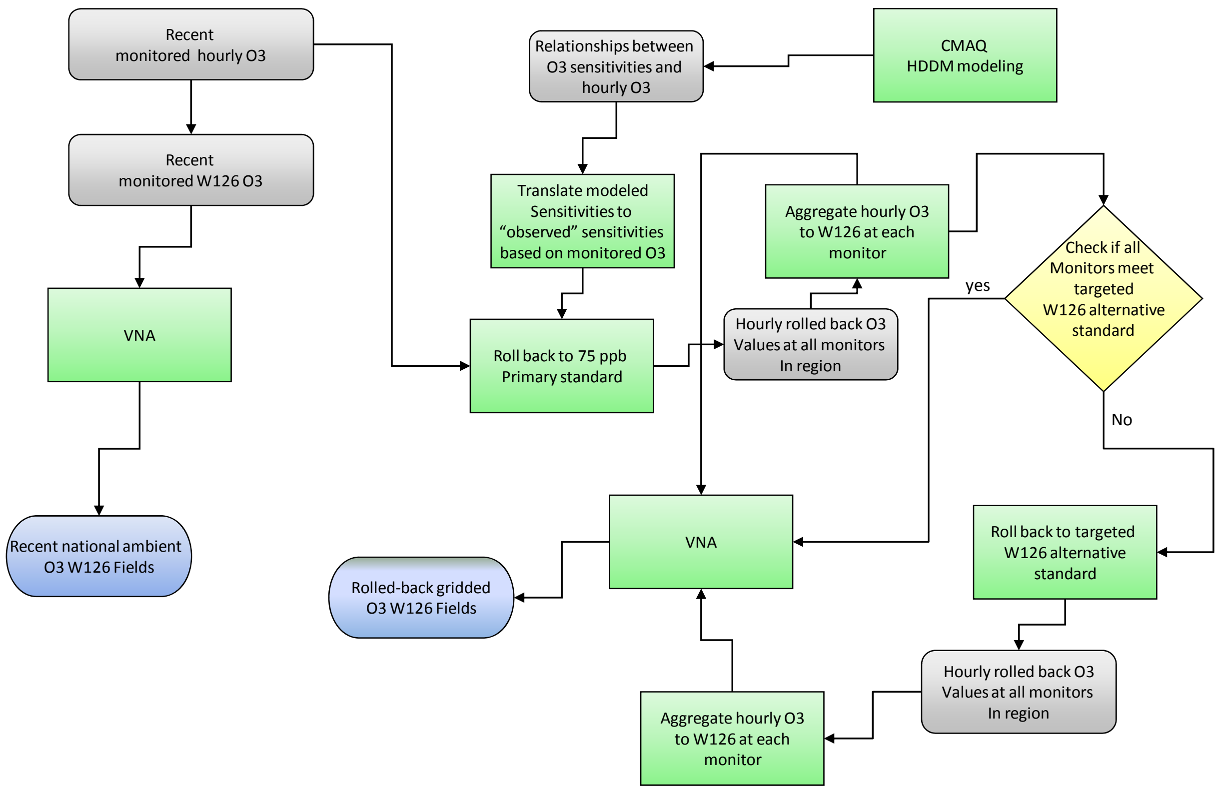

Figure 4-3 Flowchart of air quality data processing for different parts of the welfare risk and exposure assessments.

4.3.1 Air Quality Metrics

EPA focused the analyses in the welfare risk and exposure assessments on the W126 O_3 exposure metric. The W126 metric is a seasonal aggregate of hourly O_3 concentrations, designed to measure the cumulative effects of O_3 exposure on vulnerable plant and tree species, with units in parts per million-hours (ppm-hrs). The metric uses a logistic weighting function to place less emphasis on exposure to low hourly O_3 concentrations and more emphasis on exposure to high hourly O_3 concentrations (Lefohn et al, 1988).

The first step in calculating W126 concentrations was to sum the weighted hourly O_3 concentrations within each calendar month, resulting in monthly index values. Since plant and tree species are not photosynthetically active during nighttime hours, only O_3 concentrations observed during daytime hours (defined as 8:00 AM to 8:00 PM local time) were included in the summations. The monthly W126 index values were calculated from the hourly O_3 concentration data as follows:

$$\boldsymbol{Monthly\, W126 = \sum_{d=1}^{N} \sum_{h=8}^{19} \frac{C_{dh}}{1 + 4403 * \exp(-126 * C_{dh})}}$$

where N is the number of days in the month,

d is the day of the month (d = 1, 2, …, N),

h is the hour of the day (h = 0, 1, …, 23),

C_{dh} is the hourly O_3 concentration observed on day d, hour h, in parts per million.

Next, the monthly W126 index values were adjusted for missing data. If N_m is defined as the number of daytime O_3 concentrations observed during month m (i.e. the number of terms in the monthly index summation), then the monthly data completeness rate is $V_m = N_m / 12 * N$. The monthly index values were adjusted by dividing them by their respective V_m. Monthly index values were not computed if the monthly data completeness rate was less than 75 percent ($V_m < 0.75$).

Finally, the annual W126 index values were computed as the maximum sum of their respective adjusted monthly index values occurring in three consecutive months (i.e., January–March, February–April, etc.). Three-month periods spanning across two years (i.e., November–January, December–February) were not considered, because the seasonal nature of O_3 makes it unlikely for the maximum values to occur at that time of year. The annual W126 concentrations were considered valid if the data met the annual data completeness requirements for the existing standard. Three-year W126 index values are calculated by taking the average of annual W126 index values in the same three-month period in three consecutive years.[5]

[5] W126 calculations are slightly modified in the case of the model adjustment scenarios described in Section 4.3.4. When calculating W126 for the model adjustment cases, we first found the three-year average of each three-month period, and then selected the three-month period with the highest three-year average using the same three-month period for each of the three years.

4.3.2 Ambient Air Quality Measurements

Air quality monitoring data from 1,468 U.S. ambient O_3 monitoring sites were retrieved for use in the risk and exposure assessments. The initial dataset was the same as the one used for the health REA (HREA), which consisted of hourly O_3 concentrations in ppb collected between 1/1/2006 and 12/31/2010 from these monitors. Data for nearly 1,400 of these monitors were extracted from EPA's Air Quality System (AQS) database[6], while the remaining data came from EPA's Clean Air Status and Trends Network (CASTNET) database which consists of primarily rural monitoring sites.

Observations flagged in AQS as having been affected by exceptional events were included the initial dataset, but were not used in design value calculations in accordance with EPA's exceptional events policy. Missing data intervals of 1 or 2 hours in the initial dataset were filled in using linear interpolation. These short gaps often occur at regular intervals in the ambient data due to an EPA requirement for monitoring agencies to perform routine quality control checks on their O_3 monitors. Quality control checks are typically performed between midnight and 6:00 AM when O_3 concentrations are low. Missing data intervals of 3 hours or more were not replaced, and interpolated data values were not used in design values calculations.

Annual W126 concentrations were calculated from the ambient data for each year in the 2006-2010 period, as well as 3-year averages of the 2006-2008 annual W126 concentrations. Figure 4-4 shows the 2006-2008 average W126 concentrations in ppm-hrs at all monitoring sites in the contiguous U.S. Monitors outside of the contiguous U.S. were not included in the welfare analyses since they fell outside of the CMAQ 12 km modeling domain, and were already well below the existing and potential alternative standards.

[6] EPA's Air Quality System (AQS) database is a national repository for many types of air quality and related monitoring data. AQS contains monitoring data for the six criteria pollutants dating back to the 1970's, as well as more recent additions such as $PM_{2.5}$ speciation, air toxics, and meteorology data. At present, AQS receives hourly O_3 monitoring data collected from nearly 1,400 monitors operated by over 100 state, local, and tribal air quality monitoring agencies.

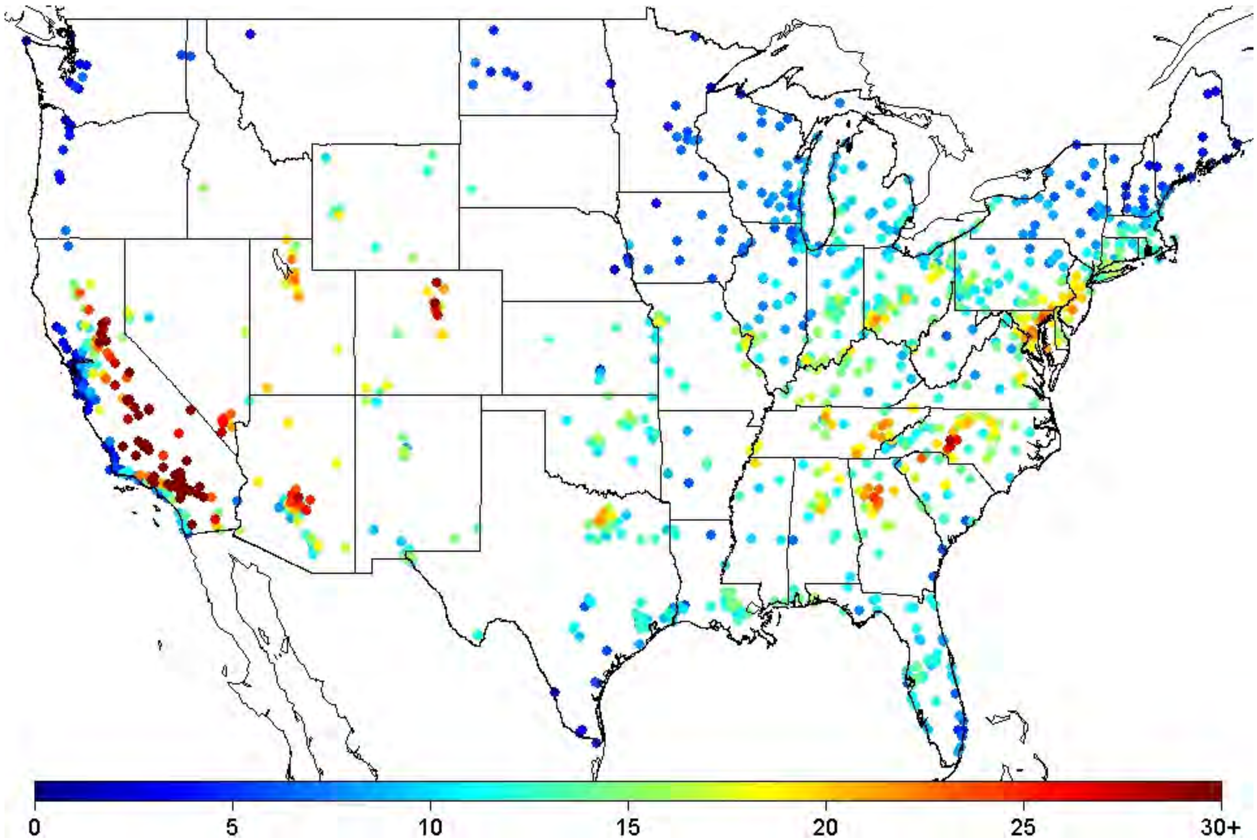

Figure 4-4 Monitored 2006-2008 average W126 concentrations in ppm-hrs

4.3.3 National-scale Air Quality Surfaces for Recent Air Quality

In addition to ambient monitoring data, the welfare risk and exposure assessments analyzed national-scale air quality surfaces. For the biomass loss analyses presented in Chapter 6, a national-scale surface was generated from the monitored 2006-2008 average W126 concentrations using the Voronoi Neighbor Averaging (VNA) technique (Gold, 1997; Chen et al, 2004) (Figure 4-5). For the foliar injury analysis presented in Chapter 7, national-scale surfaces were generated from the monitored annual W126 concentrations for individual years 2006-2010, also using VNA. Maps of the annual W126 air quality surfaces for 2006-2010 are included in Appendix 4-A.

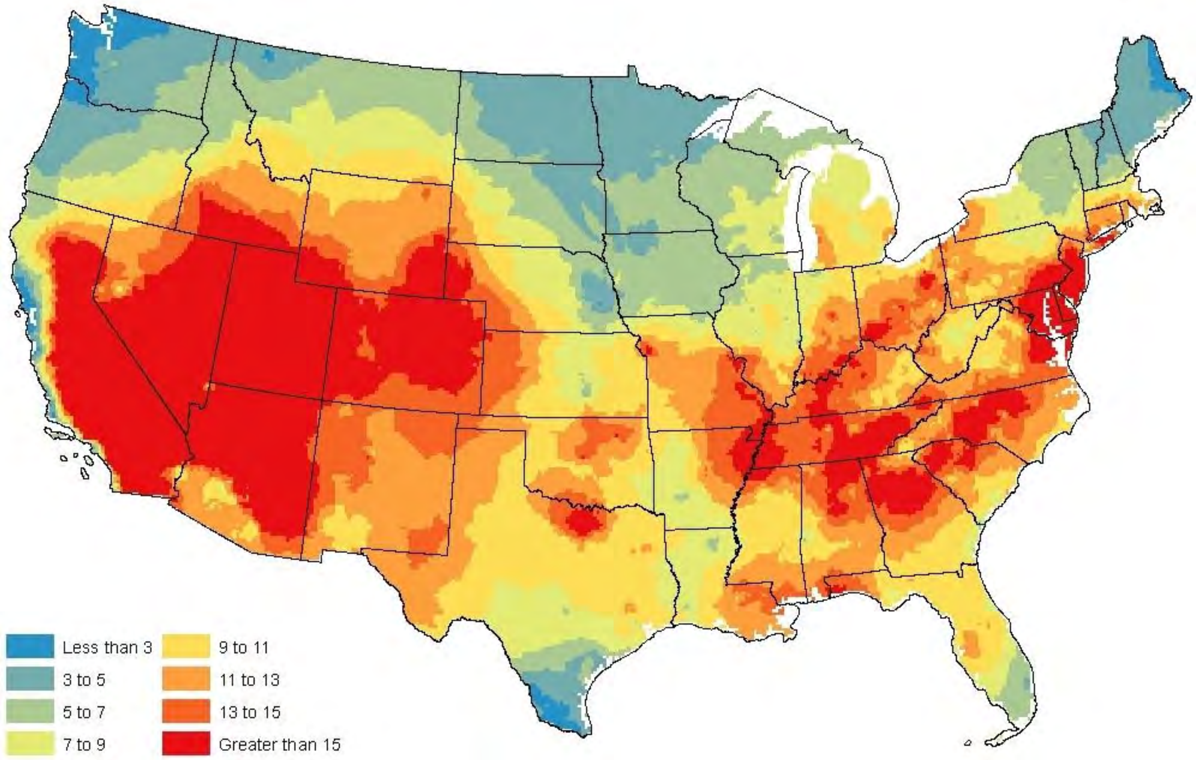

Figure 4-5 National surface of observed 2006-2008 average W126 concentrations, in ppm-hrs

In the 1st draft of the welfare REA (WREA), the national-scale air quality surfaces were created by "fusing" monitored 2006-2008 average W126 concentrations with annual W126 concentrations from a 2007 CMAQ model simulation, using the enhanced Voronoi Neighbor Averaging (eVNA) technique (Timin et al., 2010). The resulting surfaces contained estimates of the 2006-2008 average annual W126 concentrations at a 12km grid cell resolution in the contiguous U.S. modeling domain. Here, the air quality surfaces of the 2006-2008 average W126 concentrations are based solely on monitored W126 concentrations and do not include CMAQ model predictions. The reason for this change from the first draft WREA is discussed below.

In addition to the VNA methodology, two alternative methods for creating the national-scale air quality surfaces were also considered: eVNA and Downscaler (Berrocal et al, 2012; used in the HREA). Both the eVNA and Downscaler methods were tested using updated 2007 12km

CMAQ modeling[7] that is described in detail in Appendix 4-B of the HREA. While each of the three methods had its own advantages and disadvantages, the VNA method was ultimately selected because large differences between the modeled W126 surface and the monitored W126 concentrations[8] made the two "data fusion" methods more uncertain in some instances, whereas VNA did not suffer from this problem since it is based solely on monitored values. Technical justification for the change from eVNA to VNA, including a cross-validation analysis, and comparisons between the resulting air quality surfaces for these three methods, can be found in Appendix 4-A.

4.3.4 Air Quality Adjustments to Meet Existing Primary and Potential Alternative Secondary O_3 Standards

In addition to observed W126 levels, the risk and exposure assessments also consider the relative change in risk and exposure after adjusting air quality to just meet the existing O_3 standard of 75 ppb, and further adjusting air quality to just meet possible alternative standards with forms based on the W126 metric and levels of 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs. The sections below summarize the methodology used to adjust observed air quality concentrations to just meet the existing standard and potential alternative standards, and discuss the resulting adjusted distributions of W126 concentrations. More details on these inputs are provided in Appendix 4A.

4.3.4.1 Adjustment Methods

The model-based HDDM O_3 adjustment approach used for this analysis is the same general methodology developed for evaluating air quality distributions that could occur if meeting various alternate levels of the primary standard. This methodology is described in detail in Chapter 4 and Appendix 4D of the HREA and additional details on HDDM itself are also provided in Appendix 4D of the HREA. A brief description of the HDDM adjustment process and key differences from the HREA are provided in this section.

The first step of the HDDM adjustment technique is to obtain modeled sensitivities (responses) of O_3 concentrations to perturbations in U.S. anthropogenic NOx emissions. Monitor,

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[7] The updated CMAQ modeling used wildfire emissions based on a multi-year average instead of 2007-specific wildfires.

[8] The 2007 CMAQ simulation over-predicted W126 values by an average of 4 ppm-hrs in monitored locations. A more in depth model evaluation of CMAQ W126 values is provided in Appendix 4A.

season and hour-of-day specific relationships between sensitivities and modeled ozone concentrations were developed based on the modeling data. These responses are then applied to ambient data to create a 3-year time-series of hourly O_3 concentrations at each monitor location which is consistent with meeting various potential levels of the ozone NAAQS for 2006-2008.

There are a few key differences between the adjustments made in the HREA and those performed here. First, the adjustments in HREA focused on 15 urban study areas while those used in the WREA cover all monitoring sites across the US. In the HREA, a uniform reduction of U.S. anthropogenic emissions was applied to all sites within an urban area. By applying equal proportional decreases in emissions throughout the contiguous U.S., we were able to estimate how hourly O_3 concentrations would respond to changes in ambient NOx concentrations without simulating a specific control strategy. Note that the HDDM-adjustment approach was not designed to produce an optimal control scenario but instead aimed to characterize a potential distribution of air quality across a region when all monitors are meeting the existing standard and potential alternative standards. In contrast to the 15 study area analyses performed for the HREA, both the ecosystem services analysis (Chapter 5) and biomass loss analysis (Chapter 6) require nationally consistent surfaces of W126 values as inputs. To create these surfaces, we balanced the need for nationally consistent surfaces and the regional nature of W126 values with the potential scale over which the secondary standard might be evaluated. If considering two potential bounding scenarios, d using a single emissions reduction scenario for the entire U.S. could overstate the amount of NOx reductions needed to just meet alternative W126 levels in different regions of the U.S., while creating numerous distinct locally adjusted areas could lead to a patchwork of disjointed W126 surfaces. Consequently in this analysis, we determined the level of U.S. NOx emissions reduction that would result in O_3 just meeting the potential alternative W126 levels independently for nine distinct regions of the contiguous U.S. (Figure 4-6) based on the National Oceanic and Atmospheric Administration (NOAA) climate regions (Karl and Koss, 1984). NOAA characterizes each region as being "climatically consistent" and routinely uses these regions to describe regional climate trends. These regions were deemed an appropriate delineation for this analysis since geographic patterns of both O_3 and plant species are driven by climatic features such as temperature and precipitation and because they broadly align with distinct emissions regions (for instance the central region contains a greater density of the nation's coal-fired power plants while the northeast region contains the highly urbanized northeast corridor). The regions are large enough to account for pollutant transport but not so large as to unrealistically include the impacts of emissions reductions at locations far from the monitors in the region with the highest W126 values.

Analogous to the procedure used in the HREA for the urban study areas, a single NOx emissions adjustment was used to adjust ambient air quality data at all O_3 monitoring sites within each region and for each air quality standard scenario considered. The magnitude of this emissions adjustment was determined independently for each region and standard by determining the smallest adjustment necessary to ensure all sites within a region would meet the existing standard or the potential alternative standards (Table 4-1). In a few cases, all monitors in the region met one or more of the alternative standards based on 2006-2008 observations, and thus there was no need for model-based adjustments. These cases are represented by values of "0" in Table 4-1. By evaluating the effect of U.S. anthropogenic emissions reductions on all monitoring sites within a region, our analysis incorporates the effects of emissions reductions on both local O_3 production and regional transport. Since each region is treated independently, the effects of the emissions reductions required to bring a particular region down to the targeted standard levels do not affect other regions which require less drastic emissions reductions. In portions of the country with lower W126 values than nearby locations, the emissions adjustment determined by the controlling or design monitor in the region may be larger than the emissions reductions that would be required if the nine climate regions were replaced by many smaller localized areas. However, by considering larger regions, we are able to account for the fact that nearby emissions reductions will affect O_3 monitors already meeting the targeted standard level.[9]

[9] Another rationale for the use of large regions is that the air quality adjustments are computationally intensive, and focusing on a small number of large regions, rather than many localized areas, greatly reduces the problem size.

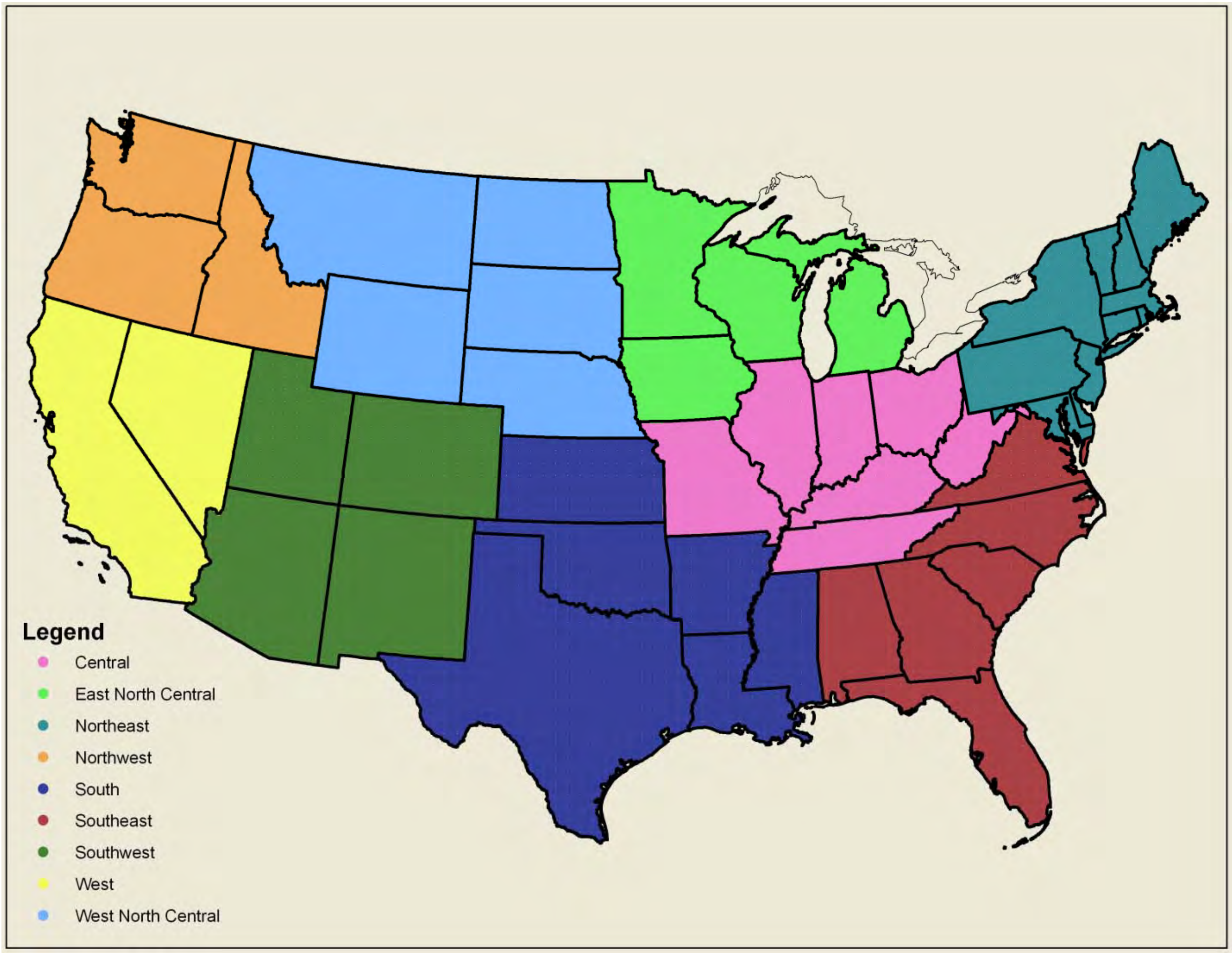

Figure 4-6 Map of the 9 NOAA climate regions (Karl and Koss, 1984) used in the national-scale air quality adjustments

Table 4-1 Percent reductions in U.S. anthropogenic NOx emissions applied to independently reach existing and alternative secondary standards in the nine climate regions

Region	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Central	48	14	58	70
East North Central	65	0	23	61
Northeast	96	36	51	81
Northwest	51	0	0	0

Region	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
South	54	44	56	66
Southeast	64	14	38	58
Southwest	55	67	85	90
West	90	91	93	95
West North Central	23	0	6	39

A second distinction between the welfare air quality adjustments and those in the HREA is that only U.S. anthropogenic NOx emissions reductions were applied in the HDDM adjustment methodology for the welfare assessment (i.e., changes in U.S. anthropogenic VOC emissions changes were not considered). NOx emissions reductions are believed to be the most effective method for reducing O_3 regionally, since most areas outside of urban population centers tend to be NOx limited in terms of O_3 formation. Uncertainties introduced by this assumption are discussed further in Section 4.4.

Finally, it should be noted that this analysis includes adjustment to four standard levels: 1) the existing standard of 75 ppb based on the 3-year average of the 4^{th} highest daily maximum 8-hour average O_3 concentration, 2) a W126-based standard with a level of 15 ppm-hrs, 3) a W126-based standard with a level of 11 ppm-hrs, and 4) a W126-based standard with a level of 7 ppm-hrs. The 2006-2008 average W126 concentrations and 4^{th} highest daily maximum 8-hour average O_3 concentrations were calculated for every monitor in each adjusted air quality scenario. For the analysis of each of the W126 standards, we started with W126 air quality values resulting from emission reductions required to just meet the existing standard at all monitors in the region, and only applied the HDDM adjustments to those regions where all sites were not already below the targeted W126 standard. In some cases, the emissions reductions necessary to meet the existing standard resulted in W126 values below the level of one or more potential alternative standards at all monitors within the region. In those cases, there is no change in air quality between the scenario meeting the existing standard and the scenario meeting the potential alternative standard (compare Table 4-1 and Table 4-2). For instance, Table 4-1 shows that a 6 percent NOx cut was applied to adjust all monitors in the East North Central region down to the current standard of 75 ppb. Since adjusting to 7 ppm-hrs only required 61 percent cut in US anthropogenic NOx, the primary standard was determined to be "controlling" and the 65 percent NOx cut was applied to the East North Central region to create all four W126 surfaces (75 ppb, 15 ppm-hrs, 11 ppm-hrs, 7 ppm-hrs). Table 4-2 shows the actual NOx reductions that were applied to create the W126 surfaces for each standard when first adjusting to the 75 ppb standard.

Table 4-2 Percent reductions in U.S. anthropogenic NOx emissions applied to create the W126 surfaces representing just meeting existing and alternative standards in the nine climate regions

Region	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Central	48	48	58	70
East North Central	65	65	65	65
Northeast	96	96	96	96
Northwest	51	51	51	51
South	54	54	56	66
Southeast	64	64	64	64
Southwest	55	67	85	90
West	90	91	93	95
West North Central	23	23	23	39

National-scale spatial surfaces that represent 2006-2008 W126 concentrations when just meeting the existing standard and the potential alternate standards (at the highest monitor in the region) were then created using the monitor values from the appropriate adjustment scenario and the Voronoi Neighbor Averaging (VNA) spatial interpolation technique. Additional details on the VNA technique can be found in Appendix 4-A. Note that since each region was adjusted independently, in some cases distinct boundaries may be visible in the adjusted surfaces. These boundaries may be obscured to some degree due to the VNA interpolation procedure.

4.3.4.2 Results

Table 4-3 shows the highest monitored 2006-2008 average W126 concentration in each region for observed air quality and air quality adjusted to meet the existing O_3 standard of 75 ppb, and the highest monitored 2006-2008 8-hour O_3 design value in each region for observed air quality and air quality adjusted to meet alternative standards based on the W126 metric with levels of 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs. Recall that the adjusted air quality surfaces used in the welfare risk and exposure analyses adjusted each region down to the existing O_3 standard before applying additional reductions to meet the alternative standards. So effectively, Table 4-1 shows which standard was the "controlling" standard in each region. For example, when all monitors in the Central region were adjusted to meet the existing standard, the highest resulting W126 value was 14 ppm-hrs. Thus, in the Central region, no further adjustments were necessary to meet the alternative standard of 15 ppm-hrs, but further adjustments were necessary to meet the alternative standards of 11 ppm-hrs and 7-ppm-hrs.

Table 4-3 Highest 2006-2008 average W126 concentrations in the observed and existing standard air quality adjustment scenarios; highest 2006-2008 8-hour O_3 design values in the observed and potential alternative standard air quality adjustment scenarios

Region	Highest W126 value (ppm-hrs)		Highest 8-hour maximum-based design value (ppb)			
	Observed	75 ppb adjustment	Observed	15 ppm-hr adjustment	11 ppm-hr adjustment	7 ppm-hr adjustment
Central	18.3	14.0	88	83	72	66
East North Central	13.8	6.4	86	86	83	76
Northeast	17.9	2.6	92	94	89	76
Northwest	6.6	3.8	76	76	76	76
Southeast	22.2	11.9	95	81	74	67
South	18.1	6.4	91	89	91	79
Southwest	24.3	17.7	86	71	65	62
West	48.6	18.9	119	71	66	61
West North Central	12.2	9.3	80	80	79	72

From Table 4-3, it can be inferred that while each of the 9 regions had at least one monitor with 2006-2008 air quality data not meeting the existing O_3 standard, there were 3 regions (East North Central, Northwest, West North Central) with all monitors meeting the potential alternative standard with a W126 level of 15 ppm-hrs based on 2006-2008 air quality data. Furthermore, all monitors in the Northwest region met the alternative standards of 11 ppm-hrs and 7-ppm-hrs based on 2006-2008 ambient data. When the air quality was adjusted to meet the existing standard, only two regions (West and Southwest) had monitors with W126 concentrations remaining above 15 ppm-hrs. In addition, there were 4 regions (East North Central, Northeast, Northwest, and South) that already met 7 ppm-hrs when air quality was adjusted to meet the existing standard.

Figure 4-7 shows the national-scale 2006-2008 average W126 surface adjusted to just meet the existing O_3 standard of 75 ppb using the HDDM adjustment procedure described in Section 4.3.2.1, and Figure 4-8 shows the difference between the recent air quality surface (Figure 4-5) and Figure 4-7. Figure 4-9, Figure 4-11, and Figure 4-13 show the 2006-2008 average W126 surfaces further adjusted to just meet 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs, respectively, while Figure 4-10, Figure 4-12, and Figure 4-14 show the differences between the surface adjusted to just meet the existing O_3 standard of 75 ppb, and the surfaces further adjusted to just meet the potential alternative standards based on the W126 metric with levels of 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs. It is immediately apparent from these figures that the reductions in W126 between recent air quality and air quality just meeting the existing standard (Figure 4-8) are much larger than the additional reductions in W126 between air quality just meeting the existing standard and air quality meeting the alternative standards (Figure 4-10, Figure 4-12, Figure 4-14).

This is further exemplified in Figure 4-15 and Figure 4-16, which show empirical probability density and cumulative distribution functions based on the monitored 8-hour O_3 design values (Figure 4-15) and W126 concentrations (Figure 4-16) for each of the air quality scenarios. Both sets of density functions show a large shift leftward going from observed air quality to just meeting the existing standard, followed by much smaller leftward shifts from air quality just meeting the existing standard to air quality just meeting the potential alternative standards. The shift between air quality just meeting the existing standard and air quality just meeting the potential alternative standard based on the W126 metric with a level of 15 ppm-hrs is especially small, since only a few monitors in the Southwest and West regions did not meet a W126 level of 15 ppm-hrs when air quality was adjusted to meet the existing standard.

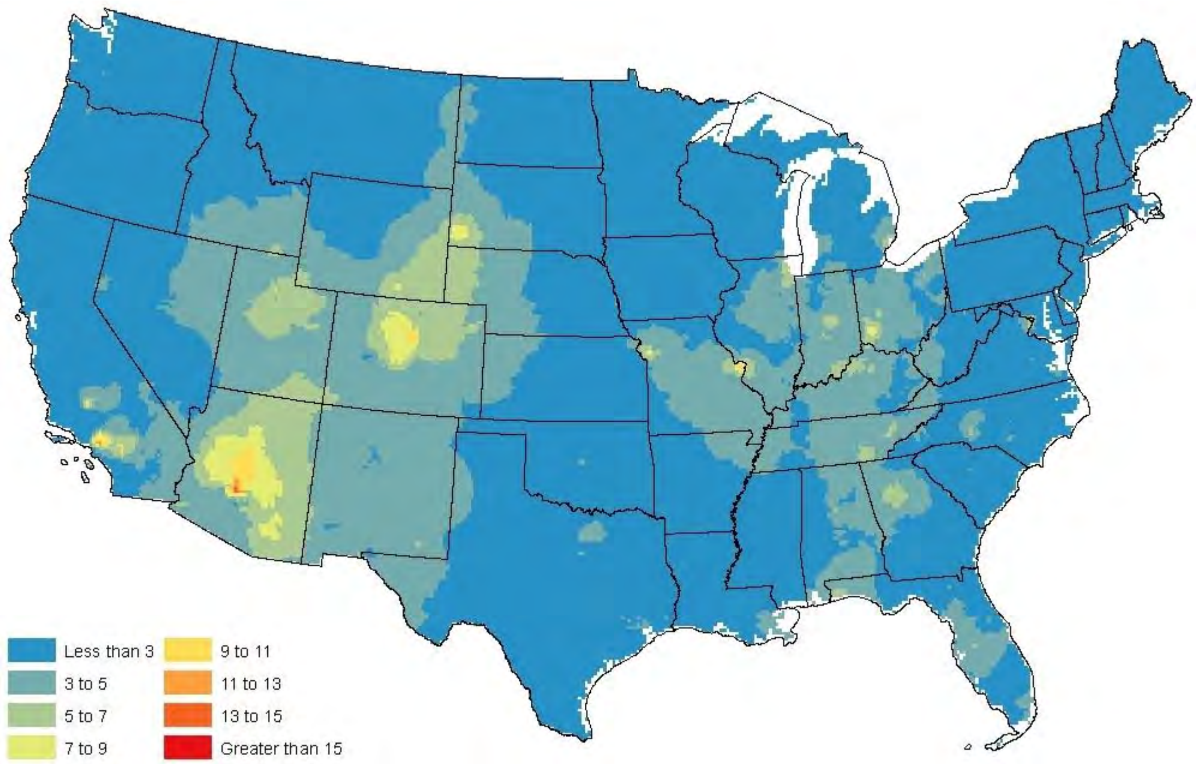

Figure 4-7 National surface of 2006-2008 average W126 concentrations (in ppm-hrs) adjusted to just meet the existing O_3 standard of 75 ppb

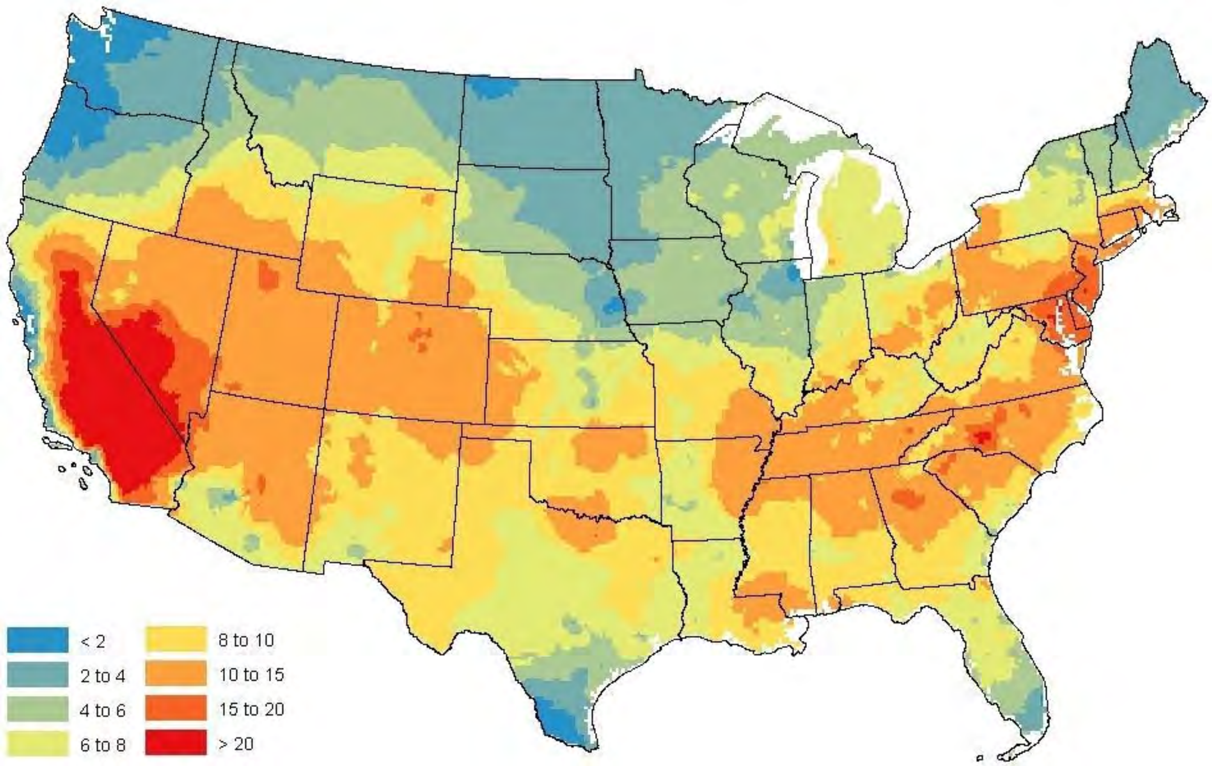

Figure 4-8 Difference in ppm-hrs between the national surface of observed 2006-2008 average W126 concentrations and the national surface of 2006-2008 average W126 concentrations adjusted to just meet the existing O_3 standard of 75 ppb

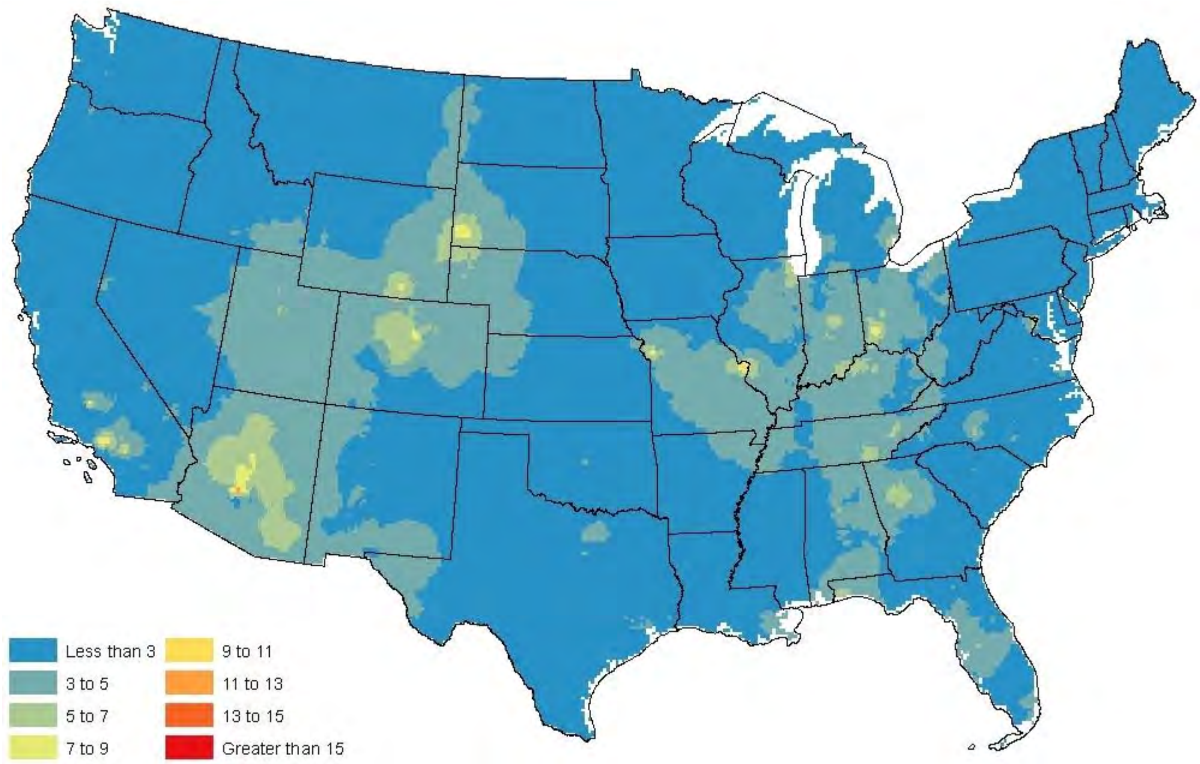

Figure 4-9 National surface of 2006-2008 average W126 concentrations (in ppm-hrs) adjusted to just meet the potential alternative standard of 15 ppm-hrs

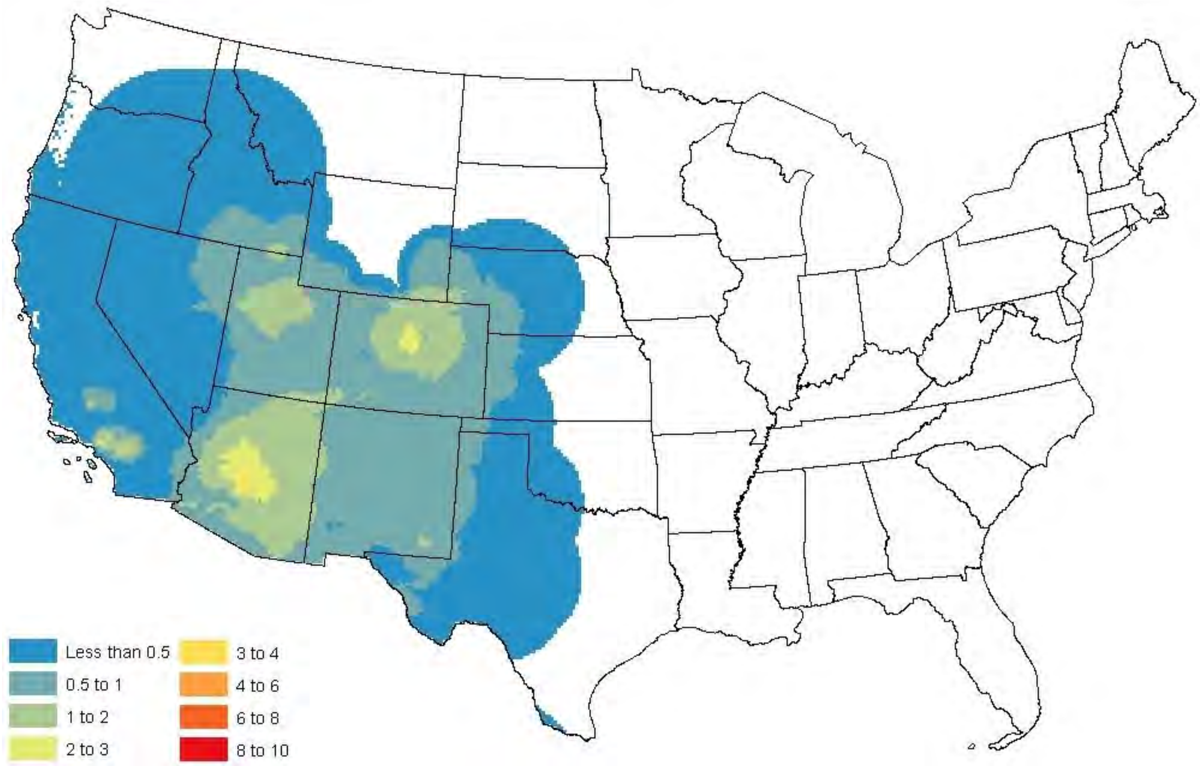

Figure 4-10 Difference in ppm-hrs between the national surface of 2006-2008 average W126 concentrations adjusted to just meet the existing O_3 standard of 75 ppb and the national surface of 2006-2008 average W126 concentrations adjusted to just meet the potential alternative standard of 15 ppm-hrs. White areas indicate no difference.

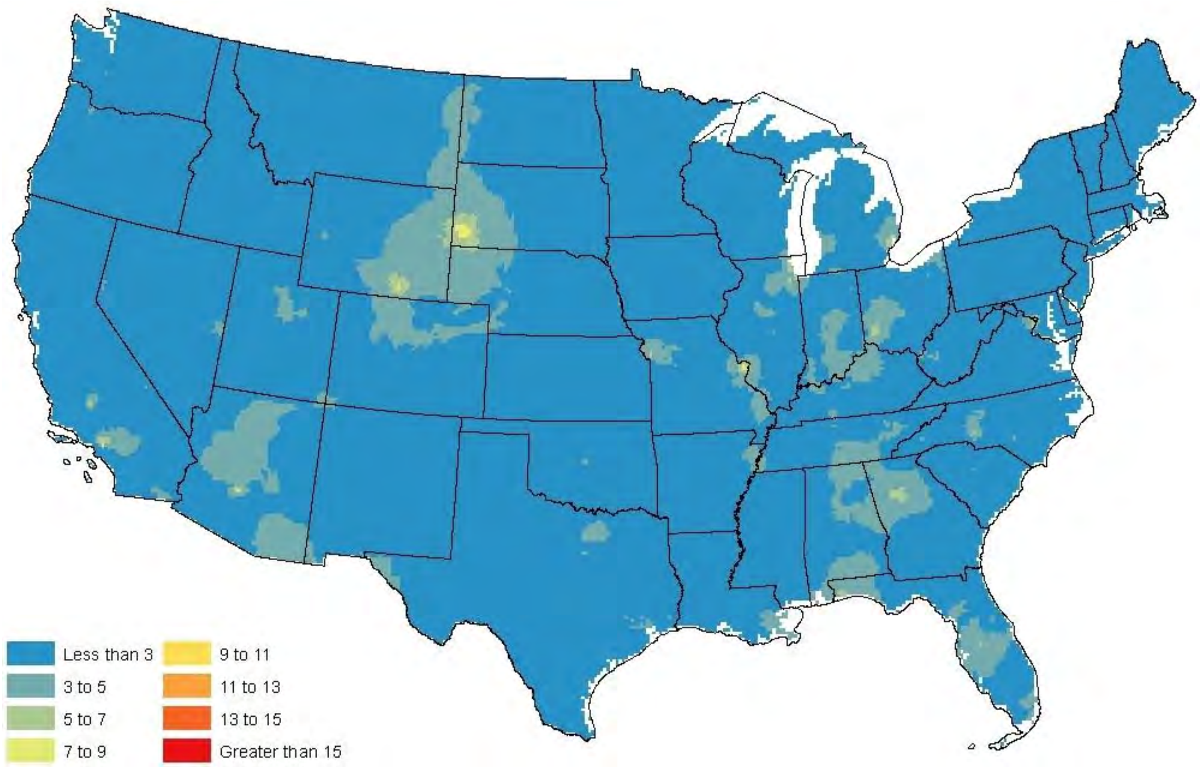

Figure 4-11 National surface of 2006-2008 average W126 concentrations (in ppm-hrs) adjusted to just meet the potential alternative standard of 11 ppm-hrs

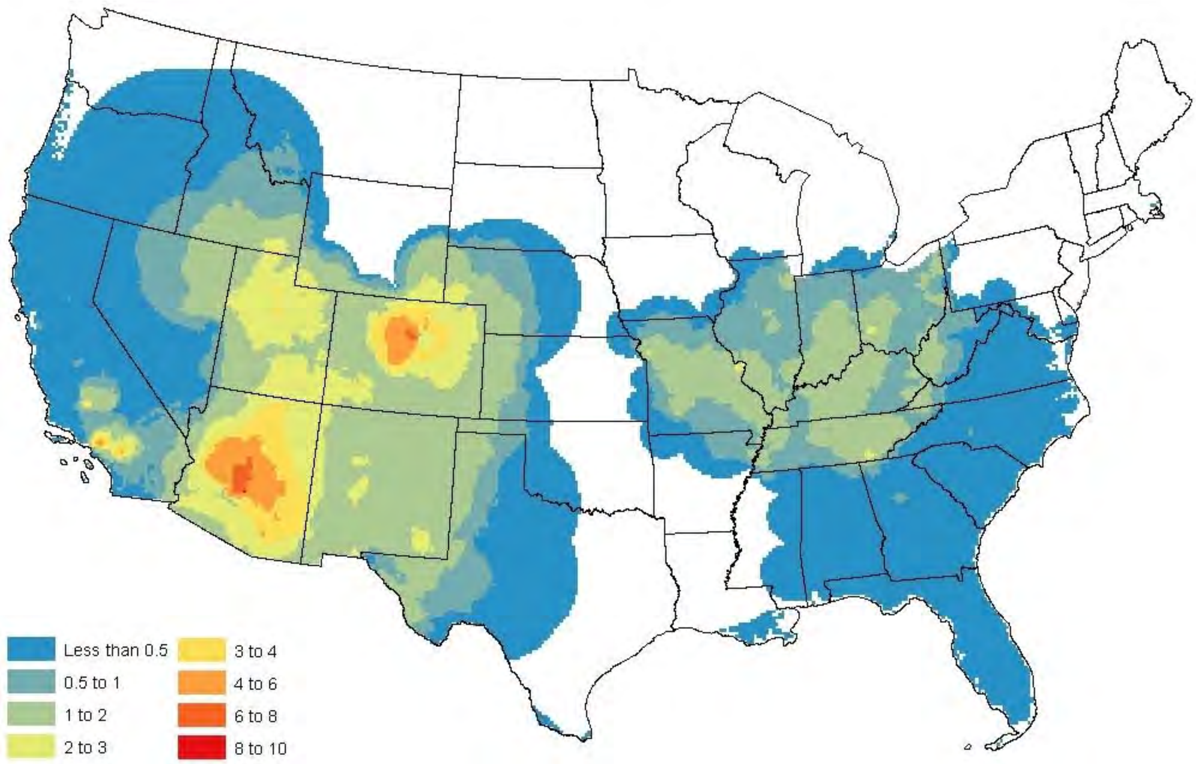

Figure 4-12 Difference in ppm-hrs between the national surface of 2006-2008 average W126 concentrations adjusted to just meet the existing O_3 standard of 75 ppb and the national surface of 2006-2008 average W126 concentrations adjusted to just meet the potential alternative standard of 11 ppm-hrs. White areas indicate no difference.

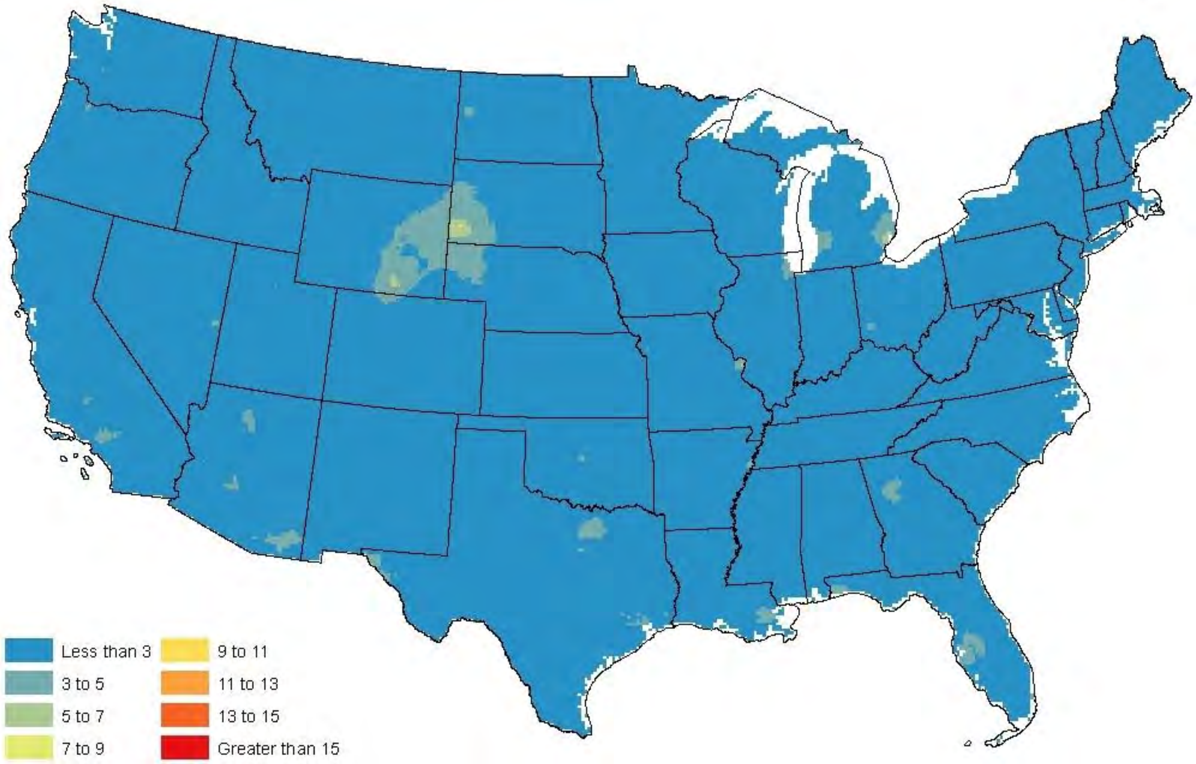

Figure 4-13 National surface of 2006-2008 average W126 concentrations (in ppm-hrs) adjusted to just meet the potential alternative standard of 7 ppm-hrs

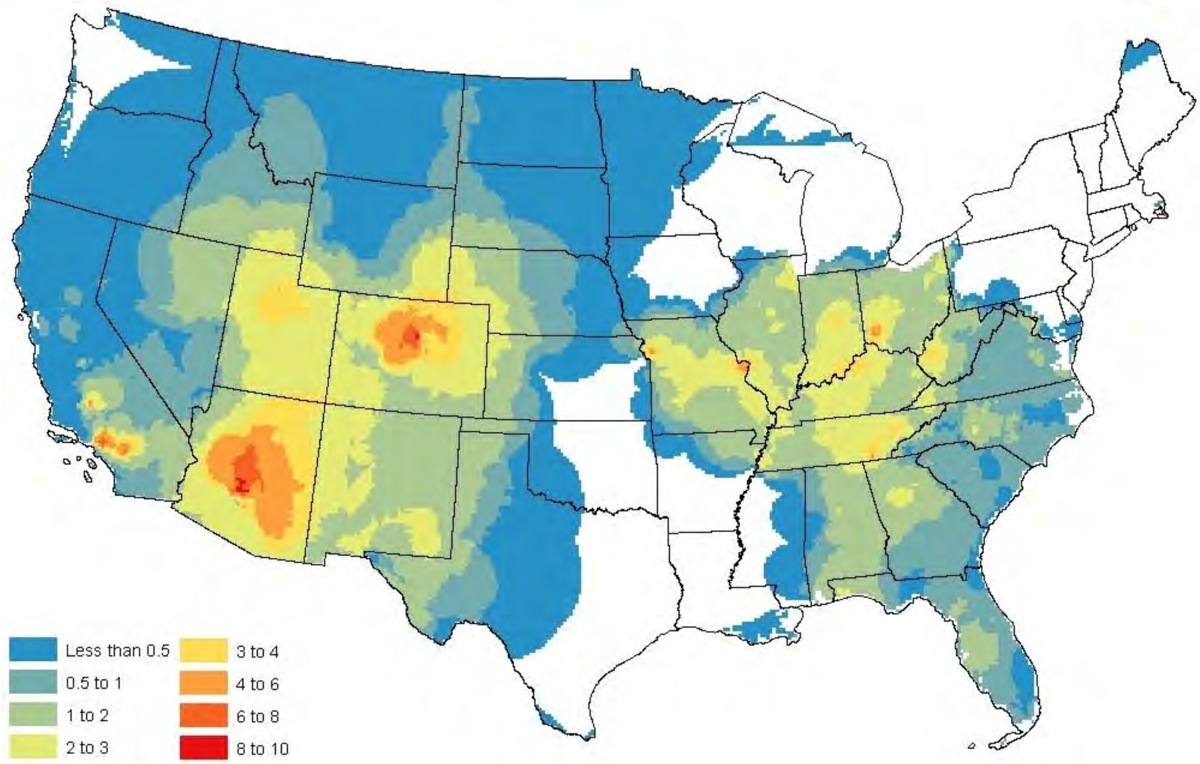

Figure 4-14 Difference in ppm-hrs between the national surface of 2006-2008 average W126 concentrations adjusted to just meet the existing O_3 standard of 75 ppb and the national surface of 2006-2008 average W126 concentrations adjusted to just meet the potential alternative standard of 7 ppm-hrs. White areas indicate no difference.

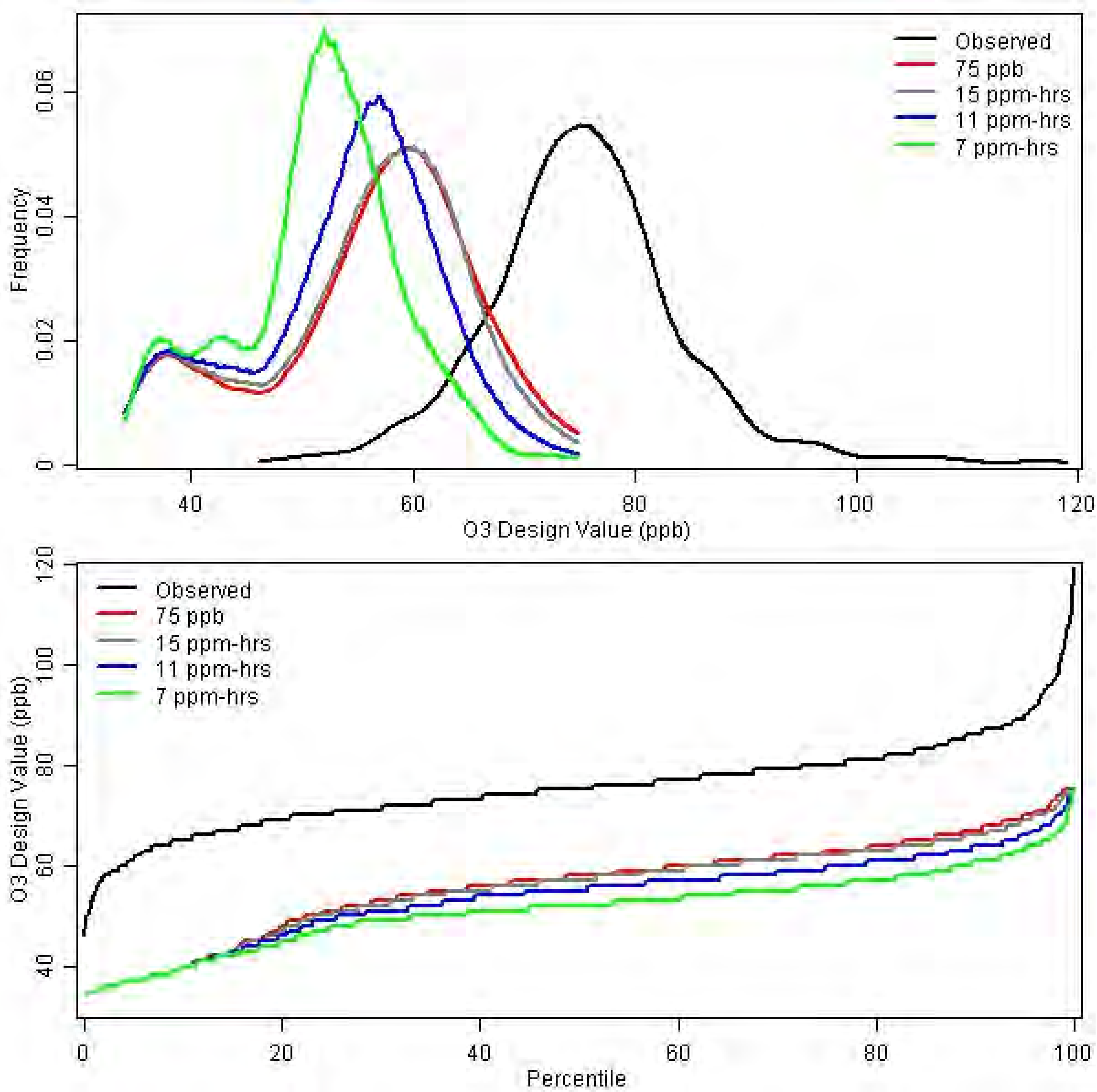

Figure 4-15 Empirical frequency distribution (top) and cumulative distribution (bottom) functions for the monitored 2006-2008 8-hour O_3 design values, and the 2006-2008 8-hour O_3 design values after adjusting to just meet the existing and potential alternative standards

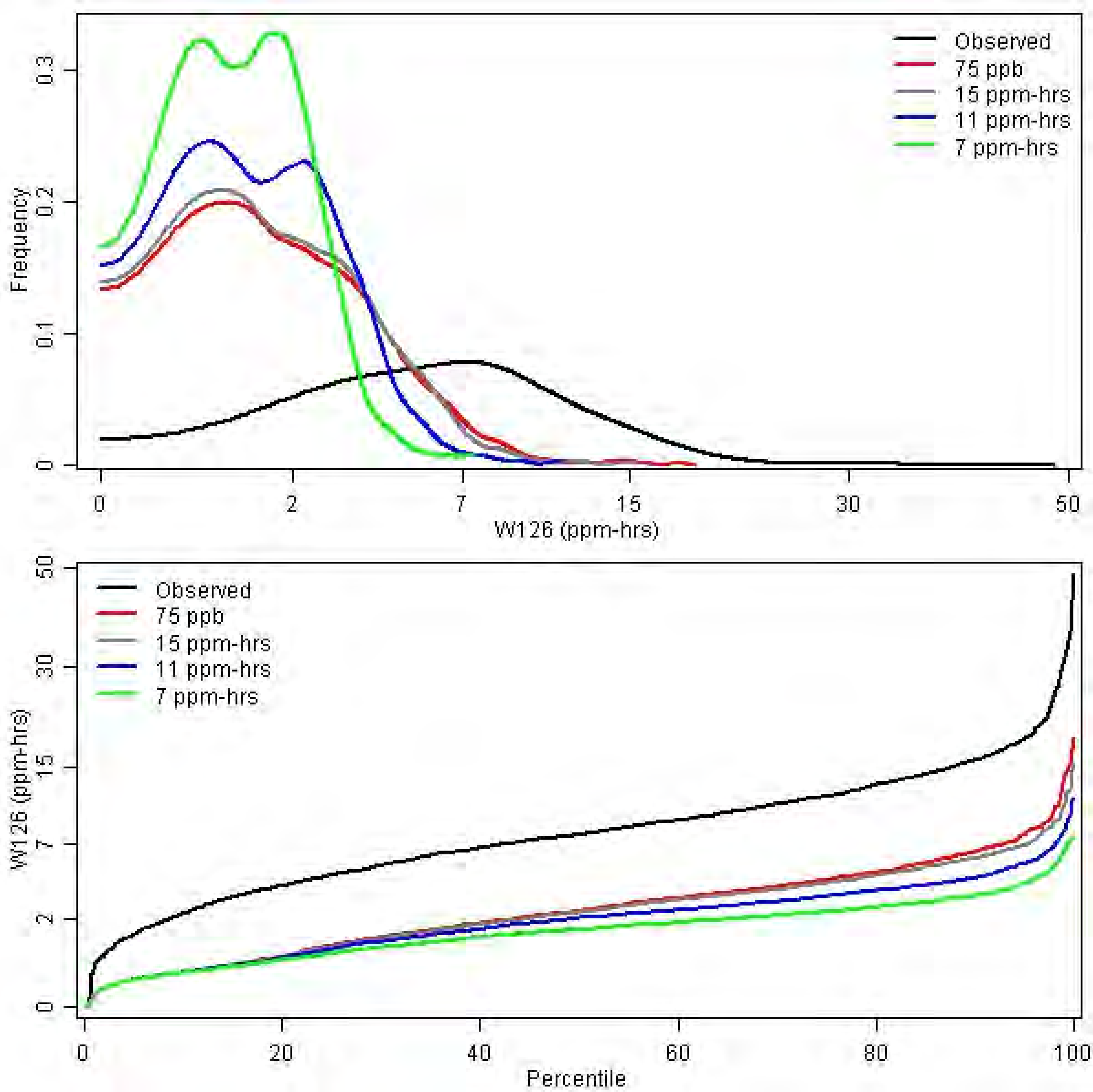

Figure 4-16 Empirical frequency distribution (top) and cumulative distribution (bottom) functions for the monitored 2006-2008 average W126 concentrations, and the 2006-2008 average W126 concentrations after adjusting to just meet the existing and potential alternative standards. Note W126 concentrations are displayed using a square root scale.

4.4 ASSESSMENT OF UNCERTAINTY

As noted in Chapter 3, we have based the design of the uncertainty analysis for this assessment on the framework outlined in the WHO guidance (WHO, 2008). In this section, we provide quantitative assessments where possible in addition to an overall qualitative uncertainty analysis in which we described each key source of uncertainty and qualitatively assessed its potential impact (including both the magnitude and direction of the impact) on risk results, as specified in the WHO guidance. In general, this assessment includes qualitative discussions of the potential impact of uncertainty on the results (WHO Tier1) and quantitative sensitivity analyses where we have sufficient data (WHO Tier 2).

Table 4-5 includes a summary the key sources of uncertainty identified for the O_3 REA. For each source of uncertainty, we have (a) provided a description, (b) estimated the direction of influence (over, under, both, or unknown) and magnitude (low, medium, high) of the potential impact of each source of uncertainty on the risk estimates, (c) assessed the degree of uncertainty (low, medium, or high) associated with the knowledge-base (i.e., assessed how well we understand each source of uncertainty), and (d) provided comments further clarifying the qualitative assessment presented. The categories used in describing the potential magnitude of impact for specific sources of uncertainty on risk estimates (i.e., low, medium, or high) reflect our consensus on the degree to which a particular source could produce a sufficient impact on risk estimates to influence the interpretation of those estimates in the context of the secondary O_3 NAAQS review. Where appropriate, we have included references to specific sources of information considered in arriving at a ranking and classification for a particular source of uncertainty. Discussion of elements in Table 4-5 is provided below.

There is inherent uncertainty in all deterministic air quality models, such as CMAQ, the photochemical grid model which was used to develop the model-based O_3 adjustment methodology. Evaluations of air quality models against observed pollutant concentrations build confidence that the model performs with reasonable accuracy despite both structural and parametric uncertainties. A comprehensive model performance evaluation provided in Appendix 4-B of the HREA shows generally acceptable model performance which is equivalent to or better than typical state-of-the science regional modeling simulations as summarized in Simon et al. (2012). Dynamic evaluations of CMAQ in the literature have evaluated the ability of the modeling system to predict ozone response to emissions changes. As described in more detail in Appendix 4-B of the HREA, these analyses generally conclude that the predicted model ozone response is conservative meaning that this analysis may overestimate the required emissions reductions needed to meet any standard level. The use of the Higher Order Decoupled Direct Method (HDDM) within CMAQ to estimate O_3 response to emissions adjustments adds uncertainty to that inherent in the model itself. HDDM allows for the approximation of O_3 concentrations under alternate emission scenarios without re-running the model simulation with different inputs. This approximation becomes less accurate for larger emissions adjustments. To accommodate increasing uncertainty at larger emissions adjustments, the HDDM modeling was performed at three distinct emissions levels to allow for a better characterization of O_3 response over the entire range of emissions levels. The accuracy of the HDDM estimates can be quantified at distinct emissions levels by re-running the model with modified emissions inputs and comparing the results. This method was applied to quantify the accuracy of 3-step HDDM O_3 estimates for 50 percent and 90 percent NOx cut conditions for each urban study areas (as shown in Appendix 4-D of the HREA). At 50 percent NOx cut conditions, HDDM using information from these multiple simulations predicted hourly O_3 concentrations with a mean bias and a mean error less than +/- 1 ppb in all study areas compared to brute force model simulations. At 90 percent NOx cut conditions, HDDM using information from these multiple simulations predicted hourly O_3 concentrations with a mean bias less than +/- 3ppb and a mean error less than +/- 4 ppb in all study areas. These small bias and error estimates show that uncertainty due to the HDDM approximation method is small up to 90 percent emissions cuts.

In order to apply modeled O_3 response to ambient measurements, simple linear regression relationships were developed which relate O_3 response to emissions adjustments with ambient O_3 concentrations for every season, hour-of-the-day, and monitor location. Applying modeled O_3 responses to ambient data based on these relationships adds uncertainty because the variability in the individual responses is collapsed into a central tendency estimate (i.e., the regression line). Preliminary work showed that the relationships developed with these regressions were generally statistically significant for most season, hour-of-the-day, and monitor location combinations for 2005 modeling in Detroit and Charlotte (Simon et al, 2013). Statistical significance was not evaluated for each regression in this analysis here since there were over 280,000 regressions created (1,300 monitors × 2 sensitivity coefficients × 3 emissions levels × 3 seasons × 12 hours =

280,800 regressions). Statistical inferences can quantify the goodness of fit for the modeled relationships and can quantify the uncertainty in the central tendency estimate at any given O_3 concentration. The simple linear regression model provided both a central tendency estimate and a standard error estimate for O_3 response at each measured hourly O_3 concentration.

The propagation of hourly standard error estimates to W126 is not a straightforward calculation due to the nonlinear weighting function which is applied to the hourly concentrations. Thus, a bootstrapping approach was employed to estimate the uncertainty in the 3-year average W126 values adjusted to meet the current and alternative standards due to the use of a central tendency estimate to represent O_3 response. Starting with 3 years of hourly O_3 concentrations and standard errors for a given monitor adjusted to meet a given standard level, 1,000 random hourly time-series were generated using Equation 1:

Equation 1: $$\boldsymbol{O3_{boot}(h,i) = O3_{obs}(h) + R(d,i) * SE(h)}$$

where $O3_{boot}(h,i)$ is the ith random hourly value for hour h

$O3_{obs}(h)$ is the adjusted hourly concentration value for hour h

R(d,i) is the ith random value sampled from a Normal(0,1) distribution for day d

SE(h) is the standard error estimate for hour h

Note that a single random value was drawn for each day and applied to all hourly concentrations within that day in order to account for any temporal correlation between the hourly values.

Three-year average W126 values were then calculated from each of the 1,000 random hourly time-series, and the resulting standard error of the adjusted 3-year average W126 value at the monitor was the standard deviation of these 1,000 values. This process was repeated for all 1,300 monitors in the contiguous U.S. for the existing standard of 75 ppb, and the alternative standards of 15, 11, and 7 ppm-hrs. Figure 4-17 shows boxplots of the standard errors in ppm-hrs at each monitor for the various standards, and Figure 4-18 to Figure 4-21 show maps of the standard errors in ppm-hrs at each standard level.

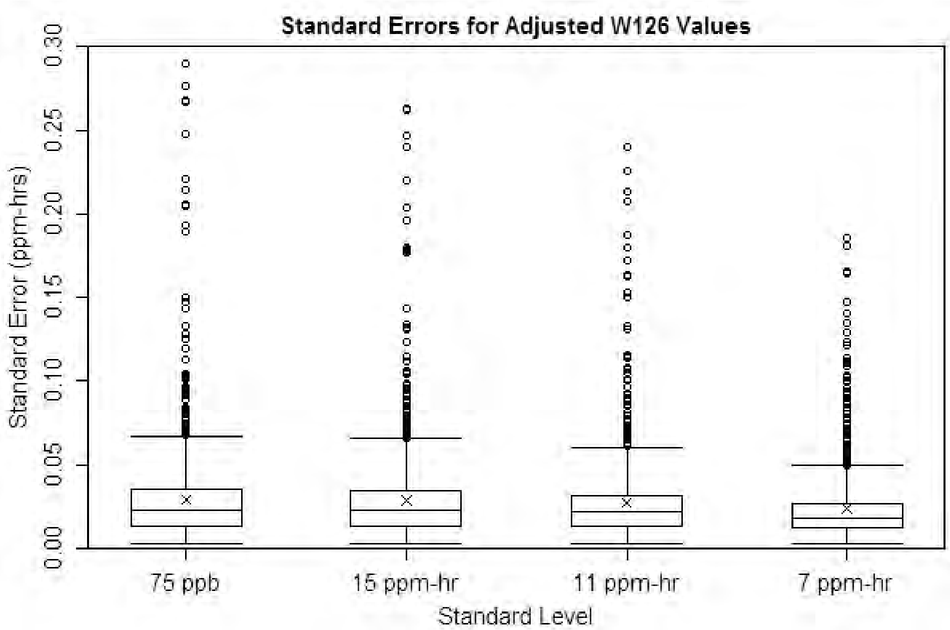

Figure 4-17 Boxplots of standard errors for 2006-2008 average W126 values adjusted to meet the existing and alternative standards. Boxes represent the median and quartiles, x's represent mean values, whiskers extend up to 1.5x the inter-quartile range from the boxes, and circles represent data points outside this range.

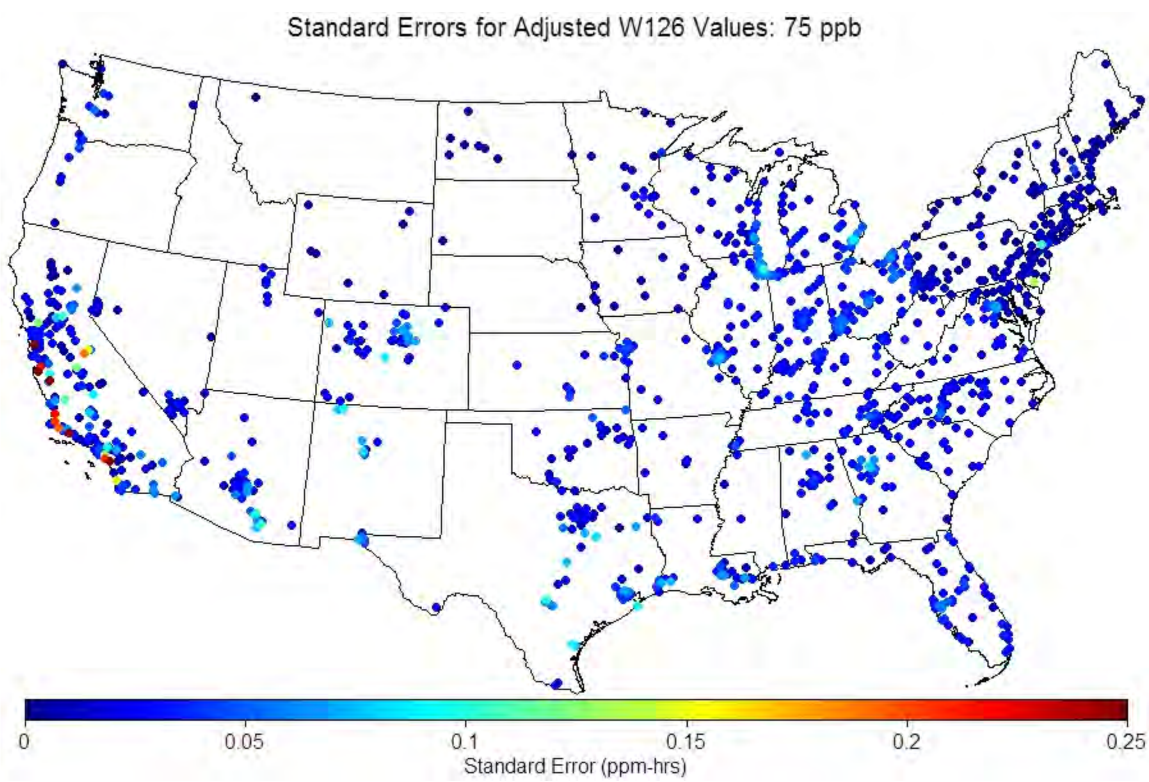

Figure 4-18 Map of standard errors for 2006-2008 average W126 values (in ppm-hrs) adjusted to meet the existing standard of 75 ppb

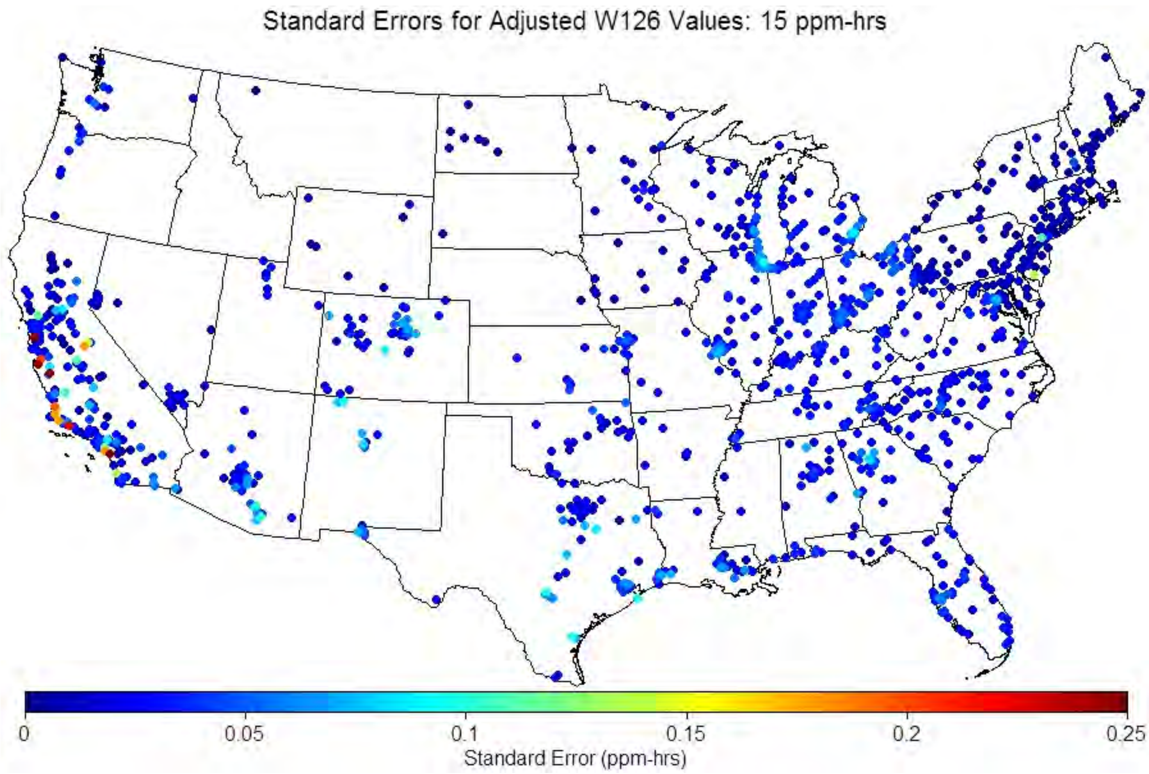

Figure 4-19 Map of standard errors for 2006-2008 average W126 values (in ppm-hrs) adjusted to meet the alternative standard of 15 ppm-hrs

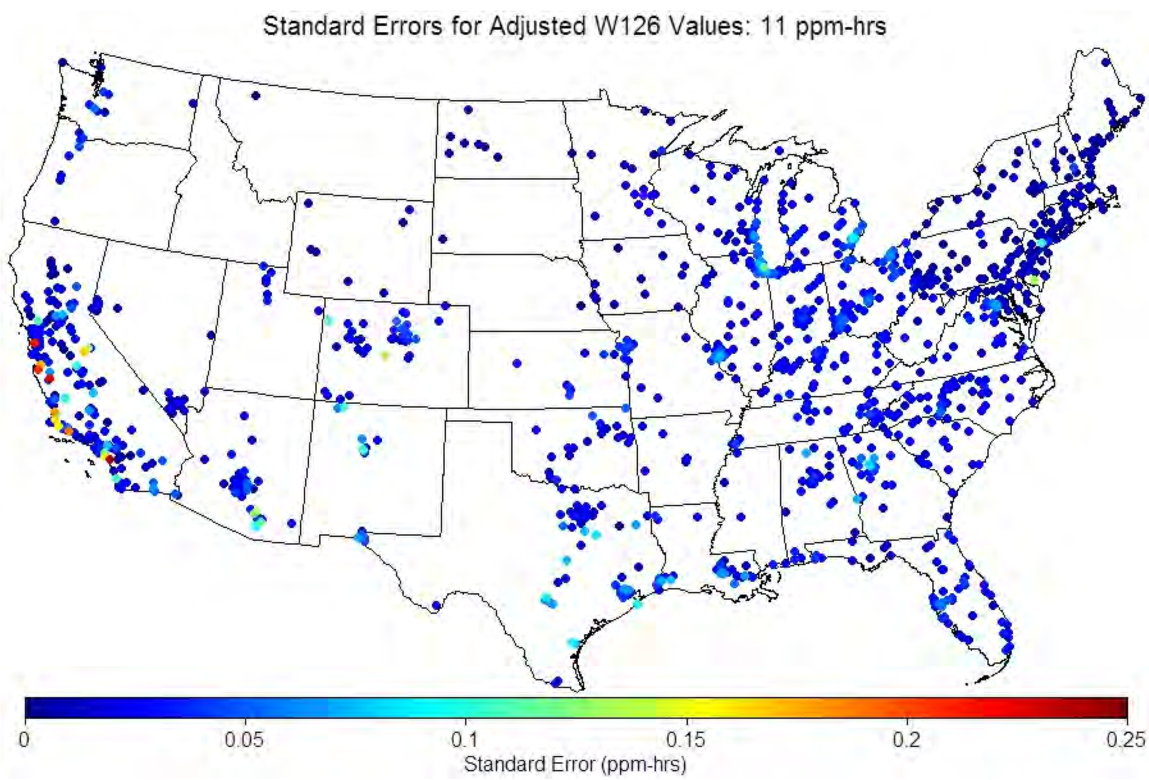

Figure 4-20 Map of standard errors for 2006-2008 average W126 values (in ppm-hrs) adjusted to meet the alternative standard of 11 ppm-hrs

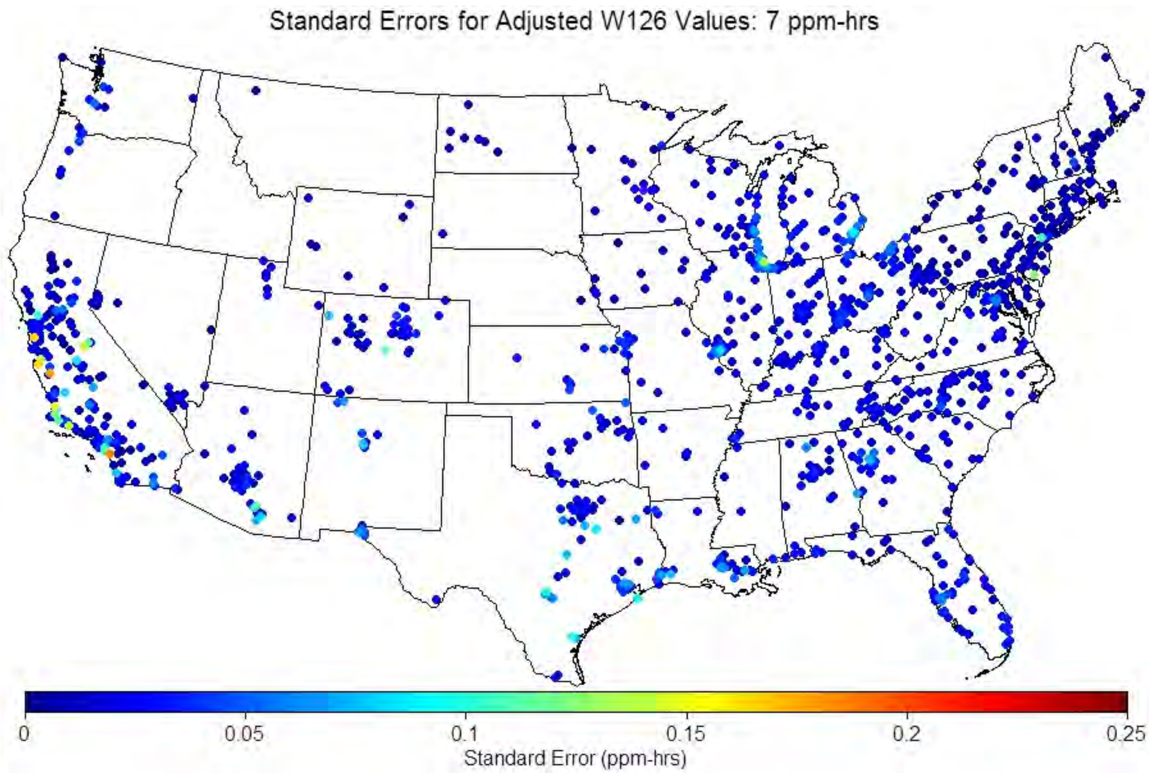

Figure 4-21 Map of standard errors for 2006-2008 average W126 values (in ppm-hrs) adjusted to meet the alternative standard of 7 ppm-hrs

The resulting standard error values were generally quite small: all monitors had standard errors of less than 0.3, and about 98 percent of monitors had standard errors of less than 0.1 ppm-hr. The standard errors tended to decrease slightly with lower standard levels. In general, the hourly standard errors increased with larger reductions associated with meeting lower standard level. Simultaneously, the largest decreases in the peak O_3 concentrations which have the greatest impact upon W126 levels also occurred at lower standard levels. These two factors tended to offset one another, resulting in only a slight decrease in standard error values when adjusting to meet lower standard levels. Finally, the largest standard errors tended to occur in urban core areas, which is expected for two reasons. First, the simple linear regression models tended to fit more poorly in urban core areas due to non-linearities in the ozone chemistry in those locations, resulting in higher hourly standard error values. Second, the highest standard errors tended to occur at monitors with the highest adjusted W126 values, which tended to be located in urban areas under the various adjustment scenarios.

Relationships between O_3 response and hourly O_3 concentration were developed based on 8 months of modeling: April-October 2007. These relationships were applied to ambient data from 2006-2008 leading to an additional source of uncertainty. The eight months that were modeled capture a variety of meteorological conditions. However, in cases where other years have drastically different meteorological conditions, there is uncertainty in how well the regression central tendency estimates would represent O_3 responses in those years. In addition, if emissions were to change drastically between the modeled period and the time of the ambient data measurements this could also change the relationship between O_3 response and O_3 concentrations. The regressions derived from the 2007 modeling period are only applied to measurements made within one year of the modeled time period. Although some emissions changes did occur over this time period, we believe it is still reasonable to apply 2007 modeling to this relatively small window of measurements which occurs before and after the modeling.

Ozone responses were modeled for “across-the-board” reductions in U.S. anthropogenic NOx and were applied independently for nine climate regions, e.g. for each region, we looked at how W126 responded to NOx emissions reductions across the entire U.S. We recognize that this means that when considered together, the adjusted W126 values will not reflect any single specific NOx emissions reductions across the U.S. These reductions were chosen for illustrative purposes and were not meant to reflect actual emissions control strategies. The “across-the-board” reductions do not optimize the lowest cost or least total emissions combinations that state and local agencies will likely attempt to achieve to bring NOx emissions levels down uniformly across time and space within each region. So the reductions do not reflect spatial and temporal heterogeneity that may occur in local and regional emissions reductions.

To further investigate the implications of the regionally-derived “across-the-board” NOx reduction scenarios that were used here we evaluate past emissions reductions and EPA projected future changes to emissions. An EPA analysis (EPA, 2006) has shown that some past efforts to meet ozone NAAQS have resulted in regional emissions reductions. Specifically, the NOx SIP Call program implemented to help areas meet the 1997 ozone standard resulted in substantial reductions in power plant NOx emissions from states across the eastern U.S. We further evaluated EPA projected emissions changes between 2007 and 2020 (EPA, 2012). These emissions projections take into account “on the books” controls from state and federal regulations that were in place at the time of the analysis as well as population growth and do not consider any actions that would be undertaken to meet a new O_3 NAAQS level. Nationally, NOx is projected to decrease by 45 percent between 2007 and 2020. Two-thirds of these NOx reductions are projected to come from on-road vehicles as a result of tighter emissions standards and fleet turnover. Smaller but still substantial reductions are predicted to occur from power plants, off-road equipment, railroad and marine sources. Figure 4-22 and Figure 4-23 show the magnitude of NOx reductions that are projected to occur. These figures broadly show large state and regional reductions in anthropogenic NOx on the order of 40-60 percent. These reductions are not limited to densely populated states or to current nonattainment areas. In fact, in several regions larger reductions in NOx emissions are projected to occur in attainment counties than in nonattainment counties. Table 4-4 compares these projected emissions changes to those applied to meet the various standard levels in the WREA analysis. In all regions except the West and Southwest, the projected emissions changes, which are expected to be fairly regional in nature, are greater than what would be required to meet a 15 ppm-hrs standard based on the HDDM methodology. In addition, in all regions the projected emissions changes make up at least 40 percent of what would be required to just meet a W126 standard of 7 ppm-hrs and in many cases they make up a substantially larger portion. These comparisons build confidence that the regionally-based NOx control scenarios applied in this analysis are not unrealistic since substantial regional NOx reductions are projected to occur regardless of whether the O_3 NAAQS is changed. The comparisons also build confidence in the finding that most areas would have W126 values below 15 ppm-hrs after meeting the existing 75 ppb standard. In some potential future scenarios, a portion of the controls applied to just meet a W126-based NAAQS might come from local controls. While the scenarios implemented in this analysis show that by bringing down the highest monitor in a region would lead to reductions below the targeted level through the rest of the region, to the extent that the regional reductions from on-the-books controls are supplemented with more local controls the additional benefit may be overestimated. In addition, the assumption of a NOx-only control scenario adds uncertainty. The 2020 projections predict a 20 percent reduction in US anthropogenic VOC from 2007 levels and some locations may undertake additional VOC emissions reductions. Since ozone in urban areas is more responsive to VOC emissions reductions than ozone in rural areas, these VOC emissions would result in lower required NOx reductions and would tend to reduce the W126 benefits in rural areas.

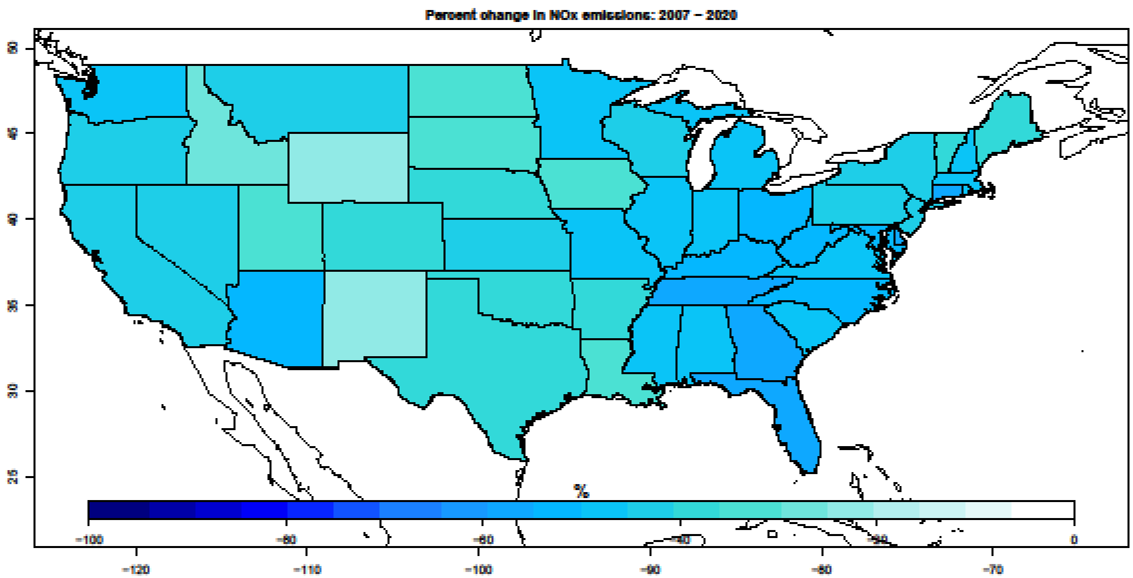

Figure 4-22 Percent reduction in state NOx emissions projected to occur between 2007 and 2020

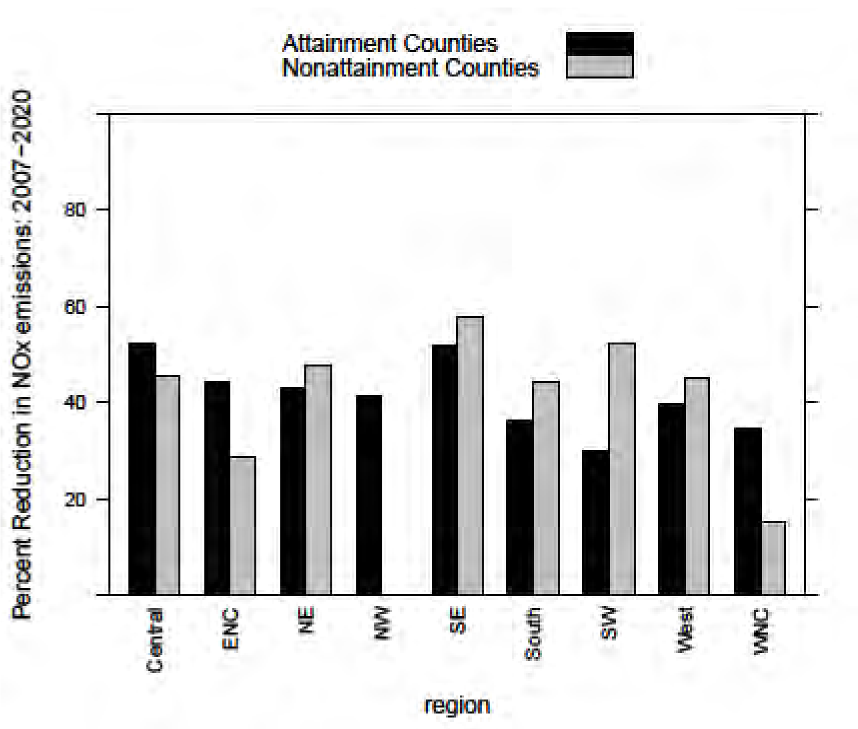

Figure 4-23 Percent NOx reductions projected to occur from 2007 to 2020 aggregated by climate region for counties designated in attainment with the 2008 O_3 NAAQS and counties designated nonattainment for the 2008 O_3 NAAQS

Table 4-4 Comparison of projected NOx emissions reductions to those applied to meet various standard levels in the WREA analysis

Region	Percent NOx Emissions Reductions				
	Applied to meet 75 ppb	Applied to meet 15 ppm-hrs	Applied to meet 7 ppm-hrs	Projected from 2007-2020 (Regional)	Range of projected 2007-2020 (State-level)
Central	48	14	70	51.3	46.4-59.7
ENC	65	0	61	44.1	34.6-47.8
Northeast	96	36	81	45.6	37.8-56.6
Northwest	51	0	0	41.6	29.8-45.2
Southeast	54	44	66	37.6	46.5-58.0
South	64	14	58	52.6	31.1-46.1
Southwest	55	67	90	35.9	17.6-50.2
West	90	91	95	44.0	41.1-44.3
WNC	23	0	39	32.9	19.6-42.2

Table 4-5 Summary of Qualitative Uncertainty Analysis of Key Air Quality Elements in the O_3 NAAQS Risk Assessment

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base uncertainty*	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
A. Ambient air quality measurement data	O_3 concentrations measured by ambient monitoring instruments have inherent uncertainties associated with them. Additional uncertainties due to other factors may include: - monitoring network design - required O_3 monitoring seasons - monitor malfunctions - wildfire and smoke impacts - interpolation of missing data	Both	Low	Low	KB: O_3 measurements are assumed to be accurate to within ½ of the instrument's Method Detection Limit (MDL), which is 2.5 ppb for most instruments. EPA requires that routine quality assurance checks are performed on all regulatory instruments, and that all data reported to AQS are certified by both the monitoring agency and the corresponding EPA regional office. See 40 CFR Part 58, Appendix A for details. The CASTNET monitoring data were subject to their own quality assurance requirements. KB: Monitor malfunctions sometimes occur causing periods of missing data or poor data quality. Monitoring data affected by malfunctions are usually flagged by the monitoring agency and removed from AQS. In addition, the AQS database managers run several routines to identify suspicious data for potential removal. KB: There is a known tendency for smoke produced from wildfires to cause interference in O_3 instruments. Measurements collected by O_3 analyzers were reported to be biased high by 5.1–6.6 ppb per 100 $\mu g/m^3$ of PM2.5 from wildfire smoke (Payton, 2007). However, smoke concentrations high enough to cause significant interferences are infrequent and the overall impact is believed to be minimal. KB: Missing intervals of 1 or 2 hours in the measurement data were interpolated, which may cause some additional uncertainty. However, due to the short length of the interpolation periods, and the tendency for these periods to occur at night when O_3 concentrations are low, the overall impact is believed to be minimal. INF: EPA's current O_3 monitoring network requirements (40 CFR Part 58, Appendix D) are primarily focused on urban areas. Rural areas where O_3 concentrations are lower tend to be under-represented by the current monitoring network. The network requirements also state that at least one monitor within each urban area must be sited to capture the highest O_3 concentrations in that area, which may cause some bias toward higher measured concentrations. INF: Each state has a required O_3 monitoring season which varies in length from May – September to year-round. Some states turn their O_3 monitors off during months outside of the required season, while others leave them on. This can cause differences in the amount of

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base uncertainty*	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
					data available throughout the year across states, especially in months outside of the required O_3 monitoring season.
B. Veronoi Neighbor Averaging (VNA) spatial fields	VNA is a spatial interpolation technique used to estimate W126 concentrations in unmonitored areas, which has inherent uncertainty	Both	Low-Medium	Low-Medium	KB: VNA interpolates 2006-2008 average W126 values estimated from hourly ambient air quality measurements at each CMAQ grid cell in each of the 9 NOAA climate regions. The VNA estimates are weighted based on distance from neighboring monitoring sites, thus the uncertainty tends to increase with distance from the monitoring sites becomes greater. As a result, there is less uncertainty in the VNA estimates near urban areas where the monitoring networks are dense, and more uncertainty in sparsely populated areas where monitors are further apart, particularly in the Western U.S.
C.CMAQ modeling	Model predictions from CMAQ, like all deterministic photochemical models, have both parametric and structural uncertainty associated with them	Both	Medium	Medium	KB: Structural uncertainties are uncertainties in the representation of physical and chemical processes in the model. These include: choice of chemical mechanism used to characterize reactions in the atmosphere, choice of land surface model and choice of planetary boundary layer model. KB: Parametric uncertainties include uncertainties in model inputs (hourly meteorological fields, hourly 3-D gridded emissions, initial conditions, and boundary conditions) KB: Uncertainties due to initial conditions are minimized by using a 10 day ramp-up period from which model results are not used. KB: Evaluations of models against observed pollutant concentrations build confidence that the model performs with reasonable accuracy despite the uncertainties listed above. A comprehensive model evaluation provided in Appendix 4-B of the hREA shows generally acceptable model performance which is equivalent or better than typical state-of-the science regional modeling simulations as summarized in Simon et al (2012). However, both under-estimations and over-estimations do occur at some times and locations. Generally the largest mean biases occur on low ozone days during the summer season. In addition, the model did not fully capture rare wintertime high ozone events occurring in the Western U.S. Both of these types of biases are not likely to substantially affect W126 performance since low ozone days are not heavily weighted in the W126 calculation and since the highest 3-month W126 values were only calculated for April-October in this analysis.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base uncertainty*	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
D. Higher Order Decoupled Direct Method (HDDM)	HDDM allows for the approximation of ozone concentrations under alternate emissions scenarios without re-running the model simulation multiple times using different emissions inputs. This approximation becomes less accurate for larger emissions perturbations especially under nonlinear chemistry conditions.	Both	Medium	Medium	KB: To accommodate increasing uncertainty at larger emissions perturbations, the HDDM modeling was performed at three distinct emissions levels to allow for a better characterization of ozone response over the entire range of emissions levels. The replication of brute force[10] hourly ozone concentration model results by the HDDM approximation was quantified for 50% and 90% NOx cut conditions for each urban study areas (as shown in Appendix 4-D of the hREA). At 50% NOx cut conditions, HDDM using information from these multiple simulations predicted hourly ozone concentrations with a mean bias and a mean error less than +/- 1 ppb in all urban study areas compared to brute force model simulations. At 90% NOx cut conditions, HDDM using information from these multiple simulations predicted hourly ozone concentrations with a mean bias less than +/- 3ppb and a mean error less than +/- 4 ppb in all urban study areas.
E. Application of HDDM sensitivities to ambient data	In order to apply modeled sensitivities to ambient measurements, regressions were developed which relate ozone response to emissions perturbations with ambient ozone concentrations for every season, hour-of-the-day and monitor location. Applying ozone responses based on this relationship adds uncertainty.	Both	Low-Medium	Low-Medium	KB: Preliminary work showed that the relationships developed with these regressions were generally statistically significant for most season, hour-of-the-day, and monitor location combinations for 2005 modeling in Detroit and Charlotte. Statistical significance was not evaluated for each regression in this analysis since there were over 280,000 regressions created (1300 monitors × 2 sensitivity coefficients × 3 emissions levels × 3 seasons × 12 hours = 280,800 regressions). Statistical inferences can quantify the goodness of fit for the modeled relationships. However it is not possible to quantify the applicability of this modeled relationship to the actual atmosphere. KB: The regression model provided both a central tendency estimate and a standard error estimate for ozone response at each measured hourly ozone concentration. The base analysis used the central tendency which will inherently dampen some of the variability in ozone response. A bootstrapping analysis was used to estimate the uncertainty in 3-year average W126 concentrations due to use of the central tendency prediction for ozone response. This analysis showed that the uncertainty was small: the standard errors were less than 0.3

[10] Brute force model concentrations refer to model results obtained by changing the emissions inputs and re-running the CMAQ model. HDDM concentration estimates are an approximation of the model results that would be obtained by re-running the simulation with different inputs.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base uncertainty*	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
					ppm-hrs at all monitors, and less than 0.1 ppm-hrs at about 98% of monitors.
F. Applying modeled sensitivities to un-modeled time periods	Relationships between ozone response and hourly ozone concentration were developed based on 7 months of modeling: April-October 2007. These relationships were applied to ambient data from 2006-2008.	Both	Medium	Medium	KB: The seven months that were modeled capture a variety of meteorological and emissions conditions. Applying these 2007 sensitivities to other years with potentially different meteorology and emissions adds uncertainty to the relationship between ozone response and ozone concentrations. The regressions derived from the 2007 modeling period are only applied to measurements made within one year of the modeled time period. Although some emissions changes did occur over this time period, we believe it is still reasonable to apply 2007 modeling to this relatively small window of measurements which occurs before and after the modeling.
G. Assumptions of regionally-determined across-the-board emissions reductions	Ozone response is modeled for across-the-board reductions[11] in U.S. anthropogenic NOx. These across-the-board cuts do not reflect actual emissions control strategies.	Overestimates W126 benefits	Medium	Medium	KB: The form, locations, and timing of emissions reductions that would be undertaken to meet various levels of the ozone standard are unknown. The across-the-board emissions reductions bring levels down uniformly across time and space to show how ozone would respond to changes in ambient levels of precursor species but do not reflect spatial and temporal heterogeneity that may occur in local and regional emissions reductions.

* Refers to the degree of uncertainty associated with our understanding of the phenomenon, in the context of assessing and characterizing its uncertainty. Sources classified as having a "low" impact would not be expected to impact the interpretation of risk estimates in the context of the O_3 NAAQS review; sources classified as having a "medium" impact have the potential to change the interpretation; and sources classified as "high" are likely to influence the interpretation of risk in the context of the O_3 NAAQS review.

[11] "Across the board" emission reductions refer to equal percentage NOx emissions cuts in all source categories and all locations at all times.

4.5 SUMMARY OF AIR QUALITY RESULTS

Observed W126 levels in 2006-2008 were highest in the Western US (maximum monitored value was 48.6 ppm-hrs) followed by the Southwest, Southeast, Central and Northeast (24.3, 22.2, 18.3, and 17.9 ppm-hrs respectively). All monitored W126 values in other regions of the US were below 15 ppm-hrs with the lowest values in the Northwestern U.S. all falling below 7 ppm-hrs. The air quality adjustments to meet the current 75 ppb standard brought all areas except the West and Southwest (18.9 and 17.7 ppm-hrs) below 15 ppm-hrs. The air quality adjustments to meet the current 75 ppb standard additionally resulted in four regions being below 7 ppm-hrs (East North Central, Northeast, Northwest, and South). The reductions in W126 between recent air quality and air quality just meeting the existing standard are much larger than the additional reductions in W126 between air quality just meeting the existing standard and air quality meeting the alternative standards. The shift between air quality just meeting the existing standard and air quality just meeting the potential alternative standard based on the W126 metric with a level of 15 ppm-hrs is especially small, since only a few monitors in the Southwest and West regions did not meet a W126 level of 15 ppm-hrs when air quality was adjusted to meet the existing standard.

4.6 REFERENCES

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5 O_3 RISK TO ECOSYSTEM SERVICES

5.1 INTRODUCTION

The EPA is using an ecosystem services framework as described in Chapter 2 to help define how the damage to ecosystems informs determinations of the adversity to public welfare associated with changes in ecosystem functions. Figure 9-1 of the O_3 ISA (U.S. EPA, 2013) is reproduced below (Figure 5-1) as a summary of exposure and effects that lead to potential loss of ecosystem services. Figure numbers in this figure refer to Chapter 9 of the O_3 ISA.

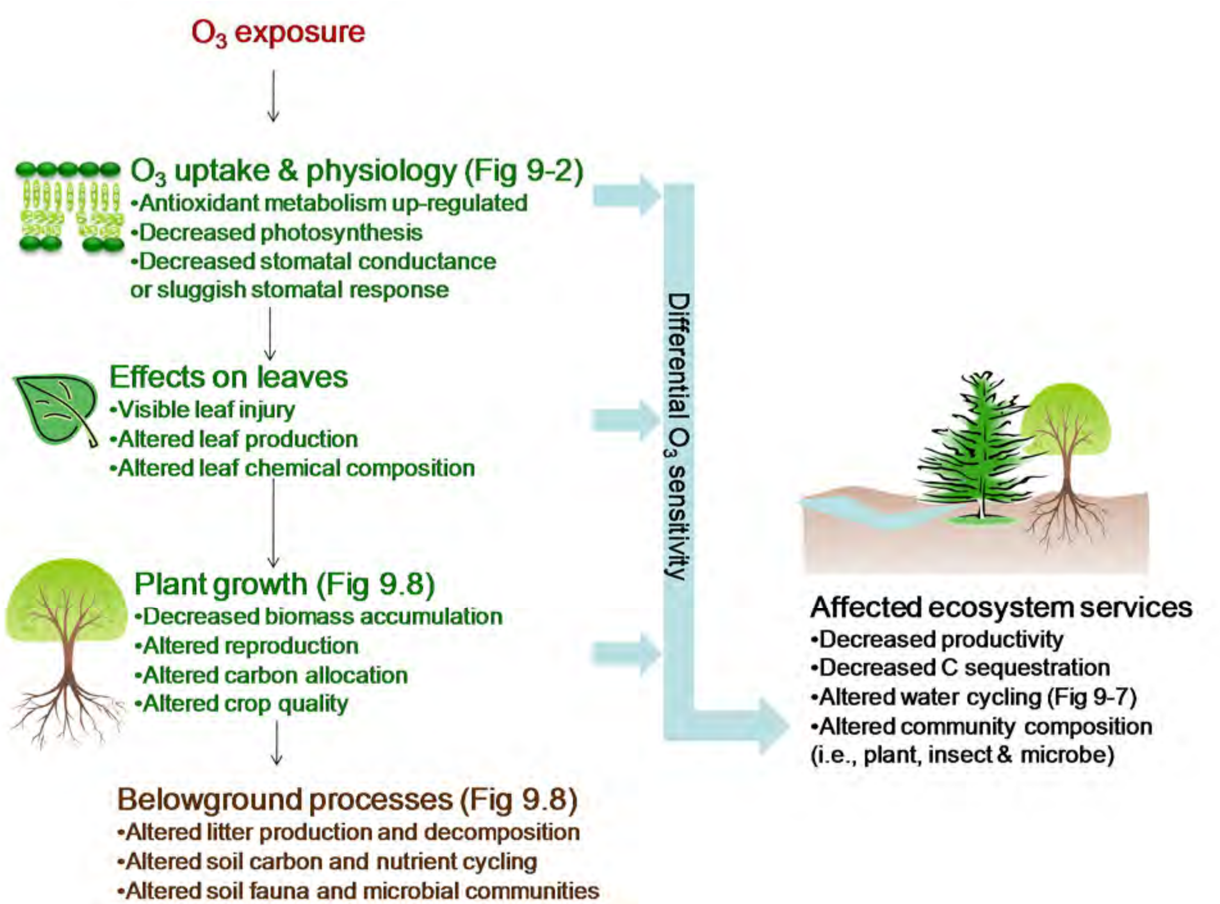

Figure 5-1 Conceptual Diagram of the Major Pathway through which O_3 Enters Plants and the Major Endpoints that O_3 May Affect in Plants and Ecosystems

This chapter focuses primarily on those ecosystem services anticipated to be at risk from O_3 exposure that we were only able to assess qualitatively, due to a lack of sufficient data, methods, or resources to allow quantification of the incremental effects of O_3. It also includes semi-qualitative, GIS-driven, correlational assessments of the potential impacts of O_3 on risks of fire and bark beetle damage and identifies additional anticipated adverse effects associated with O_3 exposure that we are not able to assess, even qualitatively. In contrast, Chapters 6 and 7 provide quantitative assessments for risks related to tree biomass loss, timber and crop yield loss and visible foliar injury. Figure 5-2 illustrates the relationships between the ecological effects of O_3 and the anticipated ecosystem services impacts that will be discussed in the following sections.

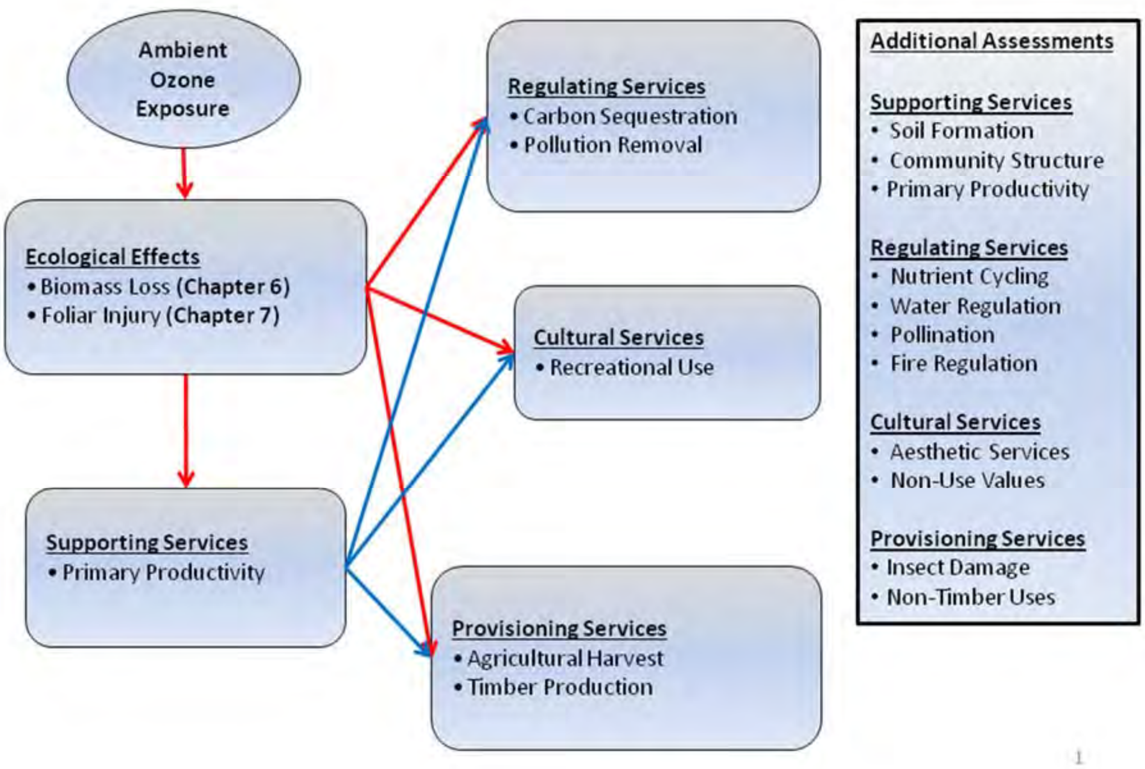

Figure 5-2 Relationship between Ecological Effects of O3 Exposure and Ecosystem Services

While most of the impacts of O_3 on these services cannot be specifically quantified, it is important to provide an understanding of the magnitude and significance of the services that are anticipated to be negatively impacted by O_3 exposures. For many services, we can estimate the current total magnitude and, for some, we can estimate the current value of the services in question. The estimates of current service provision will reflect the loss of services potentially occurring from historical and current O_3 exposure and provide context for the importance of any potential impacts of O_3 on those services, e.g., if the total value of a service is small, the likely impact of O_3 exposure will also be small. Likewise, if the total value is large, there is a higher potential for significant damage, even if the relative contribution of O_3 as a stressor is small. Also, in some cases we can provide information on locations where high O_3 exposures occur in conjunction with significant ecosystem service impairment. Specifically, we can provide information on areas where high W126 index values may have the greatest contribution to the service impairment caused by fires in California and bark beetle damage in forests. This assessment will address O_3 impacts on ecosystem services following the framework of the Millennium Ecosystem Assessment (MEA, 2005). In line with the framework, the subsequent sections are divided into regulating, supporting, provisioning, and cultural ecosystem services.

5.2 REGULATING SERVICES

Regulating services as defined by the MEA (2005) are those services that regulate ecosystem processes. Services such as air quality, water, climate, erosion, and pollination regulation fit within this category. The next sections describe potential impacts of O_3 on some of these services.

5.2.1 Hydrologic Cycle

Regulation of the water cycle is another ecosystem service that 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 have shown that ambient O_3 exposures resulted in increased water use in O_3-sensitive species, which led to decreased modeled late-season stream flow in those watersheds. The increased water use resulted from a sluggish stomatal response that increases water loss, which in turn increases water requirements (U.S. EPA, 2013). 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. Conversely, one model study reported in the O_3 ISA (U.S. EPA, 2013) associated reduced stomatal aperture from O_3 exposure combined with nitrogen limitation with decreased water loss, which in turn increased runoff, potentially increasing water availability. Regardless of the response, water cycling in forests is affected by O_3 exposure and potentially impacts ecosystem services associated with both water quality and quantity.

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 that provides data on the values survey respondents place on the provision of habitat for wild plants and animals. As part of the NSRE, the United States Forest Service (USFS) and the National Oceanographic and Atmospheric Administration (NOAA) jointly surveyed Americans, age 16 and over, for their report on *Uses and Values of Wildlife and Wilderness in the United States*. The NSRE specifically asked respondents to rank the importance of water quality as a benefit of wilderness. Ninety one percent of respondents ranked water quality protection as either extremely or very important; less than 1 percent of respondents ranked this service as not important at all.

5.2.2 **Pollination**

The O_3 ISA (U.S. EPA, 2013) identifies O_3 as a possible agent affecting the travel distance of and the loss of specificity of volatile organic compounds emitted by plants, some of which act as scent cues for pollinators. While it is not possible to explicitly calculate the loss of pollination services resulting from this negative effect on scent cues, the loss is reflected in the current estimated value of $18.3 billion (2010$) for all pollination services, managed and wild, in North America (U.S., Canada, and Bermuda) (Gallai et al., 2009).

5.2.3 **Fire Regulation**

Fire regime regulation is also negatively affected by O_3 exposure. Grulke et al. (2009) reported various lines of evidence indicating that O_3 exposure may be anticipated to contribute to southern California forest susceptibility to wildfires by increasing leaf turnover rates and litter. This, in turn, creates increased fuel loads on the forest floor, O_3-increased drought stress, and increased susceptibility to bark beetle attacks.

According to the National Interagency Fire Center (http://www.nifc.gov/fireInfo/fireInfo_statistics.html), in 2010 in the United States over 3 million acres burned in wildland fires. Over the 5-year period from 2004 to 2008, Southern California alone experienced, on average, over 4,000 fires per year burning, on average, over 400,000 acres per fire (National Association of State Foresters [NASF], 2009).

The short-term benefits of reducing the anticipated O_3-related fire risks include the value of avoided residential property damages; avoided damages to timber, rangeland, and wildlife resources; avoided losses from fire-related air quality impairments; avoided deaths and injury due to fire; improved outdoor recreation opportunities; and savings in costs associated with fighting the fires and protecting lives and property.

For example, the California Department of Forestry and Fire Protection (CAL FIRE) estimated that average annual losses to homes due to wildfire from 1984 to 1994 were $226 million (CAL FIRE, 1996) and were over $263 million in 2007 (CAL FIRE, 2008) in inflation adjusted 2010$. In fiscal year 2008, CAL FIRE's budgeted costs for fire suppression activities were nearly $304 million 2010 dollars (CAL FIRE, 2008).

CAL FIRE also estimates fire risk in the state on a -1 to 5 scale, with 2 being moderate risk. Using GIS, we developed maps that overlay the area of California with mixed conifer forest, an ecosystem that contains O_3-sensitive species, and the fire risk area calculated by CAL FIRE. We then generated maps overlaying the current ambient O_3 conditions and the modeled alternative scenarios with the areas of mixed conifer forest that have a fire risk in the moderate and higher range. These maps allow us to calculate the area of mixed conifer forests with moderate to high fire risk and correlate that with high W126 index values under various scenarios. Figure 5-3 shows W126 index values after just meeting the existing and alternative standard levels in areas in California with fire risk greater than 2 on CAL FIRE's scale.

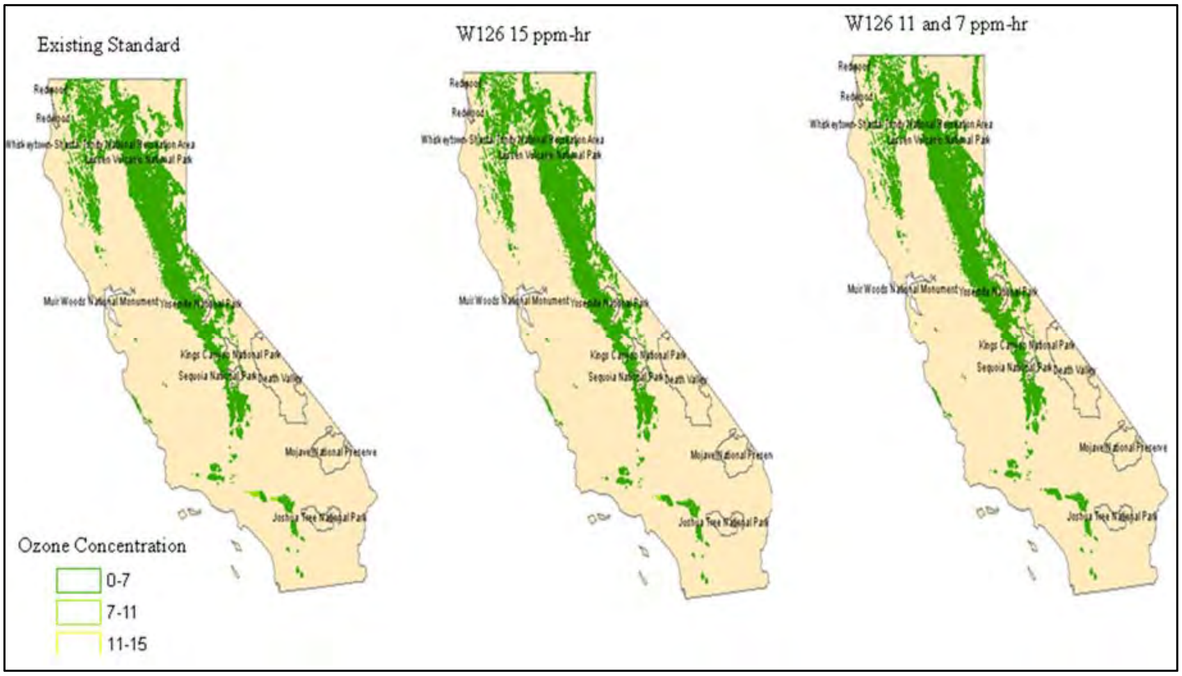

Figure 5-3 Overlap of W126 Index Values for the Existing Standard and Alternative W126 Standard Levels, Fire Threat > 2, and Mixed Conifer Forest

The highest fire risk and highest W126 index values are correlated with each other, and with significant portions of mixed conifer forest. Under recent conditions, over 97 percent of mixed conifer forests (21,800 square kilometers) have W126 index values over 7 ppm-hrs and a moderate to severe fire risk, and 74 percent (16,500 square kilometers) have W126 index values over 15 ppm-hrs with moderate to severe fire risk. When we simulate just meeting the existing standard almost all of the area of mixed conifer forest where there is a moderate to high fire threat sees a reduction in O_3 to below a W126 index value of 7 ppm-hrs. At the adjusted alternative W126 standard level of 15 ppm-hrs all but 40 km^2 are under a W126 index value of 7 ppm-hrs and at 11or 7 ppm-hrs all of the moderate to high fire threat area is under 7 ppm-hrs. Table 5-1 summarizes the reductions in areas of moderate to high-fire threat, mixed conifer forests at the existing and alternative standard levels.

Table 5-1 Area of Moderate to High-Fire Threat, Mixed Conifer Forest for Existing and Alternative Standard Levels (in km^2)

	<7ppm-hrs	7-11ppm-hrs	11-15 ppm-hrs	>15 ppm-hrs
Recent Conditions	482	2,542	5,271	16,544
Existing Standard (75 ppb)	22,180	117	0	0
15 ppm-hrs	22,257	40	0	0
11ppm-hrs	22,297	0	0	0
7 ppm-hrs	22,297	0	0	0

In the long term, decreased frequency of fires could result in an increase in property values in fire-prone areas. Mueller et al. (2007) conducted a hedonic pricing study to determine whether increasing numbers of wildfires affect house prices in southern California. They estimated that house prices would decrease 9.7 percent after one fire and 22.7 percent after a second wildfire within 1.75 miles of a house in the study area. After the second fire, housing prices took between 5 and 7 years to recover.

Figure 5-4 shows the locations of fires in the mixed conifer forest range in 2010. There were 961 fires detected in these areas, including many in the national parks. While we can't conclude that O_3 reductions would have prevented these fires because there are many contributing factors, we can conclude that air quality adjusted to just meet the existing standard will, in many areas, decrease the anticipated role of O_3 as a contributing factor by reducing the W126 index value to below 7 in most areas. Meeting alternative W126 standards results in small to no additional reductions in the area of forests above a 7 ppm-hrs W126 standard level. Additionally, long- term decreases in wildfire would be expected to yield outdoor recreation benefits consistent with the discussion of scenic beauty in subsequent sections.

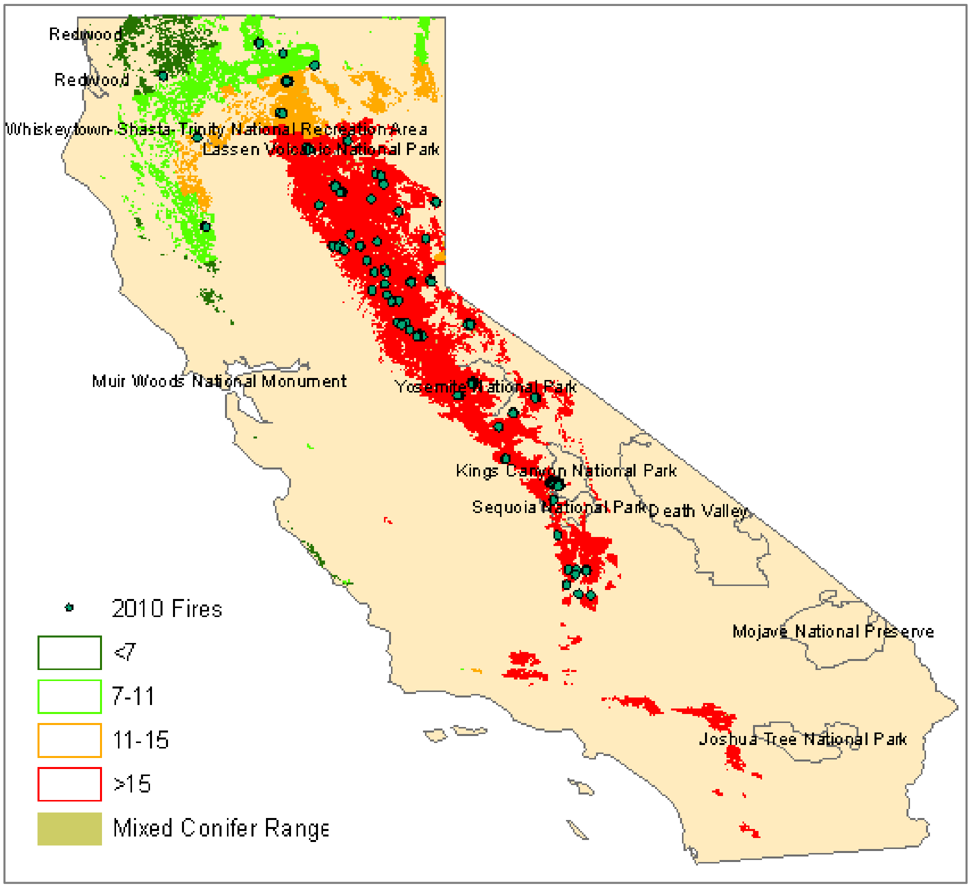

Figure 5-4 Location of Fires in 2010 in Mixed Conifer Forest Areas (under Recent O_3 Conditions)

5.3 SUPPORTING SERVICES

Supporting services are the services needed by all of the other ecosystem services. Other categories of services have relatively direct or short-term impacts on humans, while the impacts on public welfare from supporting services are generally either indirect or occur over a long time. The next sections describe potential impacts of O_3 on some of these supporting services.

5.3.1 Net Primary Productivity

Primary productivity underlies the provision of many subsequent ecosystem services that are highly valued by the public, including provision of food and timber. The O_3 ISA determined that biomass loss due to O_3 exposure may reduce net primary productivity (NPP). According to the O_3 ISA (U.S. EPA, 2013), when compared to 1860's era preindustrial conditions, NPP in

U.S. Mid-Atlantic temperate forests decreased 7-8 percent per year from 1991-2000 due to O_3 exposure, even with growth stimulation provided by elevated carbon dioxide and nitrogen deposition. Also, compared to a presumed pristine condition in 1860, NPP for the conterminous U.S from 1950-1995 decreased as much as 13 percent in some areas in the agricultural region of the Midwest during the mid-summer. While there are models available to help quantify changes in NPP and in the hydrologic cycle discussed in Section 5.2.1 we were not able to attempt quantification of NPP or hydrology due to resource limitations. Additionally these services are more difficult to interpret in ways that are meaningful to people.

5.3.2 Community Composition and Habitat Provision

Community composition or structure is also affected by O_3 exposure. Since species vary in their response to O_3, those species that are more resistant to the negative effects of O_3 are able to out-compete more susceptible species. For example, according to studies cited in the O_3 ISA (U.S. EPA, 2013), the San Bernardino area community composition in high-O_3 sites has shifted toward O_3-tolerant species such as white fir, sugar pine, and incense cedar at the expense of ponderosa and Jeffrey pine. Changes in community composition underlie possible changes in associated services such as herbivore grazing, production of preferred species of timber, and preservation of unique or endangered communities or species, among others. Table 5-2 summarizes the responses to survey questions regarding the value of wildlife habitat and preservation of unique or endangered species.

Table 5-2 Responses to NSRE Wildlife Value Questions

Service	Percent of Respondents Considering the Service Important			
	Extremely Important	Very Important	Moderately Important	Total*
Wildlife Habitat	51	36	9	96
Preserving Unique Wild Plants and Animals	44	36	13	93
Protecting Rare or Endangered Species	50	33	11	94

*The remaining respondents felt these services were not important.

There exist meta-analyses on the monetary values Americans place on threatened and endangered species. One such study (Richardson and Loomis, 2009) estimates the average annual willingness to pay (WTP) for a number of species. The authors report a wide range of values dependent on the change in the size of the species population, type of species, and whether visitors or households are valuing the species. The average annual WTP for surveyed species ranged from $9/year for striped shiner for Wisconsin households to $261/year for Washington state households value for anadromous fish, such as salmon, in constant 2010$.

5.4 PROVISIONING SERVICES

Provisioning services include market goods, such as forest and agricultural products. The direct impact of O_3-induced biomass and yield loss can be predicted for the commercial timber and agriculture markets, respectively, using the Forest and Agriculture Optimization Model (FASOM). This model provides a national-scale estimate of the effects of O_3 on these two market sectors, including producer and consumer surplus estimates (see Section 6.3 for a discussion of producer and consumer surplus). Chapter 6 of this document provides detailed analyses of the potential impact of biomass and yield loss on these services. Non-timber forest products (NTFP), such as foliage and branches used for arts and crafts or edible fruits, nuts, and berries, can be affected by the impact of O_3 through biomass loss, foliar injury, insect attack, fire regime changes, and effects on reproduction. Acknowledging that services lost in this sector can be the result of interacting effects of O_3 with other stressors, we also have included details for the magnitude of the NTFP services in Chapter 6.

Figure 5-5 Southern Pine Beetle Damage Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

In addition to the direct effects of O_3 on tree growth, O_3 is anticipated to cause increased susceptibility to infestation by some chewing insects (U.S. EPA, 2006). This potentially includes tree species that are not considered sensitive to either biomass loss or foliar injury such as Douglas fir.

Chewing insects include the southern pine beetle and western bark beetle, species that are of particular interest to commercial timber producers and consumers. These infestations can cause economically significant damage to tree stands and the associated timber production. Figure 5-5 and Figure 5-6 illustrate the damage caused by southern pine beetles in parts of the south.

Figure 5-6 Southern Pine Beetle Damage Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

According to the USFS Report on the southern pine beetle (Coulson and Klepzig, 2011), "Economic impacts to timber producers and wood-products firms are essential to consider because the SPB causes extensive mortality in forests that have high commercial value in a region with the most active timber market in the world." The economic impacts of beetle outbreaks are multidimensional. In the short-term, the surge in timber supply caused by owners harvesting damaged timber depresses prices for timber and benefits consumers. In the long-term, beetle outbreaks reduce the stock of timber available for harvest, raising timber prices to the benefit of producers and the detriment of consumers.

The USFS further reports that over the 28 years covered in their analysis (1977-2004), because of beetle outbreaks, timber producers have incurred losses of about $1.4 billion, or about $49 million per year, and wood-using firms have gained about $966 million, or about $35 million per year. This results in a $15 million per year net negative economic impact. (All dollar values are reported in constant 2010$.) These annual figures mask that most of the economic impacts result from a few catastrophic outbreaks, causing the impacts to pulse through the system in large chunks rather than being evenly distributed over the years. It is not possible to attribute a portion of these impacts resulting from the effect of O_3 on trees' susceptibility to insect attack; however, such losses are already reflected in the losses cited, and any welfare gains from decreased O_3 would positively impact the net economic impact.

In the western United States, O_3-sensitive ponderosa and Jeffrey pines are subject to attack by bark beetles. Ozone exposure is anticipated to increase susceptibility to these insect infestations in sensitive species.

Figure 5-7 shows areas considered ‘at risk’ of losing 25 percent or more basal area in the contiguous United States to the top seven pine beetle species over the next 15 years (pine beetle projections were calculated by the Forest Health Technology Enterprise Team). Under recent conditions, approximately 48,000 km^2 have W126 index values above 15 ppm-hrs. After just meeting the existing standard, all areas are under a W126 index value of 7 ppm-hrs with the exception of about 4,000 km^2 in Arizona and Colorado. After just meeting an alternative standard level of 15 ppm-hrs, no area is above 7 ppm-hrs. Table 5-3 and Table 5-4 provide summaries of areas at risk of higher pine beetle loss and millions of square feet of basal tree area at high risk at various W126 index values.

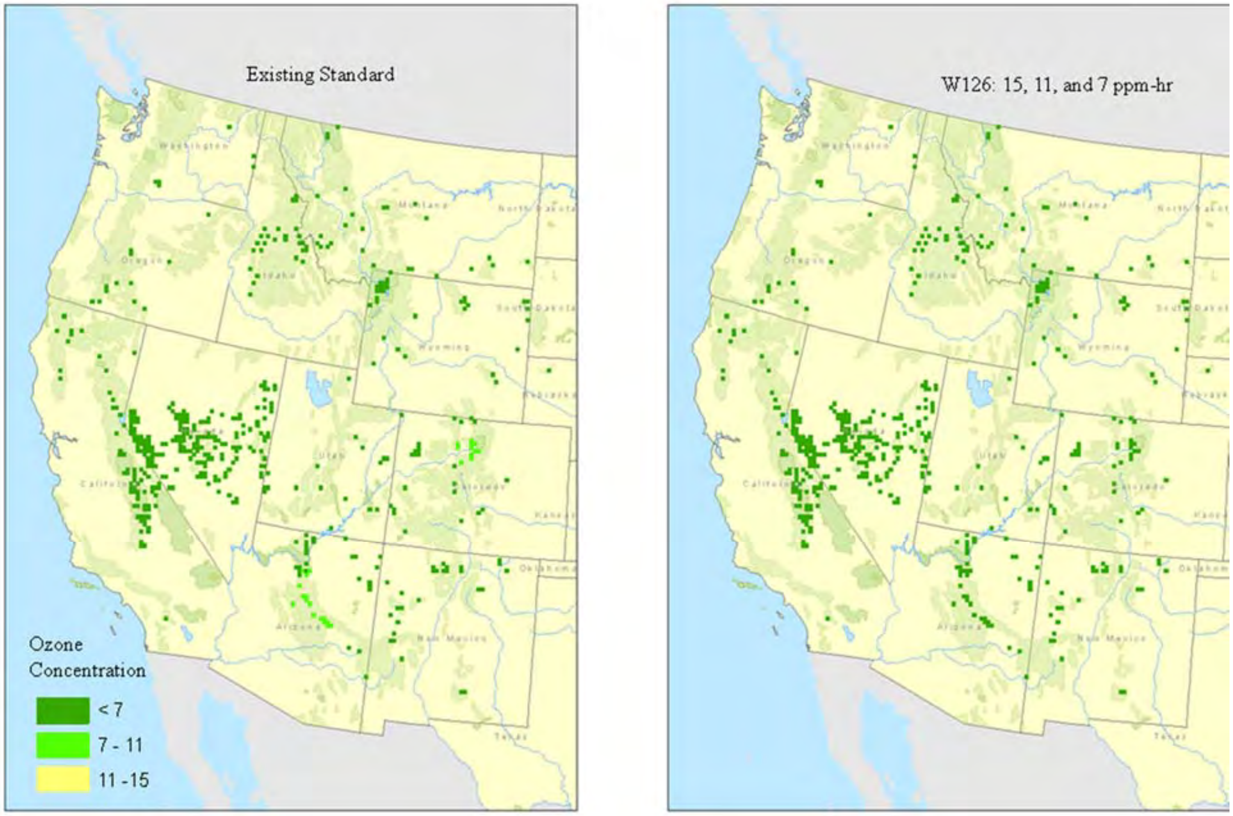

Figure 5-7 W126 Index Values for Just Meeting the Existing and Alternative Standard Levels in Areas Considered 'At Risk' of High Basal Area Loss (>25% Loss)

Table 5-3 Area (km^2) 'At Risk' of High Pine Beetle Loss at Various W126 Index Values

	<7 ppm-hrs	**7-11ppm-hrs**	**11-15 ppm-hrs**	**>15 ppm-hrs**
Recent Conditions	3,456	19,440	13,536	48,096
Existing Standard (75 ppb)	80,640	3,888	0	0
15 ppm-hrs	84,528	0	0	0
11ppm-hrs	84,528	0	0	0
7 ppm-hrs	84,528	0	0	0

Table 5-4 Tree Basal Area Considered 'At Risk' of High Pine Beetle Loss By W126 Index Values after Just Meeting the Existing and Alternative Standard Levels (in millions of square feet)

	<7 ppm-hrs	7-11ppm-hrs	11-15 ppm-hrs	>15 ppm-hrs
Recent Conditions	90	368	145	488
Existing Standard (75 ppb)	982	110	0	0
15 ppm-hrs	1,091	0	0	0
11ppm-hrs	1,091	0	0	0
7ppm-hrs	1,091	0	0	0

In 2006, California was the largest producer of ponderosa and Jeffrey pine timber from public lands. California accounted for 99 million board feet of saw logs – almost 40 percent of the total U.S. production (U.S. Forest Service, 2009, available at: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php). California also experiences high W126 index values that may contribute to susceptibility to bark beetle attack. It is not possible to attribute a quantified impact of O_3 exposure to economic loss from bark beetle damage because that impact is already reflected in the loss attributed to bark beetle infestation. Reducing O_3 impacts would potentially reduce economic loss to California timber production.

Figures 5-5 and 5-6 also illustrate the impact insect outbreaks can have on aesthetic values such as scenic beauty, as well as to the impacts on timber production. As shown in the NOx/SOx Policy Assessment (U.S. EPA, 2011e), the value of the impact of O_3 and insect attack susceptibility on aesthetic values may be even greater than the market value of the timber. We will address timber production effects from reduced growth rates in Chapter 6 and effects of foliar injury on related ecosystem services in Chapter 7.

5.5 CULTURAL SERVICES

Cultural services include non-use values (i.e., existence and bequest values) that can be directly or indirectly impacted by O_3 exposure. According to responses to the NSRE, a large majority of Americans wishes to preserve natural or pristine areas, even if they do not intend to visit these areas. Outdoor recreation is another cultural service that may be affected by O_3 exposure. Foliar injury caused by O_3 exposure and insect attack aided by O_3 exposure may have negative impacts on people's satisfaction with outdoor activities, especially those activities associated with the quality of natural environments.

According to the National Report on Sustainable Forests (USDA, 2011) there are approximately 751 million acres of forest lands in the U.S., one-third of which is federally owned (Figure 5-8). All of these lands are assumed to be protected to some degree, but specific protections apply to wilderness areas, which comprise about 20 percent of public land. Of the remaining lands, 7 percent is protected as national parks; 13 percent is designated as wildlife refuges; and 60 percent is protected, managed forests, including national forests, Bureau of Land Management lands, and other state and local government lands. The protections afford preservation of cultural, social, and spiritual values.

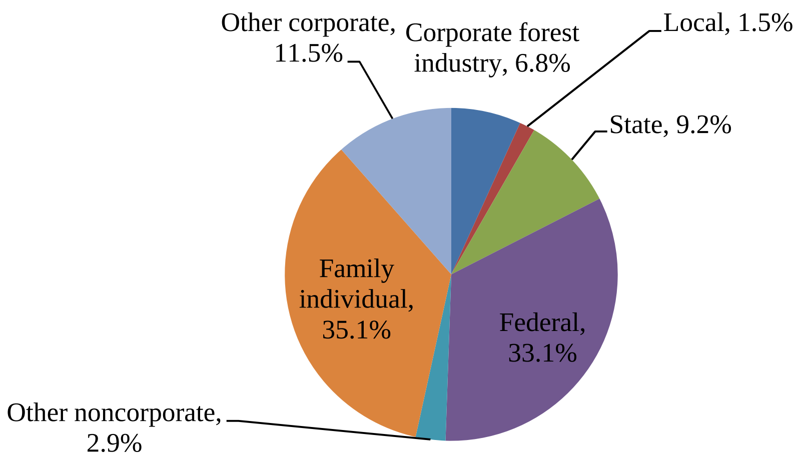

Figure 5-8 Percent of Forest Land in the US by Ownership Category, 2007
Source: USFS (Almost all forest lands are open for some form of recreation, although access may be restricted.)

5.5.1 **Non-Use Services**

The NSRE surveys also track American's attitudes toward various benefits derived from the environment, including non-use values. When people value a resource even though they may never visit the resource or derive any tangible benefit from it, they perceive an existence service. When the resource is valued as a legacy to future generations, a bequest service exists. Additionally, there exists an option value to knowing that you may visit a resource at some point in the future. Data provided by the NSRE indicates that Americans have very strong preferences for existence, bequest, and option services related to forests. Significantly, according to the survey, only 5 percent of Americans rate wood products as the most important value of public forests and wilderness areas, and for private forests, only 20 percent of respondents rated wood products as most important. Table 5-5 details the survey responses to these questions.

Table 5-5 NSRE Responses to Non-Use Value Questions For Forests

Service	Percent of Respondents Considering the Service Important			
	Extremely Important	Very Important	Moderately Important	Total*
Existence	36	38	18	92
Option	36	37	17	90
Bequest	81	12	4	97

*Remaining respondents felt these services were not important.

Studies (Haefele et al., 1991, Holmes and Kramer, 1995) indicate that the American public places a high value on protecting forests and wilderness areas from the damaging effects of air pollution. These studies assess willingness-to-pay (WTP) for spruce-fir forest protection in the southeast from air pollution and insect damage and confirm that the non-use values held by the survey respondents were in fact greater than the use or recreation values. The survey presented respondents with a sheet of color photographs representing three stages of forest decline and explained that, without forest protection programs, high-elevation spruce forests would all decline to worst conditions. Two potential forest protection programs were proposed. The first program (minimal program) would protect the forests along road and trail corridors spanning approximately one-third of the ecosystem at risk. This level of protection may be most appealing to recreational users. The second level of protection (more extensive program) was for the entire ecosystem and may be most appealing to those who value the continued existence of the entire ecosystem. Median household WTP was estimated to be roughly $29 (in 2007 dollars) for the minimal program and $44 for the more extensive program. Respondents were then asked to decompose their value for the extensive program into use, bequest, and existence values. The results were 13 percent for use value, 30 percent for bequest, and 57 percent for existence value (Table 5-6).

While these studies are specific to damage due to excess nitrogen deposition and the wooly balsam adelgid (a pest in Fraser fir), the results are relevant to O_3 exposure in forests because the effects are similar. In the southeast, loblolly pine is a prevalent species and O_3 foliar injury can cause visible damage. Ozone exposure is also anticipated to result in trees more susceptible to insect attack, which in the southeast would include damage caused by the southern pine beetle.

Table 5-6 Value Components for WTP for Extensive Protection Program for Southern Appalachian Spruce-Fir Forests

Type of Value	Proportion of WTP	Component Value ($2007)
Use	0.13	5.72
Bequest	0.30	13.20
Existence	0.57	25.08
Total	1.0	44.00

5.6 QUALITATIVE ASSESSMENT OF UNCERTAINTY

As noted in Chapter 3, we have based the design of the uncertainty analysis for this assessment on the framework outlined in the WHO guidance (WHO, 2008). For this qualitative uncertainty analysis, we have described each key source of uncertainty and qualitatively assessed its potential impact (including both the magnitude and direction of the impact) on risk results, as specified in the WHO guidance. In general, this assessment includes qualitative discussions of the potential impact of uncertainty on the results (WHO Tier1) and quantitative sensitivity analyses where we have sufficient data (WHO Tier 2).

Table 5-7 includes the key sources of uncertainty identified for the O_3 WREA. For each source of uncertainty, we have (a) provided a description, (b) estimated the direction of influence (over, under, both, or unknown) and magnitude (low, medium, high) of the potential impact of each source of uncertainty on the risk estimates, (c) assessed the degree of uncertainty (low, medium, or high) associated with the knowledge-base (i.e., assessed how well we understand each source of uncertainty), and (d) provided comments further clarifying the qualitative assessment presented. The categories used in describing the potential magnitude of impact for specific sources of uncertainty on risk estimates (i.e., low, medium, or high) reflect our consensus on the degree to which a particular source could produce a sufficient impact on risk estimates to influence the interpretation of those estimates in the context of the secondary O3 NAAQS review. Where appropriate, we have included references to specific sources of information considered in arriving at a ranking and classification for a particular source of uncertainty.

Table 5-7 Summary of Qualitative Uncertainty Analysis in Semi-Quantitative Ecosystem Services Assessments

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
A. National W126 surfaces	The fire risk and bark beetle analyses in this chapter use the national W126 surfaces for recent conditions and adjusted to just meet the existing standard and alternative W126 standards.	Both	Low-Medium	Low-Medium	KB and INF: See Chapter 4 for more details.
B. Incremental impact of O_3 on ecosystem services	Many ecosystem services affected by O_3 exposure are discussed qualitatively or semi-quantitatively, including supporting services (e.g., net primary productivity and community composition), regulating services (e.g., hydrologic cycle and pollination), and cultural services (e.g., recreation and non-use).	Under	High	Low	KB: The O_3 ISA concludes that there is a causal relationship between O_3 exposure and productivity in terrestrial ecosystems and biogeochemical cycles, and a likely to be causal relationship between O_3 exposure and terrestrial water cycling and terrestrial community composition (U.S. EPA, 2011). However, we do not have sufficient data, methods, or resources to adequately quantify the incremental effects of changes in O_3 on many ecosystem services. INF: For many services, we can estimate the current total magnitude and, for some, we can estimate the current monetized value. The estimates of current service provision will reflect the loss of services occurring from historical and current O_3 exposure and provide context for the importance of any potential impacts of O_3 on those services, e.g., if the total value of a service is small, the total value of the likely impact of O_3 exposure will also be small. Likewise, if the total value is large, there is a higher potential for significant damage, even if the relative contribution of O_3 as a stressor is small.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
C. Areas with fire risk in California	Maps of areas with moderate and higher fire risk have uncertainty, and thus the potential overlap with areas with higher W126 index values and mixed conifer forests are also uncertain.	Unknown	Medium	High	KB: California's fire risk maps are systematically developed including consideration of factors such as defensible space, non-flammable roofs, and ignition resistant construction reduce fire risk. (See http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland_zones_development.php). INF: In 2010, over 3 million acres burned in wildland fires (NIFC, 2010). The economic value of homes lost due to wildfire and fire suppression activities can be hundreds of millions of dollars per year in California (CAL Fire, 2006, 2007, 2008).
D. Areas at risk due to bark beetle	In the western U.S., O_3-sensitive ponderosa and Jeffrey pines are subject to attack by bark beetles. Maps that identify areas considered 'at risk' of losing 25 percent or more basal area to pine beetle have uncertainty, and thus the potential area of overlap with areas with higher W126 index values are also uncertain.	Unknown	Medium	Medium	KB: Ozone causes increased susceptibility to infestation by some chewing insects (U.S. EPA, 2006, 2013), including the southern pine beetle and the western bark beetle. It is not possible to attribute a portion of these impacts resulting from the effect of O_3 on trees' susceptibility to insect attack; however, such losses are already reflected in the losses cited, and any welfare gains from decreased O_3 would positively impact these numbers. INF: Insect infestations can cause economically significant damage to tree stands and the associated timber production. USFS estimates a $15 million per year net negative economic impact due to bark beetle infestations (Coulson and Klepzig, 2011).

5.7 KEY OBSERVATIONS

Ozone damage to vegetation and ecosystems from recent conditions causes widespread impacts on an array of ecosystem services. Biomass loss impacts numerous services, including supporting and regulating services such as net primary productivity, community composition, habitat, and climate regulation. The provisioning services of timber production can be affected by the increased susceptibility to insect attack caused by O_3 exposure. Non-use values, including existence and bequest values, are also affected by the damage to scenic beauty caused by insect attack (an indirect effect of O_3) and foliar injury (a direct effect). Below we offer a few observations on the challenges of explicitly valuing ecosystem services, highlight the importance of continuing to consider the services in our assessments, and indicate where additional analyses and discussion on valuing the ecosystem services are located in this document.

- Most of the impacts of O_3 exposure on ecosystem services cannot be specifically quantified, but it is very important to provide an understanding of the magnitude and significance of the services that may be harmed by O_3 exposure. For many ecosystem services, we can estimate the current total magnitude and, for some, we can estimate the current value of the services in question.

- **Regulating ecosystem services** include hydrologic cycle, pollination, and fire regulation. Hydrologic, or *water cycling* in forests is affected by O_3 exposure and has impacts on ecosystem services associated with both water quality and quantity. While the NSRE results show that 91 percent of respondents rank water quality protection as either extremely important or very important, because of data and methodology limitations, quantifying the loss of value to the public from incremental changes in O_3 exposure on water cycling is not currently feasible. For *pollination services*, it is not currently feasible to explicitly calculate the loss of pollination resulting from O_3 exposure, but the loss is reflected in the current total estimated value of $18.3 billion (2010$) for pollination services in North America. Lastly, *fire regulation* may be negatively affected by O_3 exposure through forest susceptibility to wildfires, drought stress, and insect attack. The value of this ecosystem service is reflected in avoided damage to residential property, timber, rangeland, and wildfire fighting resources, as well as improved outdoor recreation opportunities. As an example, the California Department of Forestry and Fire Protection (CAL FIRE) estimated that average annual losses to homes due to wildfire from 1984 to 1994 were $163 million (CAL FIRE, 1996) and were over $250 million in 2007 (CAL FIRE, 2008). In fiscal year 2008, CAL FIRE's costs for fire suppression activities were nearly $300 million (CAL FIRE, 2008).

- The impacts on public welfare from **supporting services** are generally either indirect or occur over a long time. The O_3 ISA determined that biomass loss due to O_3 exposure may have adverse effects on *net primary productivity*. But because of data and methodology limitations, quantifying the loss of value to the public from incremental changes in O_3 exposure on NPP on a national level is not feasible at this time. Also, it is currently not feasible to quantify the impacts of O_3 exposure on *community composition*.

- **Provisioning services** include market goods, such as forest and agriculture products. The direct impact of O_3-induced biomass loss can be predicted for the *commercial timber and agriculture markets* using the Forest and Agriculture Optimization Model. Chapter 6 of this document provides detailed analyses of the potential impact of biomass and yield loss on these services. In addition, *non-timber forest products* (NTFP), such as foliage and branches used for arts and crafts or edible fruits, nuts, and berries, can be affected by the impact of O_3 through biomass loss, foliar injury, insect attack, fire regime changes, and effects on reproduction. We include details for the magnitude of the NTFP services in Chapter 6.

- In addition, to estimate the magnitude of insect attacks related to O_3 exposure on **provisioning services**, such as forest products, we reviewed the USFS Report on the Southern Pine Beetle (Coulson and Klepzig, 2011). The USFS further reports that over the 28 years covered in their analysis (1977-2004), because of beetle outbreaks, timber producers have incurred losses of about $1.4 billion, or about $49 million per year, and wood-using firms have gained about $966 million, or about $35 million per year. This results in a $15 million per year net negative economic impact.[1] While it is not currently feasible to attribute a portion of these impacts resulting from the effect of O_3 on trees' susceptibility to insect attack, these losses are reflected in the values cited.

- *Outdoor recreation* is a **cultural service** that may be affected by O_3 exposure. Foliar injury caused by O_3 exposure and insect attack aided by O_3 exposure may have negative impacts on people's satisfaction with outdoor activities, especially those activities associated with the quality of natural environments. These impacts are discussed in Chapter 7 on foliar injury. In addition, some cultural services, such as *existence or bequest services*, lend themselves to evaluating total importance and measuring total value, but assessing the impact of O_3 effects on these services is not currently feasible.

[1] All values are reported in constant 2010$.

6 BIOMASS LOSS

6.1 INTRODUCTION

The previous O_3 AQCDs (U.S. EPA, 1996, 2006) and current O_3 ISA (U.S. EPA, 2013) concluded that there is strong and consistent evidence that ambient O_3 decrease photosynthesis and growth in numerous plant species, but the magnitude of the effects are variable both across species and across regions of the U.S.

The ecosystem services most directly affected by biomass loss include: (1) habitat provision for wildlife, particularly habitat for threatened or endangered wildlife, (2) carbon storage, (3) provision of food and fiber, and (4) pollution removal (see Figure 6-1). Although we cannot quantify reduction in habitat provision due to O_3 exposure on either a national or case study scale, there is evidence that this service is important to the public.

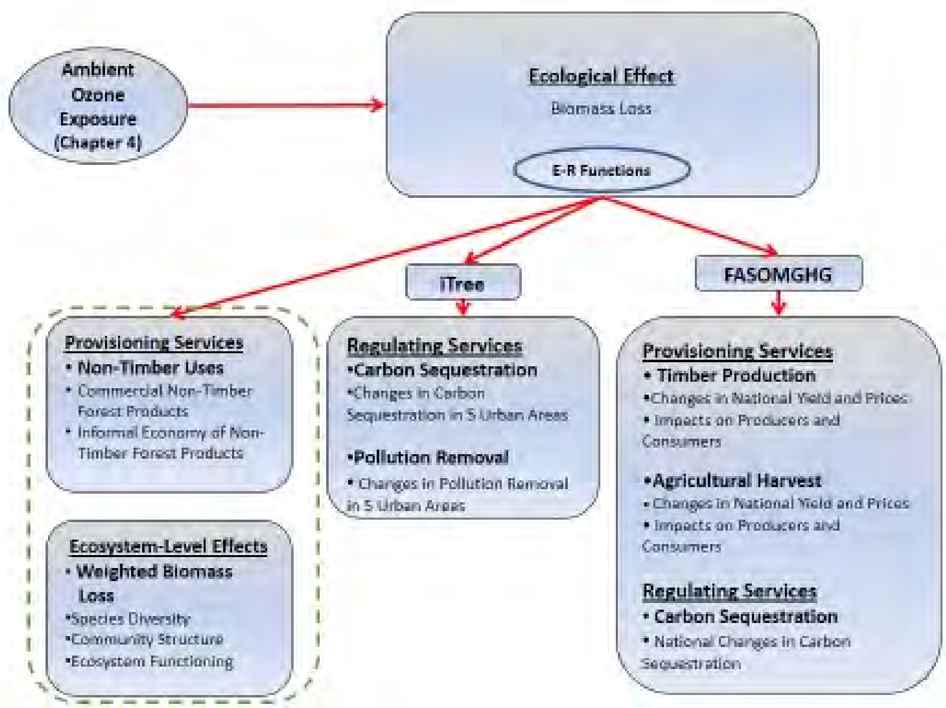

Figure 6-1 Conceptual Diagram of Relationship of Relative Biomass Loss to Ecosystem Services [The dashed box indicates those services for which direct quantification was not possible.]

In the cases of carbon storage and food and fiber provision, the analyses presented here used the exposure-response (E-R) functions developed for trees and crops to model, at the national scale, the approximate loss of services and the marginal benefits of alternative levels of a W126 standard.

We included national parks at the case-study scale, as well as Class I areas. Class I areas are designated as areas in which visibility has been determined to be of important value (C.F.R. 40, 81.400). The determination is primarily based on air quality limitations on visibility, but in this assessment we are using them in the context of protected areas of interest to address potential impacts. The national parks are meant to be preserved for the enjoyment of present and future generations, as well as for the unique or sensitive ecosystems and species in the parks. The parks are not a source of food or fiber production and are not included in the analysis of those services. And although the parks do provide carbon sequestration and storage and pollution removal, neither of the models for these ecosystem services available for this review was able to include national parks. The model used for the urban case study areas allows analysis of carbon sequestration and storage and pollution removal services; it does not include habitat provision or food and fiber production.

The remainder of this Chapter includes Section 6.2 – Relative Biomass Loss; Section 6.3 – Commercial Timber Effects; Section 6.4 – Non-Timber Forest Products; Section 6.5 – Agriculture; 6.6 – Climate Regulation; Section 6.7 – Urban Case Study Air Pollution Removal; and Section 6.8 – Ecosystem Level Effects.

6.2 RELATIVE BIOMASS LOSS

The 1996 and 2006 O_3 AQCDs relied extensively on results from analyses conducted on commercial crop species for the National Crop Loss Assessment Network (NCLAN) and on analyses of tree seedling species conducted by the EPA's National Health and Environmental Effects Laboratory Western Ecology Division (NHEERL/WED). Results from these studies have appeared in numerous publications, including Lee et al. (1994; 1989, 1988b, 1987), Hogsett et al. (1997), Lee and Hogsett (1999), Heck et al. (1984), Rawlings and Cure (1985), Lesser et al. (1990), and Gumpertz and Rawlings (1992). Those analyses concluded that a three-parameter Weibull model is the most appropriate model for the response of absolute yield and growth to O_3 exposure because of the interpretability of its parameters, its flexibility (given the small number of parameters), and its tractability for estimation. See equation 6-1 for an example of a three-parameter Weibull model.

$$Y = \alpha e^{-\left(\frac{W126}{\eta}\right)^{\beta}}$$

Equation 6-1

In addition, if the intercept term, α, is removed, the model estimates relative yield or biomass without any further reparameterization. Formulating the model in terms of relative yield or biomass loss (RBL) in relation to the 3-month W126 index is essential for comparing exposure-response across species or genotypes or for experiments for which absolute values of the response may vary greatly. See equation 6-2 for the reformulated model.

$$RBL = 1 - \exp[-(W126/\eta)^{\beta}]$$

Equation 6-2

In the 1996 and 2006 O_3 AQCDs, the two-parameter model of RBL was used to derive common models for multiple species, multiple genotypes within species, and multiple locations. Relative biomass loss (RBL) functions for the 12 tree species used in this assessment are presented in Table 6-1 (see the O_3 ISA (U.S. EPA, 2013) for a more extensive review of the calculation of the E-R functions), and RBL functions for the 10 crop species used in this assessment are presented in Table 6-2. Relative biomass loss is annual.

Table 6-1 Relative Biomass Loss Functions for Tree Species

Species	RBL Function	η (ppm)	β
Red Maple (*Acer rubrum*)	**$1 - \exp[-(W126/\eta)^{\beta}]$**	318.12	1.3756
Sugar Maple (*Acer saccharum*)		36.35	5.7785
Red Alder (*Alnus rubra*)		179.06	1.2377
Tulip Poplar (*Liriodendron tulipifera*)		51.38	2.0889
Ponderosa Pine (*Pinus ponderosa*)		159.63	1.1900
Eastern White Pine (*Pinus strobus*)		63.23	1.6582
Loblolly Pine (*Pinus taeda*)		3,966.3	1.0000
Virginia Pine (*Pinus virginiana*)		1,714.64	1.0000
Eastern Cottonwood (*Populus deltoides*)		10.10	1.7793
Quaking Aspen (*Populus tremuloides*)		109.81	1.2198
Black Cherry (*Prunus serotina*)		38.92	0.9921
Douglas Fir (Pseudotsuga menzeiesii)		106.83	5.9631

Table 6-2 Relative Biomass Loss Functions for Crop Species

Species	RBL Function	η (ppm)	β
Barley	**$1 - \exp[-(W126/\eta)^{\beta}]$**	6,998.5	1.388
Field Corn		97.9	2.968
Cotton		96.1	1.482
Kidney Bean		43.1	2.219
Lettuce		54.6	4.917
Peanut		96.8	1.890
Potato		99.5	1.242
Grain Sorghum		205.3	1.957
Soybean		110.2	1.359
Winter Wheat		53.4	2.367

Figure 6-2 shows a comparison of W126 median RBL response functions for the tree species used in this assessment, and Figure 6-3 shows a comparison of W126 median RBL response functions for the crop species used in this assessment. The figures illustrate how the two parameters affect the shape of the resulting curves. Differences in the shapes of these curves are important for understanding differences in the analyses presented later in this chapter. The two parameters of the RBL equation (Equation 6-2) control the shape of the resulting curve. The value of η in the RBL function affects the inflection point of the curve, and β affects the steepness of the curve. Species with smaller values of β (e.g., Virginia Pine) or species with η values that are above the normal range of ambient W126 measurements (e.g., Ponderosa Pine and Red Alder) have response functions with more gradual and consistent slopes. This results in a more constant rate of change in RBL over a range of O_3 exposure consistent with ambient exposure concentrations.

In contrast, the species with larger β values (e.g., Sugar Maple) have response functions that behave more like thresholds, with large changes in RBL over a small range of W126 index values and relatively small changes at other index values. In these cases the "threshold" is determined by the **η** parameter of the model.

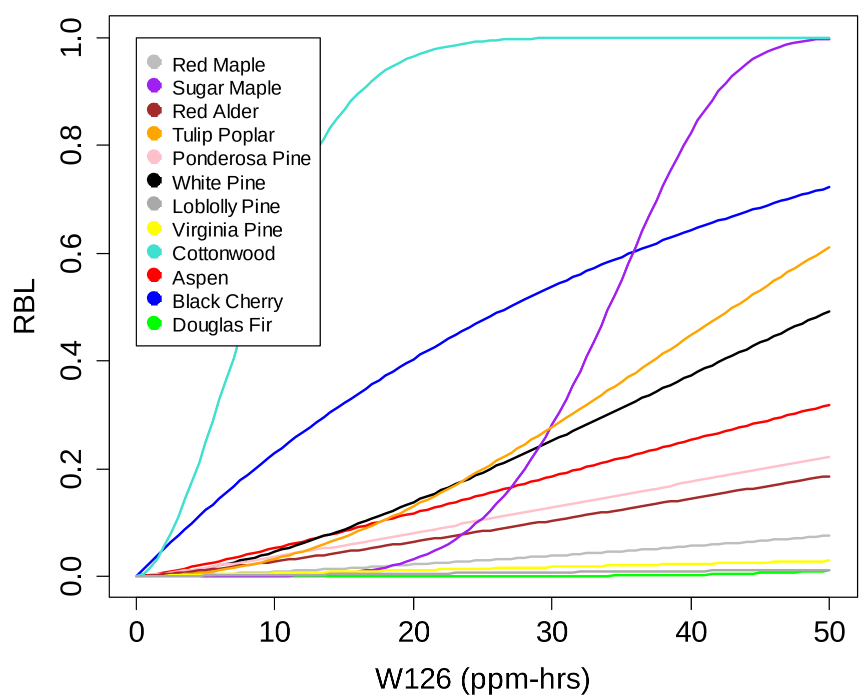

Figure 6-2 Relative Biomass Loss Functions for 12 Tree Species

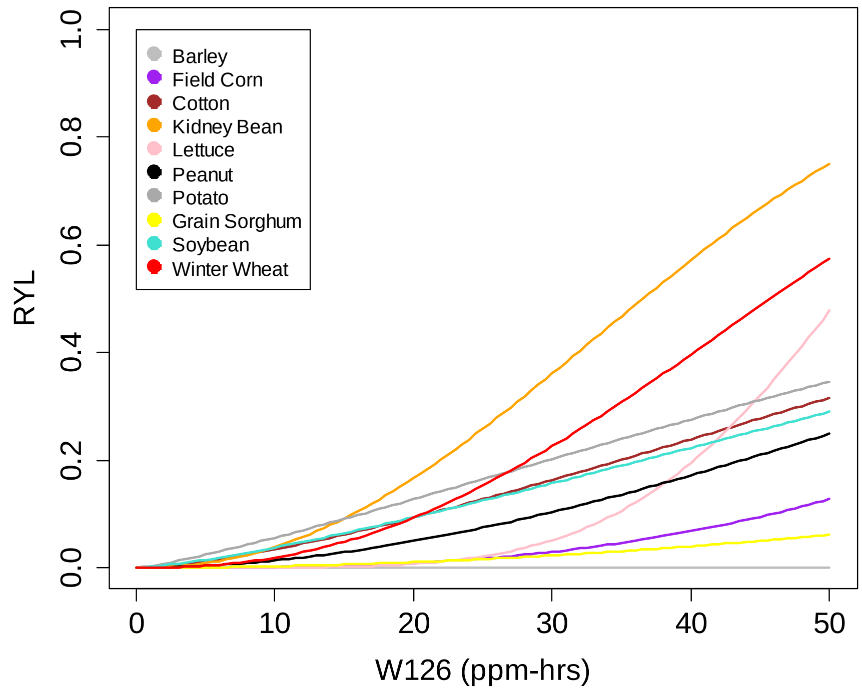

Figure 6-3 Relative Yield Loss Functions for 10 Crop Species

The shape of curves presented in Figure 6-2 and Figure 6-3 also determine how sensitive the RBL value is to changes in O_3. In addition, Figure 6-4 illustrates the elasticity in RBL relative to W126. The percent change in RBL relative to a 1 percent change in W126 is plotted on the y-axis across a range of W126 values. Two species, Loblolly Pine (dark grey line) and Virginia Pine (yellow line) have E-R functions that are linear within the W126 range represented on the x-axis, meaning that a 1 percent change in W126 produces an equal change in RBL. Black Cherry (blue line) has an E-R function that is asymptotic (Figure 6-2), which produces a smaller change in RBL relative to the change in W126. The E-R function for Cottonwood (turquoise line) produces large changes in RBL at W126 values below 10, but then rapidly levels off. The remaining species all have E-R functions that produce consistent percent changes in RBL relative to changes in W126.

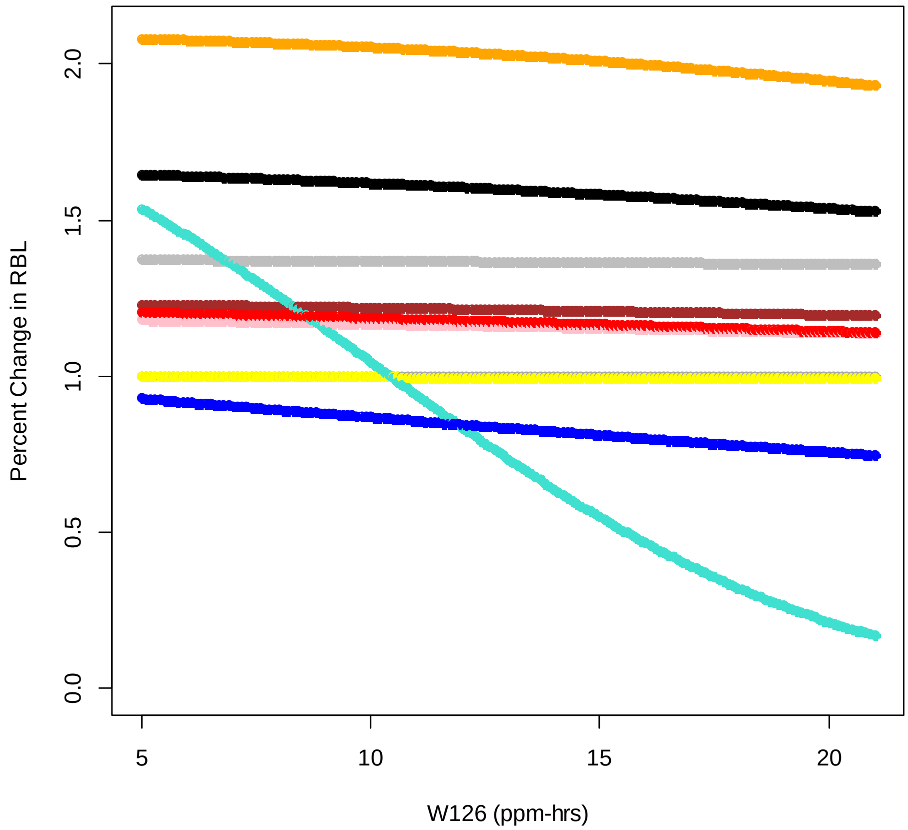

Figure 6-4 Elasticity in Relative Biomass Loss Compared to Changes in W126
[The line colors correlate with the colors used in Figure 6-2]

6.2.1 Species-Level Analyses

6.2.1.1 Comparison of seedling to adult tree biomass loss

The response functions for tree species used in this analysis are all based on seedlings grown in open top chambers (OTC). Since the 2006 O_3 AQCD (U.S. EPA, 2006), several studies were published based on the Aspen Free-Air Carbon Dioxide Enrichment (FACE)[1] experiment using "free air," O_3 and CO_2 exposures in a planted forest in Wisconsin. Overall, the studies at the Aspen FACE experimental site were consistent with many of the open-top chamber (OTC) studies that were the foundation of previous O_3 NAAQS reviews. These results strengthen our

[1] The Aspen FACE experiment is a multidisciplinary study to assess the effects of increasing tropospheric O_3 and carbon dioxide levels on the structure and function of northern forest ecosystems.

understanding of O_3 effects on forests and demonstrate the relevance of the knowledge gained from Aspen tree seedlings grown in OTC studies.

In the 2006 AQCD (U.S. EPA, 2006), the TREGRO and ZELIG models were used to simulate growth of adult trees. For this analysis we did not conduct new TREGRO or ZELIG simulations. We used several existing publications, which modeled tree species used in this analysis. For this analysis, we calculated the W126 index values from the hourly concentrations at the monitors used in the studies. The seedling RBL was calculated from this W126 and compared to the study results and adjusted to reflect an annualized RBL. The results are summarized below in Table 6-3.

Table 6-3 Comparison of Adult to Seedling Biomass Loss

Study	W126	Adult RBL TREGRO	Adult RBL ZELIG	Seedling RBL	Comments
Constable and Taylor, 1997	0.18 8.98 46.37 89.40 149.22	0% 0.3% 3.1% 6.4% 12.1%	*N/A*	0.03% 3.2% 20.5% 39.5% 60.3%	This study used TREGRO and included the western and eastern subspecies of *Ponderosa Pine*. Ozone data were not available for the western subspecies, which was found to be more sensitive than the eastern subspecies. The seedling E-R function used does not differentiate between subspecies.
Weinstein et al., 2001	 0.32 15.38 59.17 0.32 15.38 59.17 0.32 15.38 59.17	Tulip Polar 4.7% 10.6% 16.8% Red Maple 2.5% 4.9% 8.2% Black Cherry 0.2% 0.3% 0.5%	Tulip Polar +3.2% 5.3% 11.2% Red Maple 0% 15.6% 15.6% Black Cherry 11.2% 4.2% +9.1%	Tulip Poplar 0% 7.7% 73.89% Red Maple 0.01% 1.5% 9.4% Black Cherry 0.9% 32.8% 78.0%	This study used TREGRO and ZELIG to model Tulip Poplar, Red Maple, and Black Cherry.

These studies indicate that overall, the seedling biomass loss values are much more consistent with the adult loss, as estimated by TREGRO and ZELIG, at lower W126 index values. The Constable and Taylor (1997) study implies that for the eastern subspecies of Ponderosa Pine, the seedling RBL rate overestimates the adult RBL rate. Ozone data for the western subspecies were not available, but Constable and Taylor (1997) found the western subspecies to be more sensitive. The Weinstein et al. (2001) study indicates that the seedling RBL estimates are comparable to the adult estimates, except at higher W126 index values of O_3 for Tulip Poplar. The Black Cherry results are an exception, which tells us that this species is possibly less sensitive as an adult than as a seedling. As such, the seedling RBL rate would overestimate RBL loss in adult trees. Another study (Samuelson and Edwards, 1993) on Red Oak, another hardwood species, found the exact opposite pattern -- adult trees are much more sensitive to O_3-related biomass loss than seedlings.

Mclaughlin et al. (2007) assessed the interactive effects of O_3 and climate on tree growth and water use. We used the monitored O_3 concentrations in this study to calculate the W126 index value and then used these values to compare the predicted seedling RBL to observations in the study. The study did not use absolute biomass loss, instead relying on measurements of circumference to address growth, so can only be used as a general comparison to estimates of RBL. In addition, the results were presented as comparisons in growth in 2002 and 2003 relative to 2001. Table 6-4 presents a summary of the results.

Table 6-4 Comparison of Seedling Biomass Loss to Adult Circumference

Species	W126			Study Results (% change in circumference)		RBL (seedling)			Comparison	
	2001	2002	2003	2002	2003	2001	2002	2003	2002	2003
Tulip Poplar	23.31	39.82	20.15	-26%	-38%	-17.5%	-44.4%	-13.9%	-60.7%	32.4%
Tulip Poplar	19.78	32.14	11.25	-49.6%	7.5%	-12.7%	-31.3%	-4.1%	-59.4%	210%
Tulip Poplar	14.71	17.50	9.22	-62%	*N/A*	-7.1%	-10.0%	-2.7%	-72.8%	*N/A*
Black Cherry	14.71	17.50	9.22	-75%	*N/A*	-31.7%	-36.4%	-21.3%	-41.5%	*N/A*
Red Maple	14.71	17.50	9.22	-59.6%	*N/A*	-1.5%	-1.8%	-0.8%	-58.4%	*N/A*
Sugar Maple	14.71	17.50	9.22	-43.5%	*N/A*	-0.5%	-1.5%	-0.04%	-97.5%	*N/A*

Relative to the observed changes in circumference, the seedling RBL estimates are mixed for Tulip Polar. A loss was overestimated estimated in 2002 (as compared to 2001) but was underestimated in 2003. The results for Sugar Maple were similar to Tulip Poplar, with loss overestimated in 2002. In contrast to the TREGRO results presented above, the results in this study found much greater loss in Black Cherry, and the seedling RBL underestimated the change for adult trees in 2002. The results for Red Maple were very similar for 2002. Table 6-5 summarizes the uncertainty for all species used in this study.

Table 6-5 Summary of Uncertainty in Seedling to Adult Tree Biomass Loss Comparisons

Species	Summary of Seedling-Adult Uncertainty
Red Maple (*Acer rubrum*)	Seedling E-R functions underestimated RBL relative to estimates of adult biomass loss from TREGRO and ZELIG. The seedling RBL was comparable to field results of changes in circumference.
Sugar Maple (*Acer saccharum*)	No TREGRO data were available. Seedling RBL overestimated loss compared to field results of changes in circumference.
Red Alder (*Alnus rubra*)	No data were available.
Tulip Poplar (*Liriodendron tulipifera*)	Seedling E-R functions underestimated RBL relative to results from TREGRO and ZELIG at lower W126 index values of O_3, and overestimated RBL at the very high index values. Seedling RBL overestimated loss compared to field results of changes in circumference in 2002, but underestimated loss in 2003.
Ponderosa Pine (*Pinus ponderosa*)	Seedling E-R functions overestimated RBL relative to TREGRO results for the eastern subspecies. Data were not available for the western subspecies, but the western subspecies is known to be more sensitive.
Eastern White Pine (*Pinus strobus*)	No data were available.
Loblolly Pine (*Pinus taeda*)	No comparable data were available; however this species is very non-sensitive as measured by the seedling E-R function, so the risk of overestimating loss is low.
Virginia Pine (*Pinus virginiana*)	No comparable data were available; however this species is very non-sensitive as measured by the seedling E-R function, so the risk of overestimating loss is low.
Eastern Cottonwood (*Populus deltoides*)	No data were available for this species. Two studies on the closely related Black Poplar (*Populus nigra*) found that species to be highly sensitive to O_3 exposure as measured by tree ring width (Novak et al., 2010) and growth rate (Bortier et al., 2000). This supports the high sensitivity in Eastern Cottonwood as measured by the seedling E-R function, but there is risk of overestimating loss in this species.

Quaking Aspen (*Populus tremuloides*)	Ozone gradient studies and FACE experiments have found effects on adult trees consistent with earlier OTC studies on seedlings (Karnosky et al., 1999).
Black Cherry (*Prunus serotina*)	Seedling E-R functions overestimated RBL relative to results from TREGRO and ZELIG, except the ZELIG results at the lowest W126 index values. Seedling RBL underestimated loss relative to field results of changes in circumference.
Douglas Fir (Pseudotsuga menzeiesii)	No comparable data were available; however this species is very non-sensitive as measured by the seedling E-R function, so the risk of overestimating loss is low.

6.2.1.2 W126 for Different levels of Biomass Loss

The E-R functions can be plotted as a function of the percent biomass loss against varying W126 index values. This allows us to compare the W126 index values associated with a range of biomass loss values. Figure 6-5 and Figure 6-6 reflect two separate graphical representations of these results for trees and crops respectively.

In each graph, the red line represents the median W126 index value associated with the percent biomass value on the x-axis when all 54 crop studies or 52 tree seedling studies are included. The green line is the value when only the composite E-R function is used for each of the species included (10 crop species and 12 tree species). The grey lines are included as sensitivity analyses to assess the effect of within-species variability. For each grey line, a E-R function for each species was randomly selected from the available studies, with the resulting line representing the median value of the 12 tree species and 10 crops. For some species only one study was available (e.g., Red Maple), and for other species there were as many as 11 studies available (Ponderosa Pine). The process was repeated 1,000 times, and the median value is plotted as the red points for biomass loss values of 1 percent to 7 percent, and 10 percent. The error bar associated with the points represents the 25th and 75th percentiles. For tree and crop species, the median W126 index values are similar, when using all of the studies or just the composite E-R function for each species; however, the median value is higher when within-species variability is included.

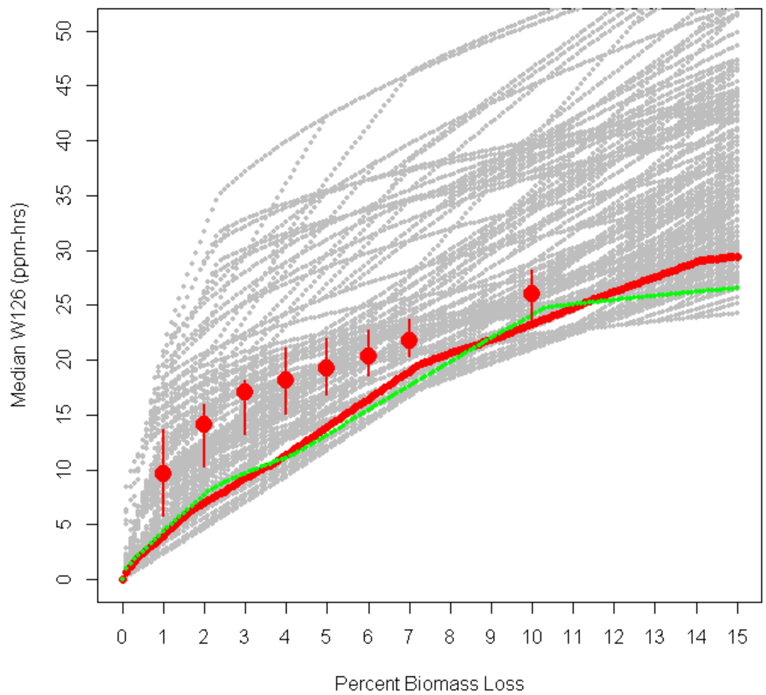

Figure 6-5 W126 Index Values for Alternative Percent Biomass Loss for Tree Species

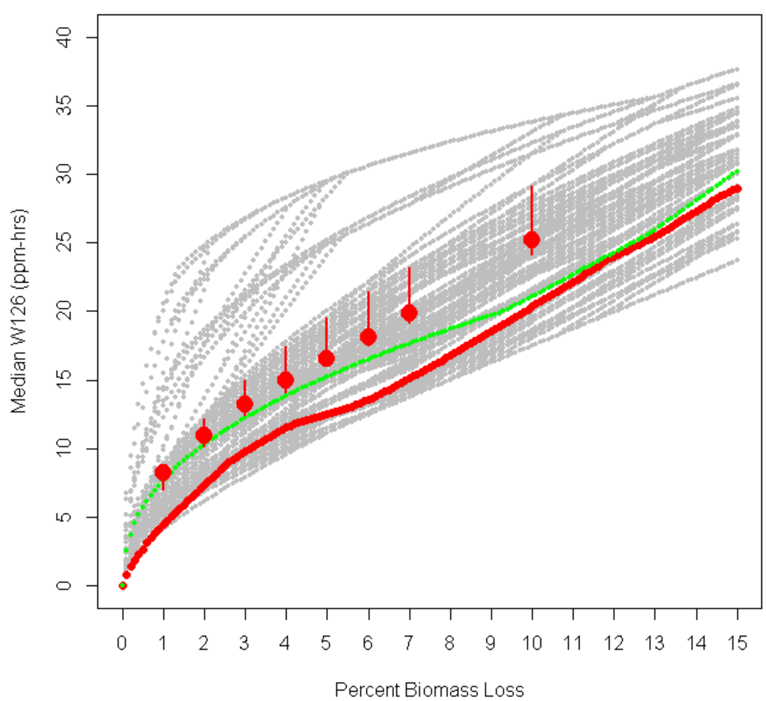

Figure 6-6 W126 Index Values for Alternative Percent Biomass Loss for Crop Species

6.2.1.3 Individual Species Analyses

Using GIS (ESRI®, ArcMAP™ 10), we used the E-R functions listed in Table 6-1 to generate RBL surfaces for the 12 trees species. We created the surfaces using recent ambient O_3 conditions based on monitored data from 2006 through 2008 and the four O_3 rollback surfaces simulating just meeting the existing 8-hr secondary standard of 75 ppb (4th highest daily maximum) and three alternative W126 scenarios of 7, 11 and 15 ppm-hrs (see Chapter 4 for a more detailed description of the O_3 surfaces). We present the maps for one species, Ponderosa Pine, to illustrate the results (see Figure 6-7, Figure 6-8, Figure 6-9, Figure 6-10, and Figure 6-11). RBL surfaces for 10 species are presented in Appendix 6A (Maps of Individual Tree Species). It is important to note that these maps represent the RBL value for one tree species within each CMAQ grid cell represented, so these maps should be interpreted as indicating potential risk to individual trees of that species growing in that area.

We based the ranges for the species on data from the Forest Health Technology Enterprise Team (FHTET) of the USFS (http://www.fs.fed.us/foresthealth/technology/). These data provide modeled predictions of stand density and basal area. The modeled data were estimated in 1,000 square meter grids for individual tree species, as well as total basal area. We summed these values into the larger CMAQ grid cells (12 km x 12 km) used for the O_3 surfaces. For the individual species analyses, these data were used only as a predictor of presence or absence. In the ecosystem level analysis presented in Section 6.8 these values were used to scale the biomass loss by the proportion of total basal area for each species.

Overall, the western tree species have more fragmented habitats than the eastern species. The areas in southern California have the highest W126 index values, which can be seen as the very high areas of RBL in Figure 6-7. The eastern tree species had less fragmented ranges and areas of elevated RBL that were more easily attributed to urban areas (e.g., Atlanta, GA and Charlotte, NC) or to the Tennessee Valley Authority region. In addition to the two western species not illustrated here, we include maps for the eastern species in Appendix 6A.

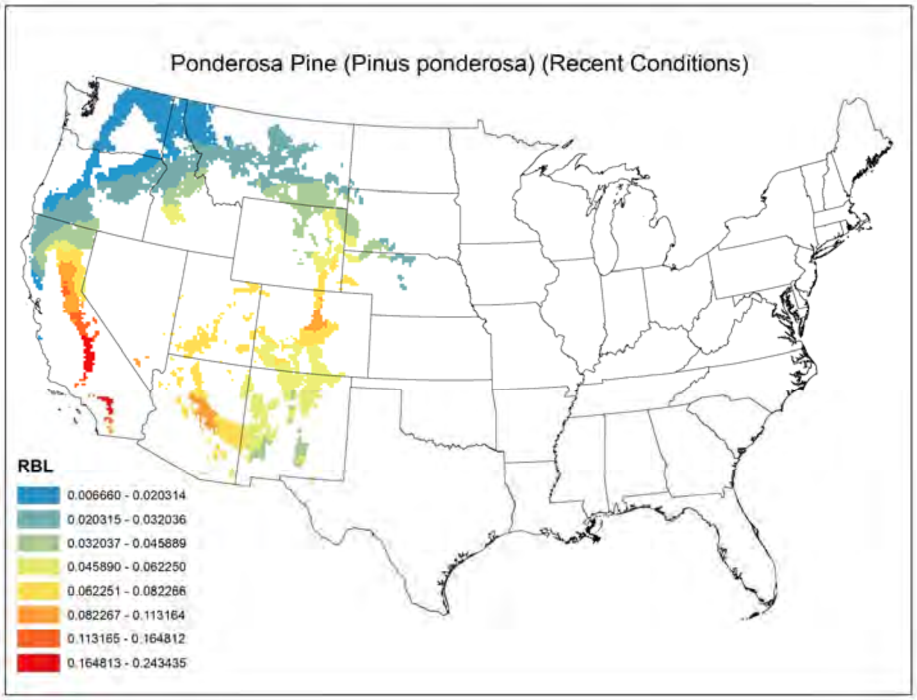

Figure 6-7 Relative Biomass Loss (RBL) of Ponderosa Pine (*Pinus ponderosa*) Seedlings under Recent Ambient W126 Index Values (2006 – 2008)

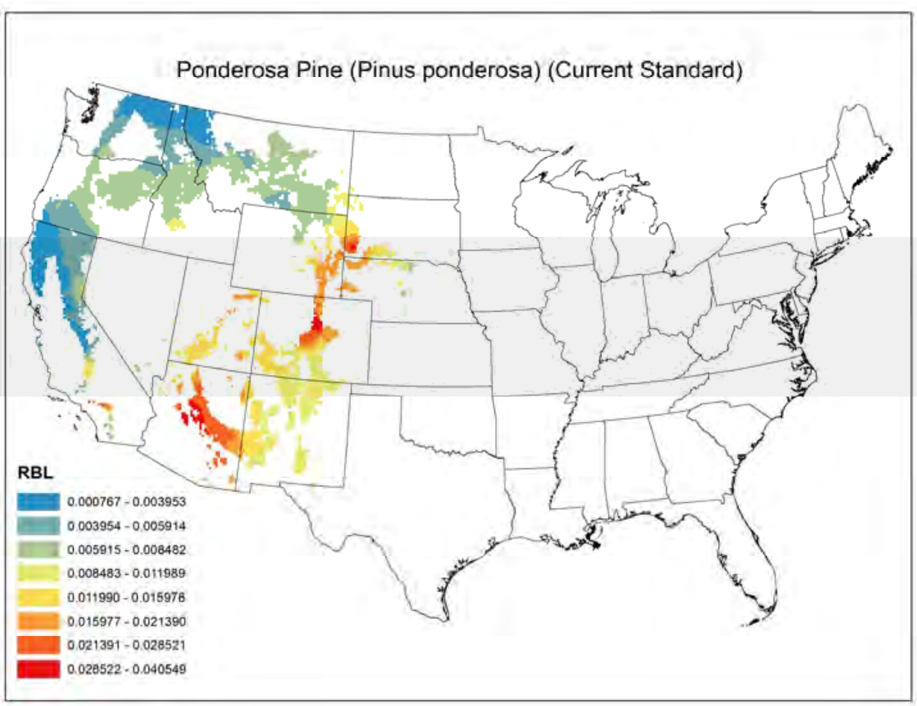

Figure 6-8 Relative Biomass Loss (RBL) of Ponderosa Pine with O_3 Exposure After Adjusted to Meet the Existing (8-hr) Primary Standard (75 ppb)

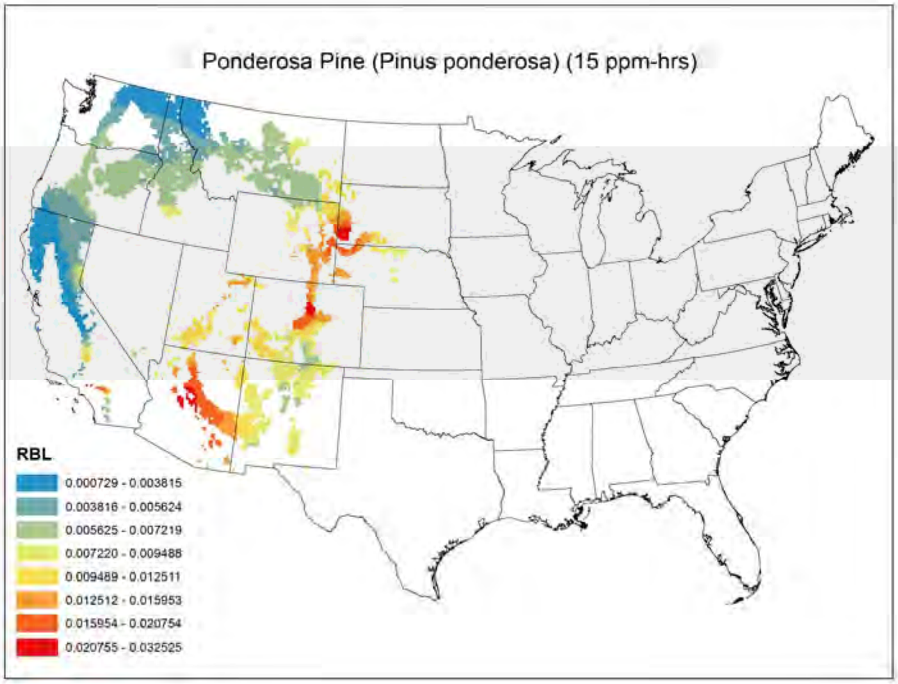

Figure 6-9 Relative Biomass Loss (RBL) of Ponderosa Pine with O_3 Exposure After Adjusted to Meet an Alternative Secondary Standard of 15 ppm-hrs (after Meeting Existing O_3 Standard)

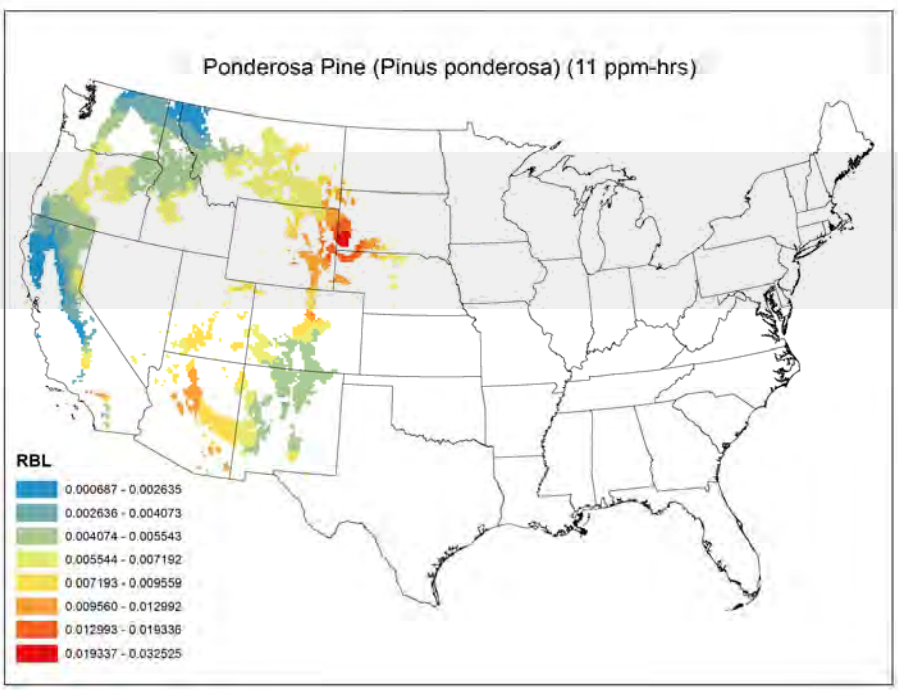

Figure 6-10 Relative Biomass Loss (RBL) of Ponderosa Pine with O_3 Exposure After Adjusted to Meet an Alternative Secondary Standard of 11 ppm-hrs (after Meeting Existing O_3 Standard)

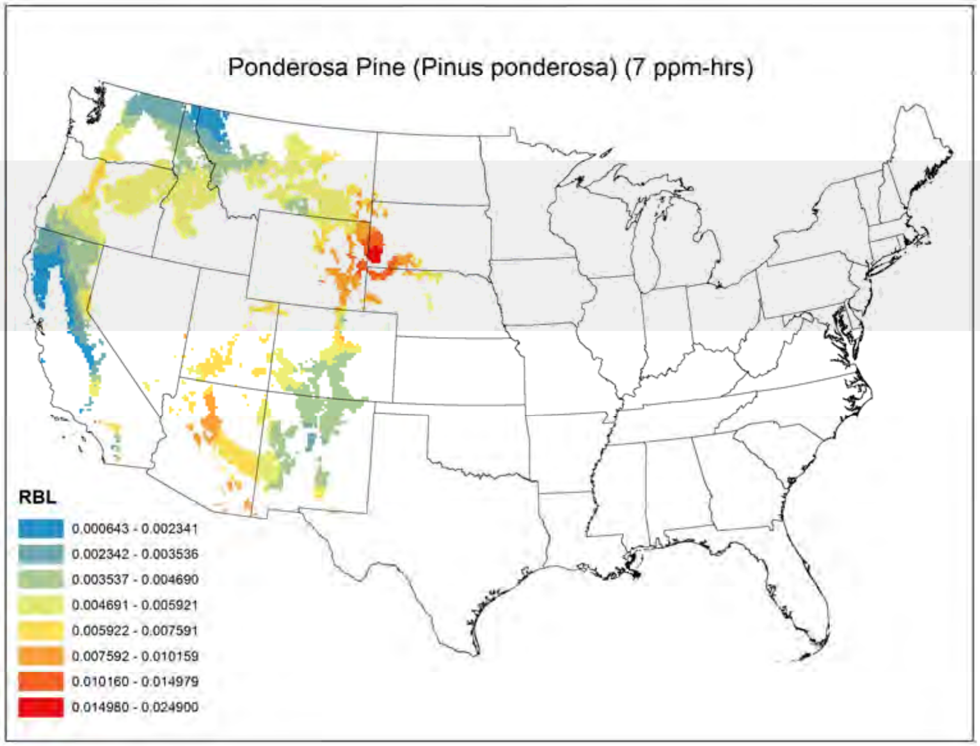

Figure 6-11 Relative Biomass Loss (RBL) of Ponderosa Pine with O_3 Exposure After Adjusted to Meet an Alternative Secondary Standard of 7 ppm-hrs (after Meeting Existing O_3 Standard)

Table 6-6 Individual Species Relative Biomass Loss Values – Median, 75th Percentile, Maximum Percentages

	Relative Biomass Loss (Median/75th Percentile/Maximum Percentages)				
Species	**Recent Conditions**	**75 ppb**	**15 ppm-hrs**	**11 ppm-hrs**	**7 ppm-hrs**
Red Maple	0.95/1.25/3.49	0.08/0.17/0.77	0.08/0.17/0.77	0.08/0.13/0.70	0.05/0.08/0.39
Sugar Maple	0.06/0.22/3.96	<0.01/<0.01/0.07	<0.01/<0.01/0.07	<0.01/<0.01/0.01	<0.01/<0.01/<0.01
Red Alder	0.83/1.15/10.10	0.32/0.40/0.78	0.32/0.40/0.78	0.32/0.40/0.78	0.31/0.39/0.78
Tulip Poplar	5.20/6.88/24.68	0.17/0.35/2.79	0.17/0.35/2.79	0.12/0.21/2.40	0.05/0.09/0.93
Ponderosa Pine	3.71/5.93/24.34	0.67/1.18/4.05	0.65/0.94/3.25	0.56/0.69/3.25	0.50/0.58/2.49
White Pine	3.33/5.58/14.70	0.10/0.40/2.66	0.10/0.40/2.66	0.10/0.30/2.05	0.09/0.17/1.60
Loblolly Pine	0.30/0.36/0.71	0.05/0.07/0.17	0.05/0.07/0.17	0.05/0.06/0.15	0.04/0.05/0.09
Virginia Pine	0.77/0.88/1.63	0.15/0.20/0.54	0.15/0.20/0.54	0.12/0.16/0.50	0.08/0.10/0.32
Cottonwood	58.32/74.03/99.79	5.93/11.97/65.90	5.87/11.68/65.90	5.26/8.06/53.33	3.74/5.06/35.29
Aspen	3.71/6.54/27.51	0.47/1.14/5.85	0.46/1.03/4.22	0.45/0.82/3.89	0.43/0.72/3.03
Black Cherry	23.97/28.54/51.51	4.89/7.94/23.90	4.89/7.94/23.90	4.51/6.31/19.42	3.41/4.41/13.68
Douglas Fir	<0.01/<0.01/0.46	<0.01/<0.01/<0.01	<0.01/<0.01/<0.01	<0.01/<0.01/<0.01	<0.01/<0.01/<0.01

Table 6-6 above includes individual species relative biomass loss values at the median, the 75th percentile, and the maximum for the 12 tree species for which we have E-R functions. The values in the table are median, 75th percentile, and maximum percentages. We include the relative biomass loss values for each species at recent conditions, when adjusted to just meet the existing standard of 75 ppb, and when adjusted to meet potential alternative standard levels of 15, 11, and 7 ppm-hrs.[2] For Ponderosa Pine, at recent conditions, the median value is 3.71 percent RBL, the 75th percentile value is 5.93 percent RBL, and the maximum value is 24.24 percent RBL. When adjusted to just meet the existing standard, the median value is 0.67 percent RBL, the 75th percentile value is 1.18 percent RBL, and the maximum value is 4.05 percent RBL; when adjusted to meet a potential alternative standard level of 15 ppm-hrs, the median value is 0.65 percent RBL, the 75th percentile value is 0.94 percent RBL, and the maximum value is 3.25 percent RBL; and when adjusted to meet a potential alternative standard level of 7 ppm-hrs, the median value is 0.50 percent RL, the 75th percentile value is 0.58 percent RBL, and the maximum value is 2.49 percent RBL. In addition, RBL values for each scenario can be viewed across the entire distribution within each species (Figure 6-12) or as a proportion of the current standard (Figure 6-13). Figure 6-12 and Figure 6-13 use Ponderosa Pine as an example - plots for the other 11 species are included in Appendix 6A. In Figure 6-12, the number of exceedances above 1 percent RBL declines across W126 index values.

Table 6-7 below, summarizes the number of species exceeding 2 percent RBL under recent O_3 conditions and under the four air quality scenarios. The maximum number of species that exceed 2 percent RBL in any one county is five, which only occurs under recent O_3 conditions. These data are presented as the number of counties with five, four, three, two, one, and no species, counties in which the median species exceeds 2 percent, and the total number of counties (out of 3,109) with at least one species exceeding 2 percent RBL. Because Cottonwood and Black Cherry are highly sensitive species and to provide a reference for the effect of these

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[2] W126 calculations are slightly modified in the case of the model adjustment scenarios described in Chapter 4, Section 4.3.4. When calculating W126 for the model adjustment cases, we first found the three-year average of each three-month period, and then selected the three-month period with the highest three-year average using the same three-month period for each of the three years. In this way, the five scenarios are for recent air quality, air quality adjusted to just meet the existing standard, and air quality further adjusted to just meet three different W126 index values: 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs.

species, the data are also presented excluding Cottonwood and excluding Cottonwood and Black Cherry.

Table 6-7 Number of Counties w/Tree Species Exceeding 2 Percent Relative Biomass Loss

Number of Species Exceeding 2 Percent RBL	Number of Counties (3,109 Total)				
	Recent Conditions	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
5	134	-	-	-	-
4	387	3	3	-	-
3	765	24	22	14	5
2	882	994	981	972	924
1	593	1,292	1,273	1,238	1,277
0	348	796	830	885	903
Median Species	2,237	685	670	651	627
Total Exceeding	2,761	2,313	2,279	2,224	2,206
Excluding Cottonwood					
5	15	-	-	-	-
4	180	-	-	-	-
3	680	3	3	-	-
2	933	46	32	14	5
1	610	1,880	1,857	1,818	1,812
0	691	1,180	1,217	1,277	1,292
Median Species	1,604	239	221	204	172
Total Exceeding	2,418	1,929	1,892	1,832	1,817
Excluding Cottonwood and Black Cherry					
5	-	-	-	-	-
4	15	-	-	-	-
3	187	-	-	-	-
2	856	29	15	2	1
1	920	95	72	19	8
0	1,131	2,985	3,022	3,088	3,100
Median Species	666	36	18	6	2
Total Exceeding	1,978	124	87	21	9

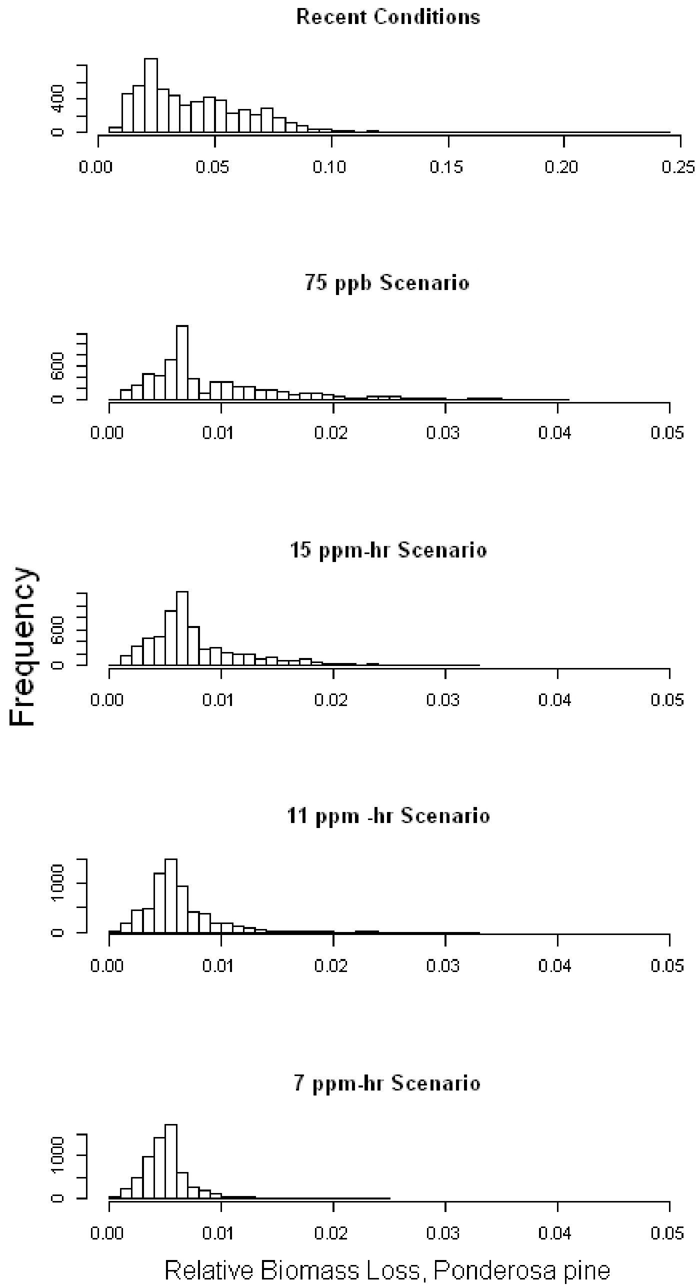

Figure 6-12 Relative Biomass Loss of Ponderosa Pine at the Existing Primary and Alternative Secondary Standards [RBL in this figure is plotted as a proportion relative to no O_3 exposure.]

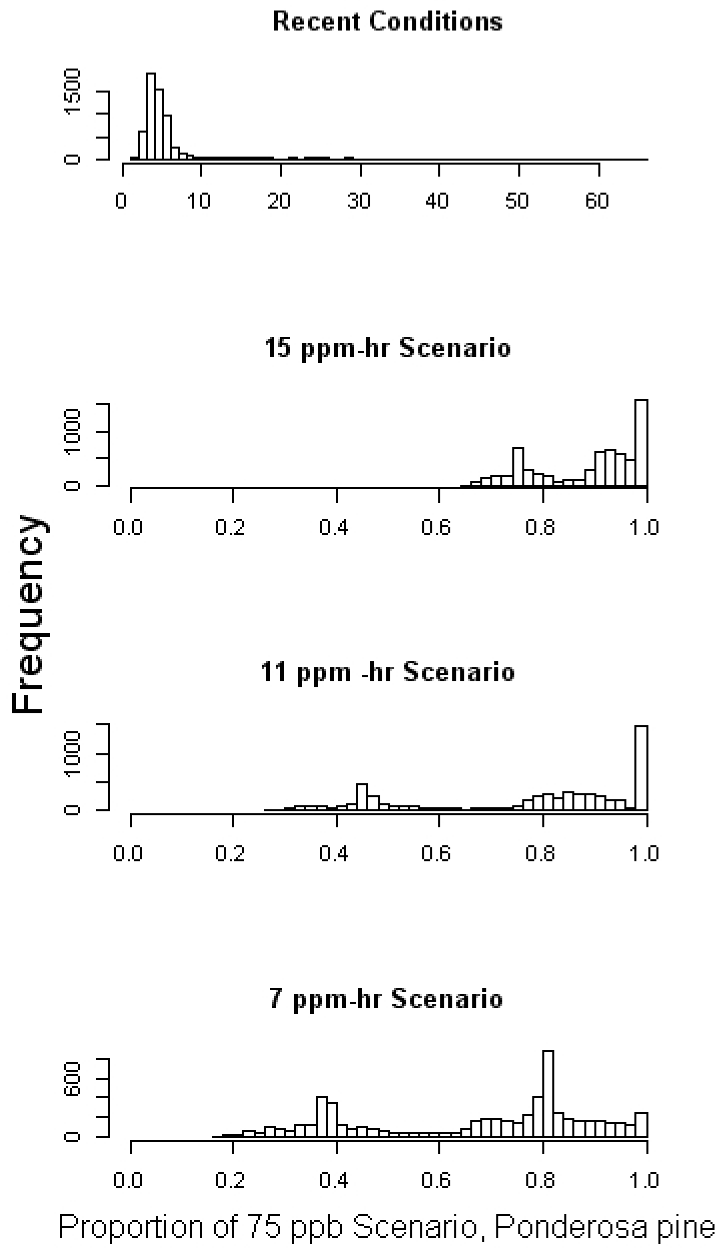

Figure 6-13 Proportion of Current Standard, Ponderosa Pine – Recent Conditions and Alternative Secondary Standards

6.2.1.4 Potential Effects of Compounding RBL

To determine potential effect of using a W126 index value averaged across three years compared to using separate values for each individual year, we compared the compounded values for examples from each of the regions, except the South. In these examples, we chose a species that occurred within that region. We used W126 values associated with just meeting the existing standard of 75 ppb. Within each region we calculated both the W126 value at each monitor in the region for each year and the three-year average W126 value using the method described in Chapter 4. The results, depicted in Figure 6-14 below, show that the use of the three-year average W126 index value may underestimate RBL values slightly, but the approach does not account for moisture levels or other environmental factors that could affect biomass loss.

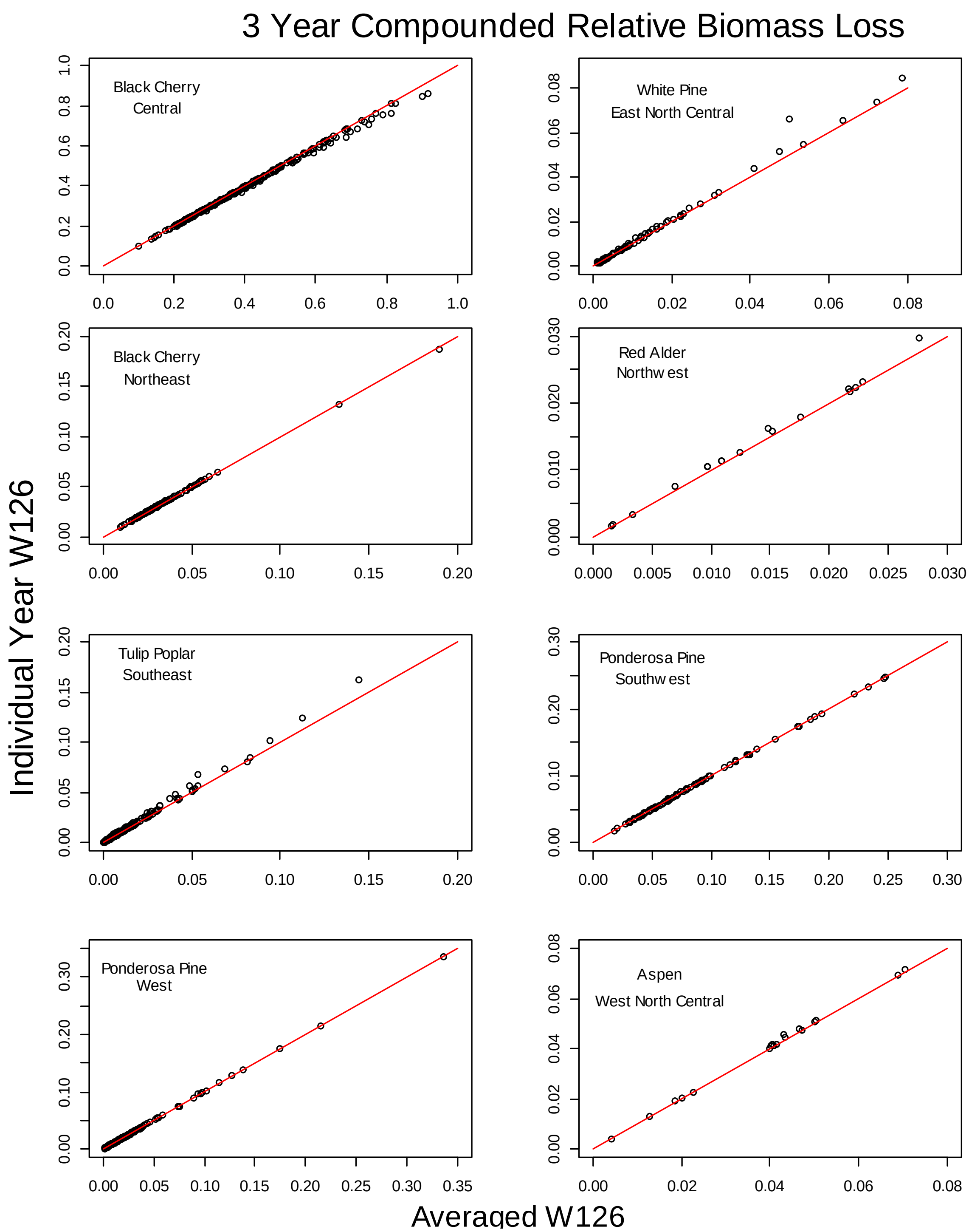

Figure 6-14 Three-Year Compounded Relative Biomass Loss, by Region

6.3 COMMERCIAL TIMBER EFFECTS

We used the Forest and Agricultural Sectors Optimization Model with Greenhouse Gases (FASOMGHG) (Adams et al., 2005) to calculate the resulting market-based welfare effects of O_3

exposure in the forestry and agriculture sectors of the United States under the scenarios outlined below. This section provides a summary of the results of those analyses. The current crop/forest budgets, which include all inputs to production and the resulting products, included in FASOMGHG are considered the budgets under recent ambient conditions. To model the effects of changing W126 index values on the forestry sector, two primary and three alternative scenarios were constructed and run through the model:

- a base scenario, consistent with recent ambient conditions;
- a scenario with crop and forest yields for O_3 exposures after simulating just meeting the existing standard of 75 ppb (4^{th} highest daily maximum) and
- three scenarios that represent O_3 exposure after just meeting alternative W126-based standard levels – 15, 11, and 7 ppm-hrs.

We used the O_3 E-R functions for tree seedlings to calculate relative yield loss (RYL), which is equivalent to relative biomass loss, for FASOMGHG trees over their entire life span. To derive the FASOMGHG region-level RYLs for trees under each scenario, we used FASOMGHG region O_3 values along with the mapping in Table 6-8. For additional details on FASOMGHG, including a map of the FASOMGHG regions, see Appendix 6B (FASOMGHG Full Results).

We calculate the FASOMGHG region-level RYLs for each tree species listed in the first column of Table 6-8 by extracting county-level W126 concentrations from the CMAQ air quality surfaces, using only the portion of each county that is identified as forested in the GIS data utilized and used the simple average across county O_3 values (forested portions of each county) for all counties falling in a given FASOM region to represent the region-level O_3 impacts on forests. Then the region-level W126 O_3 values are applied to tree species present in that region to calculate RYLs. Then, we calculate a simple average of RYLs for each tree species mapped to a FASOMGHG forest type in a given region. The mapping of tree species to FASOMGHG forest types is based on *"Atlas of United States Trees"* (Little, 1971, 1976, 1977, 1978).

Table 6-8 Mapping O_3 Impacts to FASOMGHG Forest Types

Tree Species Used for Estimating O_3 Impacts	FASOMGHG Forest Type	FASOMGHG Region(s)
Black Cherry, Tulip Poplar	Upland Hardwood	SC, SE
Douglas Fir	Douglas Fir	PNWW
Eastern White Pine	Softwood	CB, LS
Ponderosa Pine	Softwood	PNWE, PNWW, PSW, RM
Quaking Aspen	Hardwood	RM
Quaking Aspen, Black Cherry, Red Maple, Sugar Maple, Tulip Poplar	Hardwood	CB, LS, NE
Red Alder	Hardwood	PNWE, PNWW, PSW
Red Maple	Bottomland Hardwood	SC, SE
Virginia Pine	Natural Pine, Oak-Pine, Planted Pine	SC
Virginia Pine, Eastern White Pine	Natural Pine, Oak-Pine, Planted Pine	SE
Virginia Pine, Eastern White Pine	Softwood	NE

Table 6-9 presents the region-specific RYLs for the forest types by region. At the existing standard the highest yield loss occurs in upland hardwood forests in the South Central and Southeast regions at over three percent per year. The next highest yield losses at the existing standard occur in Corn Belt hardwoods with just over two percent loss per year and in hard- and softwoods of the Rocky Mountain region at an average loss across all sensitive forests of slightly over 1 percent loss per year. With the exception of the Rocky Mountain region, which has yield losses reduced to under 1 percent per year, yield losses do not appreciably change at the 15 ppm-hrs alternative. This is primarily because most areas have W126 index values lower than 15 ppm-hrs after just meeting the existing standard. The Corn Belt forests remain at about 1.5 percent loss at 11 ppm-hrs and the South Central and Southeastern forests continue to experience yield losses between 1 and 2 percent even after just meeting an alternative standard level of 7 ppm-hrs.

Table 6-9 Percent Relative Yield Loss for Forest Types by Region for Modeled Scenarios

Forest Type	Region	Existing Standard (75 ppb)	W126		
			15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Douglas Fir	PNWW	0.00	0.00	0.00	0.00
Natural Pine	SC	0.15	0.15	0.12	0.09
	SE	0.28	0.28	0.24	0.13
Oak/Pine	SC	0.15	0.15	0.12	0.09
	SE	0.28	0.28	0.24	0.13
Other Softwoods	PNWW	0.49	0.48	0.48	0.48
Planted Pine	SC	0.15	0.15	0.12	0.09
	SE	0.28	0.28	0.24	0.13
Softwoods	CB	0.78	0.78	0.46	0.23
	LS	0.13	0.13	0.13	0.13
	NE	0.05	0.05	0.04	0.02
	RM	1.13	0.91	0.64	0.53
	PSW	0.40	0.36	0.31	0.28
	PNWE	0.52	0.50	0.48	0.47
Bottomland Hardwoods	SC	0.13	0.13	0.10	0.06
	SE	0.12	0.12	0.10	0.06
Hardwoods	PNWW	0.34	0.34	0.34	0.33
	CB	2.10	2.10	1.51	0.98
	LS	0.69	0.69	0.69	0.67
	NE	0.41	0.41	0.33	0.25
	RM	1.59	1.27	0.88	0.73
	PSW	0.27	0.25	0.22	0.19
	PNWE	0.36	0.35	0.34	0.33
Upland Hardwoods	SC	3.25	3.25	2.71	2.00
	SE	3.07	3.07	2.79	1.85

Table 6-10 Percent Relative Yield Gain for Forest Types by Region with Respect to the Existing Standard

Forest Type	Region	W126		
		15 ppm-hrs - ES	11 ppm-hrs - ES	7 ppm-hrs - ES
Douglas Fir	PNWW	0.00	0.00	0.00
Natural Pine	SC	0.00	0.02	0.06
	SE	0.00	0.04	0.16
Oak/Pine	SC	0.00	0.02	0.06
	SE	0.00	0.04	0.16
Other Softwoods	PNWW	0.00	0.01	0.01
Planted Pine	SC	0.00	0.02	0.06
	SE	0.00	0.04	0.16
Softwoods	CB	0.00	0.35	0.59
	LS	0.00	0.00	0.00
	NE	0.00	0.01	0.02
	RM	0.23	0.52	0.63
	PSW	0.04	0.09	0.13
	PNWE	0.02	0.04	0.05
Bottom Hardwoods	SC	0.00	0.03	0.06
	SE	0.00	0.01	0.06
Hardwoods	PNWW	0.00	0.01	0.01
	CB	0.00	0.65	1.22
	LS	0.00	0.00	0.02
	NE	0.00	0.09	0.17
	RM	0.35	0.77	0.93
	PSW	0.03	0.06	0.09
	PNWE	0.01	0.03	0.04
Upland Hardwoods	SC	0.01	0.65	1.48
	SE	0.01	0.34	1.48

Yield gains associated with meeting alternative W126 standards compared to meeting the existing standard are relatively small on a percentage change basis, especially in the 15 ppm-hrs scenario where the highest change is 0.35 percent per year. At 11 ppm-hrs the yield gains are larger with gains between 0.35 and 0.77 percent for the most affected regions. The 7 ppm-hrs scenario generates yield gains between 0.59 and 1.48 percent for the Corn Belt, Rocky Mountain, South Central, and Southeast regions. These results are presented in Table 6-10 and graphically in Figure 6-15 and Figure 6-16. While the yield gains for the alternative scenarios are small relative to the baseline of the existing standard, when applied nationally to forest production they result in increased forest production at every alternative in all years until the last period modeled in 2040 as shown in Table 6-11. The change in relative yield between the existing standard and the alternative scenarios results in changes in timber harvests and prices, as shown in Table 6-11. In general, harvests increase and prices decrease with resulting changes in consumer and producer welfare.

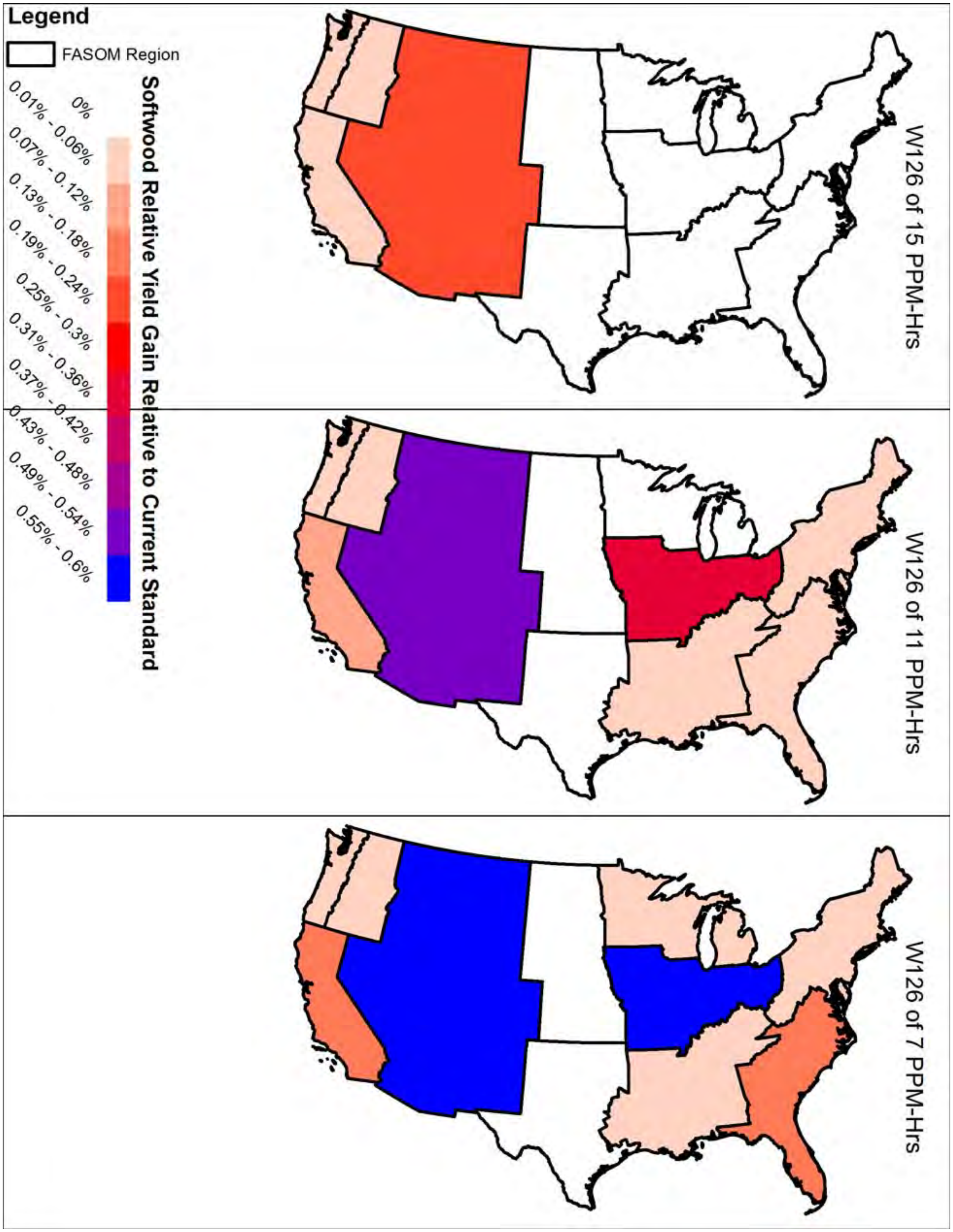

Figure 6-15 RYG for Softwoods by Region

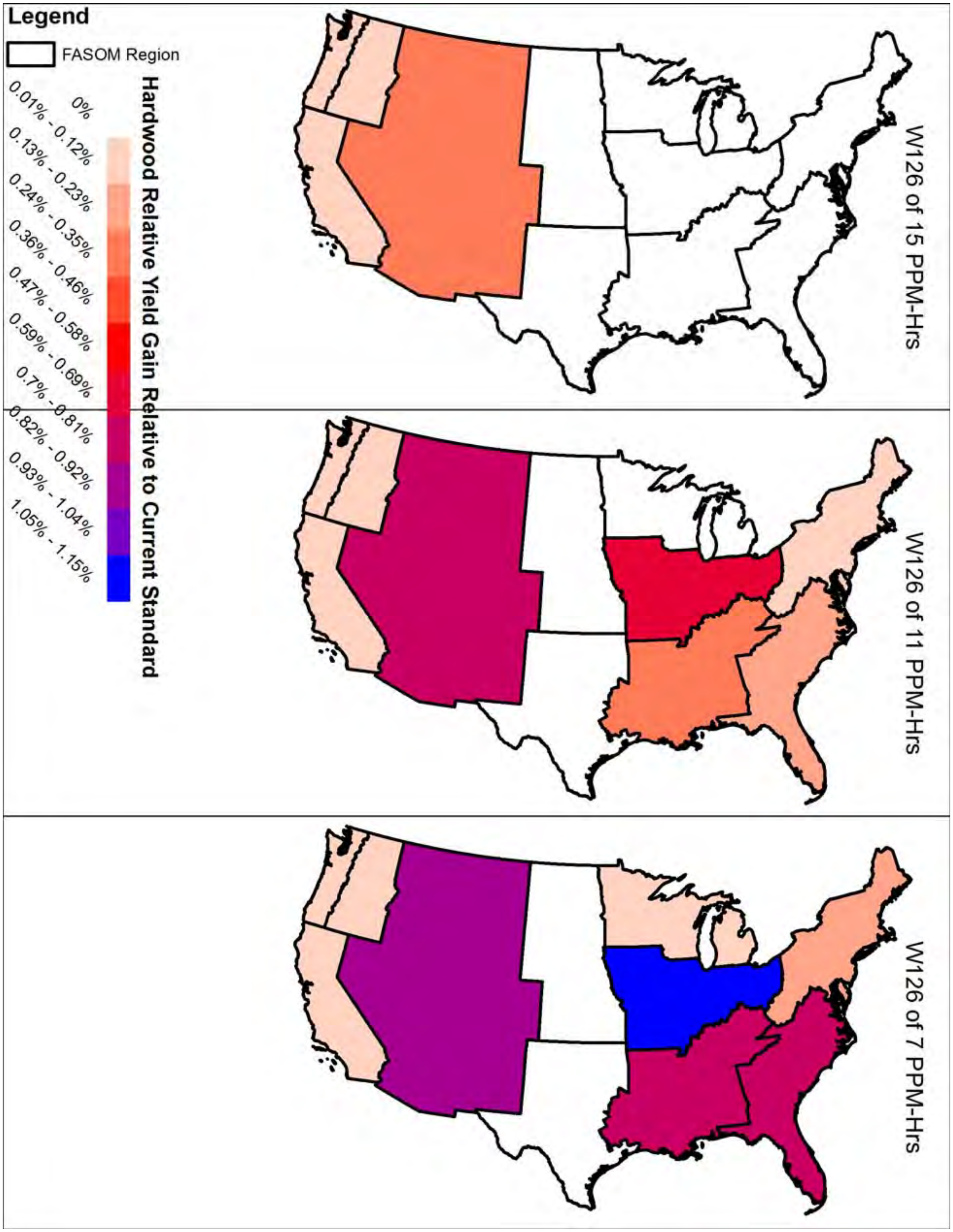

Figure 6-16 RYG for Hardwoods by Region

Table 6-11 Percentage Changes in National Timber Prices

Product	Policy	2010	2020	2030	2040
Hardwood saw logs	**75 ppb**	0.69	0.65	0.39	0.19
	Change with Respect to Existing Standard				
15 ppm-hrs		-0.28	0.13	-0.16	0.94
11 ppm-hrs		-0.79	0.13	-2.52	-1.51
7ppm-hrs		-1.59	-2.60	-8.72	-7.12
Hardwood pulp logs	**75 ppb**	0.24	0.44	0.22	0.12
	Change with Respect to Existing Standard				
15 ppm-hrs		0.00	-0.15	-0.08	-0.08
11 ppm-hrs		-0.87	-1.95	-2.06	-2.64
7 ppm-hrs		-2.10	-3.52	-4.92	-6.23
Softwood saw logs	**75 ppb**	2.31	1.91	1.60	1.31
	Change with Respect to Existing Standard				
15 ppm-hrs		-0.09	-0.33	-0.44	-0.69
11 ppm-hrs		-0.26	-1.24	-1.32	-1.40
7 ppm-hrs		-0.46	-1.54	-1.91	-2.28
Softwood pulp logs	**75 ppb**	1.42	1.12	1.34	0.94
	Change with Respect to Existing Standard				
15 ppm-hrs		-0.14	0.12	0.15	0.18
11 ppm-hrs		-0.43	0.13	-0.19	-0.51
7 ppm-hrs		-1.03	-0.42	-0.82	-2.17

Table 6-12 shows the estimated welfare changes brought about by the simulation scenarios. Consumer and producer welfare in the forest sector are more affected by the alternative scenario environments than the agricultural sector (see Section 6.5). In general, consumer welfare increases in both the forest and agricultural sectors as higher productivity tends to increase total production and reduce market prices. Because demand for most forestry and agricultural commodities is inelastic, producer welfare tends to decline with higher productivity as the effect of falling prices on profits more than outweighs the effects of higher production levels. In other words consumers do not increase their demand for the product enough in response to the falling prices created by increases production to offset the producer’s loss of revenue. The increase in consumer welfare is much larger than the loss of producer welfare resulting in net welfare gains in the forestry sector nationally.

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.

Consumers like to feel like they are getting a good deal on the goods and services they buy, and ***consumer surplus*** is an economic measure of this satisfaction. For example, assume a consumer goes out shopping for a CD player and he or 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 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.

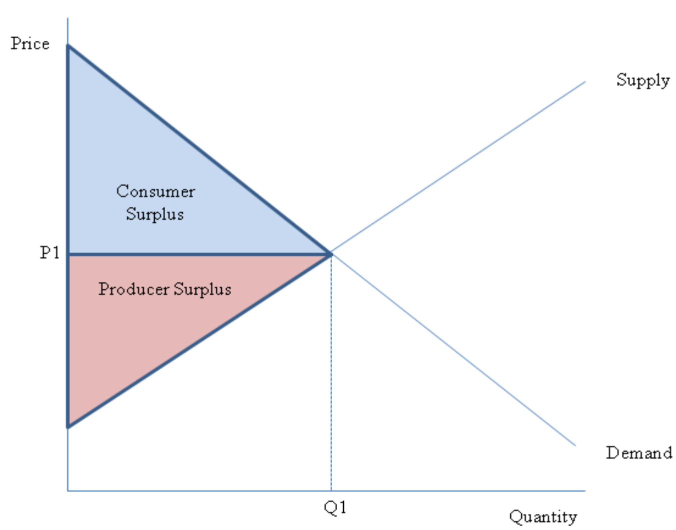

Table 6-12 Consumer and Producer Surplus in Forestry, Million $2010

Product	Policy	2010	2015	2020	2025	2030	2035	2040
Consumer surplus	**75 ppb**	721,339	793,234	809,271	826,375	875,620	894,705	934,882
		Change with Respect to Existing Standard						
15 ppm-hrs		7	31	118	105	2	6	597
11 ppm-hrs		44	48	360	202	688	56	712
7ppm-hrs		86	187	694	224	734	91	779
Producer surplus	**75 ppb**	93,322	121,476	153,997	146,275	145,913	146,115	133,132
		Change with Respect to Existing Standard						
15 ppm-hrs		-11	-7	-141	-161	15	-46	-839
11 ppm-hrs		-41	20	-503	-178	-880	55	-858
7 ppm-hrs		-136	-48	-892	-37	-786	156	-766

Key uncertainties in this approach are discussed in Section 6.6.1. It should be noted that since public lands are not affected within the model, the estimates presented would likely be higher if public lands were included. [3] See Appendix 6B for a full discussion of the model and methodology.

6.4 NON-TIMBER FOREST PRODUCTS

Non-timber forest products (NTFP) such as foliage and branches used for arts and crafts, or edible fruits, nuts, and berries can be affected by the impact of O_3 through biomass loss, foliar injury, insect attack, fire regime changes, and effects on reproduction. Commercial gathering activities in national forests are allowed by permit holders. The USDA has assessed the harvest and market value of these products in commercial markets (Emery, 2003). A significant portion of NTFP is also valuable to subsistence gatherers. Subsistence practices are much more difficult to assess because these forest users are not required to obtain a permit for use of federal public lands; as such the impacts are more difficult to enumerate. Because permits or contracts are not

[3] The FASOMGHG model includes 348.6 million acres of private, managed forests. The USFS estimates that there are approximately 751 million forest acres in the United States (USDA, 2011).

required for gathering activities for personal use the analyses done by USDA are not able to account for the subsistence use of NTFP.

In Table 6-13 we list some of the uses of the tree species known to be sensitive to the effects of O_3 on biomass. These species have a wide variety of uses ranging from the value of the timber produced to medicinal uses.

Table 6-13 O_3 Sensitive Trees and Their Uses

Tree Species	O_3 Effect	Uses
Black Cherry ***Prunus serotina***	Biomass loss, Visible foliar injury	Cabinets, furniture, paneling, veneers, crafts, toys Cough remedy, tonic, sedative Flavor for rum and brandy Wine making and jellies Food for song birds, game birds, and mammals
Douglas Fir ***Pseudotsuga menziesii***	Biomass loss	Commercial timber Medicinal uses, spiritual and cultural uses for several Native American tribes Spotted owl habitat Food for mammals including antelope and mountain sheep
Eastern Cottonwood ***Populus deltoides***	Biomass loss	Containers, pulp, and plywood Erosion control and windbreaks Quick shade for recreation areas Beaver dams and food
Eastern White Pine ***Pinus strobus***	Biomass loss	Commercial timber, furniture, woodworking, and Christmas trees Medicinal uses as expectorant and antiseptic Food for song birds and mammals Used to stabilize strip mine soils
Hemlock ***Tsuga canadensis***	Biomass loss	Commercial logging for pulp Habitat for deer, ruffled grouse, and turkeys Important ornamental species
Hickory	Biomass loss	Used in furniture and cabinets, fuelwood, and charcoal Edible nuts Food for ducks, quail, wild turkeys and many mammals
Ponderosa Pine ***Pinus ponderosa***	Biomass loss, Visible foliar injury	Lumber for cabinets and construction Ornamental and erosion control use Recreation areas Food for many bird species, including the red-winged blackbird, chickadee, finches, and nuthatches

Tree Species	O_3 Effect	Uses
Quaking Aspen ***Populus tremuloides***	Biomass loss, Visible foliar injury	Commercial logging for pulp, flake-board, pallets, boxes, and plywood Products including matchsticks, tongue depressors, and ice cream sticks Valued for its white bark and brilliant fall color Important as a fire break Habitat for variety of wildlife Traditional native American use as a food source
Red Alder ***Alnus rubra***	Biomass loss, Visible foliar injury	Commercial use in products such as furniture, cabinets, and millwork Preferred for smoked salmon Dyes for baskets, hides, moccasins Medicinal use for rheumatic pain, diarrhea, stomach cramps – the bark contains salicin, a chemical similar to aspirin Roots used for baskets Food for mammals and birds – dam and lodge construction for beavers Conservation and erosion control
Red Maple ***Acer rubrum***	Biomass loss	Revegetation and landscaping especially riparian buffer
Red Oak ***Quercus rubra***	Biomass loss	Important for hardwood lumber for furniture, flooring, cabinets Food, cover, and nesting sites for birds and mammals Bark used by Native Americans for medicine for heart problems, bronchial infections or as an astringent, disinfectant, and cleanser
Short Leaf Pine ***Pinus echinata***	Biomass loss	Second only to loblolly pine in standing timber volume Used for lumber, plywood, pulpwood, boxes, crates, and ornamental vegetation Habitat and food for bobwhite quail, mourning dove, other song birds and mammals Older trees with red heart rot provide red-cockaded woodpecker cavity trees
Sugar Maple ***Acer saccharum***	Biomass loss	Commercial syrup production Native Americans used sap as a candy, beverage – fresh or fermented into beer, soured into vinegar and used to cook meat Valued for its fall foliage and as an ornamental Commercial logging for furniture, flooring, paneling, and veneer Woodenware, musical instruments Food and habitat for many birds and mammals
Virginia Pine ***Pinus virginiana***	Biomass loss, Visible foliar injury	Pulpwood, strip mine spoil banks and severely eroded soils Nesting for woodpeckers, food for songbirds and small mammals
Yellow (Tulip) Poplar ***Liriodendron tulipifera***	Biomass loss, Visible foliar injury	Furniture stock, veneer, and pulpwood Street, shade, or ornamental tree – unusual flowers Food for wildlife Rapid growth for reforestation projects

Sources: USDA-NRCS, 2013; Burns, 1990; Hall and Braham, 1998.

6.4.1 Commercial Non-Timber Forest Products

In addition to timber, forests provide many other products that are harvested for commercial or subsistence activities. These products include:

- edible fruits, nuts, berries, and sap,
- foliage, needles, boughs, and bark,
- transplants,
- grass, hay, alfalfa, and forage,
- herbs and medicinals,
- fuelwood, posts and poles, and
- Christmas trees.

For the 2010 National Report on Sustainable Forests (USDA, 2011) these products were divided into several categories including nursery and landscaping uses; arts, crafts, and floral uses; regeneration and silviculture uses. Table 6-14 details selected categories of NTFP harvested by permit in 2007. These harvests are reported in measures relevant to the specific articles, i.e., bushels of cones, tons of foliage or boughs, or individual transplants. The harvests quantified in the table are only for permitted activities in national forests and do not include those activities that occur on private or state- or locally-owned property.

Table 6-14 Quantity of NTFP Harvested on U.S. Forest Service and Bureau of Land Management Land

Product Category	Unit	Harvest All U.S.
Arts, crafts, and florals	Bushels	70,222
	Pounds	3,442,125
	Tons	620,773
Christmas trees	Each	151,274
	Lineal foot	94.758
Edible Fruits, nuts, berries, and sap	Bushels	250
	Pounds	1,614,565
	Syrup Taps	10,686
Fuelwood	ccf	35,800
	Cords	417,692
Grass, hay, and alfalfa	Pounds	4,265,952
Forage	Tons	480
Herbs and medicinals	Pounds	101,365
Nursery and landscape	Each	766,645
	Pounds	25,689
	Tons	316
Regeneration and silviculture	Bushels	7,627
	ccf	8
	Each	21,265
	Pounds	247,543
	Tons	110,873
Posts and poles	ccf	5,281
	Each	1,684,618
	Lineal foot	326,312

Note: ccf = 100 cubic feet Source: USDA 2011

According to the O_3 ISA, O_3 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. The effects of O_3 on plant reproduction (see O_3 ISA, Table 9-1, 2013) could affect the supply of seeds, berries, and cones. Foliar injury impacts on O_3-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_3 in some evergreens may also reduce the value of a whole tree such as Christmas trees. Likewise the same O_3 effects would reduce the harvest of edible fruits, nuts, berries, and sap.[4] The use of native grasses as forage is a significant aspect of forest-land management in the western U.S. (Alexander et al. 2002). Ozone effects on community composition, particularly changes in the ratio of grasses to forbs (broad-leaved herbs other than a grass), and nutritive quality of grasses can have effects on rangeland quality for some herbivores (Krupa et al., 2004, Sanz et al., 2005) and therefore effects on grazing efficiency. The negative impacts of O_3 on plants would similarly affect the harvest in the rest of the categories.

According to the U.S. Census Bureau's County Business Patterns data from 2006, this activity is captured in the industry code 1132 -- forest nurseries and gathering of forest products -- and employed 2,098 people, accounting for an annual payroll of $71,657,000 ($2006) with an average annual income of $34,155 (U.S. Census Bureau, 2006).

The USDA estimates the proportion of the national supply of NTFP represented by USFS and BLM lands is approximately 10 percent. Retail values for NTFPs harvested on USFS and BLM lands are approximately $1.4 billion (2010$). These estimates are very rough and are based only on permit or contract sales. These estimates could be low due to harvests taken without permit or contract and sold through complex commodity chains that can combine wild-harvested and agriculturally grown commodities. It is important to note that while we cannot estimate the loss of production and value to this sector due to O_3 exposures, these losses are already reflected in the harvest and values reported.

6.4.2 Informal Economy or Subsistence Use of Non-Timber Forest Products

Most people gathering NTFPs are doing so for personal use (Baumflek et al., 2010; USDA, 2011). By one estimate (Baumflek et al., 2010) up to 80 percent of the people collecting NTFPs in Oregon and Washington are collecting for personal reasons. Such personal use may be characterized either as part of the informal economy or as subsistence activity. Participants in the informal economy may earn a wage or salary and participate in gathering NTFPs for reasons

[4] To name a few, this category includes blueberries, pine nuts, and sap for maple syrup.

other than recreation (Brown et al., 1998). The term subsistence has usually been applied to special groups such as Native Americans or the Hmong people and has generally been understood to imply extreme poverty such that these activities are essential to the necessities of life (Freeman, 1993). However, Freeman points out researchers stress that economic goals are only a part of the impetus for these activities.

Brown et al. (1998) proposed a composite definition for the terms that captures both the informal economy, as practiced by those who are not necessarily a part of a special population, and subsistence, as generally referenced to those special populations.

> "Subsistence refers to activities in addition to, not in place of, wage labor engaged in on a more or less regular basis by group members known to each other in order to maintain a desired and/or normative level of social and economic existence."

This definition allows consideration of the cultural and social aspects of subsistence lifestyles. These non-economic benefits range from maintenance of social ties and relationships through shared activity to family cohesiveness to retreatism and a sense of self-reliance for the individual practitioner (Brown et al., 1998).

While there is general acknowledgement of subsistence activities by Native Americans and specific treaty rights for tribes guaranteeing access to lands for hunting, fishing, and gathering, there has been a lack of research focused on other populations (Emery and Pierce, 2005). However, there are some studies that clarify that subsistence activities provide valued resources for a variety of people in the coterminous United States. Baumflek et al. (2010) and Alexander et al. (2011) have documented the collection and use of culturally and economically important NTFPs in Maine and the eastern United States, respectively. Brown et al. (1998) reports on subsistence activities among residents of the Mississippi Delta. Emery (2003) and Hufford (2000) examine activities in the Appalachians, and Pena (1999) reports activities by Latinos in the Southwest.

As with the commercial harvest of NTFPs, subsistence gathering of these forest products can potentially be affected by the adverse effects of O_3 on growth, reproduction, and foliar injury to the sensitive plants in use for nutrition, medicine, cultural, and decorative purposes. It is important to note that some plants may have more than one use or significance. For example, the

Mi'kmaq and Maliseet Indian tribes in Maine do not differentiate between blueberries' nutritional, medicinal, and spiritual uses. Blueberries are a food and a medicine that is often incorporated into ceremonies (Baumflek et al., 2010). And while we cannot quantify the size of the harvest of subsistence-gathered items or monetize the loss of benefit due to O_3 effects, a comparison to the commercial harvest detailed in section 6.4.1 may provide perspective on the significance of these activities to the people who engage in them.

6.5 AGRICULTURE

6.5.1 Commercial Agriculture

Because the forestry and agriculture sectors are related, and trade-offs occur between the sectors based on individual decisions given agriculture and forestry market conditions, we used the same FASOMGHG model runs outlined in the forestry/timber section (Section 6.3) to calculate the resulting market-based welfare effects of O_3 exposure in the agricultural sector of the United States. This section provides a summary of the results of the agricultural sector analyses. We have included results at the national scale for both sectors and at the regional and subregional scale for agriculture. Table 6-15 defines the production and market regions available in FASOMGHG. The regional-scale analysis provides an estimate of the changes due to alternative levels of the standard for 63 subregions and indicates the disparate results between regions. The full model results, including a county-level analysis and a full explanation of interactions between the forestry and agriculture sectors, are reported in Appendix 6B. Of note in the county-level analysis is that the relative yield loss estimates mirror the associated subregion. Under recent conditions, there are significant numbers of counties with greater than 5 percent yield loss -- for soybeans 1,718 out of 1,729, or 99 percent, of soybean-producing counties. When adjusting air quality scenarios to just meet the existing standard of 75 ppb, no counties have relative yield losses above 5 percent for any crop.

Table 6-15 Definition of FASOMGHG Production Regions and Market Regions

Key	Market Region	Production Region (States/Subregions)
NE	Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
LS	Lake States	Michigan, Minnesota, Wisconsin
CB	Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio (IllinoisN, IllinoisS, IndianaN, IndianaS, IowaW, IowaCent, IowaNE, IowaS, OhioNW, OhioS, OhioNE)
GP	Great Plains (agriculture only)	Kansas, Nebraska, North Dakota, South Dakota
SE	Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
SC	South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, Eastern Texas
SW	Southwest (agriculture only)	Oklahoma, All of Texas but the Eastern Part (Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos)
RM	Rocky Mountains	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
PSW	Pacific Southwest	All regions in California (CaliforniaN, CaliforniaS)
PNWE	Pacific Northwest—East side	Oregon and Washington, east of the Cascade mountain range
PNWW	Pacific Northwest—West side (forestry only)	Oregon and Washington, west of the Cascade mountain range

Using the modeled W126 index values in each subregion under the scenarios, for crops, we first calculated the RYL in the 63 subregions that have E-R functions. For those crops that do not have E-R functions, we assign them RYLs for each scenario based on the crop proxy mapping shown in Table 6-16. In addition, for oranges, rice, and tomatoes, which have O_3 E-R functions that are not W126-based (they are defined based on alternative measures of O_3 concentrations), we directly used the median RYG values under the “13 ppm-hrs” O_3 concentration reported in Table G-7 of Lehrer et al. (2007). In addition, we updated RYLs for crops with county-level production data and specific E-R functions by using production-weighting. Production weighting applies a county’s share of the region’s total production to the average so that counties with less production have a smaller impact on the average.

The RYLs for proxy crops were calculated for each FASOMGHG subregion so they could be used in calculating the yield losses for other crops that occur in those regions. The weighted RYLs that were used for corn, cotton, winter wheat (hard winter wheat and soft red winter wheat), sorghum, and soybeans in the model scenarios were calculated only for their production regions. The values calculated in all 63 regions were weighted by production for these crops, which eliminated regions with no production.

Table 6-16 Mapping of O_3 Impacts on Crops to FASOMGHG Crops

CROPS	FASOMGHG Crops
W126 Crops	
Corn	Corn
Cotton	Cotton
Potatoes	Potatoes
Winter Wheat	Soft White Wheat, Hard Red Winter Wheat, Soft Red Winter Wheat, Durum Wheat, Hard Red Spring Wheat, Oats, Barley, Rye, Wheat Grazing, and Improved Pasture
Sorghum	Sorghum, Silage, Hay, Sugarcane, Sugar Beet, Switchgrass, Energy Sorghum, and Sweet Sorghum
Soybeans	Soybeans, Canola
Aspen (tree)	Hybrid Poplar, Willow (FASOMGHG places short-rotation woody biomass production in the crop sector rather than in the forest sector)
Non-W126 Crops	
Oranges	Orange Fresh/Processing, Grapefruit Fresh/Processing
Rice	Rice
Tomatoes	Tomato Fresh/Processing

The following figures (Figure 6-17 and Figure 6-18) present the yield loss relative to the existing standard and yield gains for corn and soybeans under the various adjusted air quality scenarios. We are using corn and soybeans to illustrate some of the interactions that occur between crop responses to O_3 reductions, production, prices, producer cropping decisions, and welfare effects for both producers and consumers. For full model results for all crops included in the analysis see Appendix 6B. In general, the RYL and RYG are unchanged between the existing 75 ppb standard and the 15 ppm-hrs W126 scenarios.   Also, note that in many cases, subregions that show no change in yield for a given crop have no production of that crop in that subregion in FASOMGHG. For example, soybeans are relatively sensitive to O_3 and there are large reductions in O_3 in California, but there are no impacts on soybean yields in that region because no soybeans are produced in California in FASOMGHG.

Corn is relatively insensitive to O_3-induced yield losses at the existing standard or 15 ppm-hrs. The highest loss occurs in California at 0.88 percent, while in the Corn Belt, Lake States, and Great Plains the highest loss occurs in southern Ohio with 0.34 percent. Because the yield losses are small due to corn's insensitivity to O_3 under the alternative W126 standard scenarios, the yield losses are virtually eliminated at all three alternative W126 standards. Yield gains associated with the alternative scenarios are almost nonexistent; the highest gain occurs in Arizona at 0.02 percent at the 7ppm-hrs level.

Soybeans, on the other hand, are relatively sensitive to O_3-induced yield losses. The highest losses at the existing standard or 15 ppm-hrs occur in Colorado, southern Indiana, Kentucky, and northwest Ohio at over 1 percent. Yield losses remain under all scenarios for W126, although for the 7 ppm-hrs scenario all losses are less than 0.6 percent. Yield gains across the alternative W126 standard levels generally range between 0.54 percent and 0.84 percent with northeast Ohio, Tennessee, Kentucky, Illinois, and Indiana on the high end. Colorado has the highest gain at 1.01 percent at the 7 ppm-hrs level and most soybean producing states have at least small gains at every W126 scenario.

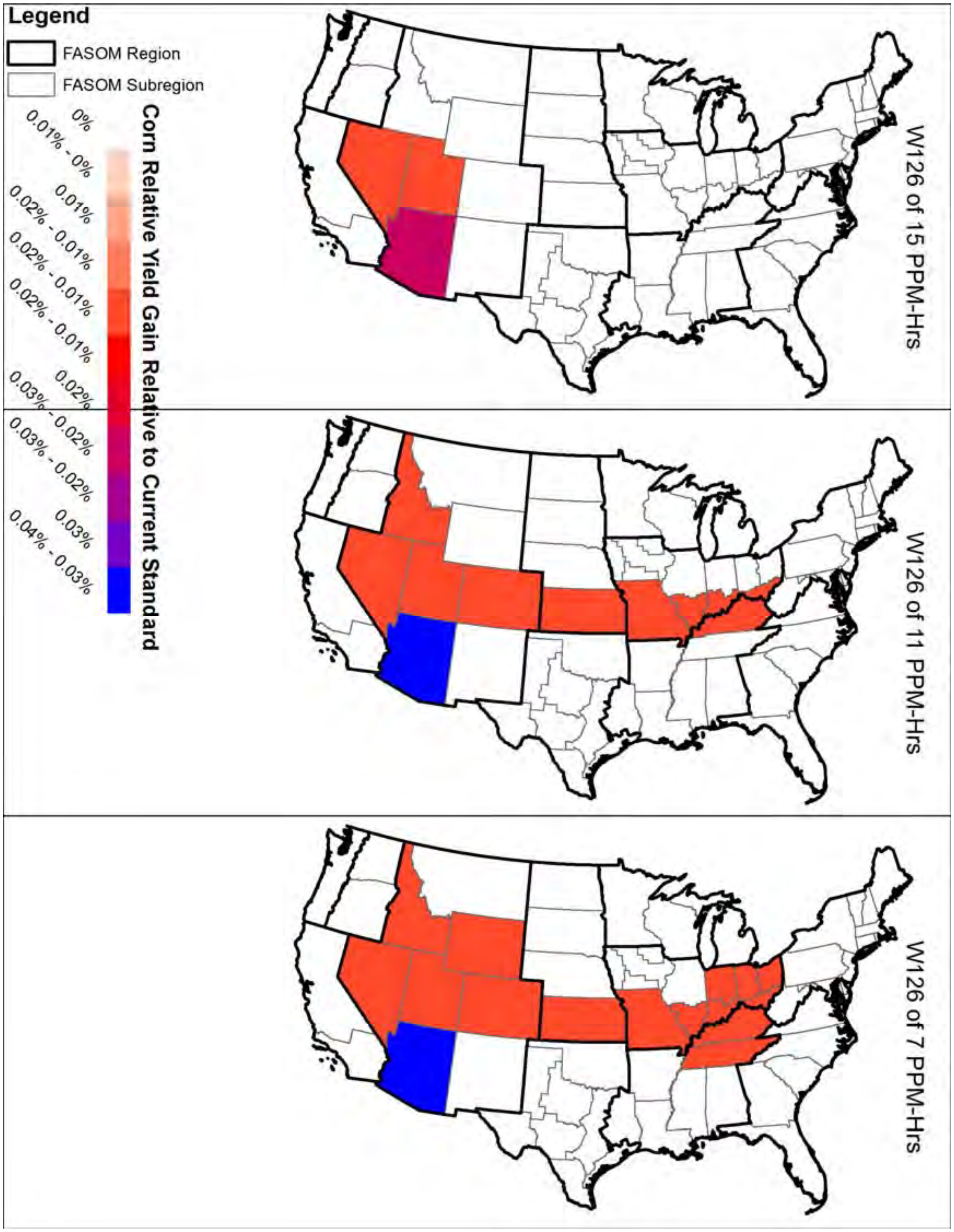

Figure 6-17 Percentage Changes in Corn RYG with Respect to 75 ppb

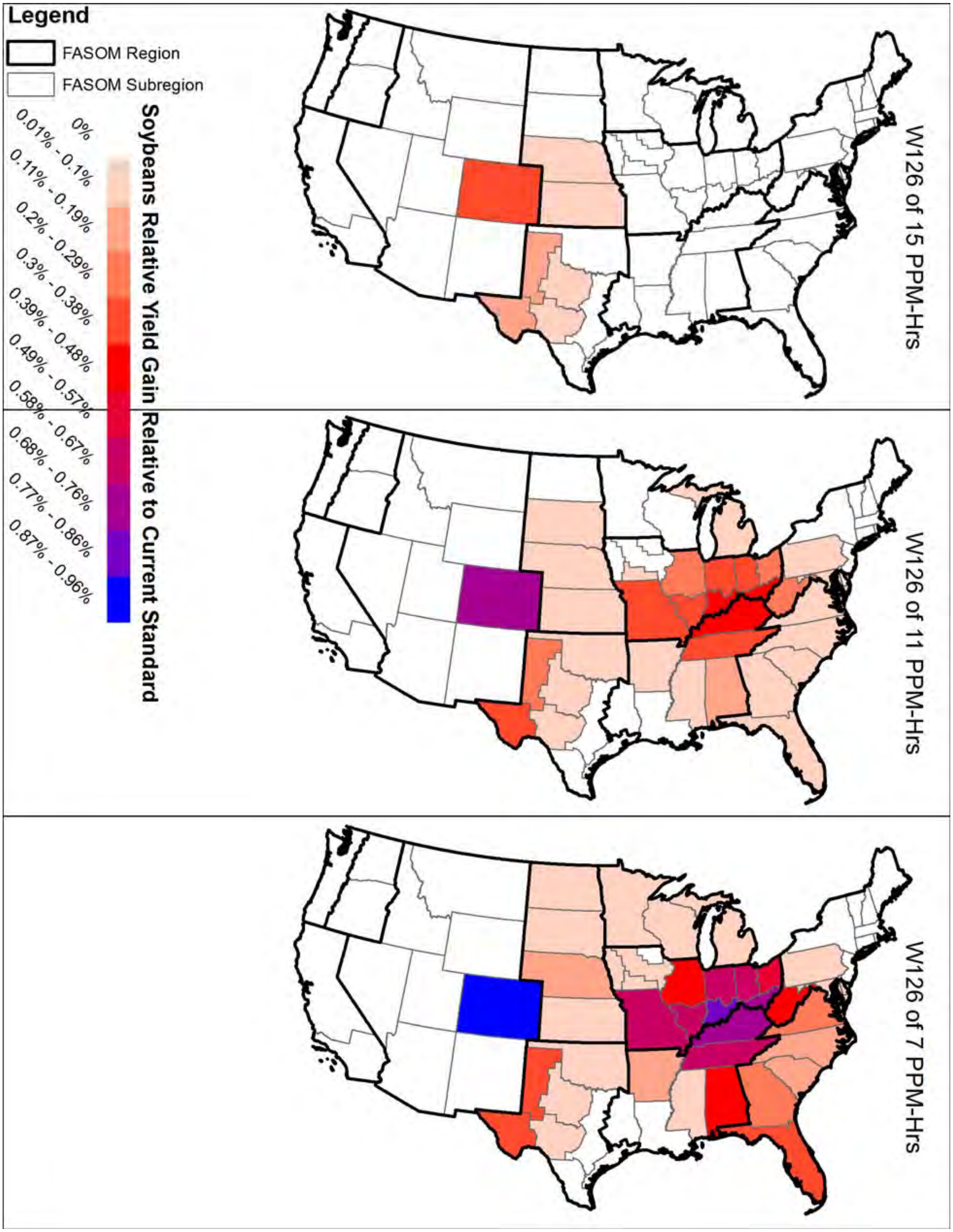

Figure 6-18 Percentage Changes in Soybean RYG with Respect to 75 ppb

In general, increased yield leads to increased supply and lower prices. Because corn does not lose or gain very much under any scenario one could expect that prices would remain relatively stable. Soybeans, however, would experience yield gains in any scenario, and prices would likely fall. In the modeled scenarios soybean prices fall, and since consumer demand does not increase enough to offset the loss of revenue due to price decreases there is a net decrease in producer welfare, but consumers always benefit from falling prices. In response to falling soybean prices, the model predicts that producers would switch to less O_3-sensitive crops with stable prices, such as corn, thereby increasing corn production. See Appendix 6C for an explanation of the supply curve shift.

Overall, across the full agriculture sector, these changes in production are small, seldom above 0.5 percent and usually 0.01 percent or less. The production increases lead to generally lower prices, with price decreases greater than the change in production. The drop in market prices, while a loss for producers, represents a gain for consumers. In terms of producer and consumer welfare across the agriculture sector, in nearly all cases producer welfare is negatively affected. Table 6-17 presents the overall welfare gains and losses. For producers, the W126 alternatives occasion welfare gains in the middle years, 2020-2030, and welfare losses in all other years. For consumers, however, the changes in production and prices occasion welfare gains in all scenarios in all years.

Since the forestry and agriculture sectors are interlinked and factors affecting one sector can lead to changes in the other, it is important to consider the overall effect of O_3 changes in the context of producer and consumer welfare across both sectors. The impacts on consumer surplus are positive for both sectors, with benefits increasing with lower W126 alternatives. For producer surplus, however, impacts are negative for the 15 ppm-hrs and 11 ppm-hrs scenarios and positive for the 7 ppm-hrs case. Table 6-18 presents the annualized surplus for both sectors.

Table 6-17 Consumer and Producer Surplus in Agriculture (Million 2010$)

Product	Policy	2010	2015	2020	2025	2030	2035	2040
Consumer Surplus	**75 ppb**	1,918,082	1,940,673	1,968,142	1,995,346	2,023,022	2,050,791	2,076,018
		Change with Respect to Existing Standard						
	15 ppm-hrs	15	-2	1	6	-7	10	3
	11 ppm-hrs	19	24	13	51	42	20	13
	7 ppm-hrs	-31	46	36	104	90	26	46
Producer Surplus	**75 ppb**	725,364	831,565	815,072	863,165	878,986	836,692	863,308
		Change with Respect to Existing Standard						
	15 ppm-hrs	612	-1,255	980	-961	90	41	697
	11 ppm-hrs	1,474	-2,197	1,013	230	232	-3,413	2,189
	7 ppm-hrs	269	-1,873	1,780	423	264	-1,052	2,991

Table 6-18 Annualized Changes in Consumer and Producer Surplus in Agriculture and Forestry, 2010-2040, Million 2010$ (4% Discount Rate)

Product	Policy	Agriculture	Forestry	Total
Consumer surplus	**75 ppb**	NA	NA	NA
Change with Respect to Existing Standard				
	15 ppm-hrs	4.5	88.1	92.5
	11 ppm-hrs	25.4	236.9	262.3
	7ppm-hrs	36.7	344.0	380.7
Producer surplus	**75 ppb**	NA	NA	NA
Change with Respect to Existing Standard				
	15 ppm-hrs	-4.7	-112.2	-116.9
	11 ppm-hrs	-4.6	-264.4	-269.0
	7 ppm-hrs	194.4	-318.4	-124.0
Total surplus	**75 ppb**	NA	NA	NA
Change with Respect to Existing Standard				
	15 ppm-hrs	-0.2	-24.2	-24.4
	11 ppm-hrs	20.8	-27.5	-6.7
	7 ppm-hrs	231.1	25.6	256.7

6.6 CLIMATE REGULATION

Biomass loss due to O_3 exposure affects climate regulation by ecosystems by reducing carbon sequestration and storage. More carbon stays in the atmosphere because carbon uptake by forests is reduced. The studies cited in the O_3 ISA demonstrate a consistent pattern of reduced carbon uptake because of O_3 damage, with some of the largest reductions projected over North America. In one simulation (Sitch et al., 2007) the indirect radiative forcing due to O_3 effects on carbon uptake by plants are shown as even greater than the direct effect of O_3 on climate change.

6.6.1 National Scale Forest Carbon Sequestration

FASOMGHG can calculate the difference in carbon sequestration by forests and agriculture due to biomass loss caused by O_3 exposure. By comparing equilibriums under the different scenarios outlined in Section 6.3, we can calculate changes in carbon sequestration potential over time. Details of FASOMGHG and the methodology for the analyses done for this risk and exposure assessment are available in Appendix 6B.

The impacts of the simulations of meeting the existing and alternative secondary O_3 standards on carbon sequestration potential in U.S. forest and agricultural sectors are presented in Table 6-19, where numbers indicate increased sequestration. As shown in the table, much greater sequestration changes are projected in the forest sector than in the agricultural sector. The 15 ppm-hrs scenario does not appreciably increase carbon storage relative to just meeting the existing standard. The vast majority of the enhanced carbon sequestration potential under the alternative secondary standard scenarios lies in the forest biomass increases over time at the 11 and 7 ppm-hrs standard levels. The forest carbon sequestration potential would increase between 593 and 1,602 million tons of CO_2 equivalents over 30 years after meeting the 11 or 7 ppm-hrs standard level, respectively, compared to just meeting the existing O_3 standard. On an annual basis when just meeting the 11 ppm-hrs W126 standard level, total forestry and agriculture carbon storage is increased by about 20 million tons per year relative to just meeting the existing O_3 standard; equivalent to taking about 4 million cars off the road as calculated by the EPA Greenhouse Gas Equivalencies Calculator[5] (U.S. EPA, 2013b). When meeting the 7 ppm-hrs W126 standard level, the increased annual carbon storage is about 53 million tons relative to just meeting the existing O_3 standard, or approximately 11 million fewer cars on the road.

The baseline stock of carbon storage decreases over time for agriculture because the agriculture sector GHG emissions sources are released every year and soil carbon sequestration stabilizes over the 30-year period. There are only small increases in net carbon storage compared to the existing standard for each of the alternative scenarios modeled.

[5] Available at http://www.epa.gov/cleanenergy/energy-resources/calculator.html.

Table 6-19 Increase in Carbon Storage, $MMtCO_2e$, Cumulative over 30 years

Product	Policy	2010	2020	2030	2040
Forestry	**75 ppb**	74,679	79,171	84,863	89,184
	Change with Respect to Existing Standard				
	15 ppm-hrs	1	0	16	13
	11 ppm-hrs	19	103	312	593
	7 ppm-hrs	50	305	832	1,602
Agriculture	**75 ppb**	18,748	15,363	12,002	8,469
	Change with Respect to Existing Standard				
	15 ppm-hrs	0	1	1	4
	11 ppm-hrs	2	5	6	10
	7 ppm-hrs	3	4	6	9

6.6.2 Urban Case Study Carbon Storage

Urban forests are subject to the adverse effects of O_3 exposure in the same ways as forests in rural areas. These urban forests provide a range of ecosystem services such as carbon sequestration, pollution removal, building energy savings, and reduced stormwater runoff. The analyses in this section focus on carbon sequestration. Pollution removal services are discussed in section 6.7. The i-Tree model[6] used in this analysis is a peer-reviewed suite of software tools provided by USFS. We used data from five urban areas to estimate the effects of O_3 (based on CMAQ modeled W126 index surfaces) on carbon storage. We used the i-Tree Forecast model to estimate tree growth and ecosystem services provided by trees over a 25-year period, using for the base case the measured inventory of trees in the area and standard growth rates over the 25-year period. The growth rates in the model were standardized from measurements of forest stands, park trees, and open space trees in their ambient O_3 conditions at the time of measurement. We adjusted the tree growth downward from the standard growth rates using the reduced growth factors for the species present in each area for which we have E-R functions (only species with W126 E-R functions were reduced). Unlike the FASOMGHG model, E-R functions were not assigned to species in the study areas that do not have specific E-R functions available from the literature because the model does not account for dynamic interactions in the

[6] Available at http://www.itreetools.org/.

community composition based on increased or decreased competitiveness of the species present. We contrasted the differences between the scenarios for the 25-year period. We ran six scenarios simulating a scenario without O_3-induced changes in biomass, recent ambient conditions, a simulation of “just meeting” the existing standard, and just meeting three alternative W126 standards of 15, 11, and 7 ppm-hrs. The model assumed an annual influx of between one and six trees/hectare/year and a three to four percent annual mortality rate. See Appendix 6D for details of the model and the methodology employed for these case studies.

We chose the five urban areas based on data availability and presence of species with a W126 E-R function. No urban area with available vegetation data had more than three qualified species present. The selected study areas include Baltimore, Syracuse, the Chicago region, Atlanta, and the urban areas of Tennessee. Table 6-20 shows details of the tree species present, the percent of sensitive trees in the top ten species present, and the percent of sensitive trees in the total species in each study area.

Table 6-20 Tree Species with Available E-R Functions in Selected Urban Study Areas

	Study Area				
Top Ten Occurring Species	**Baltimore**	**Syracuse**	**Chicago Region**	**Atlanta**	**Tennessee**
1	American beech	European buckthorn	European buckthorn	Sweetgum	Chinese privet
2	Black locust	**Sugar maple**	Green ash	Loblolly pine	**Virginia pine**
3	American elm	**Black cherry**	Boxelder	Flowering dogwood	Eastern red cedar
4	Tree of heaven	Boxelder	**Black cherry**	*Tulip tree*	Hackberry
5	White ash	Norway maple	Hardwood	Water oak	Flowering dogwood
6	**Black cherry**	Northern white cedar	American elm	Boxelder	Amur honeysuckle
7	White mulberry	Norway spruce	**Sugar maple**	**Black cherry**	Winged elm
8	*Northern red oak*	Staghorn sumac	White ash	White oak	**Red maple**
9	**Red maple**	**Eastern cottonwood**	Amur honeysuckle	**Red maple**	Black tupelo
10	White oak	Eastern hophornbeam	Silver maple	*Southern red oak*	American beech
Species w/E-R Function -- % of Top 10	8.5	18.5	7.7	6.6	9.3
Species w/E-R Function -- % of Total Trees	11.2	20.2	10.5	8.9	17.4

Bold – species with E-R function, *Italics* – species known to be sensitive, no E-R function

The largest differences in the modeled air quality are between the recent ambient conditions and meeting the existing standard. The distribution of O_3 air quality is not changed in most areas in the eastern U.S. when simulating meeting an alternative W126 standard of 15 ppm-hrs relative to the scenario of just meeting the existing O_3 standard. There are small incremental differences between just meeting the existing O_3 standard and just meeting alternative W126 standards of 11 and 7 ppm-hrs.

The model results for changes in carbon storage show substantial reductions in the capacity of these urban forests to sequester carbon for the simulation of "just meeting" the existing standard. Estimates for the five modeled areas at the existing standard or an alternative standard of 15 ppm-hrs are about 3.5 million tons of carbon storage lost over 25 years (about 140,000 tons /year). At an alternative standard of 11 ppm-hrs, loss of carbon sequestration is 128,000 metric tons per year, and at an alternative standard of 7 ppm-hrs, the estimated loss is 112,000 metric tons per year of carbon storage services.

Three of the urban areas show gains in carbon storage at alternative W126 standards below 15 ppm-hrs. Syracuse and Baltimore do not realize gains because they are currently very close to meeting the alternative standards. Of the five areas modeled, the combined urban areas of Tennessee have the largest estimated gains in carbon storage at almost 20,000 tons per year when meeting the alternative standard of 7 ppm-hrs. The Chicago region gains about 6,400 tons per year of carbon sequestration when meeting the alternative standard of 7 ppm-hrs. See Table 6-21 for details.

Compared to other activities, the yearly carbon storage gains at 11 ppm-hrs for Atlanta are only equivalent to taking 50 cars per year off the road or recycling about 90 more tons of waste every year. At the 7 ppm-hrs standard level, Atlanta would need to remove 250 cars per year to be equivalent to the gains from reduced O_3. The Chicago region would need to take 417 cars per year off the road. At 7 ppm-hrs, Chicago would need to remove more than 1,300 cars. The urban areas of Tennessee would need about 1,800 fewer cars per year at the 11 ppm-hrs standard level. To reach the carbon sequestration provided by the urban forests in Tennessee at the 7 ppm-hrs standard level, Tennessee would need 4,000 fewer cars every year.

Baltimore and Syracuse would realize no gains at the alternative standard levels chosen for this analysis. Chicago and Atlanta are in the middle of the range of results. In Tennessee, at recent ambient conditions, the urban areas are all above a W126 standard of 15 ppm-hrs and comprise a much larger area than the other four case study areas with a far larger tree population. Thus the relative gains in carbon storage in Tennessee are far larger than the other case study areas. Keeping in mind that of the 11 tree species for which we have E-R functions, only two to three species were present in a given area comprising at most 18.5 percent of the total trees present. It seems reasonable to conclude that the actual effect on carbon storage because of O_3 exposure would be higher than the estimates modeled here.

These results should not be combined with the results from the FASOMGHG model discussed in Section 6.7.1. The methodology employed for the FASOMGHG runs assigned values for O_3 exposure E-R functions for species that do not have a function calculated in the O_3 ISA. We did this to ensure the dynamic trade-offs in the model functioned properly. The i-Tree model does not provide trade-offs between species, so the species that do not have a E-R function were not assigned values. This could lead to an underestimation of the carbon storage losses in i-Tree if the other species in the study area are sensitive to O_3 exposure effects. Alternatively assigning E-R functions to species as we did for the FASOMGHG runs would likely produce an overestimation since many species, even within the same genus, may not be sensitive to O_3 effects.

Table 6-21 O_3 Effects on Carbon Storage for Five Urban Areas over 25 Years (in millions of metric tons)

Region	No O_3 Adjustment (NOA)	Existing Standard/15 ppm-hrs (ES/15)	ES/15 v NOA	11 ppm-hrs v NOA	7 ppm-hrs v BC	ES v 11ppm-hrs	ES v 7 ppm-hrs
Atlanta	1.426	1.315	-0.112	-0.106	-0.081	0.006	0.03
Baltimore	0.578	0.571	-0.007	-0.007	-0.007	0.00	0.00
Chicago Region	19.560	17.053	-2.508	-2.457	-2.346	0.05	0.16
Syracuse	0.169	0.169	-0.0015	-0.0015	-0.0015	0.00	0.00
Tennessee	20.568	19.668	-0.900	-0.676	-0.410	0.22	0.49
Total	**42.302**	**38.607**	**-3.528**	**-3.247**	**-2.845**	**0.276**	**0.68**

ES = Existing Standard
NOA = No Adjustment to Growth Rates using O_3-related E-R Functions

In addition to its direct impacts on vegetation, O_3 is a well-known GHG that contributes to climate warming (U.S. EPA, 2013). A change in the abundance of tropospheric O_3 perturbs the radiative balance of the atmosphere, an effect quantified by the radiative forcing metric. The IPCC (2007) reported a radiative forcing of 0.35 W/m^2 for the change in tropospheric O_3 since the preindustrial era, ranking it third in importance after the greenhouse gases CO_2 (1.66 W/m^2) and methane (CH_4) (0.48 W/m^2). The earth-atmosphere-ocean system responds to the radiative forcing with a climate response, typically expressed as a change in surface temperature. Finally, the climate response causes downstream climate-related ecosystem effects, such as redistribution of ecosystem characteristics because of temperature changes. While the global radiative forcing impact of O_3 is generally well understood, the downstream effects of the O_3-induced climate response on ecosystems remain highly uncertain.

Since O_3 is not emitted directly but is photochemically formed in the atmosphere, it is necessary to consider the climate effects of different O_3 precursor emissions. Controlling methane, CO, and non-methane VOCs may be a promising means of simultaneously mitigating climate change and reducing global O_3 concentrations (West et al. 2007). Reducing these precursors reduces global concentrations of the hydroxyl radical (OH), their main sink in the atmosphere, feeding back on their lifetime and further reducing O_3 production. NOx reductions decrease OH, leading to increased methane lifetime and increased O_3 production globally in the long-term. The resulting positive radiative forcing from increased methane may cancel or even slightly exceed the negative forcing from decreased O_3 globally (West et al. 2007). Of the O_3 precursors, methane abatement reduces climate forcing most per unit of emissions reduction, as methane produces O_3 on decadal and global scales and is itself a strong climate forcer. Since they may have different effects on concentrations of different species in the atmosphere, all O_3 precursors must be considered in evaluating the net climate impact of emission sources or mitigation strategies.

6.7 URBAN CASE STUDY AIR POLLUTION REMOVAL

In addition to sequestering and storing carbon, urban forests also remove pollutants from the local atmosphere. The reduction in growth rates resulting from O_3 exposure would reduce the current and future amount of pollutants removed by these forests. We used the i-Tree model described in Section 6.5.2 to estimate the removal of air pollutants by the forests in the urban areas discussed.

The preliminary results for changes in air pollution removal estimates for carbon monoxide, nitrogen dioxide, O_3, and sulfur dioxide show reduced capacity for these urban forest canopies to remove pollution (1) at recent ambient O_3 conditions and (2) after adjusting air quality to just meeting the existing standards and alternative standards. These analyses show that even at the lowest scenario urban forest capacity to remove pollution is still reduced compared to a no ozone scenario. Because of the limitations in the availability of E-R functions for all of the common tree species in urban areas, and because of the limited number of urban areas for which the i-Tree model has been applied, these reductions only reflect a portion of the impacts on pollution removal by urban forests in the U.S. Though the model does include estimates for particulate matter (PM), we do not include those estimates because the model does not yet distinguish between PM_{10} and $PM_{2.5}$, and this distinction is important for evaluating the potential health and welfare effects associated with PM. Estimates suggest that after meeting the existing standard about 1,535 tons of air pollution removal capacity is lost annually (or about 38,384 tons over 25 years) in the five areas modeled. As in the simulations for carbon storage, Syracuse and Baltimore see the least change in capacity with the urban areas of Tennessee reporting the largest changes. Syracuse and Baltimore have no change in pollution removal when meeting the existing and the modeled alternatives. Atlanta and Chicago gain about 470 and 6,500 metric tons of additional pollution removal after meeting the alternative W126 standard of 7 ppm-hrs compared to meeting the existing standard, while Tennessee gains almost 12,000 tons of potential pollution removal annually for the same comparison. For the 7 ppm-hrs scenario, about 51 percent of the pollution removal capacity lost under the existing standard is regained. See Table 6-22 for details.

We performed a simple analysis of the O_3 removal potential to show how this process might affect ambient air quality values. The analysis makes some general assumptions to estimate order of magnitude effects of O_3 removal by trees on O_3 concentrations in the five urban areas. To make this calculation, the metric tons of O_3 removed listed in Table 6-20 are spread evenly over every hour in the 25-year tree lifetime to achieve an hourly O_3 removal. Using the ideal gas-law, this mass can be converted to an equivalent volume of gas assuming standard temperature and pressure. Each urban area is treated as a well-mixed volume with the height determined as the average maximum daytime boundary layer height[7] extracted from an April-October 2007 Weather Research Forecasting (WRF) model simulation for each area of interest. The ratio of the O_3 volume to the urban area air volume multiplied by 10^9 gives an equivalent concentration in ppbv. The effects on O_3 concentration are generally small; deposition to tree surfaces results in ambient O_3 concentration reductions ranging from 0.08 ppbv in Tennessee to 0.52 ppbv in Chicago. Differences between the scenarios are minute. The base case numbers are consistent with previously published values from Song et al. (2008) who used a photochemical model to show that changes in land use from development in Austin, TX, might lead to a 0-0.3 ppbv change in O_3 concentration due solely to deposition differences. Some additional benefit may be achieved from cumulative effects, which are not accounted for here (i.e., O_3 removed at 9am will not only decrease concentrations instantaneously, but will also decrease the starting concentration to some degree at 10am, 11am, etc. throughout the day). In addition, changing the boundary layer height based on variability in this value could increase or decrease the ppbv estimates by a factor of two. But in any case, the values would still be small.

[7] The maximum daytime boundary layer height is the depth in the atmosphere over which air is well-mixed in the afternoon. The WRF modeling simulation showed that this depth was approximately 1700m in Atlanta, 1500m in Baltimore, 1150m in Chicago, 1350m in Syracuse, and 1750m in Tennessee.

Table 6-22 Comparison of Pollutant Removal Between an Unadjusted Scenario and Alternatives and Gains Between the Existing Standard and Alternatives (metric tons)

	No O_3 Adjustment (NOA)	Existing Standard (75 ppb)/15 ppm-hrs (ES/15)	NOA v ES/15	NOA v 11 ppm-hrs	NOA v 7 ppm-hrs	ES/15 v 11 ppm-hrs	ES/15 v 7 ppm-hrs
CO							
Atlanta	1,482	1,429	-54	-50	-34	3	9
Baltimore	186	186	0	0	0	0	0
Chicago	8,620	8,001	-619	-569	-476	142	235
Syracuse	55	55	0	0	0	0	0
Tennessee	12,854	12,626	-227	-97	62	131	290
NO_2							
Atlanta	6,852	6,605	-248	-231	-159	16	88
Baltimore	1,968	1,963	-5	-5	-5	5	5
Chicago	104,247	96,766	-7,481	-6,883	-5,758	598	1,723
Syracuse	50	50	0	0	0	0	0
Tennessee	54,381	53,419	-962	-408	263	554	1,226
O_3							
Atlanta	25,495	24,574	-921	-861	-591	60	331
Baltimore	6,262	6,247	-15	-15	-15	0	0
Chicago	243,701	226,214	-17,488	-16,090	-13,460	1,398	4,028
Syracuse	1,544	1,541	-4	-4	-4	0	0
Tennessee	393,205	386,247	-6,957	-2,953	1902	4,004	8,860
SO_2							
Atlanta	3,380	3,257	-122	-114	-78	8	44
Baltimore	852	850	-2	-2	-2	0	0
Chicago	29,675	27,546	-2,129	-1,959	-1,639	170	490
Syracuse	71	71	0	0	0	0	0
Tennessee	59,371	58,320	-1,050	-446	287	605	1,338
Total							
Atlanta	37,209	35,865	-1,344	-1,825	-862	87	472
Baltimore	9,268	9,246	-22	-22	-22	5	0
Chicago	386,242	358,527	-27,817	-25,501	-21,333	2,308	6,476
Syracuse	1,721	1,717	-4	-4	-4	0	0
Tennessee	519,810	510,613	-9,197	-3,904	2,514	5,294	11,714

ES = Existing Standard
NOA = No Adjustment to Growth Rates Using O_3-related E-R Functions

6.8 ECOSYSTEM-LEVEL EFFECTS

To assess the risk to ecosystems from biomass loss, as opposed to the potential risk to individual tree species, we attempted to combine the RBL values into one metric. One factor in assessing the risk to ecosystems is a measure of the overall abundance of each species. As a measure of overall abundance, we used the basal area estimates described in Section 6.2.1 to calculate the proportion of basal area for each of the 12 species assessed. Table 6-23 reflects, by region, the total basal area covered by the 12 tree species assessed. We separated the total basal area covered into different categories of percent cover of the species assessed. For example, in the Southwest region, 13 percent of the total basal area assessed had less than 10 percent cover of the 12 tree species; 7.1 percent of the total basal area assessed had between 10 and 25 percent cover of the 12 tree species; 8.8 percent of the total basal area assessed had between 25 and 50 percent cover of the 12 tree species; and 64.9 percent of total basal area assessed had no data on percent cover of the 12 tree species. The Southwest and West regions had the largest percentages of total basal area assessed with no data on percent cover of tree species, and the Central and Northeast regions had the smallest percent of total basal area assessed with no data on percent cover of tree species.

Table 6-23 Percent of Total Basal Area Covered by 12 Assessed Tree Species

	Percent of Total Basal Area Covered by 12 Assessed Tree Species					
Region	**≤ 10%**	**10% to 25%**	**25% to 50%**	**50% to 75%**	**> 75%**	**No Data**
Central	38.4%	32.0%	26.6%	2.2%	<0.1%	0.7%
East North Central	33.4%	25.7%	27.5%	8.9%	0.1%	4.3%
Northeast	7.0%	22.1%	47.9%	22.2%	0.5%	0.3%
Northwest	4.5%	7.7%	20.0%	24.5%	15.0%	28.3%
South	28.6%	4.0%	7.7%	7.7%	0.9%	51.2%
Southeast	16.0%	14.2%	48.1%	17.7%	0.3%	3.8%
Southwest	13.0%	7.1%	8.8%	5.1%	1.2%	64.9%
West	10.0%	3.7%	7.0%	5.5%	0.2%	73.5%
West North Central	20.2%	8.0%	9.7%	8.2%	6.5%	47.4%
All Regions	**20.3%**	**12.0%**	**19.1%**	**10.0%**	**2.7%**	**35.9%**

Data on basal area were available in over 64 percent of the cover area assessed, as measured by the number of grid cells. To understand the potential W126 index values in the percent of cover area not assessed, Table 6-24 includes information on the (i) number of grid cells with no data on basal area above a certain amount and (ii) total number of grid cells with no data on basal area. For those grid cells with no data on basal area, the table also shows, under recent conditions, the number of grid cells with W126 index values that would exceed potential alternative standards of 15, 11, and 7 ppm-hrs. In the Southwest, under recent conditions, 52 percent of the grid cells with no data have W126 index values above 15 ppm-hrs, 95 percent have W126 index values above 11 ppm-hrs, and 100 percent have W126 index values above 7 ppm-hrs. In contrast, in the East North Central, under recent conditions, no grid cells with no data have W126 index values above 15 ppm-hrs, 1 percent have W126 index values above 11 ppm-hrs, and 3.5 percent have W126 index values above 7 ppm-hrs.

Table 6-24 Grid Cells With No Data That Exceed W126 Index Values under Recent Conditions

Region	Number of Grid Cells with No Data	Number of Grid Cells w/No Data that Exceed W126 Index Values Under Recent Conditions		
		> 7 ppm-hrs	> 11 ppm-hrs	> 15 ppm-hrs
Central	35	34	11	3
East North Central	198	7	2	0
Northeast	11	11	11	6
Northwest	1,256	779	451	189
South	5,239	4,638	1,945	27
Southeast	200	59	15	3
Southwest	4,904	4,904	4,662	2,572
West	3,550	3,452	3,274	2,680
West North Central	4,013	1,870	1,158	283
All Regions	**19,406**	**15,754**	**11,529**	**5,763**

We used the proportion of total basal area for each species to weight the RBL value for that species in each grid cell. The weighted values for all species present in each grid cell were summed to generate a weighted RBL value for each grid cell. Table 6-25 provides a summary of the percent of total basal area that exceeds a 2 percent weighted biomass loss under recent conditions, at just meeting the existing standard (75 ppb) and at potential alternative W126 standard levels of 15, 11, and 7 ppm-hrs. The data are also presented excluding Cottonwood, which is a very sensitive species. Note that for biomass loss, 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 (Frey and Samet, 2012b). 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. We chose to use the 2 percent biomass loss recommendation in this analysis; however, the weighted RBL value is not the same as the individual species analysis (Section 6.2.1.3). These data are interpreted in a more relative manner where higher values represent a larger potential impact on the overall ecosystem.

The data in Table 6-25 shows that the total area exceeding two percent biomass loss decreases, as expected, across air quality scenarios. For example, for the Central region under recent conditions, a total of 23.4 percent of total basal area assessed would exceed a 2 percent biomass loss and when adjusted to just meet the existing standard, a total of 2.7 percent of total basal area assessed would exceed a 2 percent biomass loss. When adjusted to meet potential alternative standard levels of 15, 11, and 7 ppm-hrs, 2.7 percent, 1 percent and 0.1 percent, respectively, of total basal area assessed would exceed a 2 percent biomass loss.

While it is not possible to predict overall effects, the results from these analyses show the weighted RBL to be a potential predictor of risk in areas with species present for which E-R functions were available.

Table 6-25 Percent of Area Exceeding 2 Percent Weighted Biomass

	Percent of Area Exceeding 2 Percent Weighted Biomass Loss (12 Assessed Tree Species)				
Region	**Recent Conditions**	**75 ppb**	**15 ppm-hrs**	**11 ppm-hrs**	**7 ppm-hrs**
Central	23.4%	2.7%	2.7%	1.0%	0.1%
East North Central	13.6%	0.6%	0.6%	0.4%	0.3%
Northeast	18.0%	0.2%	0.2%	0.0%	0.0%
Northwest	2.7%	0.0%	0.0%	0.0%	0.0%
South	2.2%	0.2%	0.2%	0.1%	0.1%
Southeast	9.2%	0.0%	0.0%	0.0%	0.0%
Southwest	11.1%	0.5%	0.2%	0.1%	<0.1%
West	4.8%	0.0%	0.0%	0.0%	0.0%
West North Central	15.4%	2.2%	2.0%	1.8%	1.0%
All Regions	**10.8%**	**0.8%**	**0.7%**	**0.5%**	**0.2%**
	(11 Tree Species, excluding Cottonwood)				
Region	**Recent Conditions**	**75 ppb**	**15 ppm-hrs**	**11 ppm-hrs**	**7 ppm-hrs**
Central	15.4%	0.9%	0.9%	0.2%	<0.1%
East North Central	8.0%	0.6%	0.6%	0.4%	0.3%
Northeast	17.2%	0.2%	0.2%	0.0%	0.0%
Northwest	2.7%	0.0%	0.0%	0.0%	0.0%
South	0.2%	0.0%	0.0%	0.0%	0.0%
Southeast	9.1%	0.0%	0.0%	0.0%	0.0%
Southwest	10.7%	0.3%	0.0%	0.0%	0.0%
West	4.8%	0.0%	0.0%	0.0%	0.0%
West North Central	6.9%	0.2%	0.2%	0.2%	<0.1%
All Regions	**7.6%**	**0.2%**	**0.2%**	**0.1%**	**<0.1%**

Two important things to note with respect to the weighted RBL analysis. First, the proportional basal area values do not account for total cover, only for the relative cover of the tree species present. This is most noticeable with Cottonwood and Ponderosa pine, which are near 100 percent cover in some areas; however, the absolute cover is very different. Ponderosa pine occurs in relatively high density in some grids, exceeding 100 square feet per acre, while Cottonwood is often less than 10 square feet per acre. This affects the direct interpretation of the values presented because the overall ecosystem effect may be very different, although equally important. It is important to remember with this data set that these numbers are only useful as a very general estimate of potential effects. Second, this analysis only accounts for the 12 tree species with E-R functions; other species are known to be sensitive to O_3 exposure, but E-R functions were not available. It is also possible other species that are not sensitive may be indirectly affected through changes in community composition and competitive interactions.

6.8.1 Potential Biomass Loss in Federally Designated Areas

6.8.1.1 Class I Areas

We analyzed federally designated Class I areas in relation to the W126 air quality surface and the weighted RBL values. We completed the analyses of Class I areas in the same manner as the analyses across the entire range of data; however, we present the results as a count of the Class I areas and not as a percentage of area. We treated each Class I area as an individual geographic endpoint and calculated an average weighted RBL for all Class I areas with at least one grid cell that had a non-zero weighted RBL. Data were available in 145 of the 156 Class I areas. A complete list of Class I areas and the weighted RBL values at the existing standard and alternative W126 standard levels is included in Appendix 6E.

Table 6-26 summarizes the number of Class I areas exceeding 1 percent and 2 percent weighted RBL across varying percent cover of species and under recent conditions and when adjusted to just meet the existing standard and potential alternative standard levels of 15, 11, and 7 ppm-hrs. The number of areas exceeding 1 percent and 2 percent decreases across air quality scenarios.

Table 6-26 Weighted RBL and Percent Cover in Class I Areas

Percent of Total Basal Area	Class I Areas Covered	Number of Class I Areas Exceeding 1% Weighted RBL					Number of Class I Areas Exceeding 2% Weighted RBL				
		Recent Conditions	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs	Recent Conditions	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
No Data	11	-	-	-	-	-	-	-	-	-	-
≤10	54	6	2	2	2	1	2	1	1	1	0
10 to 25	35	8	0	0	0	0	2	0	0	0	0
25 to 50	48	20	1	1	0	0	7	0	0	0	0
50 to 75	6	1	0	0	0	0	1	0	0	0	0
> 75	2	1	1	1	1	1	1	1	1	1	1
Total Areas	**156**	**36**	**4**	**4**	**3**	**2**	**13**	**2**	**2**	**2**	**1**

6.9 QUALITATIVE ASSESSMENT OF UNCERTAINTY

As noted in Chapter 3, we have based the design of the uncertainty analysis for this assessment on the framework outlined in the WHO guidance (WHO, 2008). For this qualitative uncertainty analysis, we have described each key source of uncertainty and qualitatively assessed its potential impact (including both the magnitude and direction of the impact) on risk results, as specified in the WHO guidance. In general, this assessment includes qualitative discussions of the potential impact of uncertainty on the results (WHO Tier1) and quantitative sensitivity analyses where we have sufficient data (WHO Tier 2).

Table 6-27 includes the key sources of uncertainty identified for the O_3 WREA. For each source of uncertainty, we have (a) provided a description, (b) estimated the direction of influence (over, under, both, or unknown) and magnitude (low, medium, high) of the potential impact of each source of uncertainty on the risk estimates, (c) assessed the degree of uncertainty (low, medium, or high) associated with the knowledge-base (i.e., assessed how well we understand each source of uncertainty), and (d) provided comments further clarifying the qualitative assessment presented. The categories used in describing the potential magnitude of impact for specific sources of uncertainty on risk estimates (i.e., low, medium, or high) reflect our consensus on the degree to which a particular source could produce a sufficient impact on risk estimates to influence the interpretation of those estimates in the context of the secondary O_3

NAAQS review. Where appropriate, we have included references to specific sources of information considered in arriving at a ranking and classification for a particular source of uncertainty.

Table 6-27 Summary of Qualitative Uncertainty Analysis in Relative Biomass Loss Assessments

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
A. National W126 surfaces	The biomass loss analyses in this chapter use the national W126 surfaces for recent conditions and adjusted to just meet the existing standard and alternative W126 standards.	Both	Low-Medium	Low-medium	KB and INF: See Chapter 4 for more details.
B. Shape of the E-R function for biomass loss for different species	Biomass loss and yield loss estimates are highly sensitive to the parameters in the E-R function.	Unknown	High	Medium	KB: We conducted sensitivity analyses for 10 crops (in 54 studies) and 12 tree species (in 52 studies), which showed high intraspecific and interspecific variability. Some species only had one study, while other species had many studies. INF: The resulting E-R functions for the included species were mostly of intermediate sensitivity, with only a few species considered very sensitive and several that showed little or no sensitivity to O_3. This range of sensitivities was consistent with the additional studies included in the O_3 ISA, but further studies are needed to determine how accurately this reflects the larger suite of tree species in the U.S.
C. Absence of E-R functions for many O_3-sensitive species	E-R functions are available for only 12 tree species, thus the majority of trees in the modeled urban areas and Class I areas were not incorporated.	Under	Medium-High	Medium-Low	KB: We are certain that there are additional sensitive species based on studies cited in the O_3 ISA that reported effects. However, the studies of additional sensitive species did not provide sufficient information to generate E-R functions. Therefore, we are certain that we are underestimating tree biomass loss in urban areas and Class I areas. INF: Eighty to 90 percent of the total trees in the urban case study areas are excluded from the analysis. There are 2 tree species in the case study areas that we know are sensitive but for which no E-R function is available. The magnitude of the influence is dependent on the community composition in each area.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
D. Using E-R functions for tree seedlings rather than adult trees	E-R functions for trees are based on analyses of tree seedlings, but most biomass impacts are from effects on adult trees.	Both	Low-Medium	Medium	KB and INF: In general, estimates of relative biomass loss (RBL) in tree seedlings are comparable to the estimates for adult trees, with a few exceptions such as black cherry. Some species overestimate RBL in adult trees and some species underestimate RBL.
E. Urban tree inventory in iTree	The base inventory of urban trees, including species and distribution, in iTree has uncertainty.	Unknown	Low	High	KB: The urban tree inventories included in the iTree analyses are based on field counts and measurements of trees in the specific urban areas analyzed (personal communication, Nowak, 6/2011). Tree census data (e.g., Baltimore, Syracuse, Chicago, and Atlanta) are generally considered less uncertain than modeled tree inventories (e.g., urban areas of Tennessee). INF: The iTree model estimates carbon sequestration and pollution removal services provided by urban forests. These services are based on tree growth and pollution removal functions that are specific to the forest structure in each urban area, including the species composition, number of trees, and diameter distribution of trees. Uncertainties in the tree inventory are propagated into the estimates of carbon sequestration and pollution removal based on those inventories.
F. Pollution removal functions in iTree	The functions applied in iTree to estimate pollution removal are uncertain and vary by species.	Unknown	Medium	Medium	KB: Pollution removal is calculated based on field, pollution concentration, and meteorological data. The pollution removal functions in iTree are from Nowak et al. (2006). INF: iTree estimates that 1,535 tons/year of pollution are removed from the urban case study areas at the existing standard. Nowak et al. (2006) provides an indication of the ranges of pollution removal in the literature.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
G. VOC emissions from trees	Many tree species are biogenic sources of volatile organic compounds (VOC) that contribute to formation of ozone. Additional VOC emissions associated with biomass gains are not addressed.	Over (generally)	Medium	High	KB: According to the O_3 ISA (U.S. EPA, 2013, section 3.2.1), vegetation emits substantial quantities of VOCs, and the 2005 NEI approximately 29 MT/year of VOC emissions were from biogenic sources. INF: Vegetation may account for as much as two-thirds of the VOC production (Guenther et al., 2006). Carlton et al. (2010) found, however, that if man-made pollutants were not present, O_3 attributable to biogenic emissions would drop by as a much as 50 percent.
H. Carbon sequestration functions in iTree and FASOM	The functions applied in the models to estimate carbon sequestration are uncertain and vary by species.	Unknown	Medium	Medium	KB: The studies in the O_3 ISA show a consistent pattern of reduced carbon uptake due to O_3 damage, with large reductions projected over North America. The forest carbon accounting component of FASOMGHG is largely derived from the U.S. Forest Service's Forestry Carbon (FORCARB) modeling system, which is an empirical model of forest carbon budgets simulated across regions, forest types, land classes, forest age classes, ownership groups, and carbon pools. Multiple equations for individual species were combined to produce one predictive equation for a wide range of diameters for individual species. Formulas were combined to prevent disjointed sequestration estimates that can occur when calculations switch between individual biomass equations. If no allometric equation could be found for an individual species, the average of results from equations of the same genus is used. If no genus equations are found, the average of results from all broadleaf or conifer equations is used. INF: We estimate that carbon storage would increase by 13 million metric tons and 1.6 billion metric tons over 40 years after just meeting the existing and the alternative standard level of 7 ppm-hrs, respectively. The process of combining the individual formulas produced results that were typically within 2% of the original estimates.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
I. Use of median E-R functions for crops in FASOM	FASOMGHG incorporates median parameters from Lehrer et al. (2007) in the E-R functions for oranges, rice, and tomatoes. Using alternative E-R functions would result in lower or higher O_3 impacts on crop and tree species biomass productivity, which would potentially lead to different economic equilibrium outcomes.	Both	Low	Low	KB: These 3 crops have C-R functions based on O_3 metrics other than W126, as reported in Lehrer (2007). INF: Use of the median function could affect the estimates for those crops specifically. No other crop estimates are based on these functions.
J. Crop proxy and forest type assumptions	The crops/tree species modeled are only a subset of species present in U.S. agriculture and forestry systems. Actual impacts may differ from those of the crop proxy or the forest type. Further, FASOMGHG modeling used a simple average of tree RYLs for all forest types within a region.	Both	Medium-High	Low	KB: Aggregation of crop and tree species was conducted based on recommendations from CASAC (Frey and Samet, 2012a). As stated by CASAC, it is not feasible to obtain E-R functions for all species, and there is no reliable mechanism to infer E-R relationships in a novel species even from knowledge of a closely-related species. INF: Total economic surplus is estimated to decrease by $24 million or increase by as much as $257 million between 2010 and 2040. It is unclear how using actual species information rather than proxy species would affect these estimates. However, consistent with CASAC recommendation, we did not assign the most sensitive E-R relationships to the proxy species.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
K. FASOMGHG does not model agriculture/ forestry on public lands	Because public lands are not affected within the model, the estimates of changes in consumer and producer surplus would likely be higher if public lands were included.	Under	Medium	Medium-Low	KB: The model assumes that O_3 biomass effects would have little influence on harvest decisions because timber harvests on public lands are set by the relevant government regulating body (Forest Service, Bureau of Land Management, etc). INF: The FASOMGHG model includes 349 million acres of private, managed forests. The USFS estimates that there are approximately 751 million forest acres in the U.S., but only a small portion of this public land is logged for timber.
L. Forest adaptation to O_3	FASOMGHG modeling does not reflect changes in tree species mixes within a forest type made by natural adaptation and adaptive management by landowners due to O_3. Less sensitive tree species may gain relative advantage over more sensitive species.	Unknown	Low	Low	KB: The O_3 ISA finds that the evidence is sufficient to conclude that O_3 causes changes in community composition favoring O_3 tolerant species over sensitive species. The KBs for natural adaptation and adaptive management are different, and the relative dominance of one over the other would differ depending on the degree of active management. INF: Over time, the O_3 impacts on forests may be reduced as forests adapt to O_3 environments through forest management or natural processes.
M. International trade projections in FASOMGHG	FASOMGHG reflects future international trade projections by USDA based on recent O_3 conditions. Soybeans and wheat are major crop exports and have relatively large responses to O_3, which are not reflected in the trade projections.	Both	Medium	Medium	KB: Although FASOMGHG includes international trade for major commodities, the international trade projections do not reflect the potential for increased exports associated with increased yield from reduced O_3 exposure. The world trade quantities data in the model have been updated to reflect more recent trade data for specific commodities in the literature since the original data from the USDA SWOPSIM model (Roningen, 1986). INF: Increased exports could increase producer surplus but the impacts on consumer surplus are unclear.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
N. Estimates of tree basal area used to assess larger scale ecosystem effects	Estimates of basal area were modeled by the FHTET at a scale of 240 m^2. These values were aggregated to the 144 (12x12) km^2 CMAQ grid.	Unknown	Low-Medium	Low	KB: USDA's FHTET has been actively working to refine their models to estimate basal area for individual tree species and total basal area nationwide. INF: The effect on risk estimates would vary between ecosystems, depending on community composition, total basal area and the ecosystem services being affected. Due to the overall large number of CMAQ cells included for each species, the overall estimates presented here would likely be small.

6.10 KEY OBSERVATIONS

Relative Biomass Loss:

- We compared seedling RBL to results from several studies with mature trees with mixed results. The studies indicate that overall the seedling biomass loss values are much more consistent with the adult loss at lower W126 index values.

- The Constable and Taylor (1997) study implies that for the eastern subspecies of Ponderosa Pine, the seedling RBL rate could possibly overestimate the adult RBL rate.

- The Weinstein et al. (2001) study indicates that the seedling RBL estimates are comparable to the adult estimates, except at higher W126 index values for Tulip Poplar. The Black Cherry results are an exception, which tells us that this species is much less sensitive as an adult than as a seedling.

- Another study (Samuelson and Edwards, 1993) on Red Oak found the exact opposite pattern -- adult trees are much more sensitive to O_3-related biomass loss than seedlings.

- Overall, the western tree species have more fragmented habitats than the eastern species. The areas in southern California have the highest W126 index values. The eastern tree species had less fragmented ranges and areas of elevated RBL that were more easily attributed to urban areas (e.g. Atlanta, GA and Charlotte, NC) or to the Tennessee Valley Authority Region.

Commercial Timber Effects:

- At the existing standard of 75 ppb the highest yield loss occurs in upland hardwood forests in the South Central and Southeast regions at over 3 percent per year. The next highest yield losses occur in Corn Belt hardwoods with just over 2 percent loss per year and in hard- and softwoods of the Rocky Mountain region at an average loss across all sensitive forests of slightly over 1 percent loss per year. With the exception of the Rocky Mountain region, yield losses do not appreciably change when meeting the 15 ppm-hrs alternative incremental to meeting the existing standard. Yield gains associated with meeting alternative W126 standards are relatively small on a percentage change basis, especially in the 15 ppm-hrs scenario where the highest change is 0.35 percent per year.

- Consumer and producer welfare in the forest sector are more affected by meeting alternative W126 standards incremental to meeting the existing standard than the agricultural sector. In general, consumer welfare increases in both the forest and agricultural sectors as higher productivity tends to increase total production and reduce market prices. Because demand for most forestry and agricultural commodities is inelastic, producer welfare tends to decline with higher productivity as the effect of falling prices on profits more than outweighs the effects of higher production levels.

Climate Regulation:

- For national-scale carbon sequestration, much greater changes in carbon sequestration are projected in the forest sector than in the agricultural sector. The 15 ppm-hrs scenario does not appreciably increase carbon storage relative to just meeting the existing standard. The vast majority of the enhanced carbon sequestration potential under the scenarios is from increased forest biomass due to the yield increases accruing to forests over time at the 11 and 7 ppm-hrs alternative W126 standards. The forest carbon sequestration potential would increase between 593 and 1,602 million tons of CO_2 equivalents over 30 years after meeting the 11 or 7 ppm-hrs W126 standard level, respectively.

- For the urban case study areas, estimates suggest that in the five modeled areas relative to recent conditions, at the existing standard or at an alternative W126 standard level of 15 ppm-hrs about 3.5 million tons of carbon storage will be lost over 25 years (about 140,000 tons/year). At an alternative W126 standard level of 11 ppm-hrs, loss of carbon sequestration is approximately 128,000 metric tons per year, and meeting an alternative W126 standard of 7 ppm-hrs results in the loss of 112,000 metric tons per year of carbon storage services.

- Of the five areas modeled, the combined urban areas of Tennessee have the largest estimated gains in carbon storage at almost 20,000 tons per year when meeting an alternative W126 standard of 7 ppm-hrs relative to the existing standard.

Urban Case Study Air Pollution Removal:

- Estimates from i-Tree indicate that at the existing standard about 1,535 tons of air pollution removal capacity is lost annually in the five areas modeled. Syracuse and Baltimore have no change in pollution removal when meeting the existing standard and the modeled alternatives. Atlanta and Chicago gain about 470 and 6,500 metric tons of additional pollution removal when meeting the 7 ppm-hrs W126 alternative standard compared to the existing standard, while Tennessee gains almost 12,000 tons of potential pollution removal annually for this scenario. Under the 7 ppm-hrs scenario, about 51 percent of the pollution removal capacity lost under the existing standard is regained.

Agriculture:

- Among the major crops, winter wheat and soybeans are more sensitive to ambient O_3 levels than corn and sorghum. California, the Northeast, and the Rocky Mountain regions generally have the highest yield losses.

- For winter wheat, the highest loss occurs in California at 15 percent. In the Northeast, the losses range from 7.65 percent in Maryland to 3.69 percent in Pennsylvania, with 6.43 percent in Delaware and 6.55 percent in New Jersey. In the Rocky Mountain region, the losses in Utah are 7.26 percent. When the W126 scenarios are modeled, the yield losses are almost eliminated at all values of W126.

- For soybeans, the highest loss occurs in Maryland at 8.3 percent. In the Northeast, the losses range from 8.3 percent in Maryland to 5.38 percent in Pennsylvania, with 7.65 percent in Delaware and 7.76 percent in New Jersey. In the Corn Belt the highest loss occurs in southern Indiana at 5.1 percent. In the Rocky Mountain region, the losses in Colorado are 6.73 percent. Yield losses remain under all scenarios for W126, although for the 7 ppm-hrs scenario all losses are less than 0.6 percent.

- For corn, the highest loss occurs in California at 0.88 percent. In the Northeast, the losses range from 0.68 percent in Maryland to 0.26 percent in Pennsylvania, with 0.56 percent in Delaware and 0.48 percent in New Jersey. In the Corn Belt, Lake States, and Great Plains the highest loss occurs in southern Ohio at 0.34 percent. And in the Rocky Mountain region, the losses range from 0.67 percent in Utah to 0.42 percent in Nevada, with 0.45 percent in Colorado. When the W126 scenarios are modeled, the yield losses are virtually eliminated at all values of W126 and subsequent yield gains are almost nonexistent.

- In general, increased yield leads to increased supply and lower prices. Because corn does not lose or gain very much under any scenario prices are likely to remain relatively stable. Soybeans, however, would experience yield gains in any scenario and prices would likely fall. In response to falling soybean prices, the model predicts that producers would switch to less O_3-sensitive crops with stable prices, such as corn, thereby increasing corn production.

- For producers, the W126 alternatives results in welfare gains in the middle years, 2020-2030, and welfare losses in all other years. For consumers, however, the changes in production and prices results in welfare gains in all scenarios in all years.

7 VISIBLE FOLIAR INJURY

7.1 INTRODUCTION

Visible foliar injury resulting from exposure to ozone (O_3) has been well characterized and documented over several decades on many tree, shrub, herbaceous, and crop species (U.S. EPA, 2013, 2006, 1996, 1984, 1978). Visible foliar injury symptoms are considered diagnostic as they have been verified experimentally in exposure-response studies using exposure methodologies such as continuous stirred-tank reactors (CSTRs), open-top chambers (OTCs), and free-air fumigation (see Section 9.2 of the O_3 ISA for more detail on exposure methodologies). Although the majority of O_3-induced visible foliar injury occurrence has been observed on seedlings and small plants, many studies have reported visible injury of mature coniferous trees, primarily in the western U.S. (Arbaugh et al., 1998), and of mature deciduous trees in eastern North America (Schaub et al., 2005; Vollenweider et al., 2003; Chappelka et al., 1999a; Chappelka et al., 1999b; Somers et al., 1998; Hildebrand et al., 1996).

The ecosystem services most likely to be affected by O_3-induced foliar injury are aesthetic value and outdoor recreation. Aesthetic value and recreation services depend on the perceived scenic beauty of the environment. Studies of Americans' perception of scenic beauty are quite consistent (Ribe, 1994) in their findings -- people tend to have a reliable set of preferences for forest and vegetation with fewer damaged or dead trees and plants. Aesthetic value not related to recreation includes the scenic value of vistas observed as people go about their daily lives and the scenic value of the views of open space near and around homes. 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 (OIF, 2012; NPS, 2002a, 2002b, 2002c). Figure 7-1 illustrates the relationship between foliar injury and ecosystem services as discussed in this chapter.

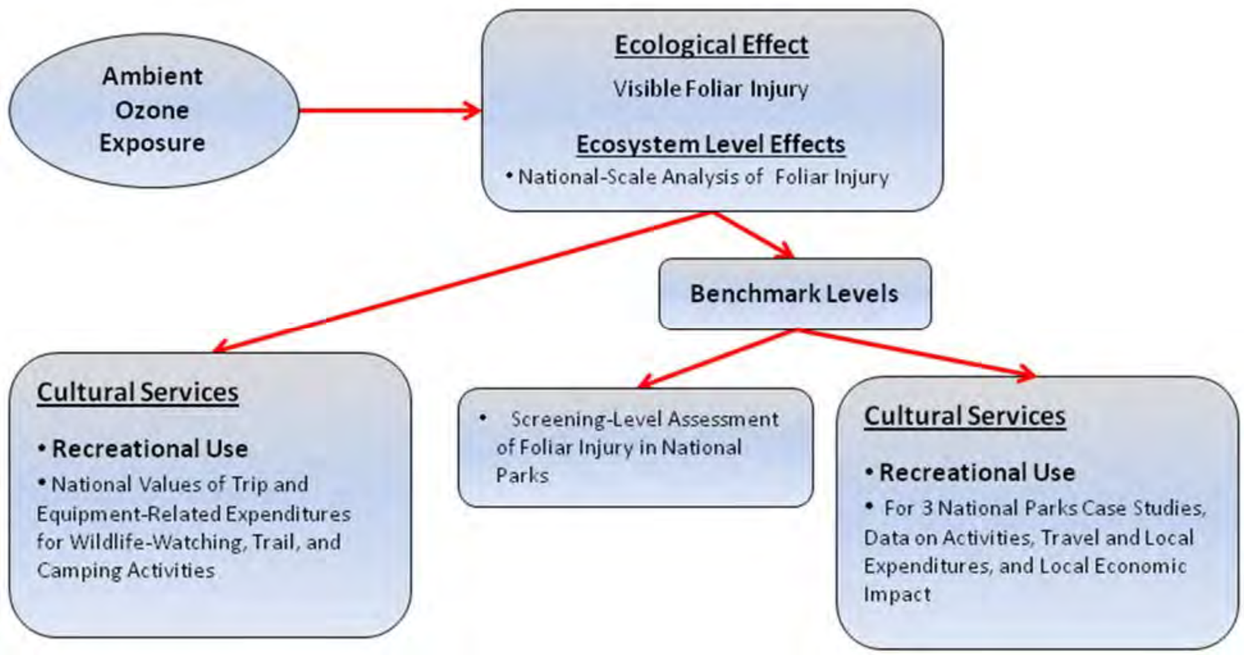

Figure 7-1 Relationship between Visible Foliar Injury and Ecosystem Services

The significance of O_3 injury at the leaf and whole-plant levels depends on how much of the total leaf area of the plant has been affected, as well as the plant's age, size, developmental stage, and degree of functional redundancy among the existing leaf area. Previous O_3 Air Quality Criteria Documents (AQCDs) and the O_3 Integrated Science Assessment (O_3 ISA) for have noted the difficulty in relating visible foliar injury symptoms to other vegetation effects such as individual plant growth, stand growth, or ecosystem characteristics (U.S. EPA, 2013, 2006, 1996). As a result, it is not currently possible to determine, with consistency across species and environments, what degree of injury at the leaf level has significance to the vigor of the whole plant. However, in some cases, visible foliar symptoms have been correlated with decreased vegetative growth (Somers et al., 1998; Karnosky et al., 1996; Peterson et al., 1987; Benoit et al., 1982) and with impaired reproductive function (Chappelka, 2002; Black et al., 2000). Conversely, the lack of visible injury does not always indicate a lack of phytotoxic effects from O_3 or a lack of non-visible O_3 effects (Gregg et al., 2006).

The National Park Service (NPS) published a list of trees and plants considered sensitive because they exhibit foliar injury at or near ambient concentrations in fumigation chambers or they have been observed to exhibit symptoms in the field by more than one observer. This list includes many species not included in Table 6-10, such as various milkweed species, asters, coneflowers, huckleberry, evening primrose, Tree-of-heaven, redbud, blackberry, willow, and many others. Many of these species are important for non-timber forest products, recreation, and aesthetic value among other ecosystem services.

Based on the NPS sensitive species list (NPS, 2003), data from the Forest Health Technology Enterprise Team of the U.S. Forest Service (described in Chapter 6, Section 6.2.1.3) were available for 15 tree species. Figure 7-2 illustrates the percent of total basal area that is accounted for by these 15 species, which include Ponderosa Pine, Loblolly Pine, Virginia Pine, Red Alder, Tulip Poplar, Aspen, Black Cherry, Jack Pine, Table Mountain Pine, Pitch Pine, White Ash, Green Ash, Sweetgum, California Black Oak, and Sassafrass.

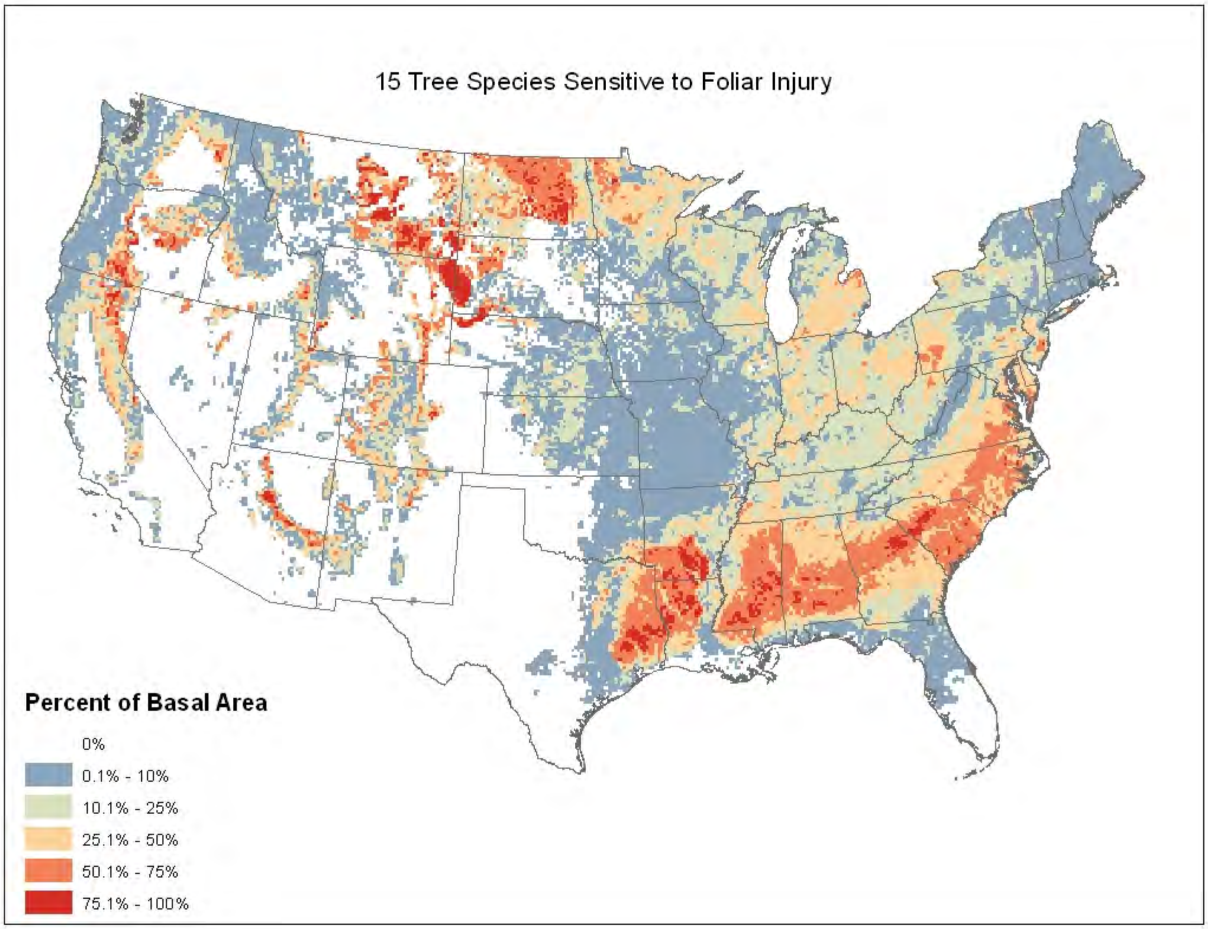

Figure 7-2 Tree Species Sensitive to Foliar Injury

Table 7-1 summarizes the overall cover of the 15 tree species and the percent of area in each cover category that exceeds varying W126 index values. It is important to note that there are additional tree species that are known to be sensitive for which cover data were not available, and there are many non-tree species listed in the NPS report that are not addressed in this analysis.

Table 7-1 Percent of Cover Category Exceeding W126 Index Values

Cover Category (percent of total basal area accounted for by the 15 species included)	National Distribution	Percent of Cover Category Area Exceeding W126 Index Values		
		> 7 ppm-hrs	>10 ppm-hrs	> 15 ppm-hrs
None Present	34.5%	85.0%	71.1%	31.4%
Less than 10%	26.0%	65.4%	39.7%	9.4%
10% to 25%	17.0%	73.4%	52.7%	13.9%
25% to 50%	12.8%	79.3%	60.9%	20.7%
50% to 75%	7.9%	83.6%	57.2%	15.7%
Greater than 75%	1.8%	82.4%	41.6%	9.5%

In addition to direct impacts on foliar injury, O_3 exposure contributes to trees' susceptibility to insect infestation (Grulke et al., 2009, U.S. EPA, 2006). These infestations can affect scenic beauty and the services associated with the perceived beauty of the environment. Foliar injury and insect attack can occur separately or in conjunction with one another and are briefly discussed together in the next section of this chapter, Section 7.1.1, on ecosystem services impacts. The remainder of this chapter provides details on the analyses we conducted and includes Section 7.2 – National-Scale Analysis of Foliar Injury; Section 7.3 –Screening-level Assessment of Visible Foliar Injury in National Parks; and Section 7.4 – National Park Case Study Areas, including Great Smoky Mountains National Park, Rocky Mountain National Park, and Sequoia and Kings Canyon National Parks. The national park case studies include discussions of the potential value of the ecosystem services affected by foliar injury resulting from O_3 exposure.

7.1.1 Ecosystem Services

7.1.1.1 Aesthetic Value

Aesthetic value services not related to recreation include the view of the landscape from houses, as individuals commute, and as individuals go about their daily routine in a nearby community. Studies find that scenic landscapes are capitalized into the price of housing and also document the existence of housing price premiums associated with proximity to forest and open space (Acharya and Bennett, 2001; Geoghegan, Wainger, and Bockstael, 1997; Irwin, 2002; Mansfield et al., 2005; Smith et al., 2002; Tyrvainen and Miettinen, 2000). In addition, according to Butler (2008), approximately 65 percent of private forest owners rate providing scenic beauty as either a very important or important reason for their ownership of forest land.

These aesthetic value services are at risk of impairment because of O_3-induced damage: directly due to foliar injury, and indirectly due to increased susceptibility to insect attack. Data are not available to explicitly quantify these negative effects; however, the damage is included in the price premium mentioned. In other words, without such damage, the associated price premium for scenic beauty that is incorporated into housing prices is likely higher.

7.1.1.2 Recreation

With few exceptions, publicly owned forests are open for some form of recreation. Based on the analysis done for the USDA National Report on Sustainable Forests (USDA, 2011), almost all of the 751 million acres of forest lands in the U.S. are at least partially managed for recreation. Of these 751 million acres, 44 percent are publicly owned (federal, state, or local). Scenic quality has been found to be strongly correlated to recreation potential and the likelihood of visiting recreation settings, and the correlations apply to both active and passive recreational pursuits (Ribe, 1994). According to Ribe (1994), differences in scenic beauty account for 90 percent of the variation in participant satisfaction across all recreation types.

Americans enjoy a wide variety of outdoor pursuits many of which are subject to negative impacts resulting from O_3 exposure, especially the effects on foliage, insect susceptibility, habitat, and community composition. The effects related to scenic beauty (foliar injury and insect damage) affect not only the scenery viewing, but also satisfaction with other scenery-dependent activities. Ninety-seven percent of National Survey on Recreation and the Environment (NSRE) survey respondents rated scenic beauty as an important or extremely important aspect of their wilderness experience.

Perceptions of scenic beauty depend on a number of forest attributes, including the appearance of forest health, the effects of air pollution and insect damage, visual variety, species variety, and lush ground cover (Ribe, 1989). The O_3 ISA concludes that there is a causal relationship between O_3 exposure and visible foliar injury. Figure 7-3 shows the effects of foliar injury on ponderosa pine, milkweed, and tulip poplar.

The presence of downed wood, whether caused by O_3 mortality, insect attack, or other causes, has a negative impact on scenic beauty assessments (Ribe, 1989; Buyhoff, et al., 1982). Figure 7-4 shows the effects of southern bark beetle damage. Species composition of forests may also influence preferences. According to Ribe (1994) these preferences may be affected by cultural, regional, or contextual expectations, which would include the expectation of the presence of certain species in specific areas (e.g., the presence of ponderosa pine in California). In addition, there is a positive effect on preferences for ground cover rather than bare or disturbed soil (Brown and Daniel, 1984, 1986). Thus, the reduced value of scenic beauty from O_3-induced effects on sensitive plants, by way of foliar injury, extends beyond large trees to the grasses, forbs, ferns, and shrubs that comprise the understory of a forest setting.

In Peterson et al. (1987), where O_3-exposure had resulted in foliar injury to ponderosa pines in the San Bernardino Forest, survey participants were asked to: (1) rank preferences for scenic views, (2) rate their recreation experiences, (3) state how decreases in tree quality would affect their visitation, and (4) specify whether they would be willing to pay for programs to mitigate the damage. This survey showed that visible foliar injury had a negative impact on perceptions of scenic beauty and a nonzero value for willingness to pay for programs to improve forest aesthetics damaged by O_3.

Figure 7-3 Examples of Foliar Injury from O_3 Exposure
Courtesy: NPS, Air Resources Division

Figure 7-4 Examples of Southern Bark Beetle Damage
Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

The NSRE provides estimates of participation for many recreation activities. According to the survey some of the most popular outdoor activities are walking, including day hiking and backpacking; camping; bird watching; wildlife watching; and nature viewing. Participant satisfaction with these activities depends wholly or partially on the quality of the natural scenery. Table 7-2 summarizes the survey results, for these and other popular activities, including the percent participation and the number of participants nationally, the number of days participants engage in recreation activities annually, and their willingness-to-pay (WTP) for their participation.

Table 7-2 National Outdoor Activity Participation

Activity	Percent Participation	Number of Participants (in millions)	Number of Activity Days (in millions)	Mean WTP/Day (in 2010$)	Mean Total Participation Value (in millions of 2010$)
Day Hiking	32.4	69.1	2,508	$60.63	$152,060
Backpacking	10.4	22.2	224.0	$13.33	$2,986
Picnicking	54.9	116.9	935.2	$20.70	$19,359
Camping (Developed and Primitive Sites)	42.3	90.1	757.5	$19.98	$15,135
Visit a Wilderness Area	32.0	68.2	975.4	N/A	N/A
Birdwatching / Photography	31.8	67.7	5,828.1	$49.74	$289,773
Wildlife Watching / Photography	44.2	94.2	3,616.5	$48.72	$176,196
Natural Vegetation Viewing / Photography	43.9	93.6	5,720.8	N/A	N/A
Natural Scenery Viewing / Photography	59.6	126.9	7,119.7	N/A	N/A
Sightseeing	50.8	108.2	2,055.0	$45.94	$94,407
Gathering (Mushrooms, Berries, Firewood)	28.6	60.9	852.7	N/A	N/A

Source: NSRE 2010 and 2003 National Report on Sustainable Forest Management. 2003 National Report: Documentation for Indicators 35, 36, 37, 42, and 43 available at: http://warnell.forestry.uga.edu/nrrt/NSRE/MontrealIndDoc.PDF and Recreation Values Database available at: http://recvaluation.forestry.oregonstate.edu/
N/A = not available

The relationship between scenic beauty and recreation satisfaction for camping was quantified by Daniel et al. (1989) in a contingent valuation study. The authors surveyed campers regarding their perceptions of scenic beauty, as indicated by a photo array of scenes along a spectrum of scenic beauty, and their WTP to camp in certain areas. All else being equal, scenic beauty and WTP demonstrated a nearly perfect linear relationship (correlation coefficient of 0.96). This suggests that campers would likely have a greater WTP for recreation experiences in areas where scenic beauty is less damaged by O_3. Since as mentioned previously, Ribe (1994) found that scenic beauty plays a strong role in recreation satisfaction and explains 90 percent of the difference in recreation satisfaction among all types of outdoor recreation, there is reason to believe that this linear relationship between scenic beauty and WTP would hold across all recreation types. We believe that it would follow that decreases in O_3 damage would generate benefits to all recreators. We cannot estimate the incremental impact of reducing O_3 damage to scenic beauty and subsequent recreation demand; however, given the large number of outdoor recreation participants and their substantial WTP for recreation, even very small increments of change in WTP or activity days should generate significant benefit to these recreators.

Another resource for estimating the economic value of consumers' recreation experiences is the data available on actual expenditures for recreation and the total economic impact of recreation activities. Economic impacts across the national economy can be estimated using the IMPLAN® model (MIG Inc, 1999).[1] For this document we refer to analyses done for the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (FHWAR) (U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, 2011) and an analysis performed by Southwick and Associates for the Outdoor Industry Foundation (OIF), The Economic Contribution of Active Outdoor Recreation – Technical Report on Methods and Findings (OIF, 2012).

The FHWAR and the OIF report provide estimates of trip and equipment-related annual expenditures for wildlife watching activities in the U.S. The OIF report also provides estimates of recreators' annual expenditures on trail-related activities, camping, bicycling, snow-related sports, and paddle sports. For this review, we include the data on trail-related activities and camping as the most relevant for analysis of O_3-related damages.

As shown in Table 7-3, the total expenditures across wildlife watching activities, trail-based activities, and camp-based activities are approximately $230 billion dollars annually. While we cannot estimate the magnitude of the impacts of O_3 damage to the scenic beauty, the losses are reflected in the values reported.

[1] IMPLAN® is a commercially available input-output model that has been used by the Department of Interior, the National Park Service, and other government agencies in their analyses of economic impacts.

Table 7-3 National Expenditures for Wildlife Watching, Trail, and Camp-Related Recreation (in billions of 2010$)

Expenditure Type	Wildlife-Watching[a]	Trail[b]	Camp[b]	Total[b]
Trip-Related	$16.7	$53.7	$109.3	$179.7
Equipment & Services	$26.3	$6.3	$8.3	$40.9
Other Expenditures	$10.2	N/R	N/R	$10.2
Total for All Expenditures				**$230.8**

[a] Data from 2011 FHWAR
[b] Data from 2012 OIF report
N/R = not reported

The impact of these expenditures has a multiplier effect through the economy, which was estimated by OIF using the IMPLAN® model.[2] The model estimates the flow of goods and money through the economy at scales from local to national. According to the OIF report (2012), trail activities generated over $190 billion in total economic activity, including $97 billion in salaries, and wages. The same report estimates the total economic activity generated by camping-related recreation at $346 billion, including $175 billion in salaries, and wages. The total economic activity estimates also include state and federal tax revenues.

7.2 NATIONAL-SCALE ANALYSIS OF FOLIAR INJURY

To assess foliar injury at a national scale, we compared data from the Forest Health Monitoring Network (USFS, 2011) with O_3 exposure estimates for individual years, described in Section 4.3.1.2, and soil moisture data, which was estimated using NOAA's Palmer Z drought index (NCDC, 2012b).

7.2.1 Forest Health Monitoring Network

The only national-scale data set pertaining to foliar injury is from the USDA Forest Service's (USFS) Ozone Biomonitoring Program (OBP). This effort was completed as part of the Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) programs (see Figure 7-5 for the locations of the O_3 biomonitoring sampling sites, or "biosites"). A biosite is a plot of land on which data was collected regarding the incidence and severity of visible foliar

[2] *Assumptions and Caveats to the IMPLAN® Results:* Statistics on the precision of the final economic impacts were not produced by OIF because of feasibility issues. Harris Interactive survey results combine several parameters from the data, and outside data from the U.S. Bureau of the Census' population estimates and IMPLAN multipliers were used.

injury on a variety of O_3-sensitive plant species. The OBP used a number of bioindicator species (O_3-sensitive plants) to monitor the potential impacts of O_3 on our nation's forests. The field methods, sampling procedures, and analytical techniques were consistent across sites and between years (USFS, 2011).

We obtained data on foliar injury from the USFS for the five years from 2006 to 2010. Because of privacy laws that require the exact location information of biosites to not be made public, the data were assigned to the CMAQ grid used for the O_3 exposure surface by the USFS (USFS, 2013). Data were not available for California, Oregon, and Washington, so we used the publically available data. In those states we assigned the data to the CMAQ grid based on the publically available geographic coordinates, which are masked for privacy concerns as mentioned above; the data in those states have additional uncertainty relating the O_3 and Palmer Z drought index data to the foliar injury data. Also, because sampling was discontinued in some states prior to this analysis, we did not include data for most of the western states (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, Oklahoma, and portions of Texas).

The "biosite index" is a measure of the severity of O_3-induced visible foliar injury observed at each biosite. The biosite index is calculated from a combination of the proportion of leaves affected on individual bioindicator plants. In order to calculate the biosite index, at least 30 individual plants of two bioindicator species must be present at each biosite. The mean severity of symptoms ranges from a score of zero to a score of 100 (USFS, 2011), with a score greater zero indicating the presence of foliar injury.

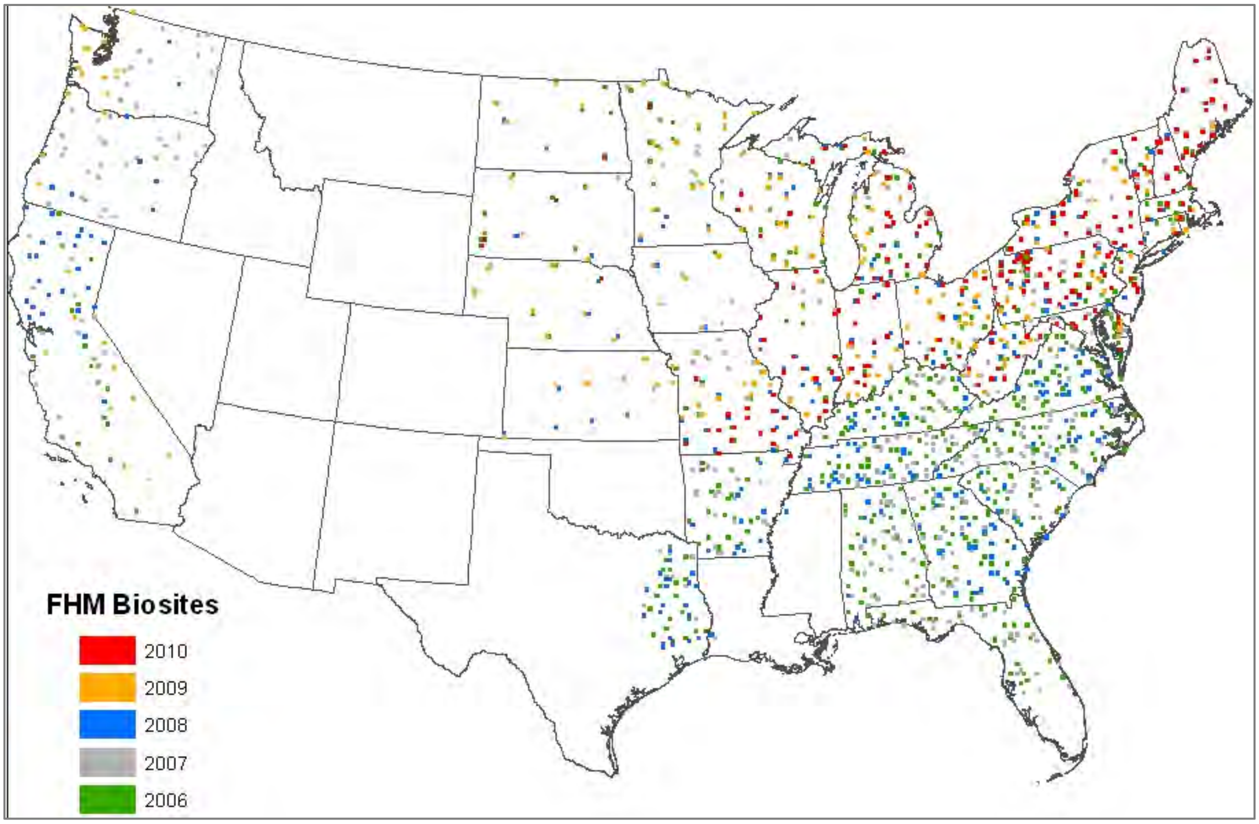

Figure 7-5 O_3 Biomonitoring Sampling Sites ("Biosites")
Note: Sites are shown as the CMAQ grid cell in which they occur. Some biosites were sampled in more than one year, but are indicated on this figure only as the most recent year sampled.

7.2.2 NOAA Palmer Z Drought Index

The Palmer Z drought index represents the difference between monthly soil moisture and long-term average soil moisture (Palmer, 1965). These data typically range from -4 to +4, with positive values representing more wetness than normal and negative values representing more dryness than normal. Values between -1.25 and +1.0 could be interpreted as normal soil moisture, whereas values beyond the range from -2.75 to +3.5 could be interpreted as extreme drought and extremely moist, respectively (NCDC, 2012c).

The soil moisture index is calculated for each of the 344 climate regions divisions within the contiguous U.S. defined by the National Climatic Data Center (NCDC) (NOAA, 2012a). Because we did not have soil moisture data outside of the continental contiguous U.S., we did not evaluate parks in Alaska, Hawaii, Puerto Rico, or Guam. We identify the NCDC climate divisions with Palmer Z data in Figure 7-6.

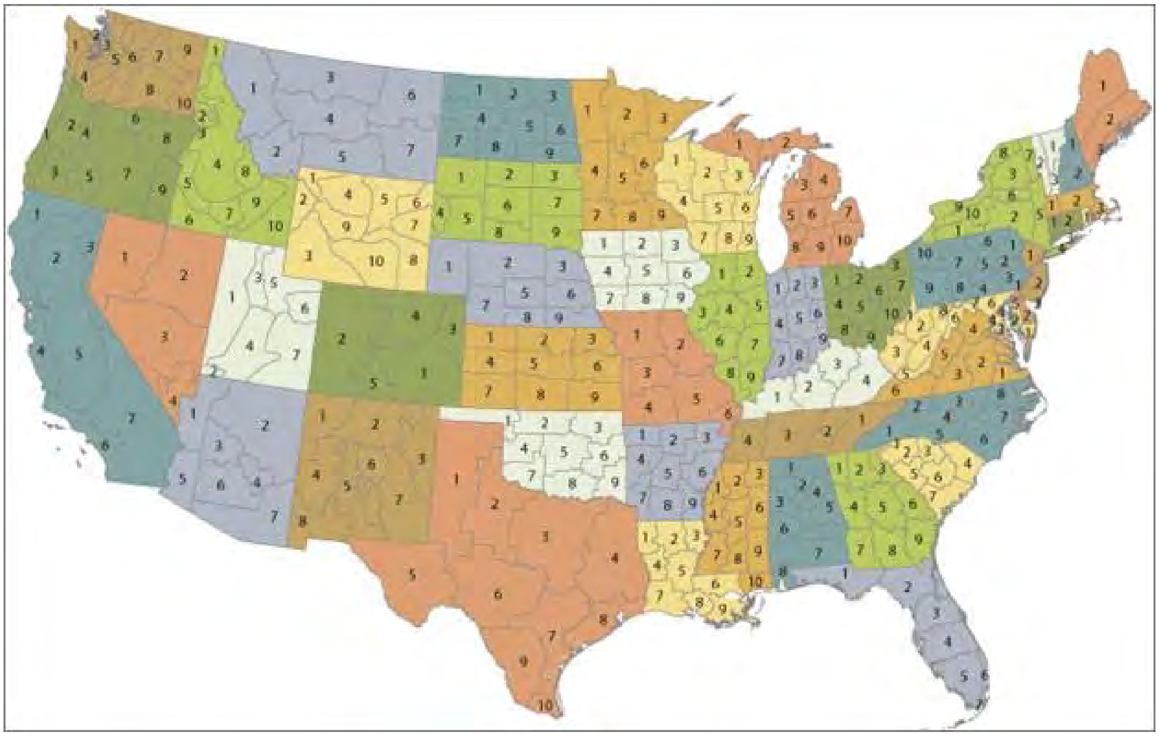

Figure 7-6 344 Climate Divisions with Palmer Z Soil Moisture Data
Source: NCDC, 2012a

7.2.3 Results of National-Scale Analysis

Data were available for a total of 5,284 biosites across the five years from 2006 – 2010 (Table 7-4, Figure 7-5). Table 7-4 summarizes the biosite index values for each year. The categories used in Table 7-4 follow the USFS risk categories with the exception of including a separate category for a biosite index of zero. We defined and use the zero category as a measure of the presence or absence of foliar injury, without relying on potentially subjective categorization of the biosite index values. We included the data to highlight that across all of the sites, over 81 percent of the observations recorded no foliar injury. This percentage was similar across all of the years, with a low value of 78 percent and a high value of 85 percent. The data showed no clear relationship between O_3 and biosite index (Figure 7-7), as well as no clear relationship between O_3 and the Palmer Z drought index (measured as an average value of the months from April to August (Figure 7-8)).

Table 7-4 Summary of Biosite Index Values for 2006 to 2010 O_3 Biomonitoring Sites
Categories modified from USFS (Smith et al., 2008)

Biosite Index	Damage	2006	2007	2008	2009	2010	Total
0	None	744	769	796	902	1,075	4,286
< 5	Very Light	139	131	98	135	183	686
5 to 15	Light	41	29	29	61	65	225
15 to 25	Moderate	15	6	8	6	12	47
≥ 25	Heavy	12	4	4	8	12	40
	Total	**951**	**939**	**935**	**1,112**	**1,347**	**5,284**

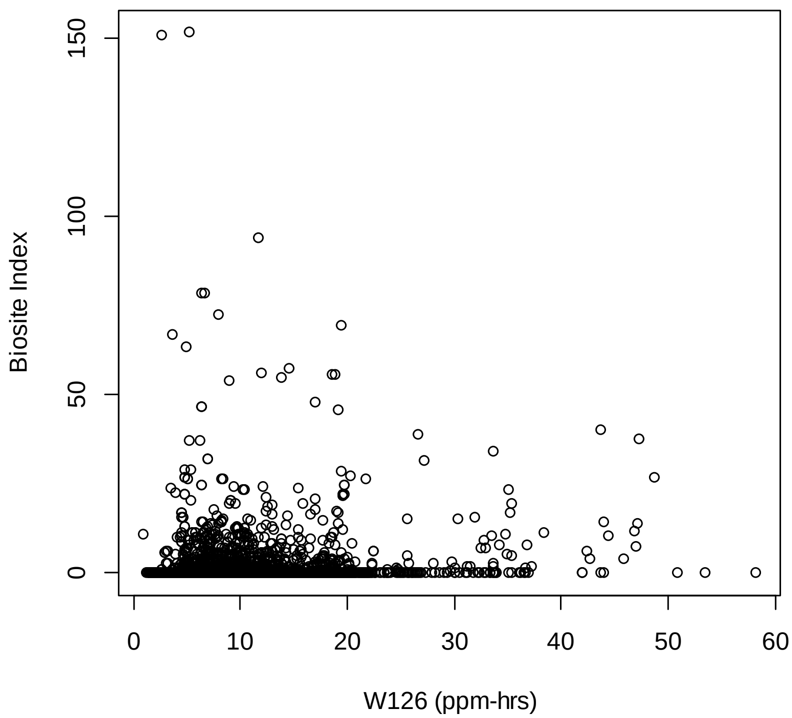

Figure 7-7 General Relationship of O_3 (ppm-hrs) and Biosite Index

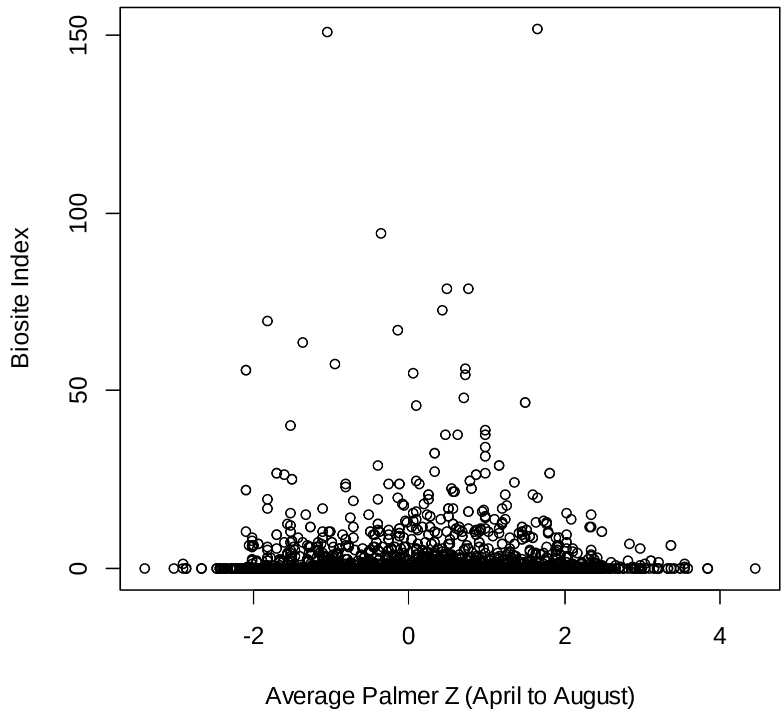

Figure 7-8 General Relationship of Average Palmer Z (April to August) and Biosite Index

The lack of a clear relationship is partly due to the high number of observations with no foliar injury (Table 7-4), which may in part be due to differing spatial resolutions of the O_3 exposure surface, NCDC climate divisions, and the biosites. Because of the high percentage of zero values, we use a censored regression to account for the non-injury observations and focus on the sites where injury was observed.[3]

The results of the regression (Table 7-5) support what is known about foliar injury (O_3 ISA Section 9.4.2), which is that there is a significant relationship between foliar injury and both O_3 and moisture (as measured by Palmer Z), and there is also a significant interaction between O_3 and moisture. The censored regression does not provide a "goodness of fit" statistic as easily interpreted as the r-squared value associated with a standard regression, so the results are more difficult to interpret. We used the regression coefficients to calculate estimated biosite index values, but when we compared those to observed values this did not provide a good estimate, again in part due to the large number of non-injury observations (data not included).

[3] A censored regression is used in cases where the variable of interest is only observable under certain conditions.

Table 7-5 Censored Regression Results

Coefficient	Intercept Estimate	Std. Error	t-value	p
Intercept	-22.5967	0.8934	-25.293	< 0.0001
W126	0.7307	0.0613	11.919	<0.0001
Palmer Z (Apr-Aug)	1.8357	0.4850	3.785	0.0002
W126: Palmer Z	0.1357	0.0437	3.104	0.0019
	Marginal Effect			
W126	0.1178	0.0099	11.918	<0.0001
Palmer Z (Apr-Aug)	0.2960	0.0777	3.812	0.0001
W126: Palmer Z	0.0219	0.0070	3.093	0.0020

To further assess the relationship between O_3 and foliar injury, we conducted a cumulative analysis (Figure 7-9 through Figure 7-11). In these analyses, we ordered the data by W126 index value, then for each W126 index value we calculated the proportion of sites exceeding the selected biosite index value for all observations at or below that W126 index value. In this analysis, we split the data into individual years, as well as into moisture categories; the moisture categories followed NOAA's Palmer Z drought index, with values less than -1.25 considered dry, values greater than or equal to 1 considered wet, and values between those considered normal.

When looking only at presence/absence of foliar injury ("any injury") (Figure 7-9), with the exception of 2008, the proportion of sites across all W126 index values exceeds 15 percent; in 2006, it exceeds 20 percent, while in 2008 the proportion of sites with foliar injury across all W126 index values was just below 15 percent.

There are two important observations that can be made in these analyses: (1) the proportion of sites exhibiting foliar injury rises rapidly at increasing W126 index values below 10 ppm-hrs, and (2) there is relatively little change in the proportions above W126 index values of 20 ppm-hrs.

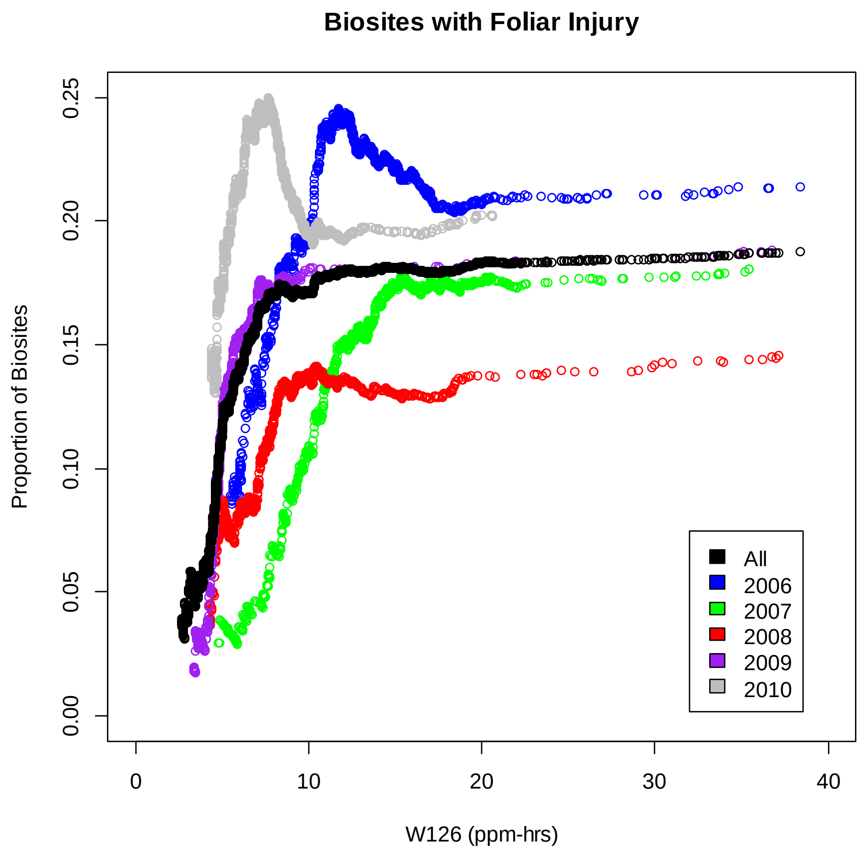

Figure 7-9 Cumulative Proportion of Sites with Foliar Injury Present, by Year

When categorized by moisture categories, as defined by the average Palmer Z drought index, the data show a more distinct pattern. Similar to the analysis by individual years, the most rapid increase in the proportion occurs at W126 index values below 10 ppm-hrs, but the moisture category has a much greater effect on the overall proportion (Figure 7-10). In addition, there is relatively little change in the proportion beyond a W126 of 20 ppm-hrs in normal and dry years.

The data for normal moisture sites are very similar to the dataset as a whole, with an overall proportion of close to 18 percent for presence/absence. Sites classified as wet (average Palmer Z $\geq$ 1) have much higher overall proportions at any injury and a much more rapid increase in proportion of sites with foliar injury present, exceeding 20 percent at W126 index values under 5 ppm-hrs. At sites considered dry (average Palmer Z < -1.25), the overall proportions are much lower, around 10 percent for presence/absence of foliar injury. This indicates that drought does provide protection from foliar injury as discussed in the O_3 ISA (U.S. EPA, 2013), but not entirely.

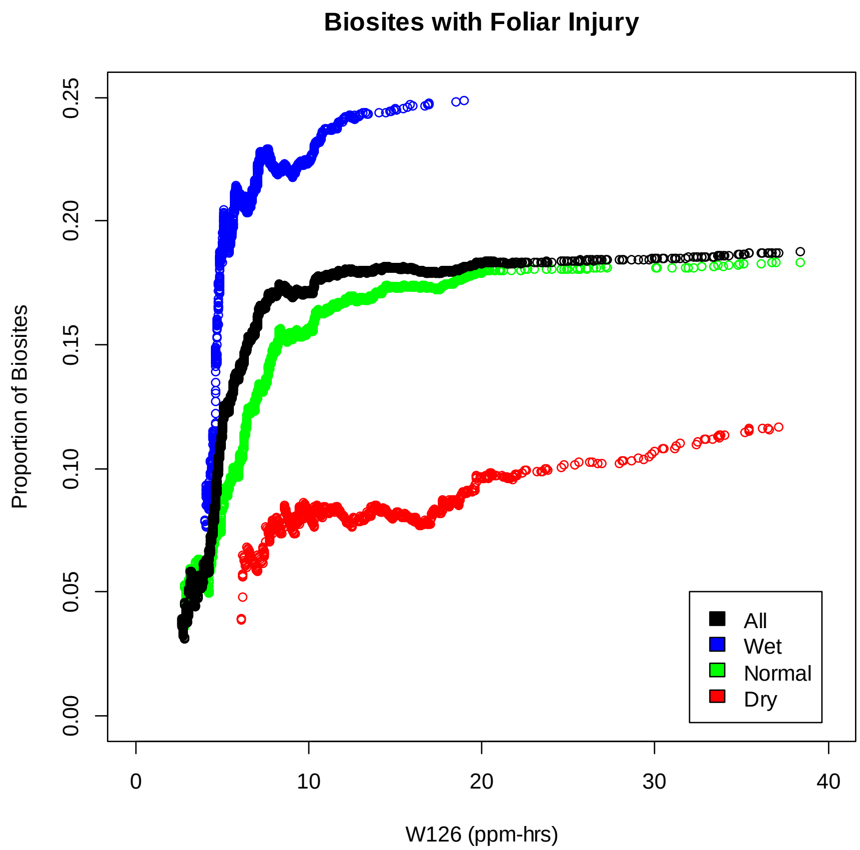

Figure 7-10 Cumulative Proportion of Sites with Foliar Injury Present, by Moisture Category

In Figure 7-11, we provide the data separated by NOAA climate regions (Karl and Koss, 1984). Although we had data for most regions of the contiguous U.S., we did not have data for the Southwest and limited data for the West and West North Central regions. For example, from 2006 to 2010, there were over 1,000 biosite index values each for the Northeast and Central regions and no biosite index values for the Southwest. When viewed by region, the pattern observed nationally is not as clear. This is possibly due to the relationship between O_3 and moisture, which can vary between regions.

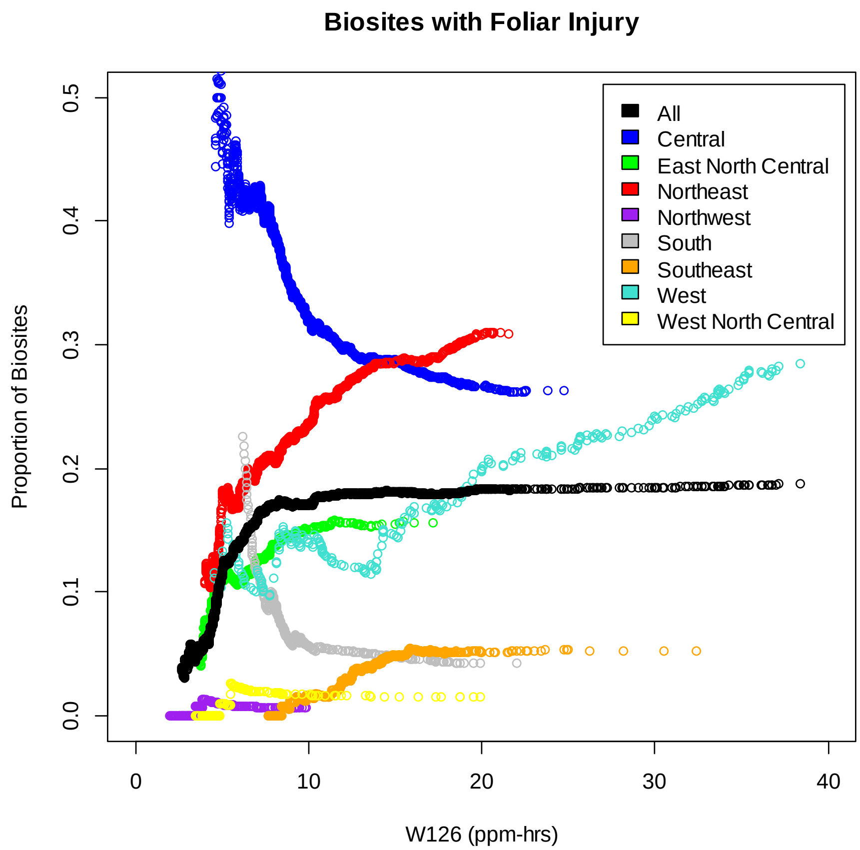

Figure 7-11 Cumulative Proportion of Sites with Foliar Injury Present, by Climate Region

7.3 SCREENING-LEVEL ASSESSMENT OF VISIBLE FOLIAR INJURY IN 214 NATIONAL PARKS

In order to assess the potential for foliar injury risk in national parks, we considered the approach in Kohut (2007). This study assessed the risk of O_3-induced visible foliar injury on O_3 bioindicators (i.e., O_3-sensitive vegetation) in 244 parks managed by the NPS. Specifically, Kohut (2007) estimated O_3 exposure using hourly O_3 monitoring data collected at 35 parks from 1995 to 1999, estimated O_3 exposure at 209 additional parks using kriging (a spatial interpolation technique), and qualitatively assessed risk. Kohut applied a subjective evaluation based on three criteria: (1) the frequency of exceedance of foliar injury "thresholds"[4] using several O_3 exposure metrics (i.e., SUM06, W126 and N100), (2) the extent that low soil moisture constrains O_3

[4] Kohut (2007) uses the term "foliar injury thresholds". In this assessment, we use the term "benchmarks" in order to avoid implying that foliar injury could not occur below these levels.

uptake during periods of high exposure, and (3) the presence of O_3 sensitive species within each park. Based on these criteria, Kohut (2007) concluded that the risk of visible foliar injury was high in 65 parks (27 percent), moderate in 46 parks (19 percent), and low in 131 parks (54 percent).[5]

In this assessment, we applied a modified screening-level approach using more recent O_3 exposure and soil moisture data for 214 parks in the contiguous U.S.[6] Consistent with advice from CASAC (Frey and Samet, 2012a), we modified the approach used by Kohut (2007) to apply the W126 metric alone, and in doing so we chose foliar injury benchmarks derived from the FHM analysis described in section 7.2 that assesses soil moisture quantitatively.[7]

7.3.1 Screening-Level Assessment Methods

7.3.1.1 O_3 Exposure

As described in Section 4.3.3, we used recent O_3 monitoring data (2006-2010) to create spatial surfaces of O_3 exposure using the Voronoi Neighbor Averaging (VNA) interpolation method, which covers the contiguous U.S. with a spatial resolution of 12 km by 12 km for each of the five years. This method allowed us to assess parks in the contiguous U.S., including parks without O_3 monitors located within their park boundaries. We provide the W126 index values estimated for each park by year in Appendix 7A.

7.3.1.2 Soil Moisture

As described in section 9.4.2 of the O_3 ISA (U.S. EPA, 2013), soil moisture is a major modifying factor for O_3-induced visible foliar injury. Low soil moisture generally decreases stomatal conductance of plants and, therefore, limits the amount of O_3 entering the leaf that can

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[5] Kohut (2007) assigned a risk rating of "high" to parks likely to experience foliar injury in most years (e.g., in at least three of the five years evaluated), a rating of "moderate" to parks likely to experience injury at some point (e.g., in one or two of the five years evaluated), and a rating of "low" to parks not likely to experience injury (e.g., no years of the five years evaluated).

[6] We did not include all of the 244 parks managed by NPS that were assessed in Kohut. Most of the excluded parks are outside of the contiguous U.S., and a few others were not identified in the shapefile of park boundaries. The parks assessed here include lands managed by the NPS in the continental U.S., which includes National Parks, Monuments, Seashores, Scenic Rivers, Historic Parks, Battlefields, Reservations, Recreation Areas, Memorials, Parkways, Military Parks, Preserves, and Scenic Trails.

[7] We applied different foliar injury benchmarks in this assessment after further investigation into the benchmarks applied in Kohut (2007), which were derived from biomass loss rather than visible foliar injury. Kohut cited a threshold of 5.9 ppm-hrs for highly sensitive species from Lefohn (1997), which was based on the lowest W126 estimate corresponding to a 10% growth loss for black cherry. For soil moisture, Kohut (2007) qualitatively assessed whether there appeared to be an inverse relationship between soil moisture and high O_3 exposure.

cause injury. Dry periods tend to decrease the incidence and severity of foliar injury. However, injury could still occur because plants must open their stomata even during these dry periods. We are unaware of a clear threshold for soil moisture below which visible foliar injury would not occur. To incorporate short-term soil moisture into the screening-level assessment, we applied Palmer Z data for 2006 to 2010 (NCDC, 2012b). Consistent with the FHM analysis in Section 7.2, we categorized soil moisture as wet, normal, and dry (NOAA, 2012c). These data are for the contiguous U.S. only.

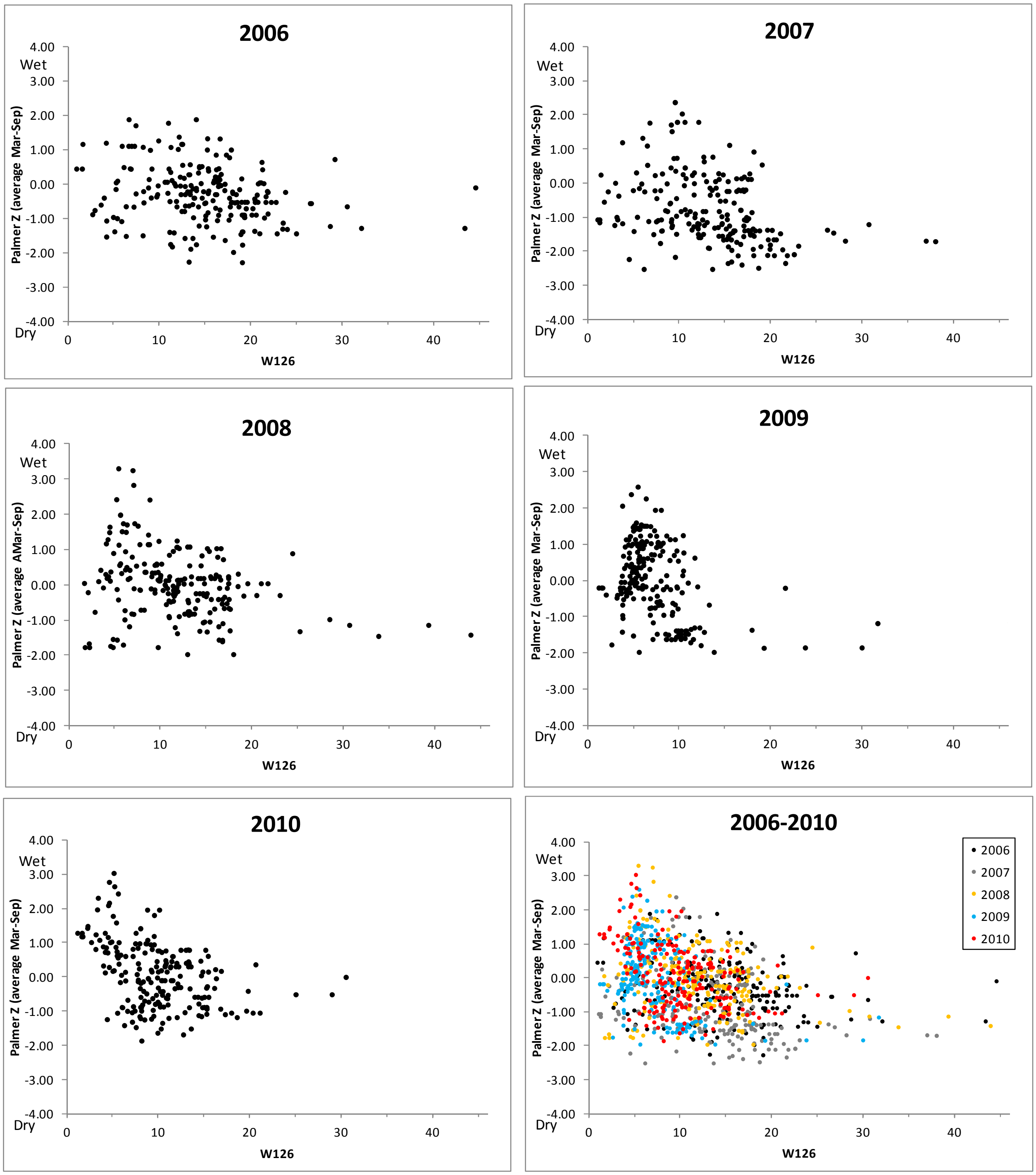
Short-term estimates of soil moisture are highly variable over time, even from month to month within a single year. For this reason, we used an average estimate of soil moisture to reflect the cumulative nature of foliar injury in each park in each year. To determine the appropriate timeframe for the soil moisture average, we identified the months corresponding to the highest W126 index value estimated for each park with an O_3 monitor. The highest 3-month W126 index value for 98 percent of monitored parks occurred between March and September across all years, which roughly corresponds to the growing season (see Figure 7A-8 in the appendix). Only 70 percent of monitored parks had the highest W126 between April and August. Based on this information, we applied the 7-month soil moisture average from March to September for each year in the core screening-level assessment for all parks. For parks with O_3 monitors, we also conducted sensitivity analyses applying the 5-month soil moisture average from April to August and the 3-month soil moisture average corresponding to the specific 3-months with the highest W126 estimate at that monitor (see results in section 7.3.3.2 and underlying data in Table 7A-1 in the appendix). We also evaluated the variability in soil moisture averages across the 7-month, 5-month, and 3-month average timeframes by year for each monitored park (see Figures 7A-9 through 7A-11 in the appendix).

7.3.1.3 GIS Analysis

Using GIS (ESRI® ArcMAP™ 10), we spatially overlaid the interpolated O_3 exposure surfaces and soil moisture data (NCDC, 2012b) with the NPS boundaries (USGS, 2003) to link these data to each park. First, we dissolved all of the internal boundaries for each park such that each park only had one park boundary. Next, we spatially joined the soil moisture data and the gridded W126 data with the park boundaries, creating an average soil moisture estimate and W126 index value estimated for each park. To identify the parks with O_3 monitors, we spatially overlaid the O_3 monitor data with the NPS park boundaries and included only those monitors located within the park boundaries.[8] We excluded all parks outside of the contiguous U.S. because of the absence of soil moisture data, resulting in 42 parks with O_3 monitors and 214 parks with O_3 exposure estimated from the interpolated W126 surface.[9] In Figure 7-12 we provide the distribution of O_3 exposure and average soil moisture estimates for the 214 parks for each year in this assessment, noting the range of “near normal” soil moisture conditions as defined by NCDC (NOAA, 2012c).

[8] There are 57 O_3 monitors located within NPS parks, and an additional 7 monitors are located within 1km of the park boundaries. Some monitors (e.g., at Rocky Mountain National Park) have addresses that imply locations within park boundaries but are actually located just outside the NPS boundary. We did not include the monitors located just outside of the parks in the monitored park assessment. In addition, nine parks contained more than one O_3 monitor. We provide the O_3 exposure and soil moisture data for the 57 monitors located within NPS parks in Appendix 7A.

[9] Along coastlines, the shapefile for soil moisture is more generalized than the shapefile for O_3 exposure. Therefore, we manually linked the soil moisture data to (a) 8 seashore parks in order to include them in the 214 park assessment and (b) 4 park monitors for the 42 park assessment.



(Shaded area represents "near normal" soil moisture (-1.25 > Palmer Z > 1)

Figure 7-12 Distribution of O_3 and Soil Moisture in 214 Parks by Year

7.3.1.4 Sensitive Vegetation Species

NPS (2003) defines a sensitive species as “species that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one expert observer.” According to NPS (2003), the lists of sensitive species is limited in number of species because few species from natural ecosystems have been fumigated in chambers or examined in the field for O_3 symptoms.

We identified the parks containing O_3-sensitive vegetation species (NPS, 2003, 2006b) and considered the results for parks without species as *potential* until species are identified in future field surveys at these parks. In addition, we conducted a sensitivity analysis where parks without sensitive species are assumed to not exceed the benchmark criteria (see results in section 7.3.3.2). Based on the NPS lists, 95 percent of the parks in this assessment contain at least one sensitive species. (See Figure 7A-7 and Table 7A-3 in the appendix for the parks with and without currently identified sensitive species.)

7.3.1.5 W126 Benchmarks for Visible Foliar Injury

For each park, we evaluated whether O_3 exposure exceeded certain foliar injury benchmark criteria in each year between 2006 and 2010. Specifically, we derived W126 benchmarks for five scenarios from the national-scale foliar injury analysis using FHM data described in section 7.2. These benchmarks do not indicate thresholds below which no foliar injury would be expected to occur. Rather, these benchmarks provide an indication of the risk of foliar injury based on analysis of the FHM data.

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. The “base scenario” represents the W126 index value where the slope of exposure-response relationship changes for FHM biosites. As shown in Figure 7-10, the percentage of biosites showing injury levels off at approximately 17.7 percent when considering all biosites in all soil moisture categories, and we used this point to derive the W126 benchmark (10.46 ppm-hrs) for the base scenario. At W126 index values above this benchmark, the percentage of FHM biosites showing foliar injury remains relatively constant. The other four scenarios explicitly consider soil moisture categorization, and these benchmarks represent the

W126 index values corresponding to different percentages of FHM biosites with injury present (i.e., 5 percent, 10 percent, 15 percent, and 20 percent) when the data is segregated by soil moisture category. In total, we evaluated ten different W126 benchmarks associated with the five scenarios.[10]

Table 7-6 provides the W126 benchmarks and the soil moisture categories for each of the five scenarios. In the appendix, we provide the figures showing the derivation of the W126 benchmarks for each scenario (see Figures 7A-1 through 7A-5 in the appendix).

Table 7-6 W126 Benchmarks by Relative Soil Moisture Category in Five Scenarios

Scenario	Description	W126 Benchmark (in ppm-hrs)		
		Wet (Palmer Z ≥1)	**Normal Moisture** (Palmer Z between -1.25 and 1)	**Dry** (Palmer Z < -1.25)
Base	17.7% of all FHM biosites showed any injury (higher W126 index values have a relatively constant percentage of FHM biosites showing injury)	10.46 (soil moisture not considered)		
5% of biosites	5% of FHM biosites showed any injury, reflects soil moisture categorization	3.76	3.05	6.16
10% of biosites	10% of FHM biosites showed any injury, reflects soil moisture categorization	4.42	5.94	24.61
15% of biosites	15% of FHM biosites showed any injury, reflects soil moisture categorization	4.69	8.18	N/A
20% of biosites	20% of FHM biosites showed any injury, reflects soil moisture categorization	5.65	N/A	N/A

N/A = Not available. We were unable to derive W126 benchmarks because of the limited number of biosites showing injury in these categories.

7.3.2 Screening-Level Assessment Results and Discussion

To assess the potential for foliar injury risk in each parks we evaluated the frequency that O_3 exposure exceeded certain W126 benchmarks and the average soil moisture conditions in

[10] For some scenarios, we were unable to derive W126 benchmarks for all soil moisture categories because of the limited number of biosites showing injury in those categories. For example, fewer than 15 percent of FHM biosites categorized as “dry” showed any injury (see Figure 7-10). Therefore, we do not have a W126 benchmark for “dry” for the 15 percent scenario.

each year from 2006 to 2010. As shown in Table 7-7, in this assessment of 214 parks based on the interpolated W126 surface, 11 percent of the parks exceeded the W126 benchmark in the base scenario (10.46 ppm-hrs) for all five years evaluated, 39 percent for at least four years, 58 percent for at least three years, 70 percent for at least two years, and 83 percent for at least one year. Table 7-7 also shows the results for each of the four scenarios that reflect soil moisture. In general, scenarios for higher percentages of FHM biosites showing foliar injury have fewer parks that exceed the benchmarks for those scenarios across multiple years. For example, nearly all parks exceeded the W126 benchmarks for at least three years in the 5 percent scenario, but only a few parks exceed the benchmarks for the 20 percent scenario.

As shown in Table 7-8, the number of parks exceeding the benchmarks in any given year varies by scenario because O_3 exposure and average soil moisture vary by year. For example, fewer parks exceeded the benchmarks in 2009 (a comparably dry, low O_3 year) than other years.

Figure 7-13 shows the national map of the results to highlight the geographic differences for the base scenario. We also provide the detailed results for each park, including additional figures to highlight the geographical differences in the other scenarios (see Table 7A-3 and Figures 7A-12 through 7A-23 in the appendix).

Table 7-7 Parks Exceeding W126 Benchmarks in Five Scenarios from 2006 to 2010 (Cumulative)

Scenario	Cumulative Number of Parks that Exceed Benchmarks (% of 214 parks)					
	All 5 years	At least 4 years	At least 3 years	At least 2 years	At least 1 year	No years
Base	23 (11%)	84 (39%)	124 (58%)	149 (70%)	177 (83%)	37 (17%)
5% of biosites	195 (91%)	27 (13%)	209 (98%)	209 (98%)	210 (98%)	4 (2%)
10% of biosites	58 (27%)	127 (59%)	172 (80%)	193 (90%)	204 (95%)	10 (5%)
15% of biosites	23 (11%)	98 (46%)	145 (68%)	175 (82%)	192 (90%)	22 (10%)
20% of biosites	0 (0%)	0 (0%)	4 (2%)	20 (9%)	72 (34%)	142 (66%)

Table 7-8 Parks Exceeding W126 Benchmarks in Five Scenarios in Individual Years from 2006 to 2010

Scenario	Number of Parks that Exceed Benchmarks in Each Year (% of 214 parks)				
	2006	2007	2008	2009	2010
Base	171 (80%)	147 (69%)	125 (58%)	26 (12%)	88 (41%)
5% of biosites	139 (65%)	66 (31%)	93 (43%)	15 (7%)	63 (29%)
10% of biosites	207 (97%)	205 (96%)	203 (95%)	206 (96%)	206 (96%)
15% of biosites	173 (81%)	119 (56%)	177 (83%)	114 (53%)	171 (80%)
20% of biosites	164 (77%)	103 (48%)	155 (72%)	71 (33%)	140 (65%)

Key: All 5 years 4 years 3 years 2 years 1 year No years

Figure 7-13 Foliar Injury Results Maps for the Base Scenario in 214 Parks

(Parks identified by park code. Not all park labels shown due to overlap. National Parks are prioritized in mapping. Maps for additional scenarios and park code explanations available in Appendix 7A.)

In the assessment of 42 parks with O_3 monitors based on the interpolated surface, 24 percent of parks exceeded the W126 benchmark for the base scenario for all five years, 36 percent for at least four years, 57 percent for at least three years, 69 percent for at least two years, and 81 percent for at least one year. These results are generally similar to the results for the 214 park assessment for the base scenario, except that the monitored park analysis showed a higher fraction of parks that exceeded the benchmark criteria for all five years rather than at least four years. This result may be because parks with consistently higher O_3 concentrations may be more likely to have an O_3 monitor. Table 7-9 provides the results of the monitored park assessment. We also evaluated three different methods for assigning O_3 exposure to parks with monitors: interpolated surface, highest monitor, and average monitor. The results of this sensitivity analysis are discussed in more detail in section 7.3.3.1.

Table 7-9 Screening-level Foliar Injury Results in 42 Parks with an O_3 Monitor using 3 Methods for Assigning O_3 Exposure to Each Park in Base Scenario

Park Name	State	Years with Monitoring Data (# years)	Years Exceeding W126 Benchmarks for Base Scenario (# years)			
			Interpolated Surface	Highest Monitor	Average Monitor	Only 1 Monitor in Park
Acadia National Park	ME	5	0	1	0	N/A
Agate Fossil Beds National Monument	NE	3	2	N/A	N/A	1
Badlands National Park	SD	5	1	1	0	N/A
Big Bend National Park	TX	5	1	N/A	N/A	3
Blue Ridge Parkway	NC	5	3	N/A	N/A	1
Canyonlands National Park	UT	5	5	N/A	N/A	5
Cape Cod National Seashore	MA	5	3	N/A	N/A	3
Carlsbad Caverns National Park	NC	4	1	N/A	N/A	2
City of Rocks National Reserve	ID	1	4	N/A	N/A	0
Colorado National Monument	CO	4	3	N/A	N/A	2
Congaree National Park	SC	5	3	N/A	N/A	2
Cowpens National Battlefield	SC	5	2	N/A	N/A	2
Craters of the Moon National Monument	ID	4	3	N/A	N/A	1
Cumberland Gap National Historical Park	KY	4	3	N/A	N/A	1
Death Valley National Park	CA	5	5	N/A	N/A	5
Devil's Tower National Monument	WY	3	2	N/A	N/A	0
Dinosaur National Monument	CO	4	4	N/A	N/A	2
Glacier National Park	MT	5	0	0	0	N/A
Grand Canyon National Park	AZ	5	5	N/A	N/A	4
Great Basin National Park	NV	5	5	N/A	N/A	4
Great Smoky Mountains National Park	TN	5	3	4	3	N/A
Indiana Dunes National Lakeshore	IN	5	1	N/A	N/A	1
Joshua Tree National Park	CA	5	5	5	5	N/A
Lassen Volcanic National Park	CA	5	4	N/A	N/A	3

<table>
<tr><th rowspan="2" colspan="2">Park Name</th><th rowspan="2">State</th><th rowspan="2">Years with Monitoring Data
(# years)</th><th colspan="4">Years Exceeding W126 Benchmarks for Base Scenario (# years)</th></tr>
<tr><th>Interpolated Surface</th><th>Highest Monitor</th><th>Average Monitor</th><th>Only 1 Monitor in Park</th></tr>
<tr><td colspan="2">Mesa Verde National Park</td><td>CO</td><td>5</td><td>5</td><td>N/A</td><td>N/A</td><td>5</td></tr>
<tr><td colspan="2">Mojave National Preserve</td><td>CA</td><td>4</td><td>5</td><td>N/A</td><td>N/A</td><td>4</td></tr>
<tr><td colspan="2">Mount Rainier Wilderness</td><td>WA</td><td>5</td><td>0</td><td>N/A</td><td>N/A</td><td>0</td></tr>
<tr><td colspan="2">Olympic National Park</td><td>WA</td><td>1</td><td>0</td><td>0</td><td>0</td><td>N/A</td></tr>
<tr><td colspan="2">Padre Island National Seashore</td><td>TX</td><td>2</td><td>0</td><td>N/A</td><td>N/A</td><td>0</td></tr>
<tr><td colspan="2">Petrified Forest National Park</td><td>AZ</td><td>5</td><td>4</td><td>N/A</td><td>N/A</td><td>4</td></tr>
<tr><td colspan="2">Pinnacles National Monument</td><td>CA</td><td>5</td><td>3</td><td>N/A</td><td>N/A</td><td>4</td></tr>
<tr><td colspan="2">Saguaro National Park</td><td>AZ</td><td>5</td><td>4</td><td>N/A</td><td>N/A</td><td>5</td></tr>
<tr><td colspan="2">Saratoga National Historical Park</td><td>NY</td><td>5</td><td>0</td><td>N/A</td><td>N/A</td><td>0</td></tr>
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<tr><td colspan="2">Theodore Roosevelt National Park</td><td>ND</td><td>5</td><td>0</td><td>0</td><td>0</td><td>N/A</td></tr>
<tr><td colspan="2">Tonto National Monument</td><td>AZ</td><td>5</td><td>5</td><td>N/A</td><td>N/A</td><td>5</td></tr>
<tr><td colspan="2">Voyageurs National Park</td><td>MN</td><td>5</td><td>0</td><td>N/A</td><td>N/A</td><td>0</td></tr>
<tr><td colspan="2">Wind Cave National Park</td><td>SD</td><td>5</td><td>2</td><td>N/A</td><td>N/A</td><td>2</td></tr>
<tr><td colspan="2">Yellowstone National Park</td><td>WY</td><td>5</td><td>1</td><td>N/A</td><td>N/A</td><td>2</td></tr>
<tr><td colspan="2">Yosemite National Park</td><td>CA</td><td>5</td><td>5</td><td>5</td><td>5</td><td>N/A</td></tr>
<tr><td rowspan="6">Summary Results by O_3 Exposure Method*</td><td colspan="2">All 5 years</td><td>71%</td><td>24%</td><td>19%</td><td>19%</td><td rowspan="6">N/A</td></tr>
<tr><td colspan="2">At least 4 years</td><td>86%</td><td>36%</td><td>36%</td><td>33%</td></tr>
<tr><td colspan="2">At least 3 years</td><td>93%</td><td>57%</td><td>43%</td><td>43%</td></tr>
<tr><td colspan="2">At least 2 years</td><td>95%</td><td>69%</td><td>60%</td><td>60%</td></tr>
<tr><td colspan="2">At least 1 year</td><td>100%</td><td>81%</td><td>76%</td><td>71%</td></tr>
<tr><td colspan="2">No years</td><td>0%</td><td>19%</td><td>24%</td><td>29%</td></tr>
</table>

* Summary results assume that parks with only one monitor exceeded the W126 benchmarks the same number of years using either the highest or average monitor method.
N/A = Not applicable.

7.3.3 Sensitivity Analyses for Screening-Level Assessment

7.3.3.1 O_3 Exposure

Monitoring provides the most accurate assessment of O_3 exposure in specific locations, but a single monitor may not reflect the differences in exposure throughout a park. For this reason, we compared the results of the assessment for parks with O_3 monitors located within the park boundaries using the interpolated surface with the results based on O_3 monitor data. As shown in Table 7-9, the results using the highest monitor and average monitor were generally similar to each other and to the results using the interpolated surface. For the 30 parks with all five years of monitoring data, 17 parks had the same results using all three methods, five parks had more years exceeding the benchmark for the base scenario using the interpolation, five parks had more years exceeding that benchmark using either monitor method, and three parks had more years exceeding using the highest monitor.

It can be informative to apply alternative screening criteria based on O_3 exposure alone. For this sensitivity analysis, we identified the parks that exceeded W126 index values that were consistent with the range of alternative standard levels considered in the Policy Assessment. Table 7-10 shows that 23 percent of parks exceeded 15 ppm-hrs for at least three years from 2006 to 2010, while 80 percent of parks exceeded 7 ppm-hrs for at least three years.

Because W126 index values can be highly variable from year to year, evaluation of different years could lead to different results. In Table 7-10, we provide the sensitivity of the results for the base scenario by splitting the data into two timeframes. In general, more parks had higher O_3 exposure during the first three years of the assessed timeframes (i.e., 2006-2008) than the last three years (i.e., 2008-2010).

Table 7-10 Foliar Injury Sensitivity Analyses for 214 Parks

Alternative Screening Criteria		Number of Parks Exceeding W126 Benchmark in 2006-2010 (% of 214 parks)					
		All 5 years	At least 4 years	At least 3 years	At least 2 years	At least 1 year	No years
O_3 Exposure only	W126>15	6 (3%)	20 (9%)	49 (23%)	83 (39%)	125 (58%)	89 (42%)
	W126>13	7 (3%)	44 (21%)	76 (36%)	110 (51%)	155 (72%)	59 (28%)
	W126>11	17 (8%)	71 (33%)	111 (52%)	142 (66%)	174 (81%)	40 (19%)
	W126>9	46 (21%)	117 (55%)	150 (70%)	165 (77%)	186 (87%)	28 (13%)
	W126>7	88 (41%)	156 (73%)	171 (80%)	183 (86%)	196 (92%)	18 (8%)
Timeframe	Base scenario using 2006-2008 only	N/A	N/A	117 (55%)	149 (70%)	177 (83%)	37 (17%)
	Base scenario using 2008-2010 only	N/A	N/A	23 (11%)	86 (40%)	130 (61%)	84 (39%)
Sensitive Species	Base scenario assuming park does not exceed if no sensitive species in park	22 (10%)	80 (37%)	116 (54%)	141 (66%)	168 (79%)	46 (21%)

N/A = Not applicable

7.3.3.2 Soil Moisture

Evaluating soil moisture is more subjective than evaluating O_3 exposure because of its high spatial and temporal variability within the O_3 season. Although we are unable to quantify the within-region variability in soil moisture for the relatively large NCDC climate regions, we can evaluate the sensitivity of the results to different averaging times for soil moisture data. Specifically, we compared the results using the 7-month average from the main analysis with alternative 5-month and 3-month soil moisture averages at O_3 monitors in parks. As shown in Table 7-11, the results for the 57 O_3 monitors in parks are not very sensitive to the different timeframes for soil-moisture data for the five scenarios. On balance, we believe that the impact of the variability in the spatial resolution of the data likely exceeds the impact of the temporal resolution of the data, and thus this assessment is likely to underestimate the potential of foliar injury that could occur in some localized areas such as stream banks.

Table 7-11 Soil Moisture Sensitivity Analyses in 57 O_3 Monitors in Parks*

Scenario and Soil Moisture Timeframe		Parks Exceeding Benchmark Criteria in 2006-2010 (% of 57 Parks)					
		All 5 years	At least 4 years	At least 3 years	At least 2 years	At least 1 year	No years
7-month Palmer Z (Mar-Sept)	5% of biosites	31 (54%)	42 (74%)	45 (79%)	49 (86%)	55 (96%)	2 (4%)
	10% of biosites	8 (14%)	24 (42%)	34 (60%)	43 (75%)	49 (86%)	8 (14%)
	15% of biosites	2 (4%)	15 (26%)	26 (46%)	39 (68%)	46 (81%)	11 (19%)
	20% of biosites	0 (0%)	1 (2%)	1 (2%)	7 (12%)	18 (32%)	39 (68%)
Change in Parks Exceeding Benchmark Criteria for Alternative Soil Moisture Timeframes (% of 57 Parks)							
5-month Palmer Z (Apr-Aug)	5% of biosites	-1 (-2%)	-1 (-2%)	NC	+1 (+2%)	NC	NC
	10% of biosites	-1 (-2%)	-5 (-9%)	-1 (-2%)	NC	-1 (-2%)	+1 (+2%)
	15% of biosites	NC	-5 (-9%)	-1 (-2%)	-1 (-2%)	-1 (-2%)	+1 (+2%)
	20% of biosites	NC	-1 (-2%)	NC	-3 (-5%)	+5 (+9%)	-5 (-9%)
Specific 3-Month Palmer Z (based on monitor)	5% of biosites	+2 (+4%)	NC	NC	NC	NC	NC
	10% of biosites	-2 (-4%)	-5 (-9%)	-2 (-4%)	-1 (-2%)	+1 (+2%)	-1 (-2%)
	15% of biosites	-1 (-2%)	-5 (-9%)	-4 (-7%)	-1 (-2%)	+1 (+2%)	-1 (-2%)
	20% of biosites	NC	NC	-1 (-2%)	NC	-5 (-9%)	+5 (+9%)

*Includes multiple monitors in 9 parks. The base scenario is not included in this table because this scenario does not include screening criteria for soil moisture.
NC=No change.

7.3.3.3 Evaluation of Existing Standard and Alternative W126 Standards

This screening-level assessment does not evaluate the model-adjusted W126 spatial surfaces for the scenarios of just meeting the existing 75 ppb (4th highest daily maximum) standard or alternative W126 standards. Because this screening-level assessment relies on year-by-year estimates of O_3 exposure and soil moisture, it would not be possible to evaluate these year-by-year impacts using the W126 surfaces derived from three years of model-adjusted W126 data. Nevertheless, we can make a few observations regarding the potential implications of just meeting the existing and alternative standards. For example, as shown in Table 7-10, 42 percent of parks did not exceed 15 ppm-hrs during 2006-2010 using annual W126 data. In addition, none of the 214 parks would exceed the annual benchmark criteria for the base scenario (W126>10.46 ppm-hrs) after adjustments to just meet the existing standard (adjustments based on 3-year average W126 data). Similarly, only eight parks would exceed 7 ppm-hrs using the 3-year average model-adjusted surfaces that just meet the existing standard. We provide the W126 index values for each of the 214 parks after just meeting the existing standard and alternative W126 standards in Appendix 7A.

7.4 NATIONAL PARK CASE STUDY AREAS

The national parks represent a set of resources the public has agreed are special areas in need of protection for this and future generations to experience and enjoy.[11] Because of this status risks to park resources are of special concern, particularly for bequest and option services because these services are specifically referenced in the creation of the parks. The NPS is responsible for the protection of all resources within the national park system. These resources include those that are related to and/or dependent upon good air quality, such as whole ecosystems and ecosystem components.

Several laws and policies protect the natural resources in national parks. The NPS, in its Organic Act (16 U.S.C. 1), is directed to conserve the scenery, natural and historic objects and wildlife and to provide for the enjoyment of these resources unimpaired for current and future generations. The Wilderness Act of 1964 (Public Law 88-577, 16 U.S. C. 1131-1136) asserts wilderness areas will be administered in such a manner as to leave them unimpaired and preserve them for the enjoyment of future generations. NPS Management Policies (2006) guide all NPS actions including natural resources management. In general, the NPS Management Policies reiterate the NPS Organic Act's mandate to manage the resources "unimpaired." Although we have not quantified the monetary value of the bequest or option services given the data and methodology limitations inherent in such an effort, the status afforded these special areas through these laws and policies is indicative of their value to the public.

The ecosystem service we can quantify, with some qualifications, is the recent monetary value of the total recreation opportunity provided by the parks. We cannot quantify the loss in monetary value for these services associated with O_3; however, the magnitude of the overall value is informative in understanding the potential significance of any O_3 damage (see Chapter 5 for more discussion). The NPS has collected data on visitation, recreational activities, and

[11] C.F.R. 40, 81.400 provides for visibility protection for federal Class I areas.

expenditures for trips to parks and modeled the economic impacts to local communities around parks. The NSRE provides WTP estimates for the value of recreation activities specific to the regions where parks are located. Together these data allow us to estimate the magnitude of the recreation services provided by parks. The loss of service provision or visitor satisfaction due to O_3 injury to sensitive species in the case study parks is reflected in these estimates.

The three parks we are highlighting for case study analysis, Great Smoky Mountains NP, Rocky Mountain NP, and Sequoia/Kings Canyon NP, represent different regions of the country, different ecosystems, and O_3 conditions. Each park contains species sensitive to O_3 injury. The text boxes accompanying each section highlight some of the reasons these parks were chosen for special protection.

For the case study areas, we used the O_3-sensitive species list from the preceding section and cover data from VegBank plots (see Section 7.2). The resulting maps give cover estimates for O_3-sensitive species at the finer scale of the NPS vegetation map. It is important to note that the cover estimates are separated into vegetation stratum (e.g., herb, shrub, tree) and it is possible to have more than one vegetation strata present in a location. As such, it is possible to have sensitive species cover at a higher cumulative proportion than is shown here. We also used the benchmarks presented in section 7.2 to assess the effect of just meeting the existing and alternative standards on W126 index values in the case study parks. We used a benchmark of 10 percent of biosites exhibiting foliar injury in a normal year as the basis for the analysis, which is depicted in Figure 7-14.

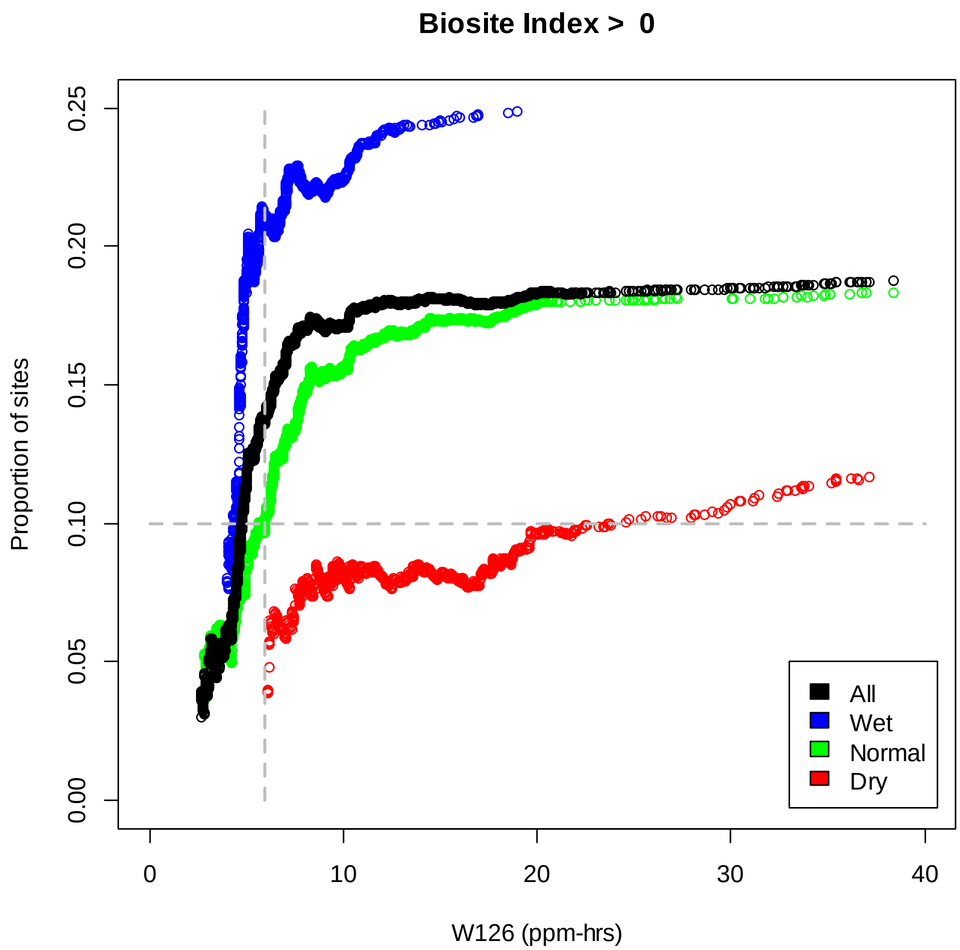

Figure 7-14 Identification of W126 Index Value where 10 Percent of Biosites Show Any Foliar Injury

7.4.1 Great Smoky Mountains National Park

In 2010, the Great Smoky Mountains National Park (GRSM) welcomed approximately 9.5 million visitors (NPS, 2010) making it the most visited national park in America.

The “whole park” services affected by potential O_3 impacts include the existence, option, and bequest values and habitat provision discussed in Chapter 5. Recreation value specific to the park is discussed later in this section.

The extent of sensitive species coverage in GRSM is substantial. Showing the percent cover of species sensitive to foliar injury and focusing the analysis on areas where recreation services are provided can provide some perspective on the potential level of harm to scenic beauty and recreation satisfaction within the Park.

The NPS 2002 Comprehensive Survey of the American Public, Southeast Region Technical Report includes responses from recent visitors to southeast parks about the activities they pursued during their visits (NPS, 2002a). Using the 2010 annual visitation rate from the NPS survey (NPS, 2010) and the regional results from the Kaval and Loomis (2003) report on recreational use values compiled for the NPS, we estimated visitors’ WTP for various activities; we present the estimates in Table 7-12. In addition to the activities listed in the table, 19 percent, or 1.8 million park visitors, benefited from educational services offered at the park by

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

Great Smoky Mountains National Park is the most visited national park in America and a UNESCO World Heritage Site. The Park is valued for the diversity of its vegetation and wildlife; the scenic beauty of its mountains, including the famous fogs that give the Smoky Mountains their name; and the preservation of the remnants of Southern Appalachian culture. It is also subject to high ambient O_3 levels. The park has recent W126 index values of 10 – 18 ppm-hrs with a mean of 14.7 ppm-hrs.

participating in a ranger-led nature tour, which suggests that visitors wish to understand the ecosystems preserved in the park.

Table 7-12 Value of Most Frequent Visitor Activities at Great Smoky Mountains National Park

Activity	Percent Participation	Number of Participants (thousands)	Mean WTP (in 2010$)	Total Value of Participation (millions of 2010$)
Sightseeing	82	7,790	53.34	416
Day Hiking	40	3,800	69.93	266
Camping	19	1,805	29.87	54
Picnicking	50	4,750	42.42	201
Total				**937**

The report *Economic Benefits to Local Communities from National Park Visitation and Payroll* (NPS, 2011) provides estimates of visitor spending and economic impacts for each park in the system. Visitor spending and its economic impact to the surrounding area are provided in Table 7-13 for the GRSM. In addition, Table 7-14 includes data on the median value that visitors spend on food, gas, lodging, and other items.

Table 7-13 Visitor Spending and Local Area Economic Impact of Great Smoky Mountains National Park

Public Use Data		Visitor Spending 2010[a]		Impacts on Non-Local Visitor Spending		
2010 Recreation Visits	2010 Overnight Stays	All Visitors	Non-Local Visitors	Jobs	Labor Income[a]	Economic Impact[a]
9,463,538	393,812	$818,195	$792,547	11,367	$303,510	$504,948

[a] ($000s)
Source: NPS (2011)

Table 7-14 Median Travel Cost for Great Smoky Mountains National Park Visitors

Expense/Visit	Median Expenditures (2010$)
Gas and Transportation	$73
Lodging	$182
Food and Drinks	$73
Clothes, Gifts, and Souvenirs	$61
Total Per Visitor Party	**$389**

Source: NPS (2002a)

Each of the activities discussed above is among those shown in the national-scale analysis to be strongly affected by visitor perceptions of scenic beauty. As discussed in Section 7.1.1.2 for visible O_3 damage (Peterson, 1987) and for visible nitrogen and adelgid damage (a pest in Fraser fir) (Haefele et al., 1991 and Holmes and Kramer, 1996) visitors have a non-zero WTP for reductions in the described scenic impairments. As in the national analysis, it is not possible to assess the extent of loss of services from impairment of scenic beauty by O_3; however, for the park these losses are captured in the estimated values for spending, economic impact, and WTP.

GRSM is prized, in part, for its rich species diversity. The large mix of species includes 37 O_3-sensitive species across vegetative strata, and many areas contain several sensitive species. For instance, there may be a sensitive tall shrub occurring under the canopy of a sensitive tree and various sensitive short shrubs or herbaceous plants occurring in the area of the tall shrub. In areas where sensitive species overlap, it is possible to have sensitive species coverage substantially higher than coverage for any one category of vegetation. Figure 7-15 shows the park coverage of various sensitive species. Nearly 40 percent of the Park's 2,185 km^2 total area has sensitive tree cover (canopy and subcanopy) greater than 20 percent. Of that, 232 km^2 has sensitive tree species cover between 20 percent and 40 percent. Shrubs account for 491 km^2 of sensitive vegetation, with over 100 km^2 having over 80 percent of the species present as sensitive. While sensitive herbaceous species occur throughout the park, the percent cover rarely exceeds 20 percent.

We can quantify the extent of the hiking trails in areas where sensitive species are at risk for foliar injury. Of the approximately 1,287 km of trails in GRSM, including approximately 114 km of the Appalachian Trail, over 1,040 km, or about 81 percent of trail area, are in areas where species sensitive to foliar injury occur. Figure 7-16 shows a summary of the overlap of the hiking trails in the GRSM, including a portion of the Appalachian Trail, with the species cover index. The accompanying pie charts in Figure 7-17 show the number of trail kilometers in each cover category. The categories likely most visible to hikers are subcanopy trees, shrubs, and herbaceous vegetation. There are 311 km, or about 24 percent, of trail area where sensitive subcanopy tree cover accounts for over 20 percent of the tree species present. Sensitive shrubs cover over 20 percent of 549 km of trail area, or about 43 percent of total area.

Although we cannot quantify the incremental loss of hiker satisfaction with their recreation experience, this analysis illustrates that very substantial numbers of trail kilometers are potentially at risk. With 3.8 million hikers using the trails every year and those hikers willing to pay over $266 million for that activity, even a small benefit of reducing O_3 damage in the park could result in a significant value.

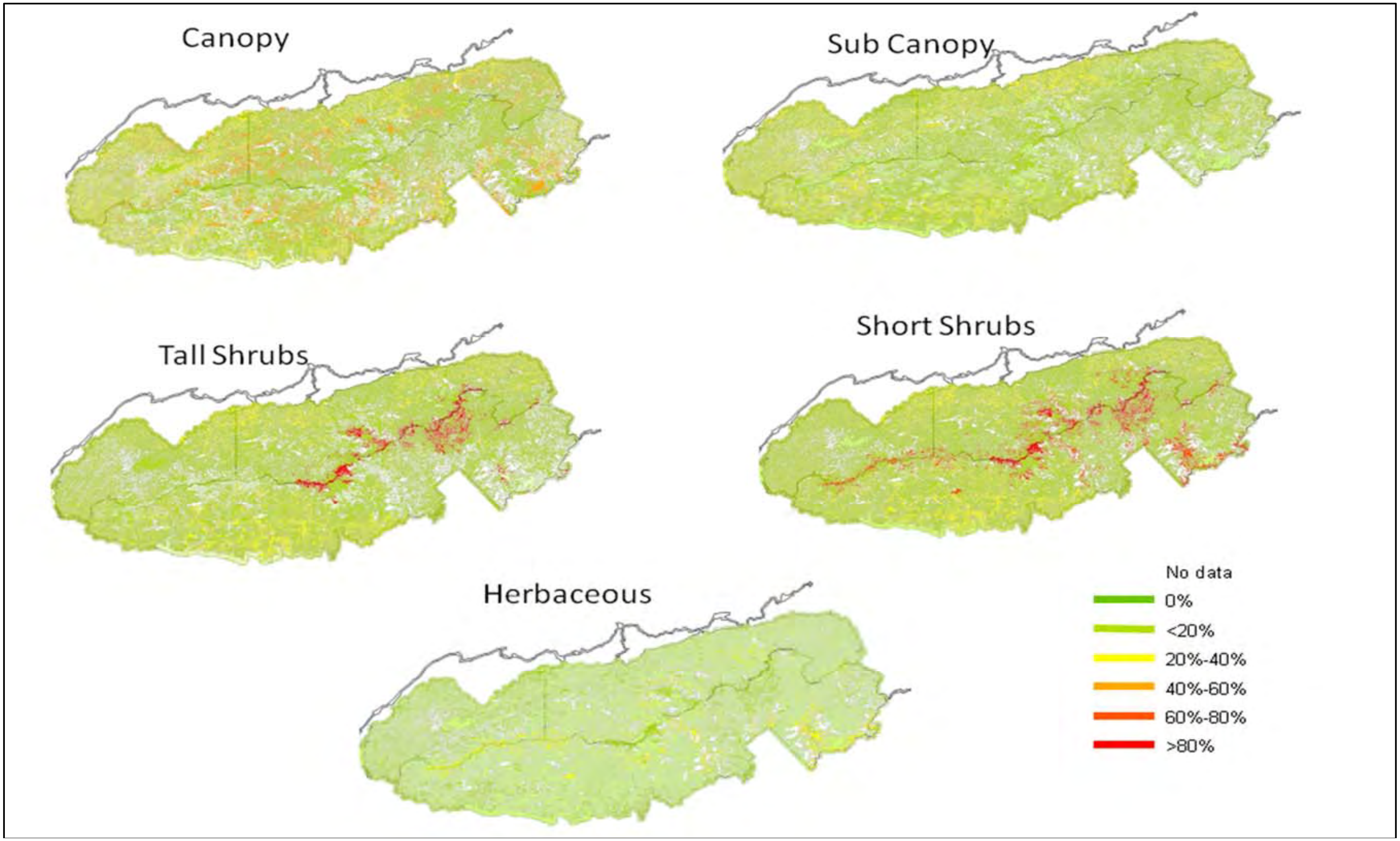

Figure 7-15 Cover of Sensitive Species in Great Smoky Mountains National Park

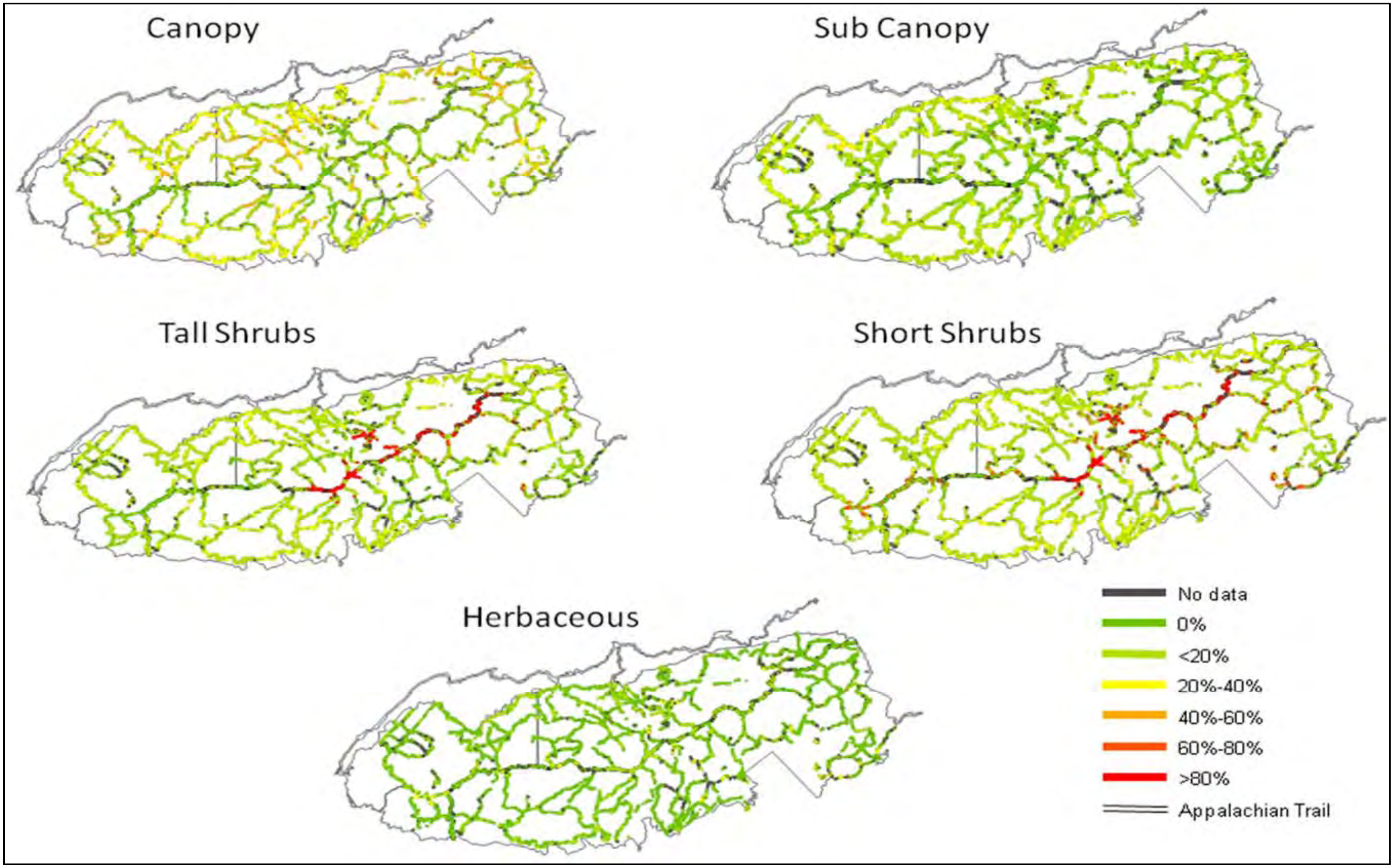

Figure 7-16 Percent of Sensitive Species Near Trails in Great Smoky Mountains National Park

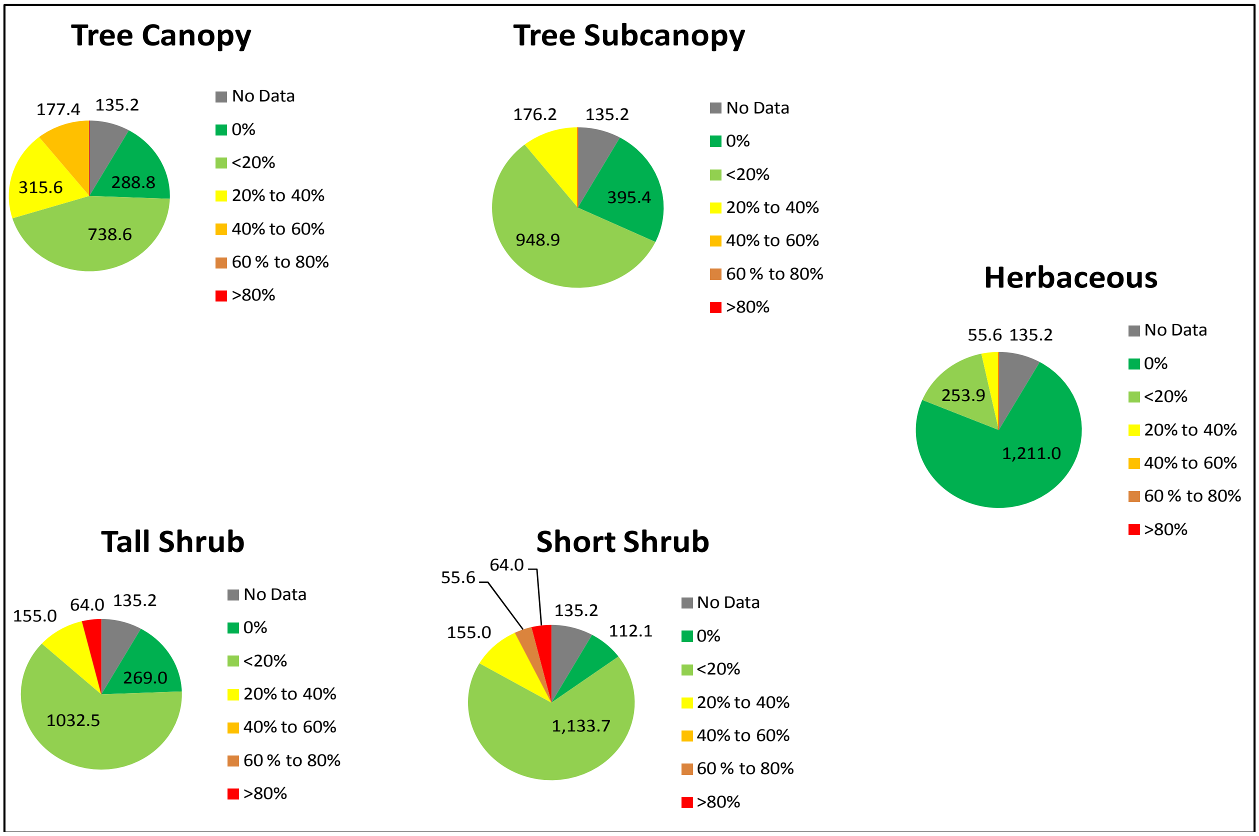

Figure 7-17 Trail Kilometers of Sensitive Species by Cover Category in Great Smoky Mountains National Park

One of the amenities provided by GRSM is the scenic views from the roads and trails -- the views from the scenic overlooks are one of the major park attractions. On a day with natural viewing conditions visitors can see about 150 km across the mountain ridges of North Carolina and Tennessee, far outside the borders of the park itself. On average viewing days visitors can still see about 40 km, again outside the park itself. Figure 7-18 shows the sensitive tree canopy cover within a 3 km buffer of the overlooks. Within these small buffers 78 km^2 have sensitive species cover over 20 percent. While there are no data on the number of visitors stopping at the overlooks, almost 8 million visitors identify sightseeing as one of their activities in the Park. With their collective WTP for this activity over $400 million, it seems reasonable to conclude that park visitors substantially value the scenic quality of the overlooks. Ozone concentrations in GRSM have been among the highest in the eastern U.S., sometimes twice as high as neighboring cities such as Atlanta and Knoxville. Under recent conditions 44 percent, or 959 km^2, of the park has W126 index values above 15 ppm-hrs. After just meeting the existing standard at 75 ppb, W126 index values are reduced such that no area is over 7 ppm-hrs. Just meeting the alternative of 15 ppm-hrs produces the same result as meeting the existing standard. The lower alternative standards of 11 and 7 ppm-hrs result in the park having W126 index values under 3 ppm-hrs for the entire park, with most of the park under 2 ppm-hrs after just meeting the 7 ppm-hrs standard level. See Table 7-15 for additional details.

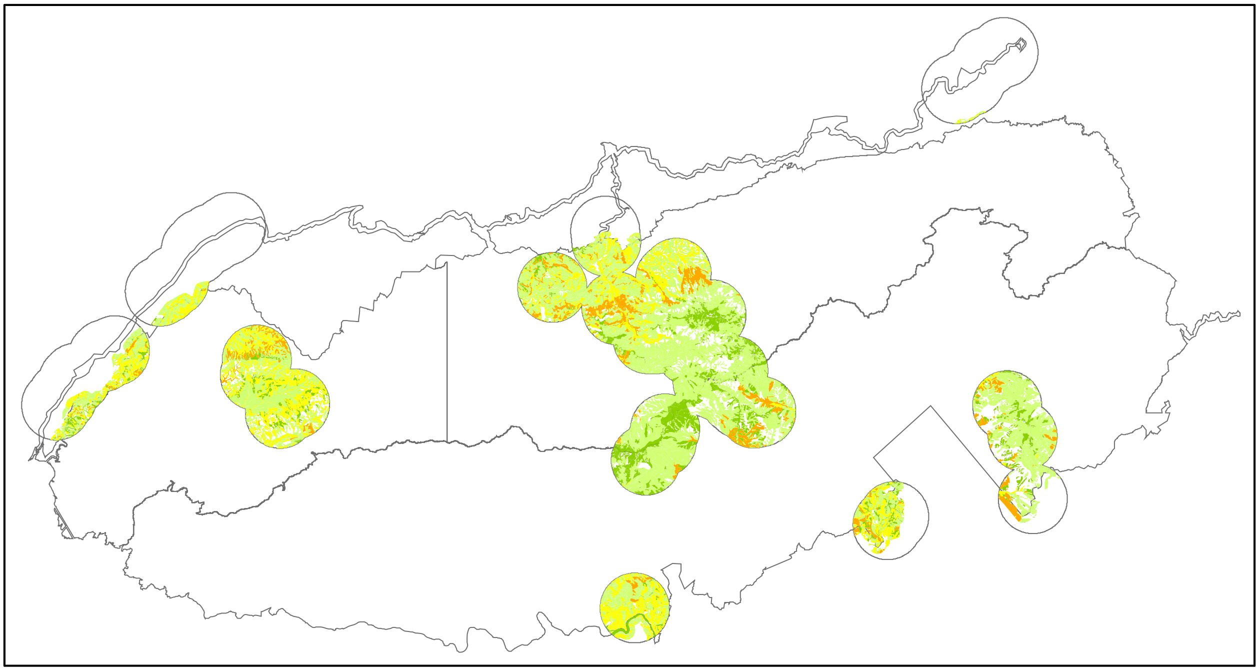

Figure 7-18 Sensitive Vegetation Cover in Great Smoky Mountains National Park Scenic Overlooks (3km)

Table 7-15 Geographic Area of Great Smoky Mountains National Park after Just Meeting Existing and Alternative Standard Levels (km^2)

	Under 5.94 ppm-hrs	Between 5.95 and 7 ppm-hrs	Between 7-11ppm-hrs	Between 11-15 ppm-hrs	Over 15 ppm-hrs
Recent conditions (2006-2008)	0	0	48	1,178	959
Just meeting 75 ppb	2,185	0	0	0	0
15 ppm-hrs	2,185	0	0	0	0
11 ppm-hrs	2,185	0	0	0	0
7 ppm-hrs	2,185	0	0	0	0

7.4.2 Rocky Mountain National Park

In 2010 Rocky Mountain National Park (ROMO) welcomed 3 million visitors (NPS, 2010) to its 1,075 km^2 of mountain ecosystems. ROMO allows visitors to enjoy vegetation and wildlife unique to these ecosystems along over 483 km of hiking trails.

The NPS 2002 Comprehensive Survey of the American Public, Intermountain Region Technical Report includes responses from recent visitors to intermountain parks about the activities they pursued during their visit (NPS, 2002b). As in the GRSM case study, using the 2010 visitation rate from the NPS survey (NPS, 2010) and the regional results from the Kaval and Loomis (2003) report on recreational use values compiled for the NPS, we present estimates for visitors' WTP for various activities in Table 7-16.

Table 7-16 Value of Most Frequent Visitor Activities at Rocky Mountain National Park

Activity	Percent Participation	Number of Participants (thousands)	Mean WTP (in 2010$)	Total Value of Participation (millions of 2010$)
Sightseeing	85	2,550	$28.17	$72
Day Hiking	51	1,520	$46.03	$70
Camping	27	810	$41.47	$34
Picnicking	38	1,140	$33.77	$38
Total				**$214**

In addition to the activities listed in Table 7-16, 11 percent of, or 330,000, park visitors took advantage of educational services offered at the park by participating in a ranger-led nature tour.

Each of the activities discussed above are among those shown in the national-scale analysis to be strongly affected by visitor perceptions of scenic beauty. As in the national analysis it is

Sheep Lakes
Courtesy: NPS
http://www.nps.gov/romo/photosmultimedia/index.htm

Rocky Mountain National Park features riparian ecosystems with 150 lakes and 450 stream miles that support lush vegetation. The montane ecosystem includes pine forests and grasslands, while subalpine elevations present spruce and fir trees weathered by the elements. The alpine ecosystems are too harsh for trees, but support low growing plants. The park has recent W126 index values of 2–54 ppm-hrs with a mean of 14.2 ppm-hrs.

not possible to assess the extent of loss of services due to impairment of scenic beauty due to O_3 damage; however those losses are captured in the estimated values for spending, economic impact, and WTP for the park. If O_3 impacts were lower these estimated values would likely be higher.

The report *Economic Benefits to Local Communities from National Park Visitation and Payroll* (NPS, 2011) provides estimates of visitor spending and economic impacts for each park in the system. Visitor spending and its economic impact to the surrounding area are given in Table 7-17 for the ROMO. Table 7-18 includes data on the median value that visitors spend on food, gas, lodging, and other items.

Table 7-17 Visitor Spending and Local Area Economic Impact of Rocky Mountain National Park

Public Use Data		Visitor Spending 2010		Impacts on Non-Local Visitor Spending		
2010 Recreation Visits	2010 Overnight Stays	All Visitors	Non-Local Visitors	Jobs	Labor Income[a]	Economic Impact[a]
2,955,821	174,202	229,032	221,896	3,316	$89,975	$ 155,157

[a]($000s)
Source: NPS (2011)

Table 7-18 Median Travel Cost for Rocky Mountain National Park Visitors

Expense/Visit	Median Expenditures (in 2010$)
Gas and Transportation	$63
Lodging	$100
Food and Drinks	$63
Clothes, Gifts, and Souvenirs	$45
Total per Visitor Party	$271

Source: NPS (2002b)

Unlike GRSM, only 7 sensitive species provide cover in ROMO as depicted in Figure 7-19. The most notable of these is Quaking Aspen, or *Populus tremuloides*. This is significant in that many of the visitors to ROMO visit specifically to see this tree in its fall foliage. In some areas of the park, cover of this species can reach 80 percent. The species is found, along with the other sensitive tree species silver wormwood and Scouler's willow, in all vegetative layers in the park. Sensitive species cover in just the tree canopy, subcanopy, and tall shrub layers is over 40 percent in 328 km^2, or 30 percent, of the park.

We were able to quantify the extent of the hiking trails present in areas where sensitive species are at risk for foliar injury. Of the approximately 562 km of trails in ROMO, including approximately 87 km of the Continental Divide National Scenic Trail, over 242 km, or about 43 percent of trail area, are in areas where species sensitive to foliar injury in the canopy, subcanopy or tall shrub category occur in greater than 20 percent coverage. Figure 7-20 maps the hiking trails in ROMO, including the relevant portion of the Continental Divide National Scenic Trail overlaid with the species cover index. The accompanying pie charts in Figure 7-21 show the number of trail km in each cover category.

Again, although we are not able to quantify the impact of this scenic damage on hiker satisfaction, given 1.5 million hikers in ROMO and their $70 million WTP for the hiking experience, even a small improvement in the scenic value could be significant. While we did not map the scenic overlooks in ROMO, given the 2.5 million visitors who come to the park to sightsee and the $72 million they are willing to pay for this activity, it is reasonable to conclude that any improvement in the scenic quality of the vistas at the overlooks would be of significant value.

Under recent conditions, all 1,067 km^2 of the park have W126 index values over 15 ppm-hrs. Meeting the existing standard would bring about 59 percent of the Park into the 7-15 ppm-hrs range, with the remaining 440 km^2 under 7 ppm-hrs. Assessing an alternative standard of 15 ppm-hrs would bring the entire park under 7 ppm-hrs. See Table 7-19 for a summary of full results.

Table 7-19 Geographic Area of Rocky Mountain National Park after Just Meeting Existing and Alternative Standard Levels (km^2)

	Under 5.94 ppm-hrs	Between 5.95-7 ppm-hrs	Between 7-11 ppm-hrs	Between 11-15 ppm-hrs	Over 15 ppm-hrs
Recent conditions (2006-2008)	0	0	0	0	1,067
Just meeting 75 ppb	37	403	627	0	0
15 ppm-hrs	986	81	0	0	0
11 ppm-hrs	1,067	0	0	0	0
7 ppm-hrs	1,067	0	0	0	0

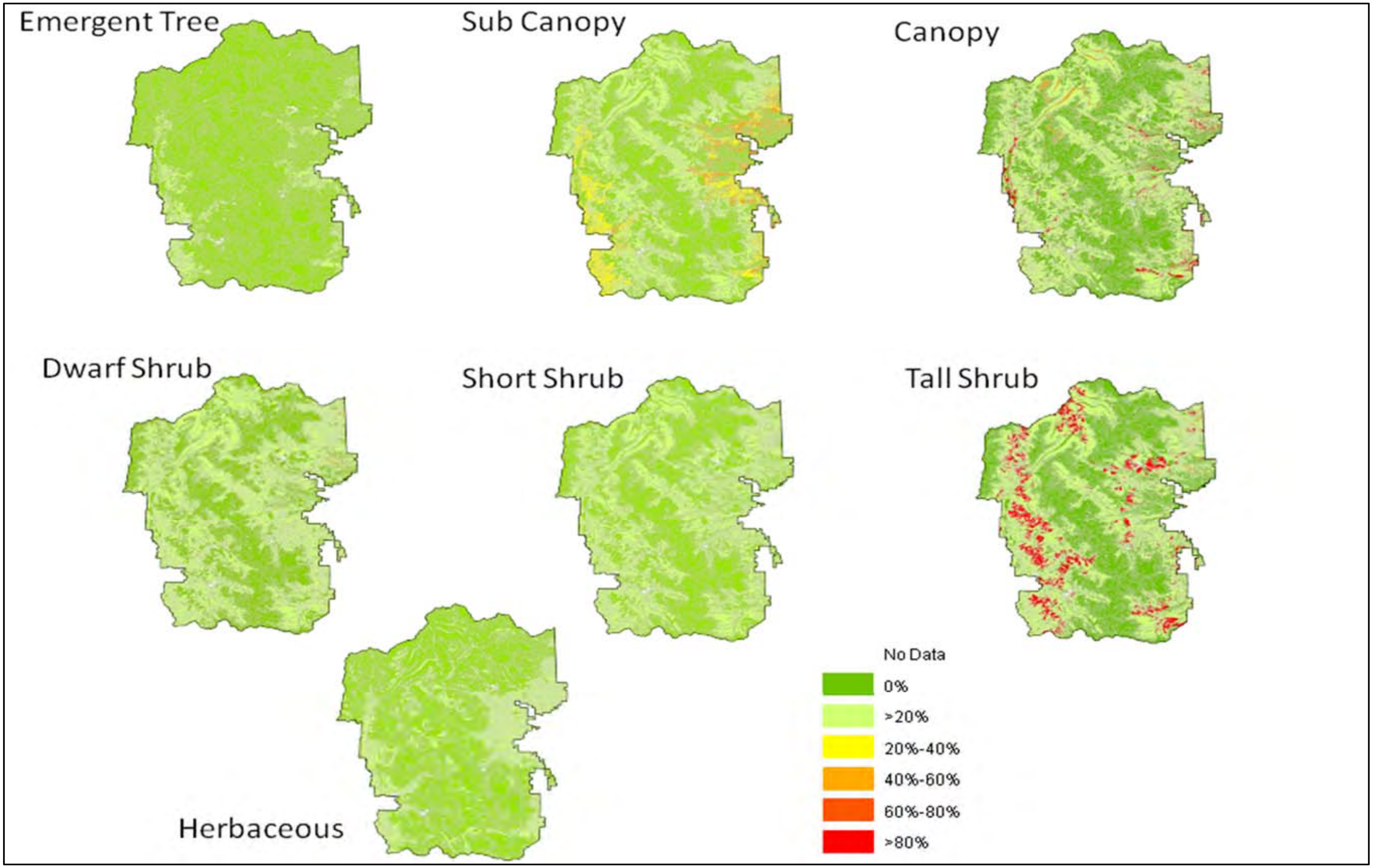

Figure 7-19 Sensitive Species Cover in Rocky Mountain National Park

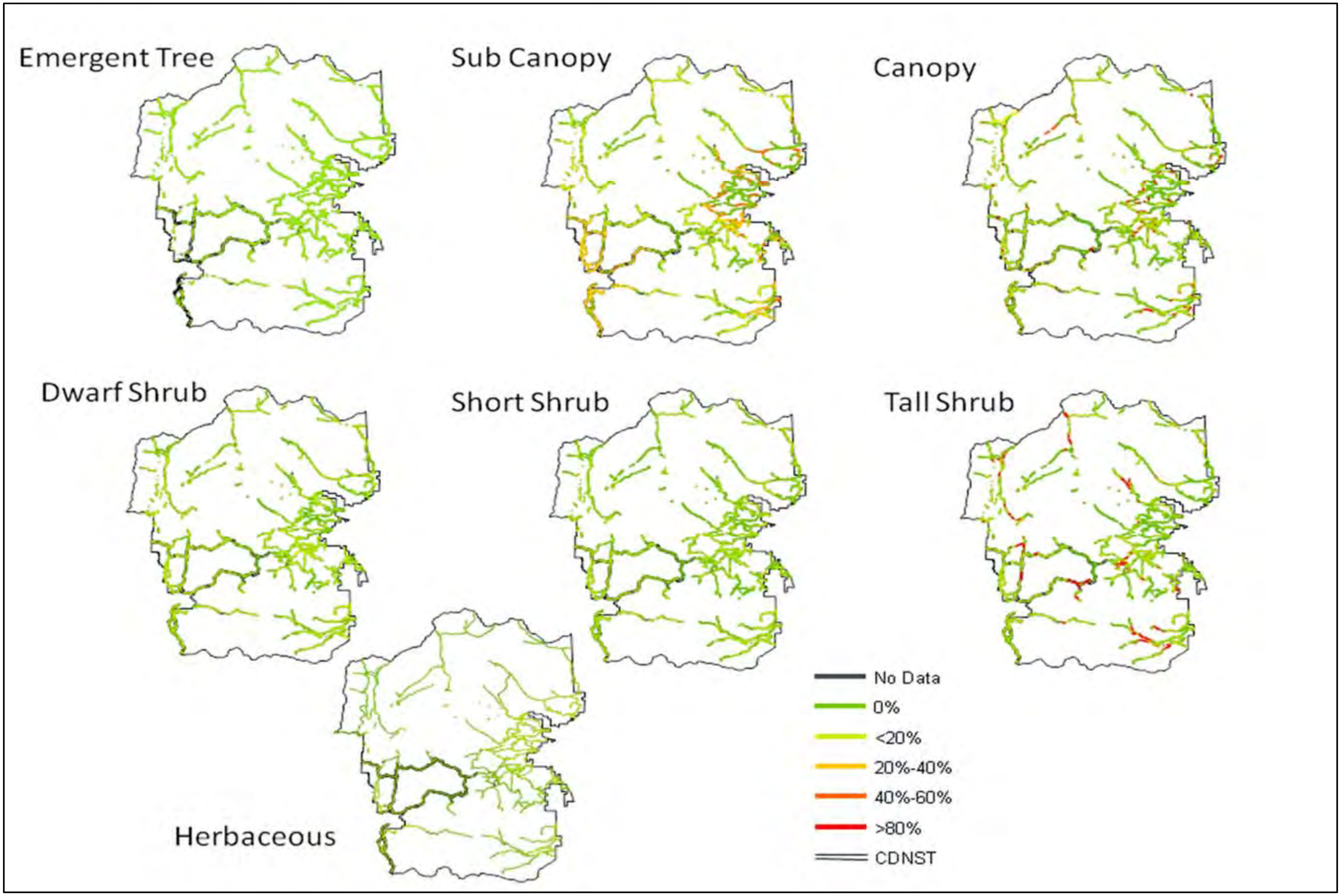

Figure 7-20 Percent Cover of Sensitive Species Near Trails in Rocky Mountain National Park

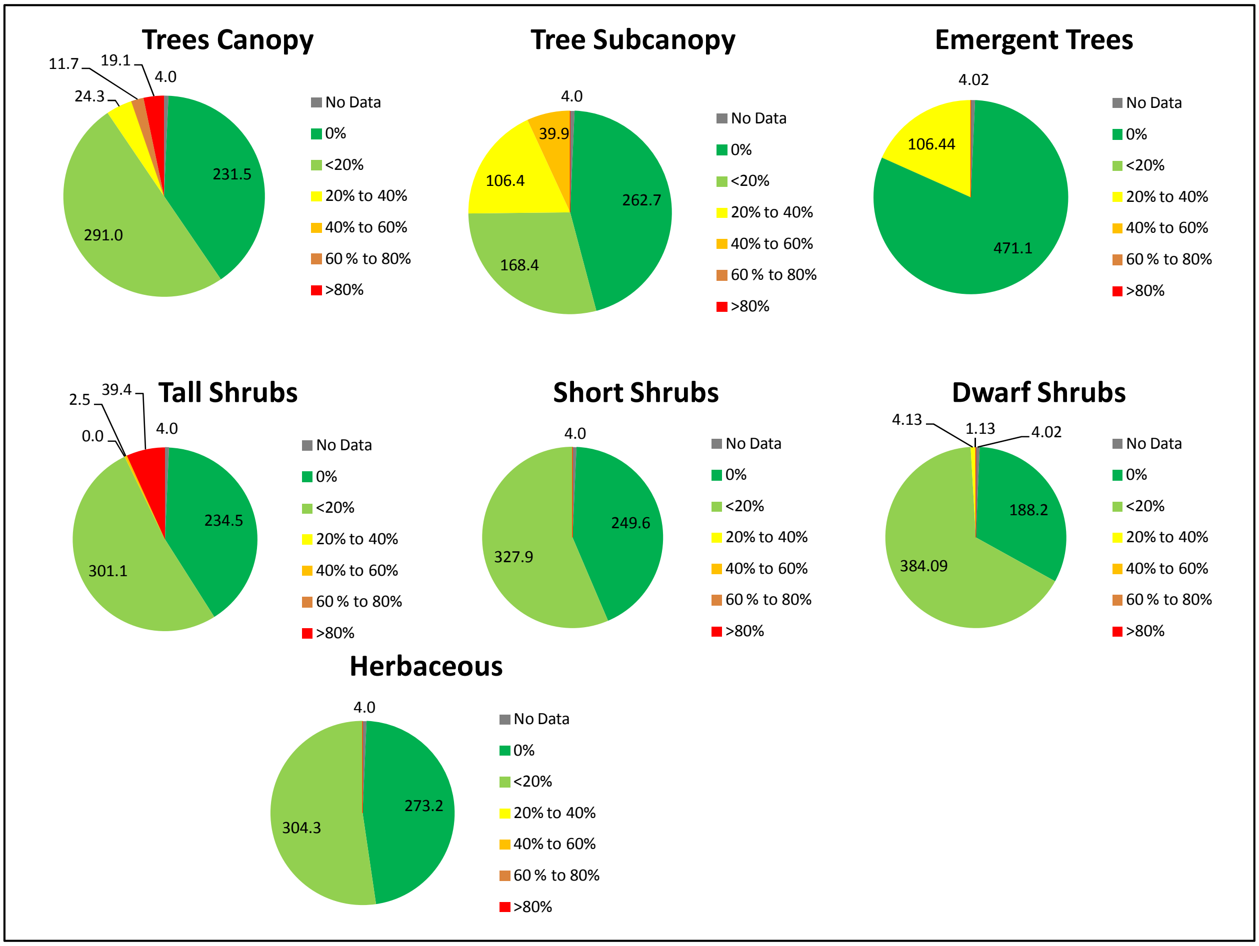

Figure 7-21 Trail Kilometers of Sensitive Species by Cover Category in Rocky Mountain National Park

7.4.3 Sequoia and Kings Canyon National Parks

Sequoia and Kings Canyon National Parks (SEKI) are located in the southern Sierra Nevada Mountains east of the San Joaquin Valley in California. The two parks welcomed 1.6 million visitors in 2010 (NPS, 2010) to experience the beauty and diversity of some of California's iconic ecosystems.

The NPS 2002 Comprehensive Survey of the American Public, Pacific West Region Technical Report includes responses from recent visitors to western parks about the activities they pursued during their visit (NPS, 2002c). By using the 2010 annual visitation rate from the NPS survey and the regional results from the Kaval and Loomis (2003) report on recreational use values compiled for the NPS, we estimated visitors' WTP for various activities; the results are presented in Table 7-20.

Kings Canyon
Courtesy: NPS,
http://www.nps.gov/seki/photosmultimedia/index.htm

The Sequoia and Kings Canyon National Parks share a boundary and natural resources. The natural resource features include the giant sequoia trees (and other species, including ponderosa and Jeffrey pine). The varied ecosystems from the top of Mount Whitney to the marble caverns provide habitat for a rich diversity of species. The park has recent W126 index values of 34 – 53 ppm-hrs with a mean of 43ppm-hrs.

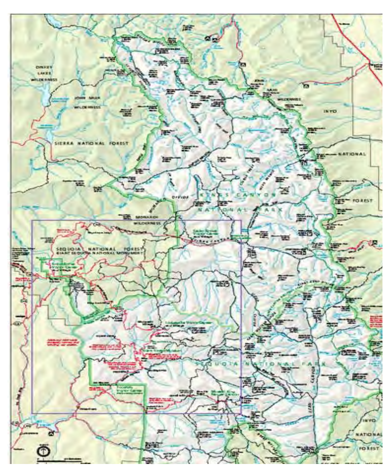

Table 7-20 Value of Most Frequent Visitor Activities at Sequoia and Kings Canyon National Parks

Activity	Percent Participation	Number of Participants (thousands)	Mean WTP (in 2010$)	Total Value of Participation (millions of 2010$)
Sightseeing	81	1,300	$24.21	$31
Day Hiking	58	928	$27.77	$26
Camping	33	528	$124.65	$66
Picnicking	45	720	$76.72	$55
Total				**$178**

In addition to the activities listed in Table 7-20, 14 percent of, or 224,000 park visitors availed themselves of educational services offered at the park by participating in a ranger-led nature tour, which suggests that visitors wish to understand the ecosystems preserved in the park.

Each of the activities discussed above is among the activities shown in the national-scale analysis to be strongly affected by visitor perceptions of scenic beauty. As in the national analysis, it is not possible to assess the extent of loss of services resulting from impairment of scenic beauty due to O_3 damage; however, these losses are captured in the estimated values for spending, economic impact, and WTP for the parks. If O_3 impacts were lower these estimated values would likely be higher.

The report *Economic Benefits to Local Communities from National Park Visitation and Payroll* (NPS, 2011) provides estimates of visitor spending and economic impacts for each park in the system. Visitor spending and its economic impact to the surrounding area are provided in Table 7-21 for SEKI. In addition, Table 7-22 includes data on the median value that visitors spend on good, gas, lodging, and other items.

Table 7-21 Visitor Spending and Local Area Economic Impact of Sequoia and Kings Canyon National Parks

Public Use Data		Visitor Spending 2010[a]		Impacts on Non-Local Visitor Spending		
2010 Recreation Visits	2010 Overnight Stays	All Visitors	Non-Local Visitors	Jobs	Labor Income[a]	Economic Impact[a]
1,320,156	438,677	$97,012	$89,408	1,283	$37,299	$60,504

[a]($000s)
Source: NPS (2011)

Table 7-22 Median Travel Cost for Sequoia and Kings Canyon National Parks Visitors

Expense/Visit	Median Expenditures (in 2010$)
Gas and Transportation	$75
Lodging	$150
Food and Drinks	$98
Clothes, Gifts, and Souvenirs	$63
Total per Visitor Party	**$386**

Source: NPS (2002c)

There are 12 identified sensitive species in SEKI. The percent coverage of these species is depicted in Figure 7-22. Areas of the parks with sensitive species cover of over 20 percent in the canopy comprise 646 km^2, or about 20 percent of the total area of SEKI. This area encompasses about 285 km of the 1,287 km (22 percent) of hiking trails available to approximately 928,000 hikers in the parks. Figure 7-23 depicts the sensitive species cover across the trail system, including the portion of the John Muir Trail that crosses the Parks' 19 km, which has sensitive species coverage over 20 percent. Figure 7-24 shows the sensitive species by type.

Again, although we are not able to quantify the impact of this scenic damage on hiker satisfaction for hikers in SEKI and their $26 million WTP for the experience, even a small improvement in the scenic value could be significant.

As in the previous case studies, moving from recent conditions to meeting the existing O_3 standard results in a large change in the area of the parks with exposures above 15 ppm-hrs. For SEKI, this means the parks move from all areas experiencing exposures above 15 ppm-hrs to all areas in the SEKI having exposures below 7 ppm-hrs. At lower alternative standards, SEKI moves to exposures below 3 ppm-hrs. See Table 7-23 for additional details.

Table 7-23 Geographic Area of Sequoia and Kings Canyon National Parks after Just Meeting Existing and Alternative Standard Levels (km^2)

	Under 5.94 ppm-hrs	Between 5.95-7 ppm-hrs	Between 7-11 ppm-hrs	Between 11-15 ppm-hrs	Over 15 ppm-hrs
Recent conditions (2006-2008)	0	0	0	0	3,466
Just meeting 75 ppb	3,466	0	0	0	0
15 ppm-hrs	3,466	0	0	0	0
11 ppm-hrs	3,466	0	0	0	0
7 ppm-hrs	3,466	0	0	0	0

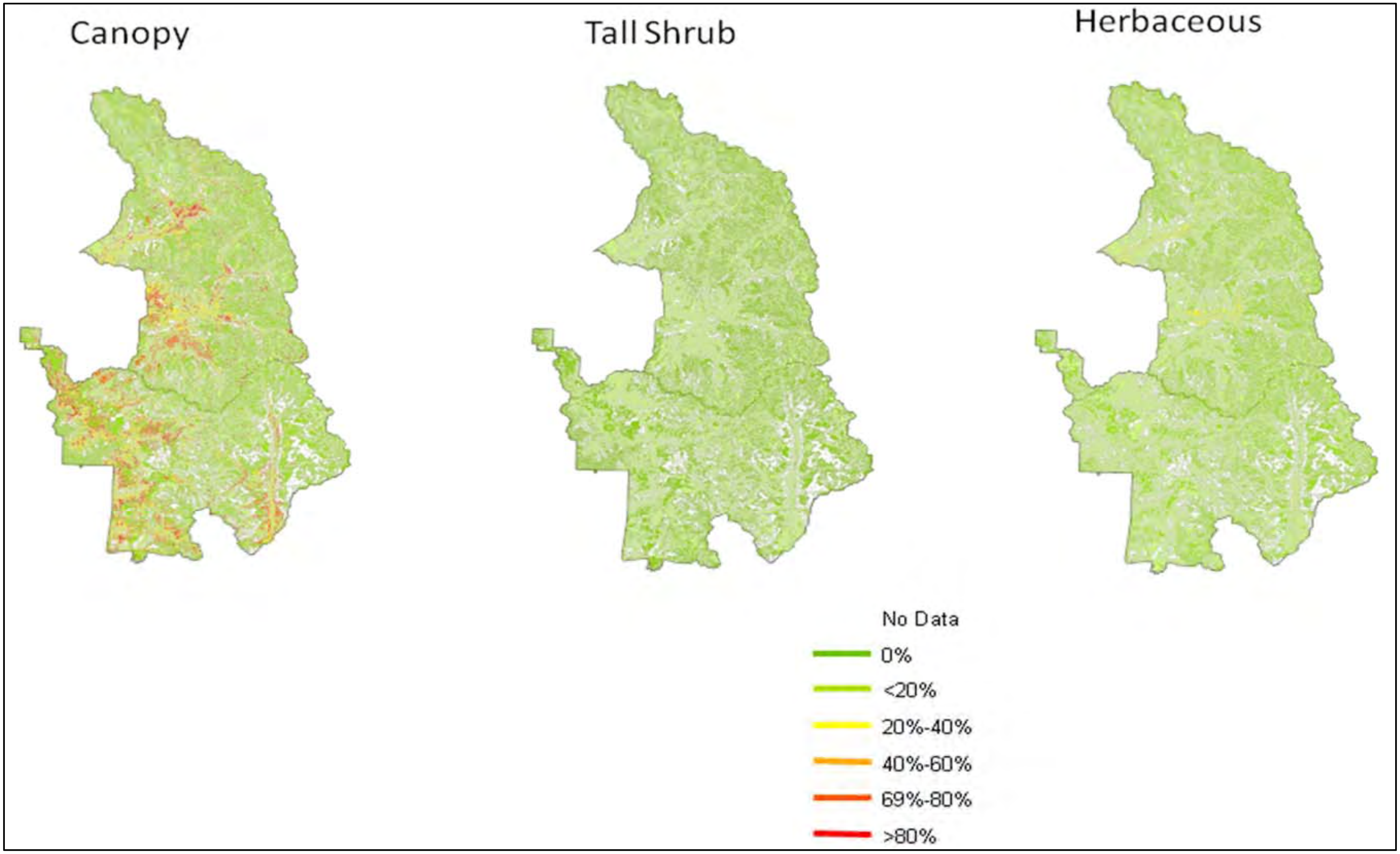

Figure 7-22 Sensitive Species Cover in Sequoia and Kings Canyon National Parks

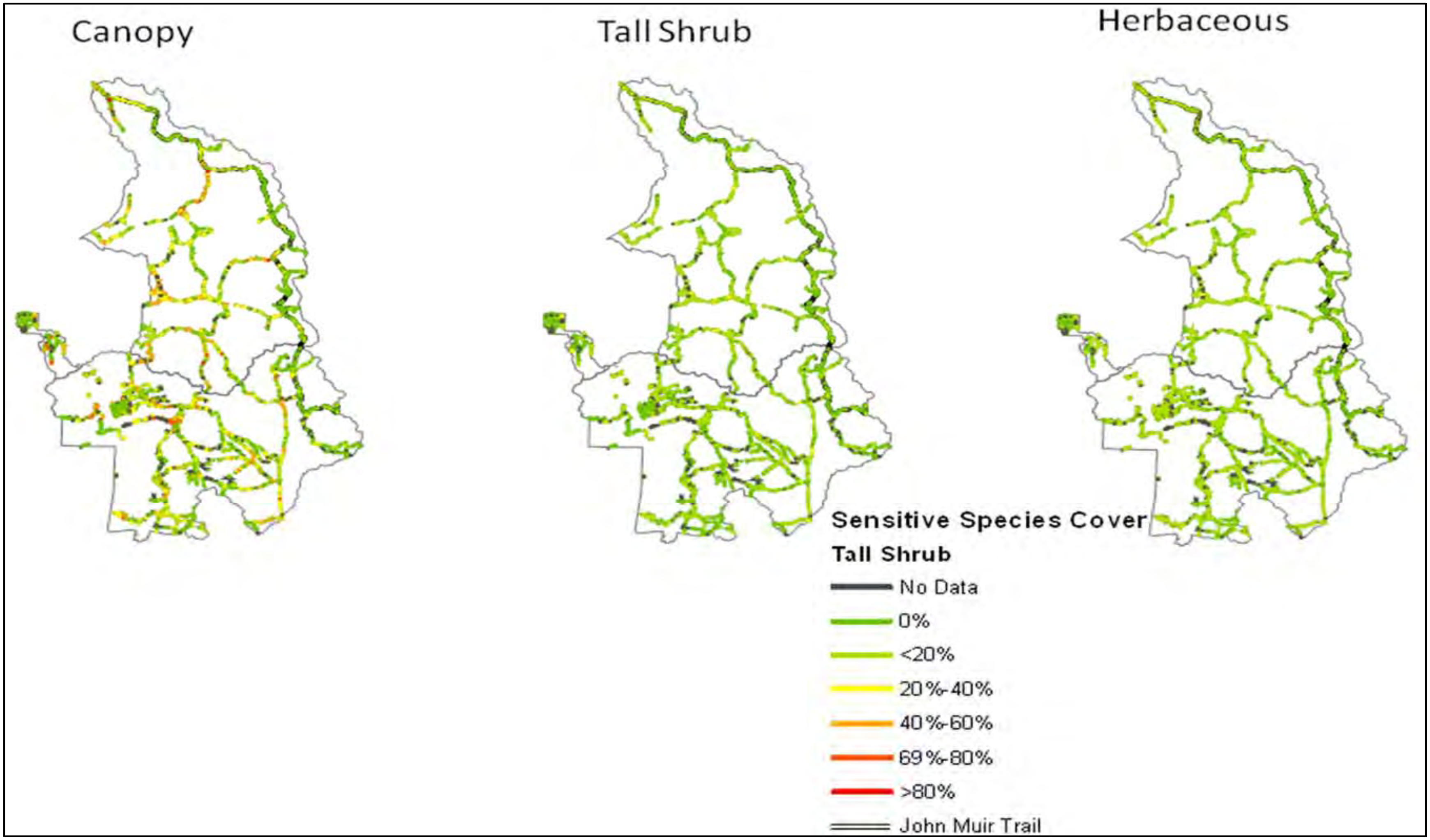

Figure 7-23 Percent Cover of Sensitive Species Near Trails in Sequoia and Kings Canyon National Parks

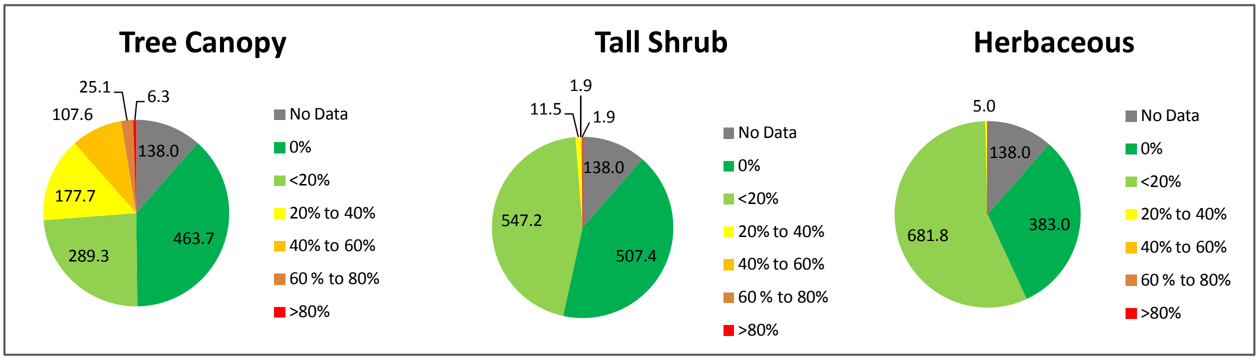

Figure 7-24 Trail Kilometers of Sensitive Species by Cover Category in Sequoia and Kings Canyon National Parks

7.5 QUALITATIVE ASSESSMENT OF UNCERTAINTY

As noted in Chapter 3, we have based the design of the uncertainty analysis for this assessment on the framework outlined in the WHO guidance (WHO, 2008). For this qualitative uncertainty analysis, we have described each key source of uncertainty and qualitatively assessed its potential impact (including both the magnitude and direction of the impact) on risk results, as specified in the WHO guidance. In general, this assessment includes qualitative discussions of the potential impact of uncertainty on the results (WHO Tier1) and quantitative sensitivity analyses where we have sufficient data (WHO Tier 2).

Table 7-24 includes the key sources of uncertainty identified for the O_3 WREA. For each source of uncertainty, we have (a) provided a description, (b) estimated the direction of influence (over, under, both, or unknown) and magnitude (low, medium, high) of the potential impact of each source of uncertainty on the risk estimates, (c) assessed the degree of uncertainty (low, medium, or high) associated with the knowledge-base (i.e., assessed how well we understand each source of uncertainty), and (d) provided comments further clarifying the qualitative assessment presented. The categories used in describing the potential magnitude of impact for specific sources of uncertainty on risk estimates (i.e., low, medium, or high) reflect our consensus on the degree to which a particular source could produce a sufficient impact on risk estimates to influence the interpretation of those estimates in the context of the secondary O_3 NAAQS review. Where appropriate, we have included references to specific sources of information considered in arriving at a ranking and classification for a particular source of uncertainty.

Table 7-24 Summary of Qualitative Uncertainty Analysis in Visible Foliar Injury Assessments.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
A. National W126 surfaces	The foliar injury analyses in this chapter use the interpolated W126 surfaces for individual years (2006-2010), as well as the surfaces for recent conditions and adjusted to just meet the existing standard and alternative W126 standards.	Both	Low-Medium	Low-medium	KB and INF: See Chapter 4 for more details.
B. Surveys of recreational activities	Survey estimates of participation rates, visitor spending/economic impacts, and willingness-to-pay are inherently uncertain. These surveys potential double-count impacts based on the allocation of expenditures across activities but also potentially exclude other activities with economic value.	Both	Medium	Medium	KB: Each survey (NSRE, FHWAR, OIF, NPS, etc) uses different survey methods, so it is not appropriate to generalize across the surveys. In general, the national level surveys apply standard approaches, which minimize potential bias. INF: Since the surveys are in agreement that there are millions of outdoor recreationists and billions of recreation days across various recreation types even small changes induced by changes in recreation satisfaction due to O_3 injury to recreation sites could potentially result in large changes in the value of outdoor recreation.
C. O_3 sensitive species	Only species identified as O_3-sensitive by NPS are included in the analyses.	Under	Medium	Medium	KB: Relatively few vegetation species have been evaluated for O_3-sensitive foliar injury in the field and continuing fieldwork will likely identify additional sensitive species (NPS, 2003). INF: The identification of additional sensitive species would likely increase the extent of foliar injury in additional locations and the percentage of injured vegetation at a location. Due to the small number of parks without sensitive species (i.e., only 11 parks, or 5 percent) and on-going fieldwork, the magnitude of this uncertainty is likely to be small for the screening-level assessment.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
D. Spatial assignment of foliar injury biosite data to 12x12 km grids	Because of privacy laws that require the exact location information of sampling sites to not be made public, the data were assigned to the CMAQ grid by the USFS. Data in California, Oregon, and Washington were assigned to the CMAQ grid based on publically available geographic coordinates; thus, these data have a higher level of uncertainty.	Both	Low	Medium-Low	KB: The FHM biosites are small relative to the 12x12 km CMAQ grids. The publically available data have the latitude and longitude fuzzed by up to 7km in any direction, so in California, Washington and Oregon so it is possible these sites were assigned to the wrong CMAQ grid. In the remaining states, the CMAQ grid was assigned from the actual locality data. INF: Having precise geographic locations would reduce uncertainty, but the direction is unclear. The sites would most likely be assigned to an adjacent CMAQ grid cell. Due to the interpolation of the surfaces, differences between adjacent cells are relatively small, so the magnitude of this effect is likely small.
E. Availability of biosite sampling data	Because sampling was discontinued in some states prior to this analysis, we did not include data for many western states (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, Oklahoma, and portions of Texas).	Unknown	Medium	Low	KB: Due to the discontinued sampling, data are not available in these areas. It appears unlikely that sampling will resume in those regions at this time. INF: It is unclear how the addition of biosites from these states would affect the risk estimates. The absence of biosite sampling data in the southwest region and limited data in the west and west north central region results in national benchmarks that may not be applicable to these region. The southwest in particular has generally higher W126 index values than other regions, so data from that region would be important. In addition, the southwest has many national parks.
F. Soil moisture threshold for foliar injury	Low soil moisture reduces the potential for foliar injury, but injury could still occur because plants must open their stomata even during periods of drought.	Over	High	Medium	KB: We are unaware of a clear threshold for drought below which visible foliar injury would not occur. The national-scale foliar injury analysis did not provide any evidence of a soil moisture threshold for injury. INF: If there is a threshold for drought, we may overestimate foliar injury at lower levels of soil moisture.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
G. Spatial resolution of soil moisture data	Some vegetation such as along riverbanks may experience sufficient soil moisture during periods of drought to exhibit foliar injury. In addition, we did not have soil moisture data for Alaska, Hawaii, Puerto Rico, or Guam.	Under	Medium	Medium	KB: Soil moisture has substantial spatial variation. The data source for soil moisture are NOAA's 344 climate divisions, which can be hundreds of miles wide. The inability to capture within-division variability in soil moisture adds some uncertainty to this assessment, particularly along riverbanks. However, we are currently unable to quantify the magnitude of this uncertainty. INF: Soil moisture can vary, even within small geographic areas. It is most likely that soil moisture is underestimated in areas considered to be in drought conditions, so if plants in these areas exhibited foliar injury, the soil moisture would be underestimated, which underestimate the importance of soil moisture's effect on foliar injury.
H Time period for soil moisture data	Short-term estimates of soil moisture are highly variable over time, even from month to month within a single year. Using averages contributes to a potential temporal mismatch between soil moisture and injury.	Unknown	Low-Medium	Low	KB: The average of monthly values is sensitive to skew by a single very wet or very dry month within that timeframe or even a single precipitation episode within a month. As shown in a sensitivity analysis, parks are not very sensitive to the different timeframes for soil-moisture data. INF: Without much more precise sampling, it is difficult to assess the effect of the soil moisture sampling period, but the overall effect of averaging appears to normalize both very high and very low moisture conditions, which would affect these results in opposite directions.
I. Drought categories	The soil moisture categories used to derive the foliar injury benchmarks (i.e., wet, normal, and dry) are uncertain.	Unknown	Unknown	Low	KB: NOAA's categorization for Palmer Z soil moisture data has been described as "rather arbitrary" (Karl, 1986). INF: Using a different categorization would lead to different benchmark criteria for O_3 exposure associated with foliar injury, but it is not clear whether this uncertainty could underestimate or overestimate the potential foliar injury.

Source	Description	Potential influence of uncertainty on risk estimates		Knowledge-Base	Comments (KB: knowledge base, INF: influence of uncertainty on risk estimates)
		Direction	Magnitude		
J. Spatial resolution for combining soil moisture, biosite, and O_3 exposure data	For the national-scale foliar injury assessment, we combined data from different spatial resolutions.	Unknown	Medium	Low	KB: In general, the biosite data is at a finer spatial resolution (usually ~ .02 km^2 than the O_3 data (144 km^2) and the soil moisture data (hundreds of miles across). INF: We used data at the finest spatial resolution available to minimize this uncertainty.
K. Maps of vegetation and recreational areas within parks	Maps of vegetation and recreational areas that overlap with areas with higher W126 index values are uncertain.	Unknown	Low	High	KB and INF: VegBank is the vegetation plot database of the Ecological Society of America's Panel on Vegetation Classification, and it consists of (1) actual plot records, (2) vegetation types, and (3) all plant taxa. (See http://vegbank.org/vegbank/general/info.html) Even though the data quality of the vegetation maps are high, extrapolating across the park using plant communities is uncertain due to unquantified variation in the defined community. The spatial resolution of the vegetation maps is higher than the gridded O_3 exposure maps (12km^2).

7.6 KEY OBSERVATIONS

National-Scale Analysis of Foliar Injury:

- Using the FHM data on biosites and the Palmer Z drought index, across all of the biosites (5,284 over five years from 2006-2010) over 81 percent of observations showed no foliar injury. Using the full dataset including all observations with or without injury, the analysis showed no clear relationship between O_3 and the biosite index and no clear relationship between O_3 and the Palmer Z drought index. This largely reflects the fact that O_3 is not a good predictor of the presence or absence of foliar injury, but not necessarily that there is no relationship between the degree of injury and O_3 in plants that do show injury.

- To better understand the relationship between O_3 and those biosites that did show foliar injury, we conducted a cumulative analysis. When analyzed by individual year and looking at the presence/absence of foliar injury, the proportion of sites exhibiting foliar injury rises rapidly (over 20 percent in 2010) at increasing W126 index values up to 10 ppm-hrs.

- When categorized by moisture category, the results show a more distinct pattern. Looking at the presence/absence of foliar injury, there is a rapid increase in the proportion of sites exhibiting foliar injury at O_3 below a W126 index value of 10 ppm-hrs. Sites classified as wet have much higher overall proportions at any injury and a much more rapid increase in proportion of sites with foliar injury present. At sites considered dry, the overall proportions are much lower for presence/absence, potentially indicating that drought may provide protection from foliar injury as discussed in the O_3 ISA.

- This analysis suggests that reductions in W126 index values at or above the W126 benchmark of 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.

Screening-level Assessment of Visible Foliar Injury in National Parks:

- Based on NPS lists, 95 percent of the parks contain at least one O_3-sensitive species.
- During 2006 to 2010, 58 percent of parks exceeded the W126 benchmark corresponding to the base scenario (W126>10.46 ppm-hrs, 17.7 percent of all biosites in all soil moisture categories) for at least three years.
- During 2006 to 2010, 98 percent, 80 percent, 68 percent and 2 percent of parks would exceed the W126 benchmarks corresponding to the 5 percent, 10 percent, 15 percent, and 20 percent scenarios for at least 3 years.
- During 2006-2010, 42 percent of parks did not exceed 15 ppm-hrs.
- None of the 214 parks would exceed the W126 benchmark for the base scenario (W126>10.46 ppm-hrs) after adjustments to just meet the existing standard at 75 ppb. Only 8 parks exceed 7 ppm-hrs after adjustments to meet the existing standard at 75 ppb.

National Park Case Study Areas:

- GRSM is prized, in part, for its rich species diversity. The large mix of species includes 37 O_3-sensitive species and many areas contain several sensitive species. With 3.8 million hikers using the trails every year and those hikers willing to pay over $266 million for that activity, even a small benefit of reducing O_3 damage in the park could result in a significant value.
- W126 index values in GRSM have been among the highest in the eastern U.S. – at times twice as high as neighboring cities such as Atlanta. Under recent conditions, 44 percent of the Park has W126 index values over 15 ppm-hrs. **After just meeting the existing standard, W126 index values are reduced such that no area is over 7 ppm-hrs.**
- Unlike GRSM, sensitive species cover in ROMO is driven by a few O_3-sensitive species (7 species) and most notably by Quaking Aspen. This is significant in that many of the visitors to ROMO visit specifically to see this tree in its fall foliage.

Given 1.5 million hikers in ROMO and their $70 million WTP for the hiking experience, even a small improvement in the scenic value could be significant.

- Under recent O_3 conditions, all 1,067 km^2 of ROMO have W126 index values over 15 ppm-hrs. Meeting the existing standard would bring about 59 percent of the Park into the 7-15 ppm-hrs range, with the remaining 41 percent under 7 ppm-hrs. **Assessing an alternative standard of 15 ppm-hrs would bring the entire park under 7 ppm-hrs.**

- SEKI is home to 12 identified sensitive species. Again, although we are not able to quantify the impact of this scenic damage on hiker satisfaction for hikers in SEKI and their $26 million WTP for the experience, even a small improvement in the scenic value could be significant.

- As in the previous national park case studies, moving from recent conditions to meeting the existing O_3 standard of 75 ppb results in a large change in the area of SEKI with exposures above 15 ppm-hrs. **For SEKI this means the parks move from all areas experiencing exposures above 15 ppm-hrs to the SEKI having exposures below 7 ppm-hrs.**

8 SUMMARY OF ANALYSES AND SYNTHESIS OF RESULTS

8.1 Introduction

The goals for this welfare risk and exposure assessment include characterizing ambient ozone (O_3) exposure and its relationship to ecological effects and estimating the resulting impacts to several ecosystem services. In particular, we characterize ambient O_3 exposures, using the W126 metric[1], on two important ecological effects – biomass loss and foliar injury – and estimate impacts to the following ecosystem services: supporting, regulating, provisioning, and cultural services. In the assessment, we conduct national- and regional-scale analyses to (1) characterize ambient O_3 exposure (Chapter 4); (2) quantify the effects of insect damage related to foliar injury (Chapter 5); (3) consider the overall risk to a subset of ecosystem services by combining the relative biomass loss (RBL) rates for multiple tree species into one metric and evaluating weighted RBL rates (Chapter 6); (4) estimate the market effects of biomass loss on timber production and agricultural harvesting and quantify the associated economic effects (Chapter 6); (5) estimate the effect of biomass loss on carbon sequestration (Chapter 6); (6) estimate the effect of foliar injury and its impact on national recreation (Chapter 7); (7) derive W126 benchmarks representing the prevalence of visible foliar injury and soil moisture considerations; and (8) apply these benchmarks to a screening-level assessment of foliar injury in 214 national parks (Chapter 7). In addition, we conduct case study-scale analyses to (1) characterize the effect of foliar injury on forest susceptibility and fire regulation in California (Chapter 5); (2) quantify the effects of biomass loss on carbon sequestration and pollution removal in five urban areas (Chapter 6); (3) characterize the effects of relative biomass loss in Class I areas (Chapter 7); and (4) assess the impacts of foliar injury on recreation in three national parks (Chapter 7). In addition, in Chapters 5, 6, and 7 we qualitatively assess additional ecosystem services, including regulating services such as hydrologic cycle and pollination; provisioning services such as commercial non-timber forest products; and cultural services with aesthetic and non-use values.

[1] 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.

To evaluate risk associated with just meeting the existing daily maximum 8-hour average standard[2] and alternative W126 standards in this welfare risk and exposure assessment, we (1) quantified ecological effects based on relationships between ecological effect and the W126 metric, (2) quantified the impact of these ecological effects on ecosystem services, and (3) qualitatively assessed potential impacts to several additional ecosystem services. The results from these assessments will help inform consideration of the adequacy of the existing O_3 standards and potential risk reductions associated with adjustments to meeting several alternative levels of the standard, using the W126 form. In addition, the assessment (1) includes information (e.g., foliar injury analyses) that could be relevant to a three-year average of a W126 standard, (2) addresses how air quality just meeting alternative W126 standard levels would affect exposures and welfare risks and associated ecosystem services, and (3) addresses uncertainties and limitations in the available data.

To facilitate interpretation of these results, this chapter provides a summary of the analyses and a synthesis of the various results, focusing on comparing and contrasting results to identify common patterns or important differences. These comparisons focus on patterns across different geographic areas of the U.S., across years of analysis, and across alternative W126 standard levels. We evaluate the degree to which the integrated results are representative of overall patterns of exposure and risk across different types of ecosystems. We also summarize overall confidence in the results, as well as relative confidence between the different analyses. The chapter concludes with an overall characterization of risk in the context of key policy relevant questions. The remainder of this chapter summarizes the results (Section 8.2) and includes discussions on patterns of risk (Section 8.3), representativeness (Section 8.4), confidence in the results (Section 8.5), and integrated risk characterization (Section 8.6).

8.2 Summary of Analyses and Key Results

We conducted a variety of analyses to assess O_3 welfare risk and exposure and to estimate the relative change in risk and exposure resulting from air quality adjustments to just meet existing and alternative standards. These analyses included national- and case study-scale analyses addressing air quality, biomass loss, foliar injury, insect damage, fire risk, and

[2] The existing secondary standard for O_3 is identical to the existing primary health-based standard, which is set at 75 ppb for the fourth-highest daily maximum 8-hour average, averaged over three years.

recreation. The remainder of this section briefly summarizes the national- and case study-scale analyses and key results.

8.2.1 National-Scale Analyses

8.2.1.1 Air Quality Analyses

The analyses used ambient air quality data from 2006 through 2008, as well as air quality data adjusted to meet the current and potential alternative secondary standard levels.[3] A Higher Order Decoupled Direct Method, or HDDM, adjustment, similar to the one used in the Health Risk and Exposure Assessment (see Chapter 4, Section 4.3.4.1 for a discussion of the methodology), independently adjusted air quality for nine climate regions as defined by the National Oceanic and Atmospheric Administration (NOAA) and shown in Figure 8-1 below (Figure 4-6 from Chapter 4).[4] We considered these regions an appropriate delineation for our analyses because geographic patterns of both O_3 and plant species are often largely driven by climatic features such as temperature and precipitation patterns. The NOAA climate regions were used for all of the adjustments between observed air quality concentrations and air quality adjusted to just meet the existing and potential alternative W126 standard levels.

In the air quality analyses in Chapter 4, we consider the changes across the distribution of W126 index values after adjusting air quality to just meet the existing standard and just meet alternative W126 standard levels, all three-year averages. As indicated above, each climate region was adjusted independently such that the entire region was adjusted based on the magnitude of across-the-board reductions in U.S. anthropogenic NOx emissions required to bring the highest monitor down to the targeted level.[5] For the biomass loss analyses, we generated a national-scale air quality surface that just meets the existing standard using the Voronoi Neighbor Averaging (VNA) interpolation technique to fill in values between monitor

[3] W126 calculations are slightly modified in the case of the model adjustment scenarios described in Chapter 4, Section 4.3.4. When calculating W126 for the model adjustment scenarios, we first found the three-year average of each three-month period, and then selected the three-month period with the highest three-year average using the same three-month period for each of the three years. In this way, the five scenarios are for recent air quality, air quality adjusted to just meet the current standard, and air quality further adjusted to just meet three different W126 index values: 15 ppm-hrs, 11 ppm-hrs, and 7 ppm-hrs.

[4] Many of the models and analytical tools used in the analyses include different definitions of geographic areas. To the extent possible, we will refer to geographic areas by the nine climate regions based on National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) regions in this chapter and note where definitions differ.

[5] All of the climate regions required adjustments to just meet the existing standard of 75 ppb.

locations. VNA national surfaces were also created for monitors adjusted to meet the existing standard and for monitors adjusted to meet alternative W126 standard levels of 15, 11, and 7 ppm-hrs. During the last O_3 National Ambient Air Quality Standards review, the Clean Air Scientific Advisory Committee (CASAC) recommended and supported a range of alternative W126 standard levels from 7 to 15 ppm-hrs. The adjusted surfaces, based on monitored, three-year average W126 index values from 2006 through 2008, are used as inputs to several assessments (described below), 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 air quality data with short-term soil moisture data we generated five national-scale air quality surfaces from the monitored annual W126 index values (unadjusted) for the individual years from 2006 through 2010, also using VNA. See Chapter 4, Section 4.3 for more detailed discussions of the air quality analyses.

The largest reduction in W126 index values occurs when moving from recent ambient conditions to meeting the existing secondary standard of 75 ppb (daily maximum 8-hour average). After adjusting 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). The Central region would meet an alternative W126 standard level of 15 ppm-hrs, but further air quality adjustment would be needed for the Central region to meet alternative standards of 11 and 7 ppm-hrs. In addition, when adjusting to just meet the existing standard, 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).

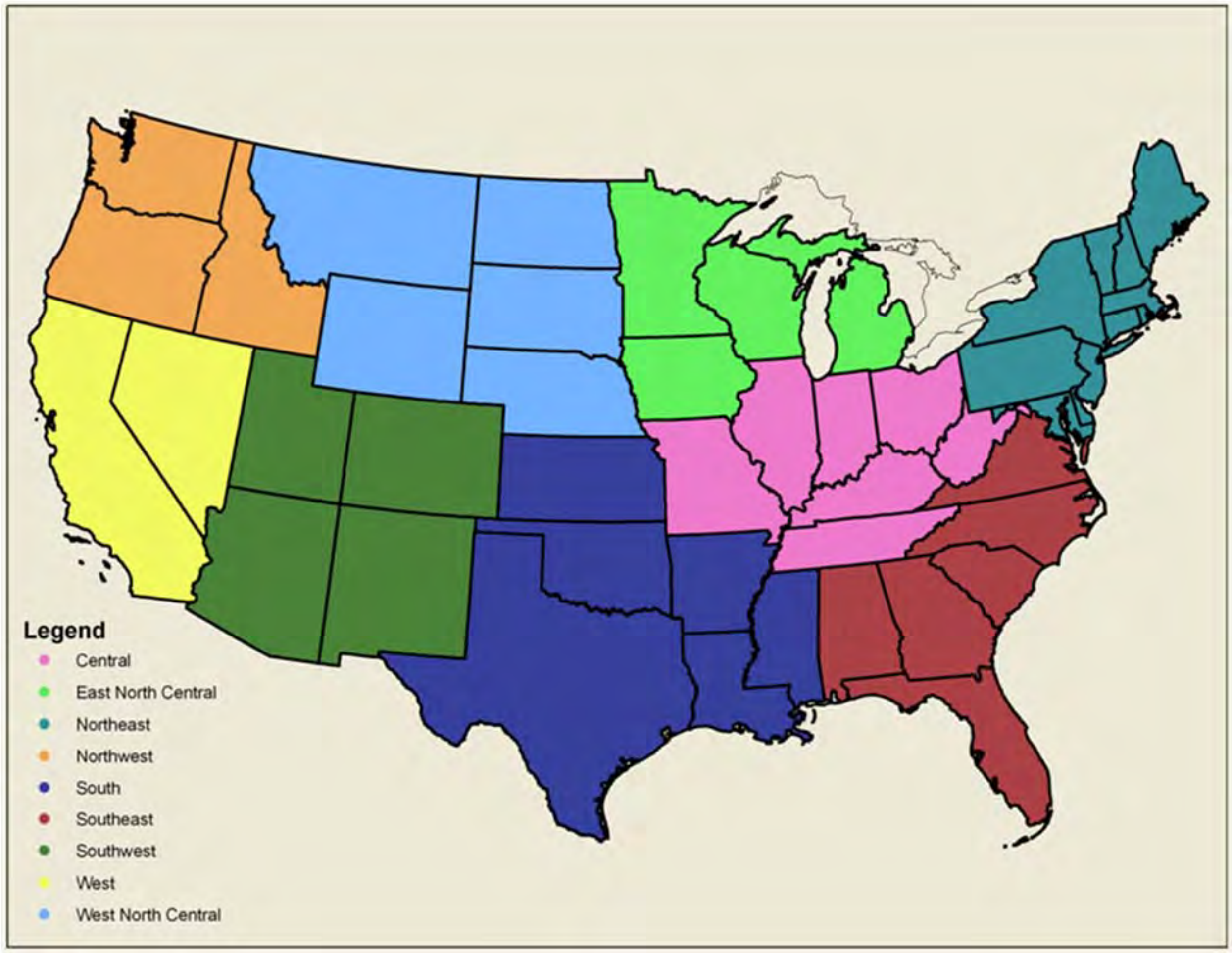

Figure 8-1 **Map of the 9 NOAA Climate Regions (Karl and Koss, 1984) used in the Welfare Risk and Exposure Assessment**

8.2.1.2 **Forest Susceptibility to Insect Infestation**

In Chapter 5, we review information on O_3 exposure and the increased susceptibility of forests to insect infestations. O_3 exposure is anticipated to result 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. 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, harming consumers and potentially benefitting some producers. The United States Forest Service (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 to 2004 (Coulson and Klepzig, 2011). It is not possible to attribute a portion of these impacts resulting from the effect of O_3 on trees' susceptibility to insect attack; however, the losses are embedded in the estimates cited and any welfare gains from decreased O_3 would positively impact the net economic impact.

In addition, in Chapter 5 we provide summaries of area at risk of high pine beetle loss (i.e., high loss due to pine beetle damage), as well as millions of square feet of tree basal area at risk of high pine beetle loss after just meeting the existing and alternative standards. For area at risk of high pine beetle loss, under recent ambient conditions approximately 57 percent of the at-risk area is at or above 15 ppm-hrs; approximately 16 percent of the at-risk area is between 15 and 11 ppm-hrs; approximately 23 percent of the at-risk area is between 11 and 7 ppm-hrs; and approximately four percent of the at-risk area is below 7 ppm-hrs. After adjusting to just meet the existing standard, approximately five percent of the at-risk area is between 11 and 7 ppm-hrs, and no at-risk area is above 11 ppm-hrs. When adjusting to a potential alternative standard level of 15 ppm-hrs, no at-risk area is above 7 ppm-hrs. In terms of millions of square feet of tree basal area at risk of high pine beetle loss, under recent ambient conditions, approximately 45 percent of the "at-risk square feet" is at or above 15 ppm-hrs; approximately 13 percent of "at-risk square feet" is between 15 and 11 ppm-hrs; approximately 34 percent is between 11 and 7 ppm-hrs; and approximately eight percent is below 7 ppm-hrs. After adjusting to just meet the existing standard, approximately ten percent of the "at-risk square feet" is between 11 and 7 ppm-hrs, and no square feet are above 11 ppm-hrs.

8.2.1.3 **Biomass Loss**

We reviewed several studies that modeled vegetation growth for several tree and crop species. For trees, we calculated seedling RBL associated with W126 index values and compared the seedling RBL values to the study results for adult trees. Overall, seedling biomass loss values are much more consistent with adult biomass loss at lower W126 index values. For example, for Tulip Poplar, at 15 ppm-hrs, the adult biomass loss rate is estimated to be 10.5 percent, and the seedling biomass loss rate is estimated to be 7.7 percent. See Chapter 6, Section 6.2.1.1 for additional information.

For biomass loss, 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 (Frey and Samet, 2012b). To assess overall ecosystem-level effects from biomass loss, we weighted the RBL values for multiple tree species using basal area[6] and combined them into a weighted RBL value and considered the weighted value in relation to the proportion of basal area accounted for by the tree species. A weighted RBL value is a relatively straight-forward metric to attempt to understand the potential ecological effect on some ecosystem services. We summarized the percent of total basal area that exceeds a two percent weighted biomass loss under recent conditions, at just meeting the existing standard (75 ppb) and at potential alternative W126 standard levels of 15, 11, and 7 ppm-hrs.[7] The data indicate that the total area exceeding two percent biomass loss decreases across air quality scenarios. For example, for the Central region under recent conditions, a total of 23.4 percent of total basal area assessed would exceed a two percent biomass loss, and when adjusted to just meet the existing standard, a total of 2.7 percent of total basal area assessed would exceed a two percent biomass loss. It is important to note that the proportional basal area values do not account for total cover, but rather the relative cover of the tree species present. See Chapter 6, Section 6.8 for additional information. We also analyzed federally designated Class I areas by calculating an average weighted RBL value for 145 of the 156 Class I areas and present the results as a count of the Class I areas and not as a percentage of area. The number of areas exceeding one percent and two percent biomass loss decreases across air quality scenarios. See Chapter 6, Section 6.8.1 for additional information.

Using the exposure-response (E-R) functions for tree seedlings and crops, we determined the range of biomass loss associated with just meeting the existing daily maximum 8-hour average standard and alternative W126 standard levels. We plotted the E-R functions as a function of the percent biomass loss against varying W126 index values. For a one percent biomass loss for tree seedlings, the estimated W126 index values were between 4 and 10 ppm-

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[6] Basal area is the term used in forest management that defines the area of a given section of land that is occupied by a cross-section of tree trunks and stems at their base. This typically includes a measurement taken at the diameter at breast height of a tree above the ground and includes the complete diameter of every tree, including the bark.
[7] We also present the data excluding Cottonwood, which is a very sensitive species.

hrs; for a two percent biomass loss for tree seedlings the estimated W126 index values were between 7 and 14 ppm-hrs; and for a five percent biomass loss for crops the estimated W126 index values were between 12 and 17 ppm-hrs. See Chapter 6, Section 6.2.1.2 for additional information.

Using the Forest and Agricultural Optimization Model with Greenhouse Gases (FASOMGHG), we conducted national-scale analyses to quantify the effects of biomass loss on timber production and agricultural harvesting, as well as on carbon sequestration.[8] We used the O_3 E-R functions for tree seedlings and crops to calculate relative yield loss (RYL), which is equivalent to relative biomass loss. Because the forestry and agriculture sectors are related, and trade-offs occur between the sectors, we simultaneously calculated the resulting market-based welfare effects of O_3 exposure in the forestry and agriculture sectors.

In the analyses for commercial timber production, because most areas are lower than 15 ppm-hrs when simulating meeting the existing standard (based on reducing nationwide emissions of NOx), RYLs are below one percent, with the exception of the Southwest, Southeast, Central, and South regions (see text box for clarification on region names). Relative yield losses remain above one percent for the parts of the Southeast, Central, and South regions at alternative W126 standard levels of 15 and 11 ppm-hrs, and for the Southeast and South regions at an alternative W126 standard level of 7 ppm-hrs.

The states included in the NOAA NCDC regions and the states included in the FASOMGHG model regions differ slightly. Below we align the different region names. To be consistent across summary discussions, we use the NCDC region names.

NCDC	**FASOMGHG**
West	primarily Pacific Southwest
Southwest	primarily Rocky Mountain
Central	primarily Cornbelt
South	primarily South West and South Central
Southeast	primarily South Central and Southeast
Northeast	primarily Northeast

In the analyses for agricultural harvest, the largest yield changes occur when comparing recent ambient conditions to just meeting the existing standard. Under recent ambient conditions, the West, Southwest, and Northeast regions generally have the highest yield losses.

[8] 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, e.g., production of different crops or livestock, in both the forest and agricultural sectors.

At alternative W126 standard levels of 15, 11, and 7 ppm-hrs, for winter wheat[9] relative yield losses are less than the five percent loss recommended by CASAC, as well as less than one percent. For soybeans, when the W126 scenarios are modeled, yield losses above both five and one percent remain at 15 ppm-hrs for the Southwest and Central regions. Yield losses are reduced to below one percent at alternative W126 standard levels of 11 and 7 ppm-hrs.

In addition to estimating changes in forestry and agricultural yields, FASOMGHG estimates the changes in consumer and producer/farmer surplus associated with the change in yields.[10] Changes in yield affect individual tree species and crops, but the overall effect 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 to substitute other crops that are less O_3 sensitive and (2) responsiveness, or elasticity, of demand and supply. Relative to just meeting the existing standard, W126 index values decrease in the Southwest, West, Central, Southeast, South, East North Central, and West North Central regions at alternative standard levels of 15, 11, and 7 ppm-hrs. These decreases in W126 index values are estimated to result in changes in patterns for agricultural production and resulting consumer and producer surplus. For example, with reductions in W126 index values, wheat crops would likely increase in one of its major production regions, the Southwest region. This expansion of wheat production may result in a decrease in wheat production in the East North Central region. The East North Central region would likely see production changes for other crops because the contraction in wheat production makes room for alternatives. Soybean production in the East North Central region would likely expand, and this expansion would induce regional shifts of soybean production at the national level, including decreases in soybean production in the West North Central and Central regions. Generally the crop producers' surplus in the Central and Southwest regions would increase and in the South region would decrease. Crop producers' surplus in the West North Central and East North Central regions would fluctuate over time.

Economic welfare impacts resulting from just meeting the existing and alternative standards were largely similar between the forestry and agricultural sectors -- consumer surplus,

[9] Among the major crops, because winter wheat and soybeans are more sensitive to ambient O_3 levels than other crops we include these crops for this discussion.

[10] See Chapter 6, Section 6.3 for a brief discussion of economic welfare and consumer and producer surplus.

or consumer gains, generally increased in both sectors because higher productivity under lower W126 index values increased total yields and reduced market prices. Because demand for most forestry and agricultural commodities is not highly responsive to changes in price, there were more cases where producer surplus, or producer gains, decline. In some cases, lower prices reduce producer gains more than can be offset by higher yields. For example, in 2040, the year with maximum changes in consumer and producer surplus, in the forestry sector at just meeting the existing standard, total producer surplus is estimated to be $133 billion and total consumer surplus is estimated to be $935 billion, or 7 times greater than producer surplus. For the forestry sector, when adjusting to meeting alternative W126 standard levels 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.[11]

In the analysis for changes in carbon sequestration related to biomass loss, relative to just meeting the existing standard, the 15 ppm-hrs W126 alternative standard level 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 alternative secondary W126 standard levels at 11 and 7 ppm-hrs. In the forestry sector, relative to just meeting the existing standard (with sequestration of 89 billion metric tons of CO_2 equivalents), at alternative W126 standard levels of 11 and 7 ppm-hrs carbon sequestration potential is projected to increase 593 million and 1.6 billion metric tons of CO_2 equivalents over 30 years (i.e., 0.66 and 1.79 percent) respectively. For the agricultural sector, relative to just meeting the existing standard (with sequestration of 8 billion metric tons of CO_2 equivalents), at alternative W126 standard levels of 11 and 7 ppm-hrs carbon sequestration potential is projected to increase 9 and 10 million metric tons of CO_2 equivalents respectively over 30 years, or about 0.1 percent.

[11] FASOMGHG is an international model and the increase in productivity caused by a reduction in O_3 results in a net increase in the present value of total global economic surplus (consumer + producer surplus). For any given year, there may be a decline in global consumer and producer surplus due to the effects on the dynamics of planting and harvesting decisions in the forestry sector.

8.2.1.4 **Visible Foliar Injury**

To assess the effects of visible foliar injury on recreation, we reviewed the National Survey on Recreation and the Environment (NSRE), as well as the 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (FHWAR) and a 2006 analysis done for the Outdoor Industry Foundation (OIF). According to the NSRE, some of the most popular outdoor activities are walking, including day hiking and backpacking; camping; bird watching; wildlife watching; and nature viewing. Participant satisfaction with these activities can depend on the quality of the natural scenery, which can be adversely affected by O_3-related visible foliar injury. According to the FHWAR and the OIF reports, the total expenditures across wildlife watching activities, trail-based activities, and camp-based activities are approximately $200 billion dollars annually. While we cannot quantify the magnitude of the impacts of O_3 damage to the scenic beauty and outdoor recreation, the existing losses associated with current O_3-related foliar injury are reflected in reduced outdoor recreation expenditures.

To assess foliar injury at a national-scale, we conducted several analyses using a national data set on foliar injury from the USFS's Forest Health Monitoring (FHM) Network. We conducted the analyses representing the prevalence (i.e., presence/absence) of foliar injury across years and different soil moisture categories in NOAA climate divisions.[12] Across years, when assessing the presence or absence of foliar injury, at an alternative W126 standard level of 15 ppm-hrs between 12 and over 20 percent of biosites indicated the presence of foliar injury; at an alternative W126 standard level of 11 ppm-hrs between 12 and over 20 percent of biosites indicated the presence of foliar injury; and at an alternative W126 standard level of 7 ppm-hrs between 4 and over 20 percent of biosites indicated the presence of foliar injury.[13] Generally, the results of all of these foliar injury analyses demonstrate a similar pattern – the proportion of biosites[14] showing foliar injury increases steeply with W126 index values up to approximately 10 ppm-hrs and is relatively constant above 10 ppm-hrs. This analysis suggests that reductions in W126 index values at or above this benchmark (W126 > 10.46 ppm-hrs) are unlikely to

[12] See Chapter 7, Section 7.2 for a more detailed discussion of the data on biosites and foliar injury from the USFS and the Palmer Z drought index data from NOAA.

[13] See Chapter 7, Section 7.2.3 for additional discussion and Figure 7-8 for additional information. The proportion of sites with foliar injury present varies by year, creating these ranges for percent of sites with foliar injury present.

[14] 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.

substantially reduce the prevalence of foliar injury. Similarly, this analysis suggests that reductions below 10 ppm-hrs are likely to relatively sharply reduce the prevalence of foliar injury. Figure 8-2, which originally appears as Figure 7-10 in Chapter 7, shows the pattern seen in the foliar injury analyses stratified by soil moisture category. We see a similar pattern when the foliar injury is stratified by year. See Section 7.2.3 for a more detailed discussion of the national-scale analyses. In addition, in Appendix 7A (Table 7A-27) we include the percentage of all biosites across all years (2006 – 2010) showing foliar injury at alternative secondary standard levels. At an alternative secondary standard of 15 ppm-hrs, 18.1 percent of all biosites show foliar injury; at 11 ppm-hrs, 17.8 percent of all biosites show foliar injury; and at 7 ppm-hrs, 15.8 percent of all biosites show foliar injury.

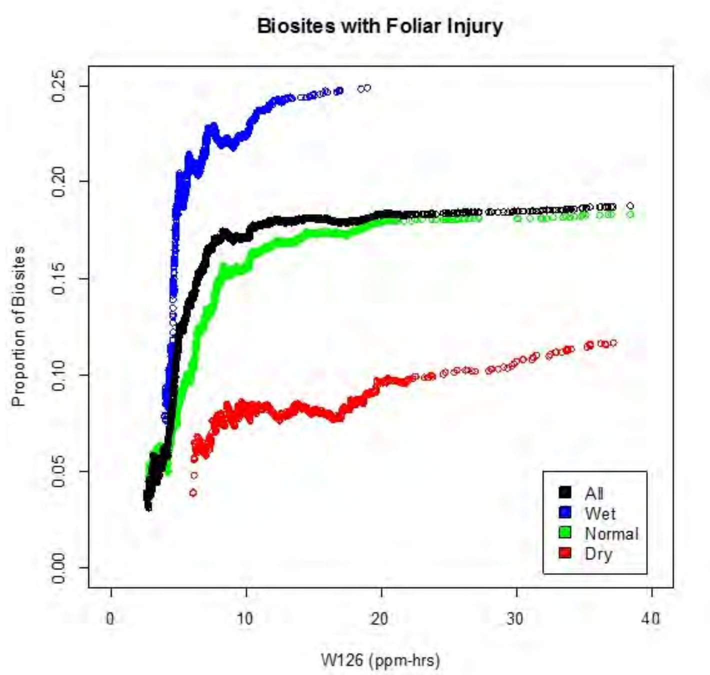

Figure 8-2 Cumulative Proportion of Biosites with Visible Foliar Injury Present, by Moisture Category

Enjoyment of recreation in national parks can be adversely affected by visible foliar injury, and national parks are areas designated for protection. We used the results of the national analysis to derive benchmarks for visible foliar injury that we apply in a screening-level assessment and case studies of national parks. We define five scenarios for evaluating potential

W126 benchmarks, representing the full range of the percentages of biosites showing visible foliar injury, including four scenarios considering soil moisture. We defined the W126 benchmark for the "base scenario" as the W126 index value where the slope of exposure-response relationship changes for all FHM biosites in all soil moisture categories. We also looked at additional scenarios based on three different categories of soil moisture (i.e., wet, normal, and dry) and the W126 index values associated with four different prevalences (e.g., 5 percent, 10 percent, 15 percent and 20 percent of biosites) of any foliar injury. In total, the welfare risk and exposure assessment evaluated ten different W126 benchmarks associated with the five foliar injury risk scenarios. The W126 benchmarks across the five 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). See Table 7-6 for the specific benchmark criteria corresponding to each of the five scenarios.

The general approach in the screening-level assessment of national parks is derived from Kohut (2007), but we apply more recent O_3 exposure and soil moisture data for 214 national parks in the contiguous U.S. combined with the benchmarks derived from the national-scale analysis. 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 three years within the 2006-2010 period. 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 three-year average air quality surfaces. However, we can observe that after adjusting the W126 surfaces to just meet the existing standard, all of the 214 parks are below 10.46 ppm-hrs, which corresponds to the W126 benchmark for the base scenario.

8.2.2 Case Study-Scale Analyses

8.2.2.1 Fire Regulation

As indicated in Chapter 5, fire regime regulation is also negatively affected by O_3 exposure. For example, Grulke et al. (2009) reported various lines of evidence indicating that O_3

exposure may contribute to southern California forest susceptibility to wildfires by increasing leaf turnover rates and litter, increasing fuel loads on the forest floor. According to the National Interagency Fire Center, in the U.S. in 2010 over 3 million acres burned in wildland fires. From 2004 to 2008, Southern California alone experienced, on average, over 4,000 fires per year burning, on average, over 400,000 acres per year. The California Department of Forestry and Fire Protection (CAL FIRE) estimated that losses to homes due to wildfire were over $250 million in 2007 (CAL FIRE, 2008). In 2008, CAL FIRE's costs for fire suppression activities were nearly $300 million (CAL FIRE, 2008).

We developed maps that overlay the mixed conifer forest area of California with areas of moderate or high fire risk defined by CAL FIRE and with surfaces of recent conditions and surfaces adjusted to just meet existing and alternative standards. The highest fire risk and highest W126 index values 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 was over 7 ppm-hrs with a moderate to severe fire risk, and 74 percent was over 15 ppm-hrs with a moderate to severe fire risk. When adjusted to just meet the existing standard, almost all of the mixed conifer forest area with a moderate to high fire risk shows a reduction in O_3 to below 7 ppm-hrs. At the alternative W126 standard level of 15 ppm-hrs, all but 0.18 percent of the area is below 7 ppm-hrs, and at alternative standard levels of 11 and 7 ppm-hrs all of the moderate to high fire threat area is below 7 ppm-hrs.

8.2.2.2 **Biomass Loss**

Using the iTree model to estimate tree growth and ecosystem services provided by trees over a 25-year period, we conducted case-study scale analyses to quantify the effects of biomass loss on carbon sequestration and pollution removal in five urban areas.[15] See Appendix 6D for details on the iTree model and the methodology used for the case study analyses.

We estimated the effects of O_3-related biomass loss on carbon sequestration and ran five scenarios, including current conditions, just meeting the existing standard, and just meeting alternative W126 standards of 15, 11, and 7 ppm-hrs. While both urban and non-urban forests have the potential to remove pollutants from the atmosphere, using iTree we also estimated the

[15] The iTree model is a peer-reviewed suite of software tools provided by USFS.

effects of O_3-related biomass loss on the potential to remove carbon monoxide, nitrogen dioxide, O_3, and sulfur dioxide pollution in the five urban areas (1) at recent ambient O_3 conditions and (2) after adjusting air quality to just meet the existing standard and alternative W126 standard levels of 15, 11, and 7 ppm-hrs. As a supplement to the iTree analysis, we also performed a simple analysis of the O_3 pollution removal potential to show how this process might affect ambient air quality values. This analysis made some general assumptions to estimate order of magnitude effects of O_3 removal by trees in the five urban areas. The results indicate that the effects on O_3 concentrations are small; when meeting the current standard, deposition to tree surfaces results in ambient O_3 concentration reductions ranging from 0.08 parts per billion by volume (ppbv) in Tennessee to 0.52 ppbv in Chicago compared to O_3 concentrations that would occur without any deposition to trees in these cities.[16] Relative changes in ambient O_3 concentrations due to changes in deposition to tree surfaces were much smaller.

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 alternative W126 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. Syracuse and Baltimore do not realize gains in carbon sequestration because recent air quality almost meets the alternative standards levels in those areas. Similar to changes in carbon sequestration, Syracuse and Baltimore have no change in pollution removal when just meeting the existing standard and the W126 alternative standards. Atlanta, Chicago, and the urban areas of Tennessee show gains in potential pollution removal at alternative W126 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.

[16] The ratio of O_3 volume to urban area air volume multiplied by 10^9 gives the concentration in ppbv.

8.2.2.3 **Foliar Injury – Three National Parks**

In addition to the national-scale analysis, we also assess foliar injury at a case-study scale because national parks are designated as special areas in need of protection. Specifically, we assess O_3-exposure risk at three national parks – Great Smoky Mountains National Park (GRSM), Rocky Mountain National Park (ROMO), and Sequoia/Kings Canyon National Parks (SEKI). 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 elevated W126 index values.

In GRSM, there are 37 sensitive species across vegetative strata, and 2011 visitor spending exceeded $800 million. W126 index values in GRSM have been among the highest in the eastern U.S. -- under recent ambient conditions, 44 percent of GRSM is over 15 ppm-hrs. After adjustments to just meet the existing standard of 75 ppb, no area in GRSM exceeds 7 ppm-hrs. ROMO has seven sensitive species, including Quaking Aspen. In 2011 visitor spending at ROMO was over $170 million. Under recent ambient conditions, all of ROMO is over 15 ppm-hrs. When adjusted to just meet the existing standard, 41 percent of the park would be below 7 ppm-hrs and 59 percent of the park would be between 7 and 11 ppm-hrs. In SEKI 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 SEKI is above 7 ppm-hrs.

8.3 Patterns of Risk

Considering the national- and case study-scale analyses and appropriate benchmarks for biomass loss and foliar injury, we reviewed whether there were patterns or trends in the risk and risk reductions – between geographic areas and across years and alternative standards. For biomass loss, 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 (Frey and Samet, 2012b). For trees, annual W126 index values for a one percent biomass loss range from approximately 4 to 10 ppm-hrs and for a two percent biomass loss range from approximately 7 to 14 ppm-hrs. For crops, annual W126 index values for a five percent biomass loss range from approximately 12 to 17 ppm-hrs. Based on this assessment, the pattern is that crops exceed CASAC's benchmarks at higher W126 index values than trees, and suggests that meeting alternative standards that are protective of trees will also protect crops. Unlike biomass, CASAC did not recommend a benchmark for foliar injury. As a result, we developed a set of W126 benchmark criteria ("scenarios") associated with the prevalence (i.e., presence/absence) of foliar injury across years and different soil moisture categories.

8.3.1 Risk Patterns Across or Between Geographic Areas

The geographic or spatial patterns of changes in W126 index values and changes in ecosystem services and related economic welfare are slightly different. Figure 8-3 and Figure 8-4, which originally appear as Figures 4-9 and 4-11 in Chapter 4, show the W126 index values after being adjusted to just meet alternative standards of 15 and 11 ppm-hrs. After adjusting to just meet an alternative standard of 15 ppm-hrs, the West, Southwest, and Central regions show the highest W126 index values between 11 and 15 ppm-hrs; after adjusting to just meet an alternative standard level of 11 ppm-hrs, all areas show W126 index values below 11 ppm-hrs. The analyses of biomass loss and affected timber and agricultural yields show that most of the remaining risk after adjusting to just meet an alternative standard level of 15 ppm-hrs is in the Southwest, South, Southeast, and Central regions; after adjusting to just meet an alternative standard level of 11 ppm-hrs, most of the remaining risk is in the South, Southeast, and Central regions.

General references to the eastern and western U.S. and the states included in the NOAA NCDC regions differ. For ease of discussion, below we align the general U.S. region and NCDC region references.

General U.S.	**NCDC**
Western U.S.	Northwest
	West
	Southwest
	West North Central
Eastern U.S.	East North Central
	Central
	South
	Southeast
	Northeast

There is substantial heterogeneity in plant responses to O_3, both within species, between species, and across regions of the U.S. The O_3-sensitive tree species are different in the eastern and western U.S. -- the eastern U.S. has far more total species (see text box for clarification on region names). O_3 exposure and risk are somewhat easier to assess in the eastern U.S. because of the availability of more data and the greater number of species to analyze. In addition, there are more O_3 monitors in the eastern U.S. but fewer national parks. In the national-scale analyses for commercial timber production, because most areas are below 15 ppm-hrs after simulating just meeting the existing standard, RYL are below one percent, with the exception of the Southwest, Southeast, Central, and South regions. In part because the South and Southeast regions have more forest land, RYL remain above one percent for parts of those regions even after just meeting an alternative W126 standard level of 7 ppm-hrs.

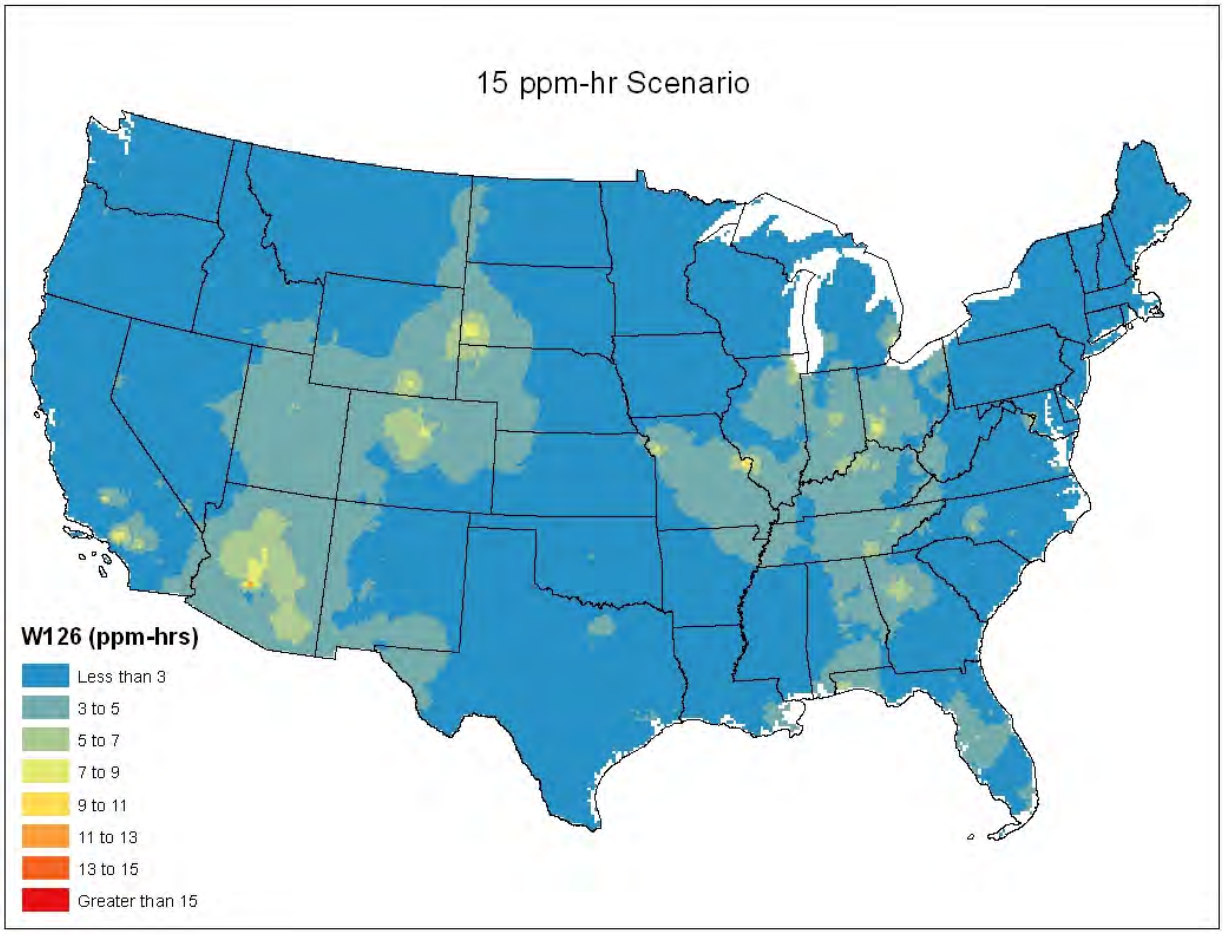

Figure 8-3 National Surface of 2006-2008 Average W126 Index Values Adjusted to Just Meet the Alternative Standard Level of 15 ppm-hrs

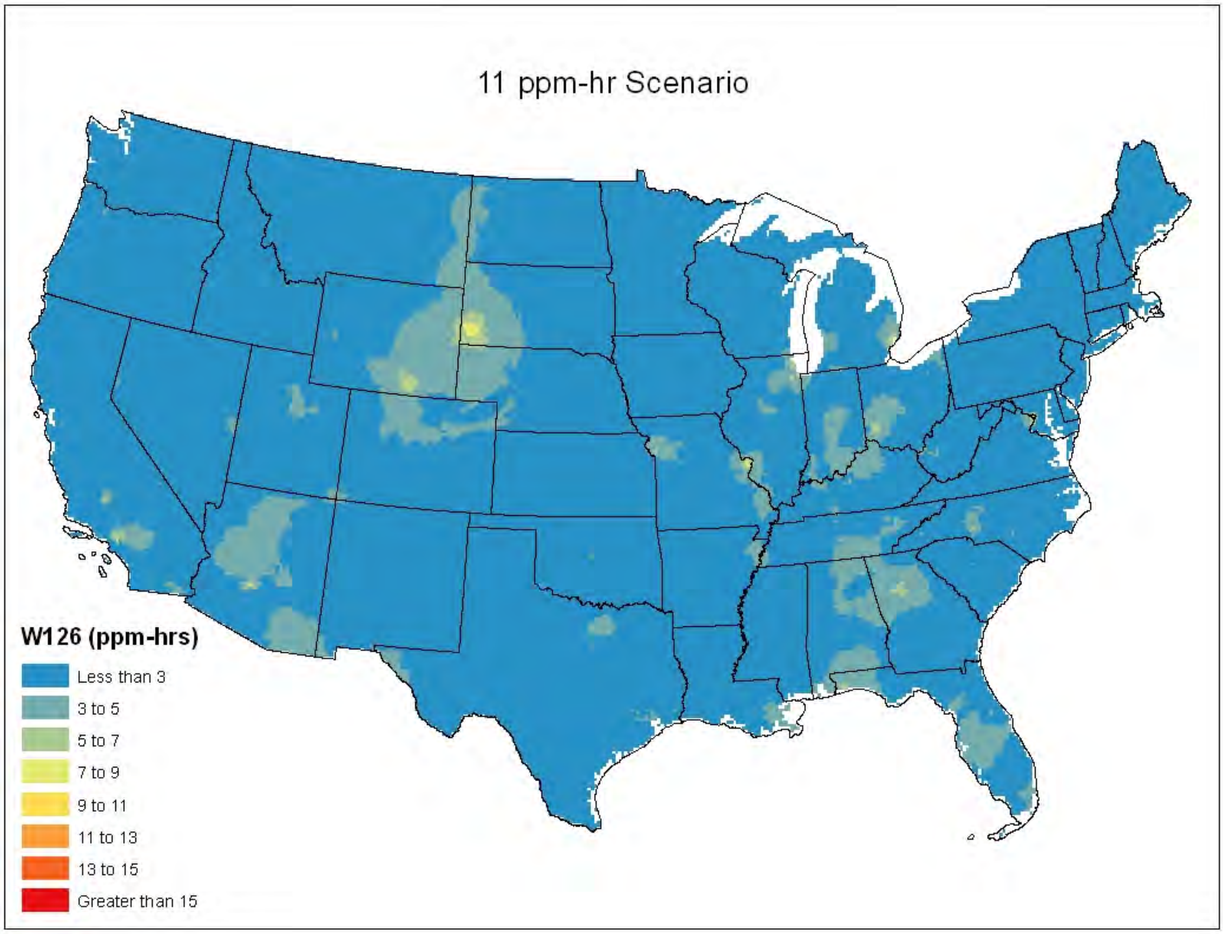

Figure 8-4 National Surface of 2006-2008 Average W126 Index Values Adjusted to Just Meet the Alternative Standard Level of 11 ppm-hrs

The largest improvements in agricultural harvesting resulting from reduced O_3 exposure are likely to occur in the West, Southwest, South, Southeast, and Central regions because those regions (1) have the most sensitive crop species present, (2) have significant agricultural production, and (3) will experience the most significant air quality improvement between recent conditions and just meeting the existing secondary standard. For soybeans, when the W126 scenarios are modeled, yield losses above both five and one percent remain at 15 ppm-hrs for the Southwest and Central regions. For all regions, yield losses are reduced to below five and one percent at alternative W126 standard levels of 11 and 7 ppm-hrs.

8.3.2 Risk Patterns Across Years

Using the FASOMGHG model to calculate forestry and agricultural yield changes, we estimated changes in consumer and producer surplus from 2010 through 2040 for alternative standard levels of 15, 11, and 7 ppm-hrs. Over the period in the forestry sector, changes in consumer surplus are always positive and range from <0.01 percent in 2010 for alternative standard levels of 15 and 11 ppm-hrs up to 0.08 percent in 2040 for alternative standard levels of 11 and 7 ppm-hrs (relative to consumer surplus at just meeting the existing standard of $721 billion in 2010 and $934 billion in 2040 (2010$)). Consumer surplus does not consistently increase between 5-year periods from 2010 to 2040.[17] For example, while always a positive value, consumer surplus decreases between 2025 and 2030, increases slightly between 2030 and 2035, and increases significantly between 2035 and 2040. Changes in producer surplus are generally negative and range from <-0.1 percent in 2010 for an alternative standard level of 7 ppm-hrs to -0.6 percent in 2040 for alternative standard levels of 15 and 11 ppm-hrs (relative to producer surplus at just meeting the existing standard of between $93 billion in 2010 and $133 billion in 2040).

In the agricultural sector over the period, changes in consumer surplus are generally positive and <0.01 percent (relative to consumer surplus at just meeting the existing standard of between $1.9 trillion in 2010 and $2.1 trillion in 2040 (2010$)). Changes in producer surplus vary and range from -0.2 percent in 2015 for alternative standard levels of 11 and 7 ppm-hrs to 0.25 and 0.35 percent in 2040 for alternative standard levels of 11 and 7 ppm-hrs (relative to producer surplus at just meeting the existing standard of between $725 billion in 2010 and $863 billion in 2040). At just meeting the existing standard, total consumer and producer surplus values are much higher in the agricultural sector than in the forestry sector. As a result, absolute changes in consumer and producer surplus values at alternative standard levels are much larger in the agricultural sector. In the agricultural sector, over time and by alternative standard, changes in consumer surplus are largely positive, with approximately 15 percent of the estimates being minor negative changes. Over time and by alternative standard, changes in producer

[17] FASOMGHG results include multi-period, multi-commodity results over 60 to 100 years in 5-year time intervals when running the combined forest-agriculture version of the model.

surplus are mixed, with approximately 30 percent of the estimates being significant negative changes. See Section 6.5 and Appendix 6B for additional discussion of these analyses.

In the national-scale assessment to identify foliar injury benchmarks, we conducted analyses using a national data set on foliar injury. Across years in the data set, we analyzed presence/absence of foliar injury. Generally, 2010 showed a more dramatic rise in the proportion of sites showing the presence of foliar injury below 10 ppm-hrs, and 2006 through 2009 showed a more subtle pattern. Figure 8-5 below, which originally appears as Figure 7-9 in Chapter 7, shows the pattern for presence/absence of foliar injury across years.

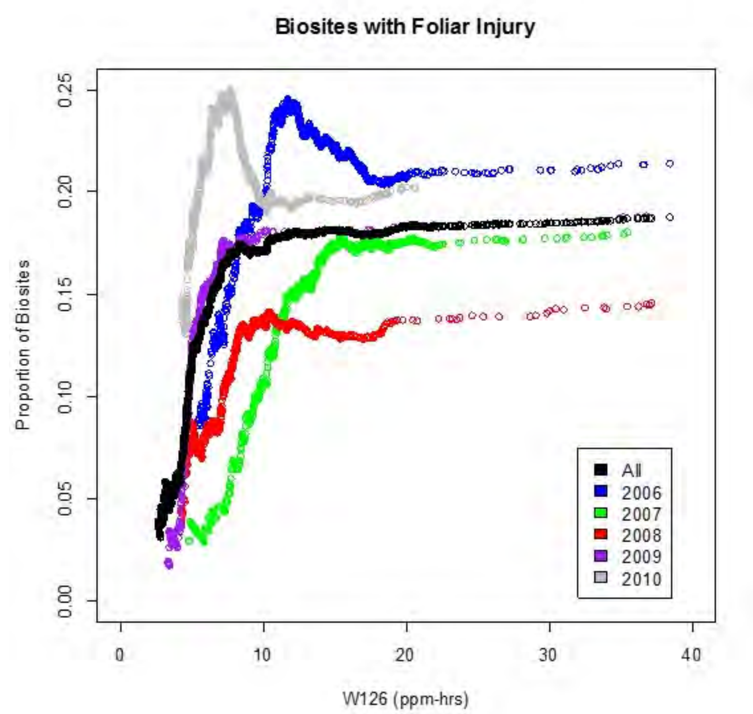

Figure 8-5 Cumulative Proportion of Sites with Foliar Injury Present, by Year

In addition to the above foliar injury analyses, the screening-level assessment for 214 national parks assessed foliar injury in individual years. This assessment, which was based on W126 index values and soil moisture that varied temporally, concluded that O_3-related foliar injury risk in parks was generally lower in the 2008-2010 time period than in the 2006-2008 time period. For the base scenario, 2009 represented the year with the lowest percentage of parks exceeding the benchmark criteria (i.e., only 12 percent of parks) and 2006 represented the year with the highest percentage of parks exceeding the benchmark criteria (i.e., 80 percent of parks). Further, this assessment determined that the three-month timeframe corresponding to the highest W126 estimates in monitored parks occurred between March and September, which roughly corresponds to the vegetation growing season.

8.3.3 Risk Patterns Across Alternative W126 Standard Levels

For the ecological effect of biomass loss, O_3-related exposure and risk decrease at lower alternative W126 standard levels. For the ecological effect of foliar injury, changes in O_3-related exposure and risk at lower alternative W126 standard levels are more challenging to directly assess because we do not have E-R functions to assess changes in foliar injury across different W126 index values. However, we observe that after just meeting the existing standard, all of the 214 parks are below 10.46 ppm-hrs, which corresponds to the W126 benchmark for the base scenario. See Table 8-1 and Table 8-2 for a summary of risk across alternative W126 standard levels for these two ecological effects.

Table 8-1 Summary of O_3-Exposure Risk Across Alternative W126 Standards Relative to Just Meeting Existing Standard – National-Scale Analyses

		15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Ecological Effect				
Biomass Loss	Average Weighted RBL Loss for Tree Seedlings (Section 6.8)	Percent of Covered Area exceeding 1 and 2 percent weighted RBL **declines by about 0.3 percent**	Percent of Covered Area exceeding 1 and 2 percent weighted RBL **declines by between 0.5 and 1.3 percent**	Percent of Covered Area exceeding 1 and 2 percent weighted RBL **declines by between 0.6 and 2 percent**
Ecosystem Services				
Provisioning	Timber Production (Section 6.3)	All regions RYL **below 1 percent**.	All regions RYL **below 1 percent**.	All regions RYL **below 1 percent**.
	Consumer and Producer Surplus (2010$) - Forestry (Section 6.3)	**Consumer surplus –** in 2010 is $7 million, or 0.01% and in 2040 is $597 million, or 0.06% **Producer surplus –** in 2010 is -$11 million, or -0.01% and in 2040 is -$839 million, or -0.6%	**Consumer surplus –** in 2010 is $44 million, or 0.01% and in 2040 is $712 million, or 0.08% **Producer surplus –** in 2010 is -$41 million, or -0.04% and in 2040 is -$858 million, or -0.6%	**Consumer surplus –** in 2010 is $86 million, or 0.01% and in 2040 is $779 million, or 0.08% **Producer surplus –** in 2010 is -$136 million, or -0.15% and in 2040 is -$766 million, or -0.6%
	Agricultural Harvest (Section 6.5)	For some sensitive crops (soybeans), RYL remain **> 1 percent** in the Southwest and Central regions. All other regions RYL **below 1 percent**.	For most sensitive crops, RYL **< 1 percent.**	For most sensitive crops, RYL **< 1 percent.**
	Consumer and Producer Surplus (2010$) - Agriculture (Section 6.5)	**Consumer surplus –** in 2010 is $15 million, or <0.01% and in 2040 is $3 million, or <0.01% **Producer surplus** – in 2010 is $612 million, or 0.08%; in 2015 is -$1,255 million, or -0.15%; and in 2040 is $697 million, or 0.08%	**Consumer surplus –** in 2010 is $19 million, or <0.01% and in 2040 is $13 million, or <0.01% **Producer surplus** – in 2010 is $1,474 million, or 0.2%; in 2015 is -$2,197 million, or -0.26%; and in 2040 is $2,189 million, or 0.25%	**Consumer surplus –** in 2010 is -$31 million, or <0.01% and in 2040 is $46 million, or <0.01% **Producer surplus** – in 2010 is $269 million, or 0.04%; in 2015 is -$1,873 million, or -0.23%; and in 2040 is $2,991 million, or 0.3%
Regulating	Carbon Sequestration (Section 6.6.1)	Little change compared to just meeting existing standard	In forestry sector, storage potential is projected to increase 593 million metric tons of CO_2 equivalents ($CO2_e$), or 0.66 percent, over 30 years. In agricultural sector, storage potential is projected to increase 9 million metric tons of $CO2_e$, or about 0.1 percent, over 30 years.	In forestry sector, storage potential is projected to increase 1.6 billion metric tons of $CO2_e$, or 1.79 percent, over 30 years. In agricultural sector, storage potential is projected to increase 10 million metric tons of $CO2_e$, or 0.1 percent, over 30 years.

Table 8-1 Summary of O_3-Exposure Risk Across Alternative W126 Standards Relative to Just Meeting Existing Standard – National-Scale Analyses, continued

		15 ppm-hrs	**11 ppm-hrs**	**7 ppm-hrs**
Ecological Effect				
Foliar Injury	National-Scale Foliar Injury Analysis[18] (Section 7.2 and Appendix 7A)	Depending on year, **between 12 and >20 percent** of biosites showed presence/absence of foliar injury during 2006 to 2010 Across all years, 18.1 percent of biosites showed presence/absence of foliar injury during 2006 to 2010 Depending on moisture category, **between 7 and >20 percent** of biosites showed presence/absence of foliar injury during 2006 to 2010	Depending on year, **between 12 and >20 percent** of biosites showed presence/absence of foliar injury during 2006 to 2010 Across all years, 17.8 percent of biosites showed presence/absence of foliar injury during 2006 to 2010 Depending on moisture category, **between 7 and >20 percent** of biosites showed presence/absence of foliar injury during 2006 to 2010	Depending on year, **between 4 and > 20 percent** of biosites showed presence/absence of foliar injury during 2006 to 2010 Across all years, 15.8 percent of biosites showed presence/absence of foliar injury during 2006 to 2010 Depending on moisture category, **between 7 and >20 percent** of biosites showed presence/absence of foliar injury during 2006 to 2010

[18] This analysis is not relative to just meeting the existing standard, but is a national-scale analysis that summarizes foliar injury at different levels.

Table 8-2 Summary of O_3-Exposure Risk Across Alternative Standards Relative to Just Meeting Existing Standard – Case Study-Scale Analyses

		15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Ecosystem Services				
Regulating (Biomass Loss)	Carbon Sequestration (Section 6.6.2 – Five Urban Areas)	W126 index values and carbon storage potential do not change relative to just meeting existing standard	Atlanta, Chicago, and the urban areas of Tennessee show gains in carbon sequestration. For example, urban areas of Tennessee gain about 8,800 tons of sequestration annually. Syracuse and Baltimore do not realize gains because recent W126 index values almost meet the alternative standards levels.	Atlanta, Chicago, and the urban areas of Tennessee show gains in carbon sequestration. For example, urban areas of Tennessee gain about 20,000 tons of sequestration annually. Syracuse and Baltimore do not realize gains because recent W126 index values almost meet the alternative standards levels.
	Pollution Removal (Section 6.7 – Five Urban Areas)	W126 index values and pollution potential do not change relative to just meeting existing standard	Atlanta, Chicago, and the urban areas of Tennessee show gains in pollution removal. For example, urban areas of Tennessee gain about 5,300 tons of pollution removal annually. Syracuse and Baltimore do not realize gains because recent W126 index values almost meet the alternative standards levels.	Atlanta, Chicago, and the urban areas of Tennessee show gains in pollution removal. For example, urban areas of Tennessee gain about 11,700 tons of pollution removal annually. Syracuse and Baltimore do not realize gains because recent W126 index values almost meet the alternative standards levels.
Ecosystem Services				
Cultural (Foliar Injury)	Recreation in National Parks – Case Studies (Section 7.4) Recreation in National Parks – Screening-Level Assessment (Section 7.3)	Rocky Mountain National Park – **No area of park exceeds** 15 ppm-hrs when adjusted to just meet the existing standard Great Smoky Mountains National Park and Sequoia/Kings National Park -- **No area of parks exceeds** 15 ppm-hrs when adjusted to just meet the existing standard In screening-level assessment, of 214 parks, 3 parks remain above 7 ppm-hrs after adjusted to 15 ppm-hrs	Rocky Mountain National Park – **59 percent of the park** would be between 11 and 7 ppm-hrs when adjusted to just meet the existing standard Great Smoky Mountains National Park and Sequoia/Kings National Park -- **No area of parks exceeds** 11 ppm-hrs when adjusted to just meet the existing standard In screening-level assessment, of 214 parks, 2 parks remain above 7 ppm-hrs after adjusted to 11 ppm-hrs	Rocky Mountain National Park – **59 percent of the park** would be between 11 and 7 ppm-hrs when adjusted to just meet the existing standard Great Smoky Mountains National Park and Sequoia/Kings National Park -- **No area of parks exceeds** 7 ppm-hrs when adjusted to just meet the existing standard In screening-level assessment, of 214 parks, no parks remain above 7 ppm-hrs after adjusted to 7 ppm-hrs

8.4 Representativeness

In conducting the national and case-study scale analyses of ecological effects and resulting impacts on ecosystem services, we worked to reflect appropriate representation of vegetation species, geographic regions, and timeframes. The following briefly discusses the representativeness across species, geography, and time in our analyses.

8.4.1 Species Representativeness

To estimate the effect of O_3 exposure on biomass loss, we used data on 12 tree species and 10 crop species. The 12 species represent a range of sensitivities normally distributed around intermediately sensitive species. Several species are not very sensitive, two species are relatively sensitive, and the remainder of the species represent moderately sensitive species. The data on the 12 species facilitate representation of other species for which we do not have data. For tree species, we used data for areas with at least one of the tree species present, resulting in approximately 46.6 percent of the contiguous U.S. constituting the area being assessed. For 74 percent of the area being assessed, the species we know about made up 50 percent or less of total basal area cover. For another 12 percent of the area being assessed, the species we know about made up between 50 and 75 percent of total basal area cover. For the remaining 14 percent of the area being assessed, the species we know about made up over 75 percent of total basal area cover. Although we know that there are additional O_3-sensitive species, we do not have E-R functions for those species. We also used these E-R functions for the tree and crop species in FASOMGHG, and to better employ the dynamic tradeoffs within the model, FASOMGHG assigns proxy functions for O_3 exposure E-R functions for additional species. For the iTree case-study scale analysis on carbon sequestration and pollution removal, we chose the five urban areas based on data availability and presence of species with a W126 E-R function. No urban areas with available vegetation data had more than three sensitive species present. Unlike FASOMGHG, the iTree model does not provide tradeoffs between species, so the species that do not have an E-R function were not assigned values, and thus were not part of the carbon sequestration and pollution removal estimates. Therefore, the majority of trees in those urban areas were not accounted for in the O_3 damages. For example, there are three tree species present in these areas that we know are sensitive but for which no E-R function is available, excluding 80 to 90 percent of the total trees present in these two study areas. The species include northern red oak in Baltimore and southern red oak and tulip tree in Atlanta.

We also qualitatively discuss many additional ecological effects and ecosystem services for which we do not have data to assess quantitatively; those ecological effects and related ecosystem services include supporting services such as net primary productivity; regulating services such as hydrologic cycle and pollination; provisioning services such as commercial non-timber forest products; and cultural services such as recreation, aesthetic and non-use values. In addition, other ecological effects that are causally or likely causally associated with O_3 exposure are not directly addressed in this risk and exposure assessment. These ecological effects include terrestrial productivity, water cycle, biogeochemical cycle, and community composition.[19]

8.4.2 Geographic Representativeness

Nine of the 12 tree species used in the biomass analyses were in the eastern U.S. and three were in the western U.S., with a few species such as Aspen and Cottonwood in both the eastern and western U.S. For the biomass loss analyses, by region we include the total basal area covered by the 12 tree species assessed. In parts of the eastern U.S. – the Central, East North Central, and Northeast regions -- from less than 1 percent to 4 percent of basal area assessed had no data on percent cover of the 12 tree species. In contrast, in parts of the western U.S. – Southwest, West, West North Central regions -- from 47 percent to 74 percent of basal area assessed had no data on percent cover of the 12 tree species.

We applied E-R functions for 12 tree species and 10 crop species in FASOMGHG to estimate nationwide effects on timber production, agricultural harvest, and carbon sequestration. While we used available E-R functions for tree and crop species, as well as the available models, we had differential and inconsistent species coverage across the U.S., e.g., data were available for more species in the eastern U.S. than in the western U.S. In addition, to assess overall ecosystem-level effects from biomass loss, we combined the RBL values for multiple tree species into a weighted RBL value and considered the weighted value in relation to proportion of basal area covered, both nationally and in Class I areas.

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[19] For additional details on these other ecological effects, see Table 2-4 of the *Integrated Science Assessment for Ozone and Related Photochemical Oxidants* (U.S. EPA, 2013).

Also, in estimating the effect of O_3 exposure on biomass loss and resulting changes in carbon sequestration and pollution removal capacity, for case-study scale analysis we used the iTree model and data from five urban areas. The urban areas represent diverse geography in the Northeast, Southeast, and Central regions, but we did not assess an urban area in the western part of the U.S. Based on the monitored data from 2006 to 2008, Atlanta, Baltimore, and the urban areas in Tennessee are over 20 ppm-hrs, with Atlanta having the highest W126 index value. After adjusting to just meet the existing standard, all of the urban areas are between 5 and 7 ppm-hrs. Because there are more monitors in urban areas in the eastern U.S., we focused on urban areas in the eastern U.S. for the case-study analyses.

For the national-scale foliar injury analysis, the biosite data covered most of the contiguous U.S., with less coverage in the Southwest, West and West North Central regions. In assessing foliar injury at parks, we conducted a screening-level assessment, as well as a case-study scale analysis of national parks. In assessing foliar injury at the case-study scale, the three national parks represent diverse geographic areas -- in the Southeast/Central (GRSM), the Southwest (ROMO), and the West (SEKI). In the screening-level assessment of foliar injury, we included 214 parks, which reflects nearly all of the parks managed by the National Park Service (NPS) in the contiguous U.S.

8.4.3 Temporal Representativeness

For the national-scale analyses of foliar injury, the national-scale surfaces used represented the individual years of 2006 through 2010. Monitored O_3 index values in those years vary considerably, and those years represent a reasonable range of meteorological conditions that affect O_3 formation. The period also includes years with varying categories of soil moisture, which impacts the sensitivity of plants to foliar injury.

The biomass loss analysis relied upon the national-scale air quality surfaces adjusted to just meet the existing and alternative standards for 2006 to 2008 (three-year average). Because the forestry and agriculture sectors are interlinked and factors affecting one sector can lead to changes in the other, we considered overall effects on producers and consumers associated with just meeting alternative W126 standard levels over time and across sectors. In estimating the effect of O_3 exposure on biomass loss and ecosystem services, we used the E-R functions for 12 tree seedlings to estimate relative yield changes over the entire lifespan of the trees, including percentage changes in national timber product market prices through 2040. At the national scale, we estimated changes in carbon sequestration by forests and agriculture through 2040. At the case-study scale, we estimated changes in carbon sequestration and pollution removal capacity in the five urban areas over a 25-year period.

8.5 Overall Confidence in Welfare Exposure and Risk Results

There are several important factors to consider when evaluating the overall confidence we can express about the estimates of exposures and risks associated with just meeting the existing and potential alternative W126 secondary standards. Foremost, we must consider the strength of the underlying body of scientific evidence. In addition, as with any complex analysis using estimated parameters and inputs from numerous data sources and models, there are many sources of uncertainty that may affect estimated results. Despite these uncertainties, the overall body of scientific evidence underlying the ecological effects and associated ecosystem services evaluated in this assessment is strong, and the methods used to quantify associated risks are scientifically sound.

The overall effect of the combined set of uncertainties on confidence in the interpretation of the results of the analyses is difficult to quantify. Due to differences in available information, the degree to which each analysis was able to incorporate quantitative assessments of uncertainty differed. In general, we followed the WHO tiered approach to uncertainty characterization, which includes both quantitative and qualitative assessments. Chapters 4, 5, 6, and 7 include tables identifying and characterizing the potential impact of key uncertainties on risk estimates, including the degree to which we were able to quantitatively address those uncertainties. Below we summarize several key limitations and uncertainties, but these uncertainties do not change our conclusions regarding overall confidence and confidence in the individual analyses.

8.5.1 Confidence and Key Uncertainties in Air Quality Analyses

Because the W126 estimates generated in the air quality analyses are inputs to the vegetation risk analyses for biomass loss and foliar injury, our confidence and any uncertainties in these analyses are propagated into those subsequent analyses. The national W126 surface was created using spatial interpolation techniques that perform better in areas where the O_3 monitoring network is denser. Therefore, we have high confidence in the W126 estimated in much of the contiguous U.S., and somewhat lower confidence in the rural areas in the West, Northwest, Southwest, and West North Central with few or no monitors. A potential source of bias comes from the adjustment methodology, which used across-the-board NOx emissions cuts and could mean that exposure in some areas could be slightly underestimated. However, this approach is reasonable given implementation of EPA regulations such as the Clean Air Interstate Rule (CAIR) and mobile source rules, both of which will lead to reductions in NOx emissions from these sources across broad regions of the country in the near future.

8.5.2 Confidence and Key Uncertainties in Biomass Loss Analyses

The scientific evidence suggests that there are additional species adversely affected by O_3-related biomass loss beyond the 12 tree species and 10 crop species with available E-R functions. This absence of information for additional species likely underestimates the O_3-related biomass loss impacts in trees and crops. The overall confidence in the E-R functions is high, but varies by species based on the number of studies available for that species. Some species have low within-species variability (e.g., many agricultural crops) and high seedling/adult comparability (e.g., Aspen), while other species do not (e.g., Black Cherry). In the national-scale analyses of agriculture and timber production, we may underestimate impacts because FASOMGHG does not include agriculture and forestry on public lands, changes in exports due to O_3 into international trade projections, or forest adaptation. In the case study analyses of five urban areas, iTree does not account for the potential additional VOC emissions from tree growth, which could contribute to O_3 formation that might somewhat offset the estimated impacts.

8.5.3 Confidence and Key Uncertainties in Visible Foliar Injury Analyses

Based on the available evidence, we cannot identify a clear threshold for drought below which visible foliar injury would not occur. On balance, we believe that the spatial and temporal resolution for the soil moisture data used in the analyses is likely to underestimate the potential of foliar injury that could occur in some areas. In general, we have high confidence in biosite injury data in most of the country, but we acknowledge limited biosite data in a few regions, which affects the benchmarks applied to these regions in the park screening-level analysis. In general, we have very high confidence in the park mapping supplied by NPS, but there are potential uncertainties related to the mapping of potential foliar injury, such as park boundaries, vegetation species cover, and park amenities, such as scenic overlooks and trails.

8.6 Conclusions

This welfare risk and exposure assessment provides information to further inform the following policy-relevant questions[20]: (1) in considering alternative standards, to what extent do alternative standard levels, averaging times, and forms 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 ISA, air quality analyses, and the welfare risk and exposure assessment; 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 quantified ecological effects of biomass loss and visible foliar injury based on the relationship with the W126 metric and assessed 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 assessed potential impacts to services. We assessed impacts on ecosystem services at the national and case-study scales, as well as across species, U.S. geographic regions and future years.

In conclusion, we estimated that exposures and risks remain after just meeting the existing standard and that in many cases, just meeting alternative standard levels results in reductions in those remaining exposures and risks. Overall, the largest reduction in O_3 exposure-related welfare risk occurs when moving from recent ambient conditions to meeting the existing secondary standard of 75 ppb (equal to the existing primary 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. When using monitored W126 index values (three-year) and adjusting for meeting the existing O_3 standard of 75 ppb, 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). When adjusting to just meet the existing standard, the Central region would meet an alternative W126 of 15 ppm-hrs, but further air quality adjustment would be needed for the

[20] The policy-relevant questions were identified in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards* (IRP, US EPA, 2011a).

Central region to meet alternative standards of 11 and 7 ppm-hrs – alternate standard levels that would protect against the recommended one to two percent biomass loss for trees and five percent for crops. Keeping in mind the potential uncertainties associated with the actual responsiveness of W126 values to the emissions reductions used in the adjustments to just meet the existing standard, at an alternative W126 standard level of 15 ppm-hrs, ambient conditions and related risk are not appreciably different than they are after just meeting the existing standard of 75 ppb. 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.

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