United States Environmental Protection Agency

Welfare Risk and Exposure Assessment for Ozone

First External Review Draft

DISCLAIMER

This preliminary draft document has been prepared by staff from the Ambient Standards Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the EPA. This document is being circulated for informational purposes and to facilitate discussion with the Clean Air Scientific Advisory Committee (CASAC) on the overall structure, areas of focus, and level of detail to be included in an external review draft Policy Assessment, which EPA plans to release for CASAC review and public comment later this year. Questions related to this preliminary draft document should be addressed to Travis Smith, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, C539-07, Research Triangle Park, North Carolina 27711 (email: smith.jtravis@epa.gov).

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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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TABLE OF CONTENTS

LIST OF ACRONYMS/ABBREVIATIONS

AGSIM	Agriculture Simulation Model
AQCD	Air Quality Criteria Document
AQS	Air Quality System
CAA	Clean Air Act
CAL FIRE	California Department of Forestry and Fire Protection
CASAC	Clean Air Science Advisory Committee
CASTNET	Clean Air Status and Trends Network
CH_4	methane
CMAQ	Community Multi-scale Air Quality
CO_2	carbon dioxide
C-R	Concentration Response Function
CSTR	continuous stirred tank reactors
EGU	electric generating unit
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute, Inc.
FACA	Federal Advisory Committee Act
FACE	Free Air CO_2 enrichment
FASOM	Forest and Agricultural Sector Optimization Model
FASOMGHG	Forest and Agriculture Sectors Optimization Model – Greenhouse Gas version
FHWAR	Fishing, Hunting, and Wildlife-Associated Recreation
FIA	U.S. Forest Service Forest Inventory and Analysis
GIS	geographic information system
GSMNP	Great Smoky Mountains National Park
HNO_3	nitric acid
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Review Plan
ISA	Integrated Science Assessment
IV	Importance Value

MATS	Modeled Attainment Test Software
MEA	Millennium Ecosystem Assessment
MT	metric ton
NAAQS	National Ambient Air Quality Standards
NCDC	National Climatic Data Center
NCLAN	National Crop Loss Assessment Network
NCore	National Core
NEI	National Emissions Inventory
NHEERL-WED	National Health and Environmental Effects Research Laboratory, Western Ecology Division
NO_2	nitrite
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
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
OH	hydroxide
OIF	Outdoor Industry Foundation
OTC	open top chamber
PA	Policy Assessment
ppm	parts per million
RBL	Relative Biomass Loss
REA	Risk and Exposure Assessment
RMNP	Rocky Mountain National Park
SAB	Science Advisory Board
SKCNP	Sequoia/Kings Canyon National Park
STE	stratosphere-troposphere exchange
USDA	U.S. Department of Agriculture

USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VNA	Voronoi Neighbor Averaging
VOC	volatile organic carbon
WTA	willingness to accept
WTP	willingness to pay

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1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the national ambient air quality standards (NAAQS) for ozone (O_3) and related photochemical oxidants. An overview of the approach to reviewing the O_3 NAAQS is presented in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards* (IRP, US EPA, 2011a). The IRP discusses the schedule for the review; the approaches to be taken in developing key scientific, technical, and policy documents; and the key policy-relevant issues that will frame our consideration of whether the current NAAQS for O_3 should be retained or revised.

Sections 108 and 109 of the Clean Air Act (CAA) govern the establishment and periodic review of the NAAQS. These standards are established for pollutants that may reasonably be anticipated to endanger public health and welfare, and whose presence in the ambient air results from numerous or diverse mobile or stationary sources. The NAAQS are to be based on air quality criteria, which are to accurately reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects on public health or welfare that may be expected from the presence of the pollutant in ambient air. The EPA Administrator is to promulgate and periodically review, at five-year intervals, "primary" (health-based) and "secondary" (welfare-based) NAAQS for such pollutants. Based on periodic reviews of the air quality criteria and standards, the Administrator is to make revisions in the criteria and standards, and promulgate any new standards, as may be appropriate. The Act also requires that an independent scientific review committee advise the Administrator as part of this NAAQS review process, a function performed by the Clean Air Scientific Advisory Committee (CASAC).[1]

The current primary NAAQS for O_3 is set at a level of 0.075 ppm, based on the annual fourth-highest daily maximum 8-hr average concentration, averaged over three years, and the secondary standard is identical to the primary standard (73 FR 16436). The EPA initiated the

[1] The Clean Air Scientific Advisory Committee (CASAC) was established under section 109(d)(2) of the Clean Air Act (CAA) (42 U.S.C. 7409) as an independent scientific advisory committee. CASAC provides advice, information and recommendations on the scientific and technical aspects of air quality criteria and NAAQS under sections 108 and 109 of the CAA. The CASAC is a Federal advisory committee chartered under the Federal Advisory Committee Act (FACA). See http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommitteesSubcommittees/CASAC%20Particulate%20Matter%20Review%20Panel for a list of the CASAC PM Panel members and current advisory activities.

current review of the ozone NAAQS on September 29, 2008 with an announcement of the development of an ozone Integrated Science Assessment and a public workshop to discuss policy-relevant science to inform EPA's integrated plan for the review of the ozone NAAQS (73 FR 56581). The NAAQS review process includes four key phases: planning, science assessment, risk/exposure assessment, and policy assessment/rulemaking.[2] A workshop was held on October 29-30, 2008 to discuss policy-relevant scientific and technical information to inform EPA's planning for the ozone NAAQS review. Following the workshop, EPA developed a planning document, the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards* (IRP; US EPA, 2011a), which outlined the key policy-relevant issues that frame this review, the process and schedule for the review, and descriptions of the purpose, contents, and approach for developing the other key documents for this review.[3] In June 2012, EPA completed the third draft of the ozone ISA, assessing the latest available policy-relevant scientific information to inform the review of the O_3 standards. The *Integrated Science Assessment for Ozone and Related Photochemical Oxidants - Third External Review Draft* (ISA; US EPA, 2012), includes an evaluation of the scientific evidence on the welfare effects of O_3, including information on exposure, physiological mechanisms by which O_3 might adversely impact vegetation, and an evaluation of the ecological evidence including information on reported concentration-response (C-R) relationships for O_3-related changes in plant biomass.

The EPA's Office of Air Quality Planning and Standards (OAQPS) has developed this quantitative welfare risk and exposure assessment (REA) describing the quantitative assessments of exposure to O_3 and O_3-related risks to public welfare to support the review of the secondary O_3 standards. This document is a concise presentation of the conceptual model, scope, methods, key results, observations, and related uncertainties associated with the quantitative analyses performed. The REA builds upon the welfare effects evidence presented and assessed in the ISA, as well as CASAC advice (Samet, 2011) and public comments on a scope and methods planning document for the REA (here after, "Scope and Methods Plan", US EPA, 2011b).

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

[3] On March 30, 2009, EPA held a public consultation with the CASAC Ozone 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.

Revisions to this draft RA will draw upon the final ISA and will reflect consideration of CASAC and public comments on this draft.

The ISA and REA will inform the policy assessment and rulemaking steps that will lead to final decisions on the primary O_3 NAAQS, as described in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards*. The policy assessment will include staff analysis of the scientific basis for alternative policy options for consideration by senior EPA management prior to rulemaking. The PA integrates and interprets information from the ISA and the REA to frame policy options for consideration by the Administrator. The PA is intended to link the Agency's scientific and technical assessments, presented in the ISA and REA, to judgments required of the Administrator in determining whether it is appropriate to retain or revise the current O_3 standards. Development of the PA is also intended to facilitate elicitation of CASAC's advice to the Agency and recommendations on any new standards or revisions to existing standards as may be appropriate, as provided for in the Clean Air Act (CAA). The first draft PA is planned for release around the middle of August 2012 for review by the CASAC O_3 Panel and the public concurrently with their review of this first draft REA September 11-13, 2012.

1.1 HISTORY

As part of the last 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 last 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 associated changes in economic value upon meeting the levels of various alternative standards were analyzed using an agricultural sector economic model. Key observations and insights from the ozone risk assessment, in addition to important caveats and limitations, were addressed in Section II.B of the Final Rule notice (73 FR 16440 to 16443, March 27, 2008).

Prior to the issuance of a proposed rulemaking in the last review, CASAC presented recommendations to the Administrator supporting revisions of the O_3 secondary standard. These recommendations cited the results of the quantitative risk assessment in recommending a range of ozone levels below the existing standard at the time (0.084 ppm) (Henderson, 2006a). In the 2008 final rule, the EPA Administrator considered the results of the exposure and risk assessments and the potential magnitude of the risk to human welfare given recent air quality data and air quality simulated to meet the current standard and alternative standards. 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 current 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 at a level within the range of 7 to 21 ppm-hrs, and (2) setting the secondary standard identical to the revised primary standard. The 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 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 final decision on the O_3 NAAQS, and on December 23, 2008, the Court set a briefing schedule in the consolidated cases. On March 10, 2009, EPA requested that the Court vacate the briefing schedule and hold the consolidated cases in abeyance. This request for extension was made to allow time for appropriate EPA officials appointed by the new Administration to review the O_3 NAAQS to determine whether the standards established in the March 2008 O_3 NAAQS decision should be maintained, modified or otherwise reconsidered. In granting EPA's request, the Court directed EPA to notify the Court by September 16, 2009 of the action it will be taking with respect to the 2008 O_3 NAAQS rule and the Agency's schedule for undertaking such action. The EPA notified the Court on September 16, 2009 of its decision to reconsider the primary and secondary O_3 NAAQS set in March 2008 to ensure they are scientifically sound and protective of public health and the environment.

In 2010 the Administrator proposed to reconsider and revise parts of that 2008 final rule. Specifically, she proposed to revise the level of the primary standard to within the range of 0.060 to 0.070 ppm and she proposed to revise the secondary standard by setting a new cumulative, seasonal standard in terms of the W126 metric, set within the range of 7-15 ppm-hours (FR 75 2938). This proposal was based on the scientific and technical record from the 2008 rulemaking, including public comments and CASAC advice and recommendations. The information that was assessed during the 2008 rulemaking included information in the 2006 Criteria Document (EPA, 2006a), the 2007 Policy Assessment of Scientific and Technical Information, referred to as the 2007 Staff Paper (EPA, 2007a), and related technical support documents including the 2007 REAs (U.S. EPA, 2007b; Abt Associates, 2007a,b).[4] Scientific and technical information developed since the 2006 Criteria Document was not considered in the 2010 proposal.

On September 2, 2011, the President requested that EPA withdraw the proposal to revisit and revise the 2008 Ozone National Ambient Air Quality Standards, noting that work was already underway on the next review (memo from President Obama, http://www.whitehouse.gov/the-press-office/2011/09/02/statement-president-ozone-national-ambient-air-quality-standards).[5] The proposed changes to the 2008 O_3 NAAQS were not finalized.

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[4]The EPA's Office of Research and Development/National Center for Environmental Assessment (ORD/NCEA) also conducted a provisional assessment of pertinent studies investigating the health and ecological effects of O_3 that were published after the cutoff for inclusion in the 2006 O_3 Criteria Document. The provisional assessment was conducted for the purpose of determining if any recent studies would materially change the conclusions of the 2006 O_3 Criteria Document. The provisional assessment concluded that, taken in context, results of more recent studies did not materially change any of the broad scientific conclusions regarding the health and ecological effects of O_3 exposure made in the 2006 O_3 Criteria Document. Thus, as stated above, the 2010 proposal was based solely on the record from the 2008 rulemaking and did not consider scientific and technical information developed since the 2006 Criteria Document.

[5]Also see letter from Cass Sunstein, Administrator of the Office of Information and Regulatory Affairs, to EPA Administrator Lisa Jackson (http://www.whitehouse.gov/sites/default/files/ozone_national_ambient_air_quality_standards_letter.pdf).

1.2 CURRENT RISK ASSESSMENT: GOALS AND PLANNED APPROACH

The goals of the current quantitative welfare risk assessments are (1) to provide estimates of the ecological effects of O3 exposure across a range of environments; (2) to provide estimates of ecological effects within selected case study areas; (3) to provide estimates of the effects of O3 exposure on specific urban and non-urban ecosystem services based on the causal ecological effects; and (4) to develop a better understanding of the response of ecological systems and ecosystem services to changing levels of O3 exposure to inform the PA regarding alternative standards that might be considered. This current quantitative risk and exposure assessment builds on the approach used and lessons learned in the last O_3 risk assessment and focuses on improving the characterization of the overall confidence in the risk estimates, including related uncertainties, by incorporating a number of enhancements, in terms of both the methods and data used in the analyses. This assessment considers a variety of welfare endpoints for which, in staff's judgment, there is adequate information to develop quantitative risk estimates that can meaningfully inform the review of the secondary O_3 NAAQS.

This first draft REA provides an assessment of exposure and risk associated with recent ambient levels of ozone and ozone air quality simulated to just meet the current primary ozone standards. Subsequent drafts of the REA will evaluate potential alternative ozone standards based on recommendations provided in the first draft of the Policy Assessment.

1.3 ORGANIZATION OF DOCUMENT

The remainder of this document is organized as follows. Chapter 2 provides a conceptual framework for the risk and exposure assessment, including discussions of ozone chemistry, sources of ozone precursors, ecological exposure pathways and uptake into plants, ecological effects, and ecosystem services endpoints associated with ozone. 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 ozone monitoring data, and important inputs to the risk and exposure assessments. Chapter 5 describes the ecological effects of O3 exposure and includes quantitative analyses of vegetation biomass loss and foliar injury. Chapter 6 describes the ecosystem services affected by the ecological effects analyzed in Chapter 5. Chapter 6 includes both quantitative assessments of the effects on ecosystem services as well as qualitative discussion of services for which effects are known to occur, but quantitative analyses were not possible. Chapter 7 provides an integrative discussion of the risk estimates generated in the analyses drawing on the results of the analyses based on quantitative analysis and incorporating considerations from the qualitative discussion of ecosystem services.

2 CONCEPTUAL FRAMEWORK

In this chapter, we summarize the conceptual framework for assessing exposures of ecosystems to O_3 and the associated risks to public welfare. This conceptual framework includes elements related to characterization of ambient O_3 and its relation to ecosystem, exposures (Section 2.1), important sources of O_3 precursors including oxides of nitrogen (NO_x) and volatile organic compounds (VOC) (Section 2.2), ecological effects occurring in O_3 sensitive ecosystems (Section 2.3), and ecosystem services that are likely to be negatively impacted by changes in ecological functions resulting from O_3 exposures (Section 2.4). The chapter concludes with key observations relevant for developing the scope of the quantitative risk and exposure assessments.

In the previous review of the secondary standards, the focus of the ecological risk assessment was on estimation of changes in biomass loss and resulting impacts on forest and agricultural yields as well as qualitative consideration of effects on ecosystem services. In this review, EPA is expanding the analysis to consider the broader array of impacts on ecosystem services resulting from known effects of ozone on ecosystem functions. This is to address the objective of this risk assessment to quantify the risks not just to ecosystems but to the aspects of public welfare dependent on those ecosystems. EPA has begun 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) presents 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 will identify the ecosystem services associated with the ecological effects caused by O_3 exposure for 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). Figure 2- 1 illustrates the relationships between the ecological effects of ozone and the anticipated ecosystem services impacts. Specific services to be evaluated are discussed in the following sections.

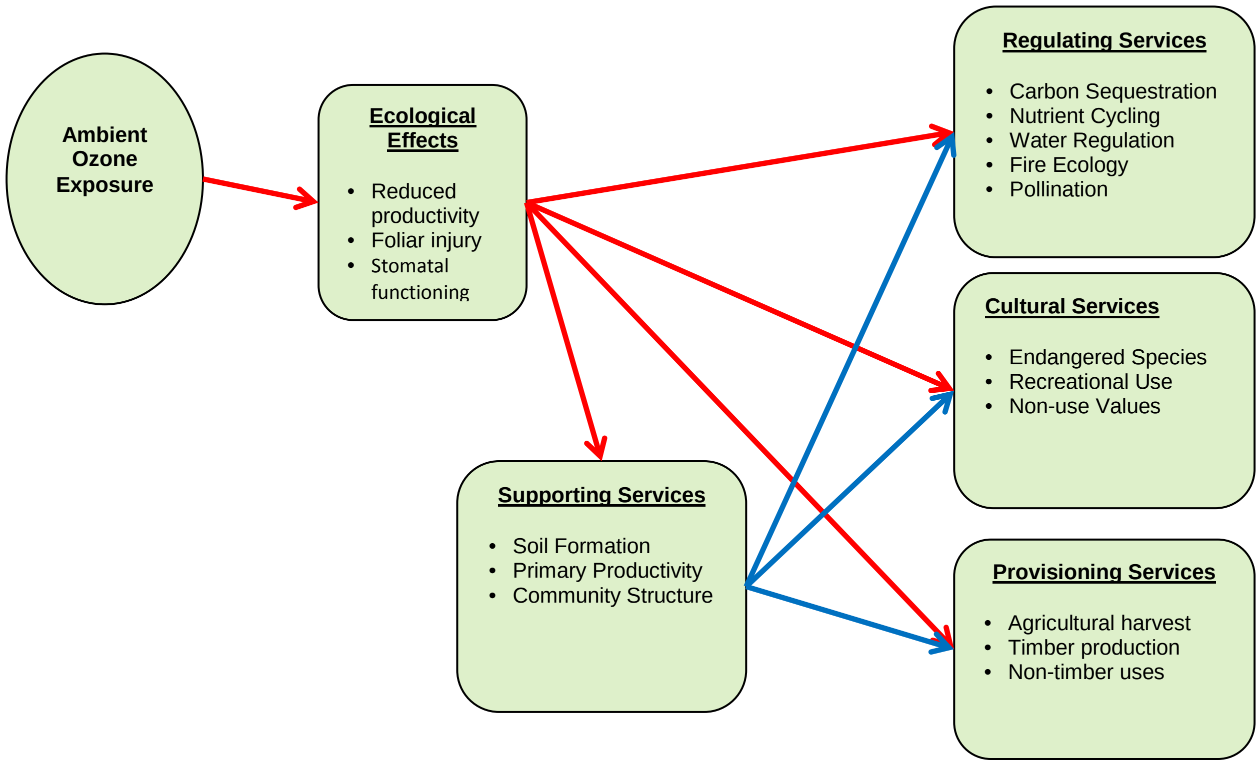

Figure 2- 1 Relationship Between Ecological Effects of Ozone Exposure and Ecosystem Services

2.1 O_3 CHEMISTRY

O_3 occurs naturally in the stratosphere where it provides protection against harmful solar ultraviolet radiation, and it is formed closer to the surface in the troposphere by both natural and anthropogenic sources. O_3 is not emitted directly into the air, but is created when its two primary precursors, volatile organic compounds (VOC) and oxides of nitrogen (NO_x), combine in the presence of sunlight. VOC 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 (US EPA, 2012, 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. NO_x 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 (HO2) radicals. In areas dominated by fresh emissions of NO_x, these radicals are removed via the production of nitric acid (HNO3), which lowers the O_3 formation rate. In addition, the scavenging of O_3 by reaction with NO is called "titration," and is often found in downtown metropolitan areas, especially near busy streets and roads, and in power plant plumes. This titration results in local valleys in which ozone concentrations are low compared to surrounding areas. Titration is usually short-lived confined to areas close to strong NO_x sources, and the NO_2 formed this way leads to O_3 formation later and further downwind. . Consequently, ozone response to reductions in NO_x emissions is complex and may include ozone decreases at some times and locations and increases of ozone to fill in the local valleys of low ozone. In areas with low NO_x concentrations, such as those found in remote continental areas to rural and suburban areas downwind of urban centers, the net production of O_3 typically varies directly with NO_x concentrations, and increases with increasing NO_x emissions.

In general, the rate of O_3 production is limited by either the concentration of VOCs or NO_x, and O_3 formation using these two precursors relies 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 referred to as being "NO_x-limited" (US EPA, 2012, section 3.2.4). In this situation, O_3 concentrations are most effectively reduced by lowering NO_x emissions, rather than lowering emissions of VOCs. When the abundance of OH and other radicals is limited either through low production or reactions with NO_x and other species, O_3 production is sometimes called "VOC-limited" or "radical limted" or "NO_x-saturated" (Jaegle et al., 2001), and O_3 is most effectively reduced by lowering VOCs. However, even in NO_x-saturated conditions, very large decreases in NO_x emissions can cause the ozone formation regime to become NO_x limited. Consequently, reductions in NO_x emissions (when large) can make further emissions reductions more effective at reducing ozone. Between the NO_x-limited and NO_x-saturated extremes there is a transitional region where O_3 is relatively insensitive to marginal changes in both NO_x and VOCs.

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. (US EPA, 2012a, Section 3.6.2.2).

2.2 SOURCES OF O_3 AND O_3 PRECURSORS

O_3 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 VOCs are important for O_3 formation. Hundreds of VOCs 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 VOCs, with roughly equal contributions to total emissions (US EPA, 2012a, Figure 3-3). 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 a year (MT/year).

On the U.S. and global scales, emissions of VOCs from vegetation are much larger than those from anthropogenic sources. Emissions of VOCs from anthropogenic sources in the 2005 NEI were ~17 MT/year (wildfires constitute ~1/6 of that total), but were 29 MT/year from biogenic sources. Vegetation emits substantial quantities of VOCs, such as isoprene and other terpenoid and sesqui-terpenoid compounds. Most biogenic emissions occur during the summer because of their dependence 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 are on-road and off-road mobile sources (e.g., construction and agricultural equipment) and electric power generation plants (EGUs) (US EPA, 2012, Figure 3-3). Emissions of NO_x therefore are highest in areas having a high density of power plants and in urban regions having 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 EGUs are sparser 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 for 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 transfered into the troposphere from the stratosphere, 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, 2012, 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, 2012, 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 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 (US EPA, 2012a, section 3.7.3).

2.3 ECOLOGICAL EFFECTS

Recent studies reviewed in the ISA support and strengthen the findings reported in the 2006 O_3 AQCD (U.S. EPA, 2006a). 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 which 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, which is focused on ambient conditions.

Chapter 9 of the O_3 ISA (U.S. EPA, 2012a) provides a detailed review of the effects of O_3 on vegetation including the major pathways of exposure and known ecological and ecosystem effects. Figure 9-1 of the ISA is reproduced below (Figure 2- 2) as a summary of exposure and 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 C sequestration, alteration in community composition and loss of recreational or cultural value.

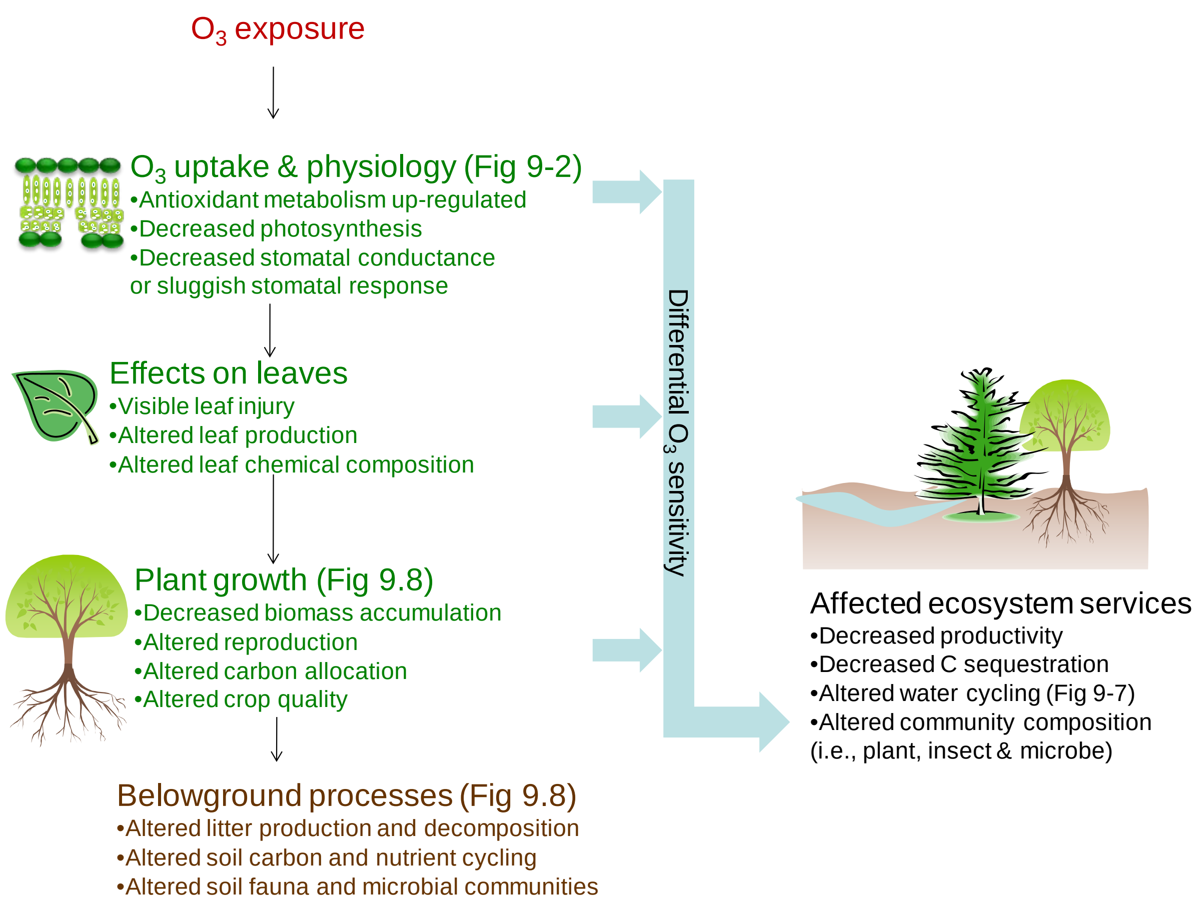

Figure 2- 2 Conceptual diagram of the major pathway through which O_3 enters plants and the major endpoints that O_3 may affect in plants and ecosystems. Figure numbers in this figure refer to Chapter 9 of the ISA.

Overall causal determinations are made based on the full range of evidence including controlled exposure studies and ecological studies. Figure 2- 3 shows the O_3 welfare effects which have been categorized by strength of evidence for causality in the O_3 ISA (US EPA, 2012a, chapter 2). These determinations support causal or likely causal relationships between exposure to O_3 and ecological and ecosystem level effects.

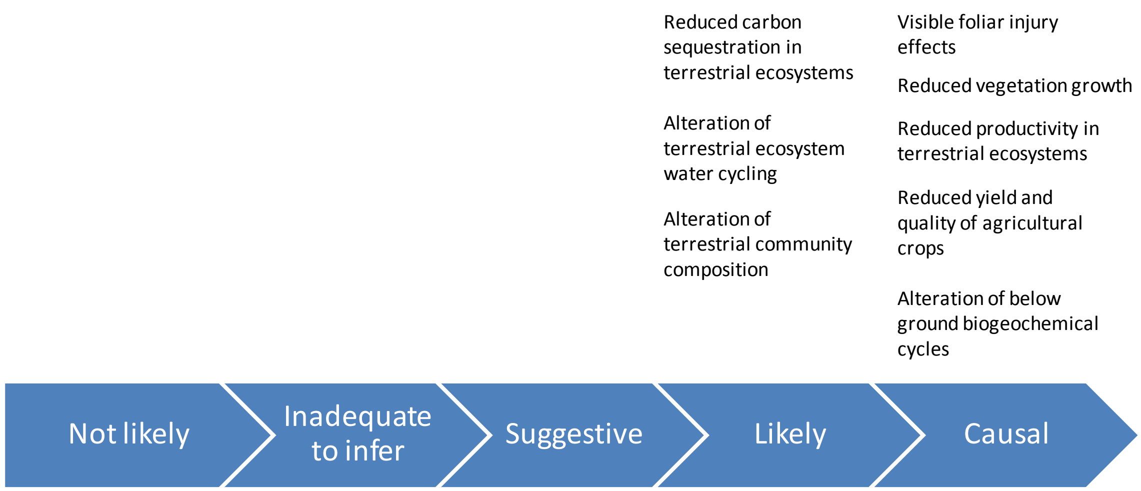

Figure 2- 3 Causal Determinations for O_3 Welfare Effects

The adequate characterization of the effects of O_3 on plants for the purpose of setting air quality standards is contingent not only on the choice of the index used (i.e. W126) to summarize O_3 concentrations (Section 9.5), 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 itself. Establishing a secondary air quality standard requires the capability to generalize those observations, in order to obtain predictions that are reliable enough under a broad variety of conditions, taking into account these factors.

Quantitative characterization of exposure-response in the 2006 O_3 AQCD was based on experimental data generated for that purpose by the National Crop Loss Assessment Network

(NCLAN) and EPA National Health and Environmental Effects Research Laboratory, Western Ecology Division (NHEERL-WED) projects, using OTCs to expose crops and trees seedling to O_3. In recent years, yield and growth results for two of the species that had provided extensive exposure-response information in those projects have become available from studies that used 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 quantitative exposure-response relationships described in the 2006 O_3 AQCD have not changed in the current draft ISA, with the exception of the addition of one new species. e assessment of quantitative exposure-response relationships that was presented in that document. The exposure-response models are summarized in the 3rd draft ISA summarizes 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 general relationship provides an adequate basis for qualitative assessment of the risk of visible foliar injury, but a detailed quantitative assessment is not possible because there are no concentration-response functions for foliar injury that can be applied across a range of ecosystems.

2.4 ECOSYSTEM SERVICES

The Risk and Exposure Assessment 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 uses both quantitative and qualitative data. For example, the previous ozone review evaluated changes in foliar injury, growth loss, and biomass reduction on trees beyond the seedling stage using the TREGRO model. The presence or absence of foliar damage in counties meeting the current 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. 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- 4 provides the World Resources Institute’s schematic demonstrating the connections between the categories of ecosystem services and human well-being. 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).

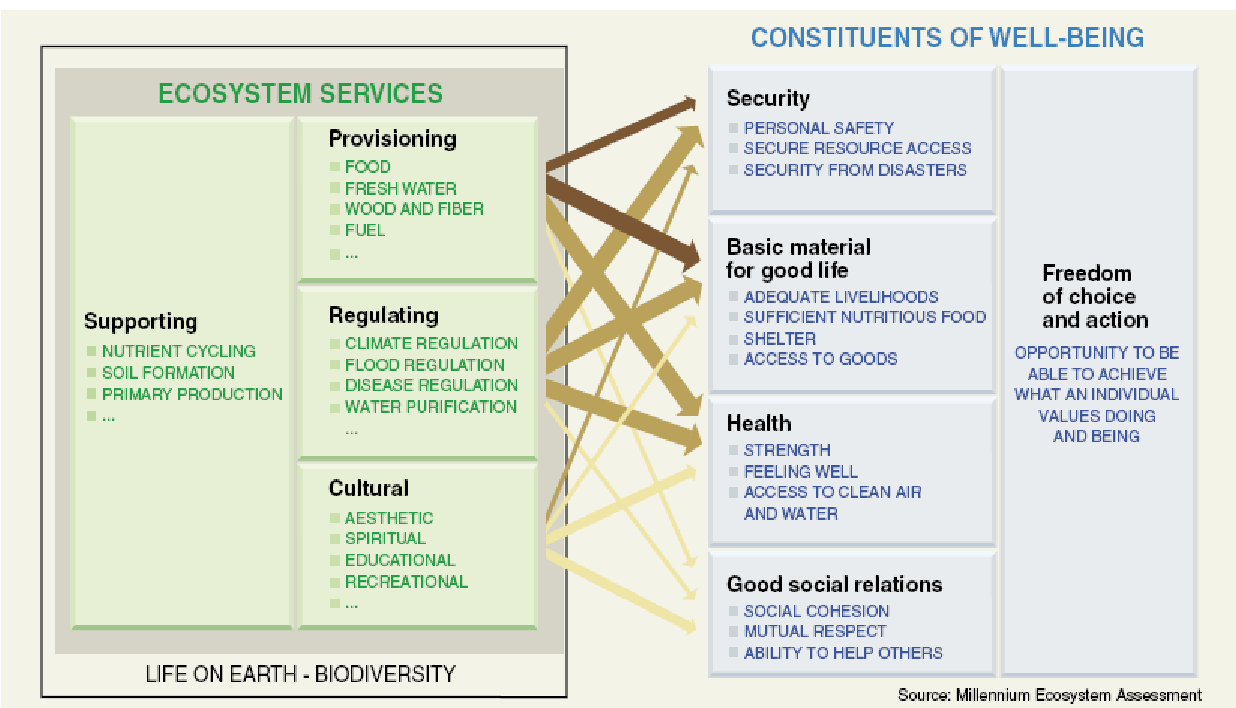

Figure 2- 4 Linkages between categories of ecosystem services and components of human well-being that are commonly indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. The strength of the linkages, as indicated by arrow width, and the

potential for mediation, as indicated by arrow color, differ in different ecosystems and regions (MEA, 2005).

Historically, ecosystem services have been undervalued and overlooked; however, more recently, the degradation and destruction of ecosystems has piqued interest in assessing the value of these services. In addition, valuation may be an important step from a policy perspective because it can be used to compare the costs and benefits of altering versus maintaining an ecosystem (i.e., it may be easier to protect than repair ecosystem effects). In this Risk and Exposure Assessment, valuation is used, where possible, based on available data in the national scale analyses and case study areas.

The economic approach to the valuation of ecosystem services is laid out as follows in EPA's *Ecological Benefits Assessment Strategic Plan*: "Economists generally attempt to estimate the value of ecological goods and services based on what people are willing to pay (WTP) to increase ecological services or by what people are willing to accept (WTA) in compensation for reductions in them" (U.S. EPA, 2006). There are three primary approaches for estimating the value of ecosystem services: market-based approaches, revealed preference methods, and stated preference methods (U.S. EPA, 2006). Because economic valuation of ecosystem services can be difficult, nonmonetary valuation using biophysical measurements and concepts also can be used. Examples of nonmonetary valuation methods include the use of relative-value indicators (e.g., a flow chart indicating uses of a waterbody, such as boatable, fishable, swimmable); another assigns values to ecosystem goods and services through the use of the common currency of energy. Energetic valuation attempts to assess ecosystem contributions to the economy by using *one kind* of energy (e.g., solar energy) to express the value of that type of energy required to produce designated services (Odum, 1996). This energy value is then converted to monetary units. This method of valuation, however, does not account for the premise that values arise from individual or societal preferences.

Valuing ecological benefits, or the contributions to social welfare derived from ecosystems, can be challenging, as noted in EPA's *Ecological Benefits Assessment Strategic Plan* (U.S. EPA, 2006). It is necessary to recognize that in the analysis of the environmental responses associated with any particular policy or environmental management action, some of the ecosystem services likely to be affected are readily identified, whereas others will remain unidentified. Of those ecosystem services that are identified, some changes can be quantified, whereas others cannot. Within those services whose changes can be quantified, only a few will likely be monetized, and many will remain unmonetized. Similar to health effects, only a portion of the ecosystem services affected by a policy can be monetized. The stepwise concept leading up to the valuation of ecosystems services is graphically depicted in Figure 2- 5.

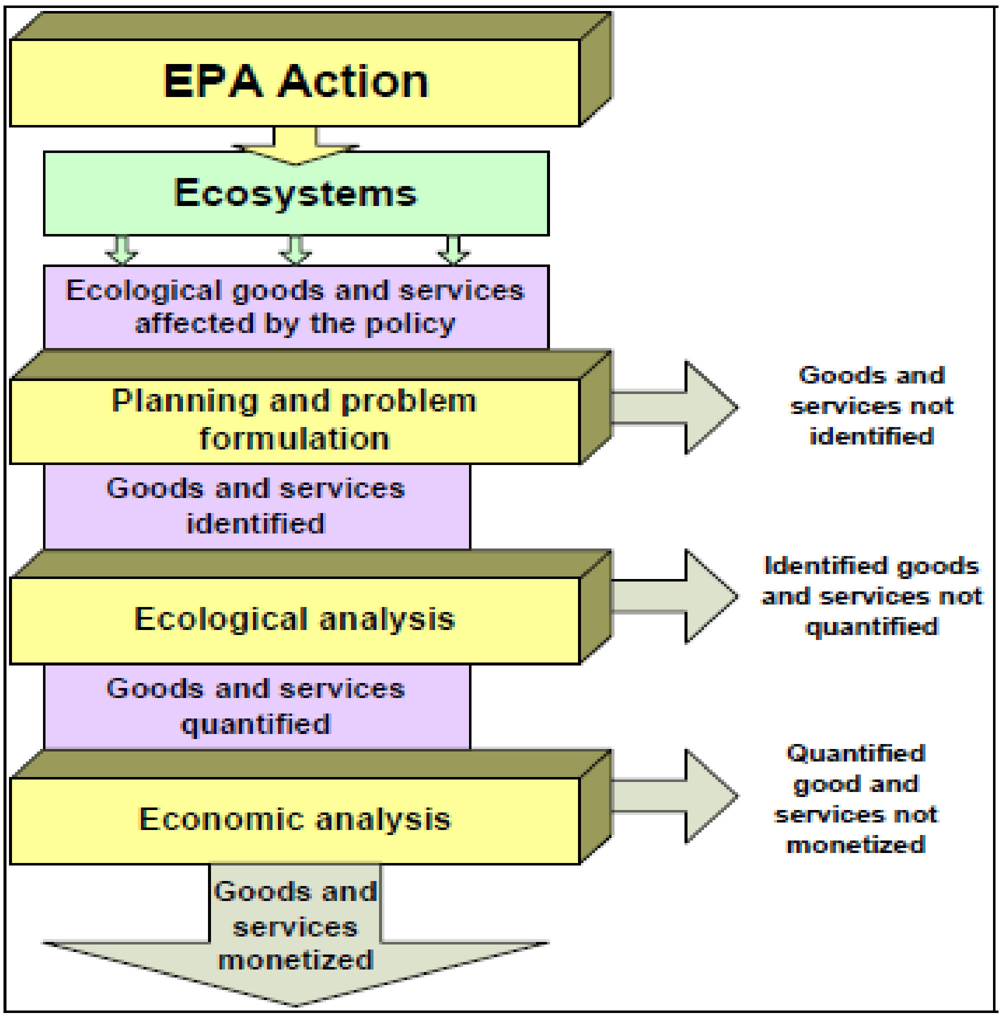

Figure 2- 5 Representation of the benefits assessment process indicating where some ecological benefits may remain unrecognized, unquantified, or unmonetized. (Modified based on the Ecological Benefits Assessment Strategic Plan report [U.S. EPA, 2006]).

Under Section 108 of the CAA, the secondary standard is to specify an acceptable level of the criteria pollutant(s) in the ambient air that is protective of public welfare. For this review, the relevant air quality indicator is interpreted as ambient O_3 concentrations that can be linked to adverse ecological effects. The air quality analyses described in Chapter 4 explore the sources and emissions, and their current contributions to ambient conditions. The national scale and case study analyses (described in Chapters 5 and 6) link O_3 effects in sensitive ecosystems (e.g., the exposure pathway) to changes in a given ecological indicator (e.g., biomass loss to changes in ecosystems and the services they provide (e.g., commercial timber production). To the extent possible for effect, ambient concentrations of O_3 (i.e., ambient air quality indicators) were linked to effects in sensitive ecosystems (i.e., exposure pathways), and then O_3 concentrations were linked to system response as measured by a given ecological indicator (e.g., biomass loss). The ecological effect (e.g., changes in tree growth) was then, where possible, associated with changes in ecosystem services and their ecological benefits or welfare effects (e.g., timber production).

Knowledge about the relationships linking ambient concentrations and ecosystem services can be used to inform a policy judgment on a known or anticipated adverse public welfare effect. For example, changes in biodiversity would be classified as an ecological effect, and the associated changes in ecosystem services—productivity, recreational viewing, and aesthetics—would be classified as ecological benefits/welfare effects. This information can then be used to characterize known or anticipated adverse effects to public welfare and inform a policy based on welfare effects.

The ecosystems of interest in this 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 health as a result of O_3 exposure may affect supporting services such as net primary productivity; provisioning services such as timber production; and regulating services such as climate regulation. In addition, such changes may provide provisioning services such as food; and cultural services such as recreation and ecotourism.

Where possible, linkages to ecosystem services from indicators of each effect identified in the ISA (U.S. EPA, 2012a) were developed. 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 air pollution-induced changes in the quantity and/or quality of ecosystem services provided. According to 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 Chapter 6 at a national scale and in case studies.

2.5 CONCLUSIONS

The conceptual basis for estimating exposures to O_3 and resulting welfare effects is strong. The ISA provides clear scientific evidence linking ambient concentrations of O_3 to a number of ecological effects, and science-based air quality models along with O_3 monitoring data, show that important ecosystems throughout the U.S. are exposed to O_3 concentrations that may result in adverse ecological impacts. There are field and laboratory studies that provide adequate information to construct concentration-response functions that can be used to estimate risk given estimates of tree or ecosystem level O_3 exposure.

Presented below are key observations for this conceptual overview of the assessment of ambient O_3 exposure and welfare risk.

- O_3 in ambient air is formed primarily by emissions of NO_x and VOC and photochemical reactions in the atmosphere. Both natural and anthropogenic sources contribute to O_3 formation. Solvents, on-road and off-road mobile sources and electric power generation plants represent significant anthropogenic sources of precursors to O_3 in ambient air. Vegetation, lightning, soils, and wildfires are significant natural sources of O_3 precursor emissions.
- The ISA has determined that the evidence supports a causal relationship between exposure to O_3 and visible foliar injury, reduced vegetation growth, reduced agricultural yield, and alteration of below ground biogeochemical cycles, and a likely causal

relationship exposure to O_3 and reduced carbon sequestration, alteration of terrestrial water cycling, and alteration of terrestrial community composition.

- The causal and likely causal ecological effects identified in the ISA have an effect on regulating, supporting, cultural and provisioning ecosystem services.

3 SCOPE

This chapter provides an overview of the scope and key design elements of this quantitative exposure and welfare risk assessment. The design of this assessment began with a review of the exposure and risk assessments completed during the last O_3 NAAQS review (US EPA, 2007a,b), with an emphasis on considering key limitations and sources of uncertainty recognized in that analysis.

As an initial step in the current O_3 NAAQS review, in October 2009, EPA invited outside experts, representing a broad range of expertise to participate in a workshop with EPA staff to help inform EPA's plan for the review. The participants discussed key policy-relevant issues that would frame the review and 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 quantitative exposure and welfare risk assessment. Based in part on the workshop discussions, EPA developed a draft IRP (US EPA, 2009) outlining the schedule, process, and key policy-relevant questions that would frame this review. On November 13, 2009, EPA held a consultation with 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 (US EPA, 2011a, chapters 5 and 6).

As a next step in the design of these quantitative assessments, OAQPS staff developed more detailed planning documents, O_3 National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment (Health Scope and Methods Plan; US 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, US EPA, 2011c). These Scope and Methods Plans were the subject of a consultation with CASAC on May 19-20, 2011 (76 FR 23809, April 28, 2011). Based on consideration of CASAC (Samet, 2011) and public comments on the Scope and Methods Plan and information in the second draft ISA, we modified the scope and design of the quantitative risk assessment and provided a memo with updates to information presented in the Scope and Methods Plans (Wegman, 2012). The Scope and Methods Plans together with the update memo provide the basis for the discussion of the scope of this exposure and risk assessment provided in this chapter.

In presenting the scope and key design elements of the current risk assessment, this chapter first provides a brief overview of the quantitative exposure and risk assessment completed for the previous O_3 NAAQS review in section 3.1, including key limitations and uncertainties associated with that analysis. Section 3.2 provides a summary of the design of the exposure assessment. Section 3.3 provides a summary of the design of the risk assessment based on application of results of human clinical studies. Section 3.4 provides a summary of the design of the risk assessment based on application of results of epidemiology studies.

3.1 OVERVIEW OF EXPOSURE AND RISK ASSESSMENTS FROM LAST REVIEW

The assessments conducted as part of the last 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 associated changes in economic value upon meeting the levels of various alternative standards were analyzed using an agricultural sector economic model. Key elements and observations from these exposure and risk 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 remained limited. Thus, the 2007 Staff Paper concluded that it was necessary to use an interpolation method in order to better characterize O_3 air quality over broad geographic areas and at the national scale. Based on the significant difference in monitor network density between the eastern and western U.S., the Staff Paper further concluded that it was appropriate to use separate interpolation techniques in these two regions: The Air Quality System (AQS; http://www.epa.gov/ttn/airs/airsaqs) and Clean Air Status and Trends Network (CASTNET; http://www.epa.gov/castnet/) monitoring data were solely used for the eastern interpolation, and in the western U.S., where rural monitoring is more sparse, O_3 outputs from the EPA/NOAA Community Multi-scale Air Quality (CMAQ) model system (http://www.epa.gov/asmdnerl/CMAQ, Byun and Ching, 1999; Byun and Schere, 2006) were used to develop scaling factors to augment the monitor interpolation. In order to characterize uncertainty associated with the exposure estimates generated using the interpolation method, monitored O_3 concentrations were systematically compared to interpolated O_3 concentrations in areas where monitors were located. In general, the interpolation method performed well in many areas in the U.S. This approach was used to develop a national vegetation O_3 exposure surface.

To evaluate changing vegetation exposures under selected air quality scenarios, a number of analyses were conducted. One analysis adjusted 2001 base year O_3 air quality distributions using a rollback method (Rizzo, 2005, 2006) to reflect meeting the current and alternative secondary standard options. For "just meet" and alternative 8-hr average standard scenarios, the associated maps of estimated 12-hr, W126 exposures were generated. Based on these comparisons, the following observations were drawn: (1) current O_3 air quality levels could result in significant cumulative, seasonal O_3 exposures to vegetation in some areas; (2) overall 3-month 12-hr W126 O_3 levels were somewhat but not substantially improved under the "just meet" current (0.08 ppm) scenario; (3) exposures generated for just meeting a 0.070 ppm, 4th-highest maximum 8-hr average alternative standard (the lower end of the then proposed range for the primary O_3 standard) showed substantially improved 3-month cumulative, seasonal O_3 air quality when compared to just meeting the current 0.08 ppm, 8-hr average standard.

A second analysis described in the Staff Paper was performed to evaluate the extent to which county-level O_3 air quality measured in terms of various levels of the current 8-hr average form overlapped with that measured in terms of various levels of the 12-hr W126 cumulative, seasonal form. While these results also suggested that meeting a proposed 0.070 ppm, 8-hr secondary standard would provide substantially improved vegetation protection in some areas, the Staff Paper recognized that this analysis had several important limitations. In particular, the lack of monitoring in rural areas where sensitive vegetation and ecosystems are located, especially at higher elevation sites, could have resulted in an inaccurate characterization of the degree of potential overlap at sites that have air quality patterns that can result in relatively low 8-hr averages while still experiencing relatively high cumulative exposures (72 FR 37892). Thus, the Staff Paper concluded that it is reasonable to anticipate that additional unmonitored rural high elevation areas with sensitive vegetation may not be adequately protected even with a lower level of the 8-hr form. The Staff Paper further indicated that it remained uncertain as to the extent to which air quality improvements designed to reduce 8-hr O_3 average concentrations would reduce O_3 exposures measured by a seasonal, cumulative W126 index. The Staff Paper indicated this to be an important consideration because: (1) the biological database stresses the importance of cumulative, seasonal exposures in determining plant response; (2) plants have not been specifically tested for the importance of daily maximum 8-hr O_3 concentrations in relation to plant response; and (3) the effects of attainment of a 8-hr standard in upwind urban areas on rural air quality distributions cannot be characterized with confidence due to the lack of monitoring data in rural and remote areas.

The Staff Paper also presented estimates of economic valuation for crops associated with the then current and alternative standards. The Agriculture Simulation Model (AGSIM) (Taylor, 1994; 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. Meeting the various alternative standards did show some significant benefits beyond the 0.08 ppm, 8-hr standard. However, the Staff Paper recognized that the modeled economic impacts from AGSIM had many associated uncertainties, which limited the usefulness of these estimates.

3.1.2 Assessment of Risks to Vegetation

The risk assessments in the last review reflected the availability of several additional lines of evidence that provided a basis for a more complete and coherent picture of the scope of O_3-related vegetation risks, especially those faced by seedling, sapling and mature tree species growing in field settings, and indirectly, forested ecosystems. Specifically, new research available at the time reflected an increased emphasis on field-based exposure methods (e.g., free air exposure and ambient gradient), improved field survey biomonitoring techniques, and mechanistic tree process models. Highlights from the analyses that addressed visible foliar injury, seedling and mature tree biomass loss, and effects on crops are summarized below.

With regard to visible foliar injury, the Staff Paper presented an assessment that combined recent U.S. Forest Service Forest Inventory and Analysis (FIA) biomonitoring site data with the county level air quality data for those counties containing the FIA biomonitoring sites. This assessment showed that incidence of visible foliar injury ranged from 21 to 39 percent of the counties during the four-year period (2001-2004) across all counties with air quality levels at or below that of the then current 0.08 ppm 8-hr average standard. Of the counties that met an 8-hr average level of 0.07 ppm in those years, 11 to 30 percent of the counties still had incidence of visible foliar injury.

With respect to tree seedling biomass loss, concentration-response (C-R) functions developed from Open Top Chamber (OTC) studies for biomass loss for available seedling tree species and information on tree growing regions derived from the U.S. Department of Agriculture's Atlas of United States Trees were combined with projections of air quality based on 2001 interpolated exposures, to produce estimated biomass loss for each individual seedling tree species. These analyses predicted that biomass loss could still occur in many tree species when O_3 air quality was adjusted to meet the then current 8-hr average standard. Though this type of analysis was not new to this review, the context for understanding these results had changed due to recent field work at the AspenFACE site in Wisconsin on quaking aspen (Karnosky et al., 2005) and a gradient study performed in the New York City area (Gregg et al., 2003), which confirmed the detrimental effects of O_3 exposure on tree growth in field studies without chambers and beyond the seedling stage (King et al., 2005).

With respect to risk of mature tree growth reductions, a tree growth model (TREGRO) was used to evaluate the effect of changing O_3 air quality scenarios from just meeting alternative O_3 standards on the growth of mature trees.[1] The model was run for a single western species (ponderosa pine) and two eastern species (red maple and tulip poplar). Staff Paper analyses found that just meeting the then current standard would likely continue to allow O_3-related

[1] 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. TREGRO has been used to evaluate the effects of a variety of O_3 scenarios on several species of trees in different regions of the U.S. (Tingey et al., 2001; Weinstein et al., 1991; Retzlaff et al., 2000; Laurence et al., 1993; Laurence et al., 2001; Weinstein et al., 2005).

reductions in annual net biomass gain in these species. Though there was uncertainty associated with the above analyses, it was important to note that recent evidence from experimental studies that go beyond the seedling growth stage continued to show decreased growth under elevated O_3 (King et al., 2005); some mature trees such as red oak have shown an even greater sensitivity of photosynthesis to O_3 than seedlings of the same species (Hanson et al., 1994); and the potential for cumulative "carry over" effects as well as compounding should be considered (Andersen, et al, 1997).

With respect to risks of yield loss in agricultural crops and fruit and vegetable species, little new information was available beyond that of the previous review. However, limited information from a free air field based soybean study (SoyFACE) and information on then current cultivar sensitivities led to the conclusion that C-R functions developed in OTCs under the National Crop Loss Assessment Network (NCLAN) program could still be usefully applied. The crop risk assessment, like the tree seedling assessment, combined NCLAN C-R information on commodity crops, fruits and vegetables, crop growing regions, and interpolated exposures during each crop growing season. The risk assessment estimated that just meeting the 0.08 ppm, 8-hr standard would still allow O_3–related yield loss to occur in some sensitive commodity crops and fruit and vegetable species growing at that time in the U.S.

3.2 OVERVIEW OF CURRENT ASSESSMENT PLAN

Since the 2008 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 through direct impacts on whole tree level water use. Newly published results from the Long-term FACE (Free Air CO_2 enrichment) studies provide additional evidence regarding chronic O_3 exposures in closed forest canopy scenarios including interspecies interactions such as decreased growth of branches and root mass in sensitive species. Also, lichen and moss communities on trees monitored in FACE sites have been shown to undergo species shifts when exposed to O_3. In addition, recent available data from annual field surveys conducted by the USFS to assess foliar damage to selected tree species is available. In light of this new scientific information, we are including additional analyses, such as combining the USFS data with recent air quality data to determine the incidence of visible O_3 damage occurring across the U.S. at air quality levels that meet or are below the current standard. Some of these analyses are not included in this first draft REA, but will be included in the second draft REA. To the extent warranted, based on new information regarding O_3 effects on forest trees, both qualitative and quantitative assessments are included in an effort to place both the estimates of risk from more recent long-term studies and historic shorter-term studies in the context of ecosystem services.

Additional information relevant to vegetation risk assessments available includes that regarding the interactions between elevated O_3 and CO_2 with respect to plant growth and how these interactions might be expected to be modified under different climatic conditions, and potential reactions of O_3 with chemicals released by plants to attract pollinators that could decrease the distance the floral "scent trail" travels and potentially change the distance pollinators have to travel to find flowers. The REA also provides an assessment of impacts occurring in designated habitat for threatened or endangered species.

To the extent warranted, qualitative and/or quantitative assessments of ecosystem services impacted by O_3 are considered to inform the current review. For example, the ecosystem services evaluation in this review includes tree biomass and crop analyses, and where possible includes impacts on 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. Carbon sequestration is another important ecosystem service (regulating) that may be affected by O_3 damage to vegetation. New preliminary evidence of O_3 effects on the ability of pollinators to find their target is also of special interest with respect to the possible implication for ecosystem services. Impairment of the ability of pollinators to locate flowers could have broad implications for agriculture, horticulture and forestry.

We are using the Forest and Agricultural Sector Optimization Model Greenhouse Gas version (FASOM) to assess the economic impacts of O_3 damage to forests, taking into account the tradeoffs between land use for forestry and agricultural. FASOM is a dynamic, non-linear programming model designed for use by the EPA to evaluate welfare benefits and market effects of carbon sequestration in trees, understory, forest floor, wood products and landfills that would occur under different agricultural and forestry scenarios. We use FASOM to model damage by O_3 to the agriculture and forestry sectors and quantify how O_3-exposed vegetation affects the ecosystem service of carbon sequestration. See Appendix X for details of the model and methodology. *[An appendix covering details of the model and methodology will be provided in supplemental materials.]*

3.2.1 Air Quality Considerations

Air quality analyses are necessary to inform and support welfare-related assessments. The air quality analyses for this review build upon those of the ISA and include consideration of: (1) summaries of recent ambient air quality data, (2) estimation approaches to extrapolate air quality values for rural areas without monitors as well as federally designated Class I natural areas important to welfare effects assessment, (3) air quality simulation procedures that modify recent air quality data to reflect changes in the distribution of air quality estimated to occur after just meeting current or alternative O_3 standards. . In addition to updating air quality summaries since the last review, these air quality analyses include summaries of the most currently available ambient measurements for the current and potential alternate secondary standard forms, and comparisons among them . These air quality analyses use monitor data from the AQS database (which includes National Park Service monitors) and the CASTNET network. In the last review, the vegetation exposure analysis used a spatial interpolation technique to create an interpolated air quality surface to fill in the gaps in ambient monitoring data, especially those left by a sparse rural monitoring network in the western United States. In this review, additional approaches that potentially could be used to fill in the gaps in the rural monitoring network, as well as opportunities for enhancing the fusion of monitoring and modeled O_3 data, are explored.

As part of the air quality analyses supporting the assessments, it is necessary to adjust recent O_3 air quality data to simulate just meeting the current standard and any alternative O_3 standards. In this first draft REA, consistent with the previous review, we are using a quadratic air quality rollback approach (U.S. EPA, 2007b), but we are evaluating alternative air quality simulation procedures for use in simulating just meeting the current and alternative standards for the second draft REA.

3.2.2 National O_3 Exposure Surface

Since the last review, little has changed in terms of the extent of monitoring coverage in non-urban areas. We consider both past and alternative approaches for generating estimates of national O_3 exposures in an effort to continue enhancing our ability to characterize exposures in these non-monitored areas. The vegetation exposure assessments conducted include assessments of recent air quality, air quality associated with just meeting the current standard and, for the second draft REA, any alternative standards that might be considered.

In addition, given the importance of providing protection for sensitive vegetation in areas afforded special protections, such as in federally designated Class I natural areas, we may also consider alternative sources of O_3 exposure information for those types of sites. For example, portable O_3 monitors are being deployed in some national parks and a current exploratory study is underway to measure O_3 concentration variations with gradients in elevation.[2] Information from these monitors could potentially inform our understanding of uncertainties associated with assessing O_3 distribution patterns in complex terrain and high elevations. New exposure data that would inform this assessment will be considered where appropriate.

To generate a national O_3 exposure surface, staff is considering several interpolation methods. We have used a previously modeled O_3 surface generated by the CMAQ model based on 2005 emissions at a 12 km grid resolution in conjunction with monitor data (2004-2006) to create a fused surface with the Modeled Attainment Test Software (MATS).[3] We have also used the Voronoi Neighbor Averaging (VNA) interpolation method in the BenMAP model (Abt Associates, Inc., 2010) to create a national O_3 surface from more recent monitor data (e.g., 2008-2010).[4] Staff will also evaluate alternate interpolation methods and sources of air quality data to assess which option is most appropriate given the analysis requirements, desire for consistency with the health risk assessment, and available resources.

In order to generate the national O_3 surface in terms of a particular index, the monitored data and CMAQ model outputs that form the basis for the interpolation need to be characterized in terms of that index. At a minimum, staff plans to generate the national surface in terms of the current secondary standard. Staff recognizes that additional indices may be selected for further evaluation upon review of the information contained in the ISA and may perform additional air quality analyses based on those indices. Any expanded evaluation of additional indices would be contained and discussed in the Policy Assessment.

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[2] For more information on portable ozone monitors in National Parks, please see http://www.nature.nps.gov/air/studies/portO3.cfm

[3] More information on CMAQ is available at http://www.epa.gov/amad/CMAQ/index.html. More information on MATS is available at http://www.epa.gov/scram001/modelingapps_mats.htm.

[4] More information on the VNA method in BenMAP is available at http://www.epa.gov/air/benmap/models/BenMAPManualAugust2010.pdf

In conjunction with the health risk assessors, staff is currently considering various approaches to simulate just meeting the current and alternative standards, including the quadratic air quality "rollback" adjustment that was used in the last review (Johnson, 1997) and variations of the proportional adjustment method. However for this first draft we have used the eVNA approach for the rollback adjustment. In addition, we are currently investigating methods for generating adjusted air quality in non-monitored areas.

The national O_3 surface, depicted as a GIS layer, provides the exposures needed as input to the crop and tree seedling risk and ecosystem service assessments described in subsequent sections.

3.3 ECOLOGICAL EFFECTS OF EXPOSURE

3.3.1 National Scale Assessment

3.3.1.1 Tree Seedling Concentration-Response Functions

We are analyzing the 11 OTC tree seedling C-R functions identified and assessed in the 2007 O_3 Staff Paper in terms of the current exposure metrics. This analysis enabled direct evaluation of estimated seedling biomass loss values expected to occur under air quality exposure scenarios expressed in terms of recent air quality and after simulation of just meeting current the standard.

3.3.1.2 Estimation of Biomass Loss for Tree Seedlings

In the 2007 O_3 Staff Paper, information on tree species growing regions was derived from the USDA Atlas of United States Trees (Little, 1971). We are using more recent information from the USDA Forest Service FIA database in order to update growing ranges for the 11 tree species studied by NHEERL-WED. The national O_3 surface is combined with the C-R function for each of the tree seedling species and information on each tree species growing region to produce estimates of biomass loss for each of the 11 tree seedling species. We are also including an additional analysis incorporating the Importance Values derived using FIA data. From this information, GIS maps are generated depicting biomass loss for each species for each air quality scenario.

3.3.2 Case Study Areas

In order to assess the ecological effects of O_3 staff will analyze ecosystem level effects in several case study areas. These areas have been selected to allow a more refined assessment of the extent of foliar injury, biomass loss and welfare related services. Criteria that were used to select case study areas include:

- Occur in areas expected to have elevated levels of O_3 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 concentration-response curves have been generated.

3.3.2.1 Estimation of Vegetation Effects in National Parks

The National Parks provide several potential case study areas. The United States Geological Survey (USGS) in conjunction with the National Park Service (NPS) is actively creating maps of the vegetation communities within the National Parks (http://biology.usgs.gov/npsveg/index.html). This provides a consistent vegetation map to compare across park units, which includes species coverage data. The NPS has also generated a comprehensive list of plant species that are known to exhibit foliar injury at ambient O_3 levels (Porter, 2003).

We have selected Great Smoky Mountains National Park, Rocky Mountain National Park, and Sequoia/Kings National Park. All three of these park units occur in areas with elevated ambient O_3 levels, have vegetation maps, and have species that are considered O_3 sensitive. We considered including Acadia National Park however it was determined not to fit our selection criteria for O_3 exposure.

The NPS vegetation maps are compared, using GIS, to the national O_3 surface to provide an overall estimate of foliar damage and total biomass loss. Potential ecological metrics that are being calculated include:

- Percent of vegetation cover affected by foliar injury.

- Percent of trails affected by foliar injury.
- Estimate of species specific biomass loss within the case study area.

3.3.2.2 Estimation of Effects in Urban Areas

Several urban areas nationally have extensive habitat management plans that include resource and vegetation mapping. These data are not as consistent or as readily available as the NPS units but in some cases can provide adequate vegetation maps in regions where O_3 sensitive species occur. We are using the iTree model developed by the U.S. Forest Service to estimate impacts on vegetation in Atlanta, Baltimore, Syracuse, the Chicago region, and the urban areas of Tennessee. We are presenting preliminary results for model runs representing current ambient conditions and runs simulating just meeting the current standard in this draft of the REA. Model runs simulating any alternative standards that may be considered will be presented in the second draft REA. *[The first draft results and an appendix with details regarding the model and methodology will be included in supplemental materials.]*

3.4 ECOSYSTEM SERVICES EVALUATION

One of the objectives of the risk assessment for a secondary NAAQS is to quantify the risks to public welfare. 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) has detailed discussions of how ecosystem services and public welfare are related and how a services framework may be employed to evaluate effects on welfare. We have identified the ecosystem services associated with the ecological effects described in Chapter 5 of this document for 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 flood control. Specific services to be evaluated are discussed in the following sections.

3.4.1 National Scale Assessment

Depending on data and resource availability, we are attempting to develop an estimate of ecosystem service impacts broadly across the United States for selected cultural, regulating, and provisioning services.

3.4.1.1 Cultural Services

We are using GIS mapping developed for the ecological effects analysis to illustrate where effects may be occurring and relate those areas to national scale statistics for recreational use available through the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. DOI, 2007) and the National Survey on Recreation and the Environment (USDA,2012) . The resulting estimates of service provision are then scaled to the current population and values assigned using existing meta-data on willingness to pay from the Recreation Values Database available at: http://recvaluation.forestry.oregonstate.edu/

We are aware 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. At this time estimates of service loss due to O_3 exposure is beyond the available data and resources; however, estimates of the current level of services would have embedded within them the current losses in service due to O_3O_3 exposure.

3.4.1.2 Regulating Services

The regulating services associated with O_3 exposure include fire regimes and fire recovery due to O_3 effects on community composition and diversity, and fuel loading due to early senescence and insect attack. There is data available through the CAL-FIRE on fire incidence, risk, and expenditures related to fires in California.

We are considering using the PnET model to estimate impacts on the hydrologic cycle for the second draft of this document. We considered the DLEM model however the resources required proved prohibitive.

3.4.1.3 Provisioning Services

Below we outline potential methods for assessing the provisioning services associated with crop yield loss and tree biomass loss, which are consistent with the methods from the previous review.

***Estimation of Yield Loss and Economic Valuation for Timber and Crops* -** The FASOM model has been utilized recently in many evaluations of effects on the timber and agriculture market sectors. We are using FASOM to assess the economic impacts of O_3 damage to forests and agricultural crops jointly. FASOM is a dynamic, non-linear programming model designed for use by the EPA to evaluate welfare benefits and market effects of O_3 induced biomass loss in trees that would occur under different agricultural and forestry scenarios. It is possible to use FASOM to model damage by O_3 to the agriculture and forestry sectors and quantify how O_3-exposed vegetation affects the provision of timber and crops. *[An appendix with details of the model and methodology will be provided in supplemental materials.]*

FASOM has been used to calculate the economic impacts of yield changes between the current ambient conditions and simulated 'just meet' scenarios for a base year. This approach will also be used to calculate the economic valuation of any alternative standards under consideration in the second draft.

3.4.1.4 Supporting Services

The supporting services associated with the vegetation effects of O_3 exposure include potential impacts on net primary productivity, and community composition. We considered using the DLEM model to estimate impacts on net primary productivity however this proved prohibitive in terms of resource availability. For the second draft we are exploring the possibility of using the PnET model to estimate these service impacts.

3.4.2 Case Study Analysis

3.4.2.1 National Park Areas

We are using GIS mapping produced for the ecological effects analysis to illustrate where effects may be occurring as a starting point to illustrate and, if possible, quantify the ecosystem services at potential risk. These are primarily, in national parks, cultural values that include existence, bequest and recreational values. We also overlay the ecological effects maps with data on where hiking trails, campgrounds, or other park amenities are found to intersect potentially affected areas. We then relate those areas to case study specific statistics for recreational use available through the National Park Service. In addition, we have described the other nonuse values associated with national parks including existence and bequest values. For the resulting estimates of service provision values are then assigned using existing meta-data on willingness to pay from Kaval and Loomis (2003). We are aware that these estimates will be limited to current levels of service provision. At this time estimates of service loss due to O_3 exposure may be beyond the available data and/or resources for many if not all ecosystem services listed above.

3.4.2.2 Urban Areas

We are using the i-Tree model to assess effects on ecosystem services provided by urban forests, pollution removal, and carbon storage and sequestration. The i-TREE model is a publicly available peer-reviewed software suite developed by the U.S. Forest Service and its partners to assess the ecosystem service impacts of urban forestry (available here: http://www.itreetools.org/). We are collaborating with the U.S. Forest Service 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. See Appendix 6A for a description of the model and methodology. *[Preliminary results will be provided in supplemental materials.]*

3.5 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 C-R functions describing the relation between O_3 and vegetation injury across selected study areas. This variability may be due to differences in ecosystems (e.g., diversity, habitat heterogeneity, and rainfall), levels 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 concentration-response functions). In any risk assessment, uncertainty is, ideally, reduced to the maximum extent possible, 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.

While the goal in designing a quantitative risk assessment is to reduce uncertainty to the extent possible, with variability the goal is 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.

For this first draft we have not included detailed analyses of uncertainty or variability. For the second draft of this document we plan to more fully differentiate variability and uncertainty in the design of the risk assessment to more clearly address (a) the extent to which the risk estimates represent the distribution of ecological impacts across ecosystems, including impacts on more sensitive species, and (b) the extent to which risk estimates are impacted by key sources of uncertainty which could prevent a clear differentiation between regulatory alternatives based on risk estimates.

4 AIR QUALITY CONSIDERATIONS

4.1 INTRODUCTION

Air quality information is used in the welfare risk and exposure analyses, described in Chapters 5 and 6, to assess risk and exposure resulting from recent O_3 concentrations, as well as to estimate the relative change in risk and exposure resulting from adjusted O_3 concentrations after simulating just meeting the current O_3 standard of 0.075 ppm. To complete these analyses, ambient monitoring data is provided for all AQS monitors in the U.S. for several relevant metrics for 2006-2010. In addition, a national-scale spatial surface is generated that estimates W126 concentrations throughout the U.S. for 2006-2008 and for simulating just meeting the current O_3 standard of 0.075 ppm. This chapter describes the air quality information used in these analyses, providing an overview of monitoring data and air quality (section 4.2) as well as 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 monitoring agencies operate O_3 monitoring sites at various locations, depending on the size of the area and typical peak O_3 concentrations (US EPA, 2012, sections 3.5.6.1, 3.7.4). In 2010, there were 1,250 State and Local O_3 monitors reporting concentrations to EPA (US EPA, 2012, Figures 3-21 and 3-22). 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% of the NAAQS, to four, for areas with a population greater than 10 million and an O_3 design value greater than 85% of the NAAQS.[1] For areas with required O_3 monitors, at least one site must be designed to record the maximum concentration for that particular metropolitan area. Since O_3 concentrations decrease significantly in the colder parts of the year in many areas, O_3 is required to be monitored only during the "O_3 season," which varies by state (US EPA, 2012, section 3.5.6 and Figure 3-20).[2] Figure 4-1 shows the location and 8-h O_3 design values (4^{th} highest 8-h daily max O_3 concentration occurring within a three-year period) for all available monitors in the US for the 2008-2010 period.

[1]The current monitor and probe siting requirements have an urban focus and do not address siting in non-urban, rural areas. States may operate O_3 monitors in non-urban or rural areas to meet other objectives (e.g., support for research studies of atmospheric chemistry or ecosystem impacts).

[2]Some States and Territories operate O_3 monitors year-round, including Arizona, California, Hawaii, Louisiana, Nevada, New Mexico, Puerto Rico, Texas, American Samoa, Guam and the Virgin Islands.

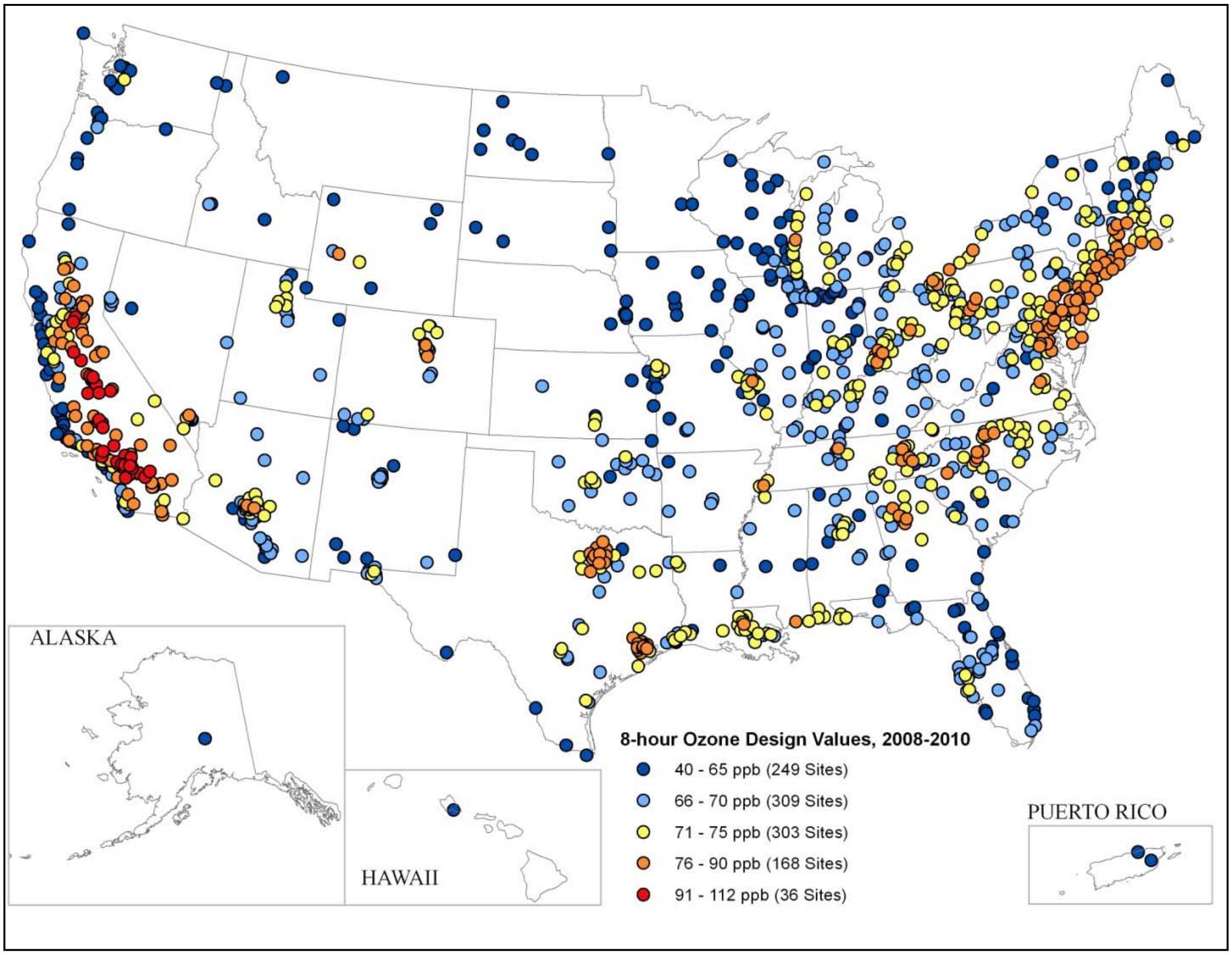


Figure 4- 1 Individual monitor 8-h daily max O_3 design values displayed for the 2008-2010 period (U.S. EPA, 2012, Figure 3-52A)

In 2010, there were approximately 112 monitoring sites being operated in rural areas. These sites included 15 National Core (NCore) monitors, 80 Clean Air Status and Trends Network (CASTNET) monitors, and 17 Portable O_3 Monitoring Systems (POMS) network monitors operated by the National Park Service (NPS). The location of these monitors is shown in Figure 4-2.

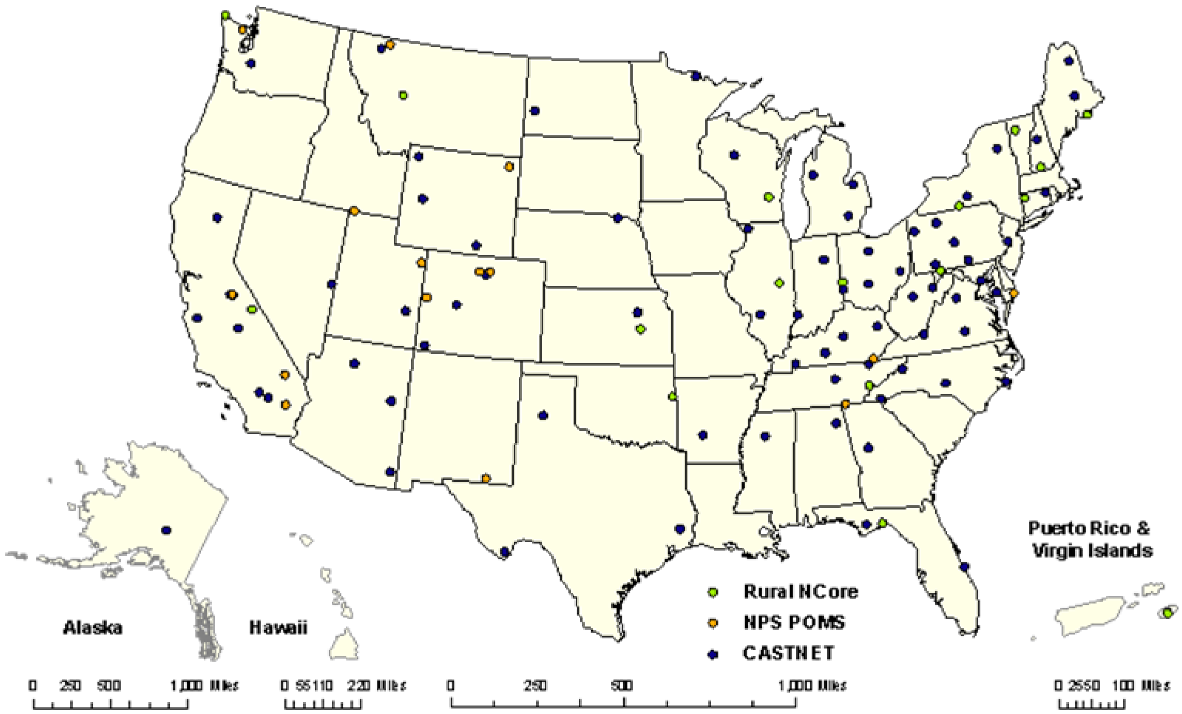


Figure 4- 2 U.S. Rural NCore, CASTNET and NPS POMS O_3 sites in 2010 (U.S. EPA, 2012, Figure 3-22)

4.3 OVERVIEW OF AIR QUALITY INPUTS TO RISK AND EXPOSURE ASSESSMENTS

The air quality information input into the welfare risk and exposure assessments includes recent air quality measurement data from the years 2006-2010, as well as a national-scale “fused” spatial surface of air quality data for recent air quality, 2006-2008, and adjusted to reflect just meeting the current O_3 standard of 0.075 ppm. In this section, we summarize these air quality inputs and discuss the methodology used to simulate air quality to meet the current standard. More details on these data and methodologies can be found in Wells et al. (2012).

4.3.1 Recent Air Quality

The air quality monitoring data used to inform the first draft O_3 Risk and Exposure Assessments were hourly O_3 concentrations collected between 1/1/2006 and 12/31/2010 from all US monitors meeting EPA’s siting, method, and quality assurance criteria in 40 CFR Part 58.

These data were extracted from EPA's Air Quality System (AQS) database[3] on June 27, 2011. Regionally concurred exceptional event data (i.e. data certified by the monitoring agency to have been affected by natural phenomena such as wildfires or stratospheric intrusions, and concurred upon by the EPA regional office) were not included in the assessments. However, concurred exception events were rare, accounting for less than 0.01% of the total observations. All concurred exceptional events in 2006-2010 were related to wildfires in California in 2008. There were no concurrences of exceptional event data for stratospheric intrusions in 2006-2010.

4.3.1.1 Ambient Measurements and Air Quality Metrics

EPA focused the analysis in the welfare exposure and risk assessment 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. The metric uses a logistic weighting function to place less emphasis on exposure to low concentrations and more emphasis on exposure to high concentrations (Lefohn et al, 1988).

The first step in calculating W126 values was to sum the hourly O_3 concentrations within each month, resulting in monthly index values. Since most plant and tree species are not photochemically 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 as follows:

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

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 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% ($V_m < 0.75$).

[3] EPA's Air Quality System (AQS) database is a state-of-the-art 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 air toxics, meteorology, and quality assurance data. At present, AQS receives O_3 monitoring data collected hourly from over 1,300 monitors, and quality assured by one of over 100 state, local, or tribal air quality monitoring agencies.

Finally, annual W126 index values were computed as the maximum sum of their respective adjusted monthly index values occurring in three consecutive months (January – March, February – April, etc.). Three-month periods spanning two years (November – January, December – February) were not considered because the seasonal nature of O_3 dictates that it is very unlikely for the maximum values to occur at that time of year. The W126 metric was analyzed for each individual year of 2006 to 2008 and for the three year period of 2006-2008.

For the specific application of the Kohut analysis, N100 and SUM06 metric were also computed. The procedures used to calculate N100 and SUM06 values are similar to the calculation of the W126 metric that is described above. Hourly O_3 concentrations are summed within each month, resulting in monthly index values, and 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 N100 and SUM06 values were calculated as follows:

$$Monthly\ N100 = \sum_{d=1}^{N}\sum_{h=8}^{19}\begin{Bmatrix} 0, & if\ C_{dh} \leq 0.100\,ppm \\ 1, & if\ C_{dh} > 0.100\,ppm \end{Bmatrix}$$

$$Monthly\ SUM06 = \sum_{d=1}^{N}\sum_{h=8}^{19}\max(0, (C_{dh} - 0.060))$$

The monthly N100 and SUM06 values were adjusted for missing data as described above for the W126 metric. Annual N100 and SUM06 values were computed as the maximum sum of their respective adjusted monthly index values occurring in three consecutive months (January – March, February – April, etc.). Three-month periods spanning two years (November – January, December – February) were not considered because the seasonal nature of O_3 dictates that it is very unlikely for the maximum values to occur at that time of year.

The N100 and SUM06 metrics were calculated for each individual year for all 5 years (2006 to 2010) and used in the Kohut analysis, which is discussed in more detail in Chapter 5. In addition, the W126 and N100 value was calculated for 3-month and 7-month values for the Kohut analysis and analyzed for each individual year of 2006 to 2010.

4.3.1.2 National-scale Air Quality Inputs

In addition to ambient monitoring data, the welfare risk and exposure assessment also analyzed a national scale spatial surface of W126 for the three-year period of 2006-2008 and for each individual year: 2006, 2007 and 2008. This analysis employed a data fusion approach to take advantage of the accuracy of monitor observations and the comprehensive spatial information of the CMAQ modeling system to create a national-scale "fused" spatial surface of seasonal average O_3. The spatial surface is created by fusing 2006-2008 measured O_3 concentrations with the 2007 CMAQ model simulation, which was run for a 12 km gridded domain, using the EPA's Model Attainment Test Software (MATS; Abt Associates, 2010), which employs the enhanced Voronoi Neighbor Averaging (eVNA) technique (Timin et al., 2010) enhanced with information on the spatial gradient of O_3 provided by CMAQ results. The 2006-2008 W126 national-scale "fused" spatial surface is shown in Figure 4-3. More details on the ambient measurements and the 2007 CMAQ model simulation, as well as the spatial fusion technique, can be found in Wells et al. (2012).

4.3.2 Air Quality After Simulating "Just Meeting" Current O_3 Standard

In addition to 2006-2008 air quality concentrations for the W126 metric, the risk and exposure assessments also consider the relative change in risk and exposure when considering the distribution of W126 after simulating "just meeting" the current O_3 standard of 0.075 ppm. The sections below summarize the methodology applied for this first draft REA to simulate just meeting the current NAAQS by "rolling back" the baseline distribution of recent O_3 concentrations. More details on these inputs are provided in Wells et al. (2012).

4.3.2.1 Methods

The "quadratic rollback" method was used in the previous O_3 NAAQS review to adjust ambient O_3 concentrations to simulate minimally meeting current and alternative standards (U.S. EPA, 2007). As the name implies, quadratic rollback uses a quadratic equation to reduce high concentrations at a greater rate than low concentrations. The intent is to simulate reductions in O_3 resulting from unspecified reductions in precursor emissions, without greatly affecting concentrations near ambient background levels (Duff et al., 1998).

Two independent analyses (Johnson, 2002; Rizzo, 2005; 2006) were conducted to compare quadratic rollback with other methods such as linear (proportional) rollback and distributional (Weibull) rollback. Both analyses used different rollback methods to reduce concentrations from a high O_3 year to simulate levels achieved during a low O_3 year, then compared the results to the ambient concentrations observed during the low O_3 year. Both analyses concluded that the quadratic rollback method resulted in an 8-hour O_3 distribution most similar to that of the ambient concentrations.

In this review, quadratic rollback was used to reduce O_3 concentrations in all areas of the U.S. with violating monitors to just meet the current NAAQS of 0.075 ppm (75 ppb). To do this, a hierarchical method was used to group all monitors in the U.S. into hypothetical "non-attainment" areas (Wells et al., 2012). For each of these areas, quadratic rollback was then employed to simulate just meeting the current standard. Hourly O_3 concentrations were reduced so that the highest design value in each area was exactly 75 ppb, the highest value meeting the NAAQS. Finally, the 2006-2008 W126 metric was calculated from the hourly rollback concentrations. It should be noted that O_3 concentrations were only adjusted relative to the other monitors included in the hypothetical “non-attainment” area. In this way, areas with all monitors below 75 ppb would not have been affected by this rollback methodology and the O_3 concentrations in those areas would not have changed. This was true even when these monitors were very close to, but outside of, other hypothetical “non-attainment” areas that were adjusted to simulate just meeting the current standard.

To generate a national-scale spatial surface that represents 2006-2008 W126 concentrations when attaining the current NAAQS, the spatial surface for 2006-2008 recent air quality was adjusted to reflect the rolled back W126 monitor concentrations. To do this, the rolled back W126 monitor values were inserted into the spatial surface at the monitor locations and the W126 surface was smoothed using the Voronoi Neighbor Averaging (VNA) spatial averaging technique to minimize any sharp gradients between the national-scale spatial surface that represents 2006-2008 W126 concentrations and the rollback W126 monitor concentrations. This is described in more detail in Wells et al. (2012).

4.3.2.2 Results

Figure 4-3 shows the national-scale 2006-2008 W126 spatial “fused” surface created as described in Section 4.3.1.1, and Figure 4-4 shows the national-scale 2006-2008 W126 surface that reflects simulation of just meeting the current standard of 0.075 ppm. Figure 4-5 shows the difference between the two spatial surfaces, and shows how W126 changed when simulating just meeting the current standard. The state of California was most affected by the rollback, with average changes in W126 of around 20. Other areas with notable changes include the areas around: Atlanta, Charlotte, Denver, Phoenix, Salt Lake City and the area between Washington, D.C. and Boston (all areas that had relatively high 8-hour O_3 concentrations above the current standard).

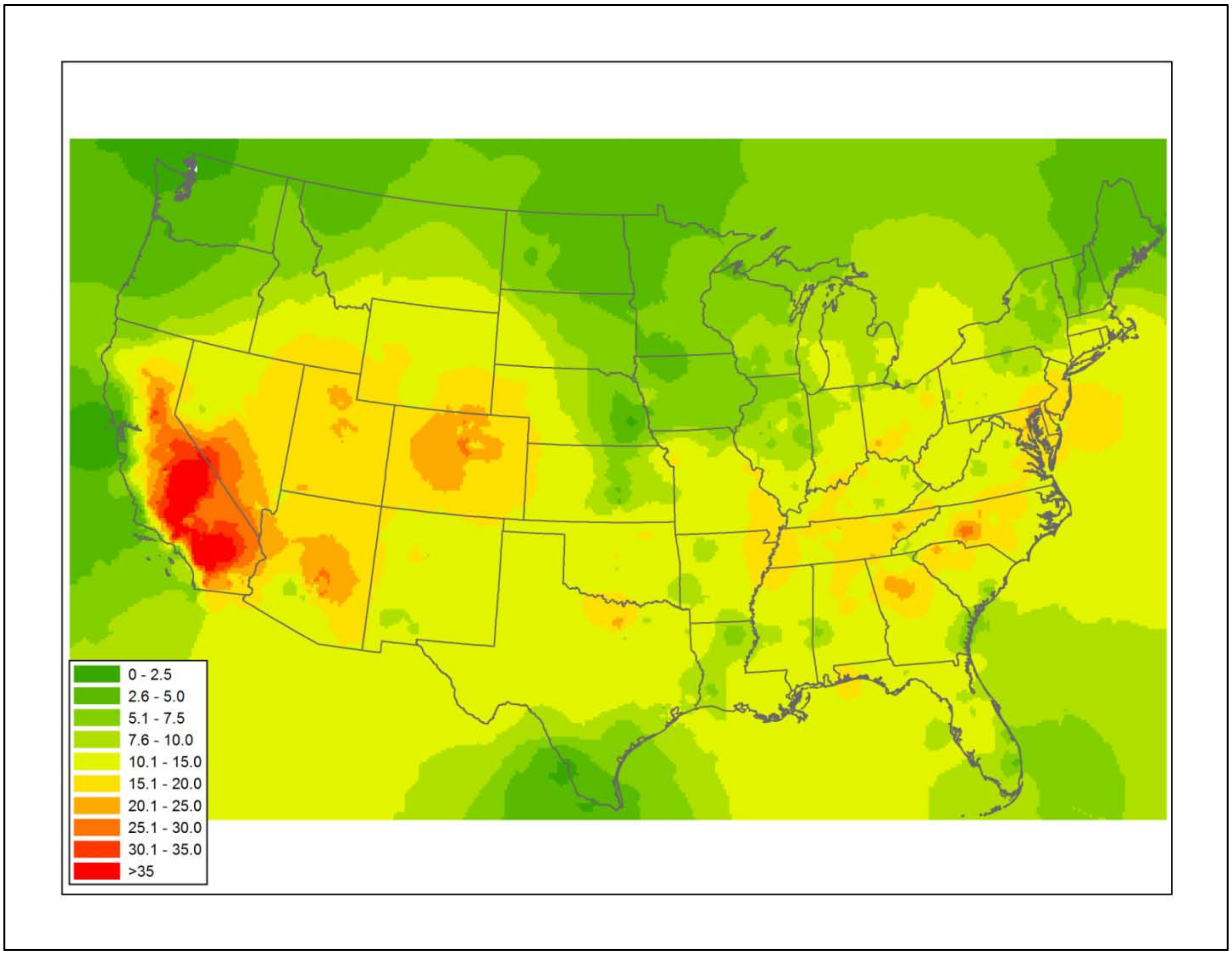


Figure 4- 3 “Fused” national-scale surface of W126 metric, 2006-2008

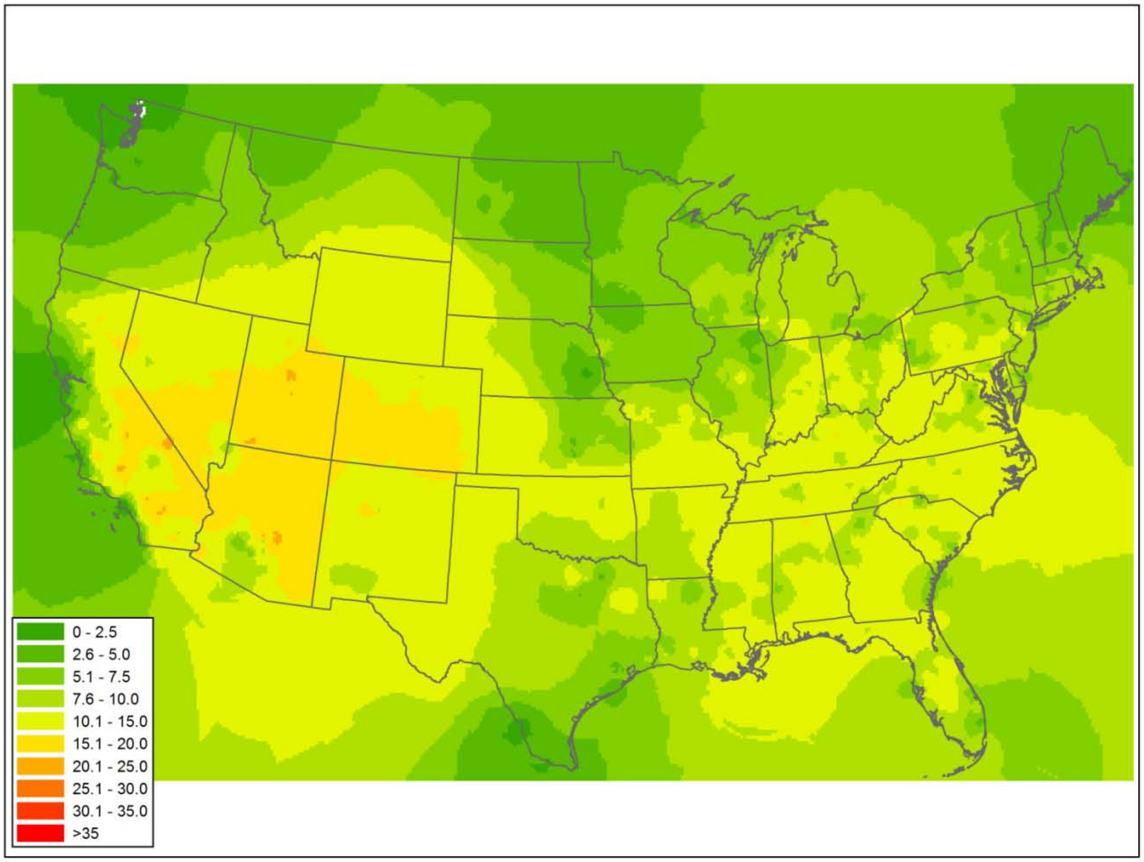


Figure 4- 4 "Fused" national-scale surface of W126 metric for 2006-2008, adjusted for simulating just meeting the current standard of 0.075 ppm.

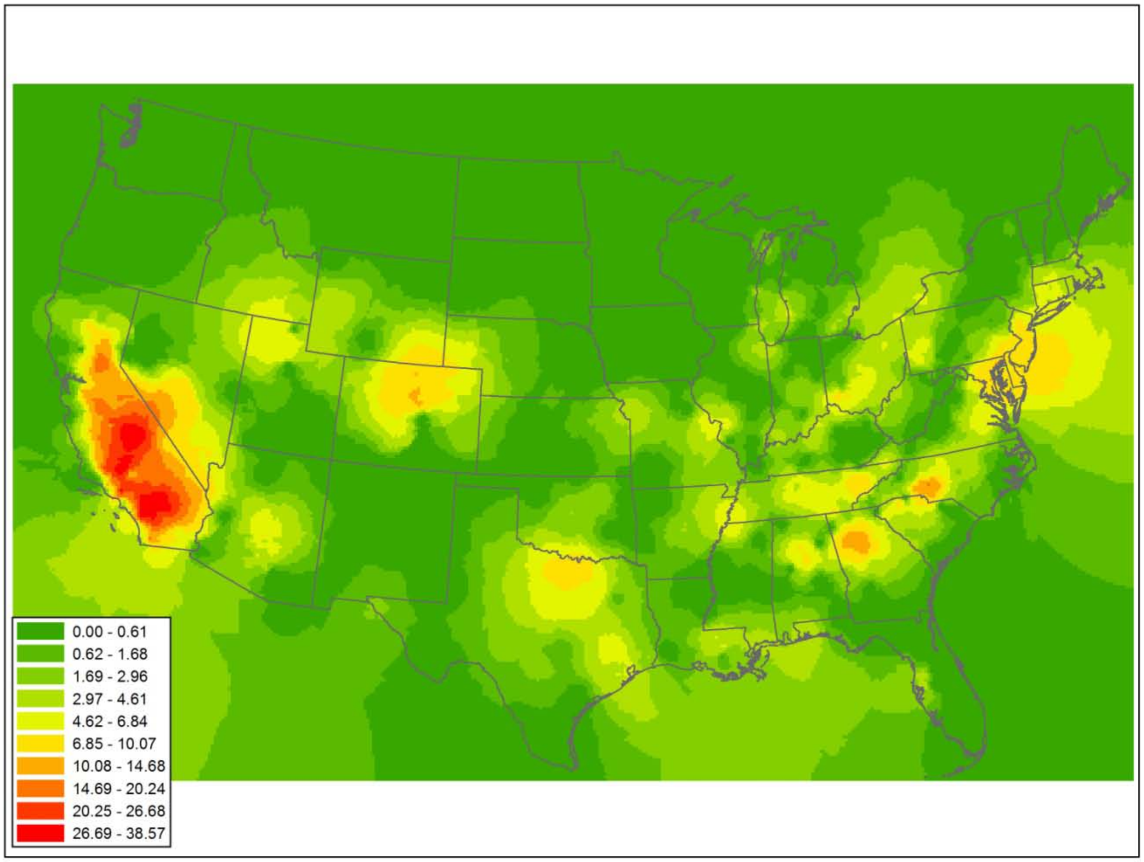


Figure 4- 5 Difference between the "fused" national-scale surfaces of W126 for 2006-2008 and for 2006-2008 adjusted for simulating just meeting the current standard of 0.075 ppm.

5 ECOLOGICAL EFFECTS

5.1 INTRODUCTION

This chapter presents the results of ecological risk analyses based on the causal and likely causal effects of O_3 on vegetation and ecosystems described in the ISA. Recent studies reviewed in the O_3 ISA (U.S. EPA, 2012a) support and strengthen the findings reported in the 2006 O_3 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 which 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, which is focused on recent ambient levels of O_3 exposure and O_3 levels simulated to meet current and alternative O_3 standards.

The causal findings reported in the ISA based on the current science are summarized in Table 5- 1. This table includes both causal and likely causal effects. Two of the effects, alteration of below-ground biogeochemical cycles and alteration of terrestrial communities are not analyzed directly in this review. However both can be inferred as components of the i-Tree and FASOM models discussed in Chapter 6 and the scaled-biomass loss analyses presented in this chapter.

Table 5- 1 Summary of O_3 causal determinations for vegetation and ecosystem effects (modified from Table 9-18 in the ISA)

Vegetation and Ecosystem Effect	Conclusions from 2012 ISA	2012 REA
Visible Foliar Injury Effects on Vegetation	Causal Relationship	Analyzed in this chapter at a National-scale and within NPS Units (Section 5.3.2) and NPS case study areas (section 5.4)
Reduced Vegetation Growth	Causal Relationship	Analyzed in this chapter at a National-scale and within NPS case study areas (section 5.3)
Reduced Productivity in Terrestrial Ecosystems	Causal Relationship	Analyzed in Chapter 6 using pNET-CN (pending)
Reduced Carbon (C) Sequestration in Terrestrial Ecosystems	Likely Causal Relationship	Analyzed in Chapter 6 using pNET-CN (pending) and i-TREE (section 6.X)

Vegetation and Ecosystem Effect	Conclusions from 2012 ISA	2012 REA
Reduced Yield and Quality of Agricultural Crops	Causal Relationship	Yield loss data are included in the FASOM model (section 6.X), but effects on agricultural crops are not a focus of this review
Alteration of Terrestrial Ecosystem Water Cycling	Likely Causal Relationship	Analyzed in Chapter 6 using pNET-CN (pending) Relationship
Alteration of Below-ground Biogeochemical Cycles	Causal Relationship	Not analyzed directly in this review
Alteration of Terrestrial Community Composition	Likely Causal Relationship	Not analyzed directly in this review

5.2 RELATIVE BIOMASS LOSS

The previous O_3 AQCDs (U.S. EPA, 1996, 2006) and current O_3 ISA (U.S. EPA, 2012) concluded that there is strong and consistent evidence that ambient concentrations of O_3 decrease photosynthesis and growth in numerous plant species across the U.S.

Meta-analyses by Wittig et al. (2007, 2009) demonstrate the coherence of O_3 effects on plant photosynthesis and growth across numerous studies and species using a variety of experimental techniques. Furthermore, recent meta-analyses have generally indicated that O_3 reduces C allocation to roots (Wittig et al., 2009; Grantz et al., 2006). Since the 2006 O_3 AQCD, several studies were published based on the Aspen FACE 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 understanding of O_3 effects on forests and demonstrate the relevance of the knowledge gained from trees grown in OTC studies.

The 1996 and 2006 O_3 AQCDs relied extensively on results from analyses conducted on commercial crop species under the auspices of the National Crop Loss Assessment Network (NCLAN) and on analyses of tree seedling species conducted by the EPA's National Health and Environmental Effect Laboratory, Western Ecology Division (NHEERL/WED). Results from these studies have been published 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 –

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

Equation 5-1

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. 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) as related to the 3-month W126 O_3 index -

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

Equation 5-2

is essential in comparing exposure-response across species, genotypes, or experiments for which absolute values of the response may vary greatly. In the 1996 and 2006 O_3 AQCDs, the two-parameter model of relative yield was used in deriving common models for multiple species, multiple genotypes within species, and multiple locations.

Relative biomass loss (RBL) functions for the 11 tree species used in this assessment are presented in Table 5-2 (see the ISA (EPA 2012a) for a more extensive review of the calculation of the C-R functions).

Table 5- 2 Relative Biomass Loss Functions for Tree Species (modified from Table 9-18 in the ISA)

Species	RBL Function	η (ppm)	β
Red Maple (*Acer rubrum*)		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*)	$1 - \exp[-(W126/\eta)^{\beta}]$	63.23	1.6582
Virginia Pine (*Pinus virginiana*)		1714.64	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

Figure 5- 1 shows a comparison of W126 median RBL response functions for the tree species used in this assessment. The figure illustrates how the two parameters affect the shape of the resulting curves. Differences in the shape of these curves are important for understanding differences in the analyses presented later in this chapter. The two parameters of the RBL equation (Equation 5-2) 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 which are above the normal range of ambient W126 measurements (e.g. ponderosa pine, red alder) have response functions with more gradual and consistent slopes. This results in more constant rate of change in RBL over a range of O_3 exposure consistent with ambient exposure levels.

In contrast, the species with larger **β** values (e.g. sugar maple, Douglas fir) have response functions that behave more like thresholds, with large changes in RBL over some ranges of O_3 and relatively small changes at other levels. In these cases the "threshold" is determined by the **η** parameter of the model. In the example of eastern cottonwood, β is relatively low, but because η is also very low relative to the other species, so the resulting C-R curve has a very steep gradient relative to other species with similar β values.

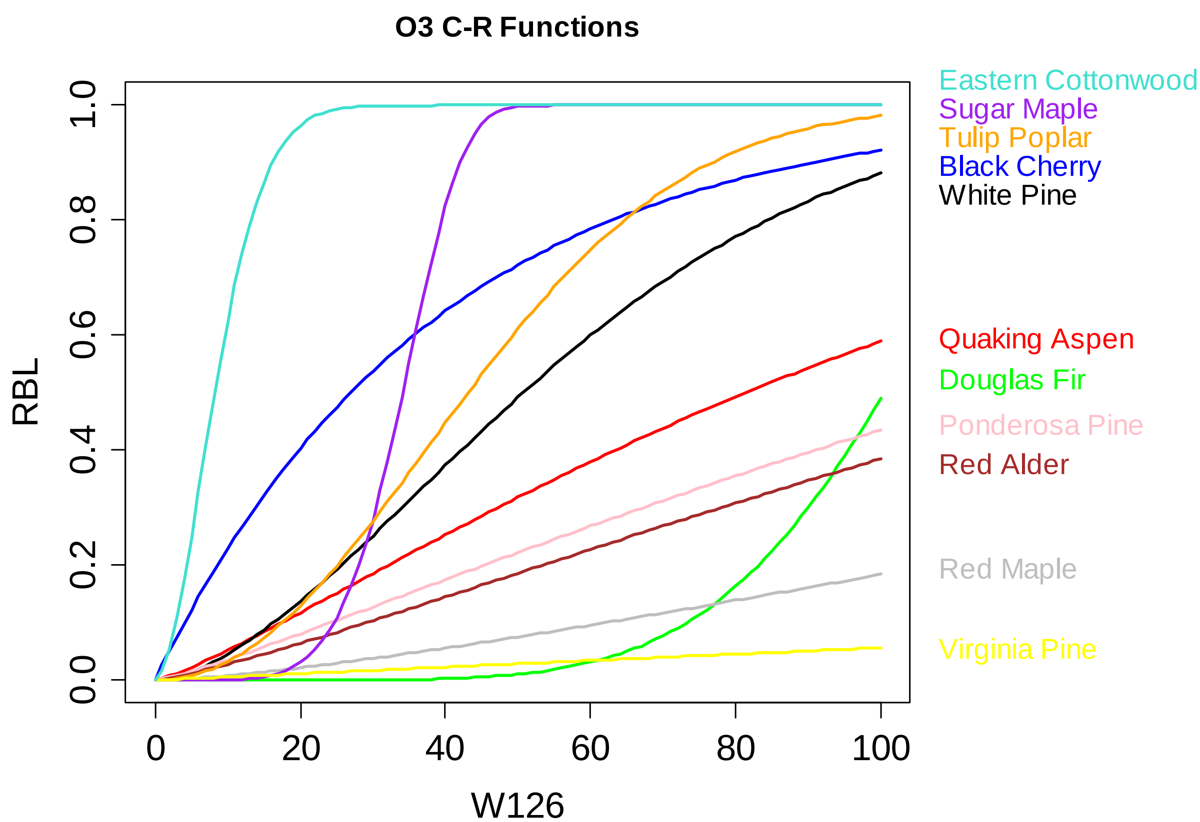


Figure 5- 1 Relative Biomass Loss Functions for 11 Tree Species

5.2.1 Species Level Analyses

5.2.1.1 Individual Species Analyses

The C-R functions listed in Table 5-2 were used to generate RBL surfaces for the 11 trees species using GIS (ESRI®, ArcMAP™ 10). A surface was created using recent ambient O_3 conditions and a scenario with O_3 levels rolled back to simulate just meeting the current 8 hr secondary standard (see Chapter 4 for a more detailed description of the O_3 surfaces). The recent ambient conditions are based on monitored data from the years 2006 to 2008 and for the remainder of this analysis we will refer to that surface as "ambient". Two species are presented here to illustrate the results, ponderosa pine (Figure 5- 2 and Figure 5- 4) and tulip poplar (Figure 5- 3 and Figure 5- 5). RBL surfaces for the remaining 8 species are presented in Appendix 5A. 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.

Three of the tree species occur entirely in the western U.S.; ponderosa pine, Douglas fir, and red alder. Ranges for the western species were taken from the U.S. Department of Agriculture's Atlas of United States Trees (Little, 1971) (Figure 5- 2 and Figure 5- 4). The western tree species have more fragmented habitats than the eastern species. The areas in souther California have the highest levels of O3, which can be seen as the very high areas of RBL in Figure 5-2. The area of high RBL in Figure 5-2 in Idaho is a result of high O3 levels from the 2007 Idaho Forest Fires. This area is still elevated in Figure 5-4 because those areas were not near areas considered out of attainment, so were not reduced significantly in the scenario just meeting the current standard.

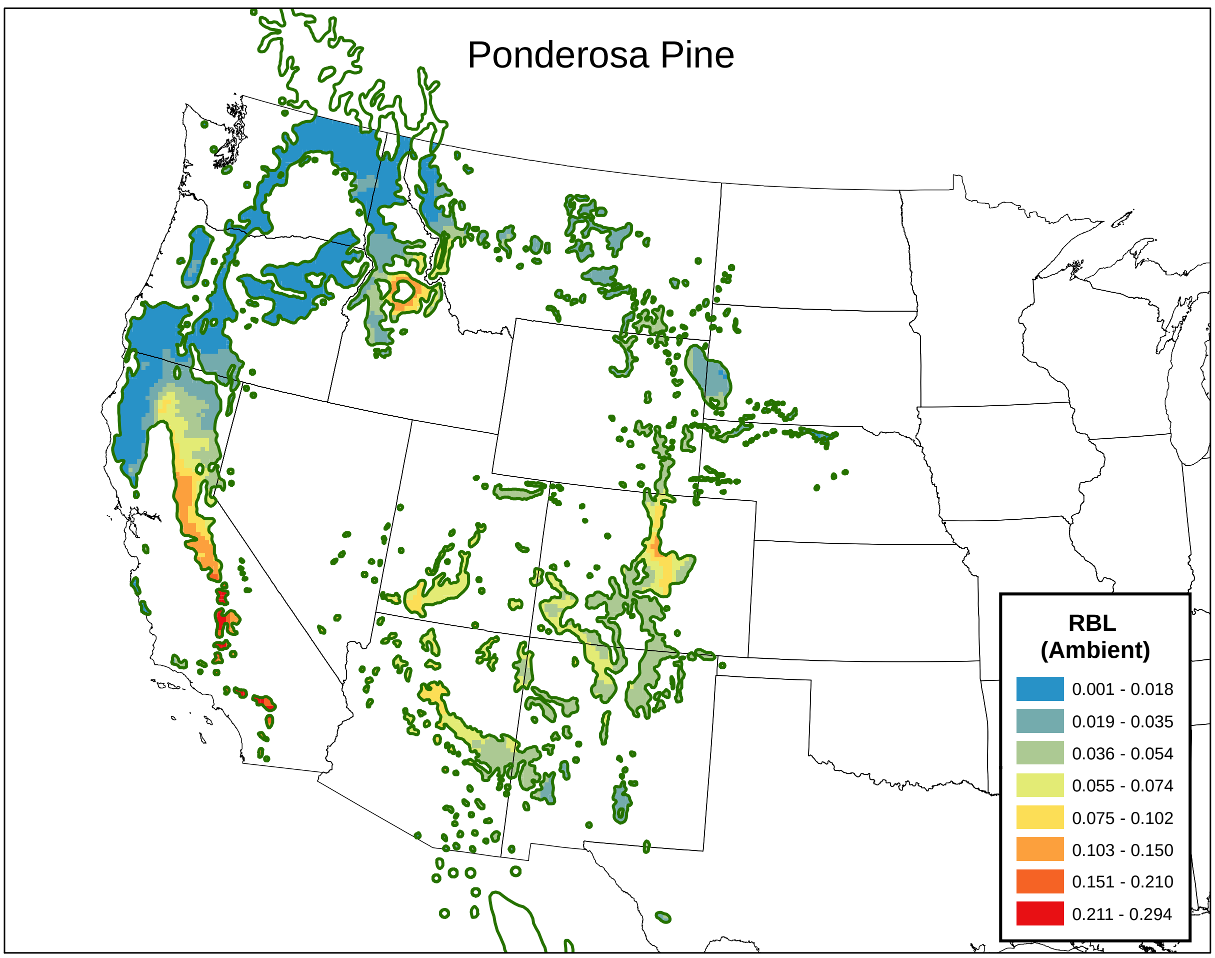


Figure 5- 2 Relative Biomass Loss of Ponderosa Pine (*Pinus ponderosa*) seedlings under recent ambient O_3 exposure levels (2006 – 2008)

Ranges for the eight eastern species were also based on the USDA Ranges (Figure 5- 3 and Figure 5- 5, green outline). Additional work by the northern research station based on Forest Inventory Analysis data (FIA) was used to update the range for the 8 eastern species (U.S. Forest Service Climate Change Atlas, http://www.fs.fed.us/nrs/atlas/littlefia/index.html). These updates can be seen in Figure 5- 3 as areas outside of the green line indicating the Little's range that are shown to have a RBL value. For this analysis, these values were only used to expand the species ranges and were not used to indicate absence inside of the Little's range. However, this was done in the scaled analyses presented in section 5.2.2.

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.

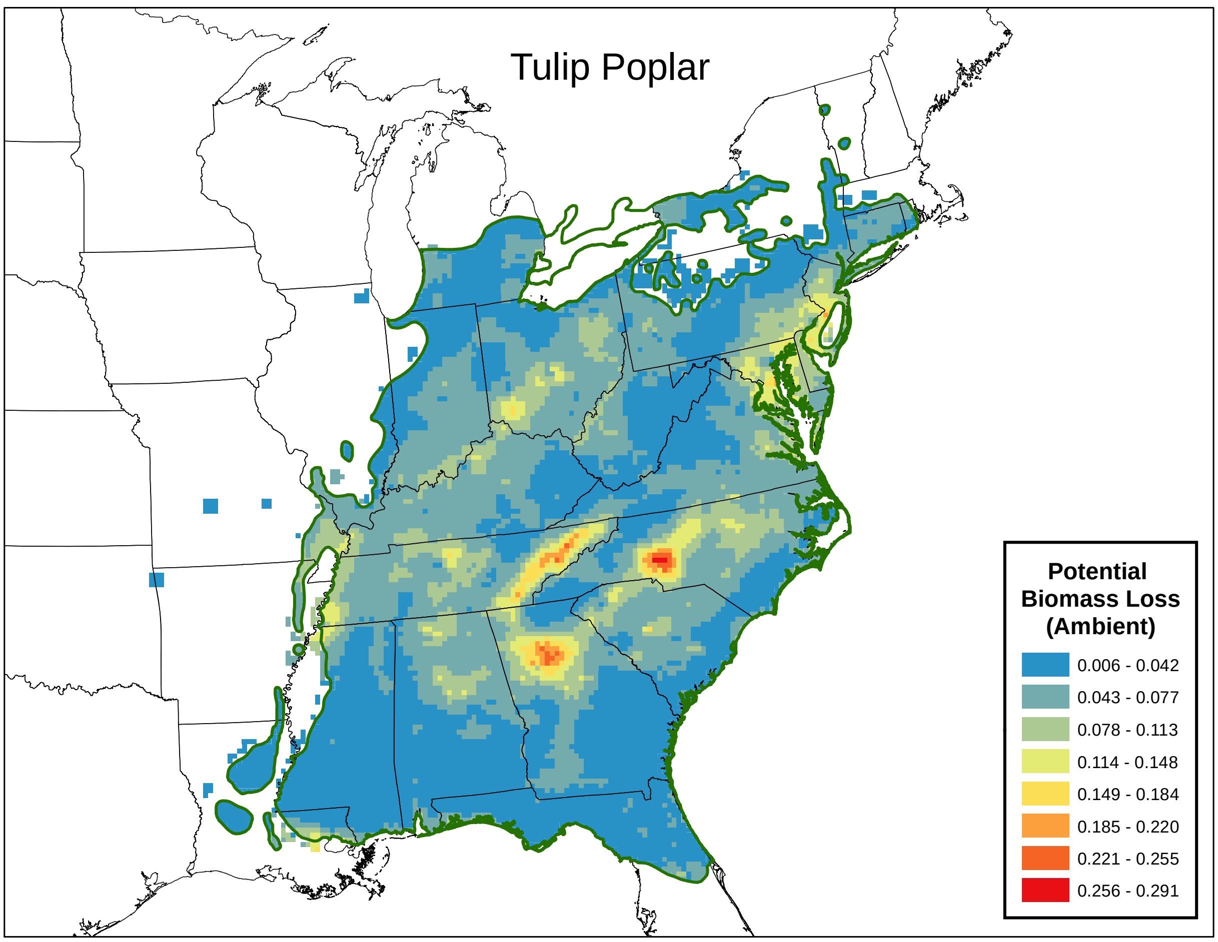


Figure 5- 3 Relative Biomass Loss of tulip poplar (*Liriodendron tulipifera*) seedlings under recent ambient O_3 exposure levels (2006 – 2008)

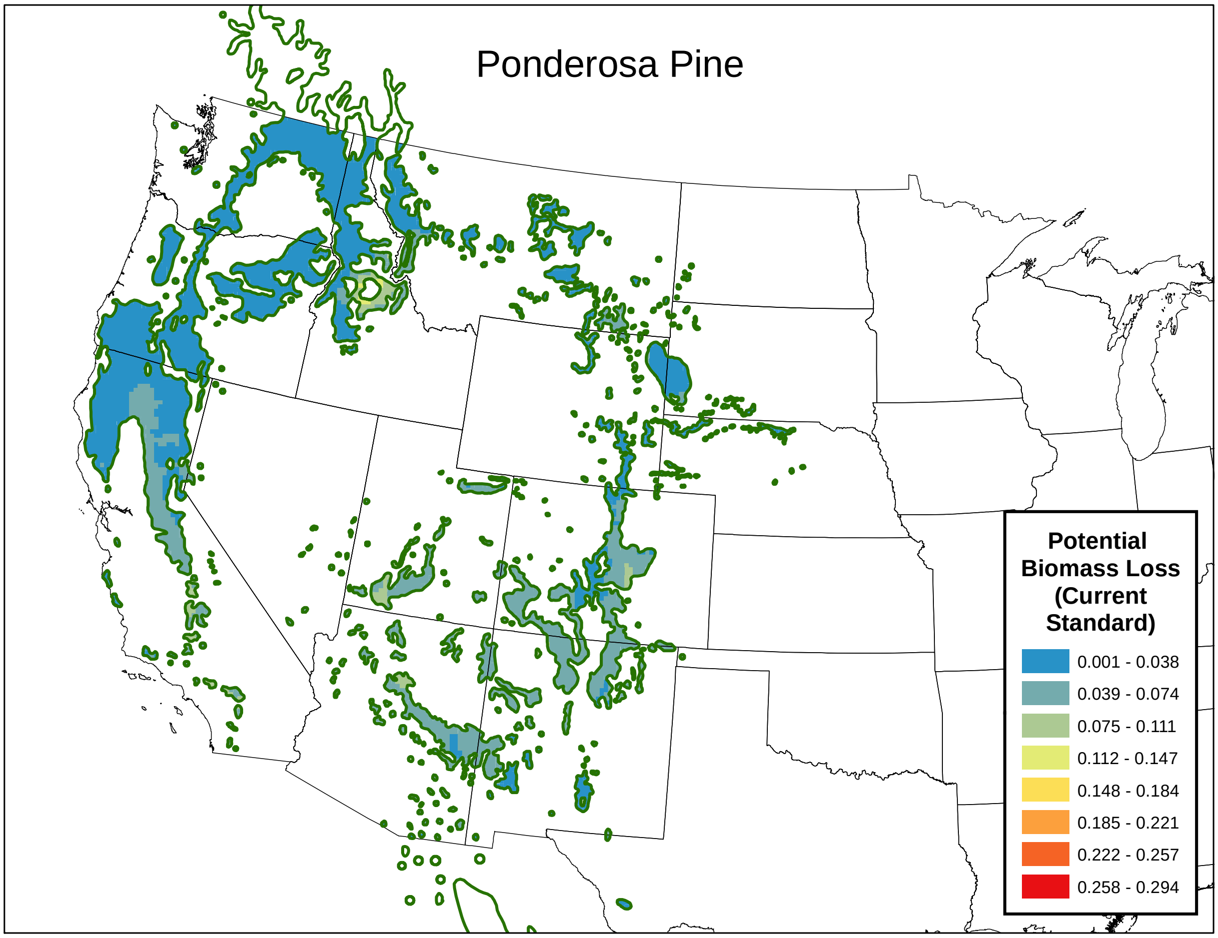


Figure 5- 4 Relative Biomass Loss of Ponderosa Pine with O_3 exposure rolled back to meet the current (8-hr) secondary standard.

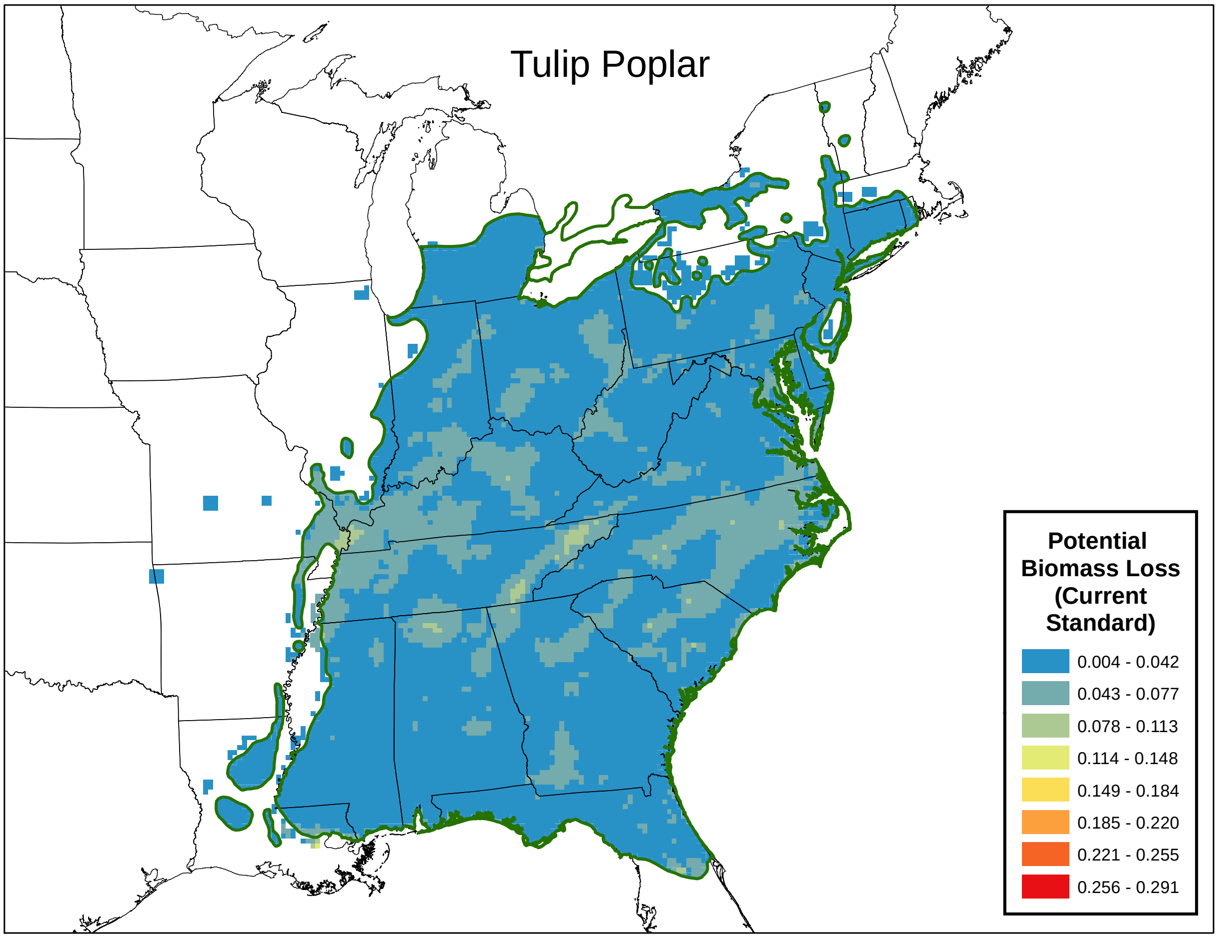


Figure 5- 5 Relative Biomass Loss of Tulip Poplar with O_3 exposure rolled back to meet the current (8-hr) secondary standard.

5.2.1.2 Combined Risk Analysis of Individual Species

To assess the combined risk of the 11 tree species, the RBL values were compared between O_3 exposure scenarios. The comparisons were done on using individual CMAQ 12km grid cells as individual points for comparison. A linear-fit model, the equivalent of a simple regression, was used to compare the RBL surfaces. The y-intercept forced through the origin so that the slopes of the resulting lines would be comparable. The results for ponderosa pine and tulip poplar are shown in Figure 5- 6 and the summary values for all of the species are listed in Table 5- 3. Plots for the remaining species are presented in Appendix 5A. The RBL surface for recent conditions was used as the baseline for comparison between rollback scenarios. This first draft includes only one O_3 scenario, with O_3 levels simulating just meeting the current standard.

The second draft will include additional scenarios with distinct secondary standards, expressed using the W126, a cumulative, seasonal index.

Using this approach provides two advantages. First, it will in part correct for variability in O_3 exposures in different regions. For example, one source of variability is the difference between O_3 concentrations measured at the height of ambient monitors and those occurring at the height of the actual tree canopy. In the 2007 Staff Paper (U.S. EPA, 2007a) this difference was addressed by applying a 10% reduction in hourly O_3 values in each grid cell. That methodology introduced uncertainty, but was a useful in comparing the effects of uncertainty in the O_3 exposure values.

The method used to generate the exposure surface in this assessment is not readily adjusted in a similar manner so the cell-by-cell comparison allows each grid cell to be compared based on the proportional change between exposure scenarios. Bias in the exposure value based on elevation should be similar between O_3 exposure scenarios, so will be factored into the proportional change. The second advantage is this provides a uniform methodology to compare between endpoints. In this analysis, individual tree species are used as the endpoint of the analysis. The analysis presented in section 5.2.2 uses designated critical habitat and Class I areas as the endpoint, and the individual case study areas analyzed in section 5.3 can each be used as a distinct endpoint, but comparable analyses can be done with all 4 different endpoints. One negative of this analysis is that by forcing the model through the origin, the r-squared values are difficult to interpret.

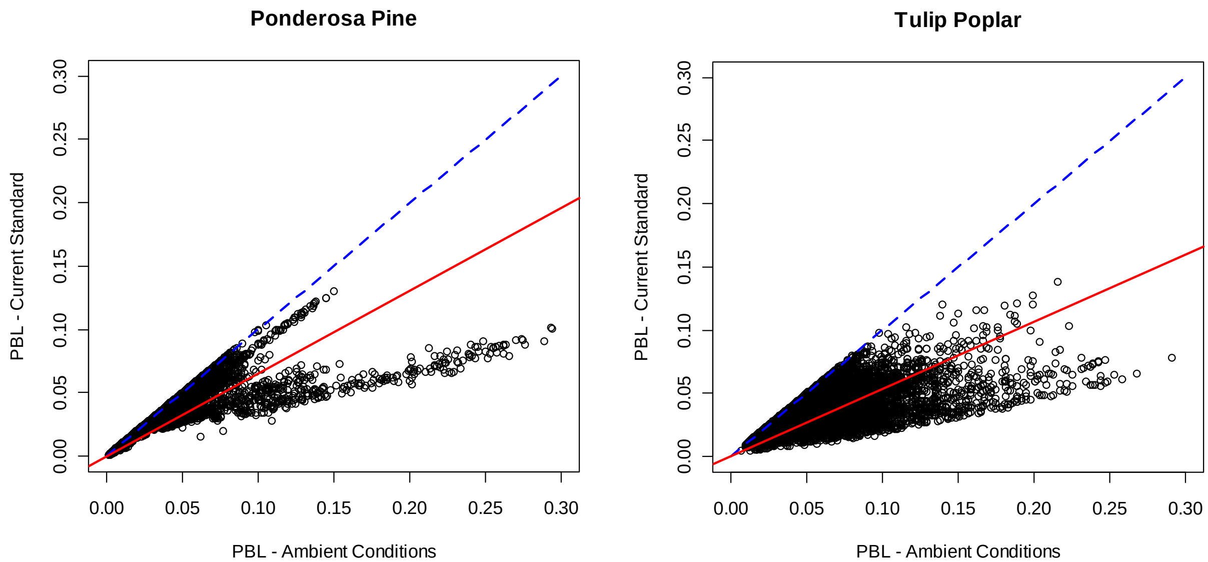


Figure 5- 6 Linear fit model of RBL under recent ambient O_3 exposure levels (2006 – 2008) conditions compared to estimated values for meeting the current (8-hr) standard for ponderosa pine and tulip poplar. The dashed blue line represents the one-to-one line. The red line is the fitted line.

The values presented in Table 5- 3 summarize the individual species analysis. The median and maximum RBL values are listed for comparison under ambient conditions. The slope of linear fit model (Figure 5- 6, red lines, Table 5- 3), can be interpreted as the average proportion of ambient RBL that is expected under the rollback scenario. A similar value is obtained by dividing the mean RBL under the rollback scenario by the RBL value under ambient conditions. Conversely, the proportion decrease could be calculated using a paired t-test and dividing the estimated difference by the mean Ambient RBL. Because some of the RBL distributions are not normally distributed, the linear fit model was determined to be more robust. In this analysis, the ambient RBL is used as the baseline, so the proportion at ambient conditions is by definition 1, and the slope for all subsequent comparisons is always the average proportion of the ambient RBL. For this 1st daft REA, we evaluate only the scenario for just meeting the current secondary O_3 standard. Scenarios for meeting alternative O_3 standards will be evaluated in the second draft REA. We have put in placeholder columns in Table 5-3 for several alternative standards to provide a sense of the structure of the comparisons. The EPA has not determined at this point the number of alternative standards that will be evaluated in the second draft REA.

Several values in Table 5- 3 are notable. Douglas fir is a relatively non-sensitive species at ambient levels of O_3, however the proportional value is very low (0.357). Referring to Figure 5- 1, this is because this species is only sensitive at very high O_3 levels. After simulating just meeting the current secondary O_3 standard, there are no areas in the country where O_3 levels are high enough to cause substantial RBL for this species, so the proportional change appears very high despite a relatively low maximum RBL value when compared to other species (Table 5- 3). However, additional reductions in O_3 resulting from lower levels of the standards will not result in similarly large proportional changes for this species because they will now be in a portion of the RBL function where this species shows very low levels of RBL, and therefore is not responsive to O_3 changes.

Sugar maple is similar, but because the maximum RBL at ambient conditions is much higher than for Douglas fir (see Figure 5- 1), reducing O_3 concentrations below the "threshold", in part controlled by the η parameter (see Table 5-2), for Sugar maple creates a much larger proportional difference.

Table 5- 3 Summary of Proportional Change in RBL for 11 Tree Species

Species	Median RBL (Ambient)	Maximum RBL (Ambient)	Proportion at Current Standard	Proportion at Alt A	Proportion at Alt B
Red Maple (*Acer rubrum*)	0.009	0.039	0.707		
Sugar Maple (*Acer saccharum*)	0.000	0.206	0.080		
Red Alder (*Alnus rubra*)	0.005	0.118	0.894		
Tulip Poplar (*Liriodendron tulipifera*)	0.045	0.291	0.533		
Ponderosa Pine (*Pinus ponderosa*)	0.038	0.294	0.653		
Eastern White Pine (*Pinus strobus*)	0.034	0.226	0.642		
Virginia Pine (*Pinus virginiana*)	0.008	0.018	0.717		
Eastern Cottonwood (*Populus deltoides*)	0.564	0.999	0.844		
Quaking Aspen (*Populus tremuloides*)	0.039	0.377	0.795		
Black Cherry (*Prunus serotina*)	0.225	0.547	0.834		
Douglas Fir (Pseudotsuga menzeiesii)	0.000	0.001	0.357		

The results of the individual species analyses can be combined into a single plot across O_3 exposure scenarios (Figure 5- 7). In this analysis, all of the values under ambient conditions are, by definition, 1 as this is the baseline so the box for that category is a line. After simulating just meeting the current secondary O_3 standard, the RBL is approximately 70% of the RBL under ambient conditions. Alternatively, this could be interpreted to say that RBL with O_3 exposure levels simulating just meeting the current secondary O_3 standard is 30% lower than under ambient conditions. We have put in placeholders in Figure 5-7 for several alternative standards to provide a sense of the structure of the comparisons. The EPA has not determined at this point the number of alternative standards that will be evaluated in the second draft REA.

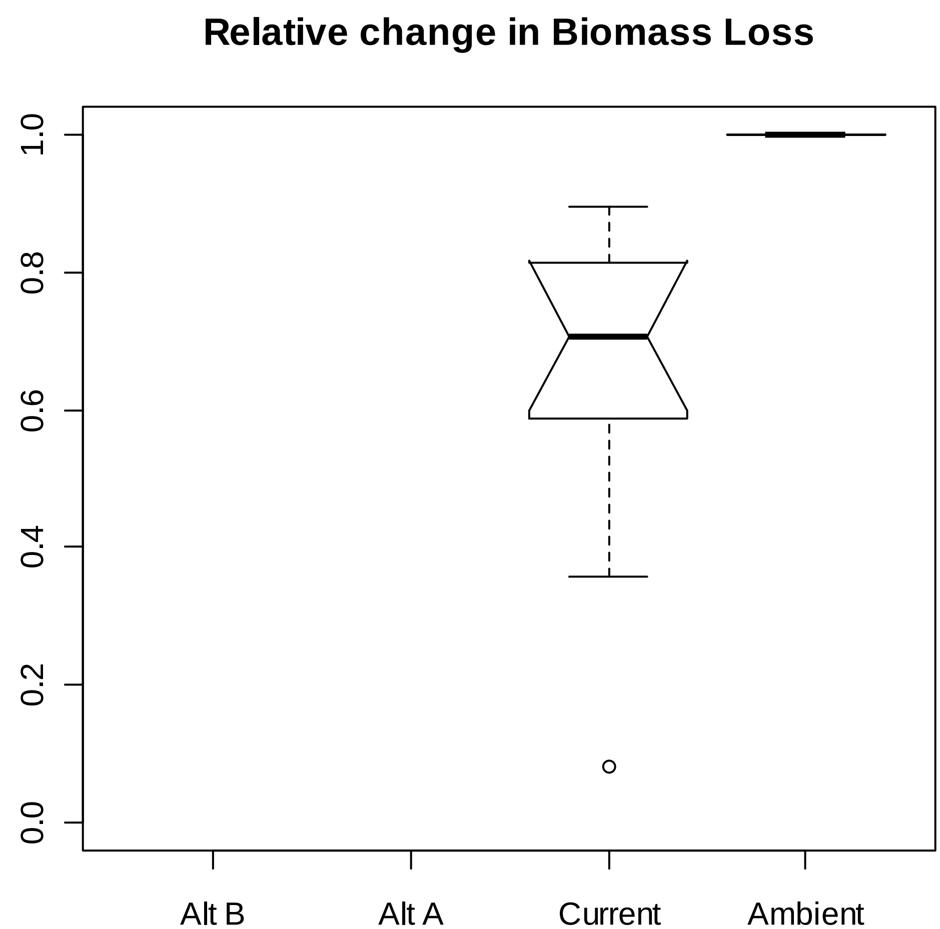


Figure 5- 7 Change in RBL across exposure scenarios for 11 tree species. Biomass loss estimates under recent ambient O_3 (2006 – 2008) conditions were used as the baseline. [Alternate levels will be included in the second draft based on simulating just attaining alternative standards]

5.2.2 Relative Biomass Loss in Federally Designated Areas

5.2.2.1 Importance Value Scaled Analyses

In order to assess the risk to ecosystems in geographic areas from biomass loss as opposed to the potential risk to individual tree species, it is necessary to scale the RBL to reflect the abundance of each species in specific forest ecosystems. As part of the U.S. Forest Service (USFS) Climate Change Atlas (http://www.fs.fed.us/nrs/atlas/littlefia/index.html) researchers at the USFS Northeastern Research Station have calculated Importance Values for eastern Tree species (Prasad and Iverson, 2003). Prasad and Iverson's (2003) calculation of Importance Values (IV) was based equally on relative basal area and the number of stems of each tree species within each FIA plot included in their analysis area with a range for each species ranging from 0 to a maximum of 100. Plot level IV's were over a $20km^2$ scale grid for the entire study area. These values were merged with the CMAQ 12 km^2 grid used for the O_3 exposure and RBL surfaces, with each CMAQ grid cell assigned a weighted mean IV for each species.

The resulting values were used in the preceding analysis (section 5.2.1) to update the Little's Ranges for the eastern species. To assess biomass loss in federally designated areas, the IV's were used to scale the RBL value for each tree species. The IV surface for tulip poplar is shown in Figure 5- 8. Similar to the preceding analysis, the Little's Range is included for reference to illustrate where the IV indicates occurrences outside of that range; however in this analysis some areas within the species range are assigned an IV of 0 and are treated as areas of non-occurrence. Figure 5- 8 shows an expected abundance pattern for tulip poplar, with the highest abundance (as estimated by IV) near the center of its reported range, and areas near the edge of its range where the species is either very low in abundance or absent all together.

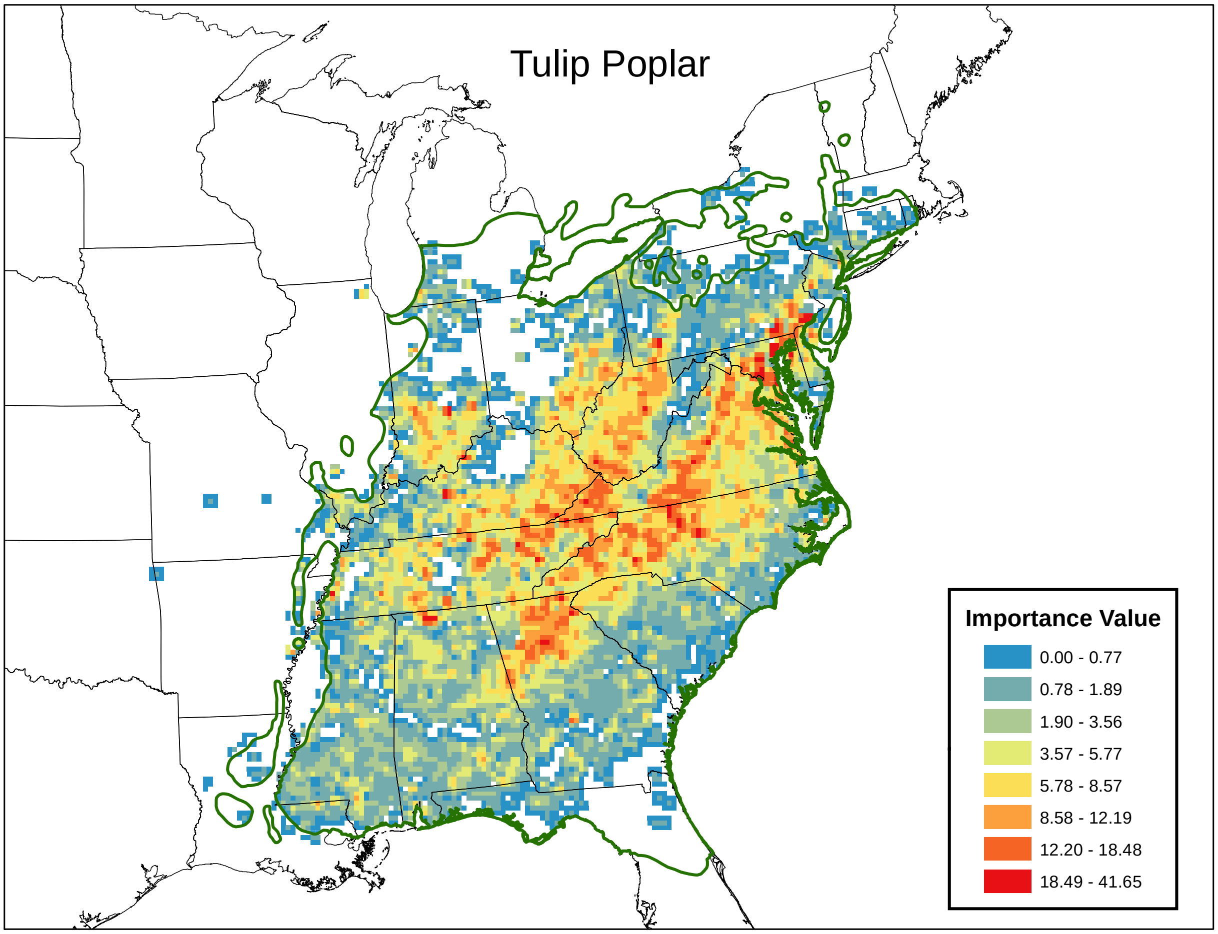


Figure 5- 8 Importance Values for Tulip Poplar. (Data from U.S. Forest Service, http://www.fs.fed.us/nrs/atlas/littlefia/index.html)

To scale RBL, the IV was divided by 100, giving a proportional value between 0 and 1 in each grid cell and the proportional IV was multiplied by the RBL for each tree species for each O_3 exposure scenario. The resulting scaled-RBL surfaces for Tulip Poplar are shown in Figure 5- 9 (Recent Conditions) and Figure 5- 10 (Current Standard).

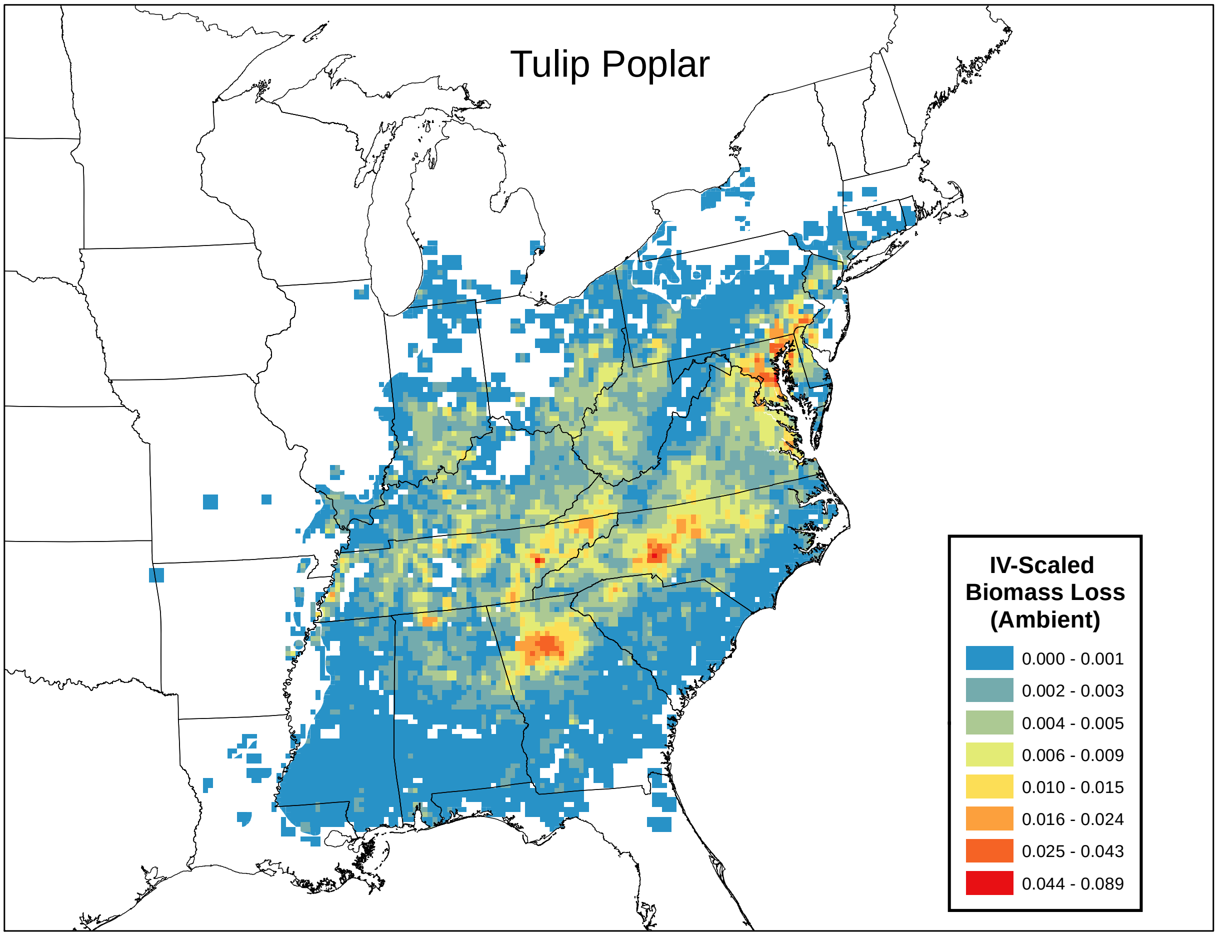


Figure 5- 9 Scaled Relative Biomass Loss for Tulip Poplar under recent ambient O_3 exposure levels (2006 – 2008)

It is important to note that the scaled-RBL values highlight different areas as being the highest area relative to the un-scaled RBL. In Figure 5- 3 the areas of highest RBL for tulip poplar, with values above 0.25 are predominantly in the south. In Figure 5- 9 the southern areas are still high, but the areas around Washington D.C and Baltimore appear much higher, as does western Pennsylvania and West Virginia, relative to the un-scaled RBL values.

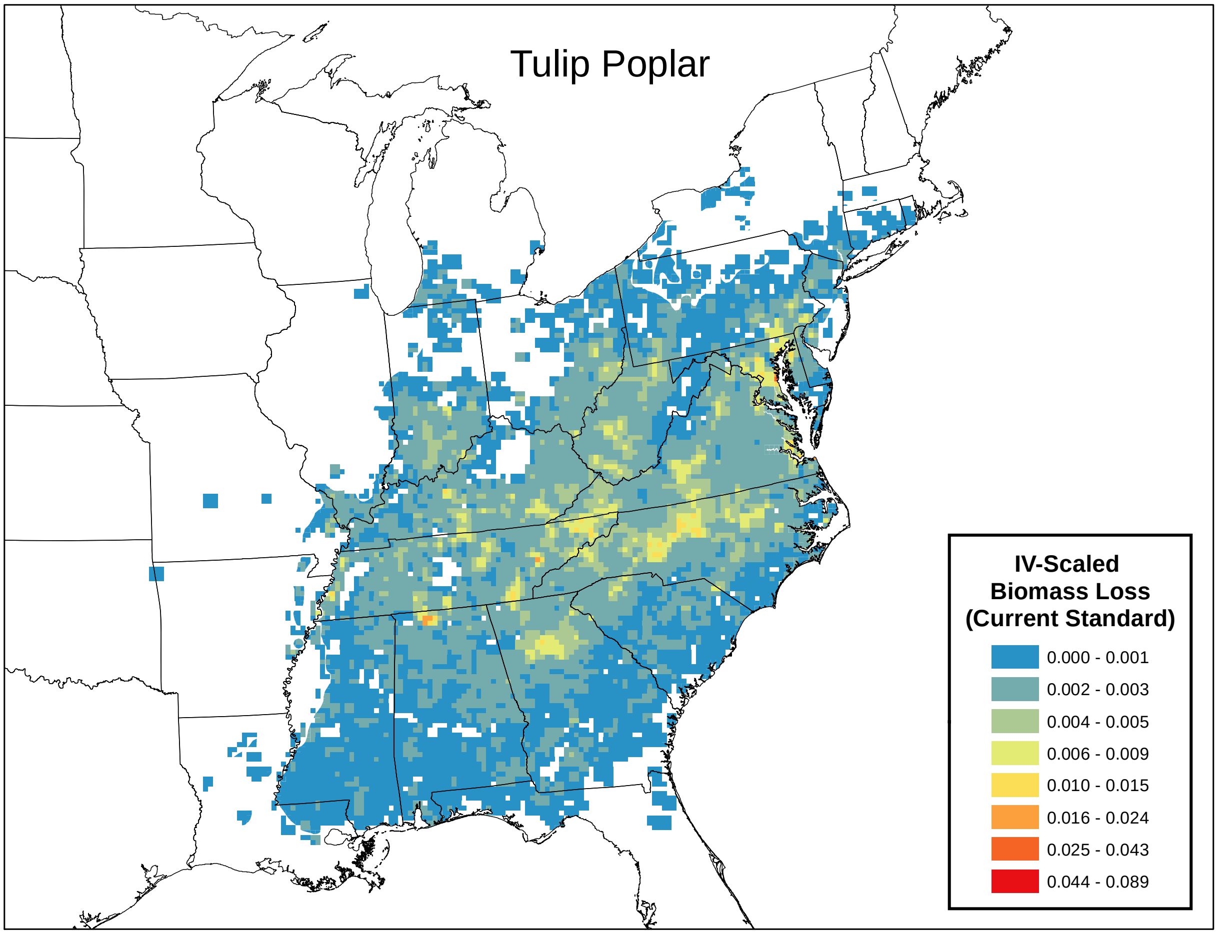


Figure 5- 10 Scaled Relative Biomass Loss for Tulip Poplar after simulating just meeting the current (8-hr) secondary O_3 standard.

To assess the overall risk to ecosystems federally designated areas, the scaled-RBL values were summed across the 8 eastern species generating a summed-RBL value, with each species weighted by its scaled-RBL. Figure 5- 11 illustrates these values across the eastern U.S. The very high values in Figure 5- 11 are directly related to the presence of Eastern Cottonwood. Cottonwood is a very sensitive species and in many areas where it occurs it is a dominant tree species. Figure 5- 12 shows the same summed value with Eastern Cottonwood removed. The highest summed-RBL value decreases from 0.854 to 0.204, demonstrating the effect of cottonwood. Figure 5- 13 and Figure 5- 14 show the summed-RBL surfaces under the current standard rollback scenario for all eastern species and excluding eastern cottonwood respectively.

There are two important things to note with respect to the IV scaled analysis. First is that the IV's do not account for total cover, only the relative cover of the tree species present. This is most noticeable with cottonwood, which has IV's near 100 in some areas (see Appendix 5A), but particularly in the western portions of its range, the absolute cover is probably much lower than 100%. Although this affects the direct interpretation of the values presented here, by focusing on the proportional changes in summed-RBL between O_3 exposure scenarios, the overall effect of the variability in absolute cover values in reduced.

The second important point is that this analysis only accounts for the 8 eastern species with C-R functions. Other species may also be sensitive to O_3 exposure and it is possible that other species that are not sensitive may be indirectly affected through changes in community composition and competitive interactions.

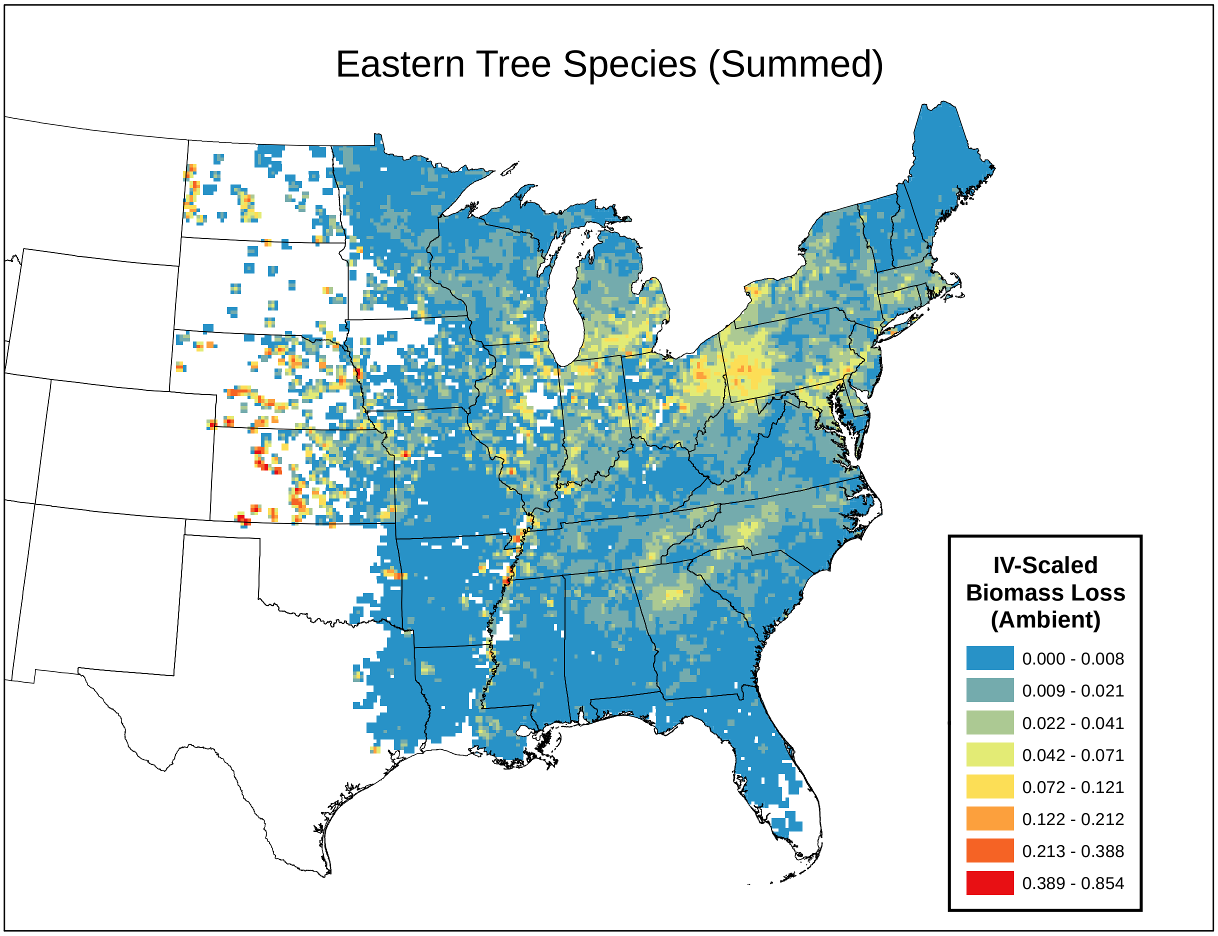


Figure 5- 11 Summed Relative Biomass Loss (scaled) for 8 Eastern tree species recent ambient O_3 exposure levels (2006 – 2008)

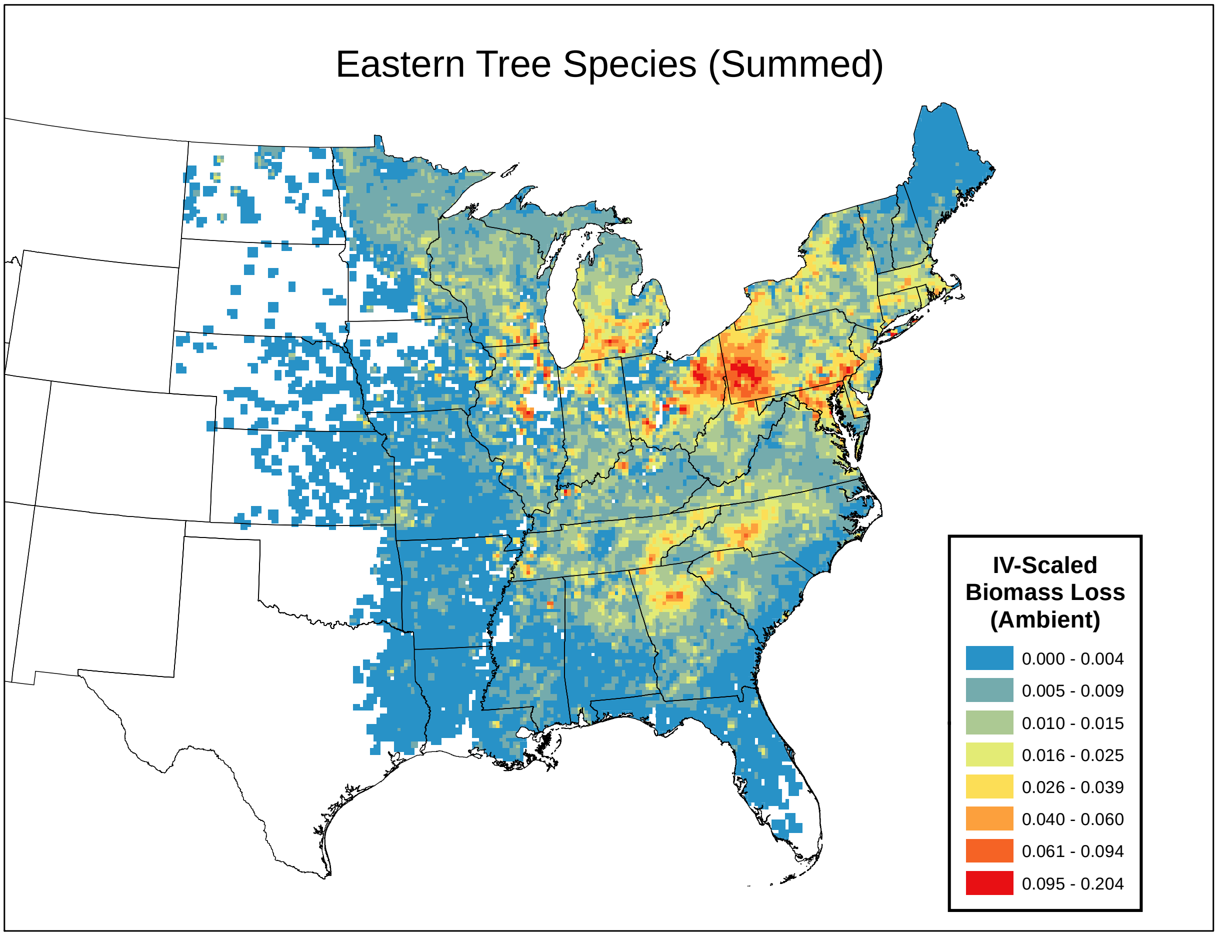


Figure 5- 12 Summed Relative Biomass Loss (scaled) for 7 species, excluding eastern cottonwood, under ambient O_3 conditions

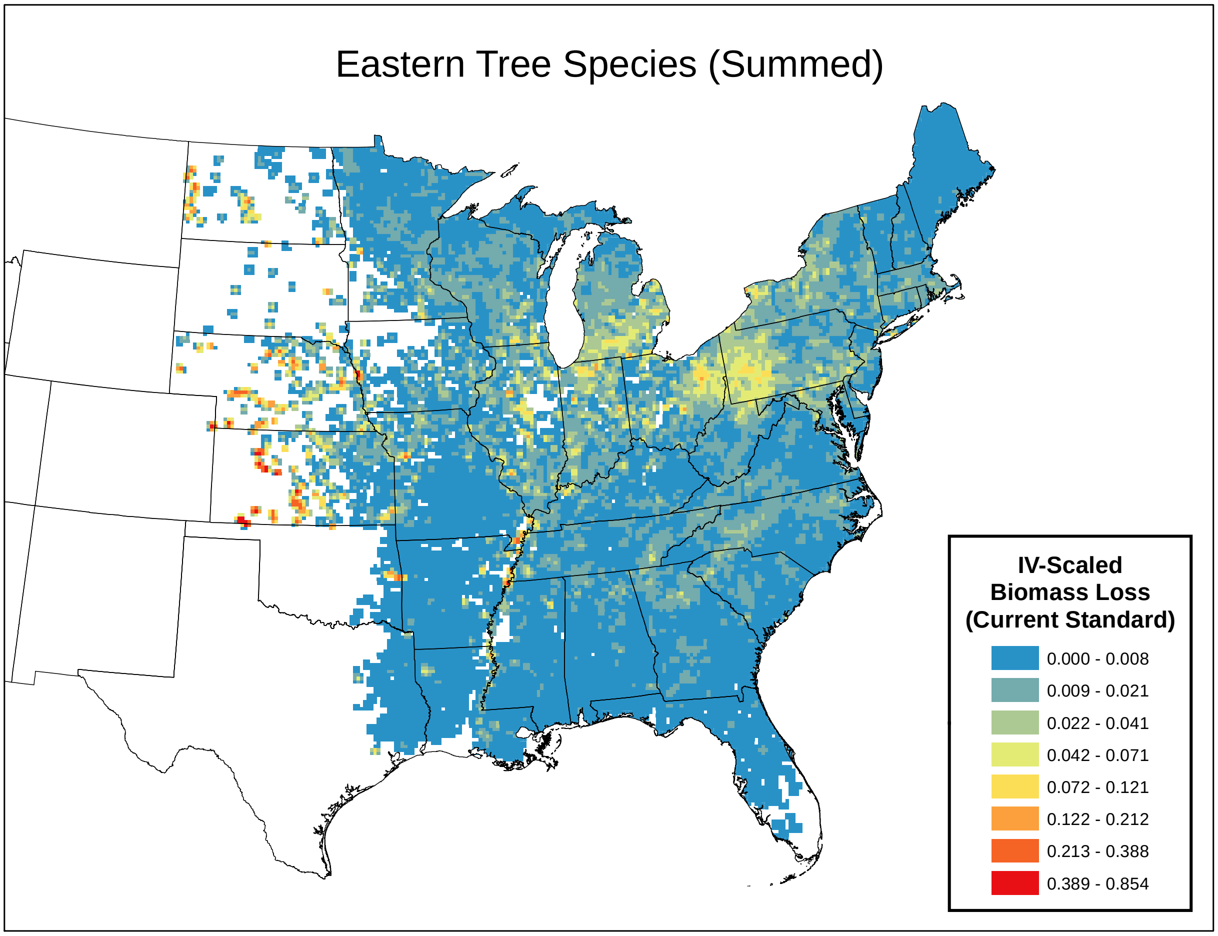


Figure 5- 13 Summed Relative Biomass Loss (scaled) for 8 Eastern tree species after simulating just meeting the current (8-hr) secondary O_3 standard.

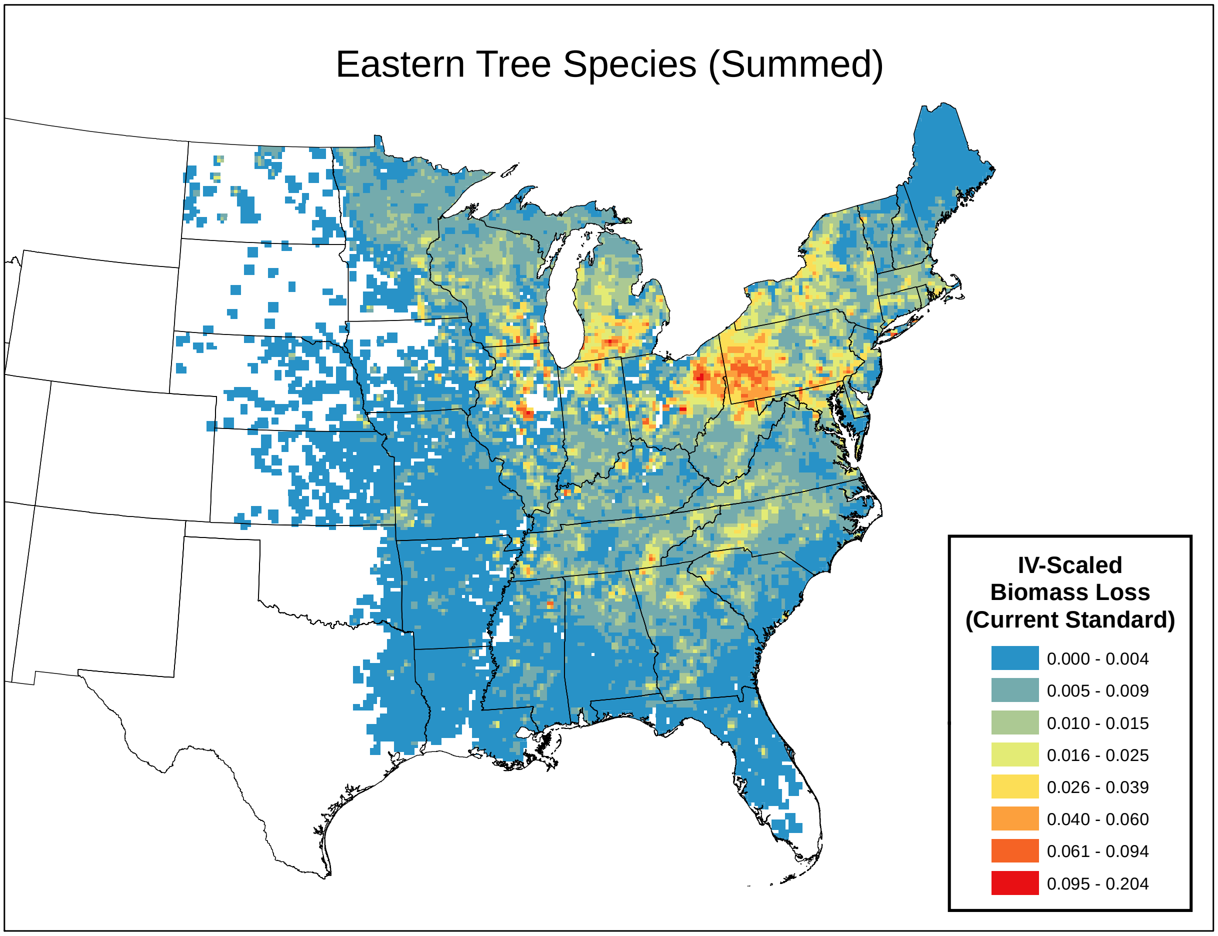


Figure 5- 14 Summed Relative Biomass Loss (scaled) for 7 species, excluding eastern cottonwood, after simulating just meeting the current (8-hr) secondary O_3 standard.

5.2.3 Potential Biomass Loss in Federally Designated Areas

5.2.3.1 Class I Areas

Federally designated Class I areas were analyzed in relation to the W126 surface and the scaled RBL surfaces. Figure 5- 15 shows the Class I areas and W126 values. Many of the Class I areas are in the western U.S., where IV's were not available to scale the RBL values. This analysis uses only the Class I areas in the eastern U.S., many of which are small, and are difficult to see at the scale of Figure 5- 15, or even when expanded to show only the eastern U.S. Maps of each area as in Appendix 5B.

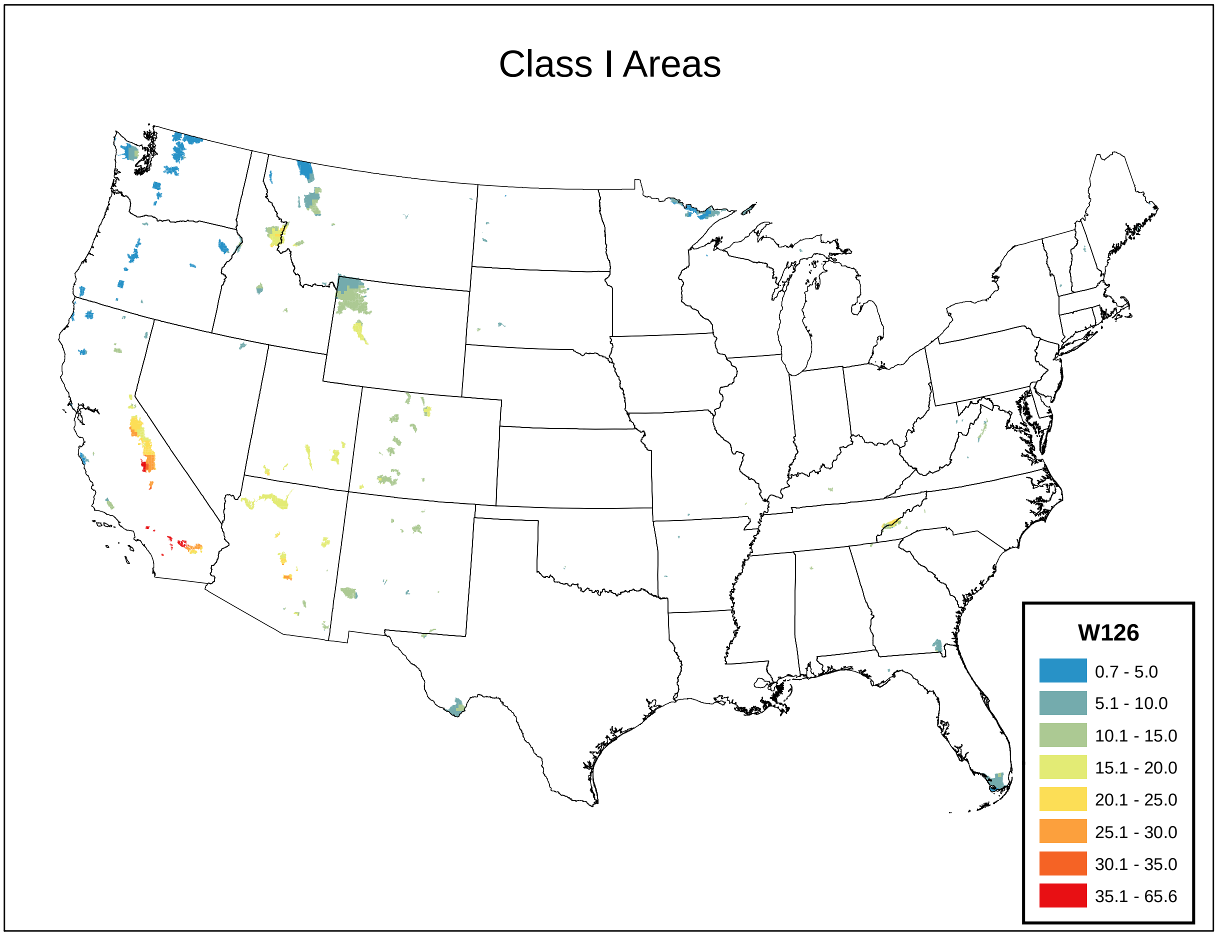


Figure 5- 15 Recent O_3 conditions in Class I Areas

The analyses of Class I areas were completed in the same manner as for individual species (see Figure 5- 6), with each designated area treated as a geographic endpoint. The areas were analyzed using the same linear model approach and the results are summarized in Table 5-4. We have put in placeholders in Figure 5-7 for several alternative standards to provide a sense of the structure of the comparisons. EPA has not determined at this point the number of alternative standards that will be evaluated in the second draft REA.

Plots of the analyses are presented in Appendix 5B. Many Class I areas occur where the ambient O_3 levels are very low and simulation of just attaining the current secondary O_3 standard resulted in very little, or no change in O_3 exposure in these areas so the cumulative analysis was done twice, first with all eastern Class I areas included (Figure 5-16A) and a second analysis excluding areas where the ambient W126 was below 10 (Figure 5-16B).

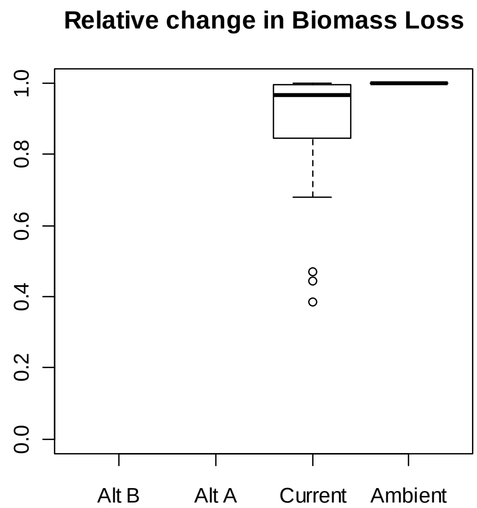
Areas in Table 5- 4 with the proportion listed as NA were not included in the analysis. These areas were excluded either due to small sample size (e.g. Rainbow Lake Wilderness), or because the summed RBL values in all, or all but 1, grid cells were 0.

Table 5- 4 Proportion of Ambient summed-RBL in Eastern U.S. Class I areas

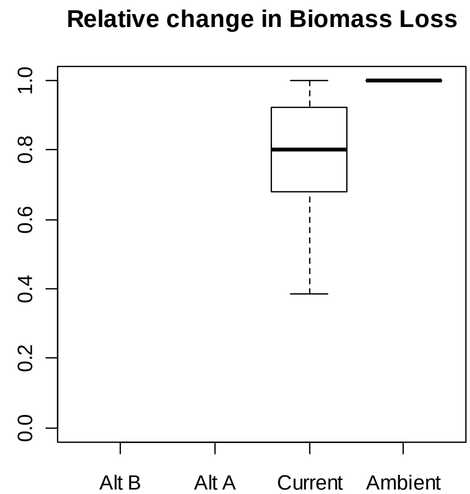
Class I Area	Mean W126 (PPM)	Number of Grids	Proportion of Current Standard	Proportion at Alt A	Proportion at Alt B
Acadia National Park	6.74	9	0.724		
Badlands/Sage Creek Wilderness	7.53	11	NA		
Boundary Waters Canoe Area Wilderness	5.24	67	1.000		
Bradwell Bay Wilderness	6.90	4	0.990		
Breton Wilderness	16.28	4	NA		
Brigantine Wilderness	13.7	2	0.386		
Caney Creek Wilderness	9.15	2	0.995		
Cape Roman Wilderness	12.63	13	1.000		
Chassahowitzka Wilderness	11.66	5	0.803		
Cohutta Wilderness	13.12	5	0.716		
Dolly Sods Wilderness	7.8	2	0.996		
Everglades National Park	7.25	62	1.000		
Great Gulf Wilderness	7.55	2	0.892		
Great Smoky Mountains National Park	16.64	26	0.445		
Hercules-Glades Wilderness	6.00	4	0.966		
Isle Royale National Park	7.11	16	1.00		
James River Face Wilderness	9.1	2	0.992		
Joyce Kilmer-Slickrock Wilderness	14.07	3	0.496		
Linville Gorge Wilderness	10.83	3	0.910		
Lye Brook Wilderness	6.83	4	0.889		
Mammoth Cave National Park	13.53	6	0.981		
Mingo Wilderness	13.6	4	0.845		
Moosehorn Wilderness	1.93	4	1.000		
Okefenokee Wilderness	8.65	21	0.993		
Otter Creek Wilderness	7.87	3	0.946		
Presidential Range-Dry River Wilderness	7.52	5	0.914		

Class I Area	Mean W126 (PPM)	Number of Grids	Proportion of Current Standard	Proportion at Alt A	Proportion at Alt B
Rainbow Lake Wilderness	5	1	NA		
Saint Marks Wilderness	8.93	9	0.999		
Seney Wilderness	7.18	4	0.990		
Shenandoah National Park	10.85	22	0.922		
Shining Rock Wilderness	12.65	4	0.679		
Sipsey Wilderness	14.53	4	0.765		
Swanquarter Wilderness	14.55	4	0.949		
Theodore Roosevelt National Park	6.78	9	1.000		
Upper Buffalo Wilderness	7.17	3	0.997		
Voyageurs National Park	5.08	13	1.000		
Wichita Mountains	9.87	6	NA		
Wind Cave National park	10.96	5	NA		
Wolf Island Wilderness	8.93	3	NA		

The combined analyses indicate that simulating just meeting the current secondary O_3 standards, the proportion of ambient summed RBL is approximately 95% relative to ambient conditions when all eastern Class I areas are included (Figure 5-16A). When only areas with ambient O_3 levels above 10 ppm are included, the proportion decreases to approximately 80% (Figure 5-16B).



A.



B.

Figure 5- 16 Proportion of ambient scaled biomass loss in (A) all analyzed eastern Class I Areas and (B) eastern Class I areas with average ambient O_3 W126 metric exceeding 10 ppm

5.2.3.2 Critical Habitats

Federally designated critical habitat areas for endangered species were analyzed in relation to the W126 surface and the scaled RBL surfaces. Figure 5- 17 shows the critical habitat areas with W126 values. Like the Class I areas, many of these are in the western U.S. where IV's were not available, so were not used in this analysis. Also like the Class I areas, many of the critical habitat areas are difficult to see at the scale of Figure 5- 17 and are included as smaller maps in Appendix 5C.

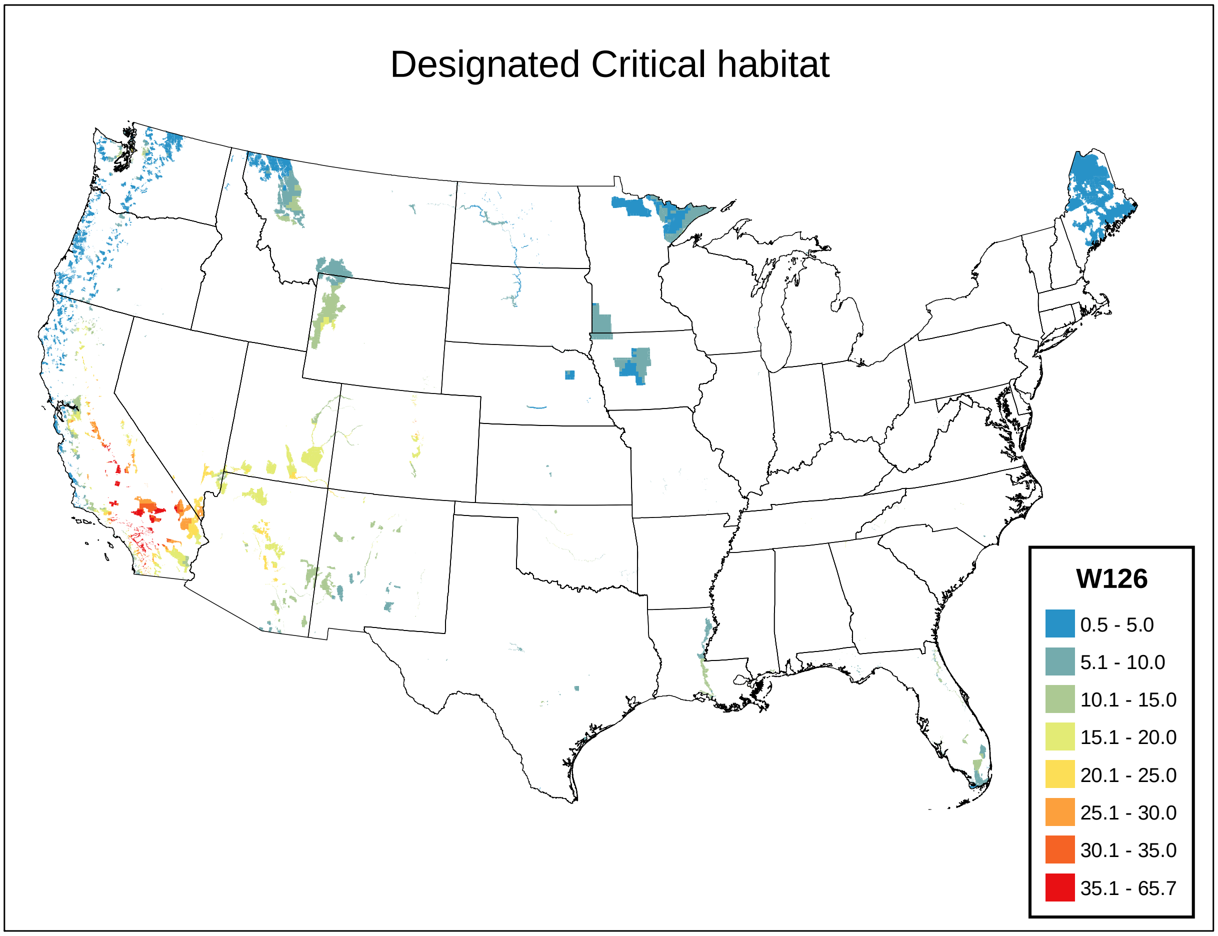


Figure 5- 17 Recent O_3 conditions in designated critical habitat areas.

Analyses of designated critical habitat areas were completed in the same manner as for Class I areas, with the linear model results summarized in Table 5- 5 and the complete analyses including figures presented in Appendix 5C. We have put in placeholder columns in Table 5-5 for several alternative standards to provide a sense of the structure of the comparisons. EPA has not determined at this point the number of alternative standards that will be evaluated in the second draft REA.

Areas in Table 5- 5 with the proportion listed as NA were not included in the analysis. These areas were excluded either due to small sample size (e.g. San Marcos gambusia), or because the summed RBL values in all, or all but 1, grid cells were 0 (e.g. Cape Sable seaside sparrow).

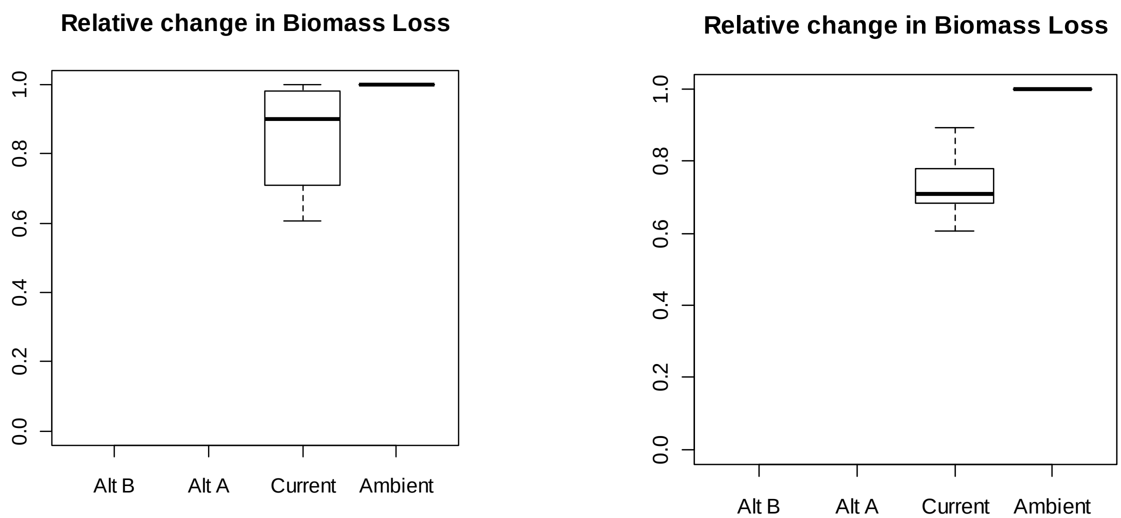
This analysis is not intended to indicate risk to the specific endangered species within the designated area; rather the intent is to use the designated critical habitat to define an endpoint for evaluating risk to locations that might be more sensitive to adverse effects from O_3 exposure. For example, analysis of the critical habitat area for Gulf sturgeon is focused on the terrestrial ecosystems within the designated habitat area, not on the aquatic system, or the Gulf sturgeon. The implication in the aquatic and marine areas in particular is that effects on neighboring terrestrial ecosystems will affect the aquatic or marine system, but quantifying that linkage is not possible at this time.

Table 5- 5 Proportion of ambient summed-RBL in Eastern U.S. Critical Habitat Areas

Designated Critical Habitat Area	Mean W126 (PPM)	Number of Grids	Proportion at Current Standard	Proportion at Alt A	Proportion at Alt B
Gulf sturgeon	14.69	116	0.695		
Appalachian elktoe	11.70	22	0.685		
Reticulated flatwoods salamander	9.16	35	0.983		
Frosted flatwoods salamander	9.16	35	0.983		
Cape Sable seaside sparrow	7.06	21	NA		
Braun’s rock-cress	15.77	3	NA		
Helotes mold beetle	11.63	6	NA		
Houston toad	7.89	7	NA		
Gray wolf	5.08	283	1.000		
Piping plover	8.51	472	1.000		
Salt Creek tiger beetle	2.93	4	NA		
Robber Baron Cave meshweaver	7.30	4	NA		
Madla’s Cave meshweaver	11.27	12	NA		
Braken Bat Cave meshweaver	10.40	31	NA		
Virginia big-eared bat	6.63	7	0.970		
American crocodile	6.65	53	NA		
Haha	5.47	17	NA		
Fountain darter	7.90	5	NA		
Niangua darter	7.88	17	0.910		
San Marcos salamander	7.90	4	NA		
San Marcos gambusia	7.90	1	NA		
Whooping crane	7.77	43	NA		
Mississippi sandhill crane	12.28	6	0.759		

Designated Critical Habitat Area	Mean W126 (PPM)	Number of Grids	Proportion at Current Standard	Proportion at Alt A	Proportion at Alt B
Johnson's seagrass	9.27	13	NA		
Comal Springs riffle beetle	7.98	5	NA		
Mountain golden heather	11.05	2	0.892		
Zapata bladderpod	4.08	4	NA		
Canada lynx	4.46	523	1.000		
Waccamaw silverside	8.30	2	0.926		
Spruce-fir moss spider	14.78	6	0.906		
Government Canyon Bat Cave spider	10.40	31	NA		
Concho water snake	5.47	17	NA		
Arkansas River shiner	12.40	78	NA		
Cape Fear shiner	14.00	7	0.667		
Topeka shiner	5.57	235	0.988		
Rice rat	5.82	6	NA		
Amber darter	18.84	7	0.708		
Conasauga logperch	19.00	4	0.686		
Leopard darter	7.04	21	0.961		
Choctawhatchee beach mouse	12.42	5	NA		
Alabama beach mouse	17.87	3	0.798		
St. Andrew beach mouse	10.70	11	0.889		
Perdido Key beach mouse	18.40	2	0.730		
Everglade snail kite	9.90	58	1.000		
Atlantic salmon	3.17	312	0.925		
Hine's emerald dragonfly	9.50	30	0.669		
Peck's cave amphipod	8.43	3	NA		
Comal Springs dryopid beetle	8.30	3	NA		
Cokendolpher Cave harvestman	7.30	4	NA		
West Indian manatee	9.45	211	0.991		
Louisiana black bear	9.95	90	0.771		
Texas wild-rice	7.90	6	NA		
Rhadine exilis (No common name)	11.35	22	NA		
Rhadine infernalis (No common name)	11	30	NA		

The cumulative analyses indicate that across all eastern critical habitat areas, the proportion of the ambient summed-RBL was between 90% and 95% under the current standard rollback scenario (Figure 5-18A). When areas with ambient O_3 levels below 10 ppm are excluded, the proportion decreases to approximately 75% (Figure 5-18B).



A. **B.**

Figure 5- 18 Proportion of ambient scaled-biomass loss in (A) all analyzed eastern critical habitat areas and (B) eastern critical habitat areas with average ambient O_3 W126 metric exceeding 10 ppm

5.2.4 National Park Case Study Areas

The National Parks provide excellent case study areas for more refined analyses of O_3 exposure risks. The National Park Service (NPS) conducts ongoing O_3 monitoring in many parks, and these monitors were used when possible in the creation of the O_3 exposure surfaces for the parks. In addition, recreational use data are available for the parks for analyses of recreational value presented in Chapter 6. Three parks were chosen as case study areas: Great Smoky Mountains National Park (GSMNP), Rocky Mountain National Park (RMNP), and Sequoia/Kings Canyon National Park (SKCNP).

Vegetation mapping has been completed in all three parks by the NPS in conjunction with the United States Geological Survey (USGS). These maps were used to estimate the percent cover of the tree species included in the risk assessment. These values were then used in a similar way to the IV's in the preceding section, but on a much finer scale. The vegetation maps for the parks are available through the USGS Vegetation Characterization Program (http://biology.usgs.gov/npsveg/apps/). The vegetation map for GSMNP was completed in 2004 (Madden et al. 2004).

The National Vegetation Community codes assigned to each vegetation community were used to obtain cover estimate data through plots stored in VegBank (http://vegbank.org/vegbank/index). Whenever possible, only plots from within the park were used. In some cases, no plots were available from within the park and in those cases plots from the same vegetation community in nearby areas were used. In a few cases there were no plots available, and those communities were excluded.

The W126 surface for each park was intersected with the vegetation polygons and the RBL values for the tree species present were scaled using the percent cover of each tree species the same as in the preceding section when IV was used. These values were then summed within each polygon in the GIS shapefile to create a detailed surface for each park. To assess the proportional change in scaled RBL in each park a linear model was used as in the preceding sections. In this analysis each polygon was treated as an individual point as opposed to CMAQ grid cells as in the preceding analyses.

[GSMNP is the only park completed at present, the linear model results will be combined into a combined analysis when more parks are included]

5.2.4.1 Great Smoky Mountain National Park

Recent (2006 – 2008) ambient O_3 levels (3-month 12-hr W126) in GSMNP range from 9.3 PPM along the southeastern boundary to 23.3 PPM along the northwestern boundary (Figure 5- 19). After simulating just attaining the current secondary O_3 standard, (Figure 5- 20) the W126 values decrease to 7.7 PPM to 13 PPM.

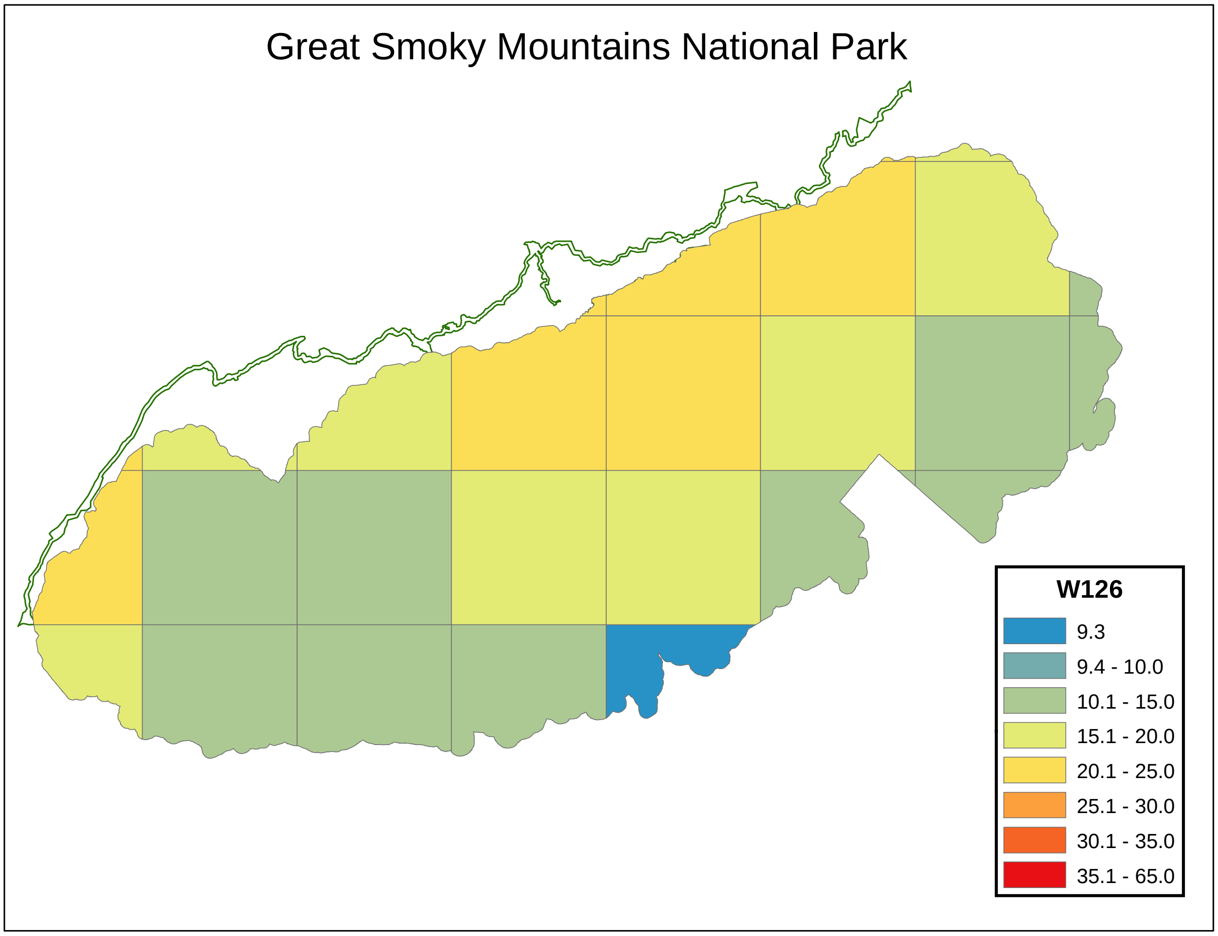


Figure 5- 19 Recent (2006 – 2008, 12-hr 3-month W126) O_3 Exposure in GSMNP

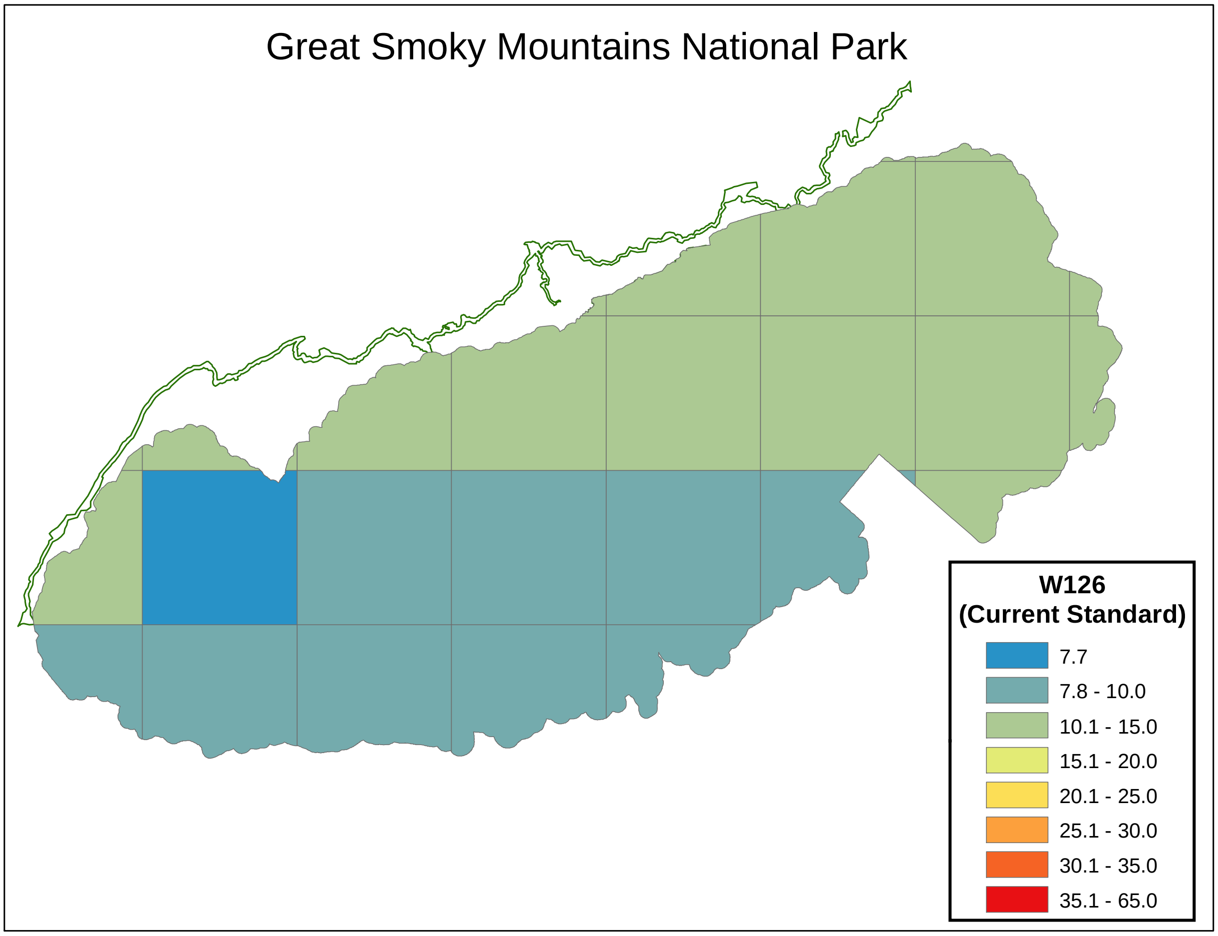


Figure 5- 20 O_3 Exposure in GSMNP after simulating just meeting the current (8-hr) secondary standard.

The vegetation map for GSMNP included 34 vegetation communities. Six of the eastern tree species occurred within the park. The resulting scaled RBL values for the ambient and current standard surfaces are shown in Figure 5- 21 and Figure 5- 22. The linear model results for GSMNP indicate a proportionally large decrease (slope = 0.493) in summed-RBL when comparing the current standard to ambient conditions (Figure 5- 23).

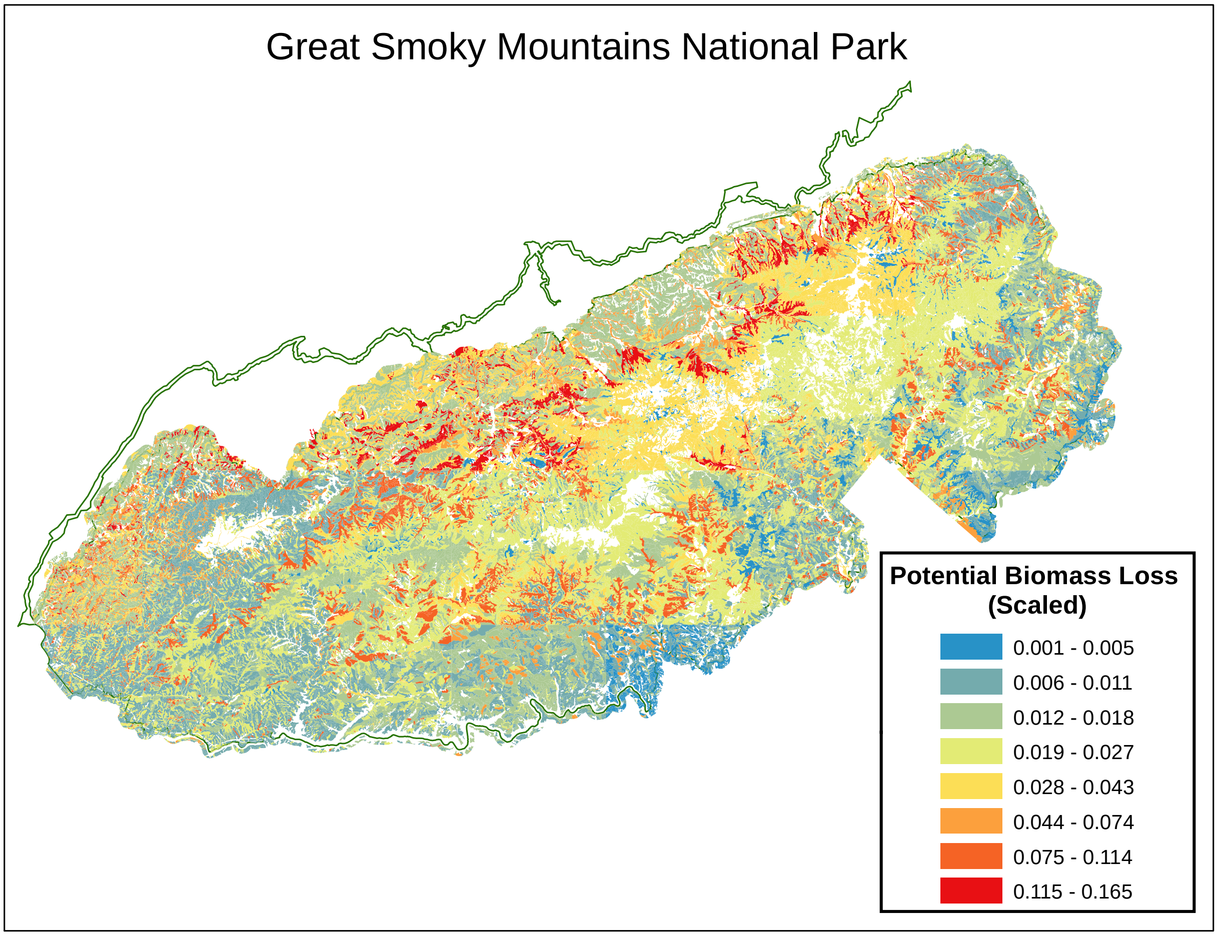


Figure 5- 21 Summed-RBL in GSMNP, scaled using percent cover of species, under recent O_3 conditions. White areas within the park represent areas where no data were available or were developed, with minimal vegetation.

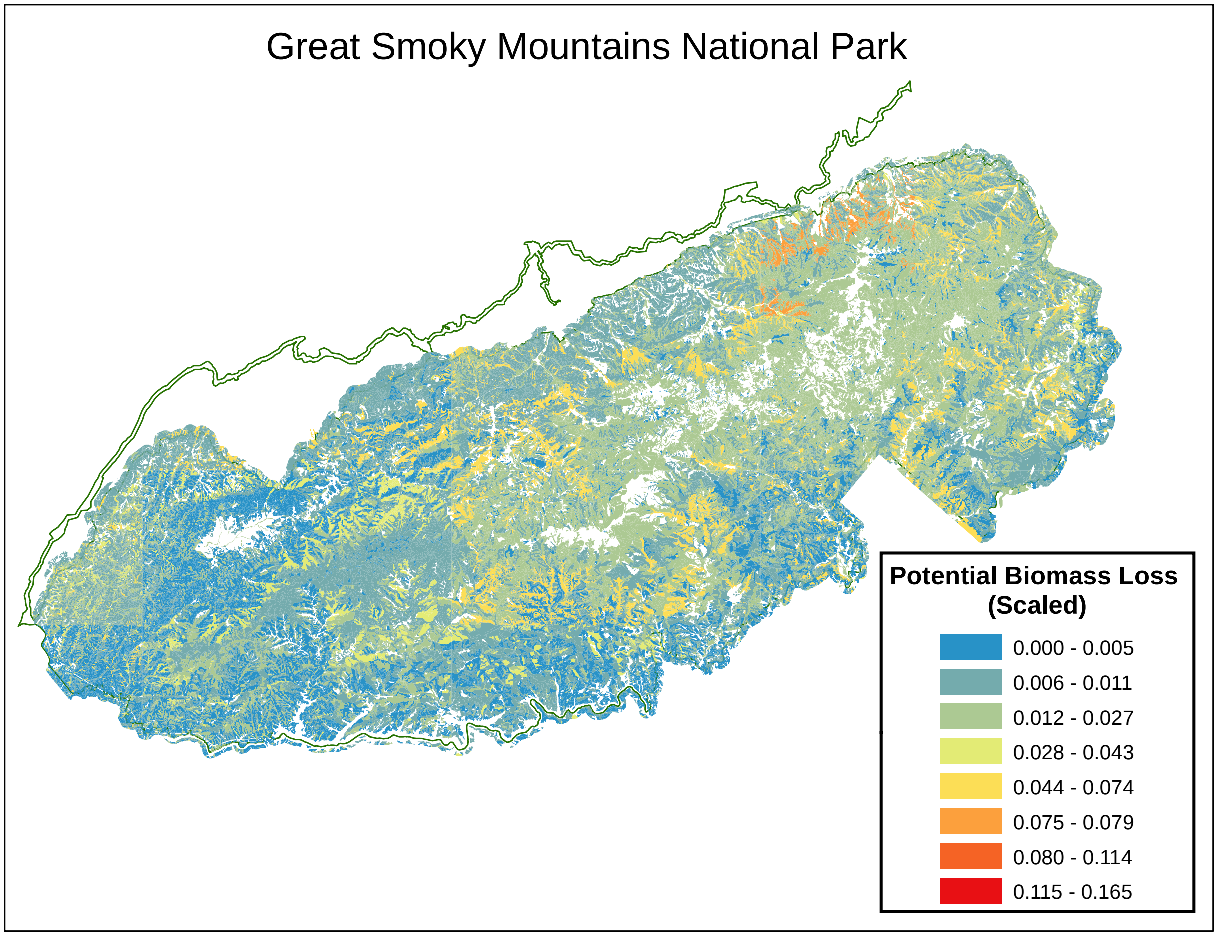


Figure 5- 22 Summed-RBL in GSMNP, scaled using percent cover of species after simulating just meeting the current secondary O_3 standard.

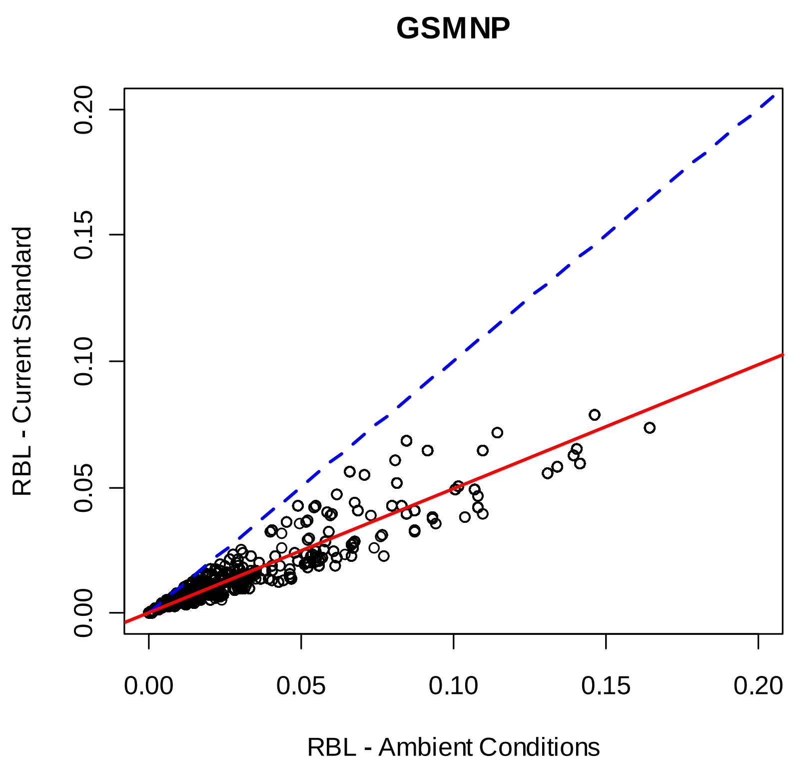


Figure 5- 23 Linear Fit Model comparing RBL under ambient conditions and a scenario just meeting the current standard.

5.2.4.2 Rocky Mountain National Park

[To be added in the second draft]

5.2.4.3 Sequoia/Kings National Park

[To be added in the second draft]

5.2.4.4 National Park Case Study Area Summary

Table 5- 6 Proportion of summed-RBL in National Park Case Study Areas

Designated Critical Habitat Area	Mean W126 (PPM)	Max W126 (PPM)	Proportion at Current Standard	Proportion at Alt A	Proportion at Alt B
Great Smoky Mountains National Park	16.45	23.30	0.493		
Rocky Mountain National Park					
Sequoia/Kings National Park					

[This will include a summary of the linear model results, presented in similar to the boxplots presented in preceding sections]

5.3 VISIBLE FOLIAR INJURY

Visible foliar injury resulting from exposure to O_3 has been well characterized and documented over several decades on many tree, shrub, herbaceous, and crop species (U.S. EPA, 2012a, 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 CSTRs, OTCs, and free-air fumigation (see Section 9.2 of the 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 to 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).

Although visible injury is a valuable indicator of the presence of phytotoxic concentrations of O_3 in ambient air, it is not always a reliable indicator of other negative effects on vegetation. 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 AQCDs 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, 2012a, 2006, 1996). As a result, it is not presently 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 concentrations of O_3 or a lack of non-visible O_3 effects (Gregg et al., 2006).

5.3.1 National-Scale Analysis of Foliar Injury

5.3.1.1 National Summed Importance Values

The NPS has published a list of known and suspected O_3 sensitive species (NPS, 2003), which was updated in 2006 (NPS, 2006). This list of species was used together with the IV's from the USFS (Prasad and Iverson, 2003). A map of the eastern U.S. was generated showing the summed IV's of species sensitive to foliar injury from O_3 (Figure 5- 24). This essentially shows the abundance of trees likely to be impacted by elevated O_3 levels.

[Analysis is not complete, waiting on data from John Coulston with the USFS to complete this analysis]

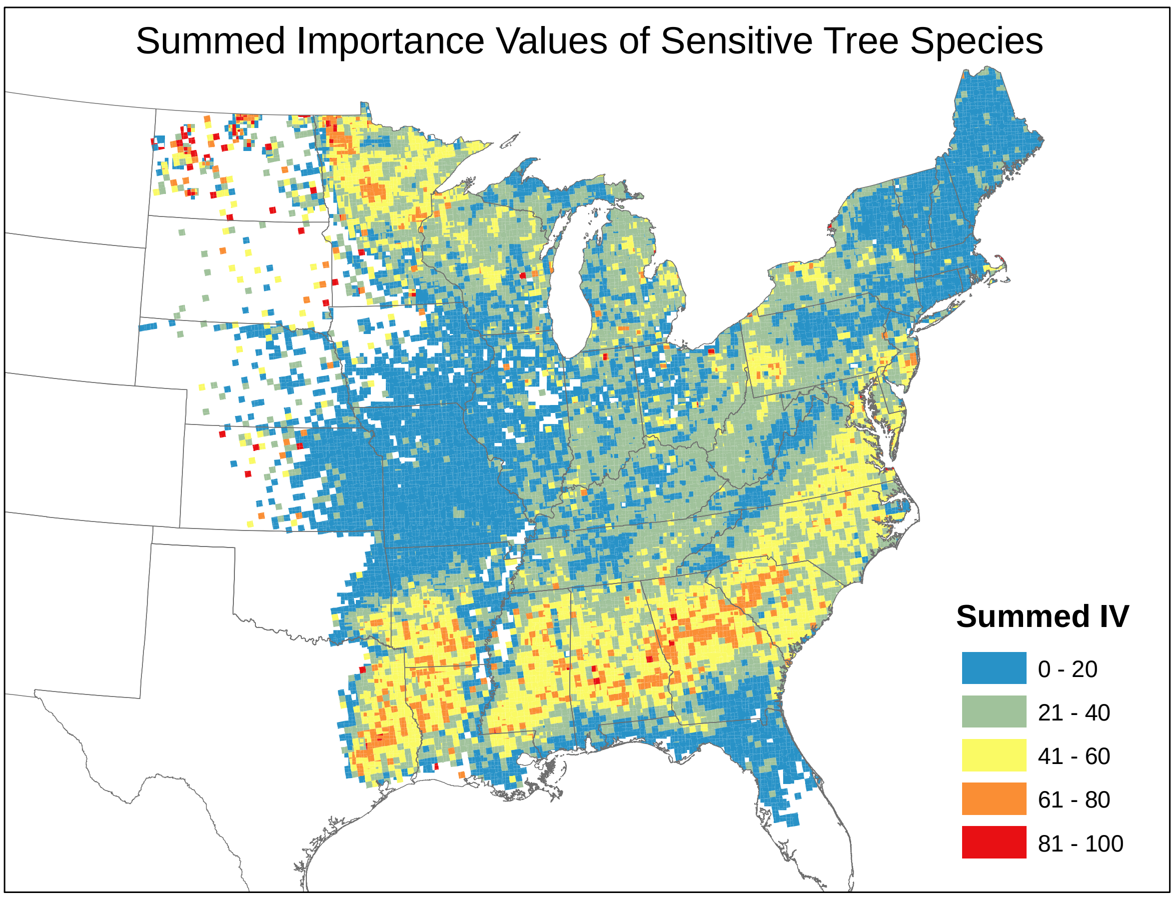


Figure 5- 24 Summed Importance Values for Sensitive Species in the Eastern U.S.

5.3.1.2 Forest Health Monitoring Network

5.3.2 Updated Assessment of Risk of Visible Foliar Injury in National Parks

A study by Kohut (2007) assessed the risk of O_3-induced visible foliar injury on O_3 bioindicators (i.e., O_3-sensitive vegetation (NPS, 2006)) in 244 national parks as part of the NPS' Vital Signs program. Kohut (2007) estimated O_3 exposure using hourly O_3 monitoring data conducted at 35 parks from 1995 to 1999 and estimated O_3 exposure at 209 additional parks using kriging, a spatial interpolation technique. Kohut (2007) qualitatively assessed risk based on evaluation of three criteria: the frequency of exceedance of foliar injury thresholds[1] using several O_3 exposure metrics, the extent that low soil moisture constrains O_3 uptake during periods of high exposure, and the presence of O_3 sensitive species within each park. Kohut (2007) concluded that the risk of visible foliar injury was high in 65 parks (27%), moderate in 46 parks (19%), and low in 131 parks (54%). We have updated this assessment using more recent O_3 exposure and soil moisture data for a subset of parks with O_3 monitors.

5.3.2.1 Foliar Injury Risk Methods

We applied the approach used in Kohut (2007) using more recent O_3 monitoring and soil moisture data from 2006 to 2010. For this 1st draft REA, because we did not replicate the spatial interpolation of monitor data in Kohut (2007) due to uncertainties introduced using this technique, we conducted this updated risk assessment only in parks with O_3 monitor data.[2] As noted by Kohut (2007), monitoring provides the most accurate assessment of O_3 exposure, but it may not reflect differences in exposure throughout the park.

O_3 *Exposure:* We used more recent monitoring data from 2006 through 2010 and the same metrics in this analysis (i.e., SUM06 (3-month), W126 (12-hr, 7-month), N100 (7-month)) as Kohut (2007). In addition, we added W126 (12-hr) and N100 metrics calculated over 3 months to be consistent with other analyses in this REA and to determine how sensitive the risk ratings were to the different W126 metrics. Each of these metrics are described in more detail in Section 4.3.1. These data reflected 59 O_3 monitors located within park boundaries covering 43

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[1] Kohut (2007) uses the term "foliar injury thresholds". It is unclear whether these are true biological thresholds below which no vegetation effects occur or whether these are simply concentration benchmarks. We use the term "thresholds" to be consistent with the terminology in Kohut (2007).

[2] For the 2nd draft REA, we anticipate expanding this updated assessment to include additional parks. One method would assign an ozone monitor if it fell within a certain distance of a park's boundaries (e.g., 10km, 50,km, etc). A second option would use the ozone surfaces for 2006, 2007, and 2008 described in Chapter 4. While either method would provide ozone exposure data at parks that has additional uncertainty relative to the data at parks with ozone monitors within their boundaries, neither would add as much uncertainty as the kriging interpolation of monitor data.

separate parks, which is more than the 35 parks with O_3 monitors in Kohut (2007). If a park contained more than one O_3 monitor, we used the highest monitor in the park as an indication of the potential risk. For two parks, Badlands National Park and Glacier National Park, we used data from an additional park monitor to fill in missing data years at the highest monitor.

Based on the foliar injury thresholds for O_3 exposure used by Kohut (2007), we assigned exposure risk ratings associated with O_3 exposure alone to each park with an monitor. Consistent with Kohut (2007), O_3 exposure must meet the criteria for both the W126 index as well as the N100 metric in order to receive a higher risk rating. We provide the specific criteria applied in this updated risk assessment, which are derived from Table 5-7 in Kohut (2007). Overall, considerably more parks exceed the W126 criteria alone than in conjunction with the N100 criteria. Specifically, 35 of 37 parks exceed 5.9 ppm-hrs using the 7-month W126 metric for at least 3 years, whereas only 5 parks exceed 6 hours using the 7-month N100 metric in any year.[3] Only 3 parks exceeded 8 ppm-hrs using the SUM06 metric in any year, which corresponds to Kohut's lowest injury threshold for natural ecosystems.

Table 5- 7 Risk Criteria for O_3 Exposure Metrics, Sensitive Vegetation, and Soil Moisture.

Risk Criterion and Metric		Higher Risk	Lower Risk
O_3 Exposure	SUM06	Exceeds 8 ppm-hrs	Less than 8 ppm-hrs
	W126/N100 (3-month)	Exceeds 4.1 ppm-hrs AND Exceeds 6 hrs over 100 ppm	Less than 4.1 ppm-hrs AND Less than 6
	W126/N100 (7-month)	Exceeds 5.9 ppm-hrs AND Exceeds 6 hrs over 100 ppm	Less than 5.9 ppm-hrs AND Less than 6
Sensitive Vegetation	Indicator species	Present	Not present
Soil Moisture	Palmer Z	No relation	Inverse (not used to lower risk rating)

The primary difference between a high risk rating and a moderate risk rating is the number of years that exceed the O_3 exposure metrics. If a park exceeded the risk criteria for 1 or 2 years, we assigned a risk rating of moderate. If a park exceeded the risk criteria for at least 3

[3] In order to assess risk using the 3-month W126 metric, we calculated an adjustment to the foliar injury threshold for highly sensitive species. Based on a regression analysis described in Appendix 5D, we determined that a foliar injury threshold of 5.9 ppm-hrs for a 7-month W126 metric is approximately equivalent to a foliar injury threshold at 4.1 ppm-hrs for a 3-month W126 metric.

years, we assigned a risk rating of high. If a park did not exceed the risk criteria in any year, we assigned a risk rating of low.

Soil Moisture: To evaluate soil moisture, we followed Kohut's approach by using Palmer Z data for 2006 to 2010 (NCDC, 2012b). The Palmer Z 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 -0.9 and +0.9 could be interpreted as normal soil moisture, whereas values beyond the range from -3 to +3 could be interpreted as extremely unusually soil moisture (either extreme drought or extreme wetness). As described in the ISA (U.S. EPA, 2012a), plants generally uptake less O_3 when soil moisture is reduced, thus the risk of foliar injury is generally lower during periods of drought.

The soil moisture index is calculated for each of the 344 climate regions within the continental U.S. defined by the National Climatic Data Center (NCDC) (NOAA, 2012a). We assigned each monitored park to the climate region in which the park was located. For the monitored parks that were located in more than one NCDC region, we selected the region corresponding to the monitor location. We decided not to average the Palmer Z values across regions because the NCDC regions are much larger geographic areas (e.g., sometimes hundreds of miles in diameter) than the parks themselves. Because we did not have soil moisture data outside of the continental U.S., we did not evaluate parks in Alaska, Hawaii, Puerto Rico, or Guam. In addition, due to the size of these regions, soil moisture will vary within each region and potentially even within a park. For example, some species along riverbanks may still experience sufficient soil moisture during periods of drought to exhibit foliar injury. For this reason, we provide the soil moisture data and assess the relationship with O_3 exposure, but we have not lowered any risk ratings in the updated assessment for insufficient soil moisture. We identify the regions in Figure 5- 25, and we provide the Palmer Z data for each park in Appendix 5D.

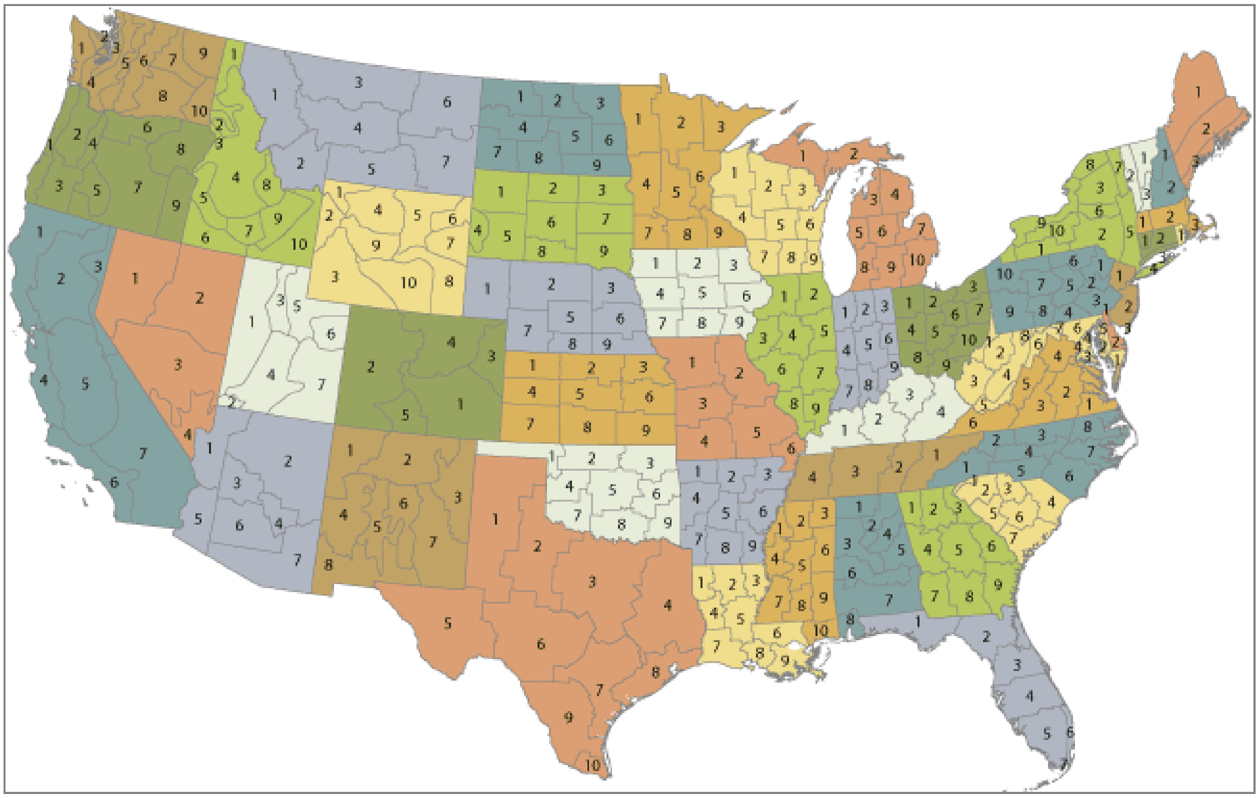

Figure 5- 25 344 climate regions with Palmer Z soil moisture data (source: NCDC, 2012a).

Because monthly estimates of soil moisture are highly variable over time, we focused on the monthly values from May to October for each year in order to be consistent with the potential time period of the W126 calculation. Evaluating soil moisture is more subjective than for O_3 exposure because Kohut (2007) did not outline specific numerical criteria for this determination. We compared the soil moisture during the years of highest O_3 exposure and during the years of lowest exposure to determine whether there was a consistent trend. Based on our review of the soil moisture data in the updated assessment, several parks showed a potentially inverse relationship between high O_3 exposure years and soil moisture.

Sensitive Vegetation Species: Consistent with Kohut (2007), we identified the parks containing O_3 sensitive vegetation species (NPS, (2003, 2006). Based on the NPS list, all of the parks in this updated assessment contain at least one sensitive species.

GIS Analysis: Using GIS (ESRI® ArcMAP™ 9.3), we spatially overlaid the O_3 exposure monitor data, NPS boundaries (USGS, 2003), and soil moisture Palmer Z data to link these data to each park. In total, 43 parks had O_3 monitoring data, including 9 parks that contained more than one O_3 monitor. We excluded 5 parks with fewer than 3 years of monitoring data[4] and one park (i.e., Denali NP in Alaska) with an absence of soil moisture data. After these exclusions, 37 parks were included in this updated risk assessment, which are identified in Figure 5- 26. All of the monitored parks excluded from this updated assessment received risk ratings of “low” in Kohut (2007), except for City of Rocks, National Reservation, which had a risk rating of “moderate”.

Figure 5- 26 37 National Parks with O_3 monitors included in the updated risk assessment.

5.3.2.1 Foliar Injury Risk Results and Discussion

As explained in Kohut (2007), determining the overall risk level is not quantitative, but instead depends on a subjective evaluation of how much and how often O_3 exposure metrics exceeded certain criteria, the soil moisture conditions during high exposure periods, and the presence of sensitive vegetation species. Similar to Kohut’s subjective evaluation, we also categorized each park as at high, moderate, or low risk for foliar injury based on these criteria.

[4] These 5 excluded parks for less than 3 years of ozone monitoring data are Agate Fossil Beds National Monument, City of Rocks National Reservation, Olympic National Park, Padre Island National Seashore, and Scotts Bluff National Monument.

For the 37 parks assessed in the updated risk assessment, we found generally similar risk levels as Kohut (2007). Based on his analysis of all 244 parks, Kohut (2007) found that the risk of foliar injury was high in 65 parks (27%), moderate in 46 parks (19%), and low in 131 parks (54%). Limiting the assessment to the same 37 parks in the updated risk assessment, Kohut found the risk of foliar injury was high in 10 parks (27%), moderate in 4 parks (11%), and low in 23 parks (62%). The updated risk assessment of 37 parks found the risk of foliar injury was high in 2 parks (5%), moderate in 4 parks (11%), and low in 31 parks (84%). We provide the risk results for each park included in the assessment in Table 5-8, and we provide all of the O_3 and soil moisture data in Appendix 5D.

Based on our updated assessment, most parks (70%) received the same risk rating as Kohut (2007), while 30% received lower risk ratings. The decrease in risk rating corresponds to lower O_3 concentrations in more recent years, particularly for the N100 metric. In general, results were insensitive to whether we used the 3-month or 7-month W126 metric. Only 1 park, Acadia National Park, would have a different risk rating if we used the 3-month W126 metric rather than the 7-month W126 metric.

In the original assessment, Kohut (2007) provided an appendix explaining the risk analysis for Cape Cod National Seashore. Based on O_3 exposure ranged from 17 to 25 ppm-hrs using the SUM06 metric, 33.6 to 40.4 ppm-hrs using the 7-month W126 metric, and 6 to 52 using the 7-month N100 metric, Kohut concluded that the risk level is high because these exposure levels are significantly greater than the injury thresholds using all metrics. In the updated assessment, we assigned a risk level of moderate to Cape Cod National Seashore based on O_3 exposure that ranged from <1 to 3 ppm-hrs using the SUM06 metric, 14.5 to 33.1 ppm-hrs using the 7-month W126 metric, and 0 to 11 using the 7-month N100 metric because exposures exceed the injury thresholds using both criteria for the W126 index (W126 and N100) in only one year.

As another example, we assigned a risk level of low to the Great Smoky Mountains National Park because O_3 exposure levels exceeded the W126 injury thresholds (7-month and 3-month) but not the N100 thresholds. When assessing the 3 other O_3 monitors in the park, only 2 monitors exceeded 100 ppm using the 7-month N100 metric once apiece between 2006 and 2010. This is a substantial decline from the 1995 to 1999 O_3 data, which showed up to 107 hours above 100 ppm in a single year at the highest monitor (NPS, 2004). While O_3 levels are still consistently high enough to elevate the W126 levels in the more recent monitoring data, there are many fewer hours where O_3 concentrations spike above 100 ppm. In addition, there appeared to be a slight inverse relationship between O_3 exposure and soil moisture in the Great Smoky Mountains National Park using more recent soil moisture data.

1 **Table 5- 8 Levels of Risk of Foliar Injury in 37 Parks with an O_3 Monitor.**

Park Name	Park Monitor State	Kohut (2007) Risk Level	Updated Risk Level	Change
Acadia National Park	ME	Moderate	Moderate	No change
Badlands National Park	SD	Low	Low	No change
Big Bend National Park	TX	Low	Low	No change
Blue Ridge Parkway	NC	Low	Low	No change
Canyonlands National Park	UT	Low	Low	No change
Cape Cod National Seashore	MA	High	Moderate	Decrease
Carlsbad Caverns National Park	NM	Low	Low	No change
Colorado National Monument	CO	Low	Low	No change
Congaree Swamp National Monument	SC	Low	Low	No change
Cowpens National Battlefield	SC	High	Low	Decrease
Craters of the Moon National Historic Park	ID	Low	Low	No change
Cumberland Gap National Historic Park	KY	High	Low	Decrease
Death Valley National Park	CA	Low	Low	No change
Devils Tower National Monument	WY	Low	Low	No change
Dinosaur National Monument	CO	Low	Low	No change
Glacier National Park	MT	Low	Low	No change
Great Basin National Park	NV	Low	Low	No change
Great Smoky Mountains National Park	NC	High	Low	Decrease
Grand Canyon National Park	AZ	Low	Low	No change
Indiana Dunes National Landmark	IN	High	Low	Decrease
Joshua Tree National Park	CA	High	High	No change
Lassen Volcanic National Park	CA	Low	Low	No change

Park Name	Park Monitor State	Kohut (2007) Risk Level	Updated Risk Level	Change
Mesa Verde National Park	CO	Low	Low	No change
Mojave National Preserve	CA	High	Moderate	Decrease
Mount Rainier National Park	WA	Low	Low	No change
Petrified Forest National Park	AZ	Moderate	Low	Decrease
Pinnacles National Monument	CA	High	Low	Decrease
Saguaro National Park	AZ	Low	Low	No change
Saratoga National Historic Park	NY	Low	Low	No change
Sequoia & Kings Canyon National Park	CA	High	High	No change
Shenandoah National Park	VA	Moderate	Low	Decrease
Theodore Roosevelt National Park	ND	Low	Low	No change
Tonto National Monument	AZ	Moderate	Low	Decrease
Voyageurs National Park	MN	Low	Low	No change
Wind Cave National Park	SD	Low	Low	No change
Yellowstone National Park	WY	Low	Low	No change
Yosemite National Park	CA	High	Moderate	Decrease

5.3.3 National Park Case Study Areas

For the National Park case study areas, staff used the O_3 sensitive species list from the preceding section and cover data from VegBank plots (see section 5.3). The resulting maps give cover estimates for sensitive O_3 sensitive species at the finer scale of the NPS vegetation map (Figure 5- 27). It is important to note that the cover estimates are separated into vegetation strata (herb, shrub, tree). In the preceding analyses we only used tree species, so the cover never exceeded 100%. For this analysis we did not distinguish between strata, so the cover metric can exceed 100. [This analysis will be completed in the 2nd draft with the addition of the 2 additional NPS case study areas]

5.3.3.1 Great Smoky Mountain National Park

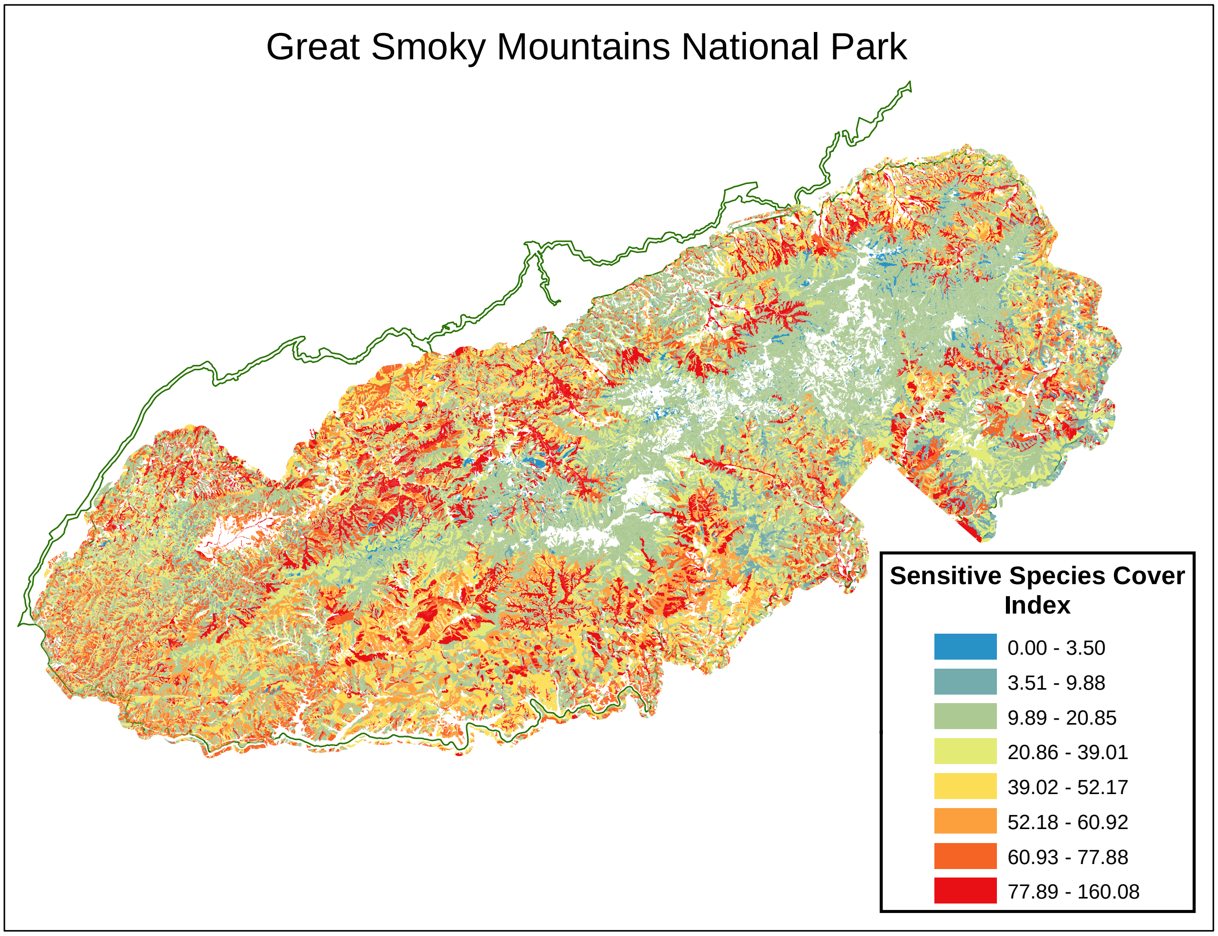

Figure 5- 27 Cover Index of Sensitive Species in GSMNP

5.3.3.2 Rocky Mountain National Park

[To be added in the second draft]

5.3.3.3 Sequoia/Kings National Park

[To be added in the second draft]

5.4 DISCUSSION

- For individual tree species the RBL was, on average, 30% less under the current standard scenario. In Class I areas with higher O_3 exposure this reduction was approximately 20% and in Critical Habitat areas it was 30%.
- Individual tree species show different patterns of change with respect to changes in O3. Douglas fir has a very large proportional change when O3 is meeting the current standard, however further reductions in O3 will likely have very little effect on that species. Sugar maple also had a large proportional change when meting the current

standard. Further reductions in O3 will have some effect to a point beyond which we expect very little change. Other species are expected to exhibit continued gradual change in RBL relative to ambient as O3 levels are reduced.

- Many Class I and Critical Habitat areas occur in areas of low ambient O3 and these areas generally show very little change in summed RBL relative to ambient. In areas with higher ambient O3 levels, the proportion of ambient summed RBL decreases by as much as 20%.
- Within the GSMNP this value was higher, around 45%, but this analysis needs to be expanded with additional parks.
- There are significant areas with high abundance of O_3 sensitive tree species. Not all of these areas co-occur with areas of high O_3. This is an analysis that is not complete.
- There are areas within GSMNP where the sensitive species cover is very high. The relationship of these to areas of recreational use is presented in Chapter 6.
- Overall, these analyses indicate that decreasing O_3 from ambient conditions to a rollback scenario just meeting the Current Standard had a significant impact, but additional rollback scenarios are needed to fully interpret this observation.

6 OZONE RISK TO ECOSYSTEM SERVICES

6.1 INTRODUCTION

EPA has begun using an ecosystem services framework to help define how the damage to ecosystems informs determinations of the adversity to public welfare associated with changes in ecosystem functions.

The following sections address the risks to ecosystem services resulting from O_3 exposure. 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 may be negatively impacted by O_3 exposures. For many services, we can estimate the current total magnitude and, for some, the current value of the services in question. The estimates of current service provision will have embedded within them the loss of services occurring due to historical and present O_3 exposure, and provide context for the importance of any potential impacts of O_3 on those services. In addition, in some cases we can provide information on locations where high O_3 exposures occur in conjunction with significant ecosystem service impairment.

6.2 NATIONAL SCALE ECOSYSTEM SERVICES ASSESSMENT

The national scale assessment will address O_3 impacts on ecosystem services following the framework of the Millennium Ecosystem Assessment (MEA, 2009). Following that framework the subsequent sections are divided into supporting, regulating, provisioning, and cultural services.

Two major effects of O_3 exposure on ecosystems considered in this assessment are biomass loss (or decrease in growth rate) and visible foliar injury. Each of these ecological effects can have negative effects on vegetation related to ecosystem services. To illustrate

Table 6- 1 lists the trees identified as sensitive to O_3 in studies cited in the ISA and their uses.

Table 6- 1 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

Tree Species	**O_3 Effect**	**Uses**
		red-winged blackbird, chickadee, finches, and nuthatches
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 esp. riparian buffer
Red Oak ***Quercus rubrum***	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

Tree Species	O_3 Effect	Uses
		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 , http://www.plants.usda.gov.plantguide; U.S. Forest Service Silvics of North America, http://www.na.fs.fed.us/spfo/pubs/silvics_**manual;** North Carolina State University, http://www.ncsu.edu/project/dendrology/

The National Park Service has published a list of trees and plants considered sensitive because they exhibit foliar injury at or near ambient concentrations in fumigation chambers or have been observed to exhibit symptoms in the field by more than one observer. This list includes many species not included in Table 6-1, such as various milkweed species, asters, coneflowers, huckleberry, evening primrose, Tree-of-heaven, redbud, blackberry, willow, and many others. The full list is included in Appendix X and the O_3 ISA (EPA, 2012). Many of these species are important for non-timber forest products, recreation, and aesthetic value among other services.

6.2.1 Supporting Services

Supporting services are the services necessary for all other services. For example nutrient cycling is required for any ecosystem service including provision of food and timber. While other categories of services have relatively direct or short-term impacts on people 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 services.

6.2.1.1 Net Primary Productivity

The ISA determined that biomass loss due to exposure to may have adverse effects on net primary productivity (NPP). According to Pan et al. (2009) net primary productivity in U.S. Mid-Atlantic temperate forests decreased 7-8% per year from 1991-2000 due to O_3 exposure when compared to preindustrial conditions in 1860 even with growth stimulation provided by elevated carbon dioxide and nitrogen deposition. In another study Felzer et al. (2004) estimated O_3 impact on NPP for the conterminous U.S from 1950-1995 compared to a presumed pristine condition in 1860. They found the largest decreases in NPP occurred in the agricultural region of the Midwest during the mid-summer. This decrease was as high as 13% per year in some areas. Primary productivity underlies the provision of many subsequent services that are highly valued by the public including provision of food and timber. Due to data and methodology limitations the loss of value to the public due to the negative effects of O_3 exposure on this supporting service is unquantifiable.

6.2.1.2 Community Composition

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 the more susceptible species. For example in the San Bernardino area Arbaugh et al. (2003) have shown that 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. See Figure 5-17 for a map showing current W126 O_3 levels in critical habitat areas.

6.2.2 Regulating Services

Regulating services as defined by the MEA (2005) are those 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.

6.2.2.1 Climate Regulation

Biomass loss due to O_3 exposure affects climate regulation by ecosystems by affecting carbon sequestration by plants and trees. Reduction of carbon uptake by forests results in more carbon in the atmosphere and negative effects on climate. The studies cited in the ISA show a consistent pattern of decrease in 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 could be even greater than the direct effect of O_3 on climate change.

The Forest and Agriculture Sectors Optimization Model – Greenhouse Gas version (FASOMGHG) can calculate the difference in carbon sequestration by forests and agriculture due to biomass loss caused by O_3 exposure. Details of the model itself and the analyses done for this risk and exposure assessment are available in Appendix X. [We will be providing results in terms tons carbon sequestered in supplemental materials. We will model current ambient conditions and the results of simulations just meeting the current standard.]

In addition to its direct impacts on vegetation, O_3 is a well-known greenhouse gas that contributes to climate warming (U.S. EPA, 2012a). 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 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 due to 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. In contrast, 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 emission 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.

6.2.2.2 Hydrologic Cycle

Regulation of the water cycle is yet another ecosystem service that can be adversely affected by the effects of O_3 on plants. McLaughlin et al. (2007) reported that increased water use by O_3 impacted forests decreased modeled late-season stream flow in watersheds in eastern Tennessee in or near the Great Smoky Mountains. Ecosystem services potentially affected by such a loss in stream flow could include habitat for species such as trout that are dependent on an optimum stream flow or temperature. Downstream effects could potentially include a reduction in the quantity and/or quality of water available for irrigation or drinking water, and recreational use. The United States Forest Service (U.S. FS) and the National Oceanographic and Atmospheric Administration (NOAA) jointly surveyed Americans age 16 and over for the report on Uses and Values of Wildlife and Wilderness in the United States as part of the National Survey on Recreation and the Environment (NSRE) (U.S.D.A., 2002). The NSRE (U.S.D.A., 2002) specifically asked for respondents to rank the importance of water quality as a benefit of wilderness. 91% of respondents ranked water quality protection as either extremely or very important. Less than 1% of respondent s ranked this service as not important at all.

6.2.2.3 Fire Regulation

Fire regime regulation is also negatively affected by O_3 exposure. Grulke et al. (2008) reported various lines of evidence indicating that O_3 pollution may contribute to forest susceptibility to wildfires by increasing leaf turnover rates, and litter thereby creating increased fuel loads on the forest floor, O_3 increased drought stress, and, because both foliar and root biomass are negatively affected, trees store carbohydrates in the bole over winter increasing susceptibility to bark beetle attack. Taken together these factors increase susceptibility to wildfire. In the United States in 2010 over 3 million acres burned in wildland fires and an additional 2 million acres were burned in prescribed fires according to the National Interagency Fire Center (http://www.nifc.gov/fireInfo/fireInfo_statistics.html). Over the 5-year period from 2004 to 2008 Southern California alone experienced, on average, over 4,000 fires a year burning, on average, over 400,000 acres (National Association of State Foresters [NASF], 2009).

The short-term benefits of reducing the 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 $163 million per year (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). Figure 6- 1 shows current ambient O_3 levels over the fire risk in California. The highest fire risk and highest O_3 levels overlap with each other and significant portions of the California range of species sensitive to O_3 damage specifically ponderosa pine.

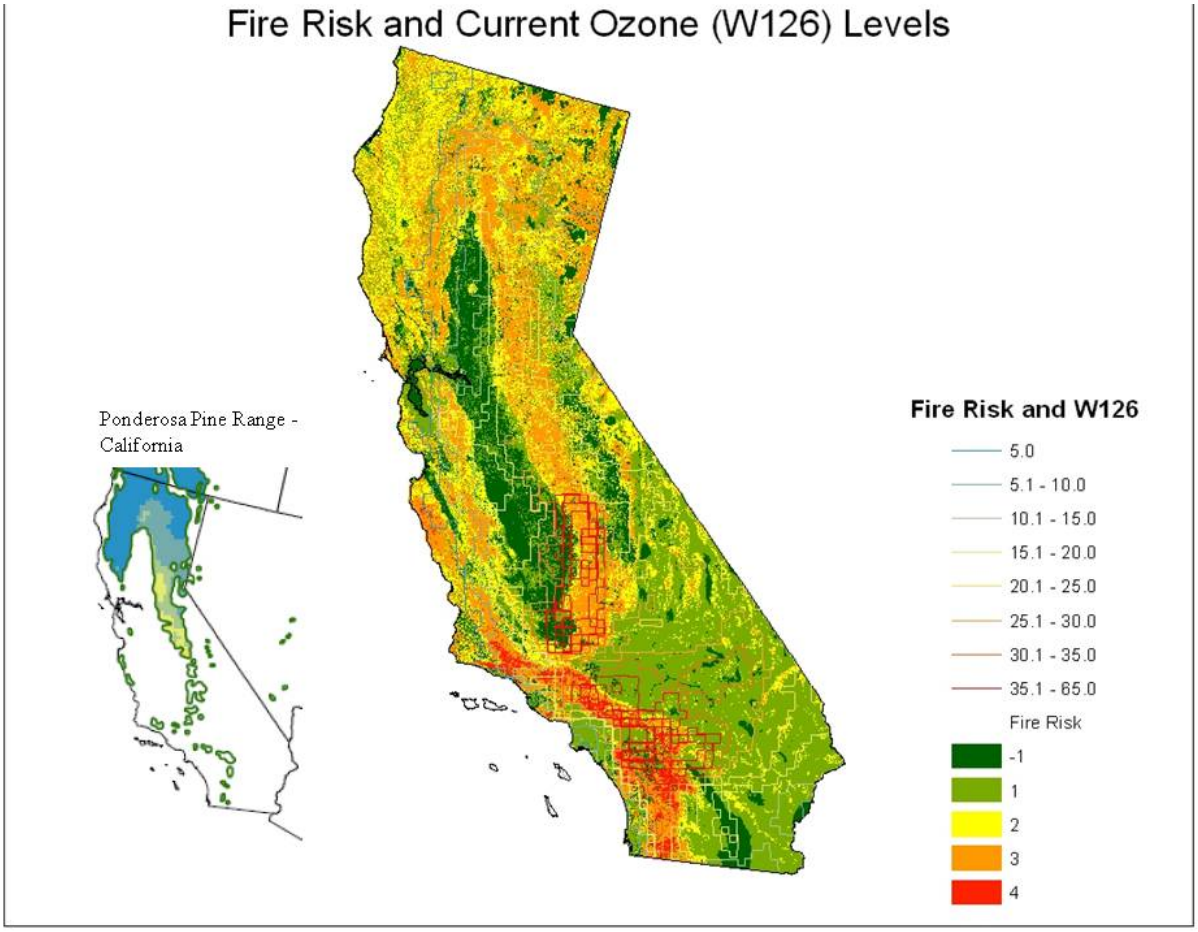

Figure 6- 1 Overlap of fire risk, current O_3 levels and California range of ponderosa pine

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 9.71% after one fire and 22.7% after a second wildfire within 1.75 miles of a house in their study area. After the second fire, the housing prices took between 5 and 7 years to recover.

Additionally, long term decreases in wildfire would be expected to yield outdoor recreation benefits consistent with the discussion of scenic beauty in subsequent sections.

6.2.2.4 Pollination

The ISA O_3(ISA) (2011 ref) identifies O_3 as a possible agent affecting the travel distance and loss of specificity of volatile organic compounds emitted by plants, some of which act as scent cues for pollinators. While it isn't possible to calculate the loss of pollination services due to this negative effect on scent the loss is embedded in the current estimated value of all pollination services, managed and wild, in North America (U.S., Canada, and Bermuda) which is $18.3 billion dollars in 2010 (Gallai et al., 2009).

6.2.3 Provisioning Services

Provisioning services include market goods such as forest and agricultural products. The direct impact of O_3 exposure induced biomass loss can be predicted for the commercial timber and agriculture markets 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. 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 and foliar injury. USDA has assessed the harvest and market value of these products in commercial markets. There is as well a significant portion of NTFP that are valuable to subsistence gatherers. Subsistence practices are much more difficult to assess as these forest users are not required to obtain a permit for use of federal public lands and are therefore more difficult to enumerate.

6.2.3.1 Commercial Timber and Agriculture

We used FASOMGHG (**F**orest and **A**gricultural **S**ector **O**ptimization **M**odel**—G**reen **H**ouse **G**as version) to calculate the resulting market-based welfare effects of O_3 exposure in the forest and agricultural sectors of the United States. Even though agricultural impacts are not a focus of this risk assessment, a proper understanding of impacts on commercial forests requires us to model the effects of O_3 on agriculture because of the interactions between competing demands for land for forestry versus agricultural crops. We used data obtained from the Forest Inventory and Analysis National Program (FIA) and the O_3 related biomass loss concentration-response functions from the ISA as inputs into FASOMGHG, which enabled us to adapt the growth rates for tree and crop species in the model to account for the impact of O_3 on vegetation. See Appendix X for a full discussion of the model and methodology.

[We will provide results of modeling runs for current ambient conditions and meeting current standards in supplemental materials. The results will be in terms of timber and crop yield loss.]

In addition to the direct effects of O_3 on tree growth O_3 causes increased susceptibility to infestation by some chewing insects (USEPA, 2006). 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 6- 2 and Figure 6- 3 illustrate the damage caused by southern pine beetles in parts of the south.

Figure 6- 2 Southern pine beetle damage. Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

According to the USDA Forest Service 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. However, USDA estimates that these long term impacts are much smaller than the short term impacts.

The Forest Service further reports that over the 28 years covered in their analysis (1977-2004) timber producers have incurred 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 due to beetle outbreaks. This results in a net $15 million per year economic impact. All dollar values are reported in constant $2010. These annual figures mask the fact that most of the economic impacts are the result of 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 due to the effect of O_3 on trees' susceptibility to insect attack however, such losses are already embedded within the losses quoted and any welfare gains from decreased O_3 would positively impact these numbers.

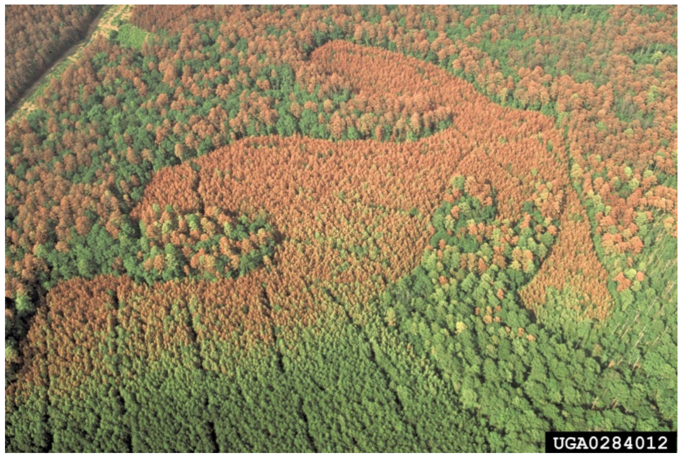

Figure 6- 3 Southern pine beetle damage. Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

In the western United States O_3 sensitive ponderosa and Jeffrey pines are subject to attack by bark beetles. Figure 6- 4 shows western bark beetle mortality from 2003- 2007. The map includes Douglas fir and other western species vulnerable to bark beetles as well as ponderosa and Jeffrey pine. According to the Western Forestry Leadership Coalition (2009) approximately 22 million acres of forest lands are at risk for bark beetle damage.

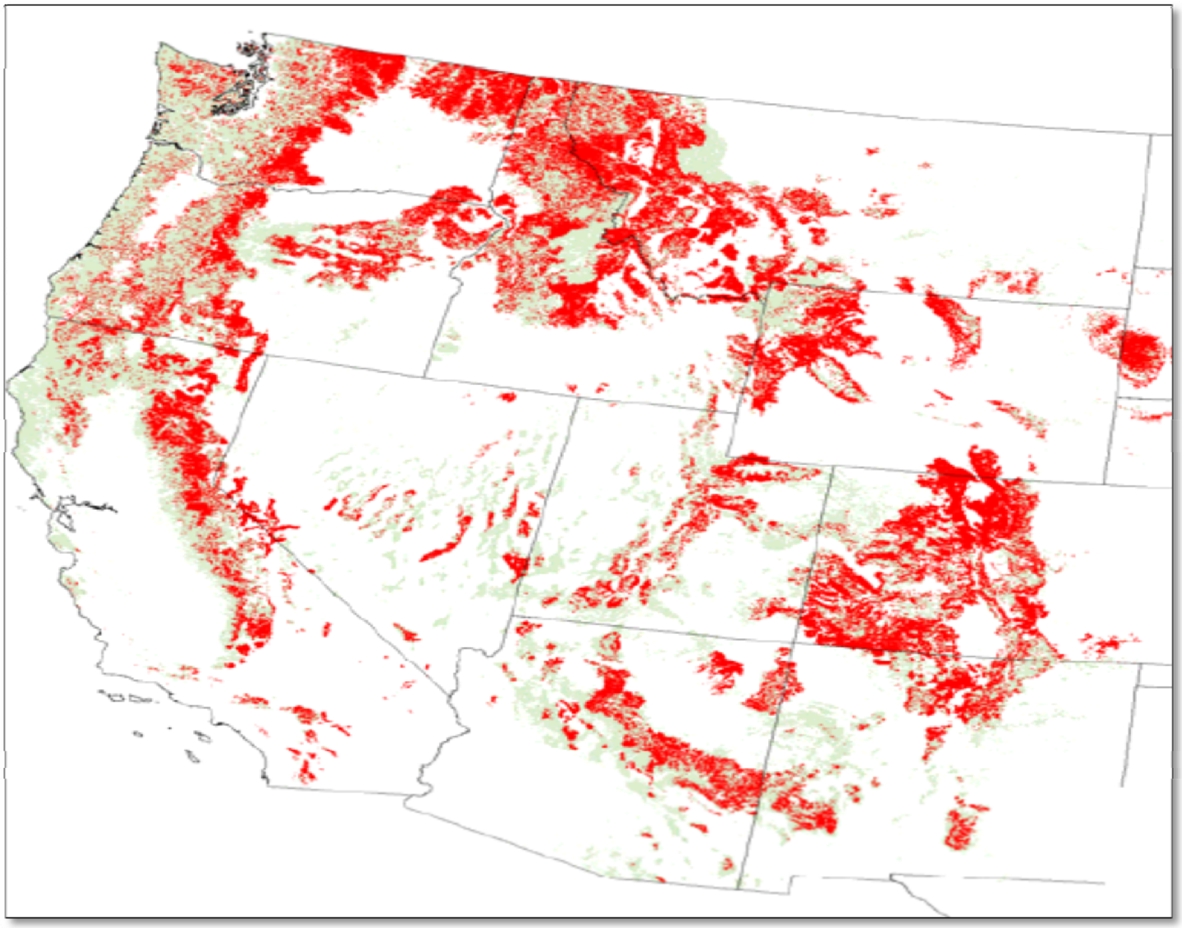

Figure 6- 4 Western bark beetle mortality obtained from State and Private Forestry aerial-detection surveys (2003-2007). Source: Western Forestry Leadership Coalition (2009) [This figure will be updated with O_3 concentrations in supplemental materials.]

In 2006 the 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% of the total production (U.S. Forest Service, 2009 available at: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php). California also experiences high O_3 levels that may contribute to susceptibility to bark beetle attack. While it isn't possible to attribute a quantified impact of O_3 to economic loss due to bark beetle damage that impact is already accounted for within the loss attributed to bark beetle infestation. Reducing O_3 impacts would likely reduce economic loss to California timber production.

The photographs and map above illustrate the impact insect outbreaks can have major effects on aesthetic values such as scenic beauty in addition to the impacts on timber production.

The value of the impact of O_3 and insect attack susceptibility on aesthetic values, as shown in the Nox/SOx Policy Assessment (EPA, 2011), may be even greater than the market value of the timber. We will address those impacts in Section 6.2.4.

6.2.3.2 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
- 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- 2 details selected categories of non-timber forest products (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, individual transplants.

Table 6- 2 Quantity of non-timber forest products 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

Product Category	**Unit**	**Harvest All U.S.**
	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 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 ISA Table 9-1, 2012) 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. Likewise the same O_3 effects would impact harvest of edible fruits, nuts, berries, and sap. Note that this category includes blueberries, pine nuts, and sap for maple syrup to name just a few. The use of native grasses as forage is a significant aspect of forest-land management in the western U.S. (Alexander et al. 2002). O_3 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 as well.

According to the Census Bureau's County Business Patterns data in 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 ($ 2006) of $71,657,000 with an average annual income of $34,155 (U.S. Census Bureau, County Business Patterns, at http://www.census.gov/econ/cbp/).

The USDA estimates the proportion of the national supply of NTFP represented by U.S. FS and BLM lands is approximately 10%. Retail values for NTFPs harvested on Forest Service and Bureau of Land Management lands are approximately $1.4 billion. These are very rough estimates 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 realize that while we cannot estimate the loss of production and therefore values for the loss of benefit to this sector that is due strictly to the effects of O_3 those losses are already embedded within the harvest and values reported here.

The preceding paragraphs detailed the harvest and value of permit or contract sales of NTFPs on Forest Service and BLM managed lands. Since permits or contracts are not required for gathering activities for personal use the analyses done by USDA are not able to account for the subsistence use of non-timber forest products.

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

Most people gathering NTFPs are doing so for personal use (Baumflek et al., 2010 and USDA, 2011). In fact by one estimate (Baumflek et al., 2010) up to 80% of the people collecting NTFPs in Oregon and Washington are collecting for personal reasons. Such personal use may be characterized as either 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 other reasons than recreation (Brown et al., 1998). The term subsistence has usually been applied to special groups such as Native Americans or the Hmong people. The term "subsistence" has generally been understood to imply an extremity of poverty such that these activities are essential to a minimum of 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 (1998) proposed a composite definition 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 make it clear that subsistence activities provide valued resources for a variety of people in the coterminous United States. Baumflek et al. and Alexander et al. (2010 and 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 may provide perspective on the significance of these activities to the people who engage in them.

6.2.4 Cultural Services

Cultural services include recreation, habitat for endangered species, and non-use values (i.e., existence and bequest values) that can be directly or indirectly impacted by O_3 exposure. The foliar injury induced by O_3 exposure may have a negative impact on people's satisfaction with outdoor activities especially those associated with natural environments. Slowed growth or changes in community composition may impact habitat for endangered species both flora and fauna. Non-use values are impacted as well. According to responses to the National Survey on Recreation and the Environment large majorities of Americans wish to preserve natural or pristine areas even if they do not intend to visit themselves.

According to the National Report on Sustainable Forests (USDA, 2011) there are approximately 751 m (Figure 6- 5); one-third is federally owned. All of these lands are assumed to be protected to some degree but specific protections apply to wilderness areas which comprise about 20% of public land, 7% is protected as national parks, 13% is designated as wildlife refuges while 60% is protected managed forests including national forests, BLM lands and other state and local government lands. The protections afford preservation of cultural, social, and spiritual values.

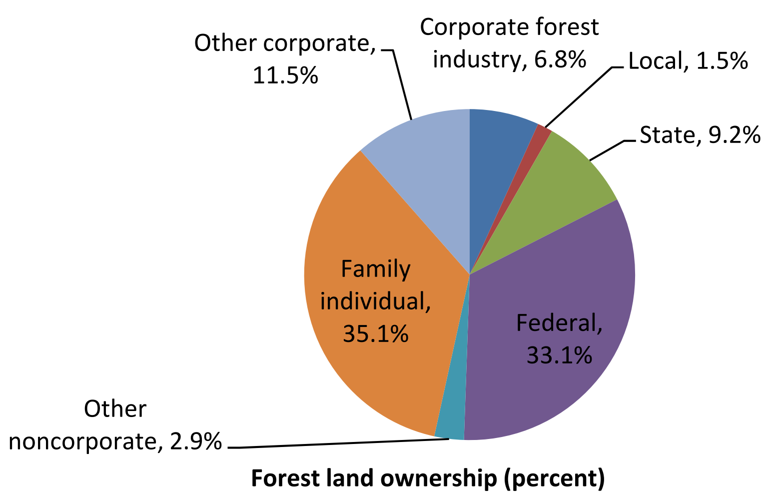

Figure 6- 5 Percent of forest land in the United States by ownership category, 2007 (percentages sum to 100) (Almost all forest lands are open for some form of recreation, although who may have access may be restricted). Source: USDA Forest Service

6.2.4.1 Non-Use Services

The National Survey on Recreation and the Environment (NSRE) (USDA, 2002) is an ongoing survey of a random sample of adults over the age of 16 on their interactions with the environment. NSRE surveys 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, option, and bequest services related to forests. Significantly, according to the survey, only 5% of Americans rate wood products as the most important value of public forests and wilderness areas and even for private forests only 20% of respondents rated wood products as most important. Table 6- 3 details the survey responses to these questions.

Table 6- 3 NSRE Reponses to Non-Use Value Questions

Service	Extremely Important	Very Important	Moderately Important	Total
Existence	36	38	18	92
Option	36	37	17	90
Bequest	81	12	4	97

Studies (Haefele et al., 1991, Holmes and Kramer, 1996) indicate that the public places a high value on protecting forests and wilderness areas from the damaging effects of air pollution. Studies conducted to assess willingness-to-pay (WTP) for forest protection for spruce-fir forests in the southeast from air pollution and insect damage (Haefele et al., 1991, Holmes and Kramer, 1996) confirm that the non-use values held by the respondents to the survey 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 would protect the forests along road, and trail corridors spanning approximately 1/3 of the ecosystem at risk. This level of protection may be most appealing to recreational users. The second level of protection 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. This resulted in values that represented components of 13% use value, 30% bequest, 57% existence value (Table 6- 4).

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

Table 6- 4 Value Components for WTP for Extensive Protection Program for Southern Appalachian Spruce-Fir Forests

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

6.2.4.2 Habitat Provision

In addition to non-use values the NSRE provides data on the values survey respondents place on the provision of habitat for wild plants and animals. Table 6- 5 summarizes the responses to survey questions regarding the value of wildlife habitat and preservation of unique or endangered species.

Table 6- 5 NSRE Reponses to Wildlife Value Questions

Service	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

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 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 to $261/year for Washington state anadromous fish, hatched in fresh water, spends most of its life in the sea and returns to fresh water to spawn, populations in constant 2010$.

6.2.4.3 Aesthetic Value

Aesthetic 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. Studies document the existence of housing price premia 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 fact according to Butler (2008) approximately 65% of private forest owners rate providing scenic beauty as either a very important or important reason for their ownership of forest land.

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

6.2.4.4 Recreation

With few exceptions, publicly owned forests at all levels are open for some form of recreation. Based on the analysis done for the USDA Report on Sustainable Forests referenced in Section 5.1.4 almost all of the 751 million acres of forest land are at least partially managed for recreation. Of the 751 million acres 44% are publicly owned (federal, state, or local).

Americans enjoy a wide variety of outdoor pursuits many of which are subject to negative impacts due to O_3 exposure especially its effect 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 satisfaction with other scenery dependent activities. 97% of NSRE survey respondents rated scenic beauty as an important to extremely important aspect of their wilderness experience.

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% of the variation in participant satisfaction across all recreation types.

Perceptions of scenic beauty are dependent on a number of forest attributes including the appearance of health and the effects of air pollution and insect damage, visual variety, species variety, and lush ground cover (Ribe 1989). The ISA concludes that there is a causal relationship between O_3 exposure and visible foliar injury. Chapter 5 of this document also discusses the effects of O_3 on foliar injury. Figure 6- 6 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 slash from harvest activities has a negative impact on scenic beauty assessments (Ribe, 1989; Buyhoff, et al, 1982). Species composition of forests may also influence preferences. According to Ribe (1982) 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 such as the presence of ponderosa pine in California. Additionally there is a positive effect for ground cover rather than bare or disturbed soil (Brown and Daniel, 1984, 1986). Thus the damage to scenic beauty O_3 inflicts 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.

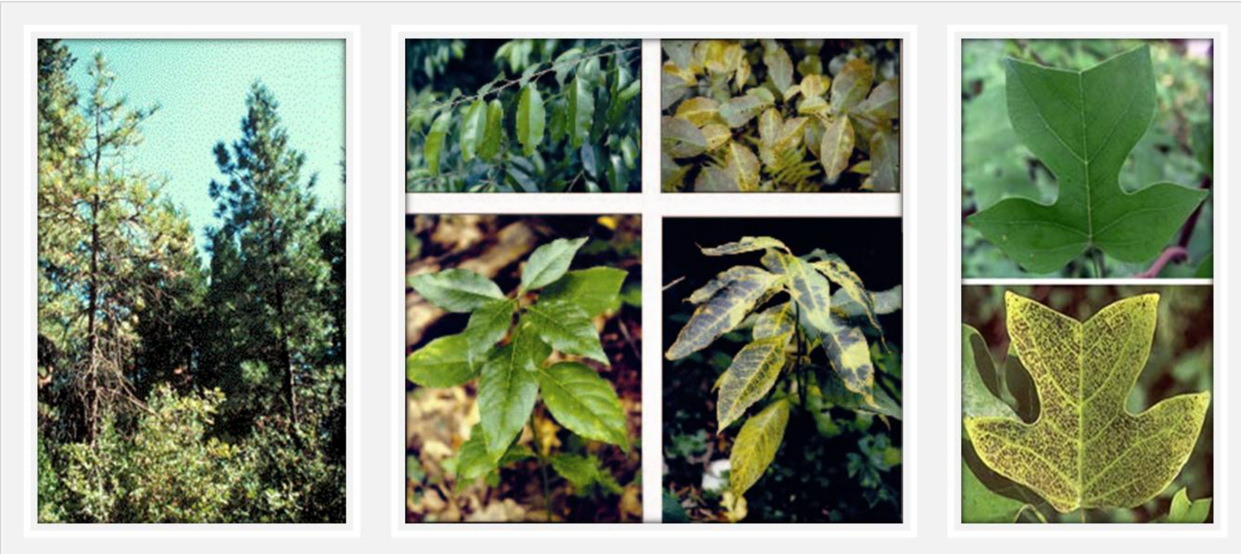

Figure 6- 6 Examples of foliar injury due to O_3 exposure. Courtesy: National Park Service

The NSRE provides estimates of participation in 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 is wholly or partially dependent on the quality of the natural scenery. Table 6- 6 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 WTP for their participation.

Table 6- 6 National Outdoor Activity Participation

Activity	% Participation	# Participants[a]	# Activity Days[a]	Mean WTP/Day[b]	Mean Total Participation Value[a,b]
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 2000-2001 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/

[a] in millions, [b]$ 2010, N/A not available

The relationship between scenic beauty and recreation satisfaction for camping has been 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 willingness to pay (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 willingness to pay for recreation experiences in areas where scenic beauty is less damaged by O_3. As mentioned previously Ribe (1994) found that scenic beauty plays a strong role in recreation satisfaction and, in fact, explains 90% 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. 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 will generate significant benefit to these recreators.

Another resource for estimating consumer's economic value for their recreation experiences is the data available on their 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, 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. For this document we will refer to analyses done for the 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (FHWAR) (U.S. Department of the Interior and U.S. Department of Commerce, 2006) and an analysis performed by Southwick and Associates for the Outdoor Industry Foundation , The Economic Contribution of Active Outdoor Recreation – Technical Report on Methods and Findings (OIF, 2006). See Appendix X for further detail.

The FHWAR and the OIF report provide estimates of trip and equipment related annual expenditures for wildlife watching activities in the United States. The Outdoor Industry Foundation (OIF) study provides estimates of recreationist's annual expenditures on trail-related activities, camping, bicycling, snow-related 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.

Table 6- 7 Expenditures for Wildlife-Watching, Trail, and Camp Related Recreation[a]

Expenditure Type	Wildlife-Watching[b]	Trail[c]	Camp[c]	Total[c]
Trip-Related	13.9	31.8	108.6	153.3
Equipment & Services	25.0	3.6	9.3	37.9
Other Expenditures	10.4			10.4
Grand Total for all Expenditures				**200.1**

[a] in $ 2010 billion, [b] data from 2006 FHWAR[c] , data from 2006 OIF report, N/R not reported

According to these analyses the total expenditures across wildlife watching activities, trail based activities, and camp based activities are approximately $200.1 billion dollars annually. See Table 6- 7 for details. While we cannot estimate the magnitude of the impacts of O_3 damage to the scenic beauty upon which satisfaction with these activities depend the losses are embedded within the values reported.

The impact of these expenditures has a multiplier effect through the economy as a whole which was estimated by OIF using the IMPLAN® model. The model estimates the flow of goods and money through the economy at scales from local to national. According to the OIF report (2006) trail activities generated over $83.7 billion dollars in total economic activity including $33.4 billion in retail sales and $42.7 billion in salaries, wages, and business earnings. The same report estimates the total economic activity generated by camping related recreation at $273 billion including $109.3 billion in retail sales and $139.2 billion in salaries, wages, and business earnings. The total economic activity estimates also include state and federal tax revenues.

Assumptions and Caveats to the IMPLAN® Results: Statistics regarding the precision of the final economic impacts were not produced by OIF due to feasibility issues, Harris Interactive survey results combine several parameters from the data, and outside data from the Census population estimates and IMPLAN multipliers were used.

6.3 CASE STUDY ANALYSIS

The next sections highlight four national parks and several urban areas selected as case study areas to provide a more detailed analysis of the ecosystem services at risk due to O_3 exposure in the protected areas of our country and in the urban areas where the majority of the U.S. population lives.

National Parks are especially significant to the public welfare in that the public as a whole, through their elected representatives, have designated these areas to be of special value by creating the parks. While national parks supply supporting and regulating services this analysis focuses on the cultural services these areas provide. The supporting and regulating services at risk are described in the national scale analysis. Provisioning services generally do not apply since timber harvest and agriculture are prohibited in the parks.

The criteria for selection of the specific parks included here are discussed in Chapter 5. The methodology for the ecosystem services analysis for each park is consistent between the case studies. For each park the maps generated in Chapter 5 were overlayed with the locations of park amenities in order to illustrate the extent of O_3 impacts on vegetation and that impact on the activities important to park visitors. Park use surveys[1] and public use statistics (National Park Service Public Use Statistics Office, http://www.nature.nps.gov/stats/index.cfm) provide data on numbers of visitors who engage in activities in the parks and recreation value surveys (Kaval and Loomis, 2003) provide estimates of average willingness to pay for these activities within the park region.

The National Park Service (National Park Service, 2011) has produced estimates of visitor spending for each park and the impact of visitor spending on local economies surrounding the parks. These analyses provide a total value related to the specific case study parks and do not model changes in value due to O_3 impacts. However the loss to the local economies due to O_3 damage in the parks is captured in the current values. These values would likely be higher absent O_3 impacts.

The urban case study analysis utilizes the iTree model developed by the Forest Service to quantify the benefits of urban forests. These urban forests are vulnerable to the adverse effects of O_3. The iTree model is designed to provide estimates of the effects of forests on carbon

[1] These studies are conducted by the Visitor Services Project at the University of Idaho. Reports for individual parks are available at: http://www.psu.idaho.edu/vsp.reports.htm

sequestration, volatile organic chemical production, and pollution removal and can be modified to allow estimation of the biomass loss due to O_3 exposure and that effect on services.

6.3.1 Southeast Region – Great Smokey Mountains National Park

Figure 6- 7 Mount Le Conte, Summer Great Smoky National Park. Courtesy: National Park Service

Great Smokey Mountains National Park (GRSM) welcomed approximately 9.5 million visitors in 2010 (NPS Public Use Statistics Office, http://www.nature.nps.gov/stats/index.cfm) making it the most visited national park in America. Overlapping the border between North Carolina and Tennessee 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.

As shown in Chapter 5 the extent of sensitive species coverage in GRSM is quite substantial. The "whole park" services affected by such potential O_3 impacts include the existence, option, and bequest values discussed in section 6.2.4.1 and habitat provision discussed in section 6.2.4.2. Recreation value specific to the park is discussed later in this section. Focusing the analysis showing the percent cover of foliar injury sensitive species in the park in Chapter 5 on the areas where recreation services are provided can give some perspective on the level of potential harm to scenic beauty and therefore recreation satisfaction within the park.

The National Park Service 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 visit. By using the annual visitation rate from 2010 and the regional results from the Kaval and Loomis (2003) report on recreational use values compiled for the NPS estimates for visitors' willingness to pay for various activities was generated and presented in Table 6-8. In addition to the activities listed in Table 6- 819% or 1.8 million park visitors availed themselves of educational services offered at the park by participating in a ranger-led nature tour suggesting that visitors wish to understand the ecosystems preserved in the park.

Table 6- 8 Value of Most Frequent Visitor Activities at Great Smoky Mountains National Park

Activity	% Participation	# Participants (thousands)	Mean WTP (in $2010)	Total Value of Participation (millions in $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 given in Table 6- 9 for the Great Smoky Mountain National Park. The median value of the components of that spending is presented in Table 6- 10.

Table 6- 9 Visitor Spending and Local Area Economic Impact of GRSM

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] ($000's) Source: Economic Benefits to Local Communities from National Park Visitation and Payroll (NPS, 2011) available at: http://www.nature.nps.gov/socialscience/docs/NPSSystemEstimates2009.pdf

Table 6- 10 Median Travel Cost for GRSM Visitors

Expense		**Median $ Amounts Spent (in $2010)**
Gas and Transportation		73
Lodging		182
Food and Drinks		73
Clothes, gifts, and souvenirs		61
Total per visitor party		389

Source: The National Park Service 2002 Comprehensive Survey of the American Public Southeast Region Technical Report (available at: http://www.nature.nps.gov/socialscience/archive.cfm)

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 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.

On the other hand, we can quantify the extent of the hiking trails present in areas where sensitive species are at risk for foliar injury. Of the approximately 1287 kilometers of trials in GRSM, including a more than 114 km of the Appalachian Trail, over 1040 km or about 81% of trail kilometers are in areas where species sensitive to foliar injury occur. Figure 6- 8 maps the hiking trails in GRSM including the relevant portion of the Appalachian Trail overlayed with the species cover index. The accompanying pie chart, Figure 6- 9, shows the number of trail miles in each cover category. The categories with species cover index from 60-160, the middle to highest values, account for 635 km of trails or about 50% of trail kilometers.

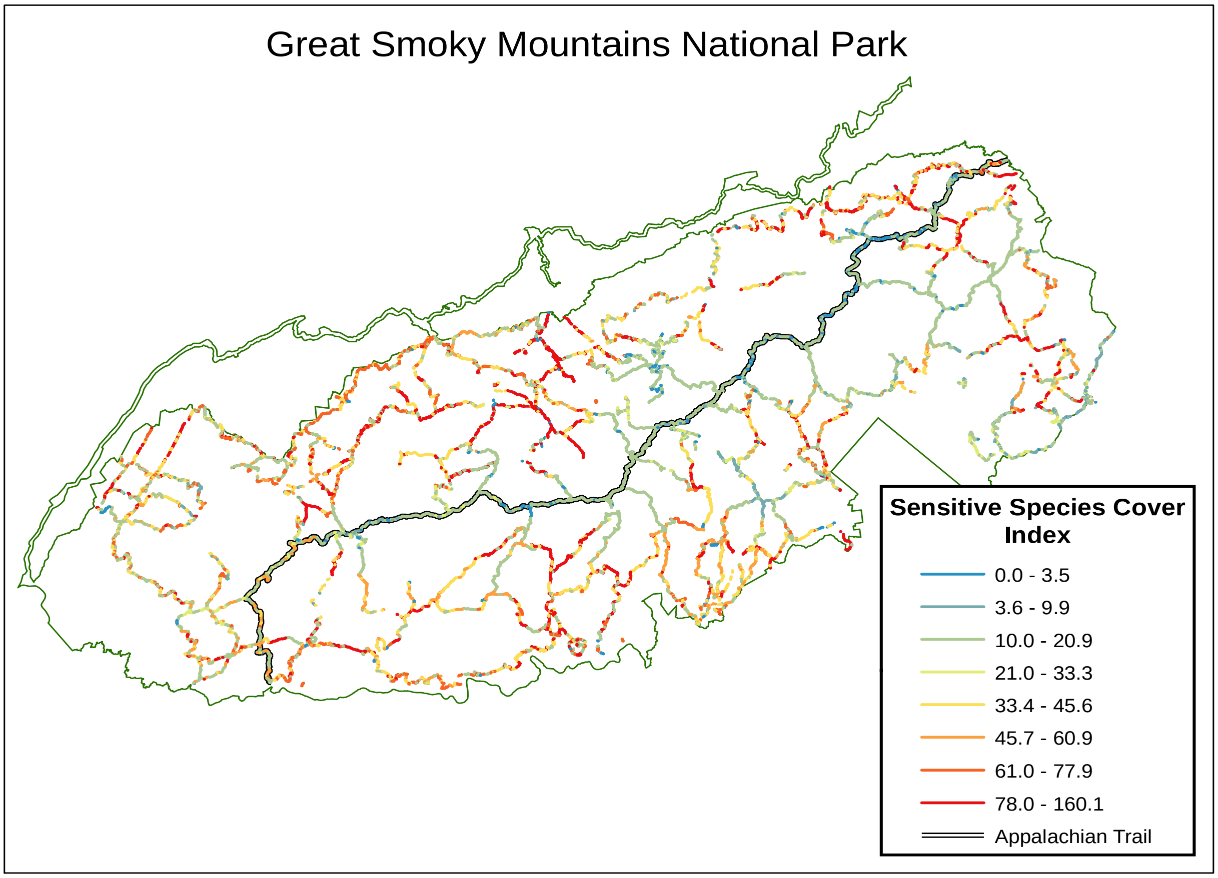

Figure 6- 8 Hiking trails within GRSM and sensitive species cover

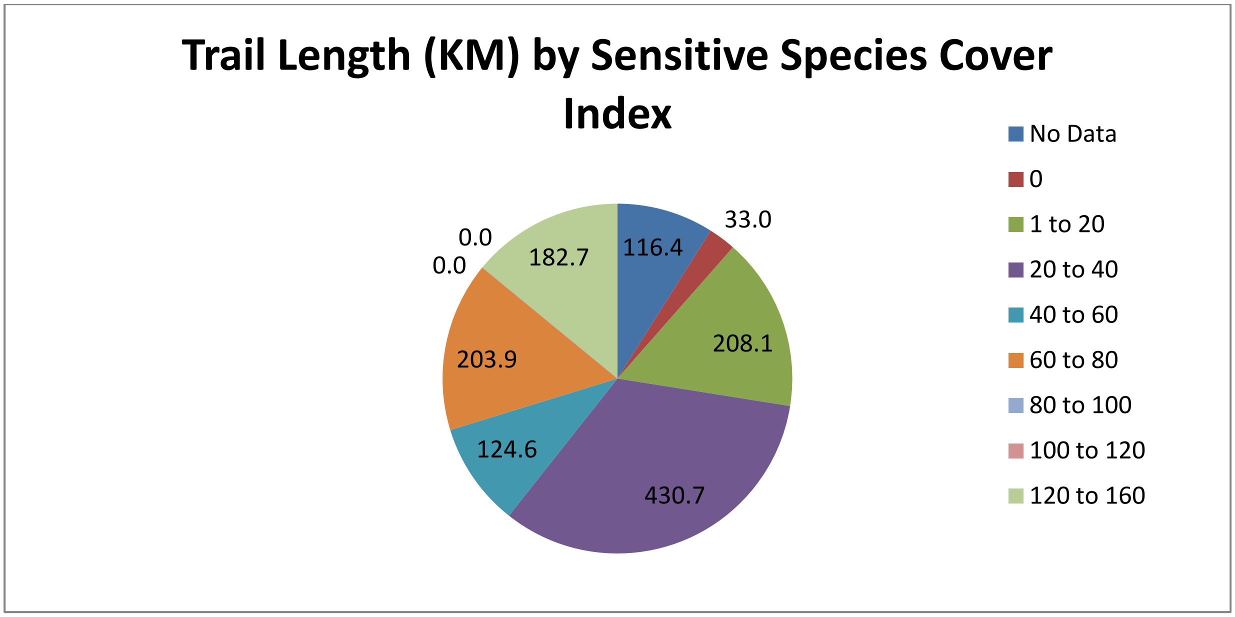

Figure 6- 9 Trail kilometers by species cover category

Although we cannot quantify the incremental loss of hiker satisfaction with their recreation experience due to the effect of O_3 on scenic beauty along the trails this analysis illustrates that very substantial numbers of trail kilometers are potentially at risk. With 3.8 million hikers using the trails every year willing to pay over $266 million for that activity the even a small benefit of reducing O_3 damage in the park could be significant for these park visitors.

[We will produce other maps of amenities (camp sites) and overlays of sensitive species for 2nd draft.]

6.3.2 Intermountain Region – Rocky Mountain National Park

Figure 6- 10 Sheep Lakes, Rocky Mountain National Park. Courtesy: National Park Service

Rocky Mountain National Park welcomed 3.0 million visitors in 2010 (NPS Public Use Statistics Office, http://www.nature.nps.gov/stats/index.cfm) to its 415 square miles of mountain ecosystems. Rocky Mountain National Park allows visitors to enjoy vegetation and wildlife unique to these ecosystems along over 300 miles of hiking trails.

[We will produce maps of amenities (hiking trails, camp sites) and overlays of sensitive species for 2nd draft.]

The National Park Service 2002 Comprehensive Survey of the American Public Intermountain Region Technical Report includes responses from recent visitors to southeast parks about the activities they pursued during their visit. By using the annual visitation rate from 2010 and the regional results from the Kaval and Loomis (2003) report on recreational use values compiled for the NPS estimates for visitors' willingness to pay for various activities was generated and presented in Table 6- 11.

Table 6- 11 Value of Most Frequent Visitor Activities at Rocky Mountain National Park

Activity	% Participation	# Participants (thousands)	Mean WTP (in $2010)	Total Value of Participation (millions in $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 6-11 11% or 330,000 park visitors availed themselves of educational services offered at the park by participating in a ranger-led nature tour suggesting that visitors wish to understand the ecosystems preserved in the park.

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 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. Were O_3 impacts decreased these estimates 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 6- 12 for the Rocky Mountain National Park. The median value of the components of that spending is presented in Table 6- 13.

Table 6- 12 Visitor Spending and Local Area Economic Impact of Rocky Mountain 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]**
2,955,821	174,202	170,804	170,804	2,641	77,625	129,666

[a]($000's) Source: Economic Benefits to Local Communities from National Park Visitation and Payroll (NPS, 2011) available at: http://www.nature.nps.gov/socialscience/docs/NPSSystemEstimates2009.pdf

Table 6- 13 Median Travel Cost for Rocky Mountain National Park Visitors

Expense		**Median $ Amounts Spent (in $2010)**
Gas and Transportation		63
Lodging		100
Food and Drinks		63
Clothes, gifts, and souvenirs		45
Total per visitor party		271

Source: The National Park Service 2002 Comprehensive Survey of the American Public Intermountain Region Technical Report (available at: http://www.nature.nps.gov/socialscience/archive.cfm)

6.3.3 Pacific West Region – Sequoia/Kings Canyon National Parks

Figure 6- 11 Kings Canyon. Courtesy: National Park Service

Sequoia/Kings Canyon National Parks 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 Public Use Statistics Office, http://www.nature.nps.gov/stats/index.cfm) to experience the beauty and diversity of some of California's iconic ecosystems.

[We will produce maps of amenities (hiking trails, camp sites) and overlays of sensitive species for 2nd draft.]

The National Park Service 2002 Comprehensive Survey of the American Public Pacific West Region Technical Report includes responses from recent visitors to southeast parks about the activities they pursued during their visit. By using the annual visitation rate from 2010 and the regional results from the Kaval and Loomis (2003) report on recreational use values compiled for the NPS estimates for visitors' willingness to pay for various activities was generated and presented in Table 6- 14.

Table 6- 14 Value of Most Frequent Visitor Activities at Sequoia/Kings Canyon National Parks

Activity	% Participation	# Participants (thousands)	Mean WTP (in $2010)	Total Value of Participation (millions in $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 6- 14 14% or 224,000 park visitors availed themselves of educational services offered at the park by participating in a ranger-led nature tour suggesting that visitors wish to understand the ecosystems preserved in the park.

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 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. Were O_3 impacts decreased these estimates 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 6- 15 for the Sequoia and Kings Canyon National Parks. The median value of the components of that spending is presented in Table 6- 16.

Table 6- 15 Visitor Spending and Local Area Economic Impact of Rocky Mountain 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]**
1,320,156	438,677	97,012	89,408	1,283	37,299	60,504

[a]($000's) Source: Economic Benefits to Local Communities from National Park Visitation and Payroll (NPS, 2011) available at: http://www.nature.nps.gov/socialscience/docs/NPSSystemEstimates2009.pdf

Table 6- 16 Median Travel Cost for Sequoia/Kings Canyon National Parks Visitors

Expense		Median $ Amounts Spent (in $2010)
Gas and Transportation		75
Lodging		150
Food and Drinks		98
Clothes, gifts, and souvenirs		63
Total per visitor party		386

6.3.3 Urban Case Study

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 described in this section focus on carbon sequestration and air pollution removal using the iTree model. The iTree model is a peer-reviewed suite of software tools provided by USDA Forest Service. See Appendix X for details of the model and the methodology employed for these case studies.

[We will provide results in the form changes in tons of carbon sequestered and tons of pollution removed due to O_3 effects on tree growth in supplemental materials.]

6.4 DISCUSSION

O_3 damage to vegetation and ecosystems 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. Provisioning services are also affected by biomass loss including timber production, agriculture, and non-timber forest products. Cultural services such as non-use values, aesthetic services, and recreation are all affected by the damage to scenic beauty caused by foliar injury due to O_3 exposure. It is possible for several aspects of O_3 effects to interact to contribute to an impact on ecosystem services. For example biomass loss directly impacts timber provision but other contributing effects include increased susceptibility to drought and insect attack.

Many of these services are very difficult to quantify and even more difficult to assign a quantified impact of O_3 exposure. For instance we were not able to quantify changes to community composition due to O_3 or even identify the current level of service provided. Some services, such as recreation, lend themselves to evaluation of total participation and measures of total value but assessing the impact of O_3 effects on these services is not possible at this time. A very few services, such as timber provision, are amenable to quantification and monetization of the actual incremental effects of O_3 exposure.

For the supporting services identified as potentially affected by O_3 exposure we were not able to quantify the impacts for community composition. [However, for net primary productivity we may have quantified results from PnET model runs for the second draft of this document.]

The regulating services indentified as potentially affected by O_3 exposure include climate, water, pollination, and fire regulation. We will have quantified impacts of O_3 on carbon sequestration in the form of results of model runs from FASOMGHG, national scale, and iTree for the urban case studies for the 2nd draft. For the 2nd draft we are considering using the PnET model to assess water cycle regulation effects. Pollination and fire effects remain unquantified however we do have measures of total values of these services.

The effects of O_3 on the provision of timber and agriculture will be quantified and monetized using the FASOMGHG model for the 2nd draft with related impacts of increased susceptibility to insect attack described but not quantified. Non-timber forest products markets are described and total values are included however subsistence use can only be described.

Cultural services are described in terms of total value since there are not data and methods available to quantify O_3 impacts on these services. For example, outdoor recreation activity participation rates range from 10% of the population for backpacking to 60% for natural scenery viewing. The millions of participants have WTP values as high as $152 billion per year for these activities and just three of these (wildlife watching, camping, and hiking) generate over $200 billion per year in expenditures and over $385 billion in total economic activity. For the case study national parks we are able to quantify the amenities potentially affected by O_3 impacts on sensitive vegetation in the parks. In Great Smoky Nation Park, for example, about 50% of the trail kilometers are in the middle and highest categories for sensitive vegetation cover. [We will have expanded case study analysis for the 2nd draft.]

The urban case studies will provide quantified and monetized iTree model results for carbon sequestration and pollution removal for urban forests in supplemental materials.

Although we are unable to quantify the O_3 impacts on these services we do know that these impacts exist and that the loss of service due to those impacts is captured in the current values of the services. Those values would be higher by some unknown amount were O_3 impacts eliminated. Given the very high values for many of the services even very small incremental changes in O_3 effects could potentially lead to large gains in benefits to the public and society.

7 SYNTHESIS

This assessment has estimated exposures to O_3 and resulting risks to ecosystems for both recent O_3 levels and O_3 levels after simulating just meeting the current secondary O_3 standard of 0.075 ppm for the 4th highest 8-hour daily maximum, averaged over 3 years, which was set to be identical to the current primary O_3 standard. The results from these assessments will form part of the basis for considering the adequacy of the current secondary O_3 standard in the first draft Policy Assessment.

The remaining sections of this chapter provide key observations regarding the biomass loss risk assessment (Section 7.1), foliar injury risk assessment (Section 7.2), ecosystem services risk assessment (Section 7.3), and a set of integrated findings providing insights drawn from evaluation of the full assessment (Section 7.4).

7.1 SUMMARY OF KEY RESULTS OF BIOMASS LOSS RISK ASSESSMENT

The first draft biomass loss risk assessment included two spatial scales of analysis including a national scale analysis and several case studies focused on national parks containing O_3 sensitive vegetation. The biomass loss risk assessment focused on relative biomass loss for 11 tree species for which concentration-response (C-R) functions are available. Relative biomass loss is measured as the proportion of biomass lost relative to biomass if ozone concentrations were zero. The assessment of individual tree species gives an estimate of the potential relative biomass loss, calculated across the established species ranges. A second analysis incorporated the abundance of those tree species in different ecosystems to assess the overall ecosystem level effects of the relative biomass loss. In addition, the biomass loss risk assessment evaluated risks occurring in several important subareas, including federally designated Class I areas, and federally designated critical habit areas for threatened and endangered species. The analysis provides estimates of the percent biomass loss associated with recent (2006-2008) O_3 concentrations, and the proportion of the O_3-related biomass loss that would remain after just meeting the current secondary O_3 standard.

Key results include:

- Relative biomass loss associated with recent O_3 concentrations varies substantially between species and across the ranges for individual species, reflecting differences in sensitivity to O_3 and differences in O_3 concentrations across the ranges of the tree species.
- Across species, the estimated potential O_3-related biomass loss associated with recent O_3 concentrations ranged from 0.1 percent for Douglas fir to almost 100 percent for Eastern Cottonwood. The estimated median potential O_3-related

biomass loss for individual species ranged from 0 percent for Douglas fir to 56 percent for Eastern Cottonwood.

- The C-R function for some species (e.g. sugar maple) demonstrates a very rapid change in biomass loss over a small range of O_3 concentrations, 30 to 35 ppm for sugar maple, that behaves similar to a threshold.
- After simulating just meeting the current secondary O_3 standard, the estimated potential O_3-related biomass loss for individual tree species was on average 70 percent of the estimated potential biomass loss at recent O_3 levels, with a range between 8 and 89 percent.
- In eastern U.S. federal Class I areas, simulating just meeting the current O_3 standard resulted, on average, in a 5 percent reduction of the estimated potential O_3-related abundance-weighted biomass loss relative to estimates at recent ambient O_3 exposure levels. When areas with recent ambient O_3 levels lower than a W126 of 10 ppm are excluded, this reduction was on average approximately 20 percent.
- In eastern U.S. federally designated critical habitat areas, simulating just meeting the current O_3 standard resulted on average in approximately a 10 percent reduction of the estimated potential O_3-related abundance-weighted biomass loss relative to estimates at recent ambient O_3 exposure levels. When areas with recent ambient O_3 levels lower than a W126 of 10 ppm are excluded, this reduction was approximately 25 percent.
- In the Great Smoky Mountains National Park case study area, simulating just meeting the current O_3 standard resulted in a 51 percent reduction of the estimated potential O_3-related abundance-weighted biomass loss relative to estimates at recent ambient O_3 exposure levels, with weighted biomass loss estimates reduced from as high as 16.5 percent to a maximum of 7.9 percent.

7.2 SUMMARY OF KEY RESULTS OF FOLIAR INJURY RISK ASSESSMENT

The first draft foliar injury risk assessment included two spatial scales of analysis including a national scale analysis and several case studies focused on national parks containing O_3 sensitive vegetation. The foliar injury risk assessment focused on recent ambient O_3 exposure. Two general assessments of foliar damage are included in this first draft: 1) maps of the abundance of tree species sensitive to foliar damage from O_3 exposure, and 2) foliar injury risk index values for 37 national parks based on the frequency of exceedance of O_3 exposure benchmarks using different O_3 exposure metrics (i.e., SUM06, W126, and N100), soil moisture, and the existence of O_3-sensitive species within each park.

Key results include:

- In the eastern U.S., where tree cover data were available, tree species that are considered sensitive to O_3-related visible foliar damage account for over 80% of the tree cover in some areas as measured by the summed importance values (measures of relative abundance of species).
- Of the 37 parks assessed, based on the screening level risk assessment method used in Kohut (2007), the estimated risk of foliar injury was high in 2 parks (5%), moderate in 4 parks (11%), and low in 31 parks (84%).
- In the Great Smoky Mountains National Park case study area, there are large areas with high cover of O_3-sensitive species based on assessment using the National Park Service sensitive species list and vegetation mapping from the United States Geological Survey.

7.3 SUMMARY OF KEY RESULTS FOR ECOSYSTEM SERVICES RISK ASSESSMENT

There are a wide range of ecosystem services associated with the ecosystem effects (biomass loss and visible foliar injury) that are causally related to O_3 exposure. These include supporting, regulating, provisioning, and cultural services. The first draft risk assessment includes both qualitative and quantitative assessments of ecosystem services. The majority of ecosystem services impacted by O_3 exposures are not quantifiable using existing tools and data. As a result, the risk assessment focuses on providing contextual information about these services in terms of overall magnitude of the service relative to public use and where possible, economic value of the service. We emphasize that for these ecosystem services this contextual information does not provide estimates of the incremental ecosystem damages associated with recent O_3 exposures, nor can it provide estimates of the reduction in O_3-related damages that would occur from just meeting the current O_3 standards. The magnitude of ecosystem services is provided solely to provide context for discussions of the adversity to public welfare posed by damages to these ecosystem services from ozone exposures.

For a few ecosystem services, including commercial forestry yields, carbon sequestration, agriculture yields, reduced productivity in terrestrial ecosystems, and alteration of terrestrial ecosystem water cycling, models exist that can be used to estimate risks from O_3 exposure. This first draft REA includes estimates of risks associated with 1) exposure of commercial forests to O_3, including estimates of changes in yields and resulting changes in welfare for producers and consumers of forest products and changes in carbon sequestration, using the FASOM model, 2) changes in carbon sequestration in urban forests and changes in urban forest pollution removal, using the iTree model. *[The iTree and FASOM results will be provided in supplemental* *materials to be submitted for public review when the first draft Policy Assessment is released in August 2012]*.

Key results include:

- While the economic costs of the O_3–related impacts on ecosystem services is largely unquantifiable, the overall economic value of the set of ecosystem services is estimated to be large, and therefore damages from O_3 have the potential to be significant.
- Ozone-related impacts on ecosystem services associated with commercial timber production include lost economic value due to yield losses and reductions in carbon sequestration. The estimated value of the yield reductions associated with recent O_3 levels for the 11 species for which we have concentration-response functions are $XXX. The estimated reduction in carbon sequestration is XXX tons of carbon per year in 2006 to 2008. *[These will be provided in supplemental materials to be released in August 2012]*
- Ozone-related impacts on ecosystem services associated with urban forests include reductions in carbon sequestration and reductions in removals of air pollution by urban trees. For the 11 species for which we were able to model O_3 damages, the estimated reduction in carbon sequestration is XXX to YYY tons of carbon per year across the urban case study areas in 2006 to 2008. The estimated reductions in tons of pollutants removed is XXX to YYY tons across the urban case study areas in 2007. *[These will be provided in supplemental materials to be released in August 2012]*
- Simulating just meeting the current O_3 standard is estimated to increase the value of commercial forest yields by $XXX in 2006 to 2008, and to increase carbon sequestered in commercial forests by XXX tons of carbon in 2006 to 2008. *[These will be provided in supplemental materials to be released in August 2012]*
- Simulating just meeting the current O_3 standard is estimated to increase carbon sequestration by urban forests in the case study areas by XXX to YYY tons of carbon. Removal of air pollution is estimated to increase by XXX to YYY tons across the urban case study areas. *[These will be provided in supplemental materials to be released in August 2012]*

7.4 OBSERVATIONS

[These observations have been prepared based on the risk estimates available for the July public release of the first draft REA. We anticipate providing an updated draft of Chapter 9 which integrates the results of the FASOM and iTREE ecosystem service risk analyses when we provide supplemental REA materials along with the submissions of the first draft Policy Assessment for public review in August]

Looking across the biomass loss, foliar injury, and ecosystem service risk analyses, there are a number of observations that can provide insight into the nature and patterns of risk. The results suggest that due to the importance of O_3 sensitive species of trees in Eastern forest ecosystems, the potential relative biomass loss associated with recent O_3 concentrations is high, with median values for the most sensitive species, eastern cottonwood, as high as 56%. The damages to forest ecosystems due to reductions in biomass loss for sensitive species include commercial losses, but may also include losses to recreational users and to subsistence populations. Because many of these trees are abundant near urban areas with elevated O_3 levels, simulating just meeting the current O_3 standard results in reductions in potential biomass loss of 30% on average.

National parks and wilderness areas that have been designated as Federal Class I areas represent important geographic endpoints (e.g. Class I and critical habitat areas) where O_3 damages may be important to consider. For the Great Smokey Mountain National Park case study area, there are areas within the park where the sensitive species cover is very high. This park has a large number of hiking trails with heavy public use. Of the approximately 1287 kilometers of trials in the park, including more than 114 km of the Appalachian Trail, over 1040 km or about 81% of trail kilometers are in areas where species sensitive to foliar injury occur. 50 percent of the trail kilometers are in the highest class of sensitive species cover.

There are several important factors to consider when evaluating risks to ecosystems associated with recent exposures to O_3. First, there is significant variability in the sensitivity of tree species to O_3 exposures. Some species, such as Douglas fir, show little response at lower concentrations, but can have substantial response at higher O_3 exposure levels (W126 > 50 to 60 ppm for Douglas fir). Other species, such as sugar maple, show a distinct threshold at lower concentrations of O_3, 30 to 35 ppm, but once the threshold is exceeded show rapid response over a very narrow range of O_3 concentrations. These differences in response functions have a direct impact on the change in biomass loss that is estimated to occur after simulating just meeting the current primary O_3 standard.

Second, as a result of the differences in concentration-response relationships, individual tree species show different patterns of change with respect to changes in O_3. Douglas fir has a very large proportional change when O_3 is meeting the current standard, however further reductions in O_3 will likely have very little effect on that species. Sugar maple also had a large proportional change when meting the current standard. Further reductions in O_3 will have some effect to a point beyond which we expect very little change. Other species are expected to exhibit continued gradual change in RBL relative to ambient as O_3 levels are reduced.

Third, many Class I and Critical Habitat areas occur in areas where the ambient O_3 is below the level of the current standard and these areas generally show very little change in summed relative biomass loss when exposure is simulated to just meeting the current standard compared to recent O_3 levels. In areas with higher ambient O_3 levels, the proportion of ambient summed relative biomass loss decreases by as much as 20 percent.

Fourth, the biomas loss assessments of Class I, critical habitat and national park areas are based on C-R functions for relatively few tree species. This makes it difficult to assess the absolute values of biomass loss because the response to O_3 levels of the remaining species in those areas is not quantifiable at this time, so the absolute values would not represent the biomass losses for the entire community. As a resultthe assessment necessarily focuses on proportional changes in the summed-biomass loss estimates.

This first draft REA provides preliminary estimates of exposures and risks which provide information that can be used to begin discussions in the Policy Assessment regarding the adequacy of the current standard. The second draft REA will further refine the estimates of exposure and risk by incorporating additional modeling of impacts on commercial forests and urban forests using FASOM and iTREE. In addition, U.S. Forest Service Forest Health Monitoring data on visible foliar injury will be included, allowing for additional insights into the impacts of recent ozone levels on this potential measure of recreational ecosystem services (associated with enjoyment during hiking activities). We are also evaluating the pNET model for use in estimating risks due to changes in productivity in terrestrial ecosystems, reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling. The second draft REA will also evaluate any alternative O_3 standards identified in the first draft Policy Assessment following evaluation of any advice and comments on those potential alternative standards provided during the review by the CASAC O_3 Panel. Finally, we anticipate that the second draft REA will incorporate an improved approach to adjusting O_3 concentrations based on simulations of just meeting the current and alternative O_3 standards.

8 REFERENCES

Abt Associates, Inc. (2010). Environmental Benefits and Mapping Program (Version 4.0). Bethesda, MD. Prepared for U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Research Triangle Park, NC. Available on the Internet at <http://www.epa.gov/air/benmap>.

Abt Associates, Inc. (2010). Model Attainment Test Software (Version 2). Bethesda, MD. Prepared for the U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Research Triangle Park, NC. Available on the Internet at http://www.epa.gov/scram001/modelingapps.mats.htm.

Abt Associates. (2007). Technical Report on Ozone Exposure, Risk, and Impacts Assessments for Vegetation. Prepared for the U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Research Triangle Park, NC.

Acharya, G., and L.L. Bennett. (2001). Valuing Open Space and Land-Use Patterns in Urban Watersheds. Journal of Real Estate Finance and Economics 22(2/3):221-237.

Adams, D.; Alig, R.; McCarl, B.A.; Murray, B.C. (2005). FASOMGHG Conceptual Structure, and Specification: Documentation. Available at http://agecon2.tamu.edu/people/faculty/mccarl-bruce/FASOM.html. Accessed on October 22, 2008.

Alexander, S.j.; Oswalt, S.N.; Emery, M.R. (2011). Nontimber forest products in the United States: Montreal Process indicators as measures of current conditions and sustainability. Gen. Tech. Rep. PNW-GTR-852. Portland, OR: U.S. Department of Agriculture, Forest Service, pacific Northwest Research Station. 36 p. Available at http://www.fs.fed.us/pnw/pubs/pnw_gtr851.pdf

Alexander, S.J.; Weigand, J.; Blatner, K.A. (2002). Nontimber forest product commerce in Nontimber forest products of the United States, Jones, E.T.; McLain, R.J.; Weigand, J., eds. University of Kansas Press.

Andersen, CP; Wilson, R; Plocher, M; Hogsett, WE. (1997). Carry-over effects of ozone on root growth and carbohydrate concentrations of ponderosa pine seedlings. Tree Physiol 17: 805-811.

Arbaugh, M; Bytnerowicz, A; Grulke, N; Fenn, M; Poth, M; Temple, P; Miller, P. (2003). Photochemical smog effects in mixed conifer forests along a natural gradient of ozone and nitrogen deposition in the San Bernardino Mountains. Environ Int 29: 401-406.

Arbaugh, MJ; Miller, PR; Carroll, JJ; Takemoto, BL; Proctor, T. (1998). Relationships of ozone exposure to pine injury in the Sierra Nevada and San Bernardino Mountains of California, USA. Environ Pollut 101: 291-301.

Baumflek, M.J.; Emery, M.R.; Ginger, C. (2010). Culturally and economically important nontimber forest products of northern Maine. Gen.Tech. Rep. NRS-68. Newton Square, PA: Y.s. Department of Agriculture, Forest Service, Northern Research Station. 74p. Available at http://nrs.fs.fed.us/sustaining_forests/conserve_enhance/special_products/maine_ntfp/

Benoit, LF; Skelly, JM; Moore, LD; Dochinger, LS. (1982). Radial growth reductions of Pinus strobus L correlated with foliar ozone sensitivity as an indicator of ozone-induced losses in eastern forests. Can J For Res 12: 673-678.

Black, VJ; Black, CR; Roberts, JA; Stewart, CA. (2000). Impact of ozone on the reproductive development of plants. New Phytol 147: 421-447.

Brown, R.B.; Xu, X.; Toth, J.F. Jr. (1998). Lifestyle options and economic strategies: susbsistence activities in the Mississippi Delta. Rural Sociology 63-4: p599-623.

Butler, B.J. (2008). Family forest owners of the United States. (2006). Gen. Tech. Rep. NRS-GTR-27. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 72 p.

Buyhoff, G.J.; Wellman, J.D.; Daniel, T.C. (1982). Predicting scenic quality for mountain pine beetle and western spruce budworm damaged forest vistas. Forest Science 28:827-838.

Byun, D.W. and J.K.S. Ching. (1999). Science algorithms of the EPA Models-3 Community Multiscale Air Qualty (CMAQ) Modeling System, (EPA/600/R-99/030 0). U.S. EPA.

Byun, D.W. and K.L. Schere. (2006). Review of the governing equations, computational algorithms, and other components of the Models-3 Community Multiscale Air Quality (CMAQ) modeling system. Applied Mechanics Reviews, 59. 51-77.

CAL FIRE (California Department of Forestry and Fire Protection). (1996). California Fire Plan. Available at http://cdfdata.fire.ca.gov/fire_er/fpp_planning_cafireplan.

CAL FIRE (California Department of Forestry and Fire Protection). (2008). CAL FIRE 2007 Wildland Fire Summary. Available at www.fire.ca.gov/communications/downloads/fact_sheets/2007Summary.pdf.

Chappelka, A; Skelly, J; Somers, G; Renfro, J; Hildebrand, E. (1999a). Mature black cherry used as a bioindicator of ozone injury. Water Air Soil Pollut 116: 261-266.

Chappelka, A; Somers, G; Renfro, J. (1999b). Visible ozone injury on forest trees in Great Smoky Mountains National Park, USA. Water Air Soil Pollut 116: 255-260.

Chappelka, AH. (2002). Reproductive development of blackberry (Rubus cuneifolius) as influenced by ozone. New Phytol 155: 249-255.

Coulson, R.N.; Klepzig, K.D. (2011). Southern Pine Beetle II. Gen. Tech. Rep. SRS-140. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station, 512p. Available at http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs140/gtr_srs140.pdf

Daniel, T.C.; Brown, T.C.; King, D.A.; Richards, M.T.; Stewart, W.P. (1989). Perceived scenic beauty and contingent valuation of forest campgrounds. Forest Science 35:76-90.

Defenders of Wildlife. (2010). 2010 Annual Report. (accessed 2011). Available at http://www.defenders.org/resources/publications/annual_reports/2010_annual_report.pdf

Dickson, RE; Lewin, KF; Isebrands, JG; Coleman, MD; Heilman, WE; Riemenschneider, DE; Sober, J; Host, GE; Zak, DR; Hendrey, GR; Pregitzer, KS; Karnosky, DF. (2000). Forest Atmosphere Carbon Transfer and Storage (FACTS-II) the Aspen Free-Air CO2 and O3 Enrichment (FACE) project: An overview. (General Technical Report NC-214). St. Paul, MN: U.S. Dept. of Agriculture, Forest Service.

Duff, M., Horst, R. L., Johnson, T. R. (1998). Quadratic Rollback: A Technique to Model Ambient Concentrations Due to Undefined Emission Controls. Presented at the Air and Waste Management Annual Meeting, San Diego, CA. June 14-18, 1998.

Emery, M.R.; Ginger, C.; Newman, S.; Giammusso, M.R.B. (2003). Special forest products in context: gatherers and gathering in the eastern United States., USDA Forest Service, Northeastern Research Station, Newton Square, PA. Available at http://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2003/gtrne306.pdf

Emery, M.R.; Pierce, A.R. (2005). Interrupting the telos: locating subsistence in contemporary U.S. forests. Environment and Planning, 37: p. 981-993.

Felzer, B; Kicklighter, D; Melillo, J; Wang, C; Xhuang, Q; Prinn, R. (2004). Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model. Tellus B Chem Phys Meteorol 56: 230-248. http://dx.doi.org/10.1111/j.1600-0889.2004.00097.x.

Gallai, N; Salles, JM; Settele, J.;Vaissiere, B.E. (2009). Economic Valuation of the vulnerability of world agriculture confronted with pollinator decline. Environmental Economics 68:810-821.

Geoghegan, J., L.A. Wainger, and N.E. Bockstael. (1997). “Spatial Landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS.” Ecological Economics 23:251-264.

Grantz, DA; Gunn, S; Vu, HB. (2006). O3 impacts on plant development: A meta-analysis of root/shoot allocation and growth. Plant Cell Environ 29: 1193-1209.

Gregg, JW; Jones, CG; Dawson, TE. (2003). Urbanization effects on tree growth in the vicinity of New York City [Letter]. Nature 424: 183-187.

Gregg, JW; Jones, CG; Dawson, TE. (2006). Physiological and developmental effects of O3 on cottonwood growth in urban and rural sites. Ecol Appl 16: 2368-2381.

Grulke, N. E.; Minnich, R.A.; Paine, T.D.; Seybold, S.J.; Chavez, D.J.; Fenn, M.E.; Riggan, P.J.; Dunn, A. (2009). Air pollution increases forest susceptibility to wildfires: a case study in the San Bernardino Mountains in southern California in Developments in Environmental Science, Volume 8. A. Bytnerowicz, M. Arbaugh, A. Riebau, and C. Anderson (eds.)

Gumpertz, ML; Rawlings, JO. (1992). Nonlinear regression with variance components: Modeling effects of ozone on crop yield. Crop Sci 32: 219-224.

Hanson, P. J., Samuelson, L. J., Wullschleger, S. D., Tabberer, T. A., and Edwards, G. S. (1994). Seasonal patterns of light-saturated photosynthesis and leaf conductance for mature and seedling Quercus rubra L. foliage: differential sensitivity to ozone exposure. Tree Physiology 14, 1351 – 1366

Heck, WW; Cure, WW; Rawlings, JO; Zaragoza, LJ; Heagle, AS; Heggestad, HE; Kohut, RJ; Kress, LW; Temple, PJ. (1984). Assessing impacts of ozone on agricultural crops: II. Crop yield functions and alternative exposure statistics. J Air Pollut Control Assoc 34: 810-817.

Henderson, R. (2006a) Letter from CASAC Chairman Rogene Henderson to EPA Administrator Stephen Johnson, February 16, 2006, EPA-CASAC-06-003. Available at http://yosemite.epa.gov/sab/sabproduct.nsf/69FBB1E21FB1E4428525712D004BA05D/$File/casac_con_06_003.pdf.

Henderson, R. (2006b) Letter from CASAC Chairman Rogene Henderson to EPA Administrator Stephen Johnson, June 5, 2006, EPA-CASAC-06-007. Available at http://yosemite.epa.gov/sab/sabproduct.nsf/0202D7053AC6E2AC852571870075C1D2/$File/casac-06-007.pdf

Hildebrand, E; Skelly, JM; Fredericksen, TS. (1996). Foliar response of ozone-sensitive hardwood tree species from 1991 to 1993 in the Shenandoah National Park, Virginia. Can J For Res 26: 658-669.

Hogsett, WE; Weber, JE; Tingey, D; Herstrom, A; Lee, EH; Laurence, JA. (1997). Environmental auditing: An approach for characterizing tropospheric ozone risk to forests. J Environ Manage 21: 105-120.

Hufford, M. (1995). Holding up the mountains: talk as a historical discourse. Smithsonian Folklife Center, Library of Congress, Washington D.C.

IPCC (Intergovernmental Panel on Climate Change). (2007). Summary for policymakers. In: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/spm.html.

Irwin, E.G. 2002. “The Effects of Open Space on Residential Property Values.” Land Economics 78(4):465-480.

Jaeglé, L., D.J. Jacob, W.H. Brune, and P.O. Wenberg, 2001: Chemistry of HO_x radicals in the upper troposphere. Atmos. Environ.,35, 469–489.

Johnson, T. (1997). Sensitivity of Exposure Estimates to Air Quality Adjustment Procedure. Letter to Harvey Richmond, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Johnson, T. (2002). A Guide to Selected Algorithms, Distributions, and Databases Used in Exposure Models Developed by the Office of Air Quality Planning and Standards. Prepared by TRJ Environmental, Inc. for U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Karnosky, DF; Gagnon, ZE; Dickson, RE; Coleman, MD; Lee, EH; Isebrands, JG. (1996). Changes in growth, leaf abscission, biomass associated with seasonal tropospheric ozone exposures of Populus tremuloides clones and seedlings. Can J For Res 26: 23-37.

Karnosky, DF; Pregitzer, KS; Zak, DR; Kubiske, ME; Hendrey, GR; Weinstein, D; Nosal, M; Percy, KE. (2005). Scaling ozone responses of forest trees to the ecosystem level in a changing climate. Plant Cell Environ 28: 965-981.

Kaval, P. and J. Loomis. (2003). Updated outdoor recreation use values with emphasis on National Park recreation. Final Report, Cooperative Agreement 1200-99-009, Project number IMDE-02-0070. Fort Collins, CO: Colorado State University, Department of Agricultural and Resource Economics.

King, JS; Kubiske, ME; Pregitzer, KS; Hendrey, GR; McDonald, EP; Giardina, CP; Quinn, VS; Karnosky, DF. (2005). Tropospheric O3 compromises net primary production in young stands of trembling aspen, paper birch and sugar maple in response to elevated atmospheric CO2. New Phytol 168: 623-635.

Kohut, R. (2007). Assessing the risk of foliar injury from ozone on vegetation in parks in the US National Park Service's Vital Signs Network. Environ Pollut 149: 348-357.

Krupa, S.; Muntifering, R.B.; Chappelka, A.H. (2004). Effects of ozone on plant nutritive quality characteristics for ruminant animals. Botanica 54, 129-140.

Lee, EH; Hogsett, WE. (1999). Role of concentrations and time of day in developing ozone exposure indices for a secondary standard. J Air Waste Manag Assoc 49: 669-681.

Lee, EH; Hogsett, WE; Tingey, DT. (1994). Attainment and effects issues regarding alternative secondary ozone air quality standards. J Environ Qual 23: 1129-1140.

Lee, EH; Tingey, DT; Hogsett, WE. (1987). Selection of the best exposure-response model using various 7-hour ozone exposure statistics. Research Triangle Park, NC: U.S. Environmental Protection Agency.

Lee, EH; Tingey, DT; Hogsett, WE. (1988a). Evaluation of ozone-exposure indices for relating exposure to plant production and for estimating agricultural losses. (EPA/600/3-88/039). Washington, DC: U.S. Environmental Protection Agency.

Lee, EH; Tingey, DT; Hogsett, WE. (1988b). Evaluation of ozone exposure indices in exposure-response modeling. Environ Pollut 53: 43-62.

Lee, EH; Tingey, DT; Hogsett, WE. (1989). Interrelation of experimental exposure and ambient air quality data for comparison of ozone exposure indices and estimating agricultural losses. (EPA/600/3-89/047). Corvallis, OR: U.S. Environmental Protection Agency.

Lesser, VM; Rawlings, JO; Spruill, SE; Somerville, MC. (1990). Ozone effects on agricultural crops: Statistical methodologies and estimated dose-response relationships. Crop Sci 30: 148-155.

Little, E.L., Jr. (1971). Atlas of United States trees, volume 1, conifers and important hardwoods: Misc. Pub. 1146. Washington, D.C.: U.S. Department of Agriculture. 9 p., 200 maps.

Madden, M., R. Welch, T. Jordan, P. Jackson, R. Seavey, and J. Seavey. (2004). Digital Vegetation Maps for the Great Smoky Mountains National Park. Prepared for the United States Geological Survey and National Park Service Inventory and Monitoring – Vegetation Mapping Program.

Mansfield, C.A., S.K. Pattanayak, W. McDow, R. MacDonald, and P. Halpin. 2005. Shades of Green: Measuring the Value of Urban Forests in the Housing Market. Journal of Forest Economics 11(3):177-199.

MEA (Millennium Ecosystem Assessment Board). (2005). Ecosystems and Human Well-being: Current State and Trends, Volume 1. Edited by R. Hassan, R. Scholes, and N. Ash. Washington: Island Press. Available at http://www.millenniumassessment.org/8 documents/document.766.aspx.pdf.

Morgan, PB; Bernacchi, CJ; Ort, DR; Long, SP. (2004). An in vivo analysis of the effect of season-long open-air elevation of ozone to anticipated 2050 levels on photosynthesis in soybean. J Plant Physiol 135: 2348-2357.

Morgan, PB; Mies, TA; Bollero, GA; Nelson, RL; Long, SP. (2006). Season-long elevation of ozone concentration to projected 2050 levels under fully open-air conditions substantially decreases the growth and production of soybean. New Phytol 170: 333-343.

Mueller, J., J. Loomis, and A. González-Cabán. (2007). Do Repeated Wildfires Change Homebuyers’ Demand for Homes in High-Risk Areas? A Hedonic Analysis of the Short and Long-Term Effects of Repeated Wildfires on House Prices in Southern California. Journal of Real Estate Finance and Economics, 1-18.

National Association of State Foresters (NASF). (2009). Quadrennial Fire Review 2009. Washington, DC: NASF. Quadrennial Fire and Fuel Review Final Report 2009.National Wildfire Coordinating Group Executive Board January 2009.

National Climatic Data Center (NCDC). (2012a).U.S. Climatological Divisions. National Oceanic and Atmospheric Administration. Available at http://www.ncdc.noaa.gov/temp-and-precip/us-climate-divisions.php

National Climatic Data Center (NCDC). (2012b). Historical Palmer Drought Indices. National Oceanic and Atmospheric Administration. Available at http://www1.ncdc.noaa.gov/pub/data/cirs/

National Interagency Fire Center (NIFC). (2012). Statistics. Available at http://www.nifc.gov/fireInfo/fireInfo_statistics.html

National Park Service (NPS). (2003). Ozone Sensitive Plant Species on National Park Service and U.S. Shish and Wildlife Service Lands: Results of a June 24-25, 2003 Workshop. Baltimore, MD.

National Park Service (NPS). (2004). Assessing the Risk of Foliar Injury from Ozone on Vegetation in Parks in the Appalachian Highlands Network. October. Available on the Internet at http://www2.nature.nps.gov/air/Pubs/pdf/03Risk/aphnO3RiskOct04.pdf

National Park Service (NPS). (2006b). Ozone Sensitive Plant Species, by Park, November 2006. Available on the Internet at http://www.nature.nps.gov/air/Permits/ARIS/docs/Ozone_Sensitive_ByPark_3600.pdf

National Park Service (NPS). (2011). Economic benefits to Local Communities from National Park Visitation and Payroll, 2010. Natural Resources Report NPS/NRSS/EGD/NRR-2011/481. Available at http://www.nature.nps.gov/socialscience/docs/NPSSystemEstimates2009.pdf

National Park Service (NPS). (2006a). Ozone bioindicators. Washington, DC. http://www.nature.nps.gov/air/Pubs/bioindicators/index.cfm.

National Wildlife Federation. (2011). National Wildlife Federation Annual Report and Financial Statements. (accessed 2011). Available at http://www.nwf.org/About/Annual-Report/Annual-Report-Archive.aspx

Odum, H.T. (1996). Ecological Accounting. New York: Wiley and Sons. Outdoor Industry Foundation. (2006). The Economic Contribution of Active Outdoor Recreation – Technical Report on Methods and Findings. Available at http://www.outdoorfoundation.org/pdf/ResearchRecreationEconomyTechnicalReport.pdf

Palmer, W.C. (1965). Meteorological drought. *Research Paper No. 45*. U.S. Weather Bureau. NOAA Library and Information Services Division. Washington, D.C. Available at http://ncdc.noaa.gov/temp-and-precip/drought/docs/palmer.pdf.

Pan, YD; Birdsey, R; Hom, J; McCullough, K. (2009). Separating effects of changes in atmospheric composition, climate and land-use on carbon sequestration of US Mid-Atlantic temperate forests. For Ecol Manage 259: 151-164. http://dx.doi.org/10.1016/j.foreco.2009.09.049.

Pena, D.G. (1999). Cultural landscapes and biodiversity: the ethnoecology of an Upper Rio Grandewatershed commons in Ethnoecology: Situated Knowledge/Located Lives Ed. V.D. Nazarea, University of Arizona Press, Tucson, AZ, pp 107-132.

Peterson, DL; Arbaugh, MJ; Wakefield, VA; Miller, PR. (1987). Evidence of growth reduction in ozone-injured Jeffrey pine (Pinus jeffreyi Grev and Balf) in Sequoia and Kings Canyon National Parks. J Air Waste Manag Assoc 37: 906-912.

Prasad, A. M. and L. R. Iverson. (2003). Little's range and FIA importance value database for 135 eastern US tree species. http://www.fs.fed.us/ne/delaware/4153/global/littlefia/index.html, Northeastern Research Station, USDA Forest Service, Delaware, Ohio.

Pregitzer, KS; Burton, AJ; King, JS; Zak, DR. (2008). Soil respiration, root biomass, and root turnover following long-term exposure of northern forests to elevated atmospheric Co-2 and tropospheric O-3. New Phytol 180: 153-161.

Rawlings, JO; Cure, WW. (1985). The Weibull function as a dose-response model to describe ozone effects on crop yields. Crop Sci 25: 807-814.

Rea et al, (2012). Using Ecosystem Services To Inform Decisions on U.S. Air Quality Standards. Environ. Sci. Technol.46 (12), 6481–6488.

Ribe, R. G. (1989). The Aesthetics of Forestry: What has empirical preference research taught us? Environmental Management 13: 55-74.

Ribe, R.G. (1994). Scenic Beauty along the ROS. Journal of Environmental Research 42:199-221.

Richardson, L.; Loomis, J. (2009). The total economic value of threatened, endangered and rare specis: and updated meta-analysis. Ecological Economics, 68:1535-1548.

Rizzo, M. (2005). A Comparison of Different Rollback Methodologies Applied to Ozone Concentrations. November 7, 2005. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_td.html

Rizzo, M. (2006). A Distributional Comparison between Different Rollback Methodologies Applied to Ambient Ozone Concentrations. May 31, 2006. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_td.html

SAB CVPESS (Science Advisory Board Committee on Valuing the Protection of Ecological Systems and Services). (2009). Valuing the Protection of Ecological Systems and Services. EPA-SAB-09-012. May. Available at http://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/SAB-09-012/$File/SAB%20Advisory%20Report%20full%20web.pdf.

Samet. JM. (2009). Consultation on Ambient Air Monitoring Issues Related to the Ozone NAAQS. EPA-CASAC-09-005. March. Available at yosemite.epa.gov/sab/sabproduct.nsf/64B88B99C37A68CF852575710072D8C0/$File/EPA-CASAC-09-005-unsigned.pdf.

Samet. JM. (2011). Consultation on EPA's *Ozone National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment* (April 2011) and *Ozone National Ambient Air Quality Standards: Scope and Methods Plan for Welfare Risk and Exposure Assessment* (April 2011). EPA-CASAC-11-008. June. Available at yosemite.epa.gov/sab/sabproduct.nsf/0594FCC1374FCC5D852578B60069CDB2/$File/EPA-CASAC-11-008-unsigned.pdf

Sanz, J.; Muntifering, R.B.; Bermejo, V.; Gimeno, B.S.; Elvira, S. (2005). Ozone and increased nitrogen supply effects on the yield and nutritive quality of *Trifolium subterraneum*. Atmospheric Environment 39: 5899-5907.

Schaub, M; Skelly, JM; Zhang, JW; Ferdinand, JA; Savage, JE; Stevenson, RE; Davis, DD; Steiner, KC. (2005). Physiological and foliar symptom response in the crowns of Prunus serotina, Fraxinus americana and Acer rubrum canopy trees to ambient ozone under forest conditions. Environ Pollut 133: 553-567.

Sierra Club Foundation (2011). Annual Reports. (accessed 2011). Available at http://www.sierraclub.org/foundation/downloads/2010-annual-report.pdf

Sitch, S; Cox, PM; Collins, WJ; Huntingford, C. (2007). Indirect radiative forcing of climate change through ozone effects on the land-carbon sink. Nature 448: 791-794. http://dx.doi.org/10.1038/nature06059.

Smith, V.K., C. Poulos, and H. Kim. (2002). Treating Open Space as an Urban Amenity. Resource and Energy Economics 24:107-129.

Somers, GL; Chappelka, AH; Rosseau, P; Renfro, JR. (1998). Empirical evidence of growth decline related to visible ozone injury. For Ecol Manage 104: 129-137.

Southwick Associates. (2006). The Economic Contribution of Active Outdoor Recreation – Technical Report For: Outdoor Industry Foundation. Available at http://www.outdoorfoundation.org/pdf/ResearchRecreationEconomyTechnicalReport.pdf

Timin B, Wesson K, Thurman J. Application of Model and Ambient Data Fusion Techniques to Predict Current and Future Year $PM_{2.5}$ Concentrations in Unmonitored Areas. (2010). Pp. 175-179 in Steyn DG, Rao St (eds). Air Pollution Modeling and Its Application XX. Netherlands: Springer.

Tyrvainen, L., and A. Miettinen. (2000). "Property Prices and Urban Forest Amenities." Journal of Economics and Environmental Management 39:205-223.

U.S. Department of Agriculture. (2004). National Report on Sustainable Forests-2003 Documentation for the 2003 National Report: Indicators 35, 36, 37, 42, & 43 Available at http://warnell.forestry.uga.edu/nrrt/NSRE/MontrealIndDoc.PDF

U.S. Department of Agriculture. (2011). National Report on Sustainable Forests-2010 Available at http://www.fs.fed.us/research/sustain/

U.S. Department of Agriculture. (2002). National Survey on Recreation and the Environment (NSRE): 2000-2002. The Interagency National Survey Consortium, Coordinated by the USDA Forest Service, Recreation, Wilderness, and Demographics Trends Research Group, Athens, GA and the Human Dimensions Research Laboratory, University of Tennessee, Knoxville, TN.

U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, U.S. Census Bureau. (2006). 2006 National Survey of Fishing, Hunting, and Wildlife-Associated recreation. Available at http://www.census.gov/prod/www/abs/fishing.html

U.S. EPA (U.S. Environmental Protection Agency). (1978). Air quality criteria for ozone and other photochemical oxidants (pp. 373). (EPA/600/8-78/004). Washington, DC.

U.S. EPA (U.S. Environmental Protection Agency). (1984). Air quality criteria for ozone and other photochemical oxidants, Vol. 3 (pp. 405). (EPA/600/8-84/020A). Research Triangle Park, NC.

U.S. EPA (U.S. Environmental Protection Agency). (1996). Review of national ambient air quality standards for ozone: Assessment of scientific and technical information: OAQPS staff paper. (EPA/452/R-96/007). Research Triangle Park, NC.

U.S. EPA (U.S. Environmental Protection Agency). (2006). Air quality criteria for ozone and related photochemical oxidants (pp. 2118). (EPA/600/R-05/004AF). Research Triangle Park, NC.

U.S. EPA (U.S. Environmental Protection Agency). (2007). Review of the national ambient air quality standards for ozone: Policy assessment of scientific and technical information: OAQPS staff paper. (EPA/452/R-07/007). July. Research Triangle Park, NC.

U.S. EPA (U.S. Environmental Protection Agency). (2009). The Risk and Exposure Assessment for Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur. (EPA-452/R-09-008a).. September. Available at http://www.epa.gov/ttn/naaqs/standards/no2so2sec/data/NOxSOxREASep2009MainContent.pdf.

U.S. EPA (U.S. Environmental Protection Agency). (2011a). Integrated Review Plan for the Ozone National Ambient Air Quality Standards - Final. (EPA 452/R-11-006). April. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/2011_04_OzoneIRP.pdf.

U.S. EPA (U.S. Environmental Protection Agency). (2011b). Ozone National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure. (EPA-452/P-11-001). Research Triangle Park, NC. April. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/2011_04_HealthREA.pdf.

U.S. EPA (U.S. Environmental Protection Agency). (2011c). Ozone National Ambient Air Quality Standards: Scope and Methods Plan for Welfare Risk and Exposure. (EPA 452/P-11-002). April. Research Triangle Park, NC. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/2011_04_WelfareREA.pdf.

U.S. EPA (U.S. Environmental Protection Agency). (2011d). Integrated Science Assessment of Ozone and Related Photochemical Oxidants (Second External Review Draft). (EPA/600/R-10/076B). September. Research Triangle Park, NC. Available at http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=226363.

U.S. EPA (U.S. Environmental Protection Agency). (2012). Integrated Science Assessment for Ozone and Related Photochemical Oxidants (Third External Review Draft). (EPA/600/R-10/076C). July. Research Triangle Park, NC. Available at http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=242490.

U.S. Geological Survey (USGS). (2003). FEDLANP020 - Federal Lands and Indian Reservations of the United States. Reston, VA. Available at http://coastalmap.marine.usgs.gov/GISdata/basemaps/boundaries/fedlands/fedlanp020.zip.

Vollenweider, P; Woodcock, H; Kelty, MJ; Hofer, R, -M. (2003). Reduction of stem growth and site dependency of leaf injury in Massachusetts black cherries exhibiting ozone symptoms. Environ Pollut 125: 467-480.

Wegman, L. 2012. Updates to information presented in the Scope and Methods Plans for the O3 NAAQS Health and Welfare Risk and Exposure Assessments. Memorandum from Lydia Wegman, Division Director, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, Office of Air and Radiation, US EPA to Holly Stallworth, Designated Federal Officer, Clean Air Scientific Advisory Committee, US EPA Science Advisory Board Staff Office. May 2, 2012.Wells, B., Wesson, K., Jenkins, S. (2012). Analysis of Recent U.S. Ozone Air Quality Data to Support the O3 NAAQS Review and Quadratic Rollback Simulations to Support the First Draft of the Risk and Exposure Assessment. Available on the Internet at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_2008_rea.html

Wells, B., Wesson, K., Jenkins, S. (2012). Analysis of Recent U.S. Ozone Air Quality Data to Support the O3 NAAQS Review and Quadratic Rollback Simulations to Support the First Draft of the Risk and Exposure Assessment. Available on the Internet at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_2008_rea.html

West, J. J., A. M. Fiore, V. Naik, L. W. Horowitz, M. D. Schwarzkopf, D. L. Mauzerall (2007). Ozone air quality and radiative forcing consequences of changes in ozone precursor emissions. Geophys Res Lett, 34, L06806, doi:10.1029/2006GL029173.

Western Forestry Leadership Coalition. (2009). Western bark beetle assessment: A framework for Cooperative Forest Stewardship. 2009 Update. Available at http://www.wflccenter.org/news_pdf/325_pdf.

Wildlife Conservation Society. (2011). Financial Documents. (accessed 2011). Available at http://www.wcs.org/about-us/financial-documents.aspx

Wittig, VE; Ainsworth, EA; Long, SP. (2007). To what extent do current and projected increases in surface ozone affect photosynthesis and stomatal conductance of trees? A meta-analytic review of the last 3 decades of experiments [Review]. Plant Cell Environ 30: 1150-1162.

Wittig, VE; Ainsworth, EA; Naidu, SL; Karnosky, DF; Long, SP. (2009). Quantifying the impact of current and future tropospheric ozone on tree biomass, growth, physiology and biochemistry: A quantitative meta-analysis. Global Change Biol 15: 396-424.

World Wildlife Fund (2011). 2010 Annual Report. (accessed 2011). Available at http://www.worldwildlife.org/who/financialinfo/2010fundingandfinancialoverview.html

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