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 Risk and Benefits 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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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

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).

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[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.

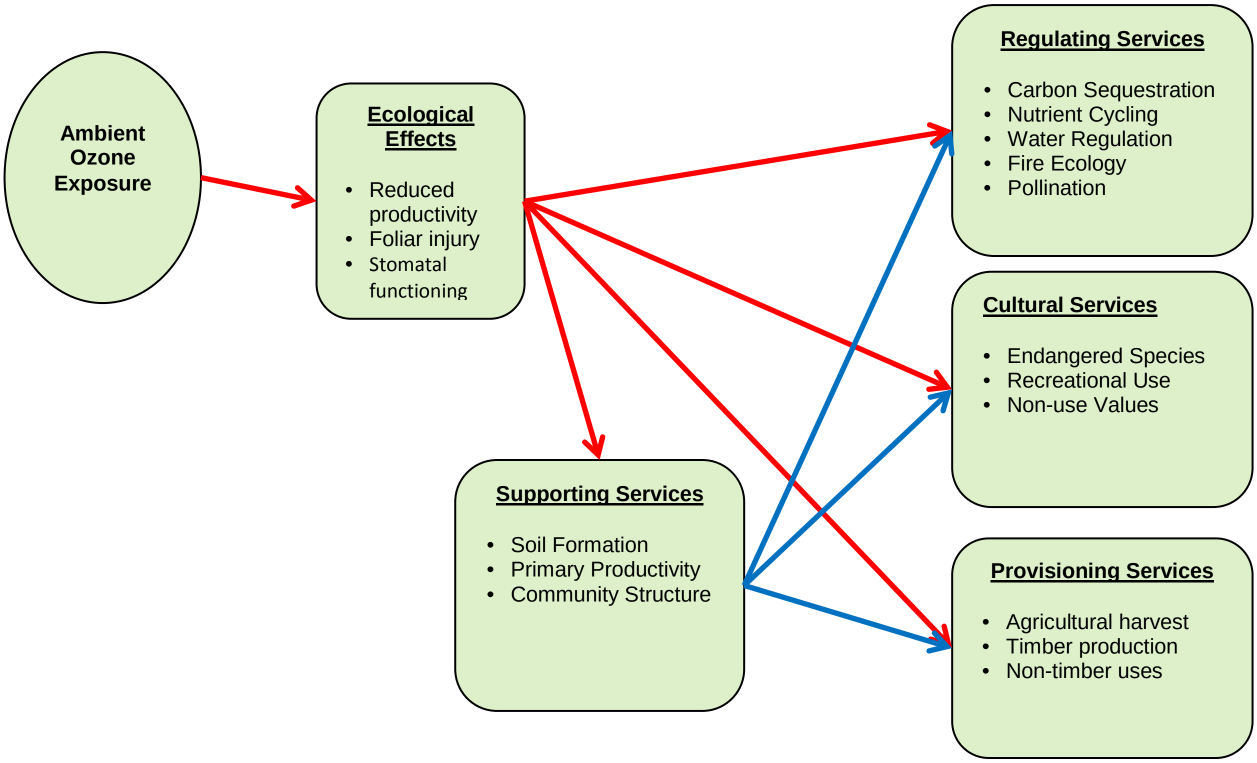

Figure 2- 1 Relationship Between Ecological Effects of Ozone Exposure and Ecosystem Services

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.

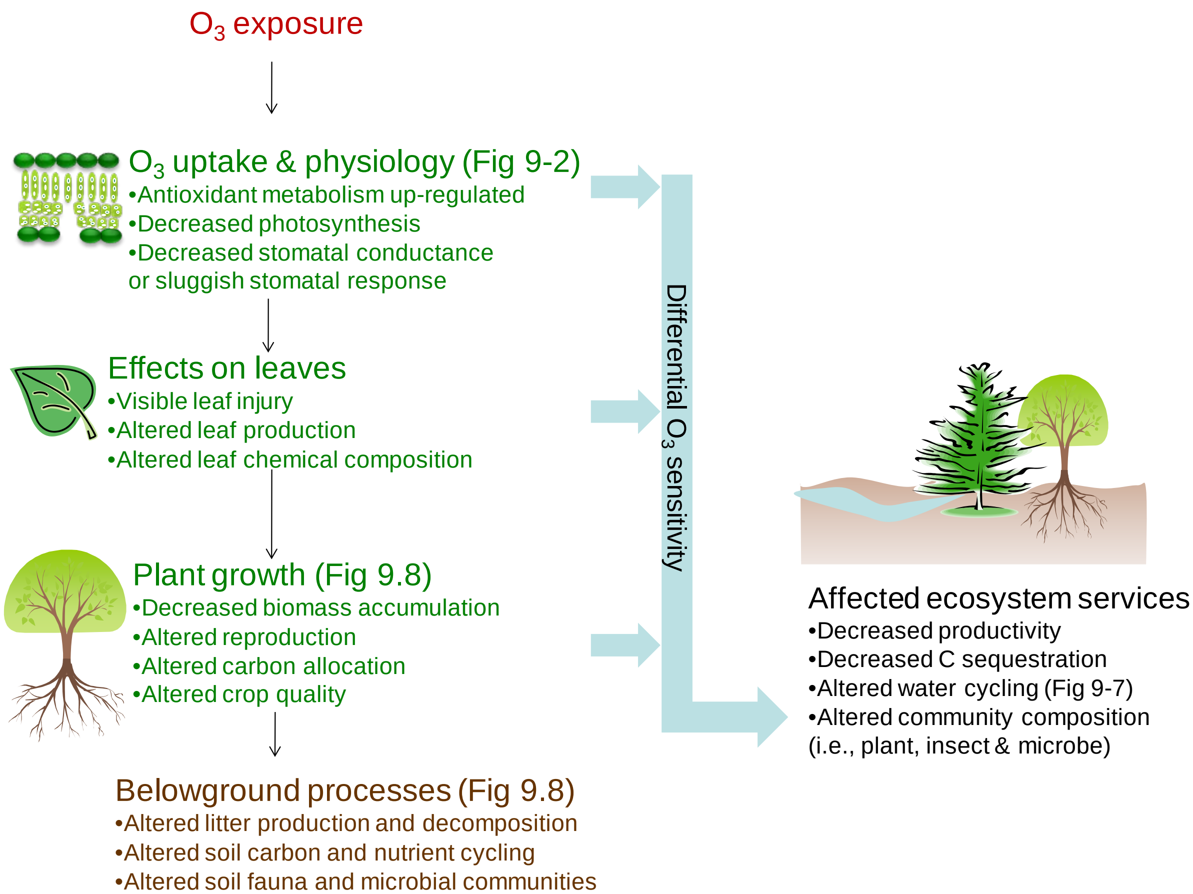

Figure 2- 2 Conceptual diagram of the major pathway through which O_3 enters plants and the major endpoints that O_3 may affect in plants and ecosystems. Figure numbers in this figure refer to Chapter 9 of the ISA.

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.

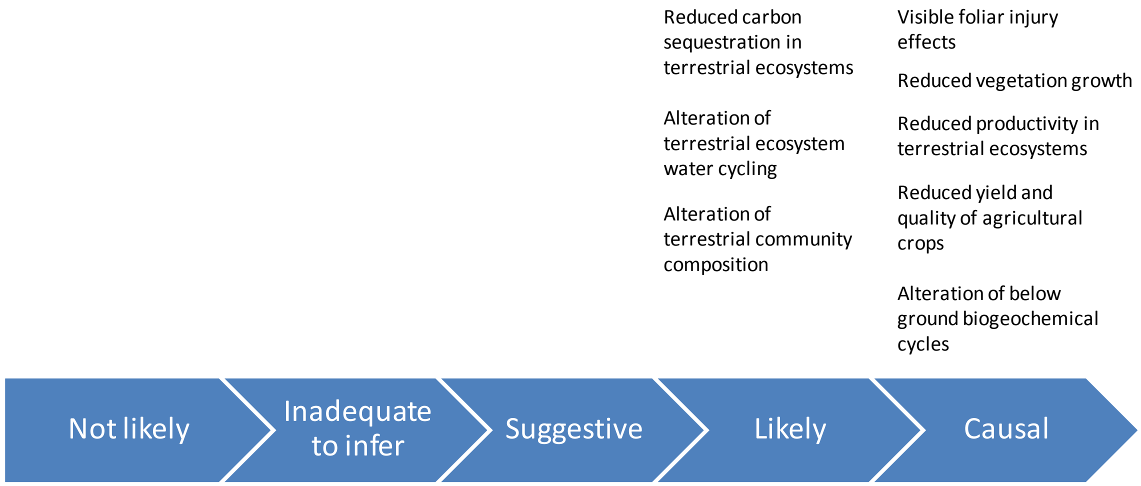

Figure 2- 3 Causal Determinations for O_3 Welfare Effects

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).

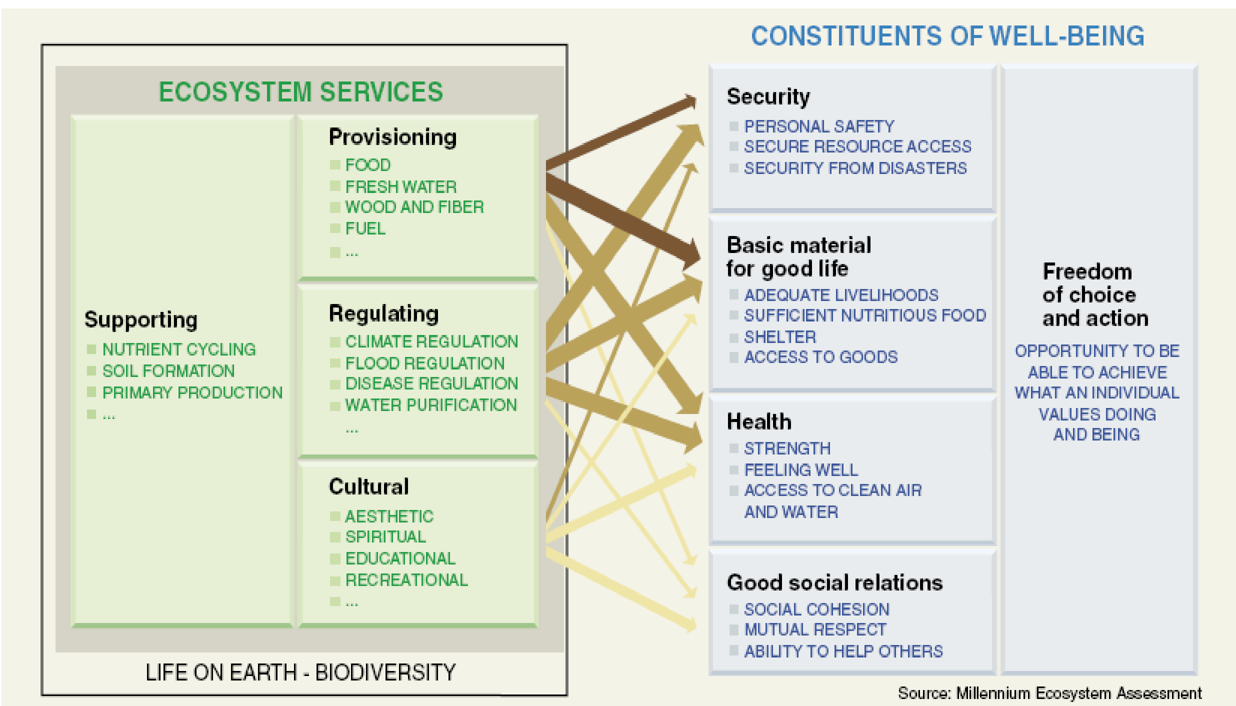

Figure 2- 4 Linkages between categories of ecosystem services and components of human well-being that are commonly indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. The strength of the linkages, as indicated by arrow width, and the

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.

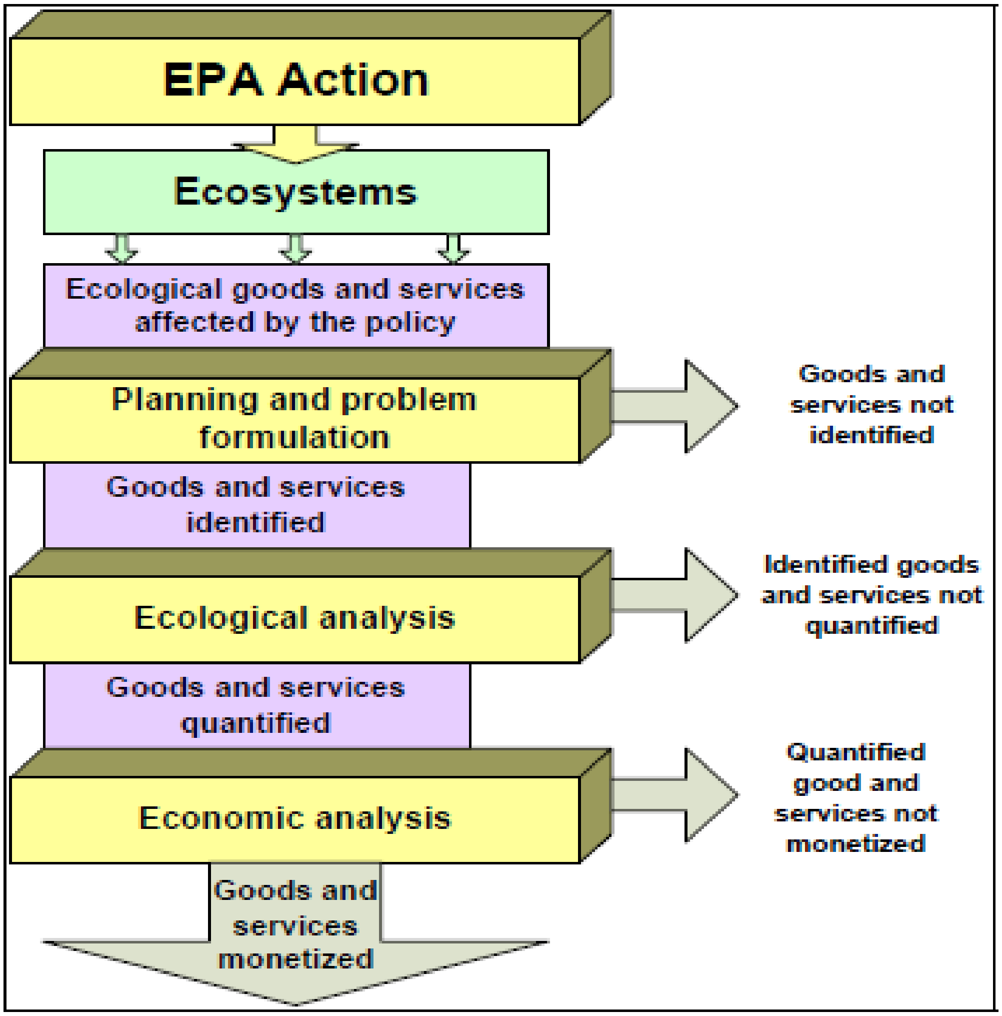

Figure 2- 5 Representation of the benefits assessment process indicating where some ecological benefits may remain unrecognized, unquantified, or unmonetized. (Modified based on the Ecological Benefits Assessment Strategic Plan report [U.S. EPA, 2006]).

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 (4th 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.

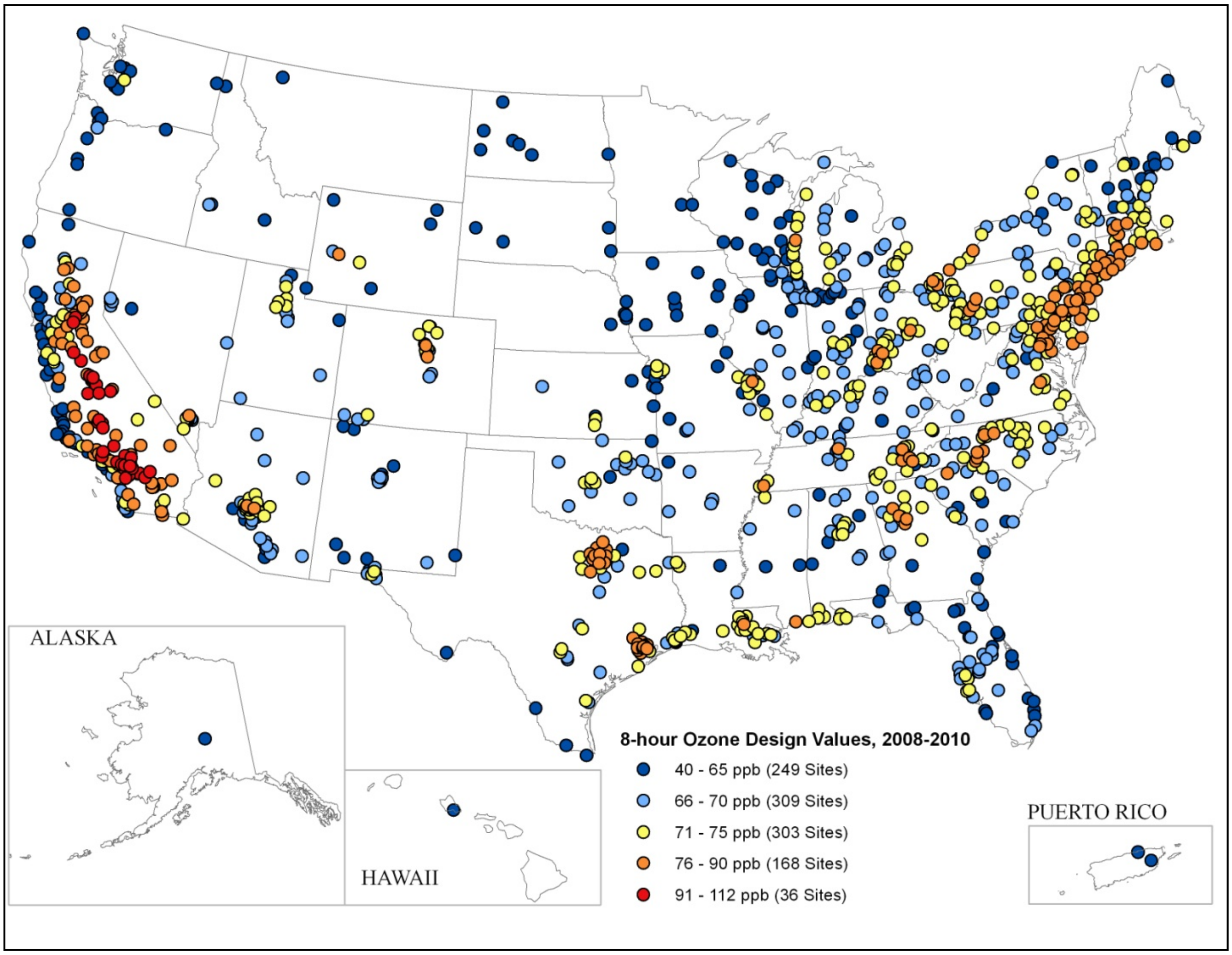


Figure 4-1 Individual monitor 8-h daily max O_3 design values displayed for the 2008-2010 period (U.S. EPA, 2012, Figure 3-52A)

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.

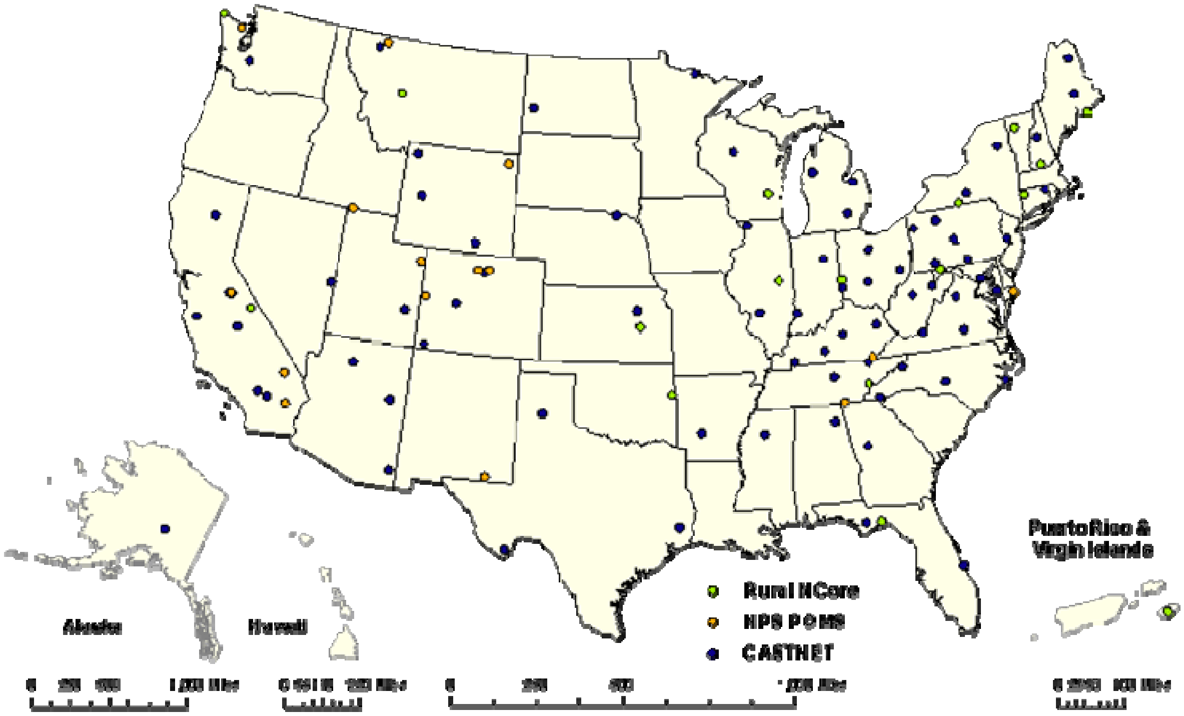


Figure 4-2 U.S. Rural NCore, CASTNET and NPS POMS O_3 sites in 2010 (U.S. EPA, 2012, Figure 3-22)

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.

[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

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% ($V_m < 0.75$).

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

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.

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:

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

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

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).

4.3.2.1 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).

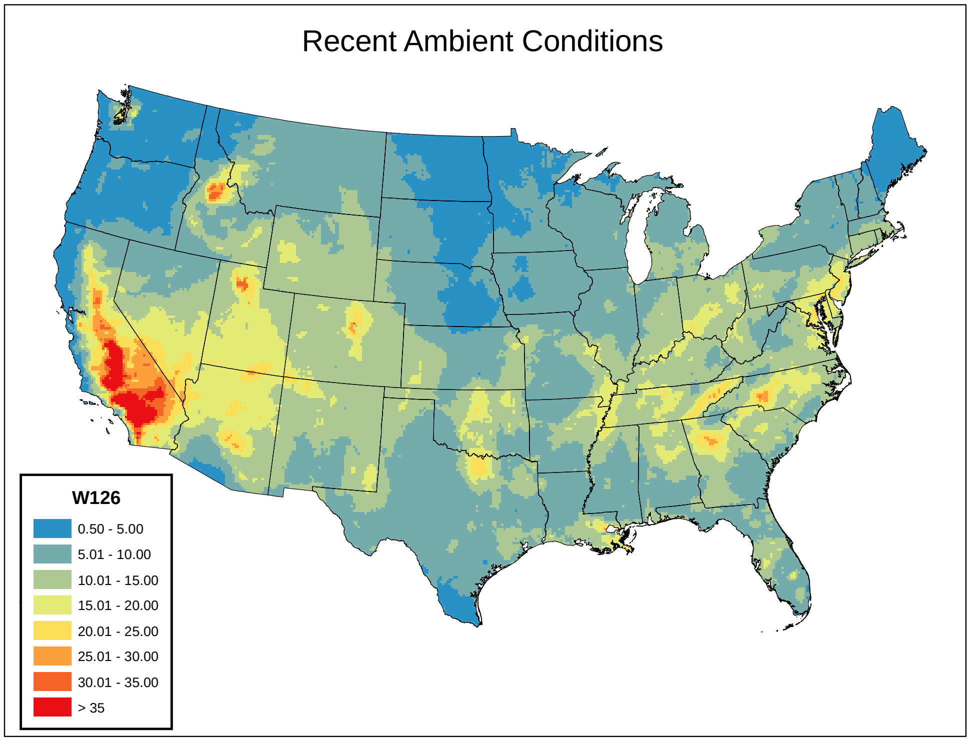


Figure 4-3 **"Fused" national-scale surface of W126 metric, 2006-2008**

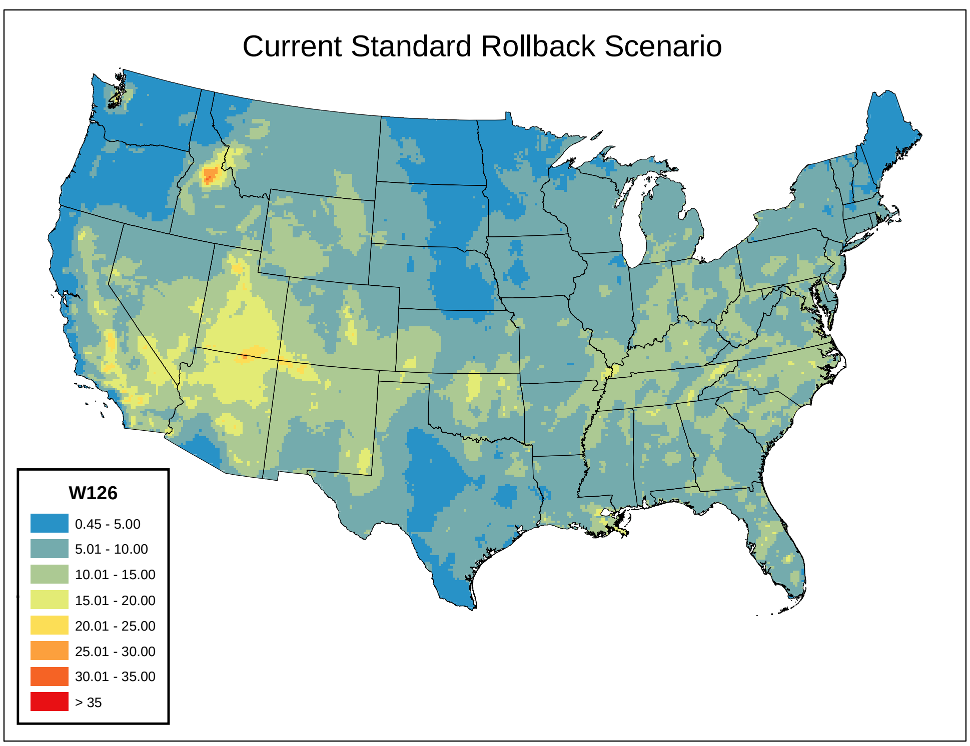


Figure 4-4 **"Fused" national-scale surface of W126 metric for 2006-2008, adjusted for simulating just meeting the current standard of 0.075 ppm.**

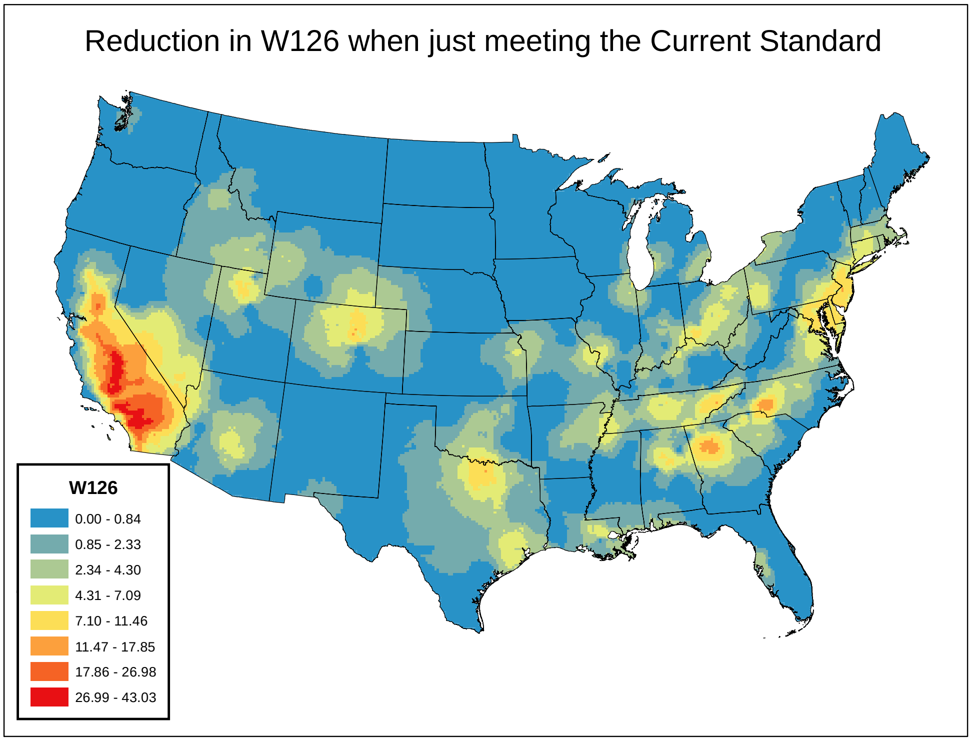


Figure 4-5 Difference between the "fused" national-scale surfaces of W126 for 2006-2008 and for 2006-2008 adjusted for simulating just meeting the current standard of 0.075 ppm.

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 -

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

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.

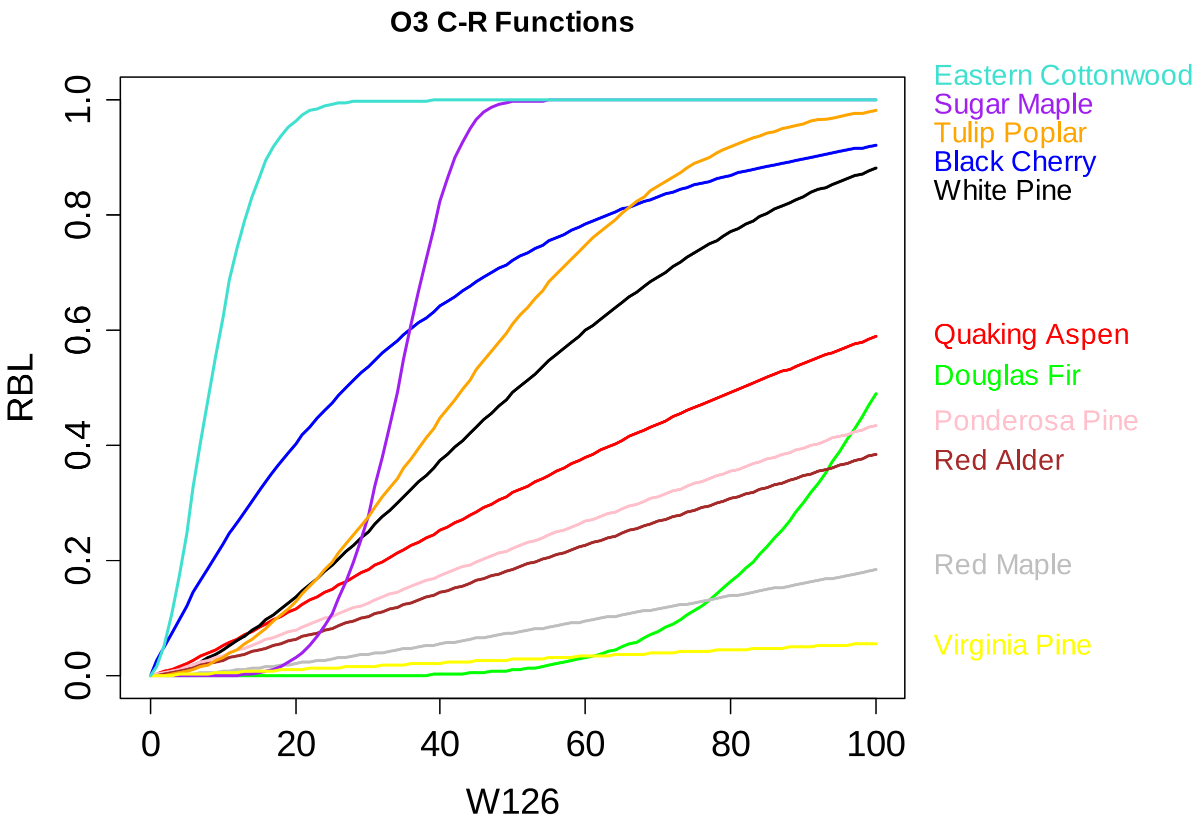


Figure 5- 1 Relative Biomass Loss Functions for 11 Tree Species

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.

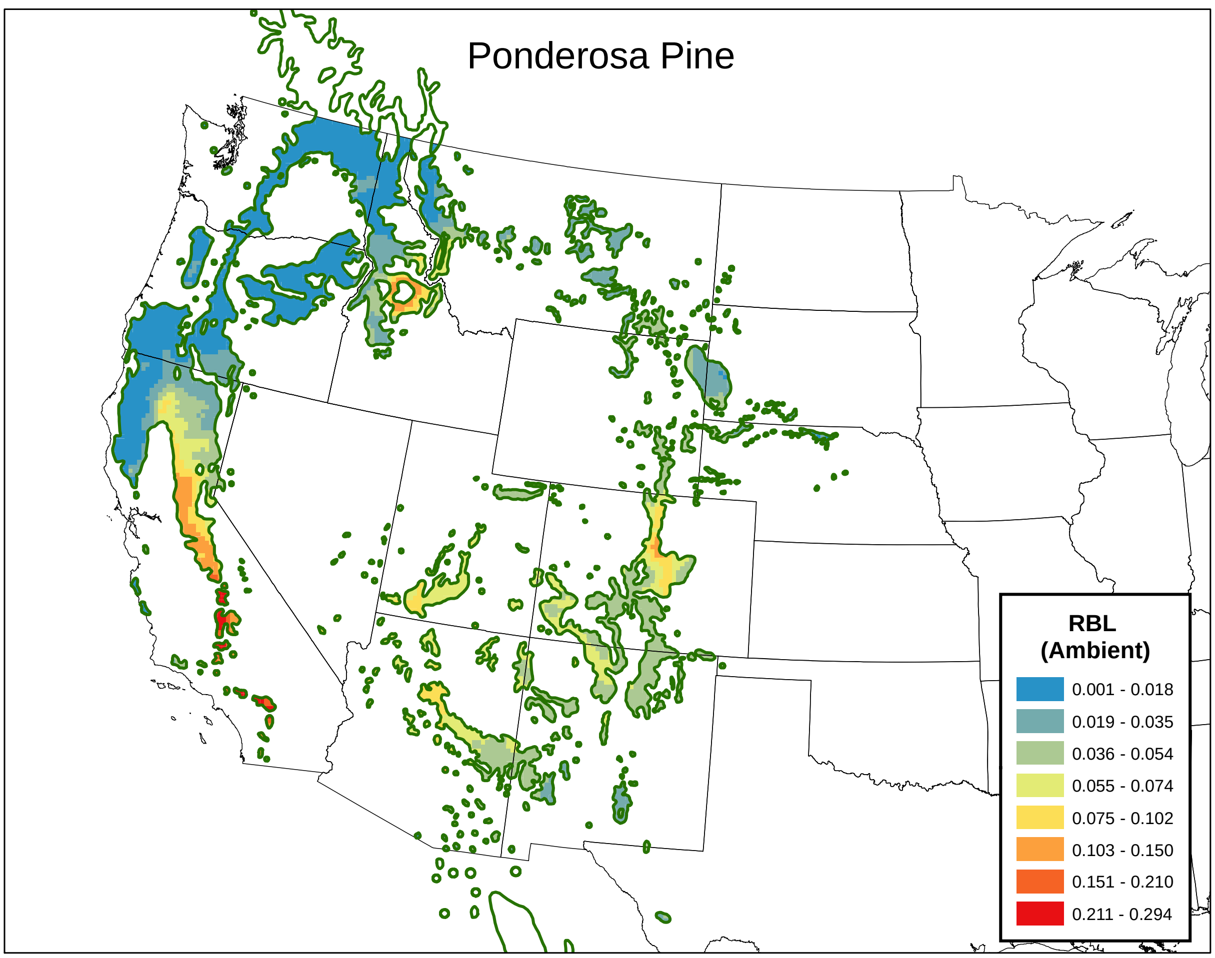


Figure 5- 2 Relative Biomass Loss of Ponderosa Pine (*Pinus ponderosa*) seedlings under recent ambient O_3 exposure levels (2006 – 2008)

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.

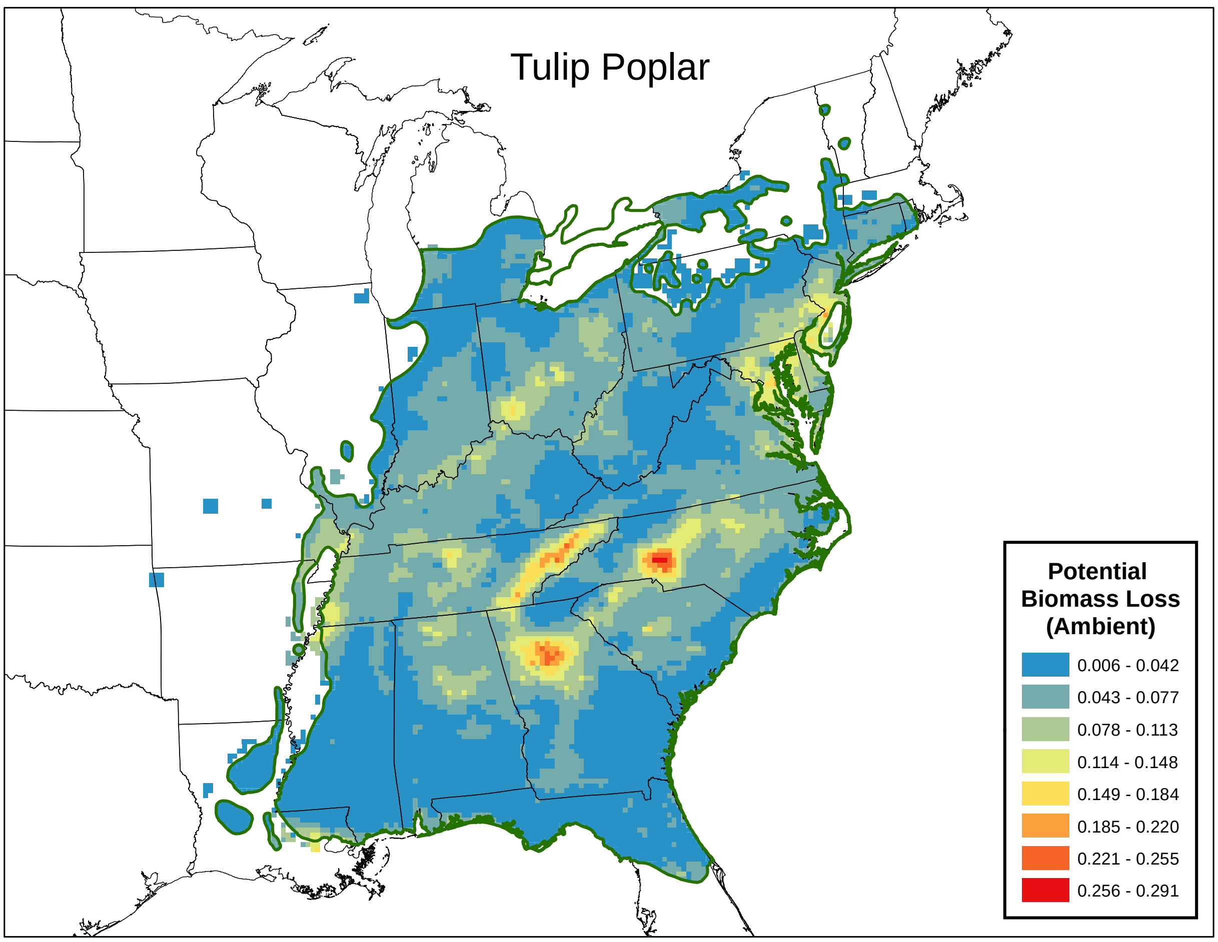


Figure 5- 3 Relative Biomass Loss of tulip poplar (*Liriodendron tulipifera*) seedlings under recent ambient O_3 exposure levels (2006 – 2008)

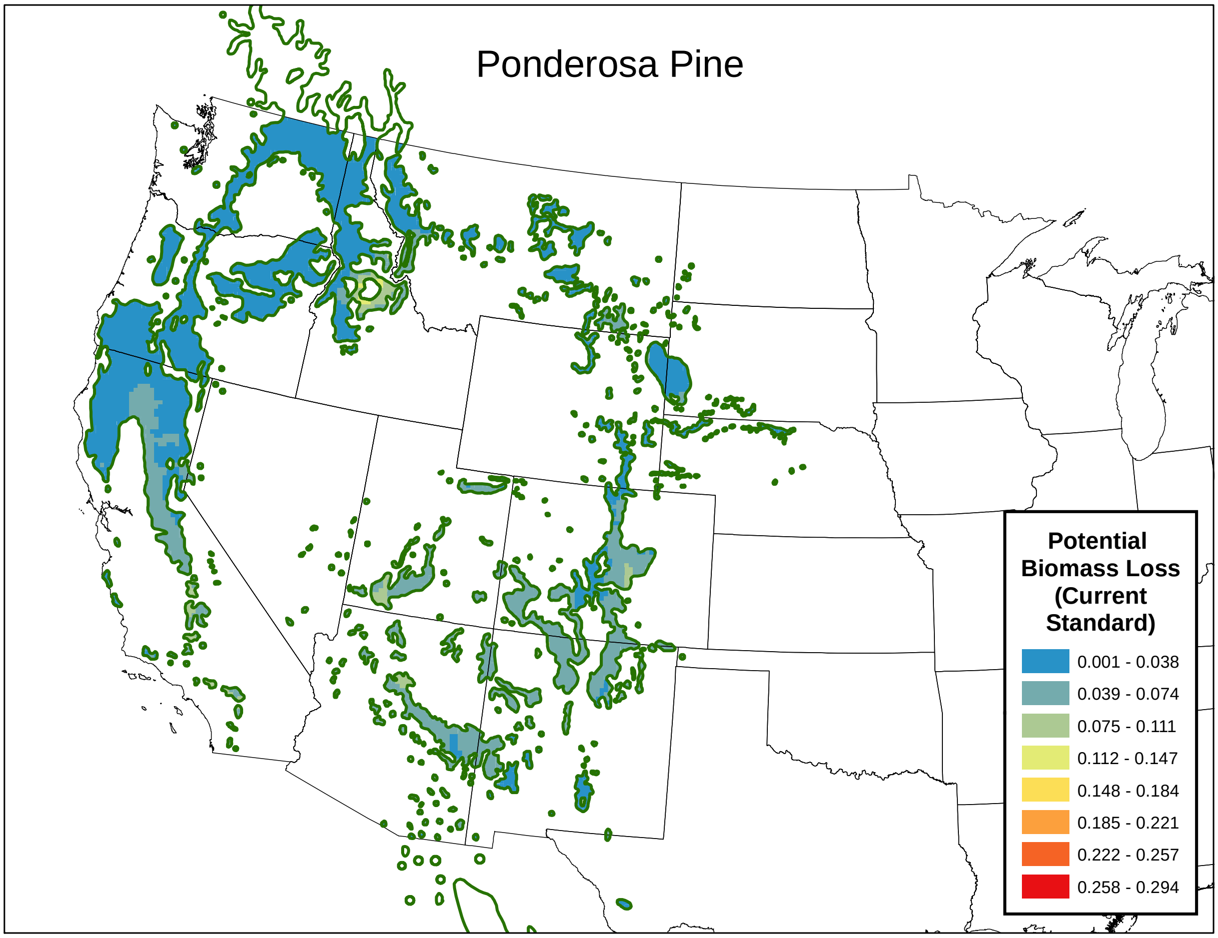


Figure 5- 4 Relative Biomass Loss of Ponderosa Pine with O_3 exposure rolled back to meet the current (8-hr) secondary standard.

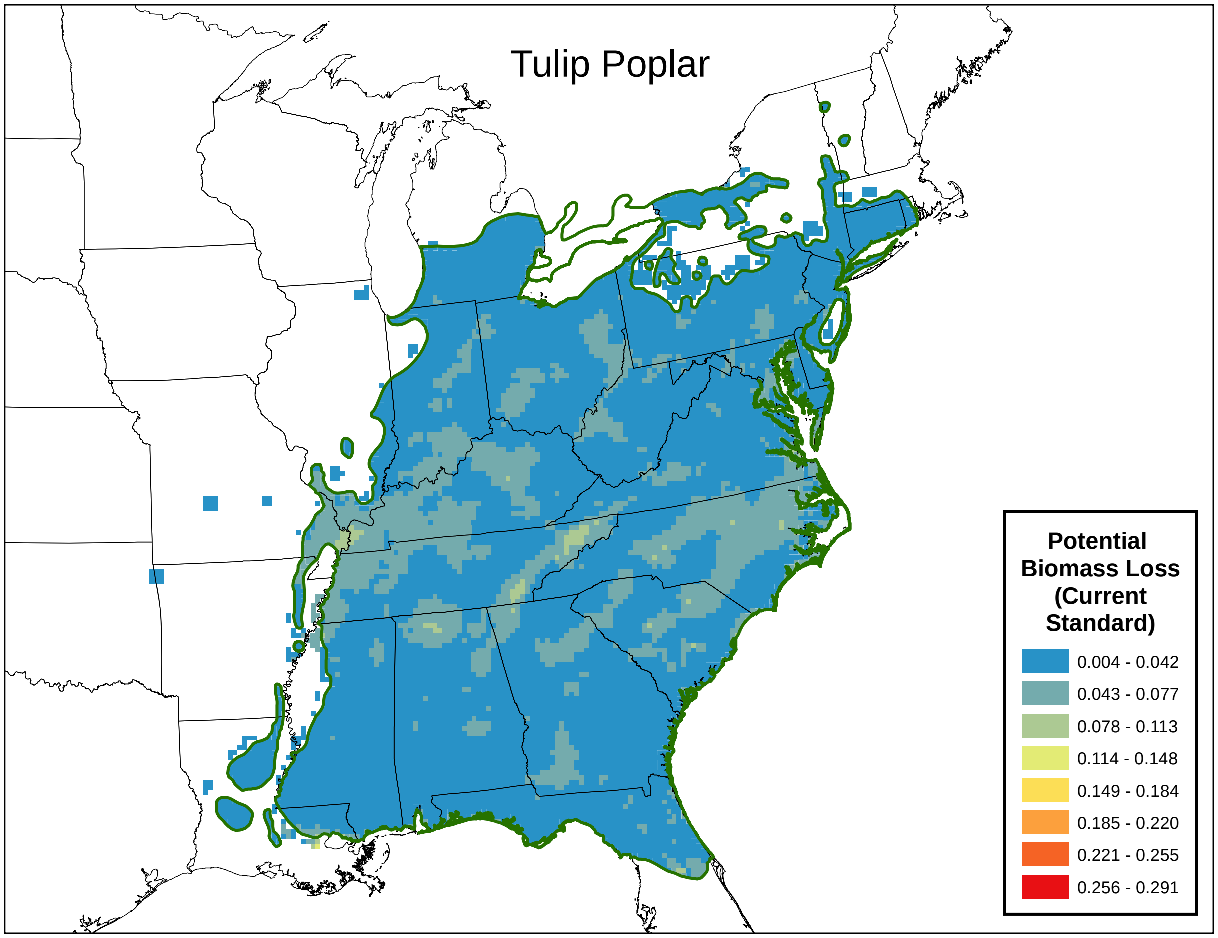


Figure 5- 5 Relative Biomass Loss of Tulip Poplar with O_3 exposure rolled back to meet the current (8-hr) secondary standard.

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.

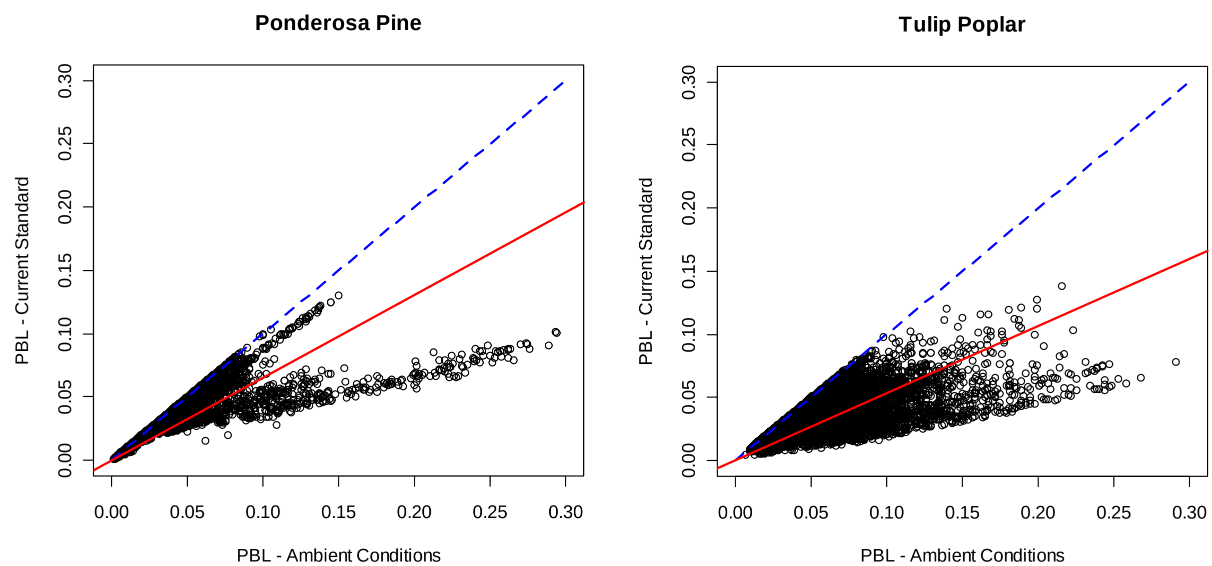


Figure 5- 6 Linear fit model of RBL under recent ambient O_3 exposure levels (2006 – 2008) conditions compared to estimated values for meeting the current (8-hr) standard for ponderosa pine and tulip poplar. The dashed blue line represents the one-to-one line. The red line is the fitted line.

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.

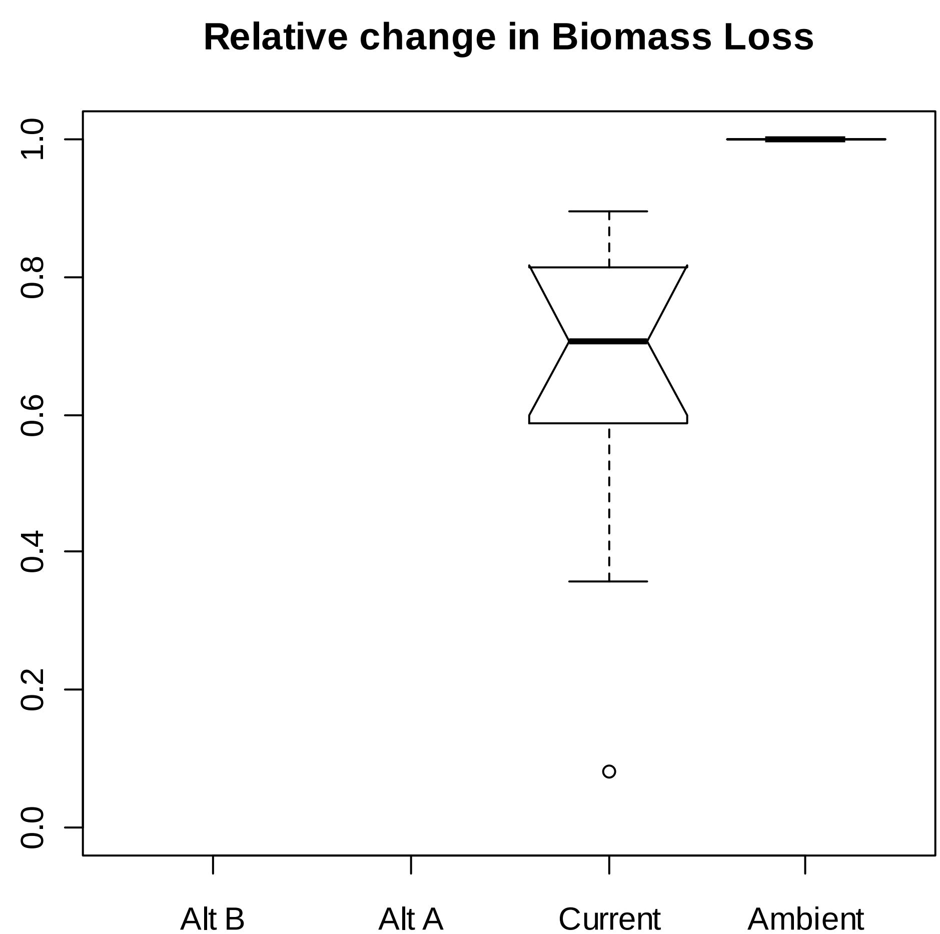


Figure 5- 7 Change in RBL across exposure scenarios for 11 tree species. Biomass loss estimates under recent ambient O_3 (2006 – 2008) conditions were used as the baseline. [Alternate levels will be included in the second draft based on simulating just attaining alternative standards]

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.

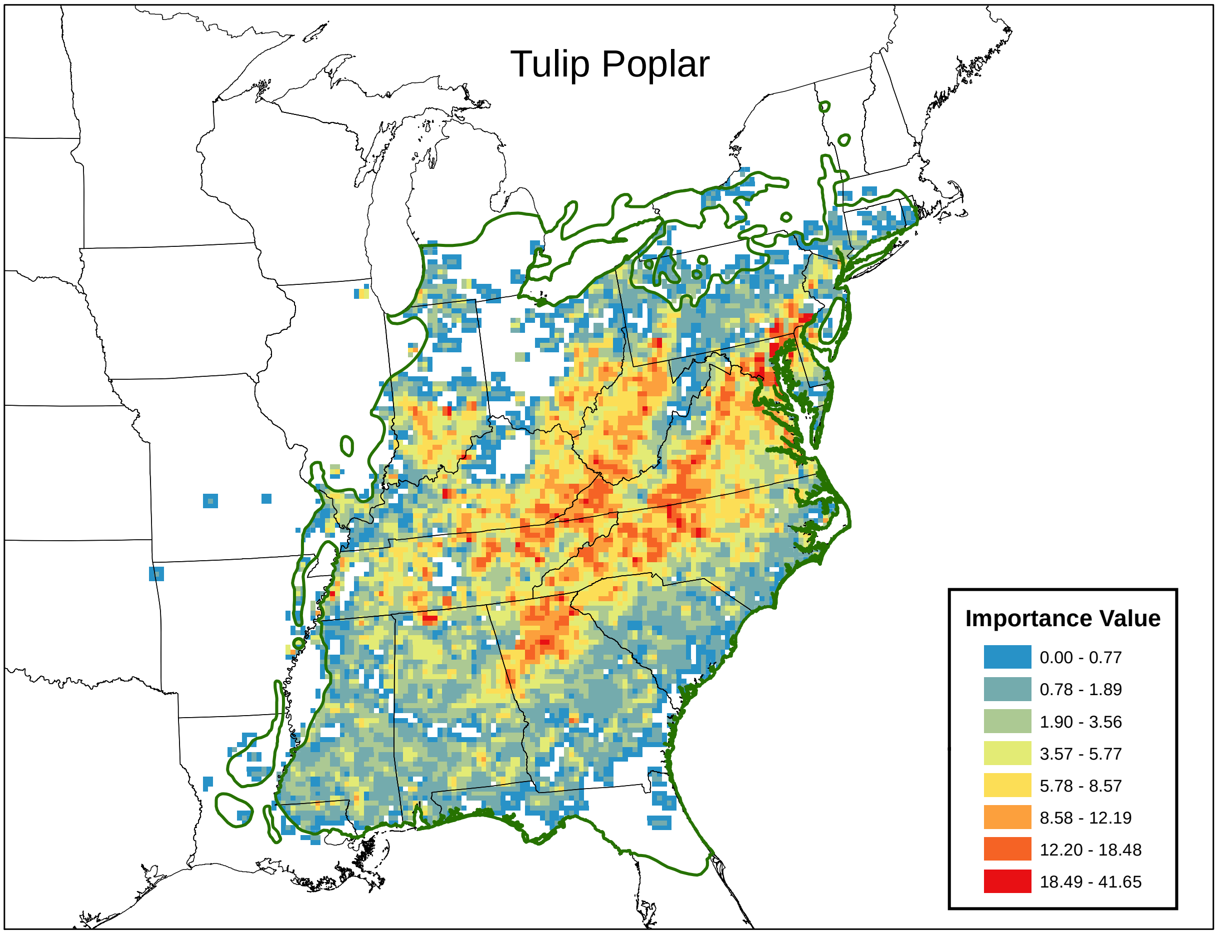


Figure 5- 8 Importance Values for Tulip Poplar. (Data from U.S. Forest Service, http://www.fs.fed.us/nrs/atlas/littlefia/index.html)

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).

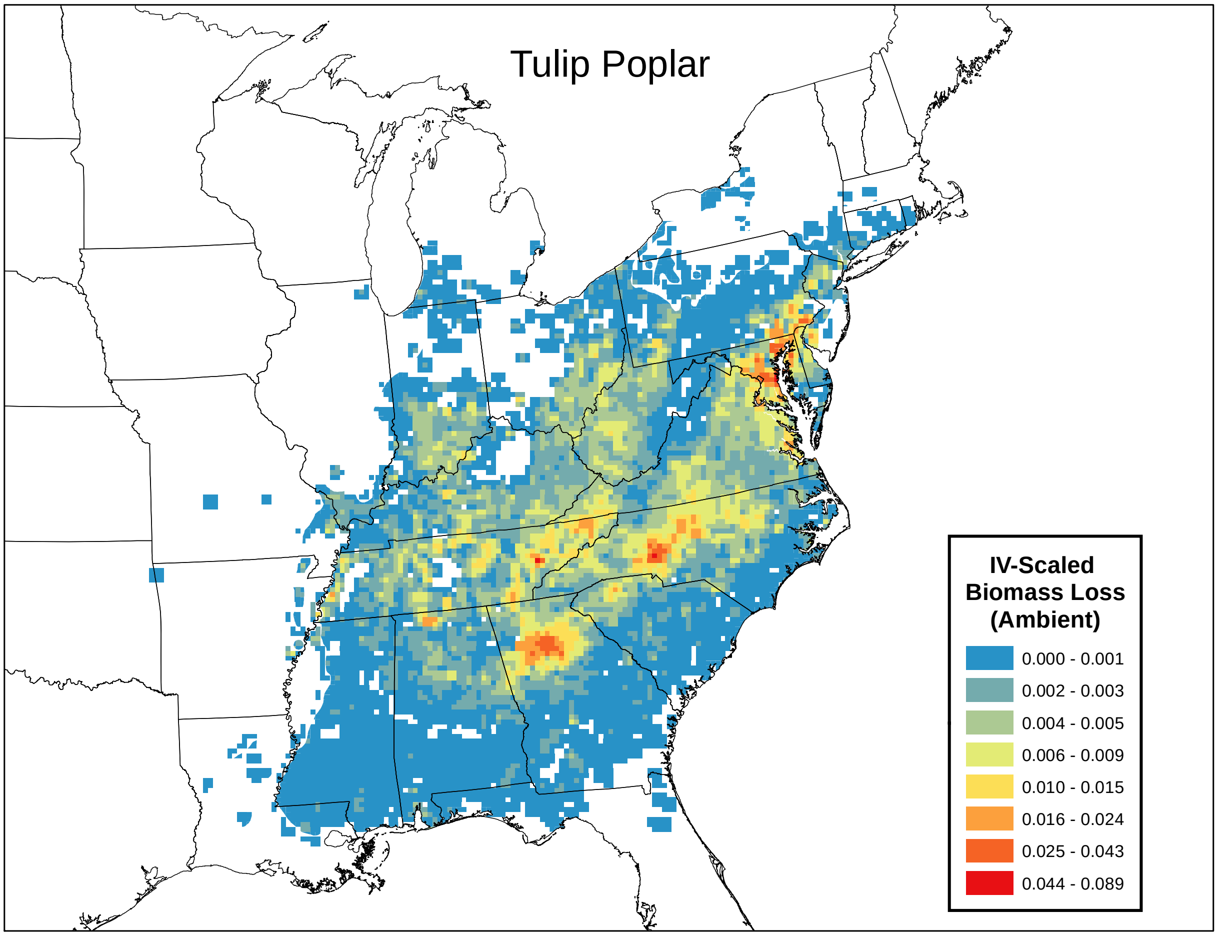


Figure 5- 9 Scaled Relative Biomass Loss for Tulip Poplar under recent ambient O_3 exposure levels (2006 – 2008)

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.

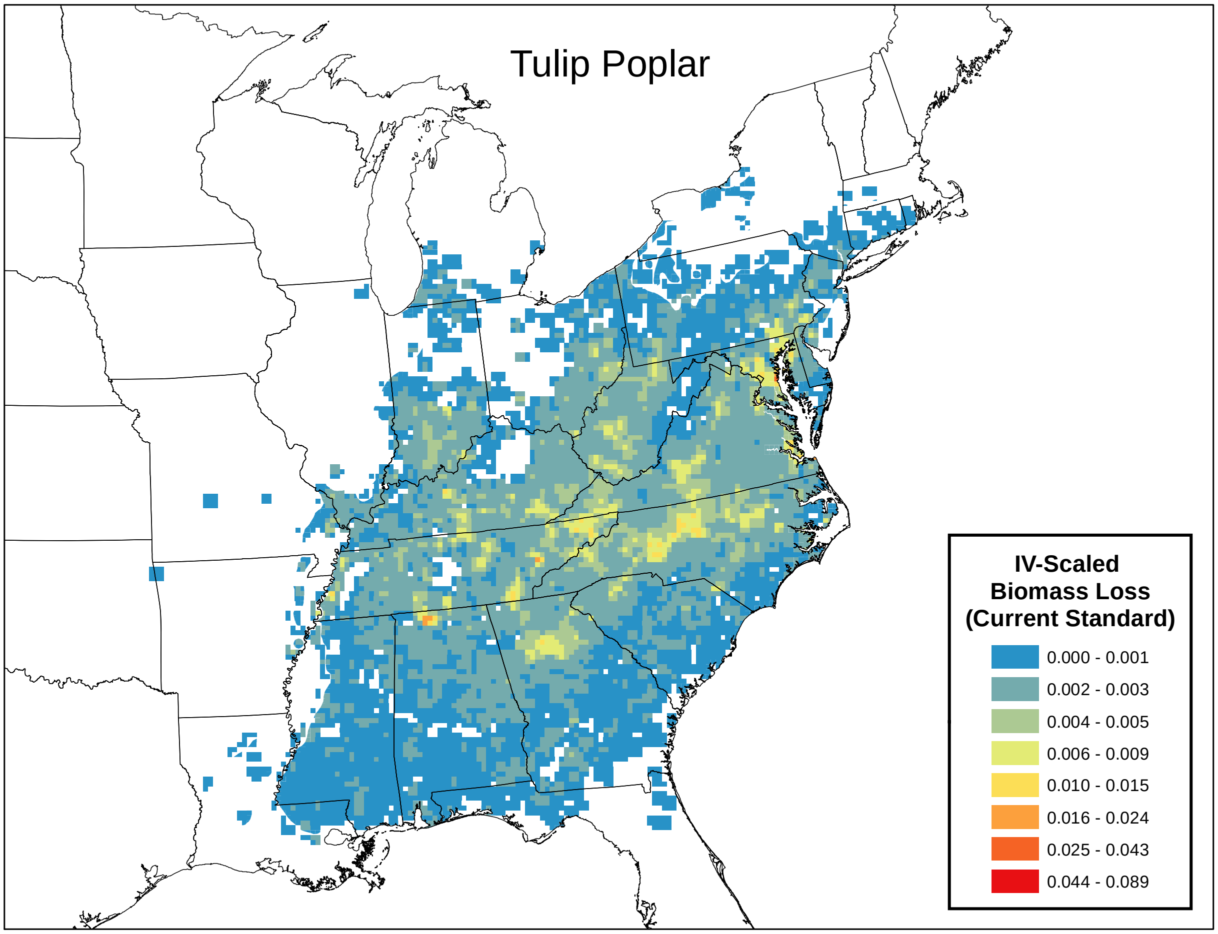


Figure 5- 10 Scaled Relative Biomass Loss for Tulip Poplar after simulating just meeting the current (8-hr) secondary O_3 standard.

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.

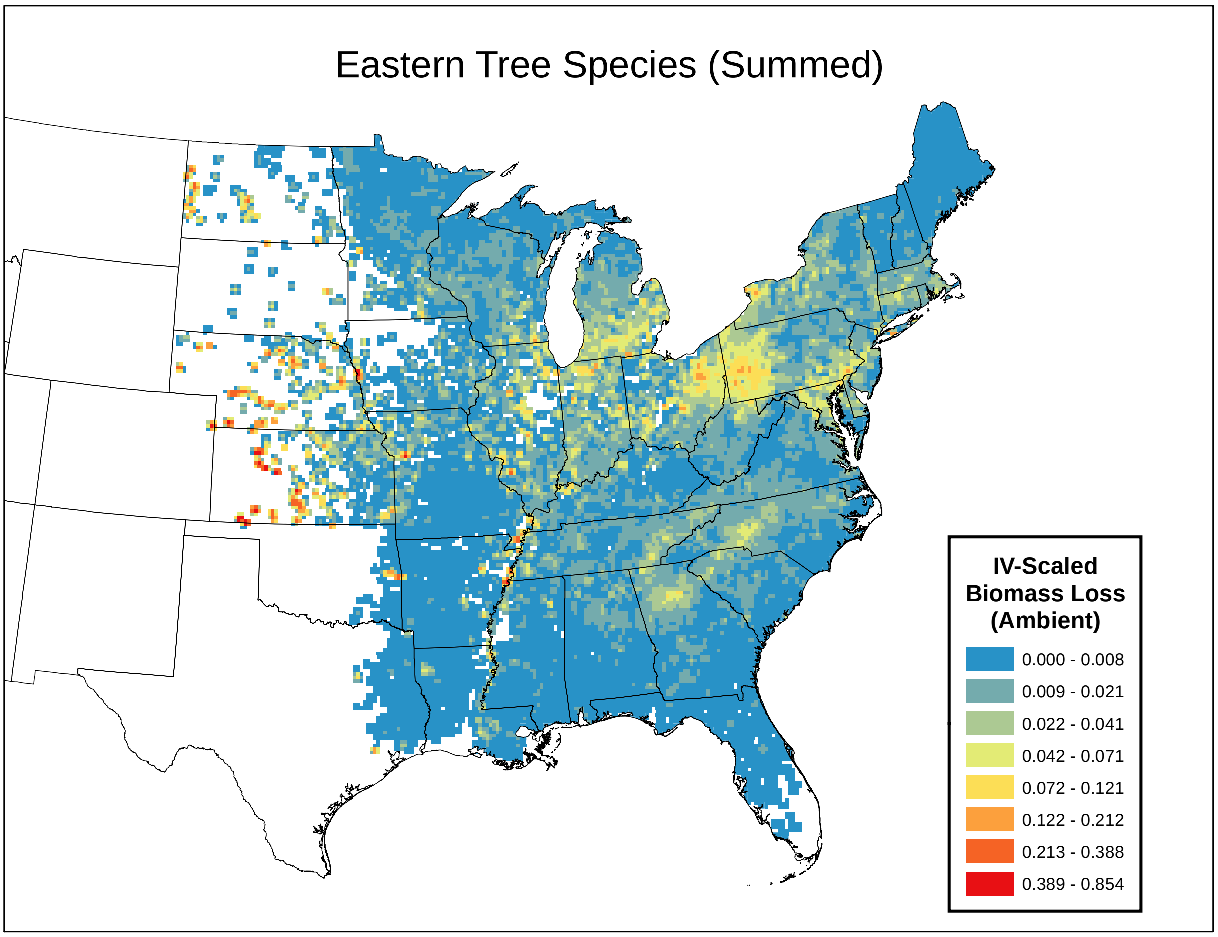


Figure 5- 11 Summed Relative Biomass Loss (scaled) for 8 Eastern tree species recent ambient O_3 exposure levels (2006 – 2008)

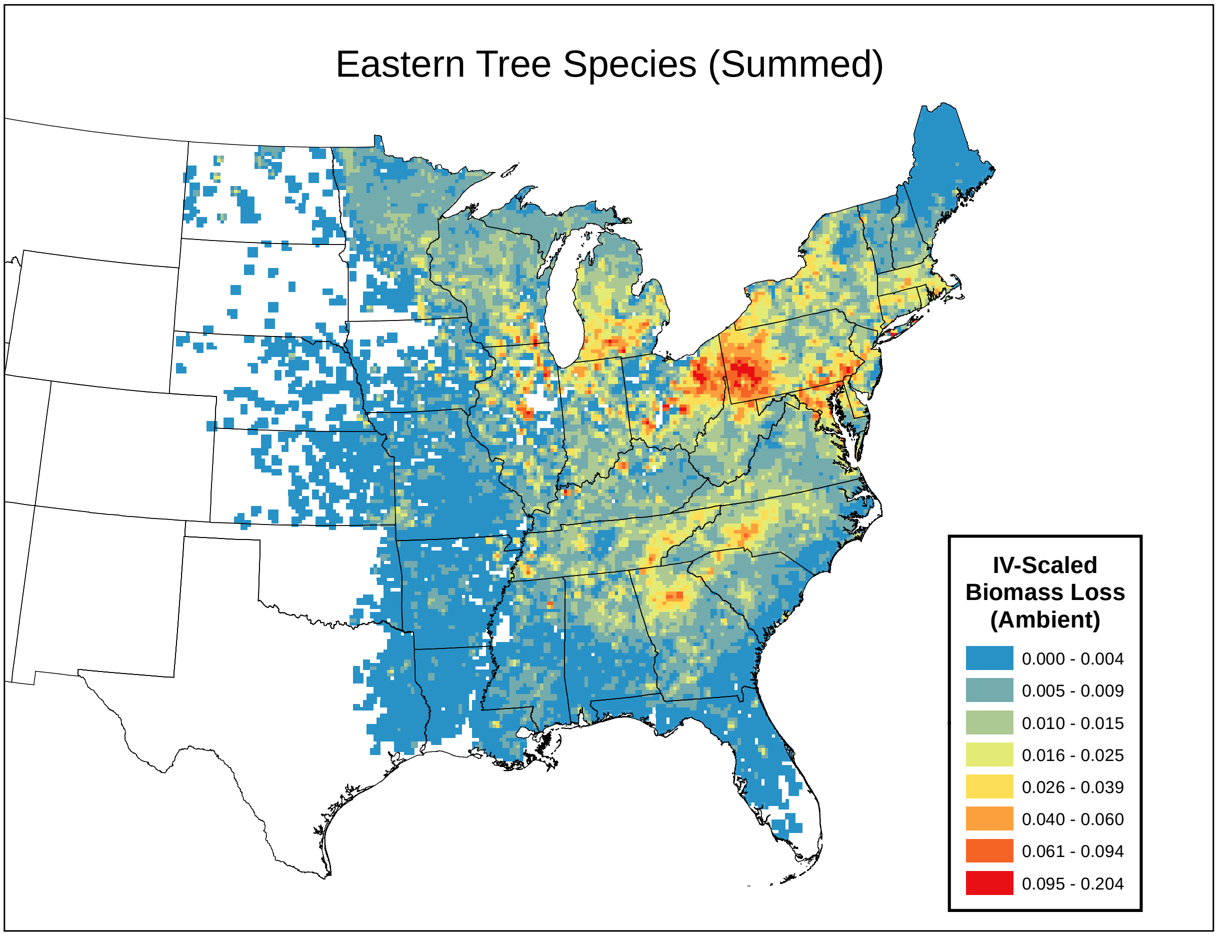


Figure 5- 12 Summed Relative Biomass Loss (scaled) for 7 species, excluding eastern cottonwood, under ambient O_3 conditions

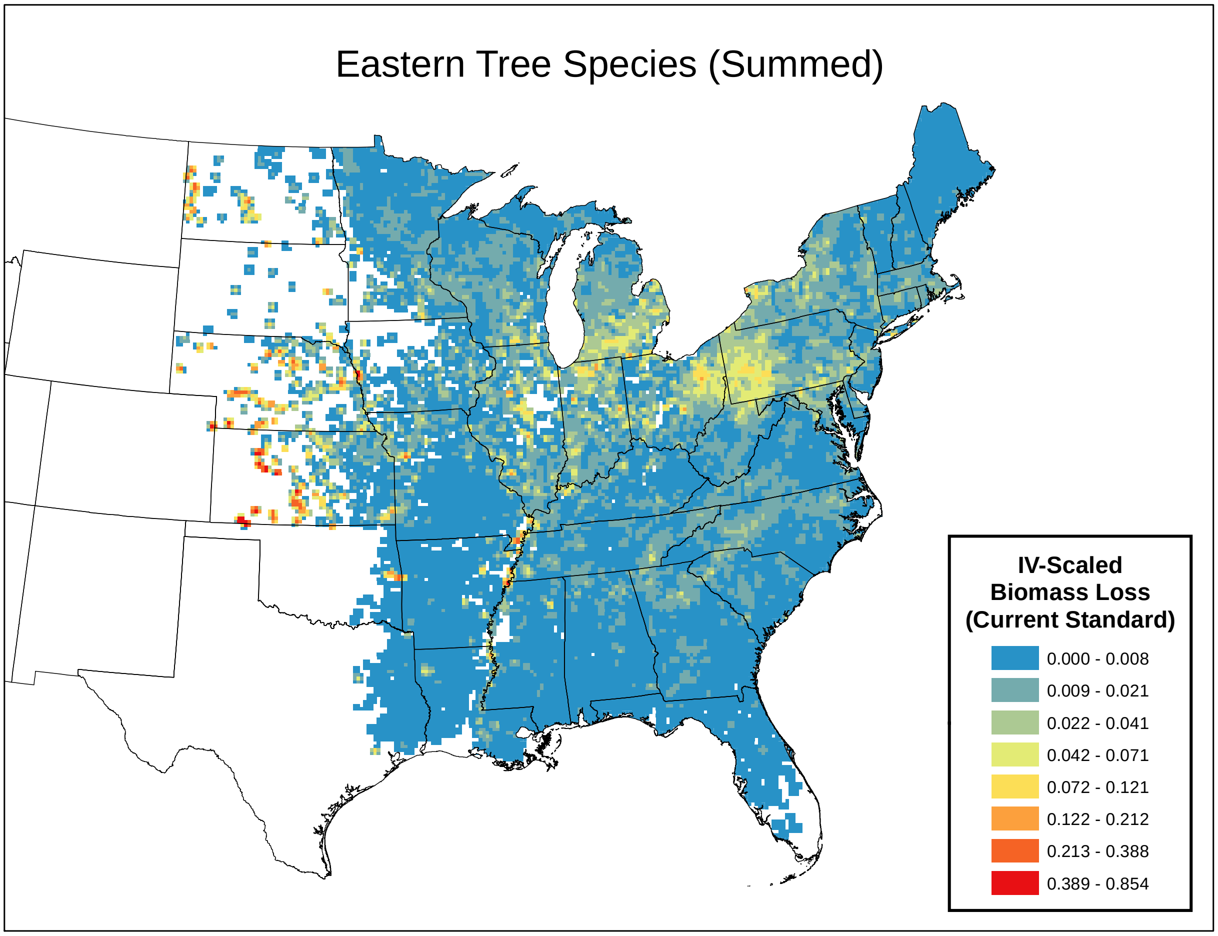


Figure 5- 13 Summed Relative Biomass Loss (scaled) for 8 Eastern tree species after simulating just meeting the current (8-hr) secondary O_3 standard.

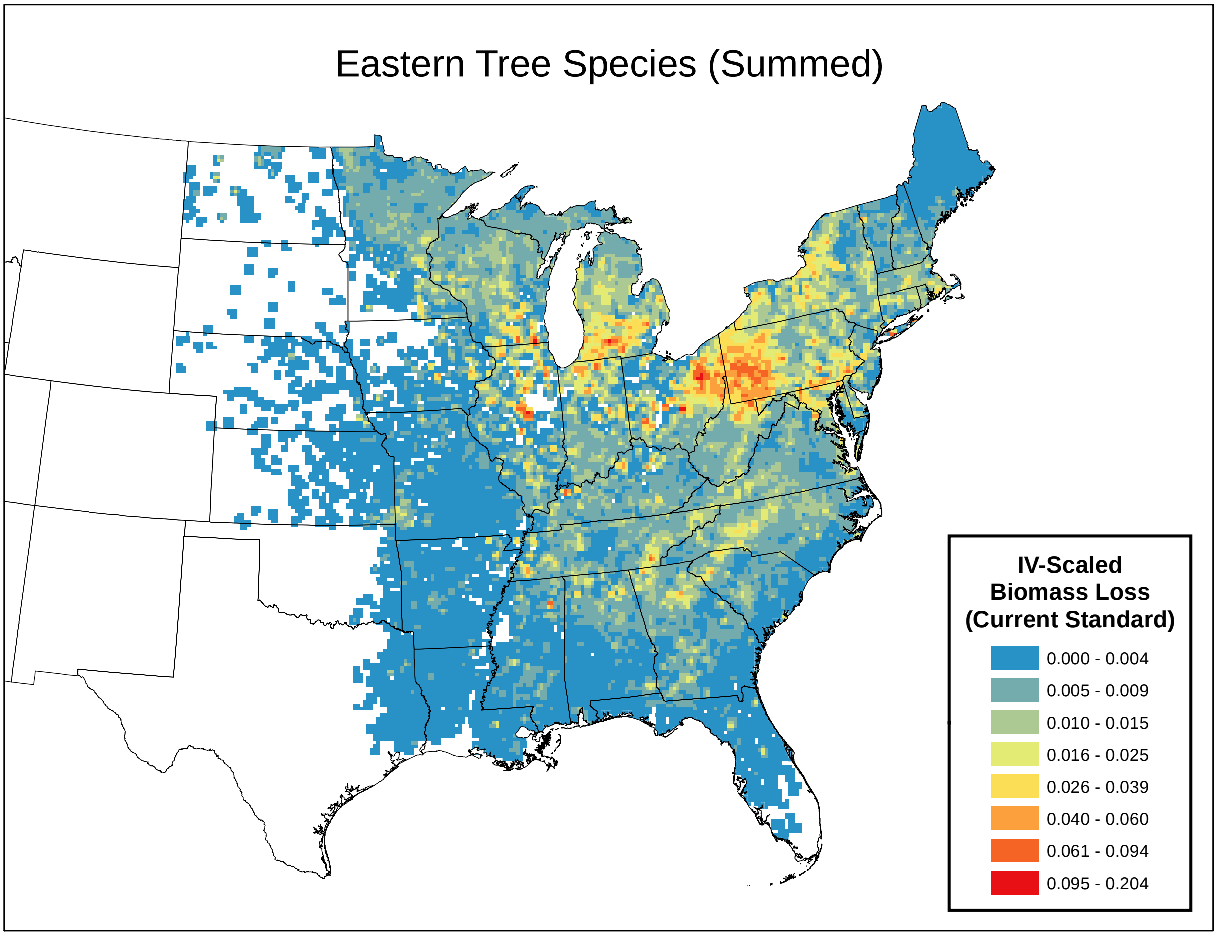


Figure 5- 14 Summed Relative Biomass Loss (scaled) for 7 species, excluding eastern cottonwood, after simulating just meeting the current (8-hr) secondary O_3 standard.

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.

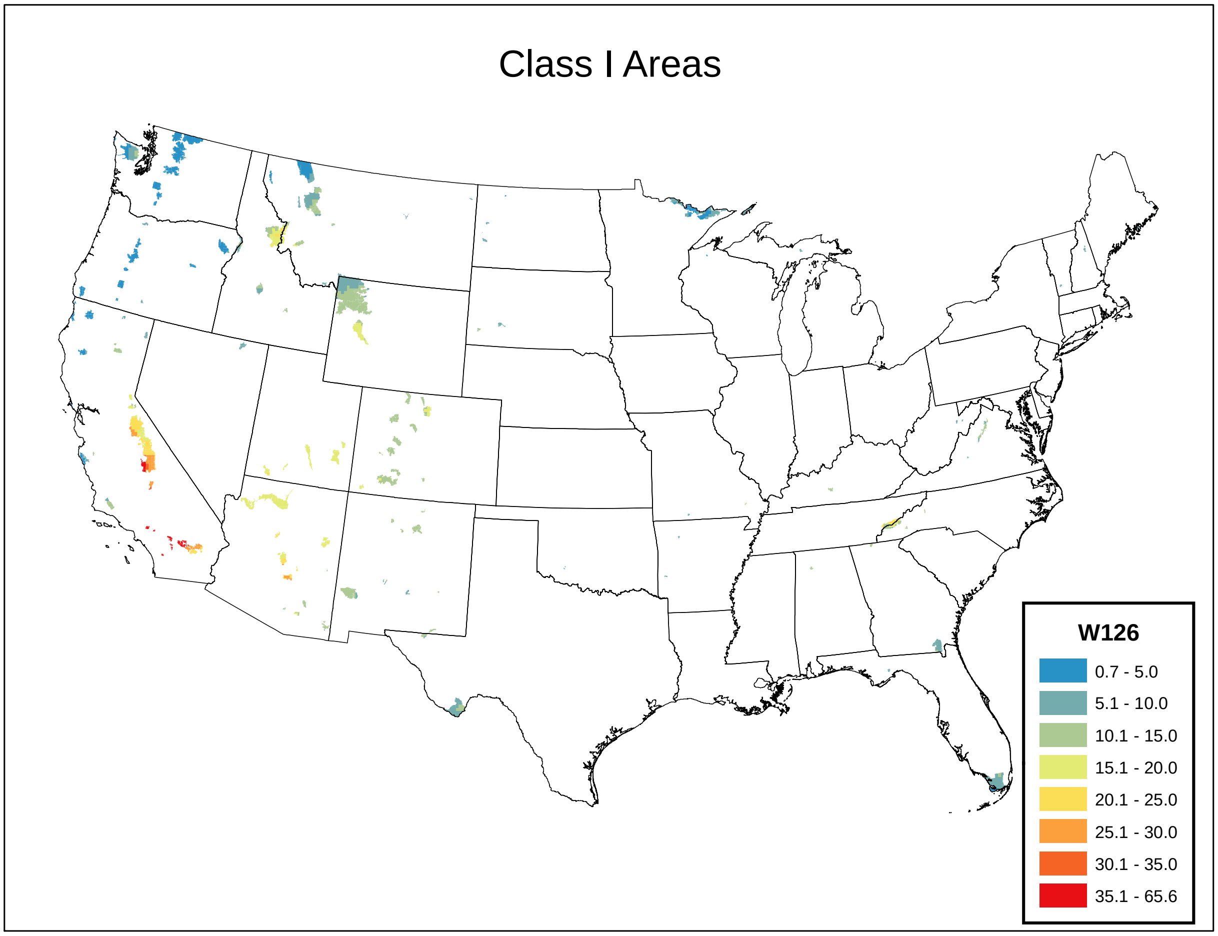


Figure 5- 15 Recent O_3 conditions in Class I Areas

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).

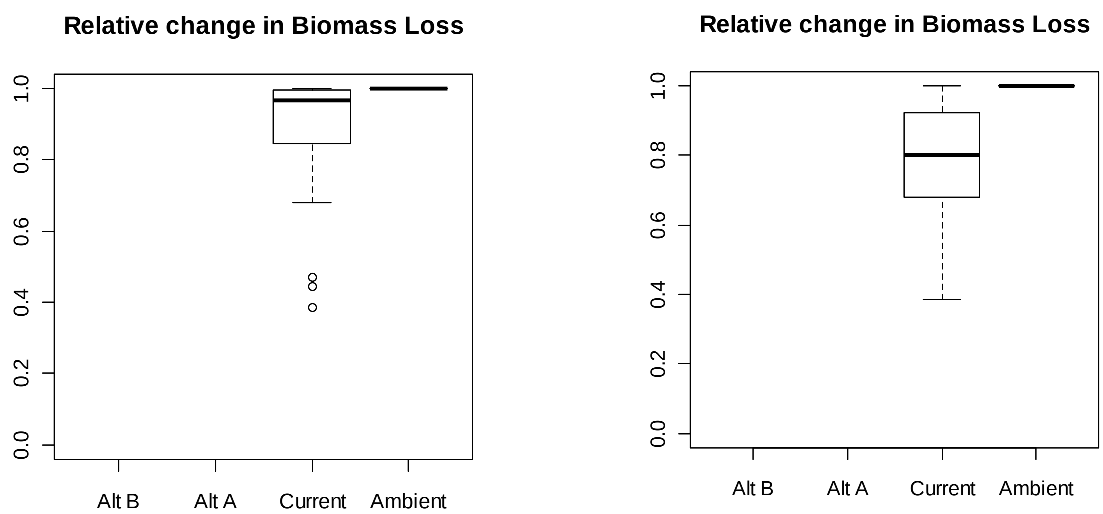
Areas in Table 5- 4 with the proportion listed as NA were not included in the analysis. These areas were excluded either due to small sample size (e.g. Rainbow Lake Wilderness), or because the summed RBL values in all, or all but 1, grid cells were 0.

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.

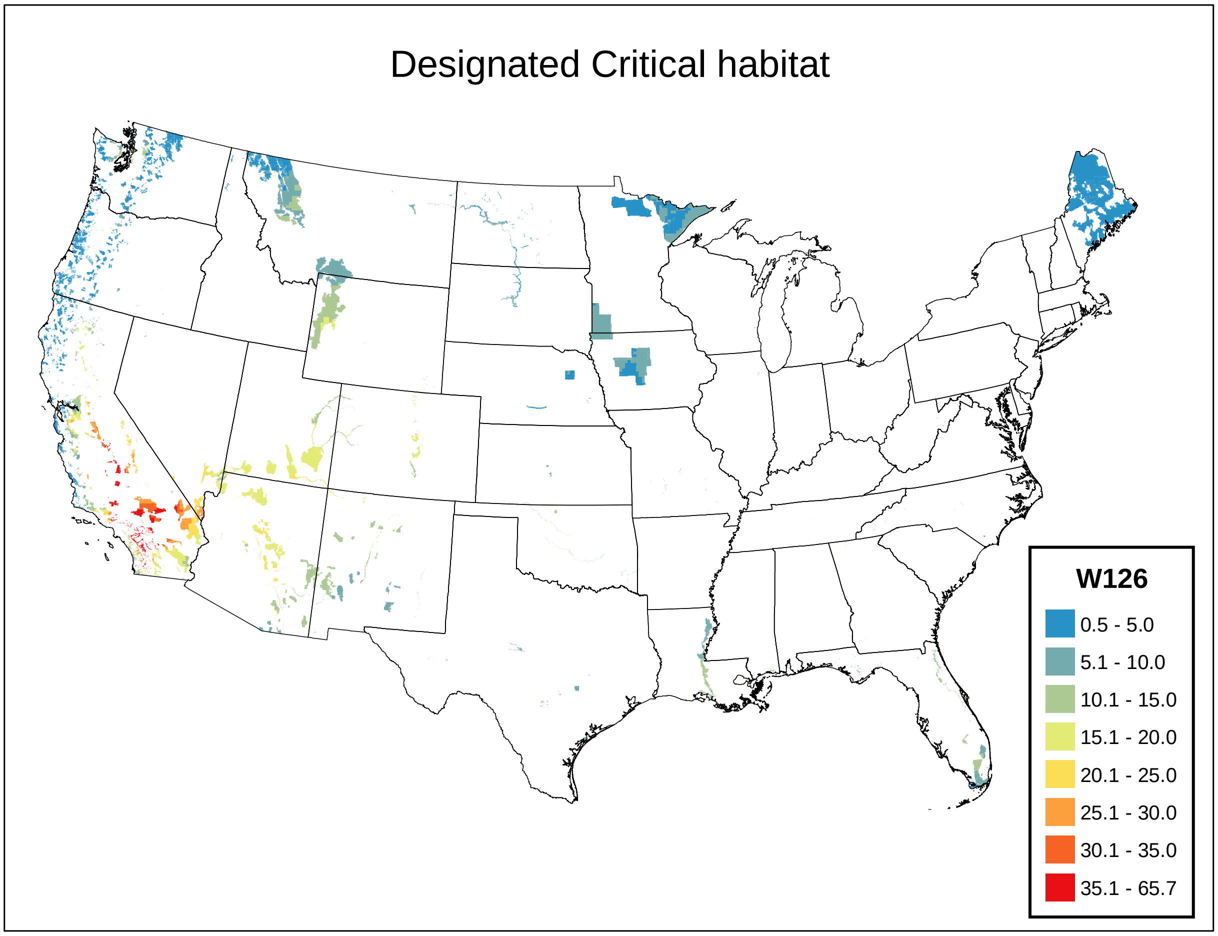


Figure 5- 17 Recent O_3 conditions in designated critical habitat areas.

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).

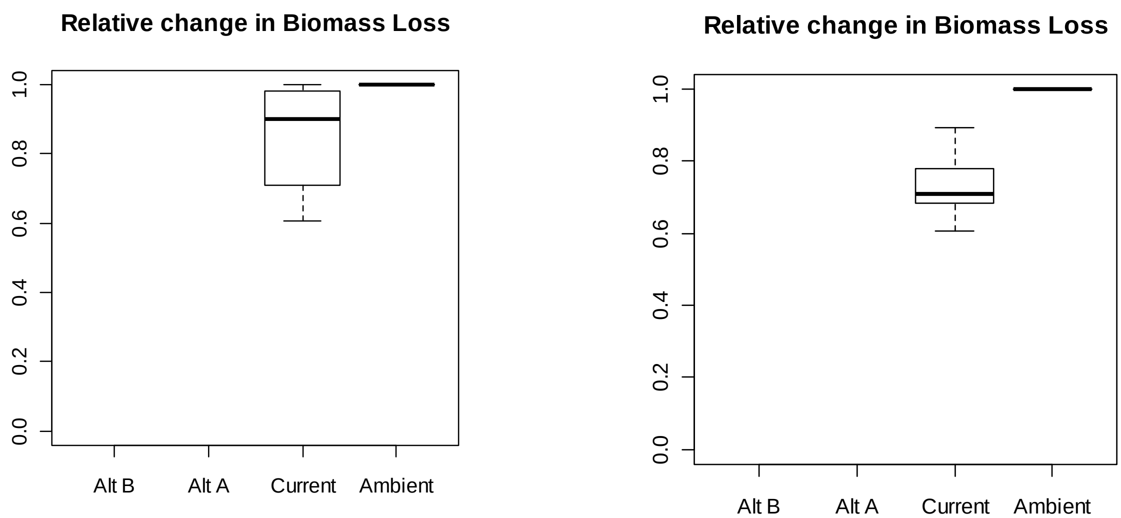
This analysis is not intended to indicate risk to the specific endangered species within the designated area; rather the intent is to use the designated critical habitat to define an endpoint for evaluating risk to locations that might be more sensitive to adverse effects from O_3 exposure. For example, 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.

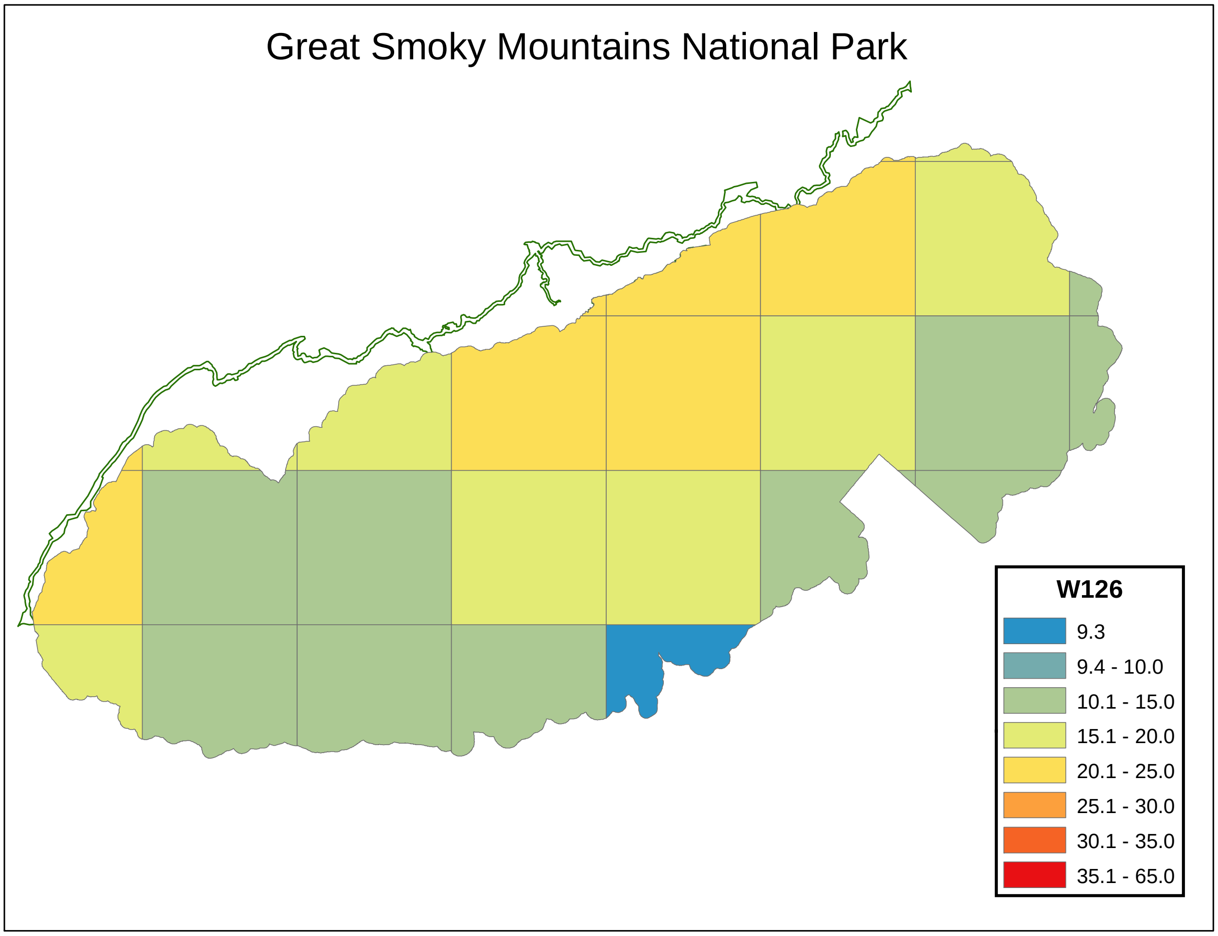


Figure 5- 19 Recent (2006 – 2008, 12-hr 3-month W126) O_3 Exposure in GSMNP

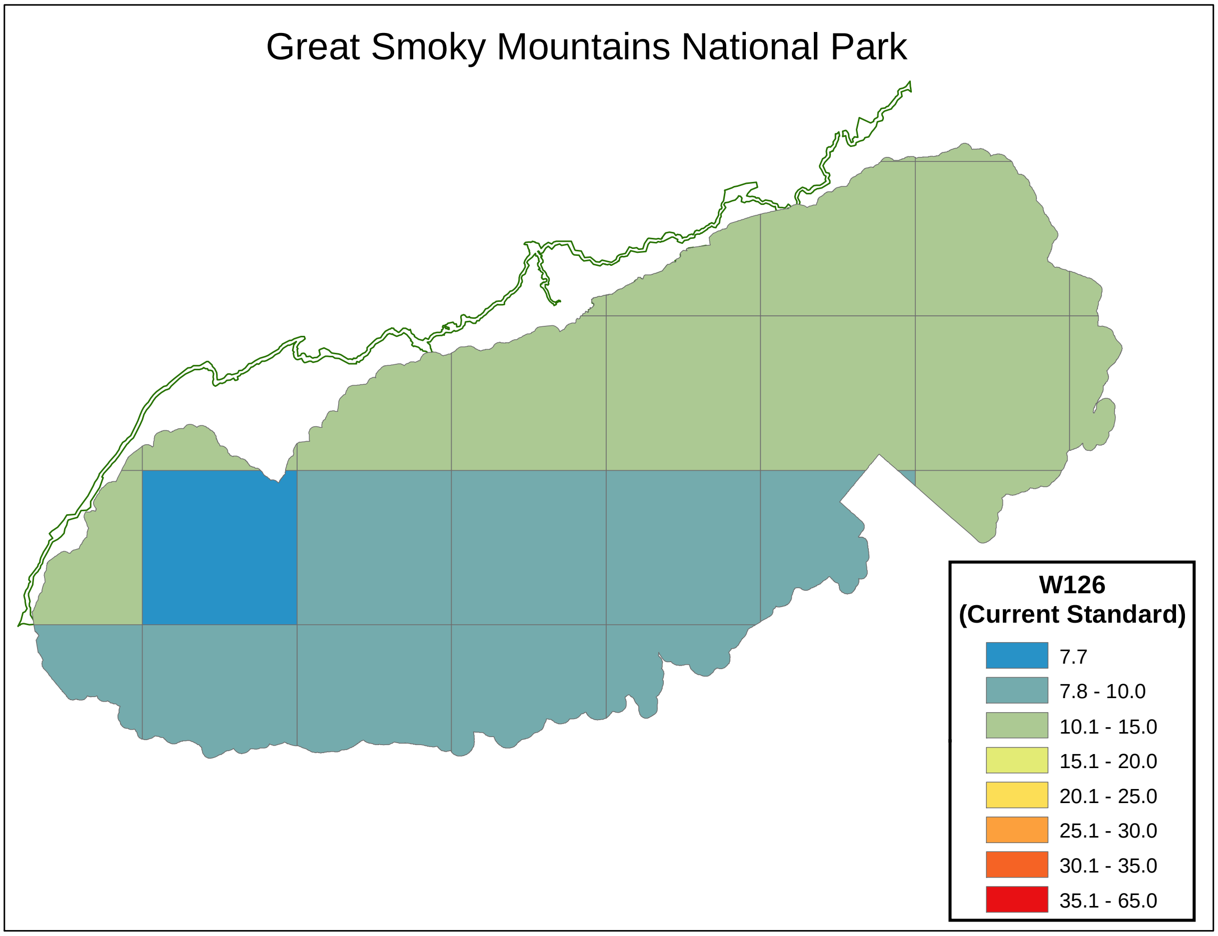


Figure 5- 20 O_3 Exposure in GSMNP after simulating just meeting the current (8-hr) secondary standard.

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).

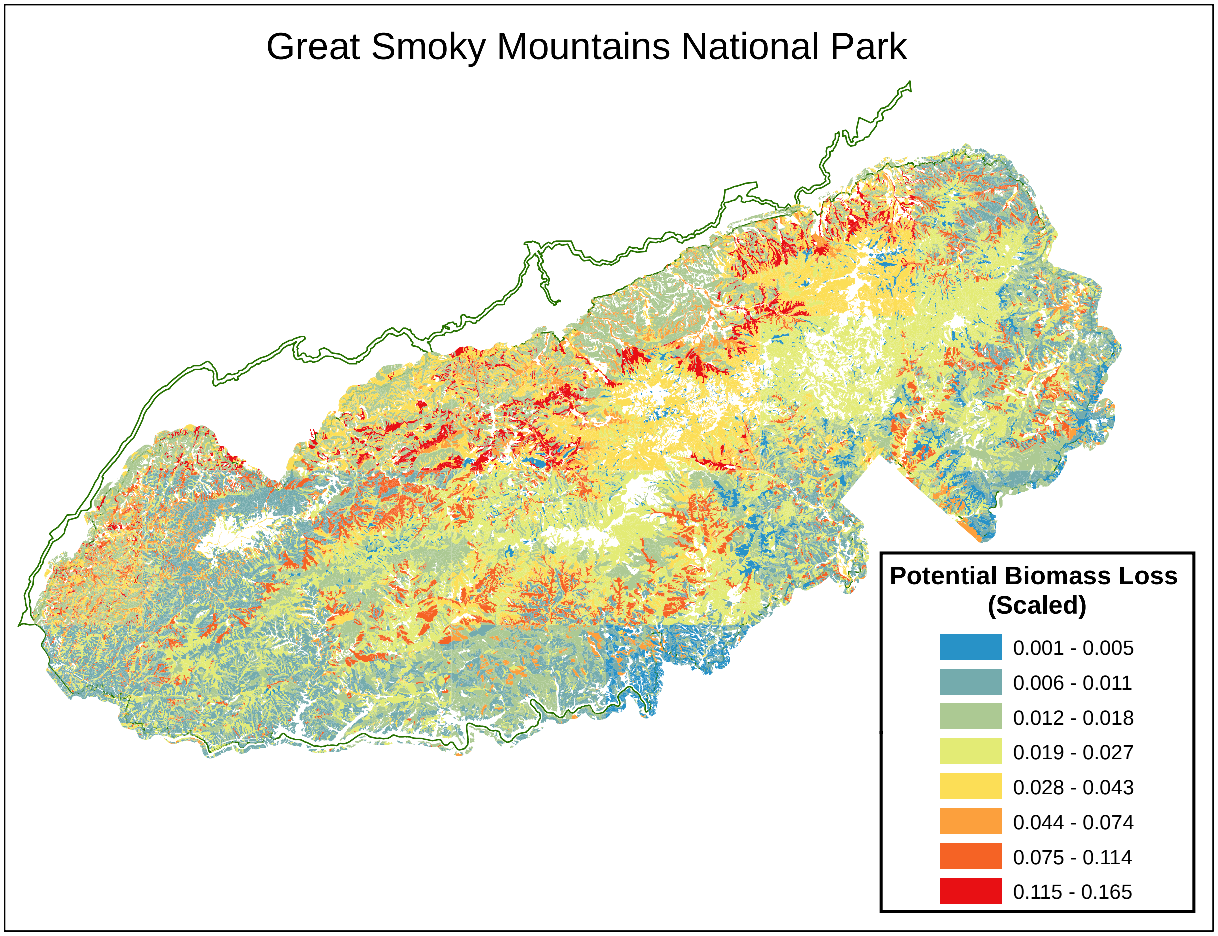


Figure 5- 21 Summed-RBL in GSMNP, scaled using percent cover of species, under recent O_3 conditions. White areas within the park represent areas where no data were available or were developed, with minimal vegetation.

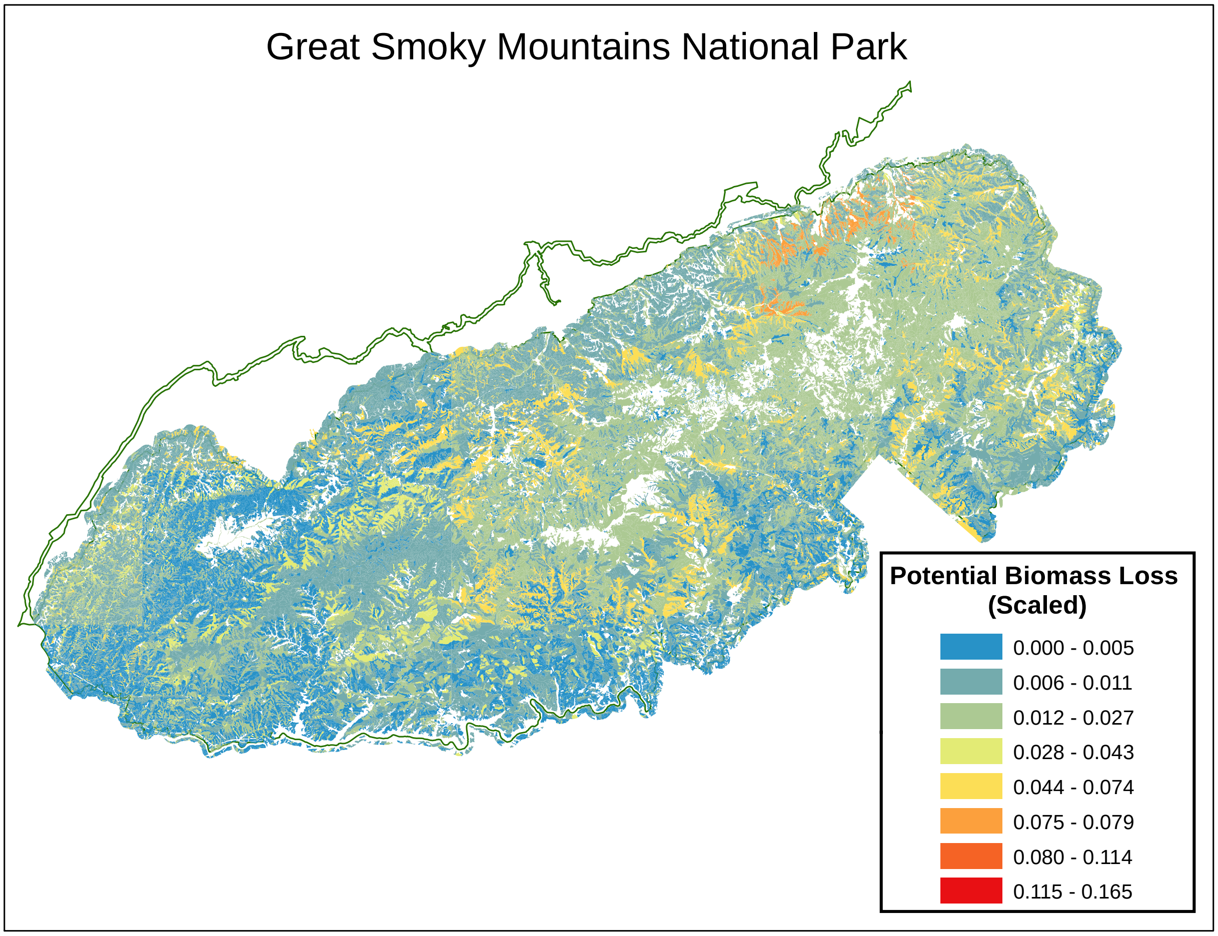


Figure 5- 22 Summed-RBL in GSMNP, scaled using percent cover of species after simulating just meeting the current secondary O_3 standard.

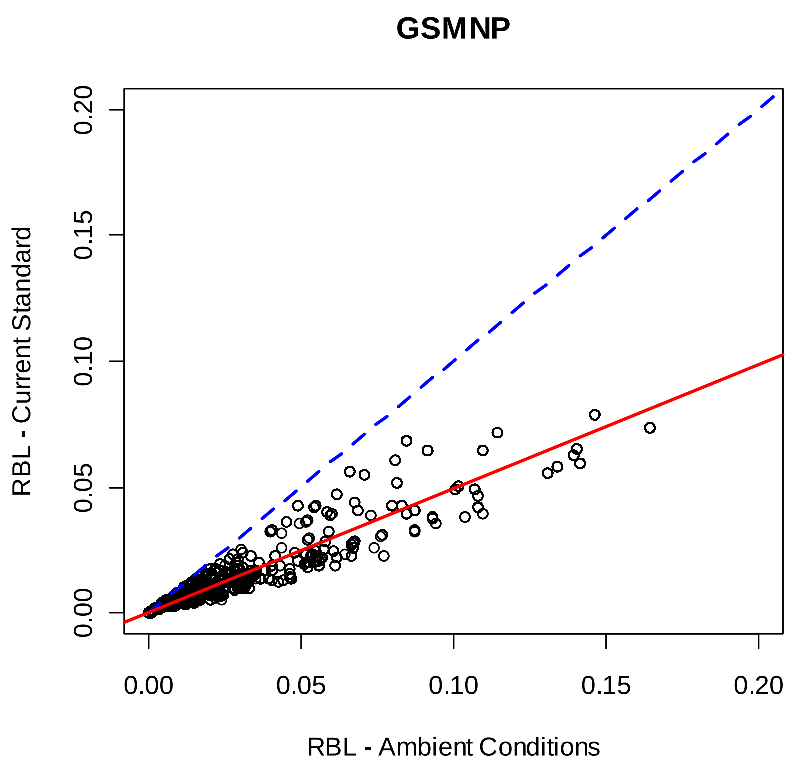


Figure 5- 23 Linear Fit Model comparing RBL under ambient conditions and a scenario just meeting the current standard.

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]

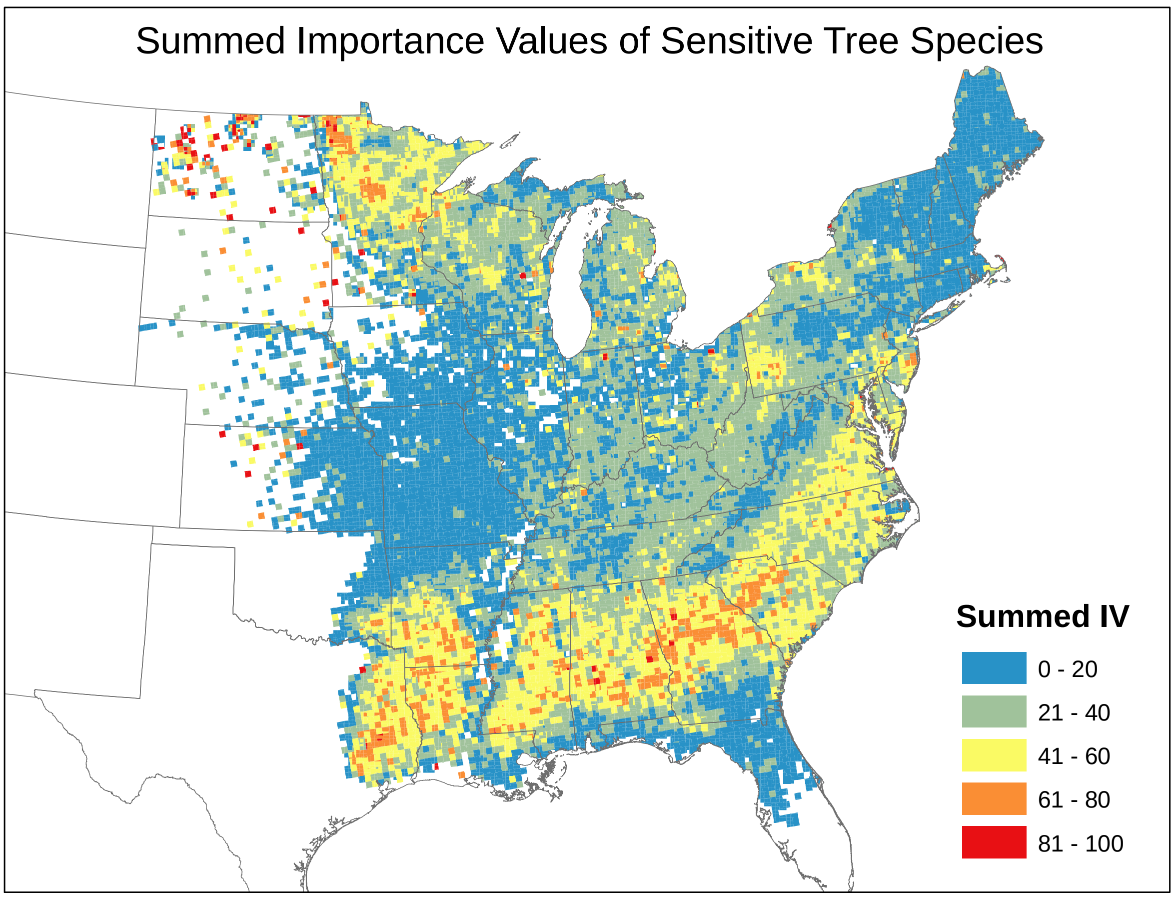


Figure 5- 24 Summed Importance Values for Sensitive Species in the Eastern U.S.

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

[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.

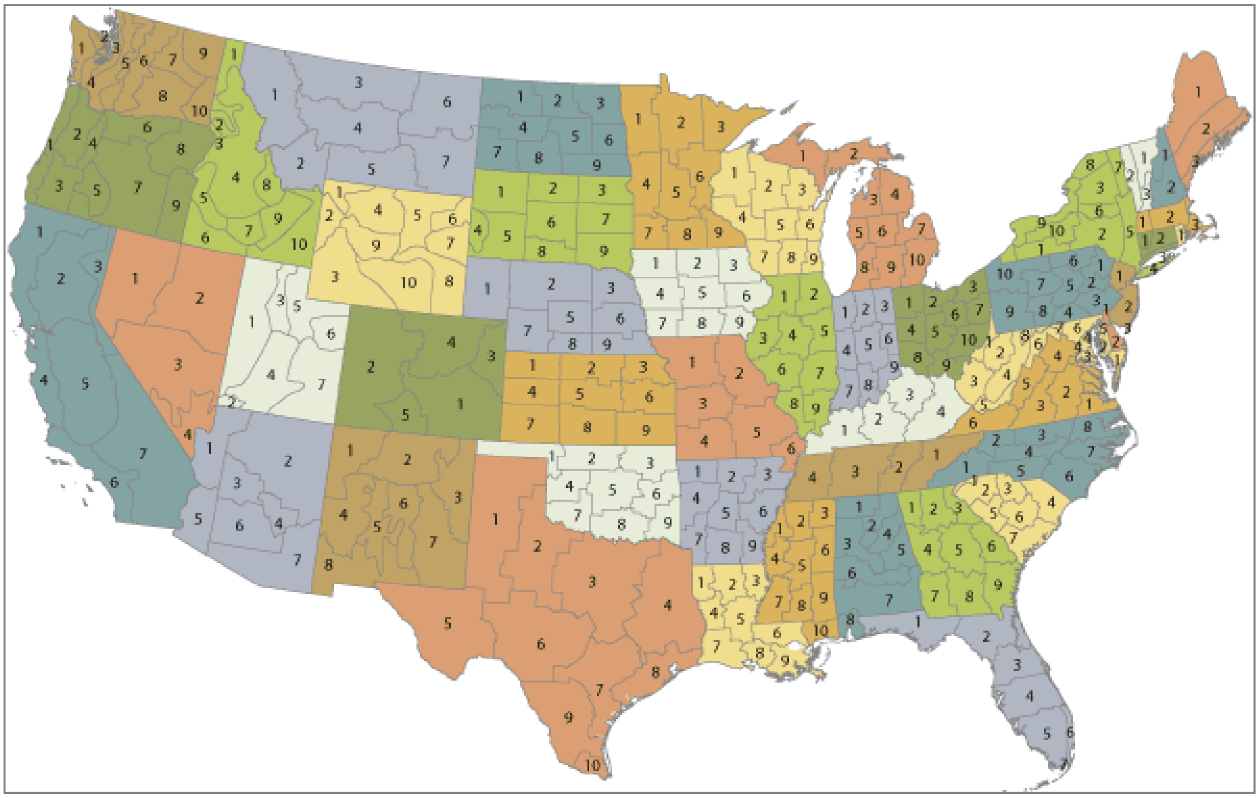


Figure 5- 25 344 climate regions with Palmer Z soil moisture data (source: NCDC, 2012a).

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

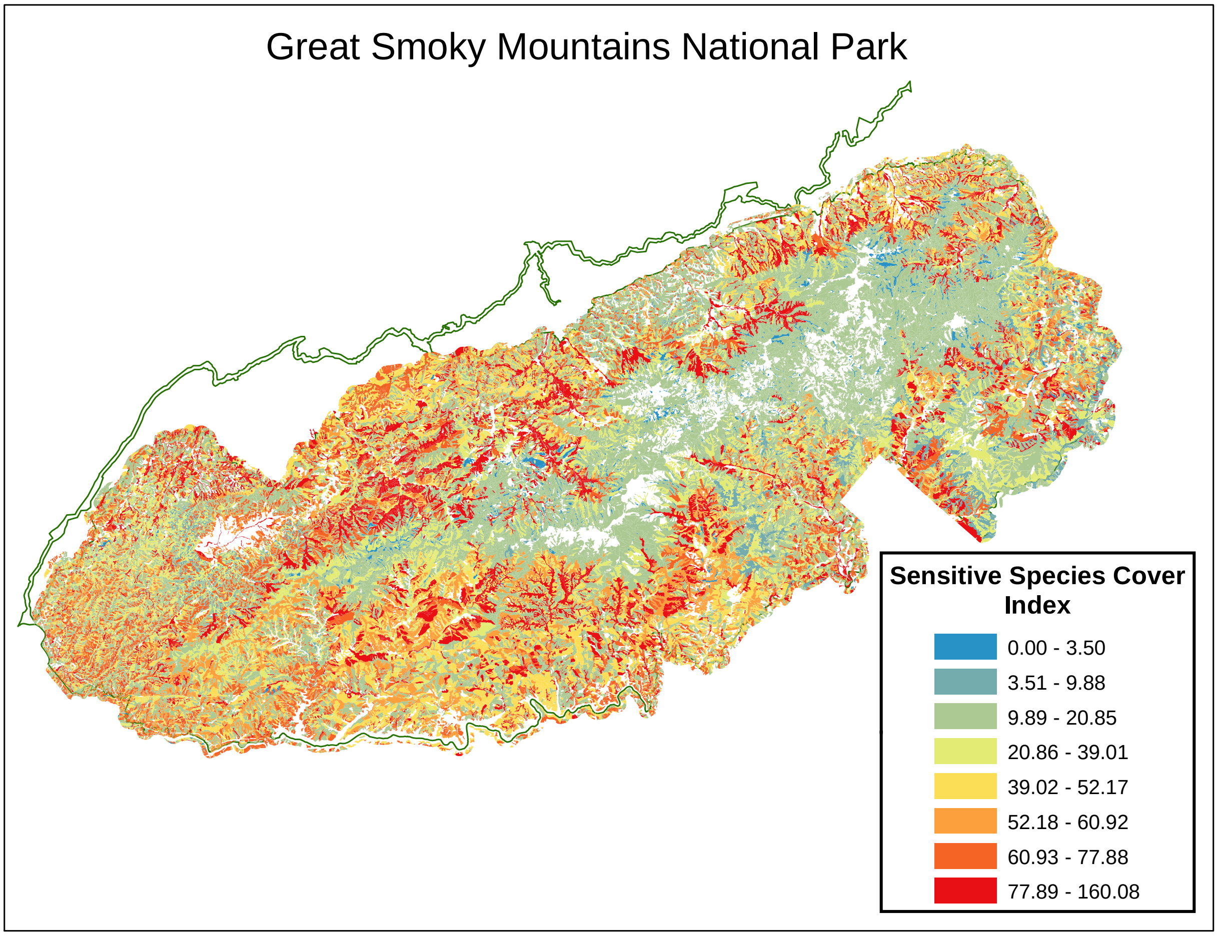


Figure 5- 27 Cover Index of Sensitive Species in GSMNP

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 O_3 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.

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 methodology for the analyses done for this risk and exposure assessment are available in Appendix 6-A.

The current crop/forest budgets included in FASOMGHG are considered as the budgets under current ambient O_3 concentrations. To model the effects of changing O_3 concentrations on the agricultural and forest sectors, two primary scenarios were constructed and run through the model:

(1) Base scenario, consistent with current ambient O_3 concentration levels;
(2) "rollback" scenario, where crop and forest yields are assumed to increase according to the calculations for the air quality simulation that just meets the current standard.

By comparing the market equilibriums under different scenarios, we can calculate changes in GHG mitigation potential over time.

The impacts of the rollback scenario on GHG mitigation potential in U.S. forest and agricultural sectors are presented in Table 6-2, where positive numbers indicate more emissions/less sequestration, and negative numbers imply the opposite.

As shown in the table, much greater GHG changes are projected in the forest sector than in the agricultural sector. The vast majority of the enhanced GHG mitigation potential under the scenario lies in the forest biomass as the rollback-induced yield increases accruing to forests accumulate over time. The forest GHG mitigation potential would increase by 222 million tons of CO_2 equivalents in the first 10 years after meeting the current standard, by 840 million tons in the second 10 years, and by 483 million tons in the third 10 years increment for a total increase of 1,823 million tons over 30 years.

[*We will include expanded analyses in the second draft.*]

Table 6-2 Changes in GHG Mitigation Potential between Recent Ozone Conditions and Just Meeting the Current Standards (million tons CO_2 equivalents)

GHG Category	**2010**	**2020**	**2030**	**2040**
Afforestation	1	95	84	248
Existing Forest Soil	15	9	34	-1
Afforested Forest Soil	6	160	128	235
Forest Management	-289	-736	-1,553	-2,253
Forest Product	-13	-31	-35	-55
Canada Forest Product	3	2	3	3
Export Forest Product	0	0	0	0
Import Forest Product	0	0	0	0
Forest Fuel	0	0	0	0
Total Forest	**-278**	**-500**	**-1,340**	**-1,823**
Agricultural Soil	-11	-47	-23	-87
Ag Fuel Use	0	0	1	3
Fertilizer Manufacture	0	-1	0	0
Fertilizer N_2O	0	-1	0	0
Pasture N_2O	0	3	5	7
Pesticide Manufacture	0	1	1	1
Biodiesel Offset	0	0	0	0
Grain Ethanol Offset	0	0	0	0
Cellulosic Ethanol Offset	0	0	0	0
Bio-Electricity Offset	-2	-17	-18	-20
Manure Emissions	0	1	1	2
Enteric Fermentation	1	0	0	1
Rice Emissions	0	0	-1	0
Miscellaneous	0	0	0	0
Total Agriculture	-12	-62	-34	-92
All Total	-289	-562	-1,375	-1,915

Key uncertainties in this approach include:

- The use of proxy CR functions for species not included in the CR functions in the ISA.
- The uncertainty in the CR functions themselves.
- The uncertainty inherent in the various model components including the uncertainty within the CMAQ air quality surfaces.

In addition it should be noted that since public lands are not affected within the model the estimates presented would likely be higher were public lands included.

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.

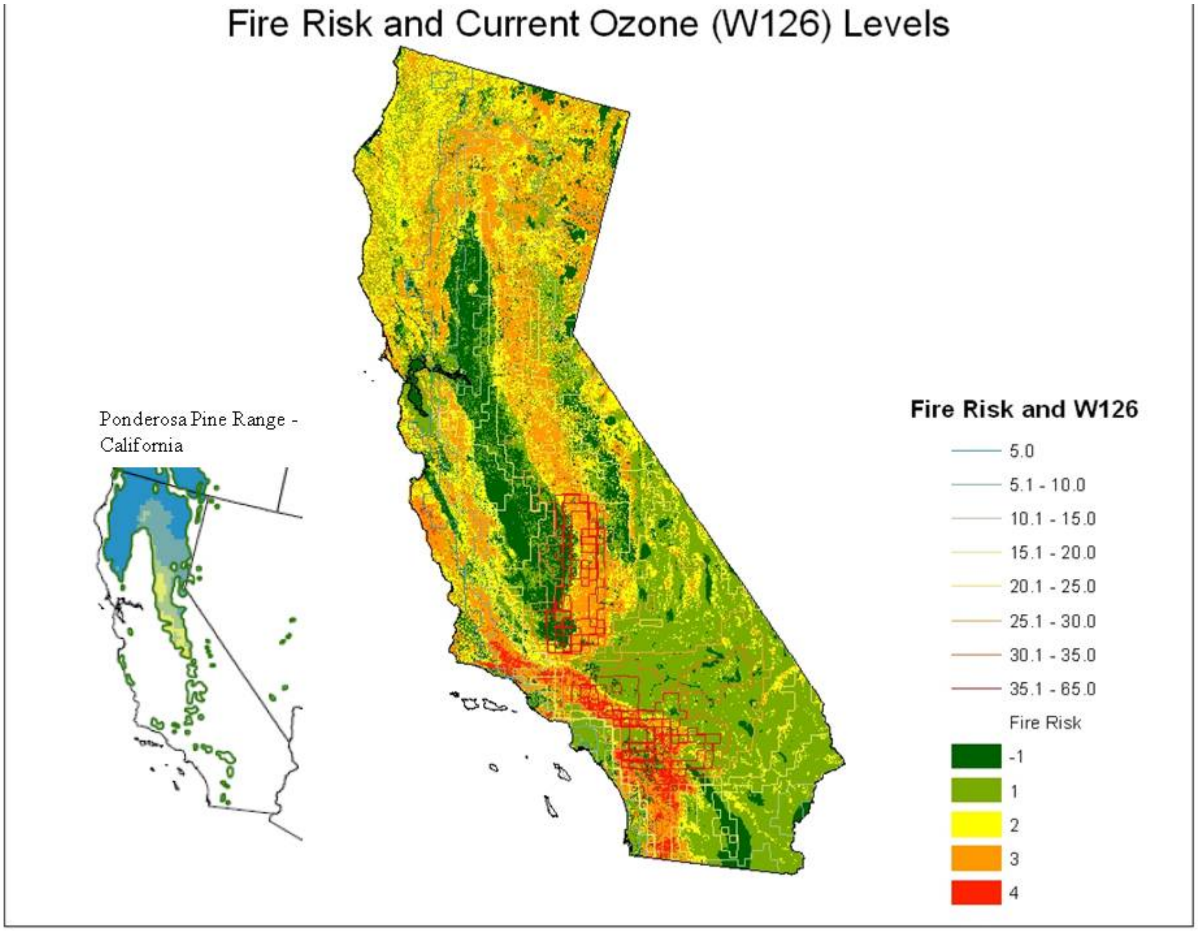


Figure 6- 1 Overlap of fire risk, current O_3 levels and California range of ponderosa pine

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 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. The model results for the agriculture sector are reported in Appendix 6-A.

The O_3 CR functions for tree seedlings were utilized to calculate relative yield loss (RYL) for FASOMGHG trees over their whole life span. To derive the FASOMGHG region-level RYLs for trees under each O_3 concentration scenario, we used FASOMGHG region O_3 values and the mapping in Table 6-3.

Specifically, the FASOMGHG region-level RYLs are first calculated for each tree species listed in first column of Table 6-3. Then, a simple average of RYLs for each tree species mapped to a FASOMGHG forest type in a given region is calculated. The mapping of tree species to FASOMGHG forest types is based on *"Atlas of United States Trees"* by Elbert L.

Little, Jr. (Little, 1971, 1976, 1977, 1978). See Appendix 6-A for a full discussion of the model and methodology.

Table 6-3 Mapping O_3 Impacts to FASOMGHG Forest Types

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

Table 6-4, 6-5, and 6-6 present the region-specific RYLs for the softwood and hardwood tree species. Under ambient conditions the highest yield loss of 27.4% occurs in black cherry and the average loss across all sensitive tree species (except Douglas fir) is 5.2%. When just meeting the current standard the highest yield loss of 22.28% also occurs in black cherry and the average loss across all sensitive species (except Douglas fir) is 4.2%. This results in a reduction in the average relative yield loss due to O_3 exposure of about 1% when reducing O_3 concentrations from the current ambient conditions to just meeting the standard. However the most sensitive species (black cherry) would see a reduction in yield loss over 5% in the Southeast.

Table 6-4 Percentage RYL Estimates for Softwood Species by Region

	Douglas Fir		**Eastern White Pine**		**Ponderosa Pine**		**Virginia Pine**	
Region	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
CB			4.97	3.56				
LS			2.19	2.08				
NE			3.50	2.57			0.49	0.41
PNWE					1.10	1.04		
PNWW	0.00	0.00			1.16	1.09		
PSW					5.22	2.71		
RM					4.64	4.04		
SC							0.62	0.52
SE			6.45	4.37			0.72	0.56

Table 6-5 Percentage RYL Estimates for Hardwood Tree Species by Region

	Black Cherry		**Tulip Poplar**		**Quaking Aspen**		**Red Maple**	
Region	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
CB	23.86	19.95	3.56	2.34	5.55	4.35	0.91	0.69
LS	15.25	14.84	1.26	1.18	3.04	2.94	0.46	0.44
NE	19.74	16.69	2.28	1.55	4.29	3.43	0.68	0.52
PNWE								
PNWW								
PSW								

	Black Cherry		Tulip Poplar		Quaking Aspen		Red Maple	
RM					6.72	5.83		
SC	24.30	20.65	3.72	2.53			0.94	0.73
SE	27.40	22.28	4.96	3.03			1.14	0.82

Table 6-6 Percentage RYL Estimates for Hardwood Tree Species by Region (continued)

	Sugar Maple		Red Alder	
Region	Current	Rollback	Current	Rollback
CB	0.08	0.02		
LS	0.00	0.00		
NE	0.02	0.01		
PNWE			0.79	0.75
PNWW			0.85	0.79
PSW			4.05	2.04
RM				
SC				
SE				

Expanding the analysis to account for tree species without express CR functions by using the CR functions for sensitive species as a proxy and applying those to the FASOMGHG forest types allows estimation of effects across the nation. Table 6-7 shows the percentage yield loss across the country by region. The relative yield gain (RYG) column is the difference between the current ambient condition and the rollback scenario. The greatest losses occur in the upland hardwood forests of the Southeast with correspondingly higher gains form meeting the current standard.

Table 6-7 Percentage RYL Estimates for FASOMGHG Forest Types by Region

Forest Type		RYL		RYG
	Region	Current	Rollback	Rollback
Softwood				
Douglas Fir	PNWW	0.00	0.00	0.00
Natural Pine	SC	0.62	0.52	0.11
Natural Pine	SE	3.51	2.41	1.17
Oak-Pine	SC	0.62	0.52	0.11
Oak-Pine	SE	3.58	2.47	1.19
Other Softwood	PNWW	1.16	1.09	0.07
Planted Pine	SC	0.62	0.52	0.11
Planted Pine	SE	3.58	2.47	1.19
Softwood	CB	4.97	3.56	1.48
Softwood	LS	2.19	2.08	0.11
Softwood	NE	1.99	1.49	0.52
Softwood	RM	4.64	4.04	0.63
Softwood	PSW	5.22	2.71	2.65
Softwood	PNWE	1.10	1.04	0.06
Hardwood				
Bottomland Hardwood	SC	0.94	0.73	0.21
Bottomland Hardwood	SE	1.14	0.82	0.32
Hardwood	CB	6.79	5.47	1.59
Hardwood	LS	4.00	3.88	0.14
Hardwood	NE	5.40	4.44	1.12
Hardwood	RM	6.72	5.83	0.95
Hardwood	PSW	4.05	2.04	2.09
Hardwood	PNWW	0.85	0.79	0.05
Hardwood	PNWE	0.79	0.75	0.04
Upland Hardwood	SC	14.01	11.59	3.03
Upland Hardwood	SE	16.18	12.66	4.54

The change in relative yield between the current ambient condition estimate and the scenario just meeting the standard results in changes in timber harvests and prices as shown in Table 6-8. In general harvests increase and prices decrease with resulting changes in consumer and producer welfare. Table 6-9 below shows the estimated welfare changes brought about by the rollback scenario. Consumer and producer welfare in the forest sector are more affected by the rollback environments than in the agricultural sector. In general, consumer welfare increases in both the forest and agricultural sectors as higher productivity tends to increase total production and reduce market prices. Because demand for most forestry and agricultural commodities is inelastic, producer welfare tends to decline with higher productivity as the effect of falling prices on profits more than outweighs the effects of higher production levels.

Table 6-8 Percentage Changes in National Timber Harvests and Prices under Rollback Scenario

		2010	2020	2030	2040
Hardwood Pulplog	Harvest	2.9	1.0	-2.6	-8.0
	Price	-25.6	-19.0	-31.0	-39.0
Hardwood Sawlog	Harvest	-0.1	0.3	3.0	4.6
	Price	-17.3	-20.9	-32.7	-44.8
Softwood Pulplog	Harvest	0.8	1.4	0.5	-2.7
	Price	-6.5	-8.2	-8.4	-8.8
Softwood Sawlog	Harvest	0.1	1.0	0.2	1.0
	Price	-2.4	-4.4	-6.1	-6.2

Table 6-9 Changes in Welfare under the Rollback Scenario Relative to Current Ambient Conditions (millions $2004)

Sector	Welfare Category	2010	2020	2030	2040
Forest	Consumer Surplus	1,804	1,977	3,567	4,082
Forest	Producer Surplus	-2,289	-1,917	-4,090	-4,503

Key uncertainties in this approach include:

- The use of proxy CR functions for species not included in the CR functions in the ISA.
- The uncertainty in the CR functions themselves.
- The uncertainty inherent in the various model components including the uncertainty within the CMAQ air quality surfaces.

In addition it should be noted that since public lands are not affected within the model the estimates presented would likely be higher were public lands included.

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 losses of about $1.4 billion or about $49 million per year and wood-using firms have gained about $966 million or about $35 million per year due to beetle outbreaks. This results in a net $15 million per year negative 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.

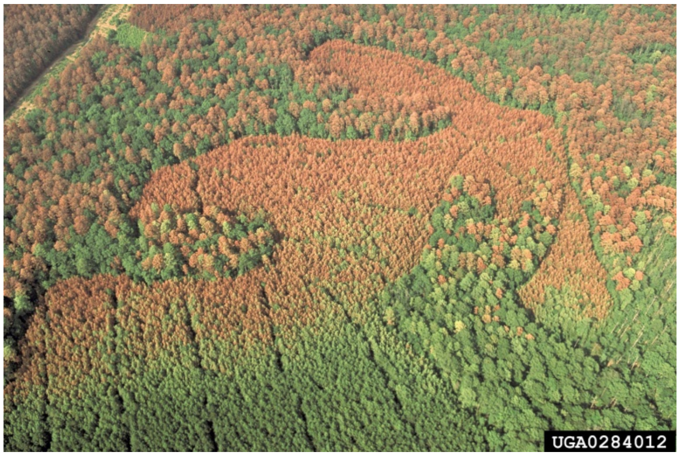


Figure 6- 3 Southern pine beetle damage. Courtesy: Ronald F. Billings, Texas Forest Service. Bugwood.org

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.

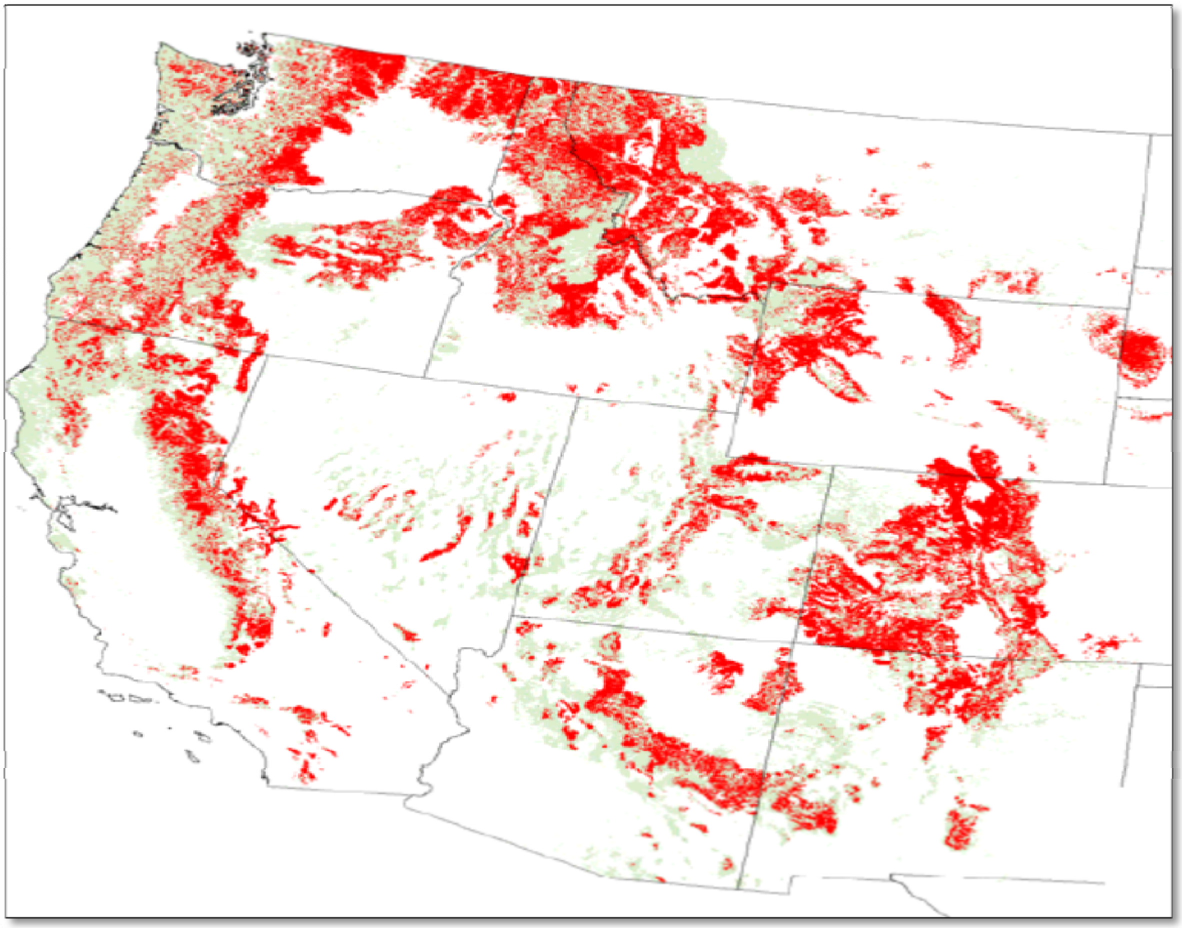


Figure 6- 4 Western bark beetle mortality obtained from State and Private Forestry aerial-detection surveys (2003-2007). Source: Western Forestry Leadership Coalition (2009) [This figure will be updated with O_3 concentrations in supplemental materials.]

In 2006 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 U.S. production (U.S. Forest Service, 2009 available at: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php). California also experiences high 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- 10 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- 10 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.

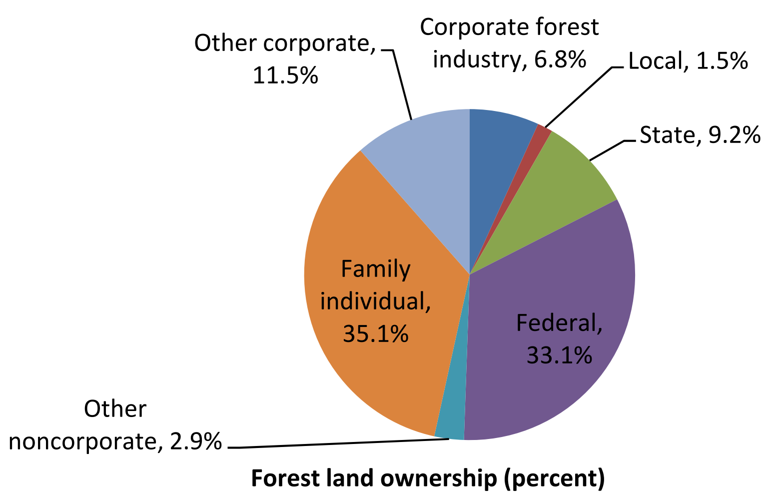


Figure 6- 5 Percent of forest land in the United States by ownership category, 2007 (percentages sum to 100) (Almost all forest lands are open for some form of recreation, although who may have access may be restricted). Source: USDA Forest Service

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- 11 details the survey responses to these questions.

Table 6- 11 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 6-12).

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- 12 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- 13 summarizes the responses to survey questions regarding the value of wildlife habitat and preservation of unique or endangered species.

Table 6- 13 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.

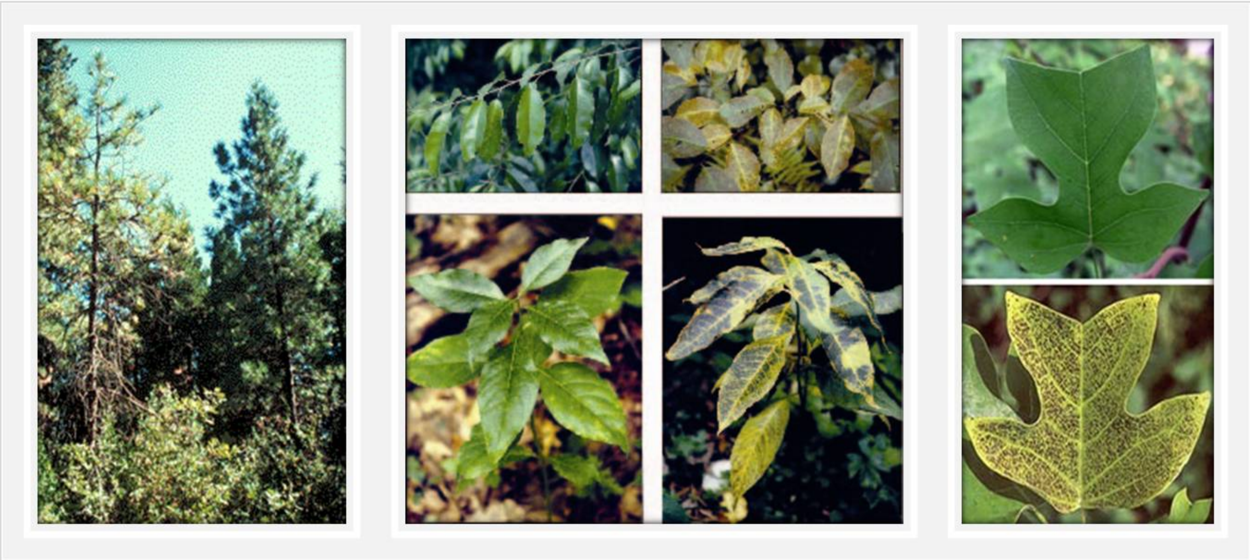


Figure 6- 6 Examples of foliar injury due to O_3 exposure. Courtesy: National Park Service

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- 14 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- 14 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 (OIF), The Economic Contribution of Active Outdoor Recreation – Technical Report on Methods and Findings (OIF, 2006). See Appendix 6-B 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 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- 15 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- 15 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 6-16. In addition to the activities listed in Table 6- 19% 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- 16 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- 17 for the Great Smoky Mountain National Park. The median value of the components of that spending is presented in Table 6- 18.

Table 6- 17 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- 18 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 overlaid 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.

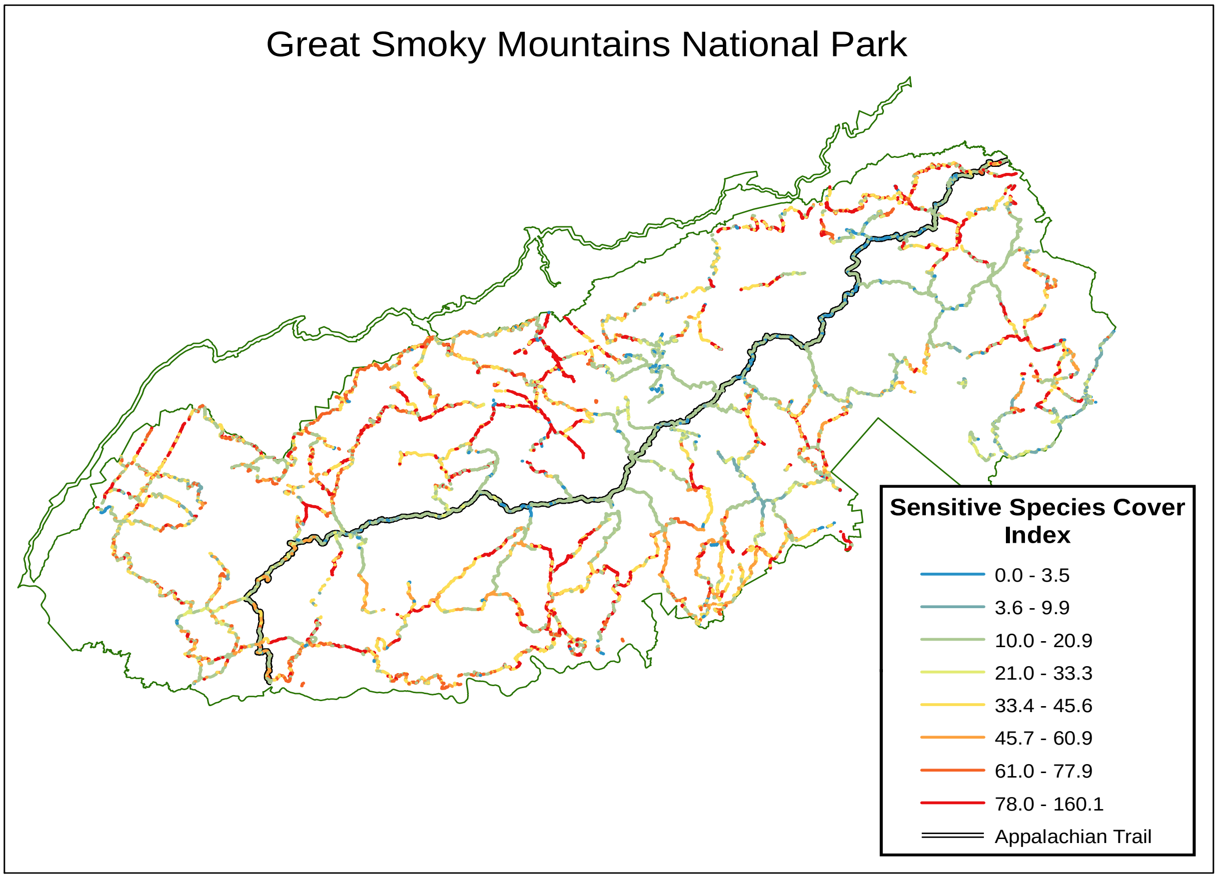


Figure 6- 8 Hiking trails within GRSM and sensitive species cover

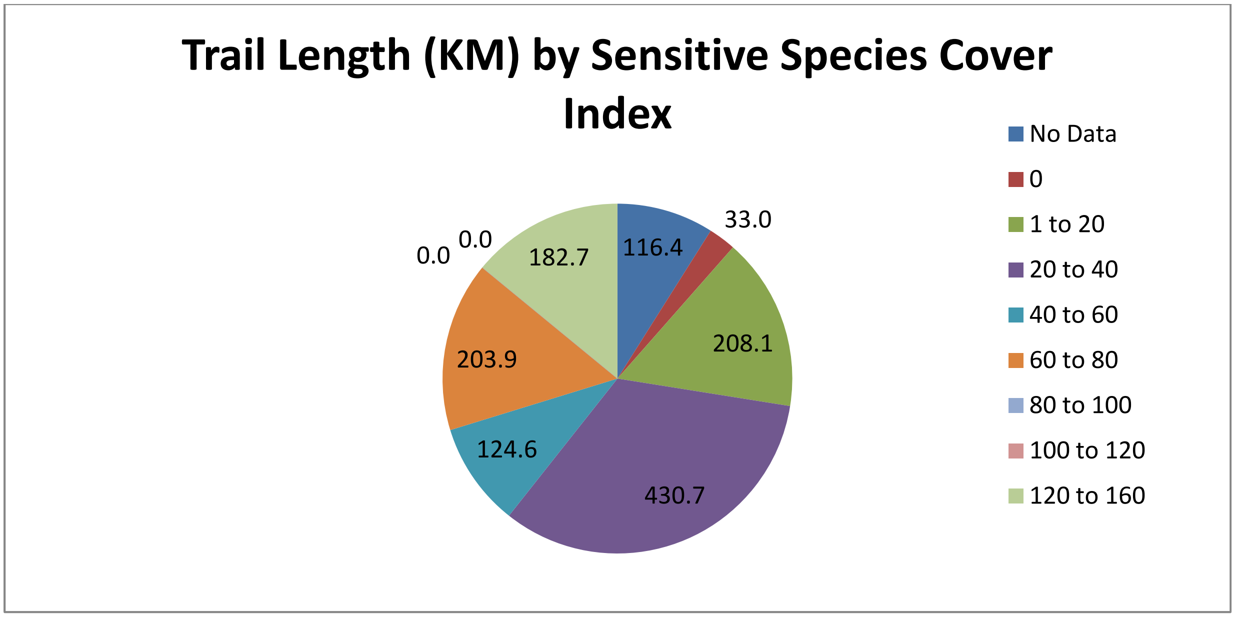


Figure 6- 9 Trail kilometers by species cover category

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- 19.

Table 6- 19 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 6-19, 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- 20 for the Rocky Mountain National Park. The median value of the components of that spending is presented in Table 6- 20.

Table 6- 20 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- 21 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- 22.

Table 6- 22 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- 22 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- 23 for the Sequoia and Kings Canyon National Parks. The median value of the components of that spending is presented in Table 6- 24.

Table 6- 23Visitor 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- 24 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. Given the limitations in the number of tree species with concentration-response function for O_3 exposure 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. Data from 5 urban areas were simulated to estimate the effect of O_3 (based on CMAQ modeled W126 index surfaces) on tree ecosystem services of carbon storage and air pollution removal. The prototype i-Tree Forecast model was used to estimate growth and ecosystem services by trees over a 25 year period. The prototype i-Tree Forecast model was used to estimate growth and ecosystem services by trees assuming the absence of O_3 effects on tree growth starting with the measured inventory of trees in the area and standard growth rates over a 25 year period for the base case. The tree growth was then adjusted downward from the base case based on the reduced growth factors for species present in the area of the 11 species for which we have concentration response functions using the W126 protocol and equations (only species with W126 concentration-response functions were reduced). Unlike the FASOM model methods in Section 6.2.2.1 concentration response functions were not assigned to the other species in the study area. The differences between the two scenarios are then contrasted for the 25 year period. Two sets of scenarios were run simulating base case v. current ambient conditions and base case v. a simulation of "just meeting" the current standard (rollback). Model assumed an annual influx of between 1-6 trees/ha/yr and a 3-4% annual mortality rate. See Appendix 6-C for details of the model and the methodology employed for these case studies.

The five urban areas were chosen based on data availability and presence of species with a W126 concentration–response function. No urban area with available vegetation data had more than three qualified species present. The selected study areas are Baltimore, Syracuse, the Chicago region, Atlanta, and the urban areas of Tennessee. Table 6-25 shows details of the tree species present, the percent of top ten species, and the percent of total species in each study area.

Table 6-25 Tree Species in Selected Urban Study Areas

Study Area					
	Baltimore	**Syracuse**	**Chicago Region**	**Atlanta**	**Tennessee**
1					
2		Sugar maple			Virginia pine
3		Black cherry			
4			Black cherry		
5					
6	Black cherry				
7			Sugar maple	Black cherry	
8					Red maple
9	Red maple	Eastern cottonwood		Red maple	
10					
% of top 10	8.5	18.5	7.7	6.6	9.3
% of total	11.2	20.2	10.5	8.9	17.4

The preliminary results for changes in carbon storage estimates show substantial reductions to the capacity of these urban forests to sequester carbon at ambient O_3 conditions and with simulations "just meeting" the current standards even with the severe limitations in the tree species concentrations. Initial estimates suggest that at current ambient conditions about5 million tons of carbon storage would be lost over 25 years (about 200,000 tons per year). In the simulation that just meets the current standard O_3 exposure still accounts for 4.5 million tons of lost carbon storage over 25 years (about 180,000 tons per year). The difference between current ambient conditions and simulating just meeting the current standard is approximately 760,000 tons over 25 years. Four of the urban areas show reductions in the loss of carbon storage between the current ambient and rollback simulations however Syracuse gains only 5 tons of additional carbon storage over the 25 year simulation due to the fact that the relative yield loss values for Syracuse are not substantially different between the two scenarios. Of the five areas modeled the combined urban areas of Tennessee has the largest estimated gains in carbon storage. See Table 6-26 for details.

Table 6-26 O_3 Effects on Carbon Storage for 5 Urban Areas

25 Year Carbon Storage (metric tons)						
Region	**Base Case**	**Recent Ambient** O_3	O_3 **Just Meeting Current Standard**	**Difference Recent Ambient vs Base Case**	**Difference Just Meeting Standard vs Base Case**	**Difference Recent** O_3 **vs Just Meeting Standard**
Atlanta	1,426,626	1,214,522	1,251,089	-212,105	-175,537	36,568
Baltimore	577,824	508,248	535,080	-69,577	-42,744	26,833
Chicago Region	19,560,361	16,869,139	17,017,363	-2,691,223	-2,542,999	148,224
Syracuse	169,356	141,308	141,313	-28,048	-28,043	5
Tennessee	20,568,155	18,314,030	18,859,868	-2,254,125	-1,708,288	545,837
Totals	42,302,322	20,194,977	37,804,708	-5,255078	-4,497,611	757,467

These results should not be combined with the results from the FASOM model discussed in Section 6.2.2.1. The methodology employed for the FASOM runs assigned values for O_3 exposure concentration-response functions for species that do not have a function calculated in the ISA. This was done to ensure the dynamic trade-offs in the model functioned properly. The iTree model does not provide these trade-offs between species so the species that didn't have a concentration-response function were not assigned values. This could lead to an underestimation of the carbon losses in iTree if in fact the other species in the study area are sensitive to O_3 exposure effects.

The preliminary results for changes in air pollution removal estimates for carbon monoxide, nitrogen dioxide, O_3, and sulfur dioxide show reductions to the capacity of these urban forests canopies to remove pollution at ambient O_3 conditions and after simulating just meeting the current standards. These reductions only reflect a portion of the impacts on pollution removal by urban forests due to the limitations in the availability of C-R functions for all of the common tree species in urban areas, and the limited number of urban areas for which the iTree model has been applied. Though the model does include estimates for particulate matter we do not include those estimates here because the model does not yet distinguish between PM_{10} and $PM_{2.5}$. Initial estimates suggest that at current ambient conditions about 3,200 tons of air pollution removal capacity is lost annually (or about 80,000 tons over 25 years) in the 5 areas modeled. After simulating just meeting the current standard O_3 exposure still accounts for 2,320 tons of lost air pollution removal capacity annually (or about 58,000 over 25 years). As in the simulations for carbon storage Syracuse and Baltimore see the least change in capacity with the urban areas of Tennessee reporting the largest changes. Syracuse has essentially no change between the current ambient condition and meeting the current standard while Tennessee gains about 635 tons of potential pollution removal annually between the two scenarios. See Table 6-27 for details.

Table 6-27 Changes in Pollution Removal between Current Ambient Conditions and After Simulating Just Meeting the Current Standards

Pollution Removal (metric tons, annualized over 25 years)						
	Base Case	**Current Ambient**	**Rollback**	**Difference Ambient v Base Case**	**Difference Rollback v Base Case**	**Difference Rollback v Ambient**
CO						
Atlanta	259.28	252.48	55.44	-6.8	-3.84	2.96
Baltimore	7.44	7.04	7.2	-0.04	-0.24	0.16
Chicago Region	344.8	314.52	318.76	-30.28	-26.04	4.24
Syracuse	2.2	1.96	1.96	-0.24	-0.24	0
Tennessee	514.16	473	488.68	-41.16	-25.48	15.68
NO2						
Atlanta	274.08	242.68	2565.36	-31.4	-17.72	13.68
Baltimore	78.72	74.52	76.2	-4.2	-2.52	1.68
Chicago Region	4,169.68	3,802.72	3,855	-366.16	-314.88	51.28
Syracuse	2	1.8	1.8	-0.24	-0.24	0
Tennessee	2,175.24	2,001.12	2,067.52	174.12	-107.72	66.4
O_3						
Atlanta	1,019.8	902.96	953.92	-116.88	-65-88	51
Baltimore	250.48	237.08	242.52	-13.4	-7.96	5.44
Chicago Region	9,748.04	8,892.16	9,012.04	-855.92	-736.04	119.88
Syracuse	61.76	54.8	54.8	-7	-7	0
Tennessee	15,728.2	14,469.16	14,949.2	-1,259	-778.96	480.04

Pollution Removal (metric tons, annualized over 25 years)						
	Base Case	**Current Ambient**	**Rollback**	**Difference Ambient v Base Case**	**Difference Rollback v Base Case**	**Difference Rollback v Ambient**
SO_2						
Atlanta	135.2	119.68	126.44	-15.48	-8.72	6.76
Baltimore	34.08	32.24	33	-1.84	-1.08	0.76
Chicago Region	1,187	1,082.8	1,097.4	-104.24	-89.64	14.6
Syracuse	2.84	2.52	2.52	-0.32	-0.32	0
Tennessee	2,374.84	2,184.72	2,257.2	-190.12	-117.6	72.52
Total						
Atlanta	1,488.36	1,317.8	1,392.2	-170.56	-96.16	74.4
Baltimore	370.72	350.88	358.92	-0.794	-11.8	8.04
Chicago Region	15,449.68	14,093.2	14,283.2	-1,356.48	-1,166.48	190
Syracuse	68.84	61.04	61.04	-7.8	-7.8	0
Tennessee	20,792.4	19,128	19,762.6	-1,664.4	-1,029.8	634.6

Note: for Syracuse there is no difference as the RYL values because recent ambient O_3 concentrations are close to attainment with the current standards.

Key uncertainties in this approach include:

- C-R functions are available for only 11 species. The urban areas chosen had a maximum of 3 of the 11 species present. This limitation neglects the effects of O_3 on species where no C-R function is available. In the areas modeled that means that the majority of trees in the cities were not accounted for in the O_3 damages.

- Uncertainties inherent within the models, both iTree itself and the CMAQ generated air quality surfaces.

If we were able to account for O_3 damages to the species without a CR function the estimates would likely be higher.

[*For the second draft we will explore expanded analyses to characterize how the changes modeled here would relate to changes in ambient concentrations of pollutants*.]

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.

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 analyses for the 2nd draft.]*

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

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 average percentage yield reductions associated with recent O_3 levels for the 11 species for which we have concentration-response functions is 5.2%.
- 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 1,100 to 90,000 tons of carbon per year across the urban case study areas over 25 years.
- The estimated reduction in tons of pollutants removed is 195 to 25,700 tons across the urban case study areas over 25 years.
- Simulating just meeting the current O_3 standard is estimated to reduce the loss of commercial forest yields by about 1%, and increase GHG mitigation potential by about 22 million tons of CO_2 equivalents per year for 2010 to 2020.
- Simulating just meeting the current O_3 standard is estimated to increase carbon sequestration by urban forests in the case study areas by 5 to 545,000 tons of carbon over 25 years. Removal of air pollution is estimated to increase by 0 to 16,000 tons across the urban case study areas over 25 years.

7.4 OBSERVATIONS

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 trails 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.

In addition, on a national scale O_3 damage to vegetation causes widespread impacts to a large collection of ecosystem services. It is possible for several aspects of O_3 effects to interact to contribute to an impact on multiple ecosystem services. For instance biomass loss directly impacts timber provision but other contributing effects include increased susceptibility to drought and insect attack that can impact timber production directly and also may contribute to increased fire risk.

Many ecosystem services are very difficult to quantify and are 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 exposure on these services is not possible at this time.

Although we are unable to quantify the O_3 impacts on the majority of ecosystem services potentially affected by O_3 exposure 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.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 result the assessment necessarily focuses on proportional changes in the summed-biomass loss estimates.

Fifth, the assessments of impacts of O_3 on the ecosystem services in urban areas related to carbon storage and air pollution removals cover only a few species and urban areas. These urban areas were selected based on the availability within the iTree model and the availability of C-R functions for tree species in the urban areas. The potential for impacts in other urban areas with elevated O_3levels has not been systematically evaluated, but we expect to provide additional information in the second draft REA. In addition, the metric used to indicate air pollution removals by urban forests is tons of pollutants removed, which for secondary pollutants like $PM_{2.5}$ and O_3, may not be as easily interpreted as a metric like changes in ambient O_3 in ppb or changes in ambient $PM_{2.5}$ in $\mu g/m^3$. We will evaluate methods for translating tons of pollution removed into reductions in ambient concentrations and consider including alternative metrics in the second draft REA.

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 also include, U.S. Forest Service Forest Health Monitoring data on visible foliar injury, 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.

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APPENDIX 5A: MAPS OF INDIVIDUAL TREE SPECIES RELATIVE BIOMASS LOSS

This appendix presents the maps and analyses for the 11 individual tree species analyzed for relative biomass loss (RBL) in Chapter 5 of this report[1]. Maps of RBL are presented for each species under recent ambient conditions using the 3-month, 12-hr W126 averaged from 2006 to 2008 and an exposure scenario of just meeting the current 8-hr secondary standard. Additional maps are included for eastern species showing the Importance Values (IV) and scaled-RBL for ambient and current standard O3 exposure scenarios. The results of the linear model analyses are included for each species. This includes the test statistics (p-values) for significant differences from zero and goodness of fit metrics, however it is important to note that because the linear model was forced through the origin, the r-squared values cannot be interpreted in the standard manner, however, they may still provide useful information about overall fit.

[1] Relative biomass loss is a measure of the proportional loss in biomass relative to biomass that would occur in the absence of exposure to ambient ozone.

PONDEROSA PINE

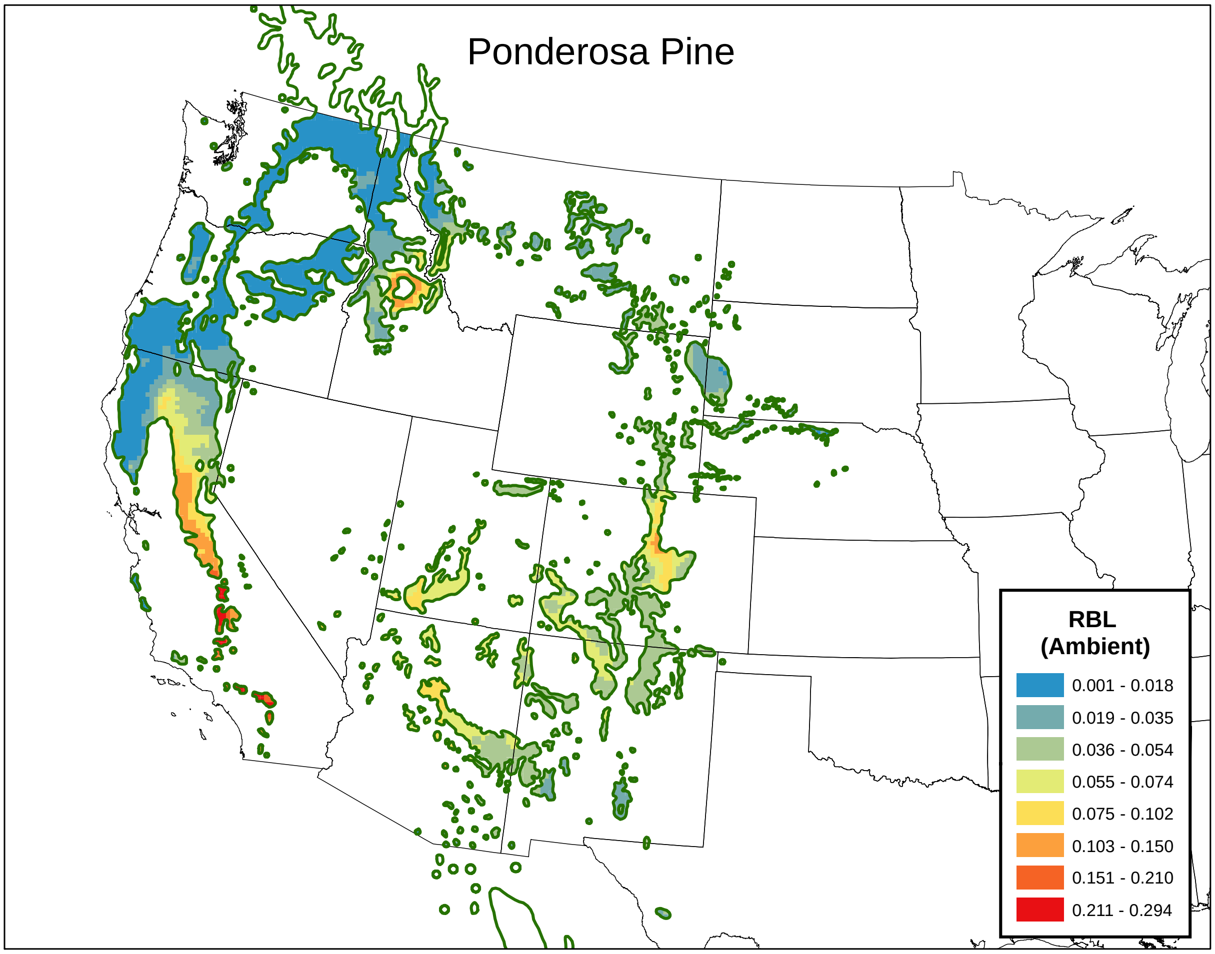


Figure 5A- 1 Relative Biomass Loss for Ponderosa Pine under ambient O3 conditions

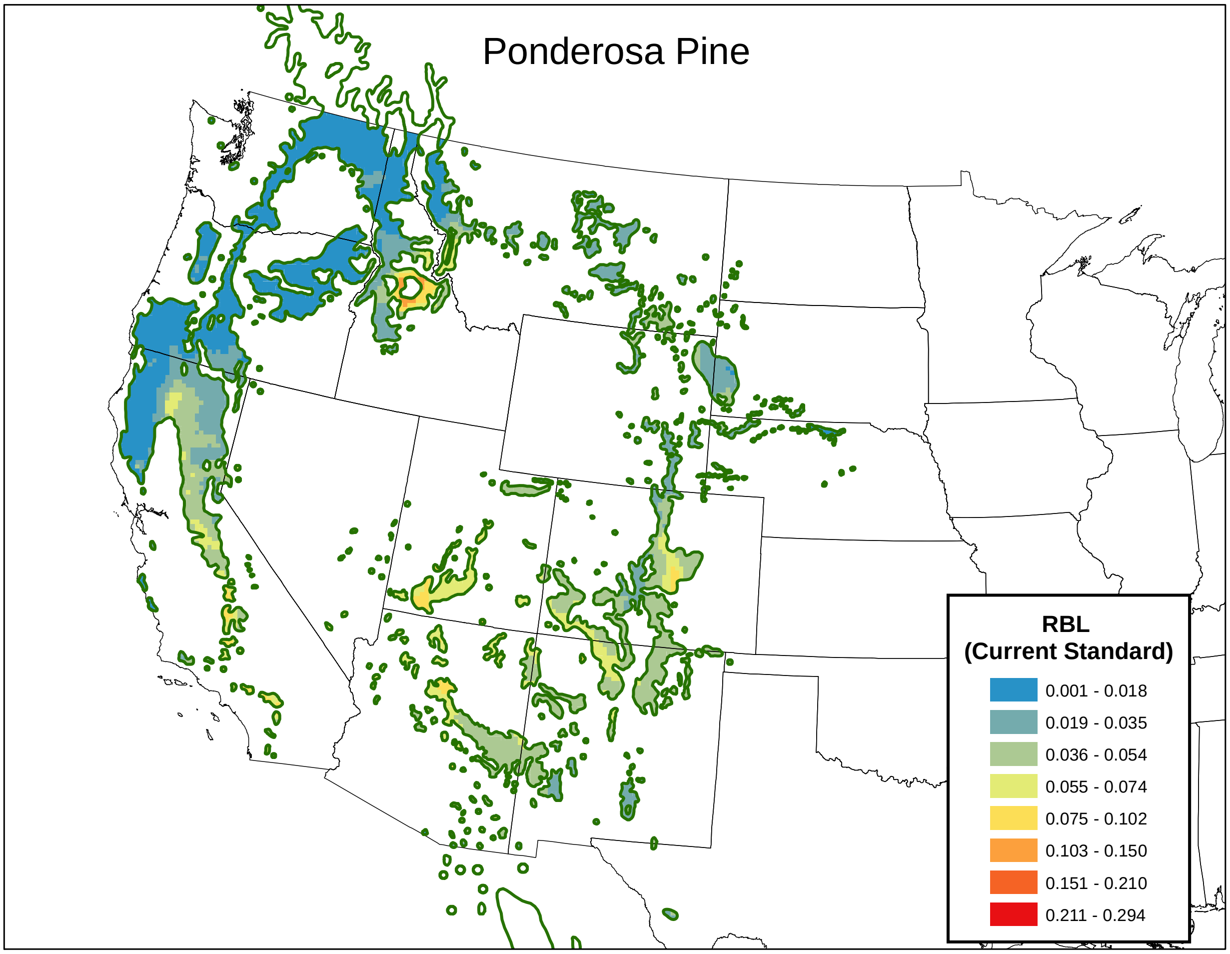


Figure 5A- 2 RBL for Ponderosa Pine under the Current Standard rollback scenario

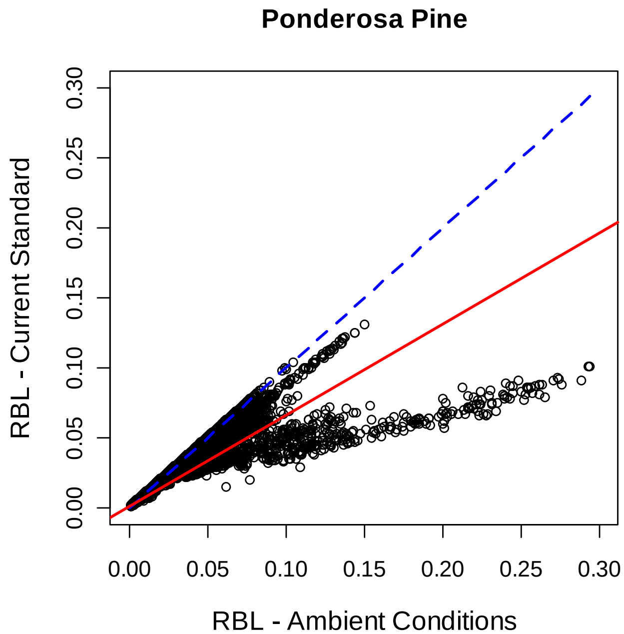


Figure 5A- 3 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Ponderosa Pine

Table 5A- 1 Summary of Linear Model Results for Ponderosa Pine

Linear Model Results	Current Standard	Alt A	Alt B
N	6322		
r-squared	0.8503		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.653		

RED ALDER

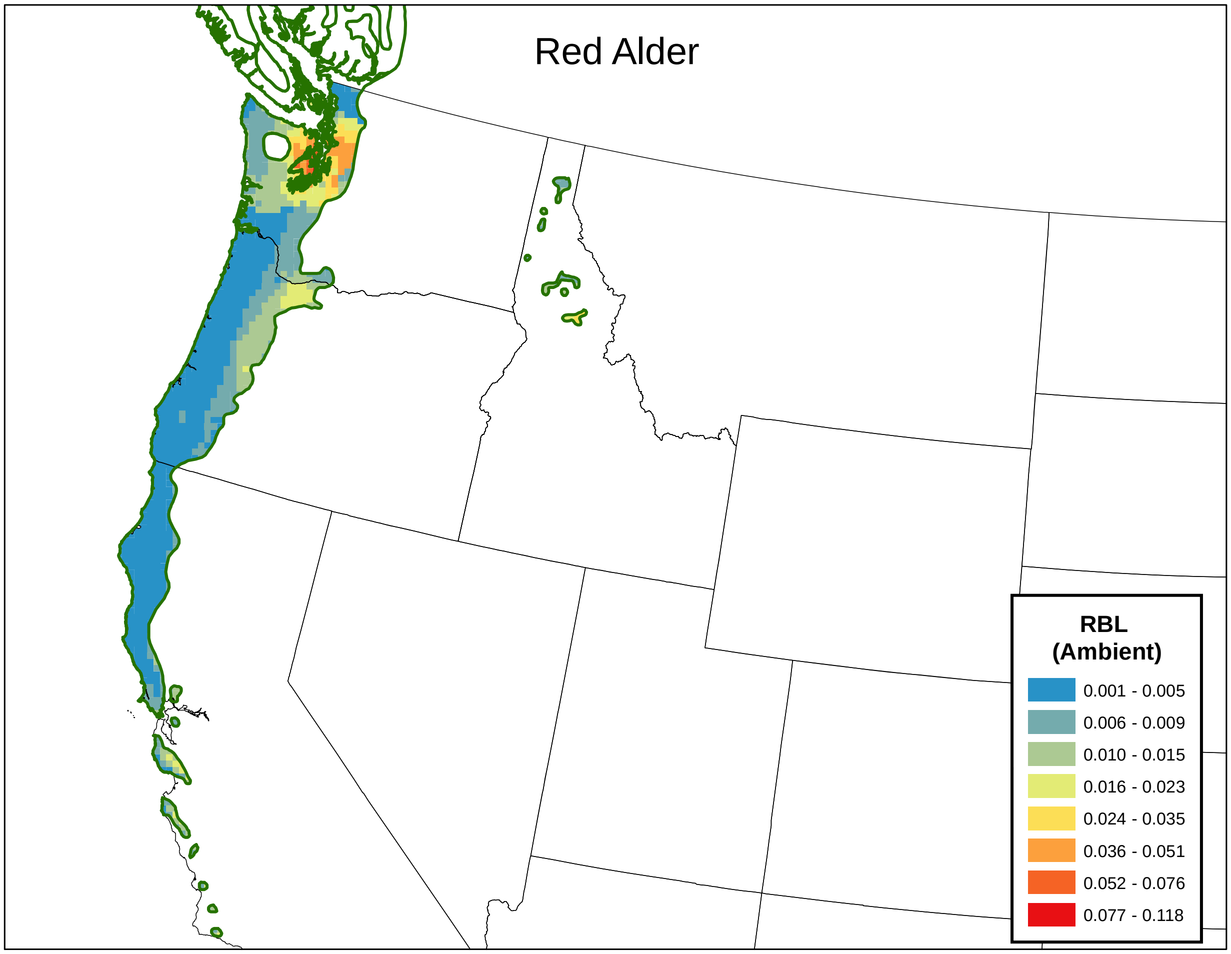


Figure 5A- 4 Relative Biomass Loss for Red Alder under ambient O3 exposure conditions

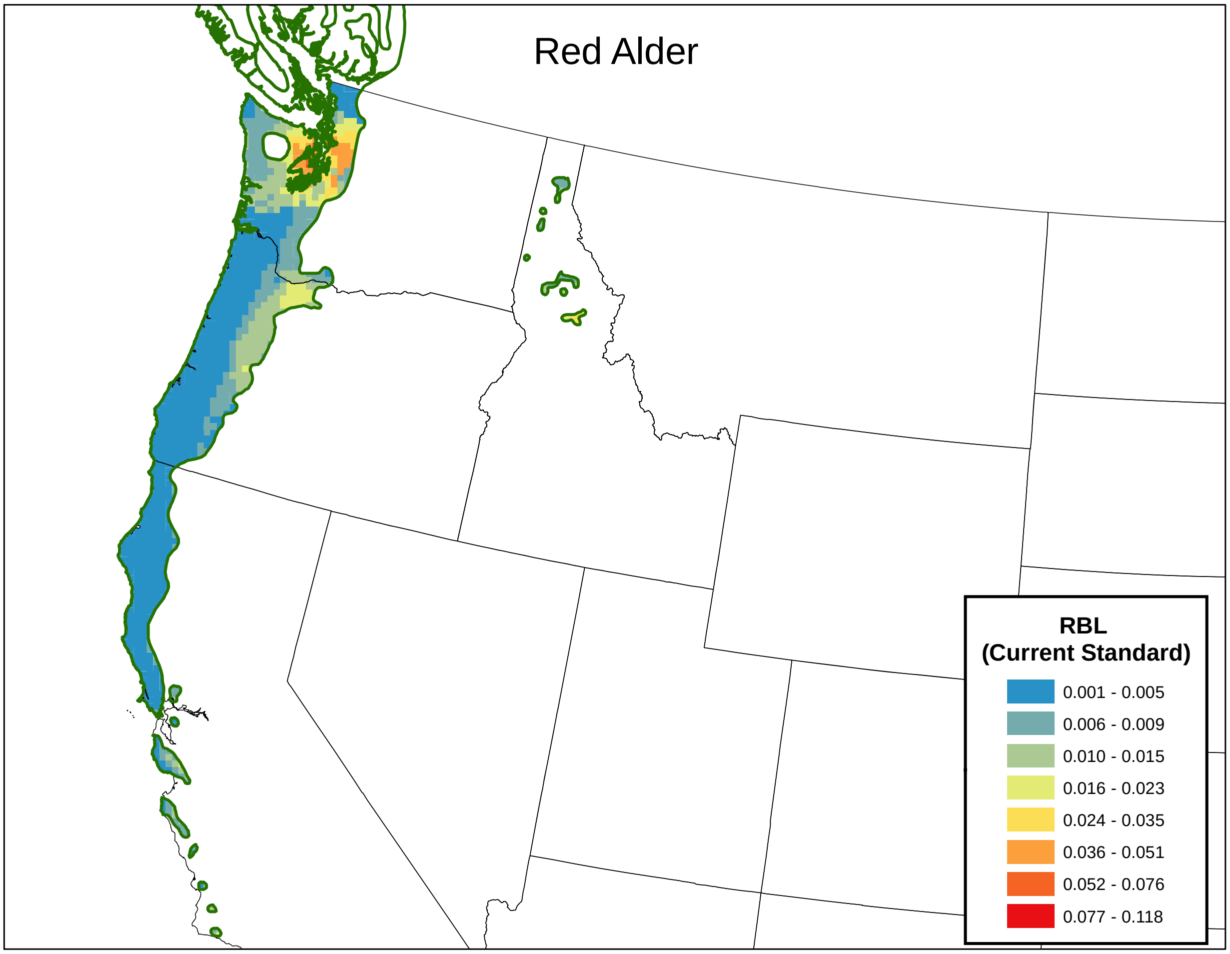


Figure 5A- 5 Relative Biomass Loss for Red Alder under the Current Standard Rollback scenario

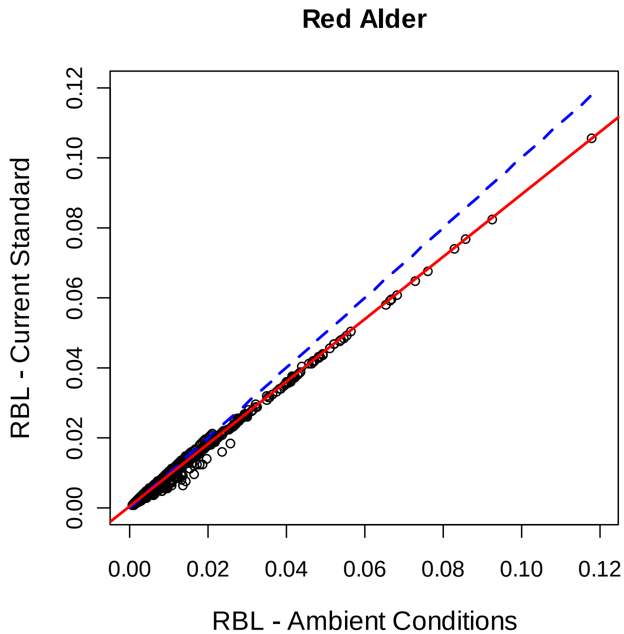


Figure 5A- 6 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Red Alder

Table 5A- 2 Summary of Linear Model Results for Red Alder

Linear Model Results	Current Standard	Alt A	Alt B
N	1250		
r-squared	0.9962		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.894		

DOUGLAS FIR

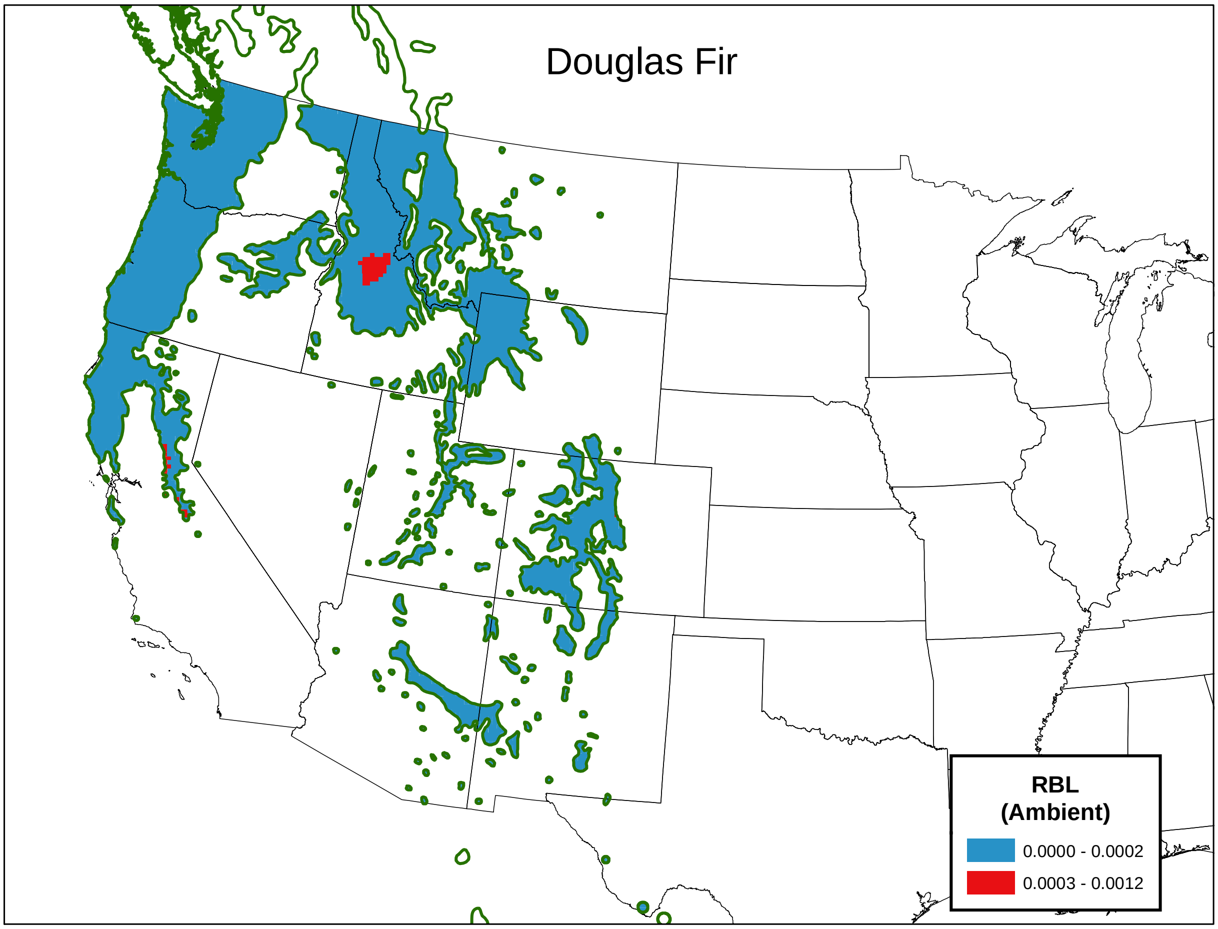


Figure 5A- 7 Relative Biomass Loss of Douglas Fir under recent ambient conditions

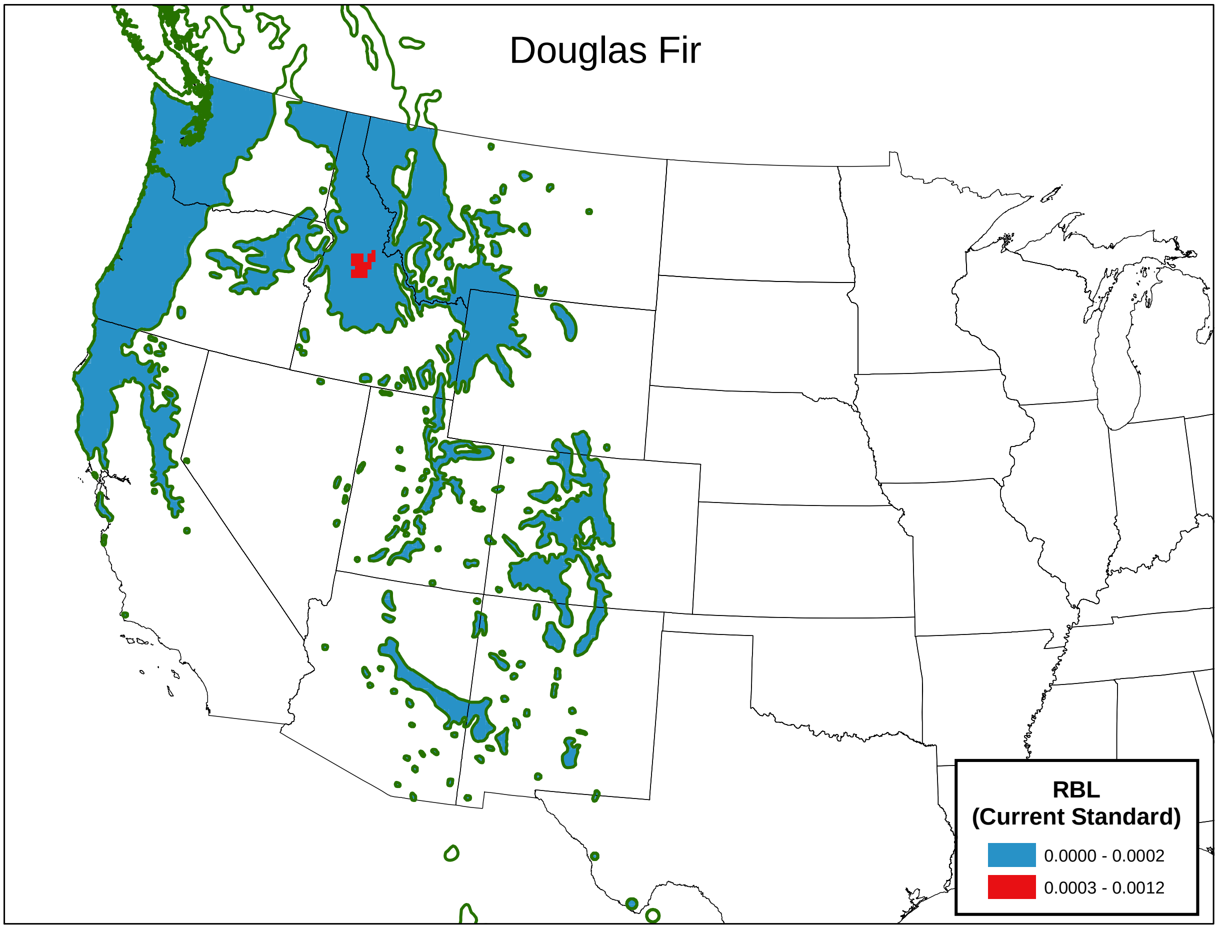


Figure 5A- 8 Relative Biomass Loss of Douglas Fir under the current standard rollback scenario

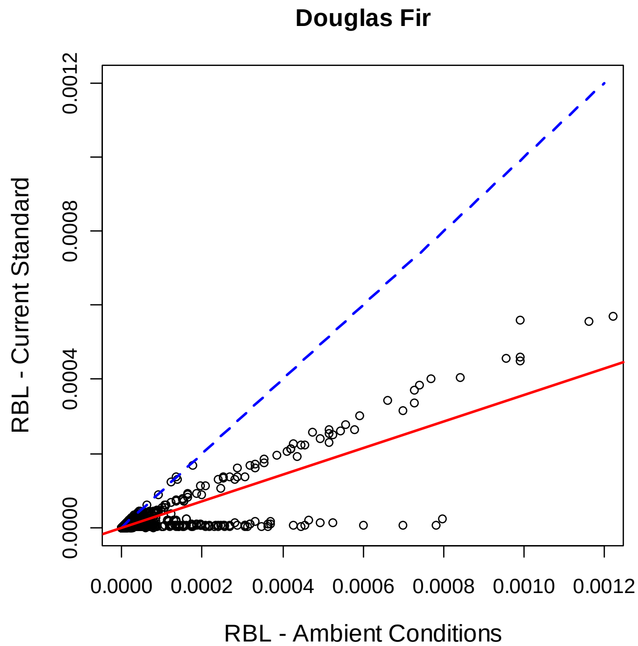


Figure 5A- 9 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Douglas Fir

Table 5A- 3 Summary of Linear Model Results for Douglas Fir

Linear Model Results	Current Standard	Alt A	Alt B
N	6535		
r-squared	0.7213		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.357		

EASTERN WHITE PINE

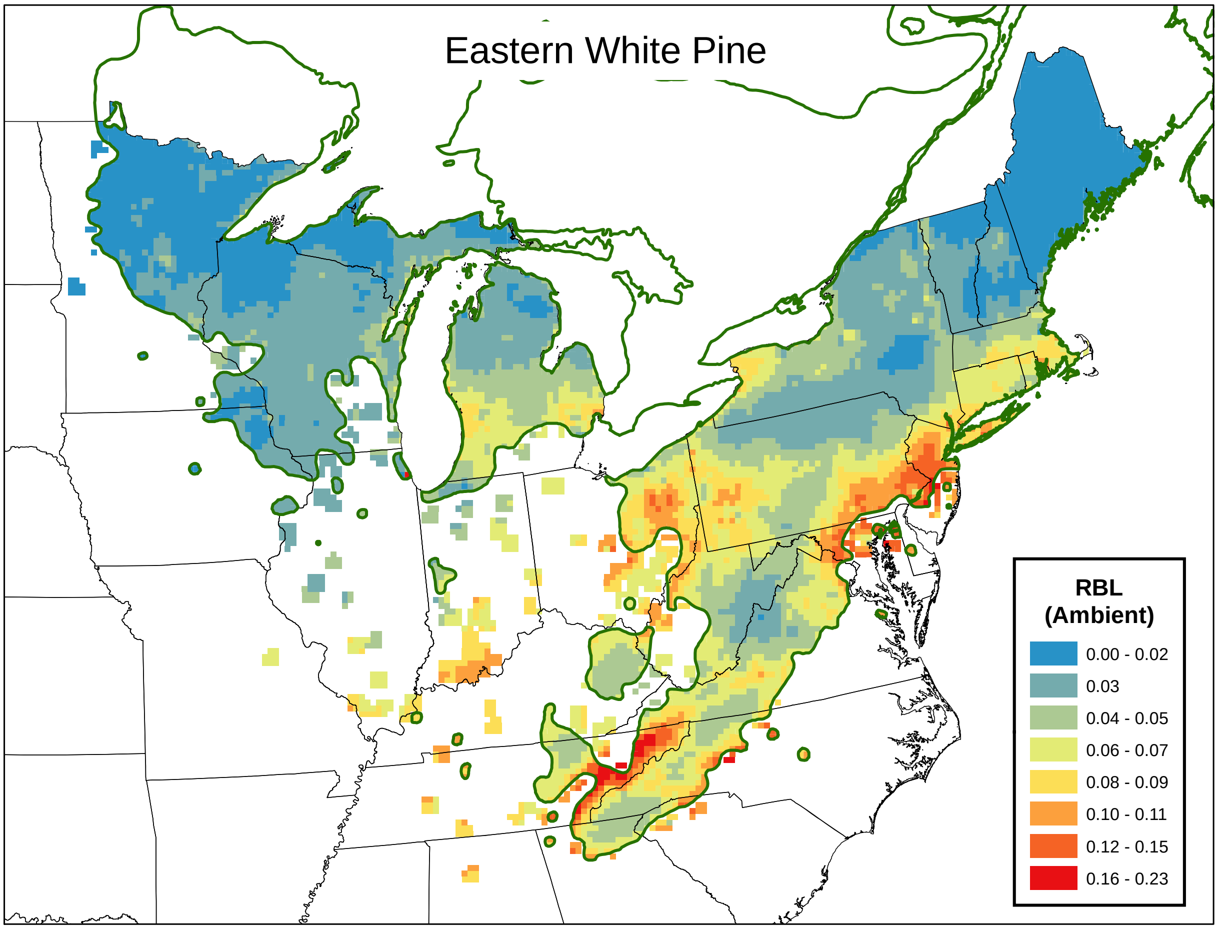


Figure 5A- 10 Relative Biomass Loss of Eastern White Pine under recent ambient conditions

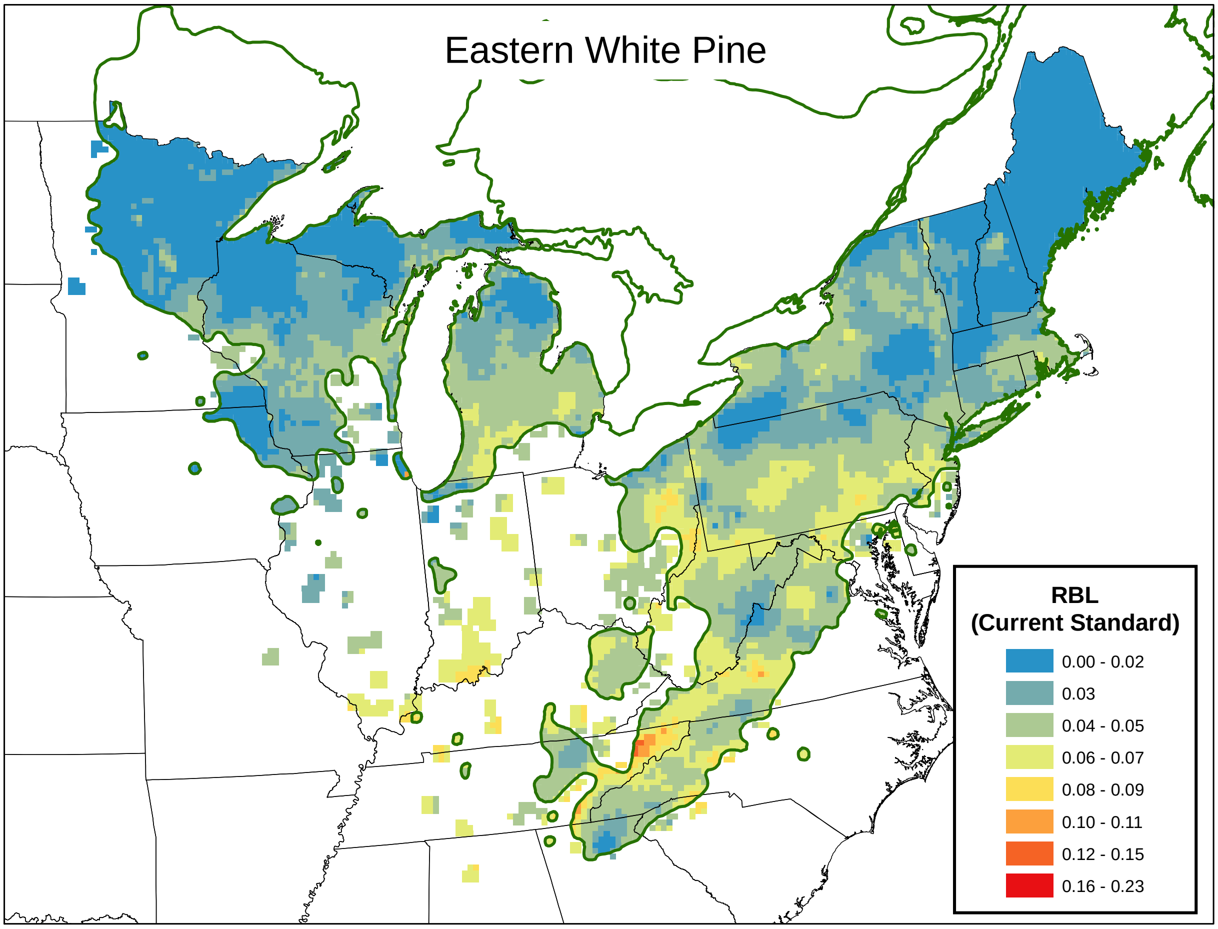


Figure 5A- 11 Relative Biomass Loss of Eastern White Pine under the current standard rollback scenario

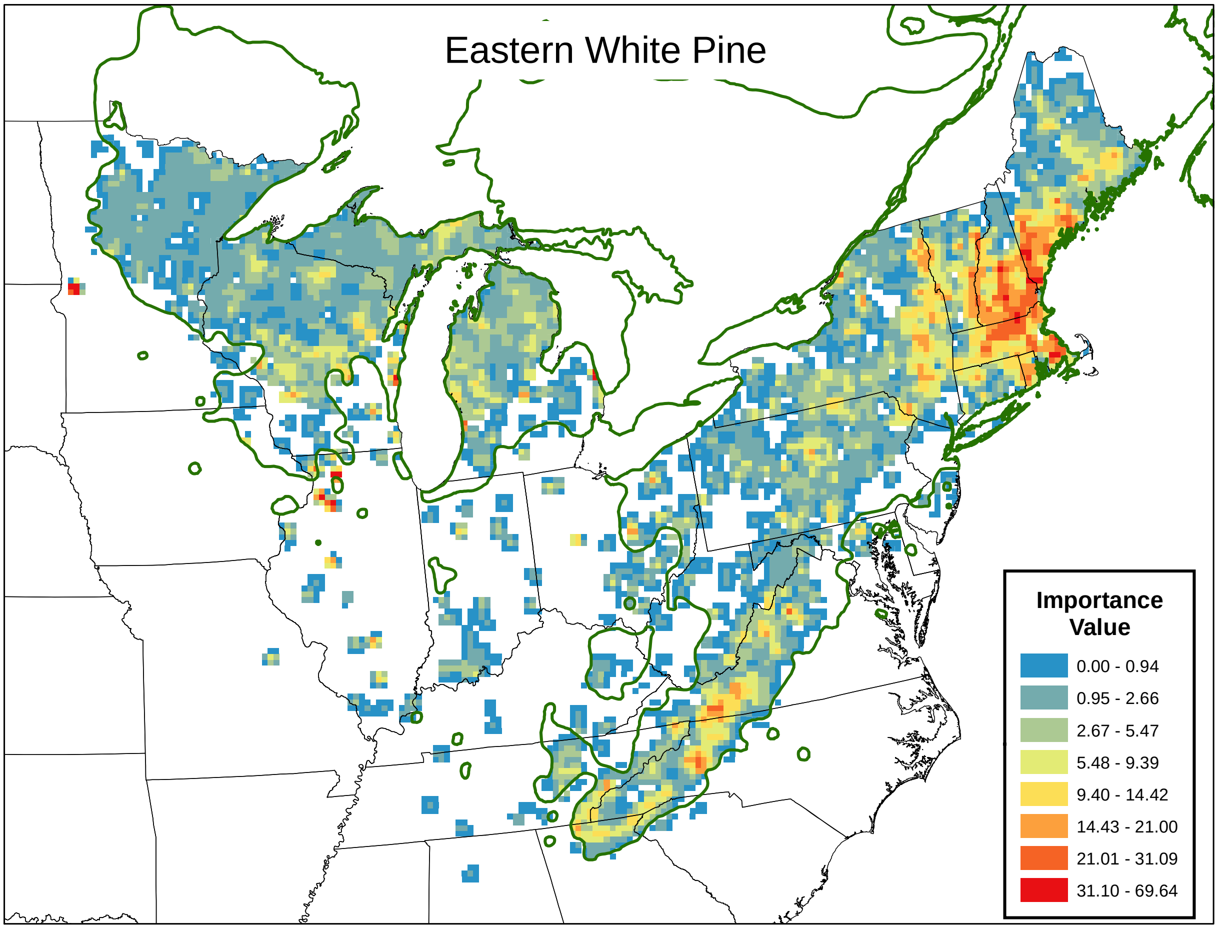


Figure 5A- 12 Importance Values for Eastern White Pine (data from Prasad and Iverson, 1997)

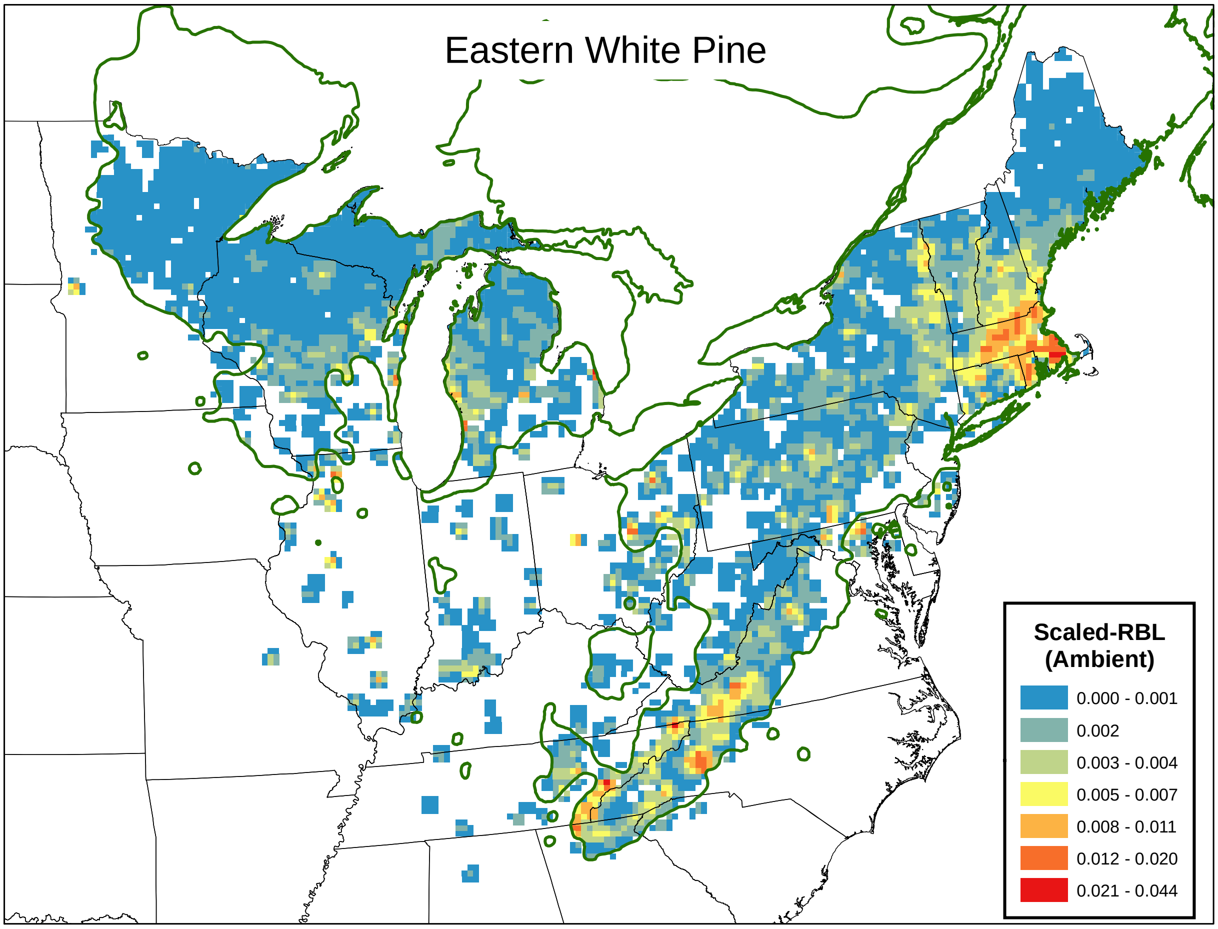


Figure 5A- 13 Scaled Relative Biomass Loss for Eastern White Pine under recent ambient conditions

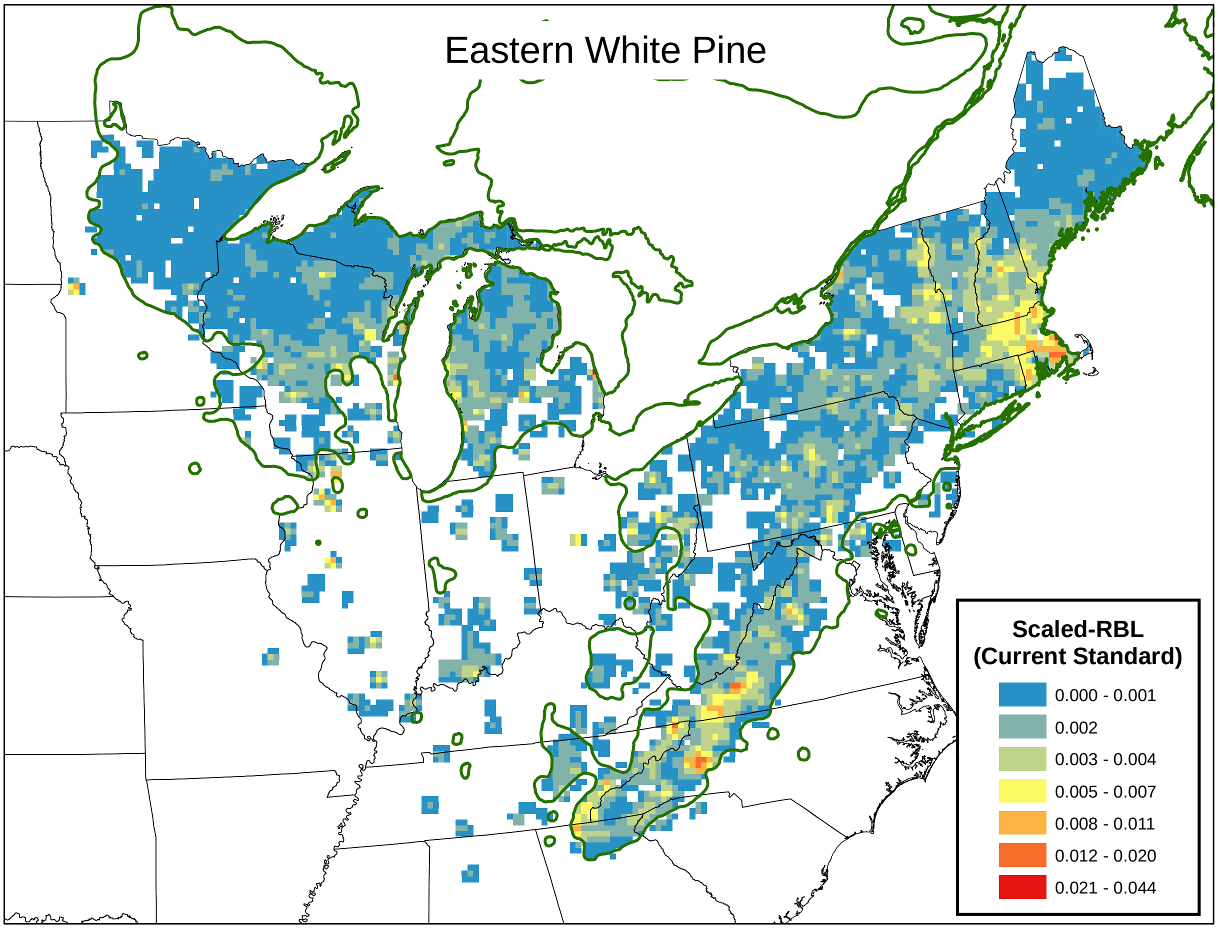


Figure 5A- 14 Scaled Relative Biomass Loss for Eastern White Pine under the current standard rollback scenario

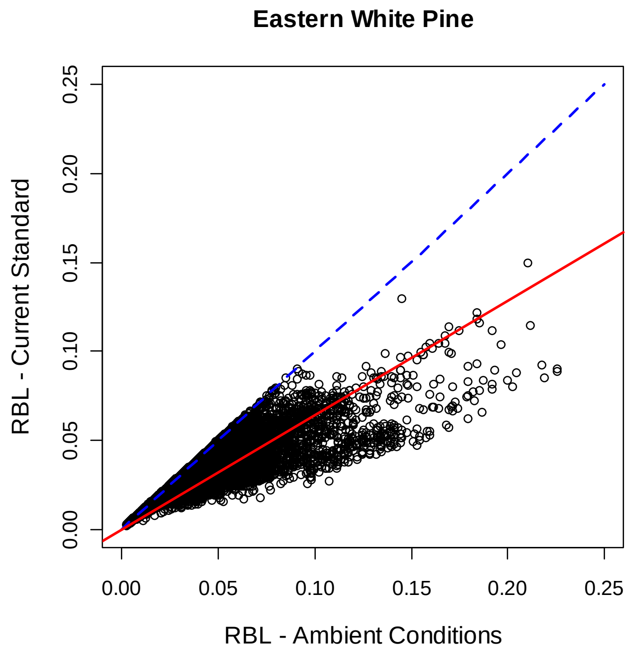


Figure 5A- 15 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Eastern White Pine

Table 5A- 4 Summary of Linear Model Results for Eastern White Pine

Linear Model Results	Current Standard	Alt A	Alt B
N	8780		
r-squared	0.9093		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.642		

VIRGINIA PINE

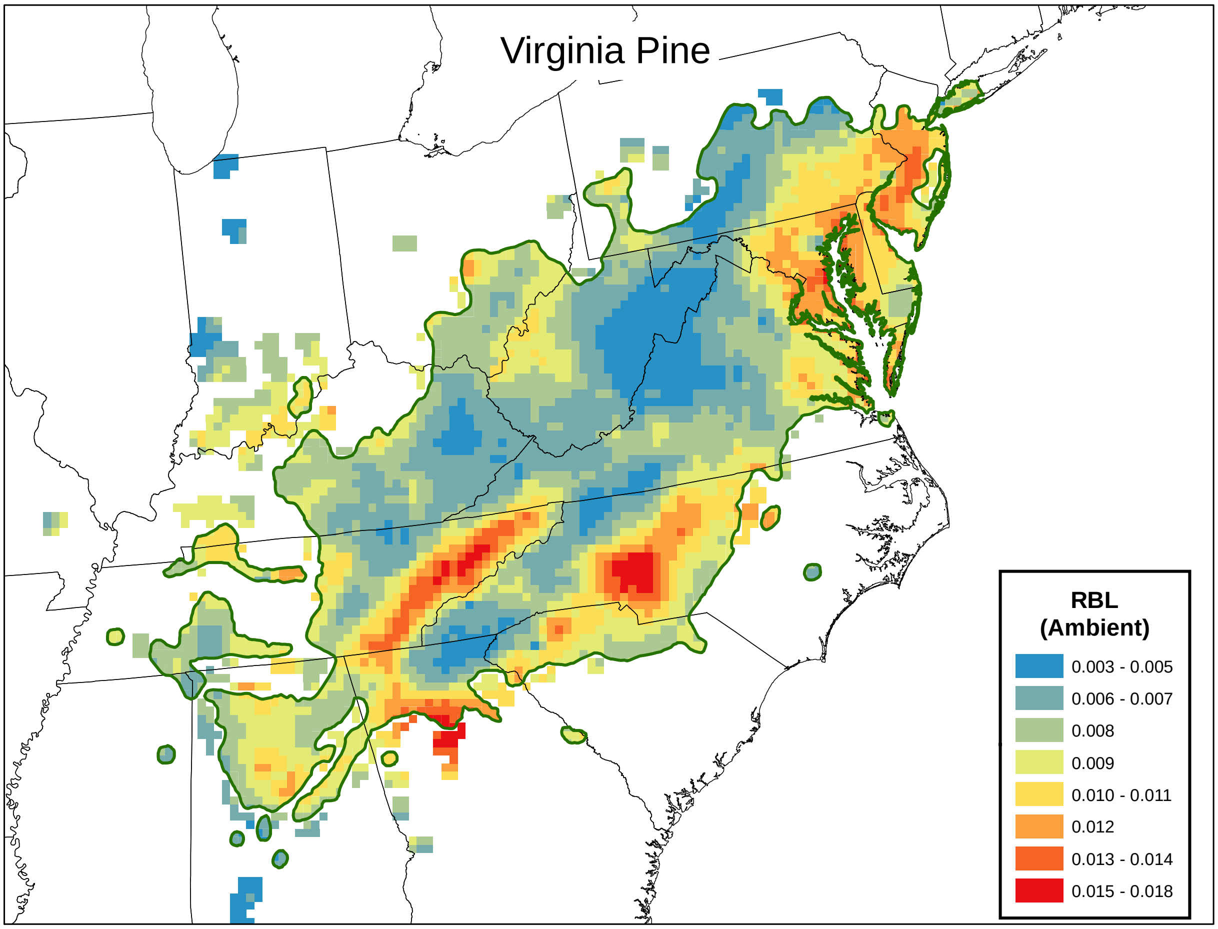


Figure 5A- 16 Relative Biomass Loss of Virginia Pine under recent ambient conditions

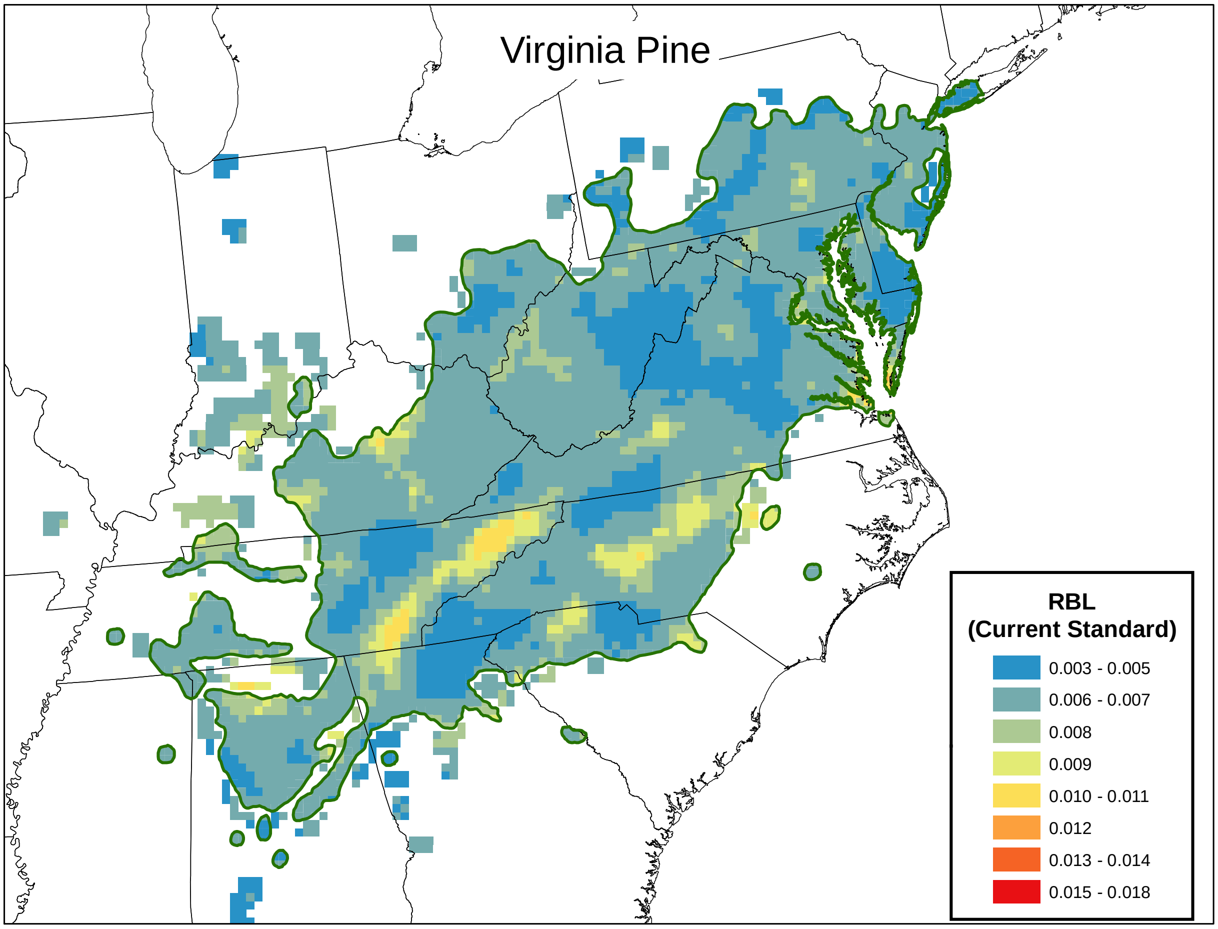


Figure 5A- 17 Relative Biomass Loss of Virginia Pine under the current standard rollback scenario

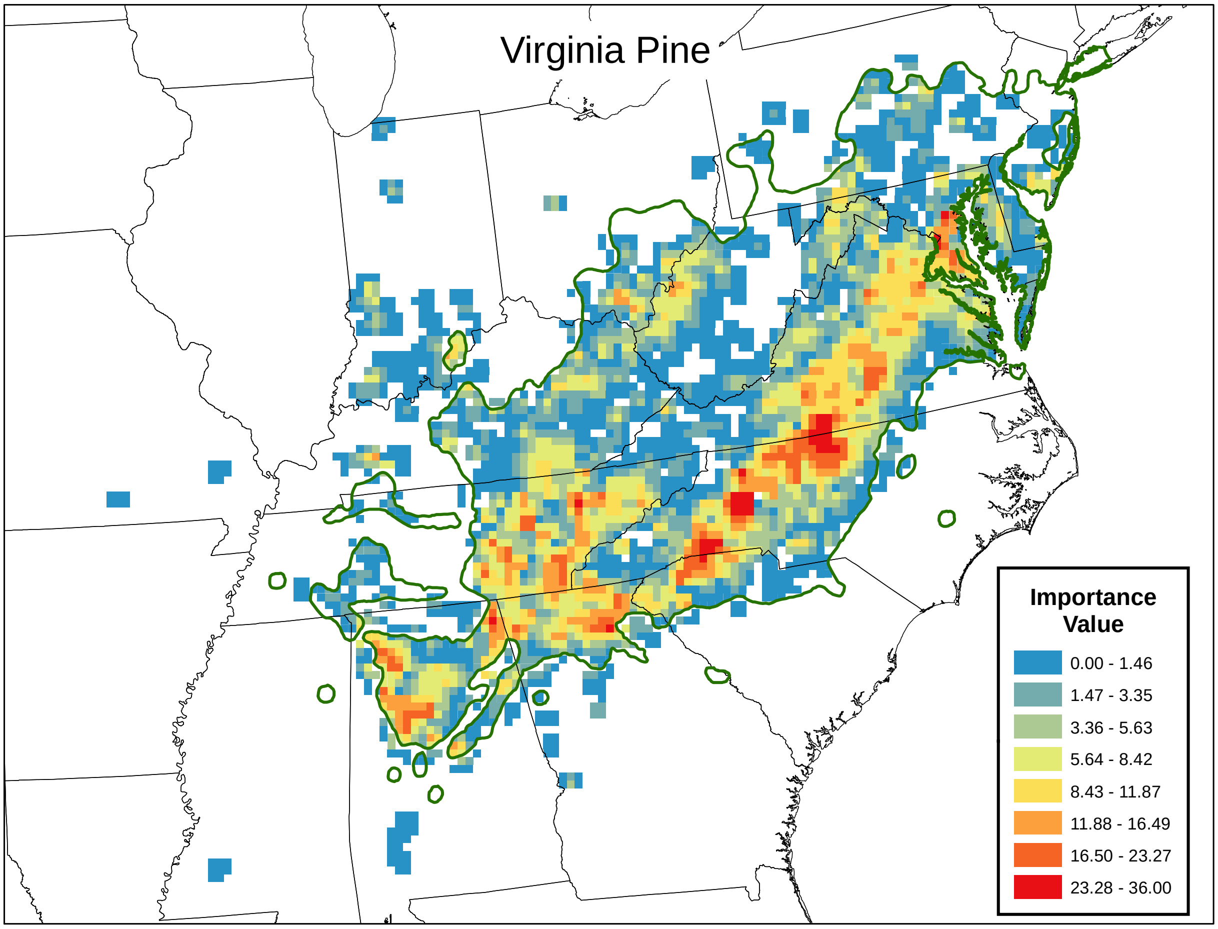


Figure 5A- 18 Importance Values for Virginia Pine

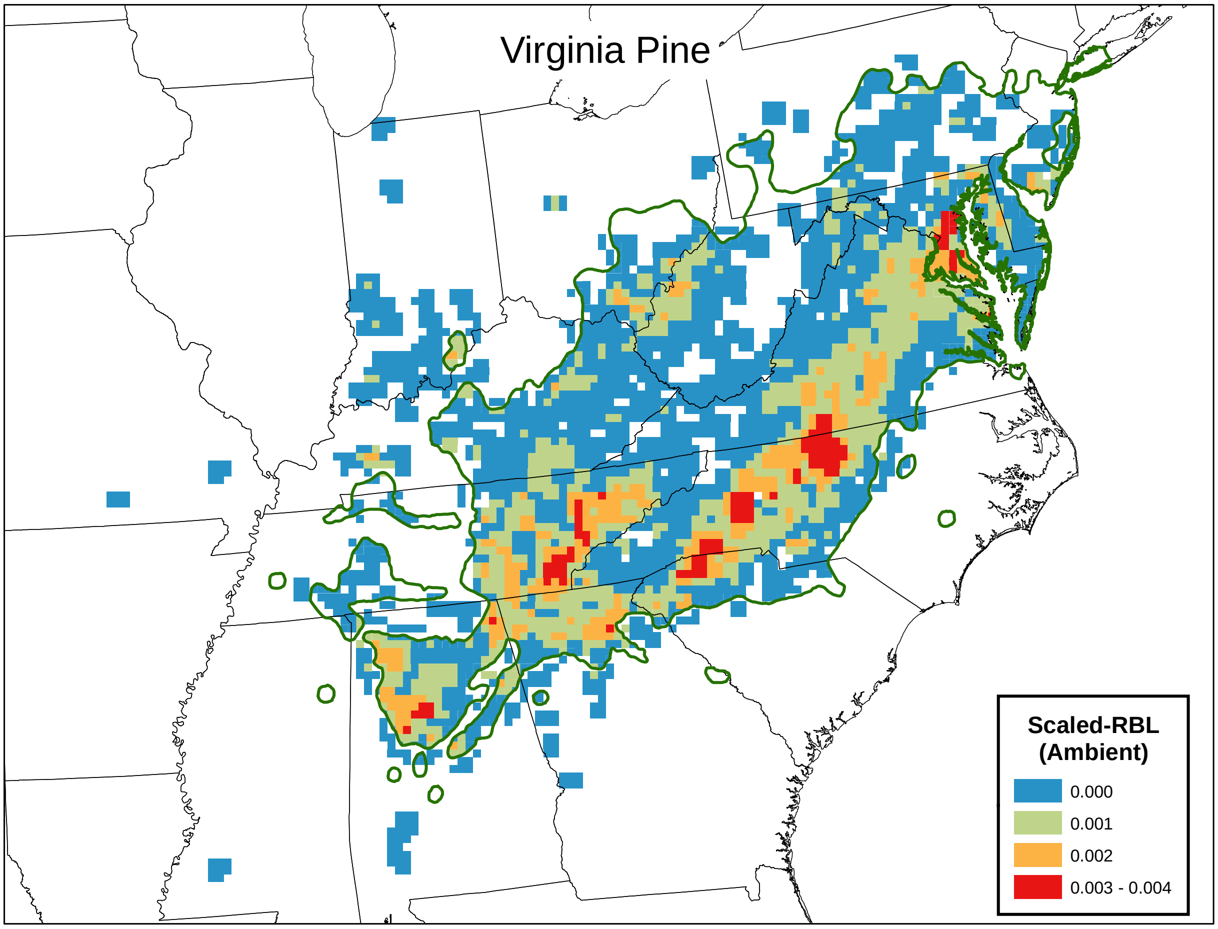


Figure 5A- 19 Scaled Relative Biomass Loss for Virginia Pine under recent ambient conditions

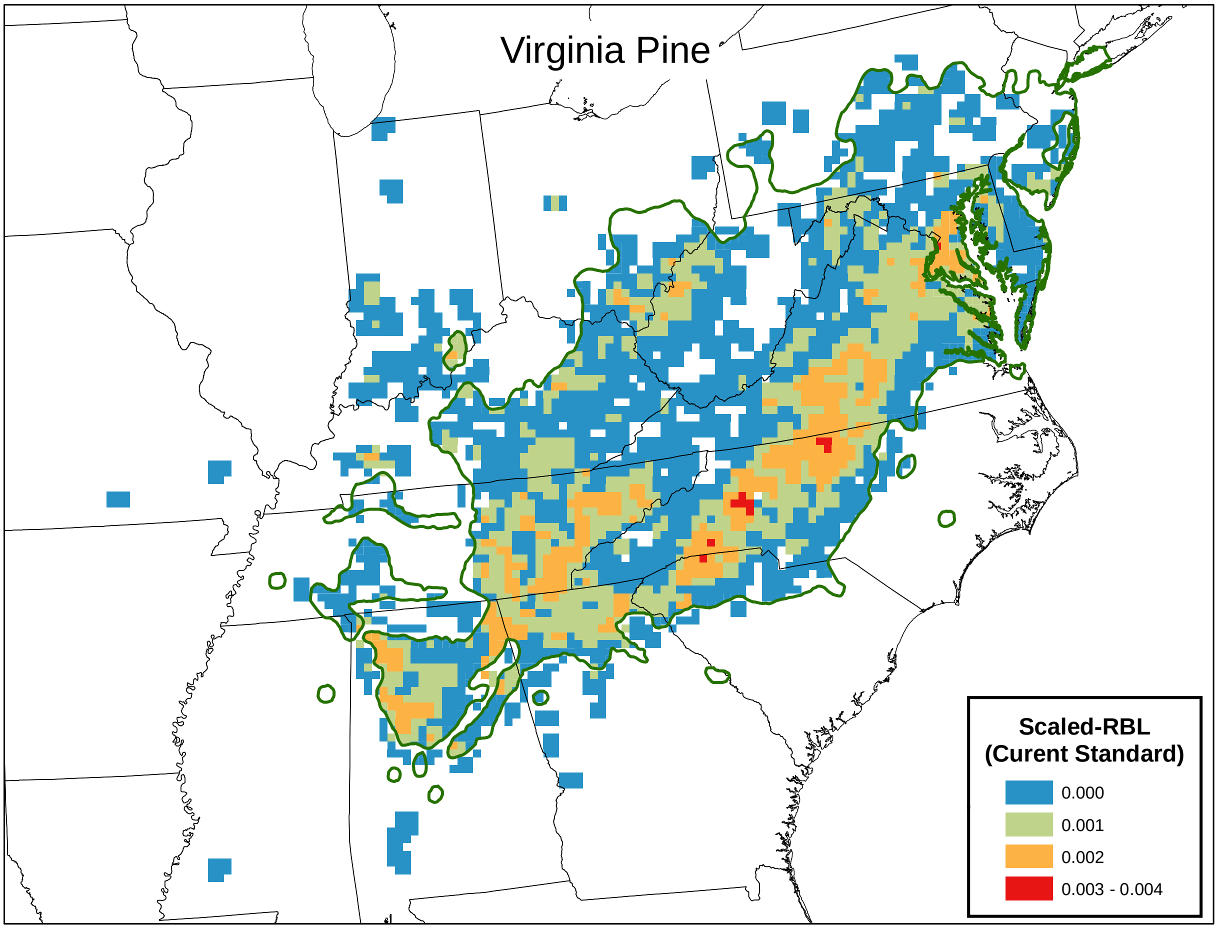


Figure 5A- 20 Scaled Relative Biomass Loss for Virginia Pine under the current standard rollback scenario

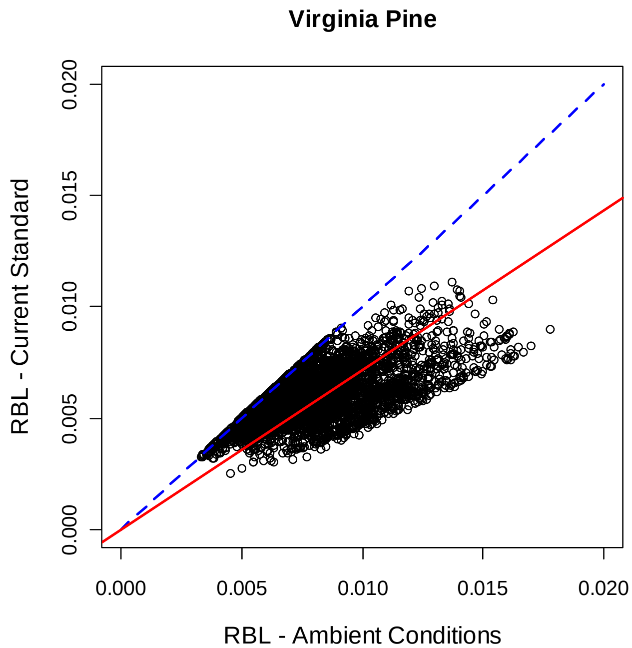


Figure 5A- 21 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Virginia Pine

Table 5A- 5 Summary of Linear Model Results for Virginia Pine

Linear Model Results	Current Standard	Alt A	Alt B
N	4596		
r-squared	0.9589		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.717		

RED MAPLE

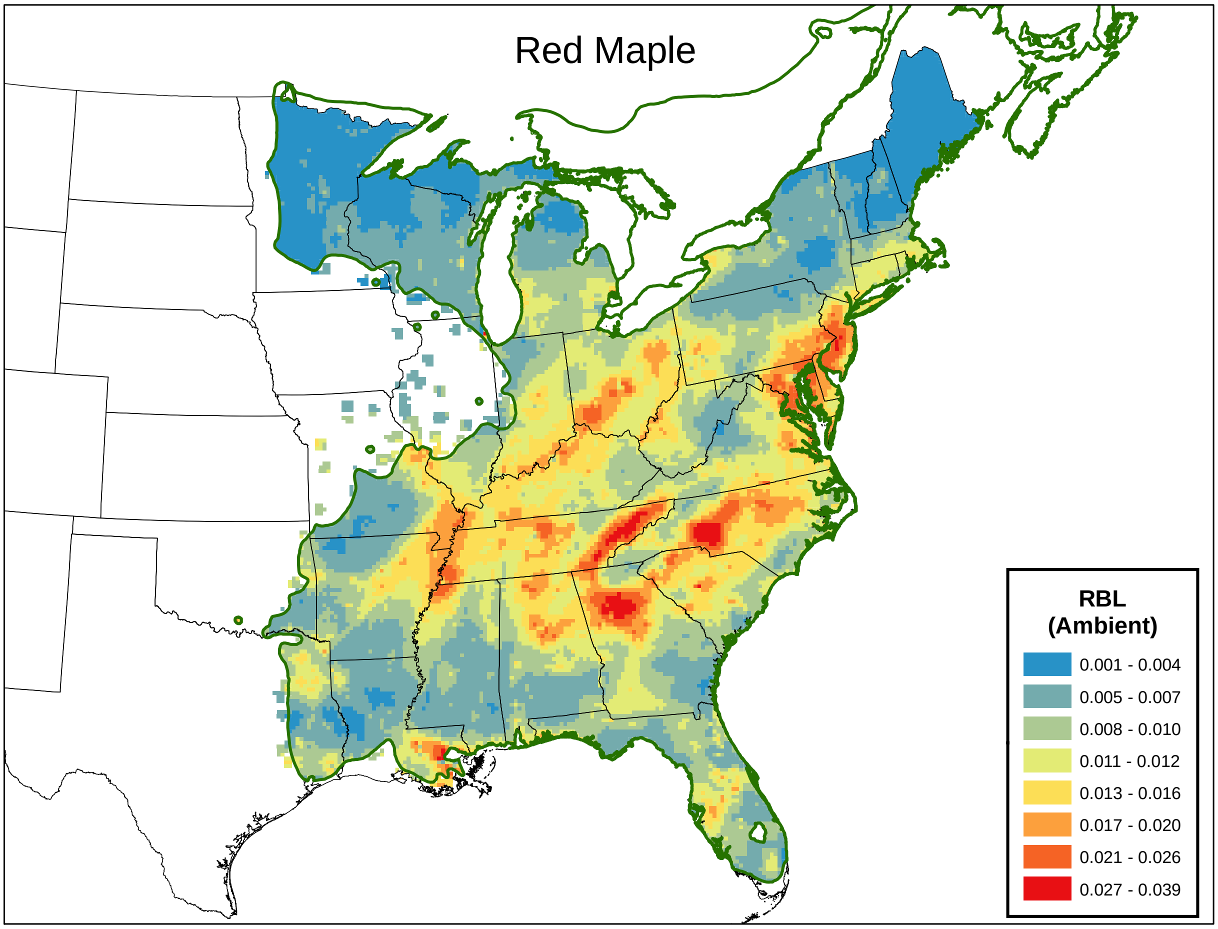


Figure 5A- 22 Relative Biomass Loss for Red Maple recent ambient conditions

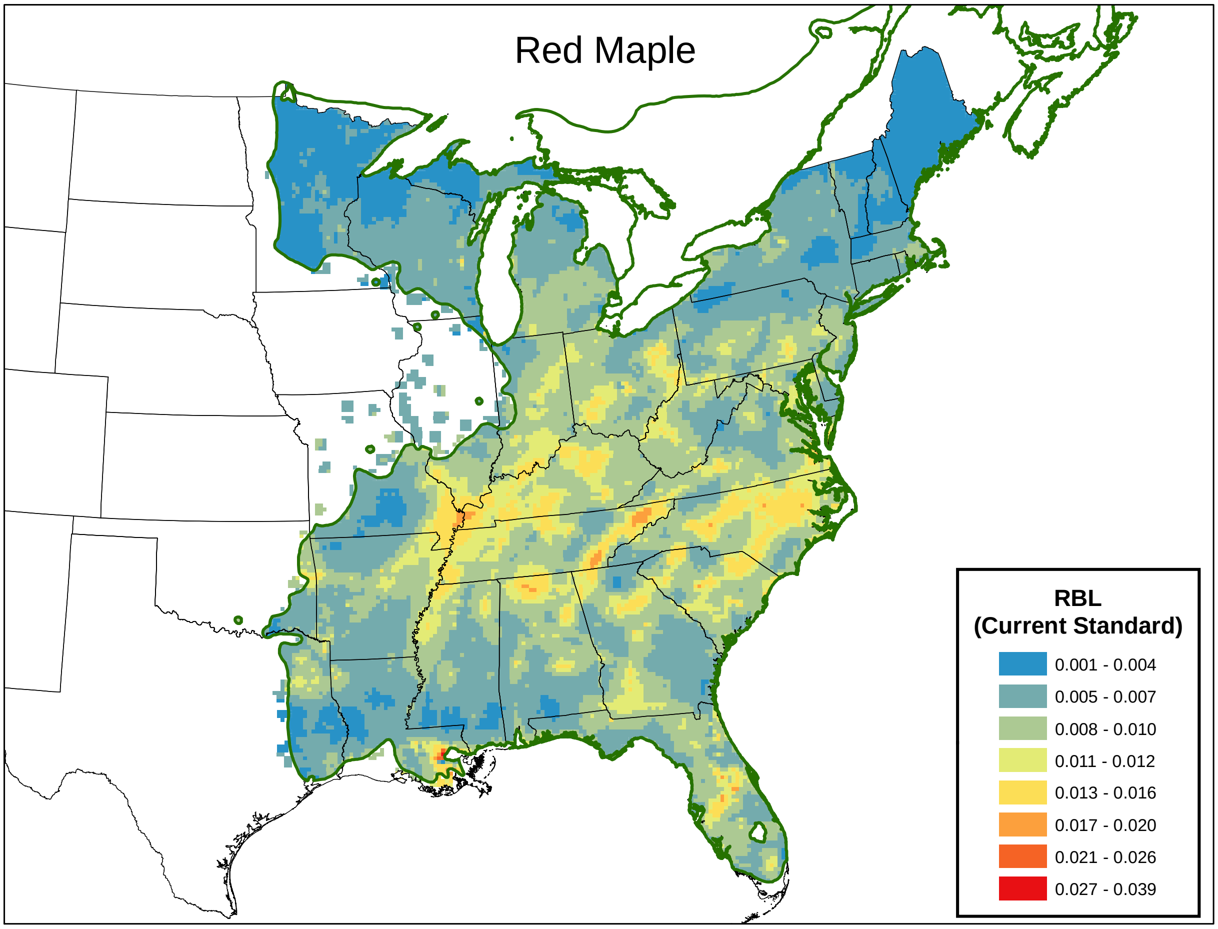


Figure 5A- 23 Relative Biomass Loss for Red Maple under the current standard rollback scenario

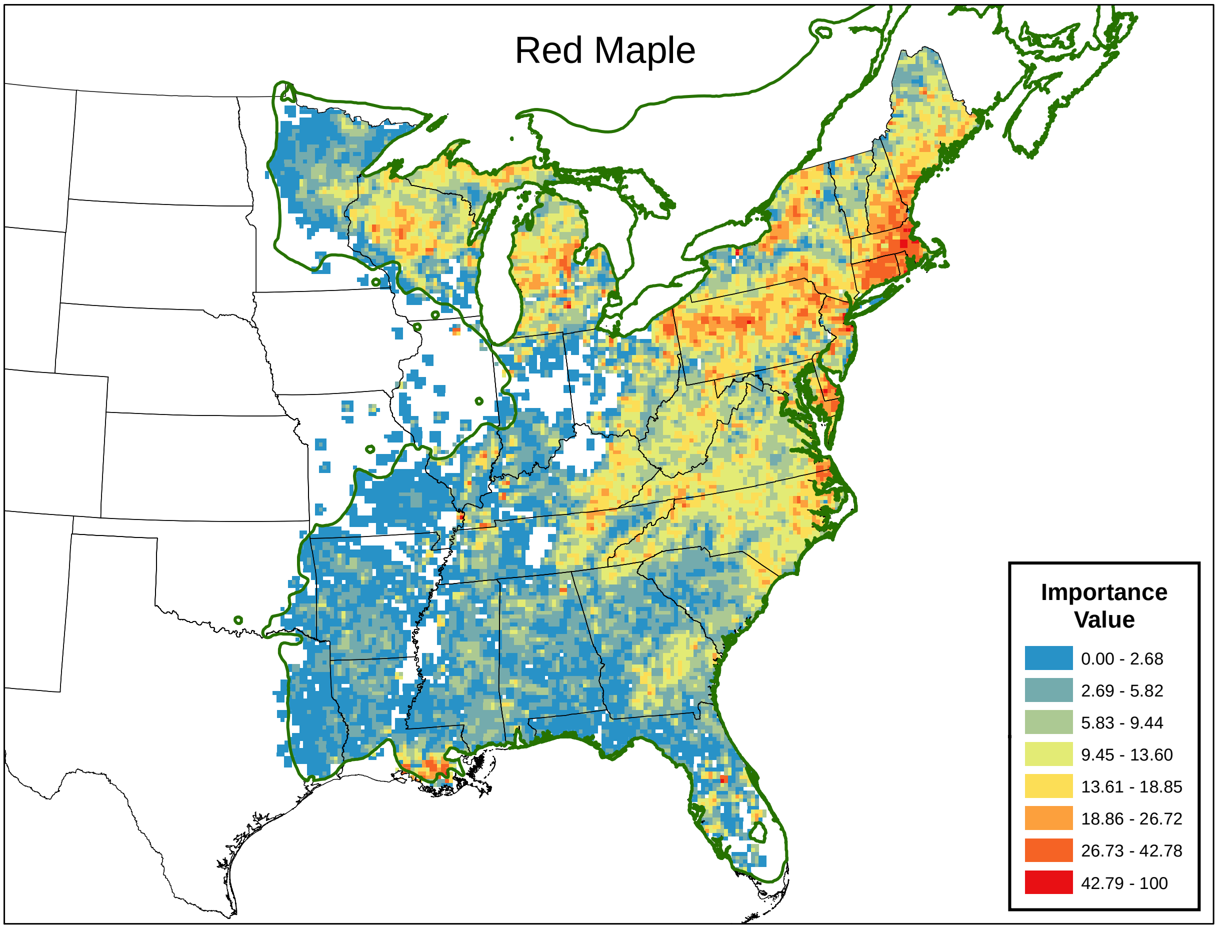


Figure 5A- 24 Importance Values for Red Maple

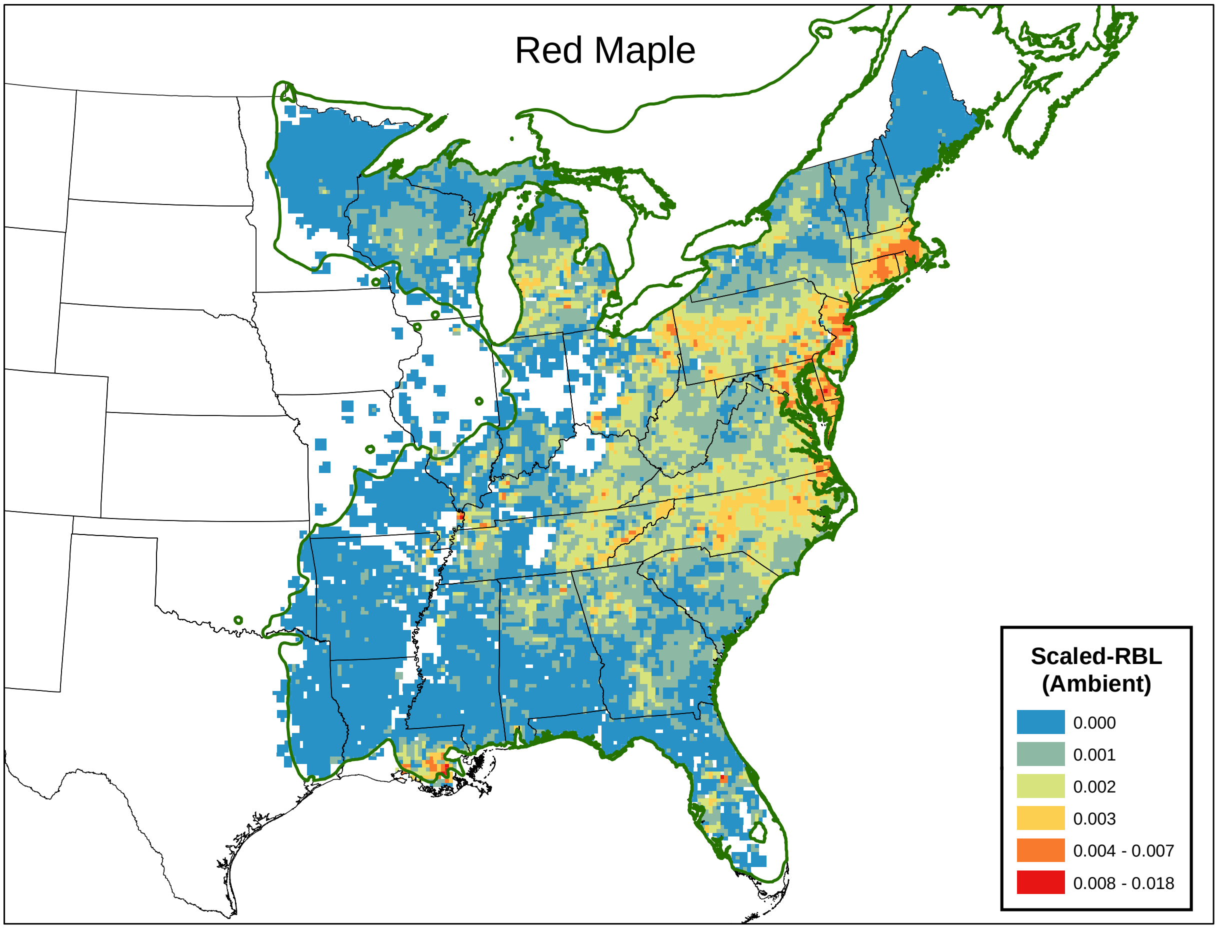


Figure 5A- 25 Scaled Relative Biomass Loss for Red Maple under recent ambient conditions

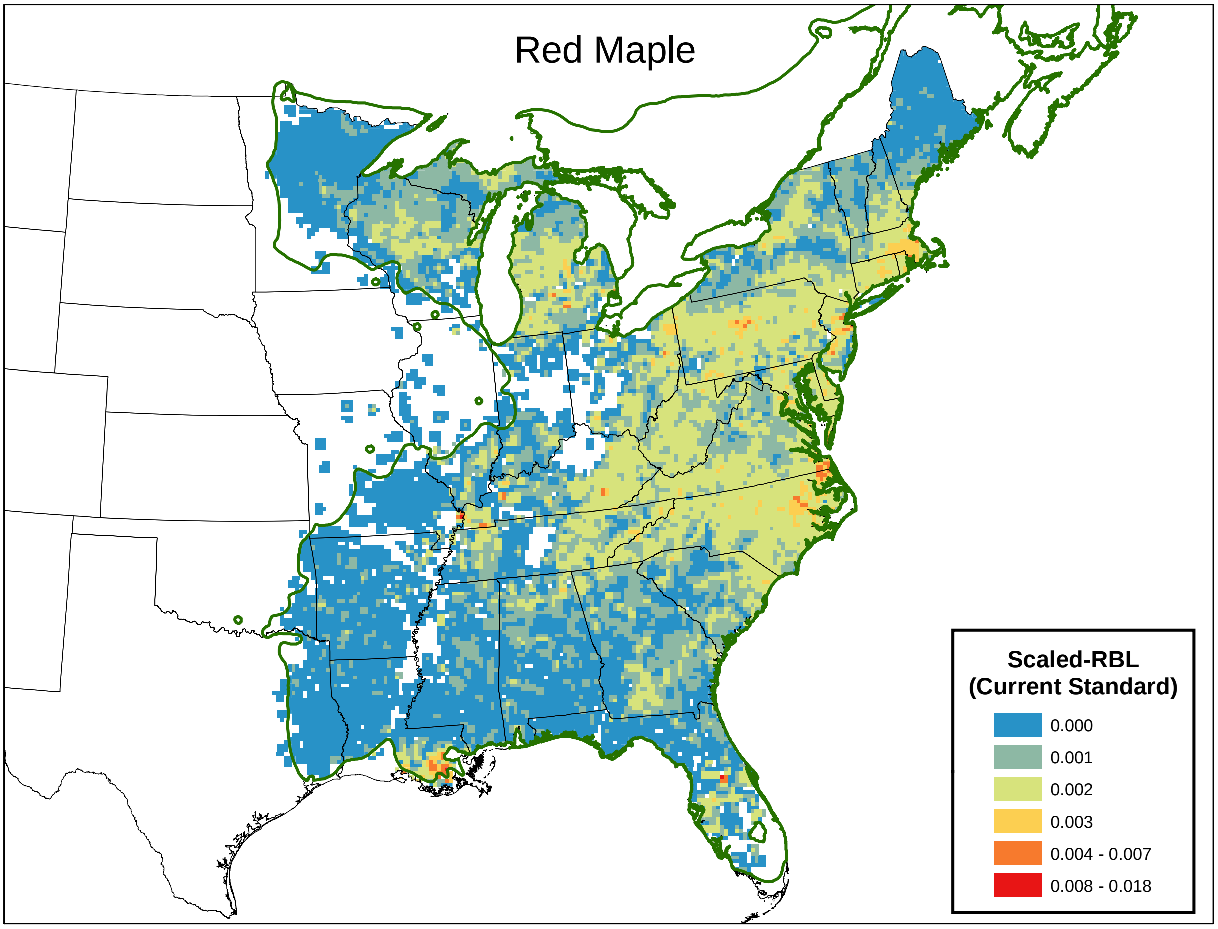


Figure 5A- 26 Scaled Relative Biomass Loss for Red Maple under the current standard rollback scenario

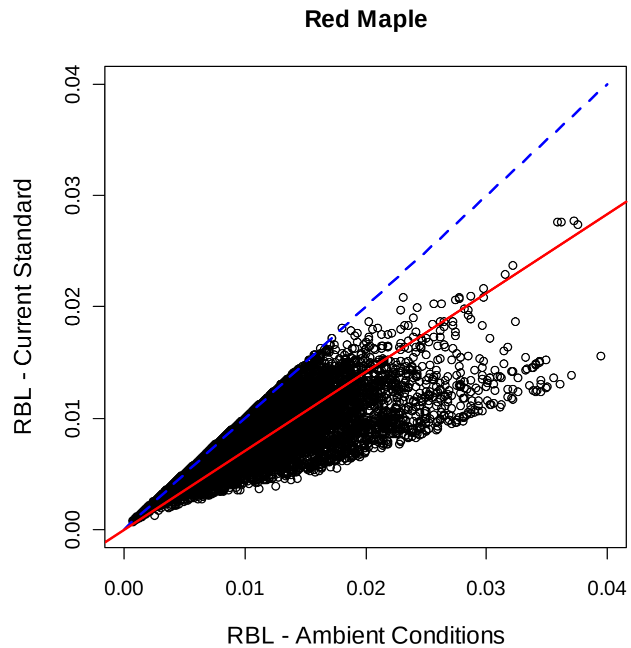


Figure 5A- 27 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Red Maple

Table 5A- 6 Summary of Linear Model Results for Red Maple

Linear Model Results	Current Standard	Alt A	Alt B
N	19,875		
r-squared	0.9349		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.707		

SUGAR MAPLE

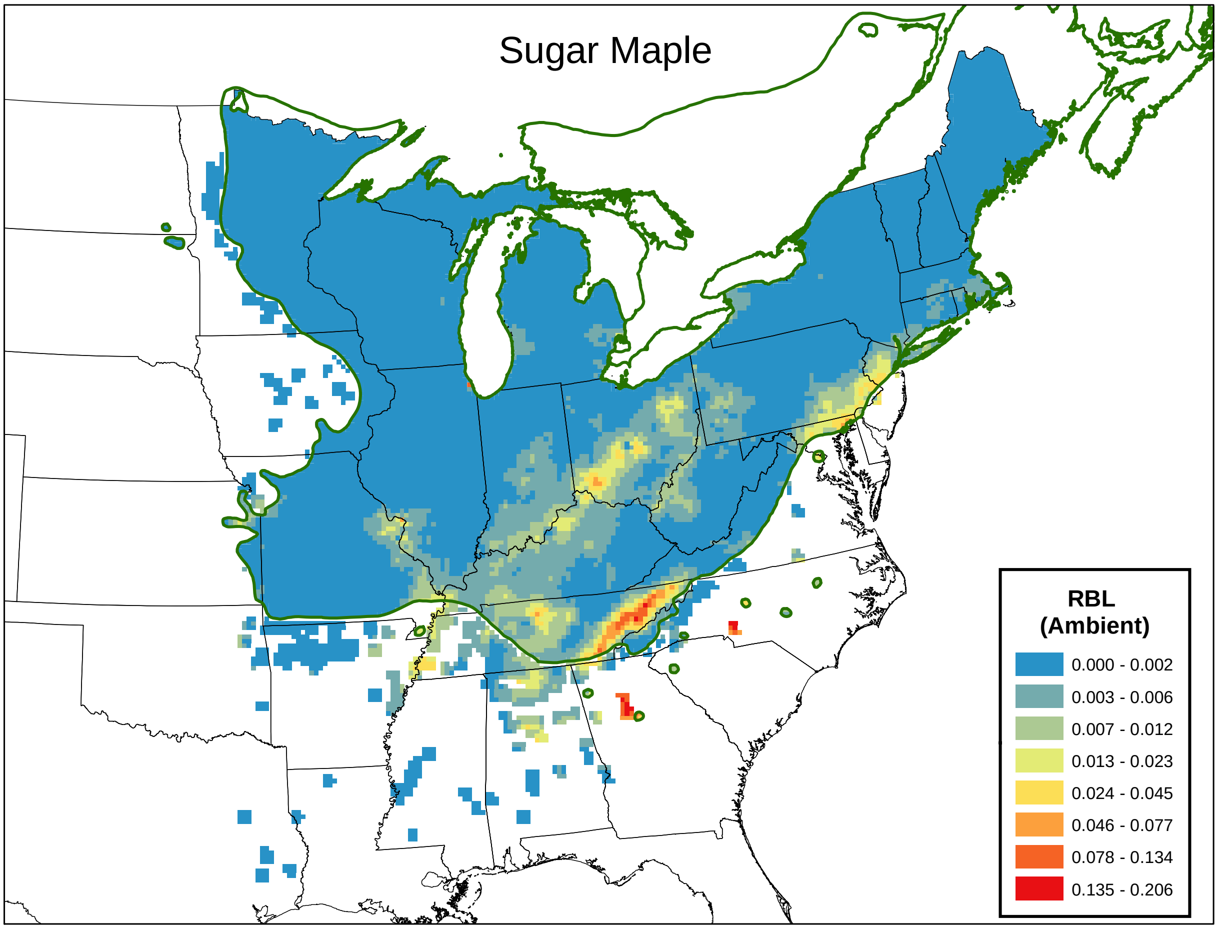


Figure 5A- 28 Relative Biomass Loss for Sugar Maple under recent ambient conditions

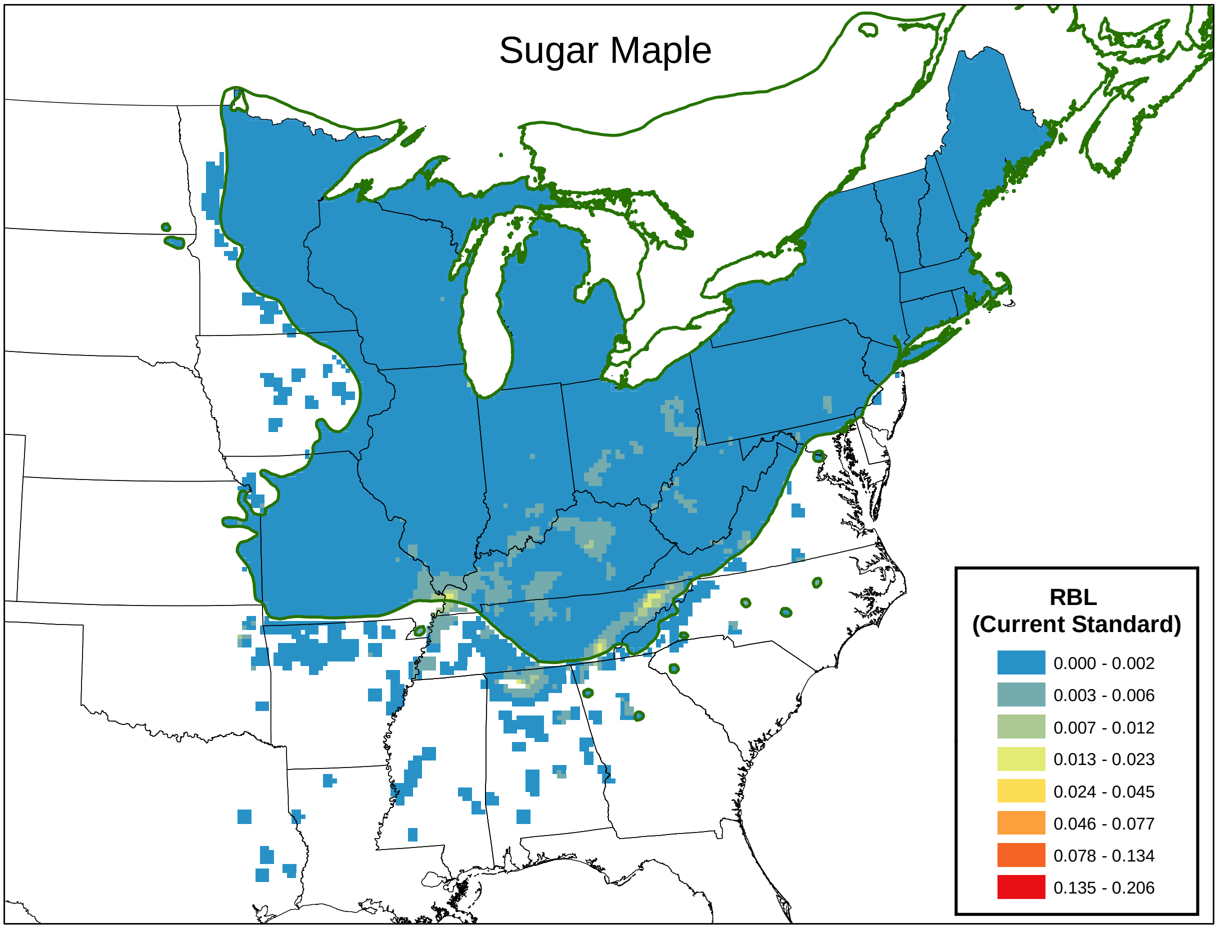


Figure 5A- 29 Relative Biomass Loss for Sugar Maple under the current standard rollback scenario

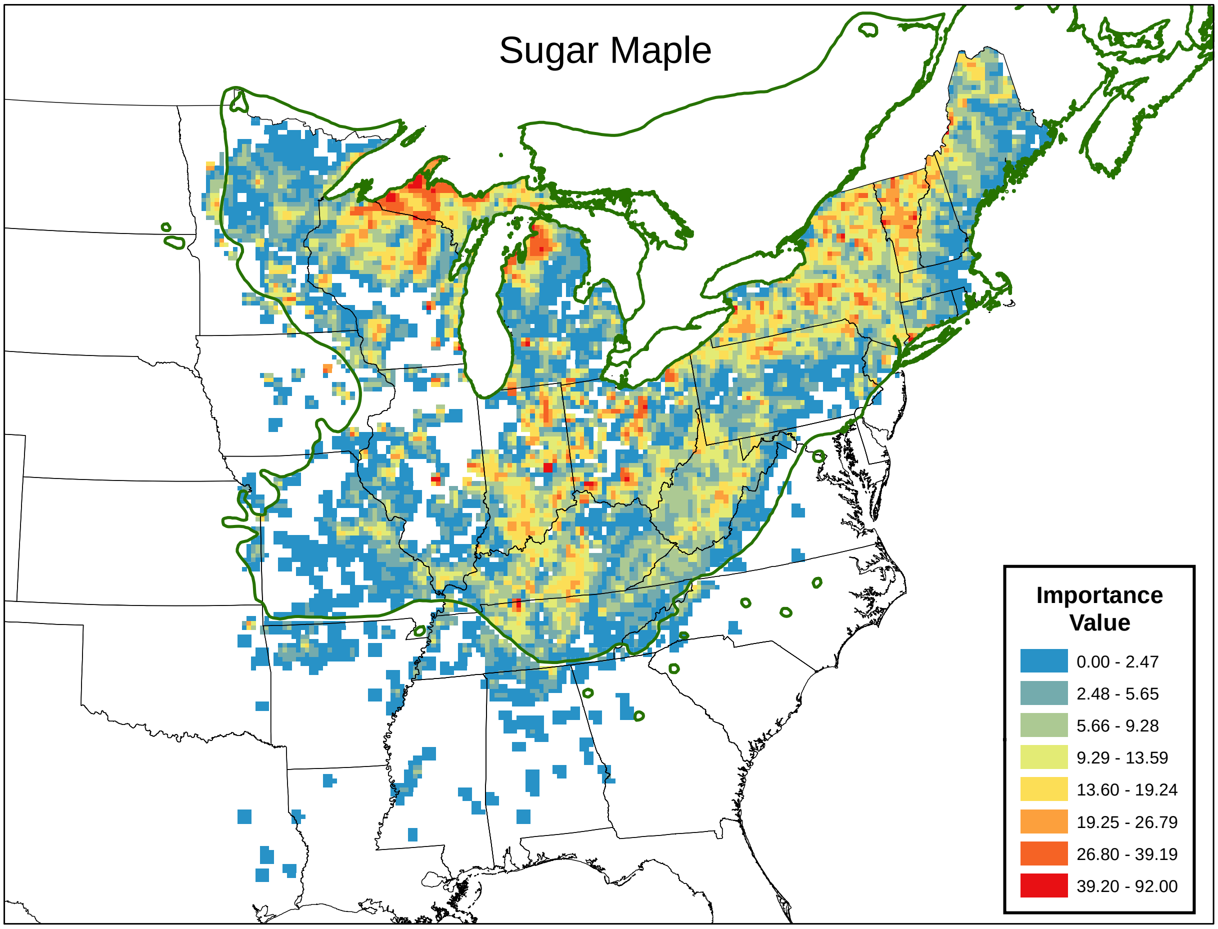


Figure 5A- 30 Importance Values for Sugar Maple

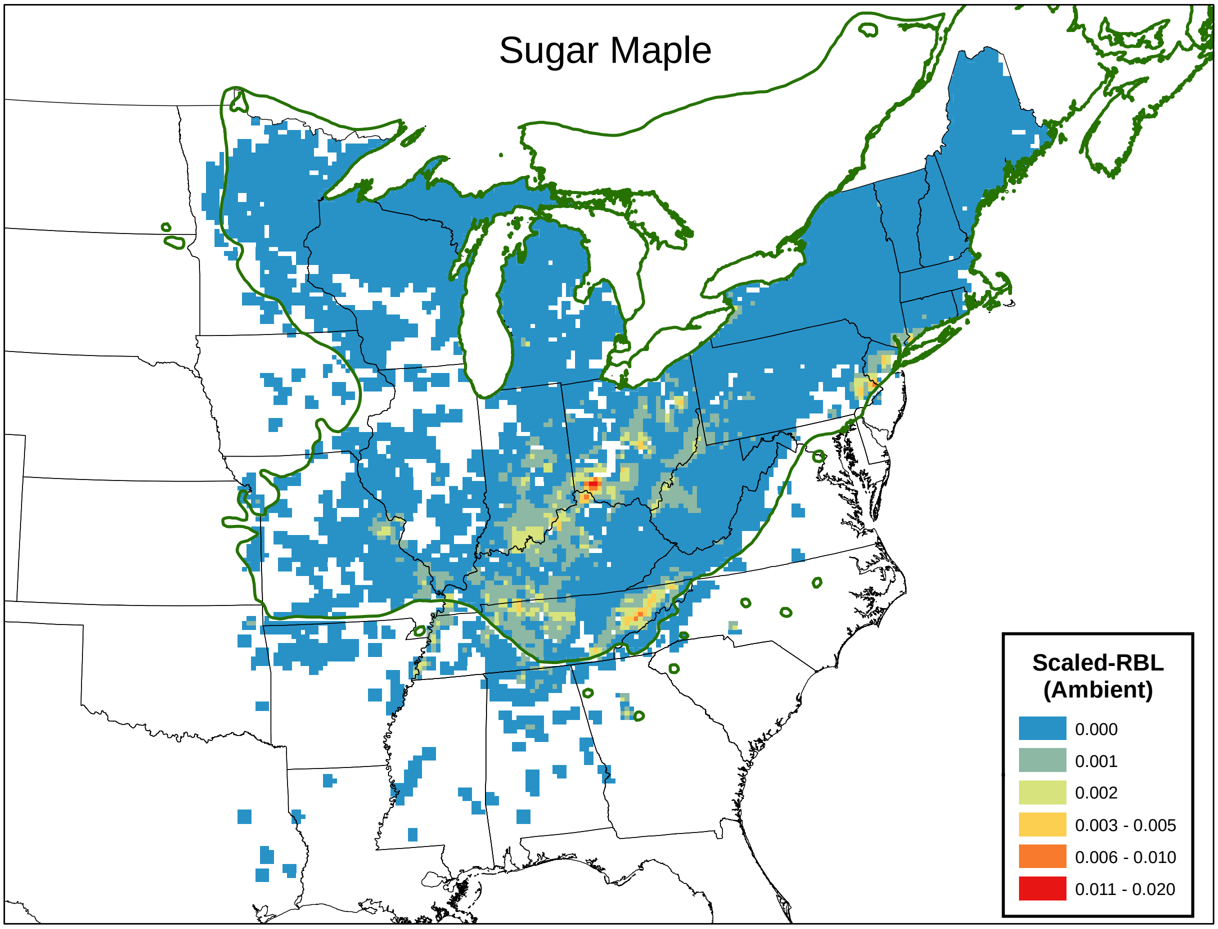


Figure 5A- 31 Scaled Relative Biomass Loss for Sugar Maple under recent ambient conditions

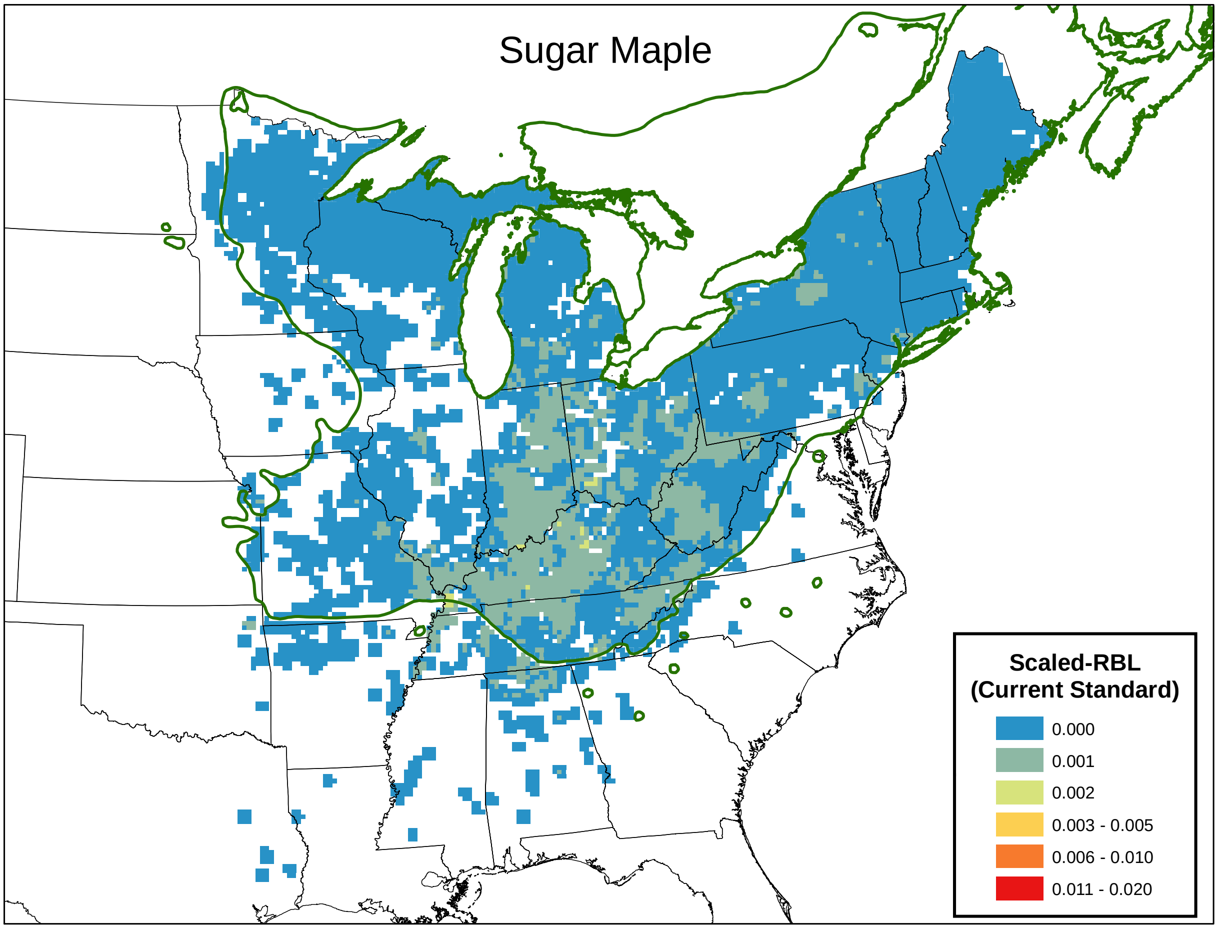


Figure 5A- 32 Scaled Relative Biomass Loss for Sugar Maple under the current standard rollback scenario

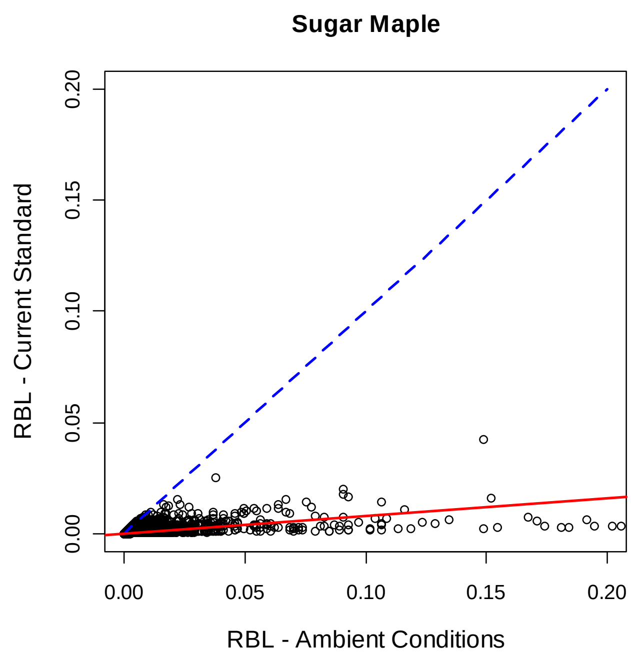


Figure 5A- 33 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Sugar Maple

Table 5A- 7 Summary of Linear Model Results for Sugar Maple

Linear Model Results	Current Standard	Alt A	Alt B
N	13,627		
r-squared	0.3732		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.080		

TULIP POPLAR

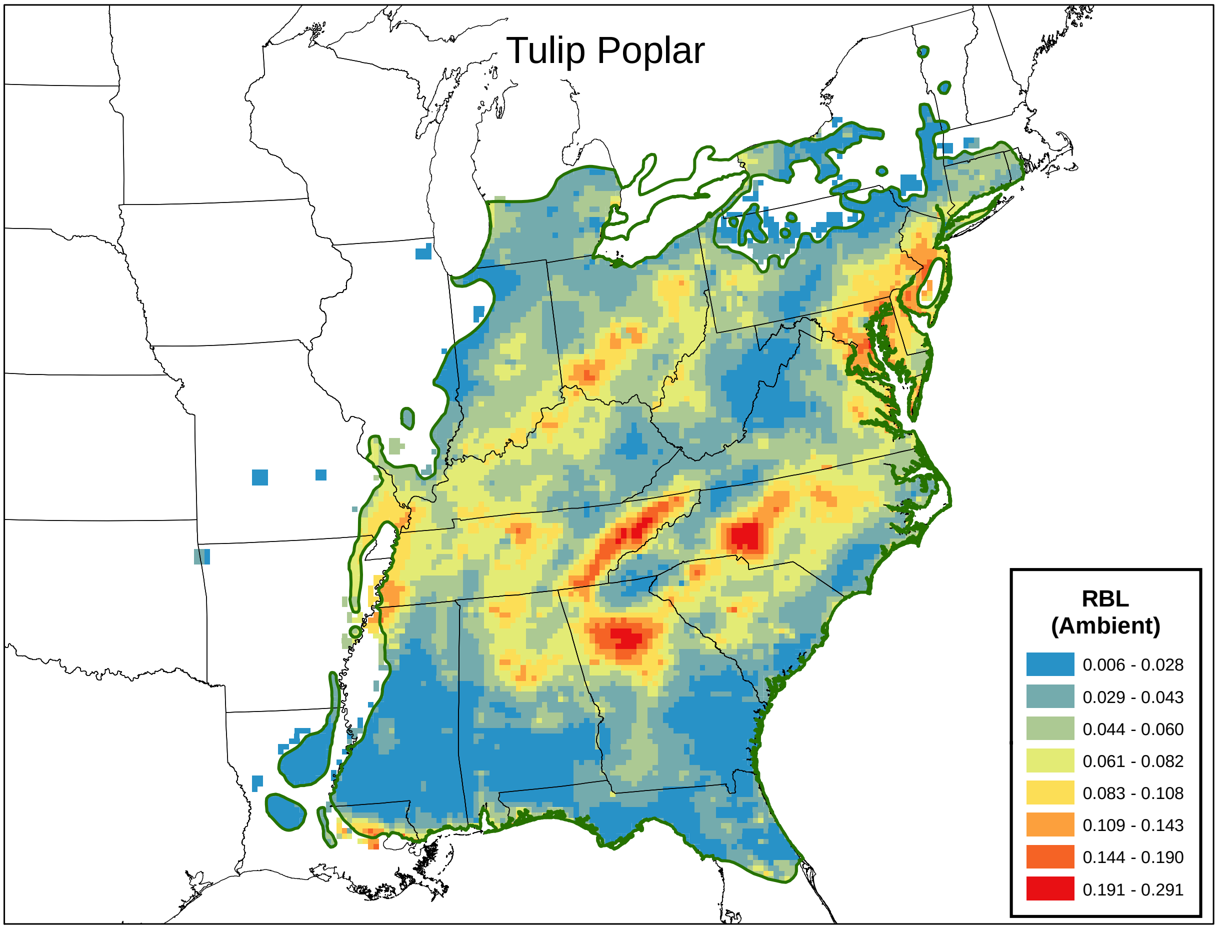


Figure 5A- 34 Relative Biomass Loss for Tulip Poplar under recent ambient conditions

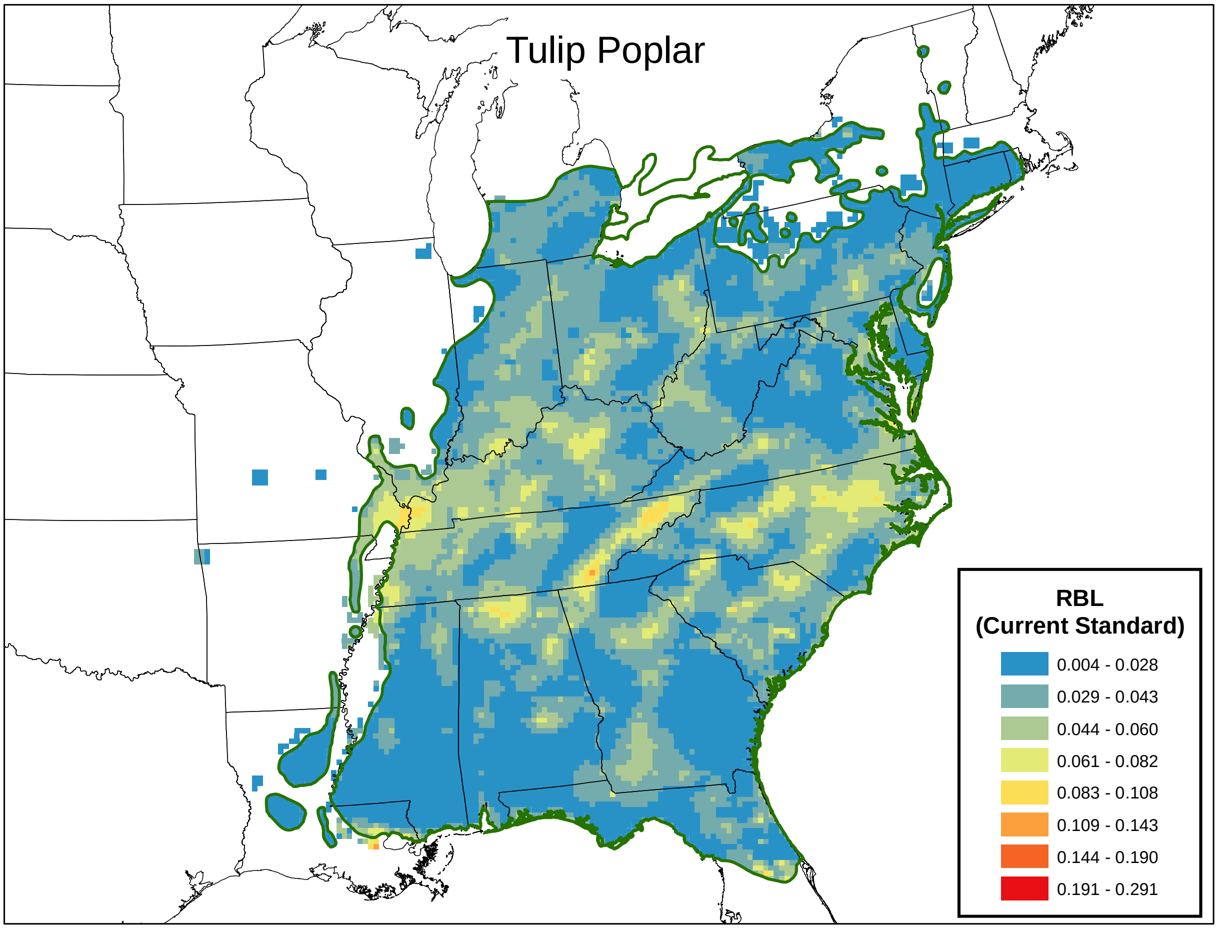


Figure 5A- 35 Relative Biomass Loss for Tulip Poplar under the current standard rollback scenario

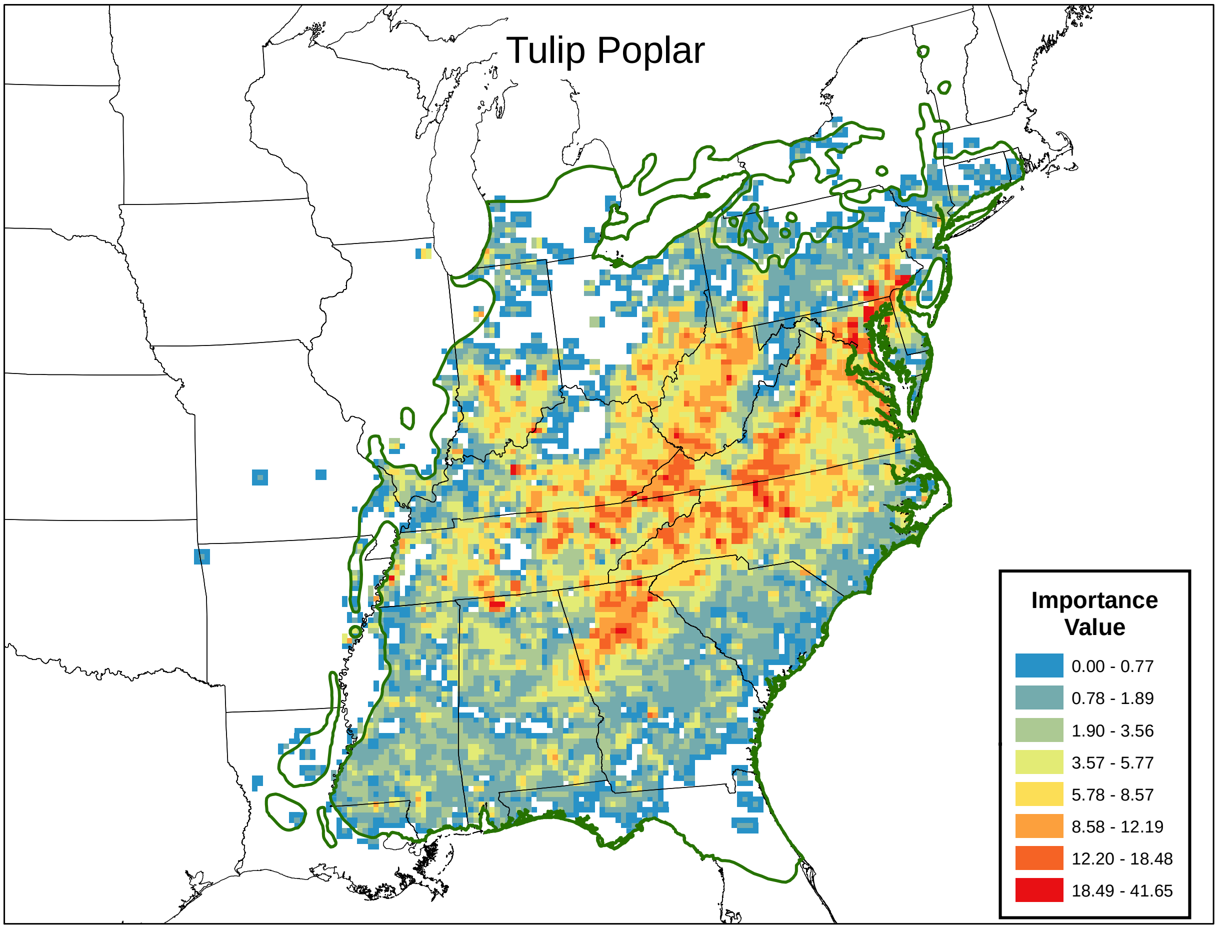


Figure 5A- 36 Importance Values for Tulip Poplar

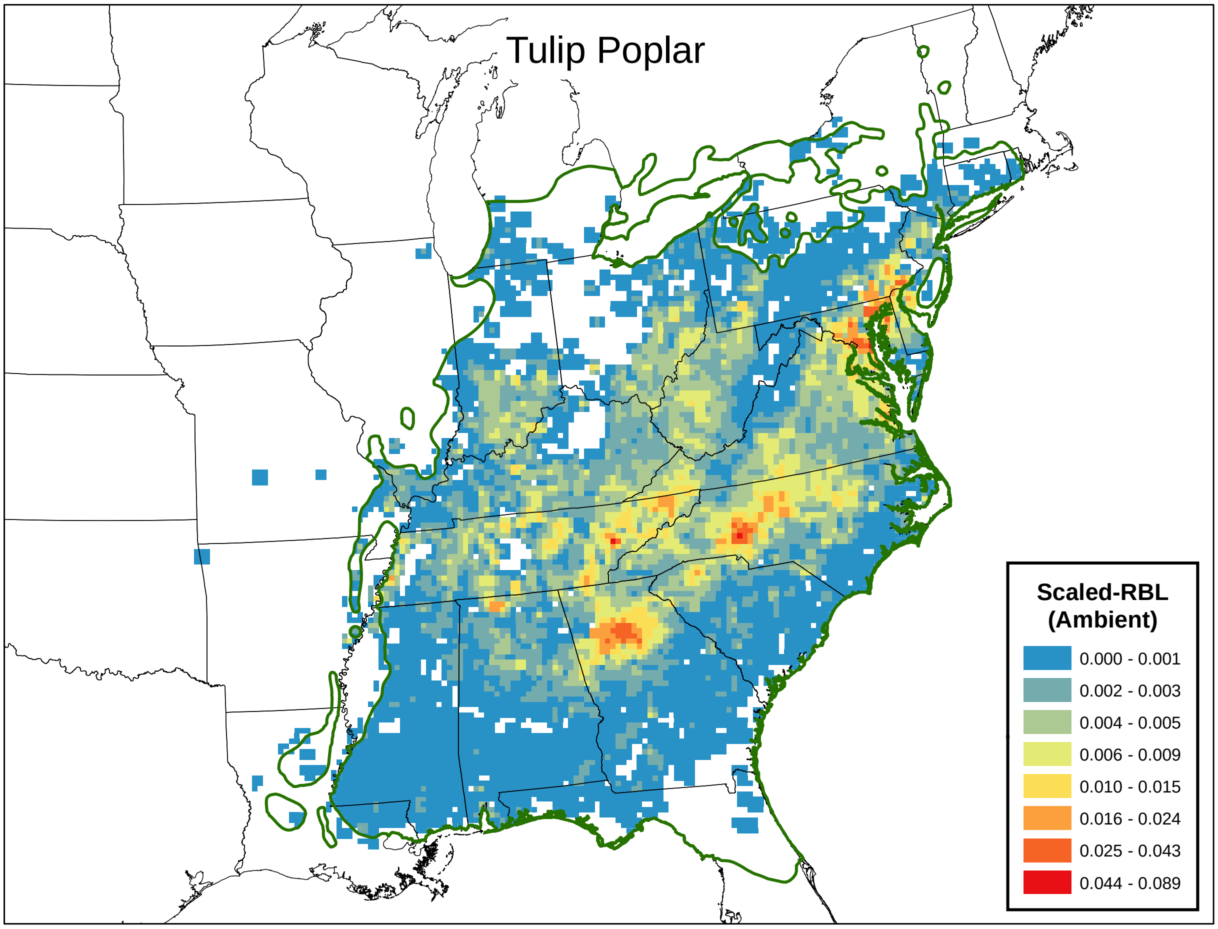


Figure 5A- 37 Scaled Relative Biomass Loss for Tulip Poplar under recent ambient conditions

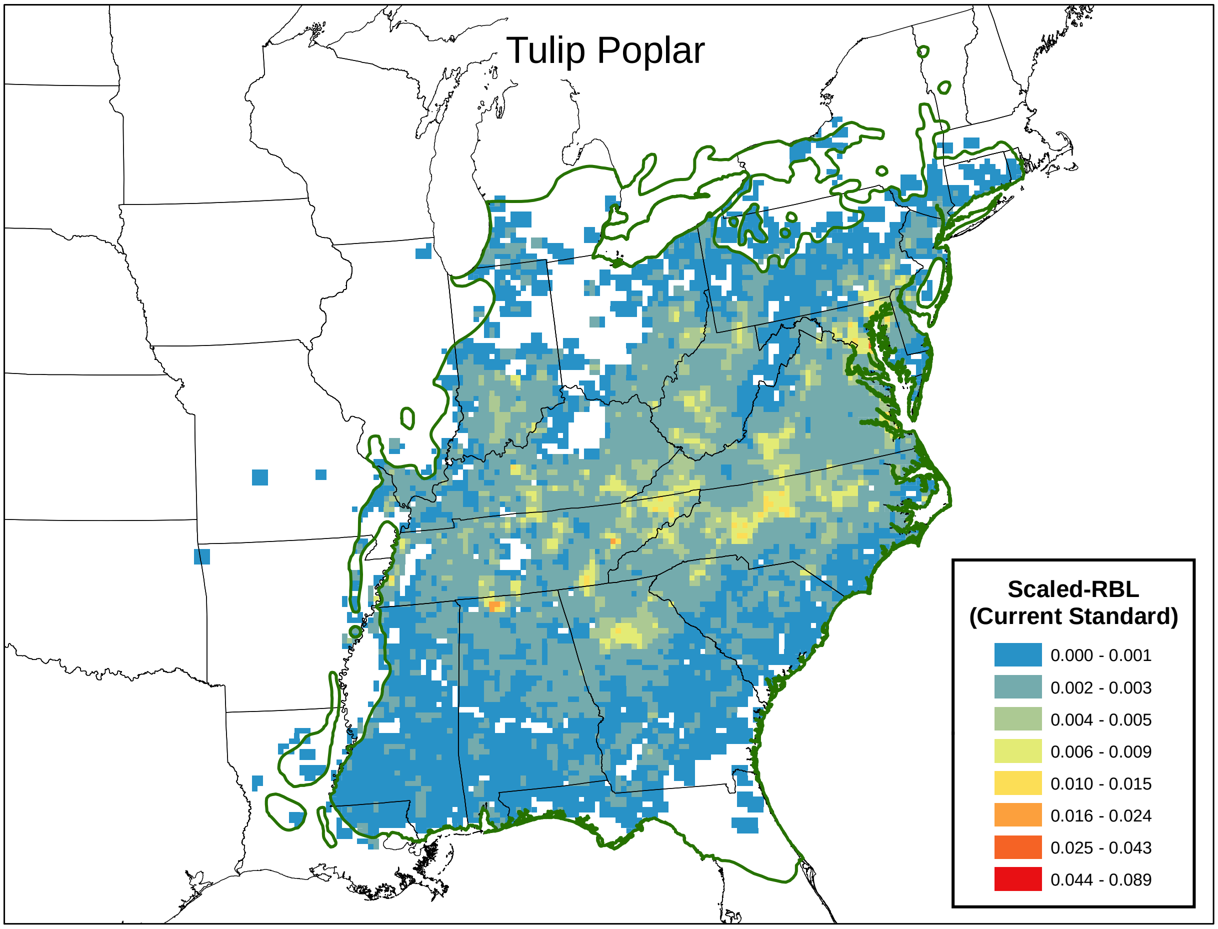


Figure 5A- 38 Scaled Relative Biomass Loss for Tulip Poplar under the current standard rollback scenario

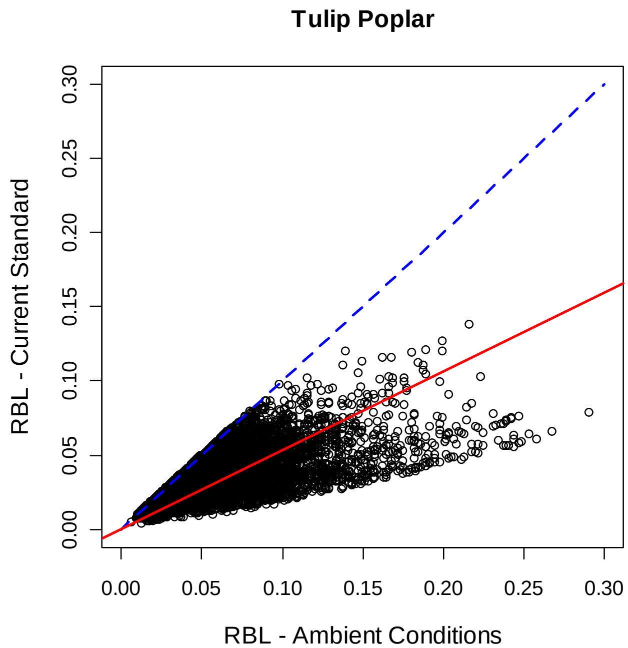


Figure 5A- 39 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Tulip Poplar

Table 5A- 8 Summary of Linear Model Results for Tulip Poplar

Linear Model Results	Current Standard	Alt A	Alt B
N	11,764		
r-squared	0.8558		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.533		

EASTERN COTTONWOOD

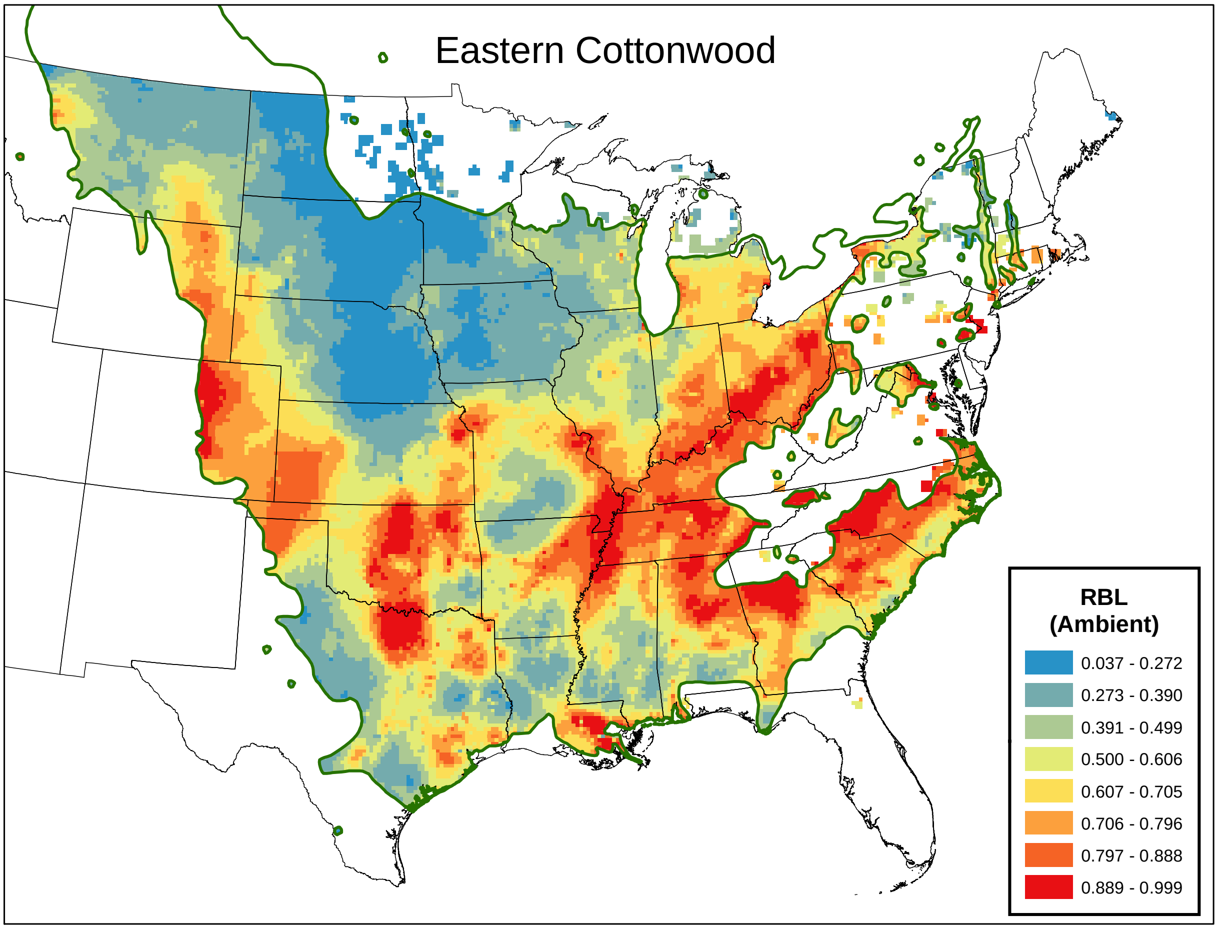


Figure 5A- 40 Relative Biomass Loss for Eastern Cottonwood under recent ambient conditions

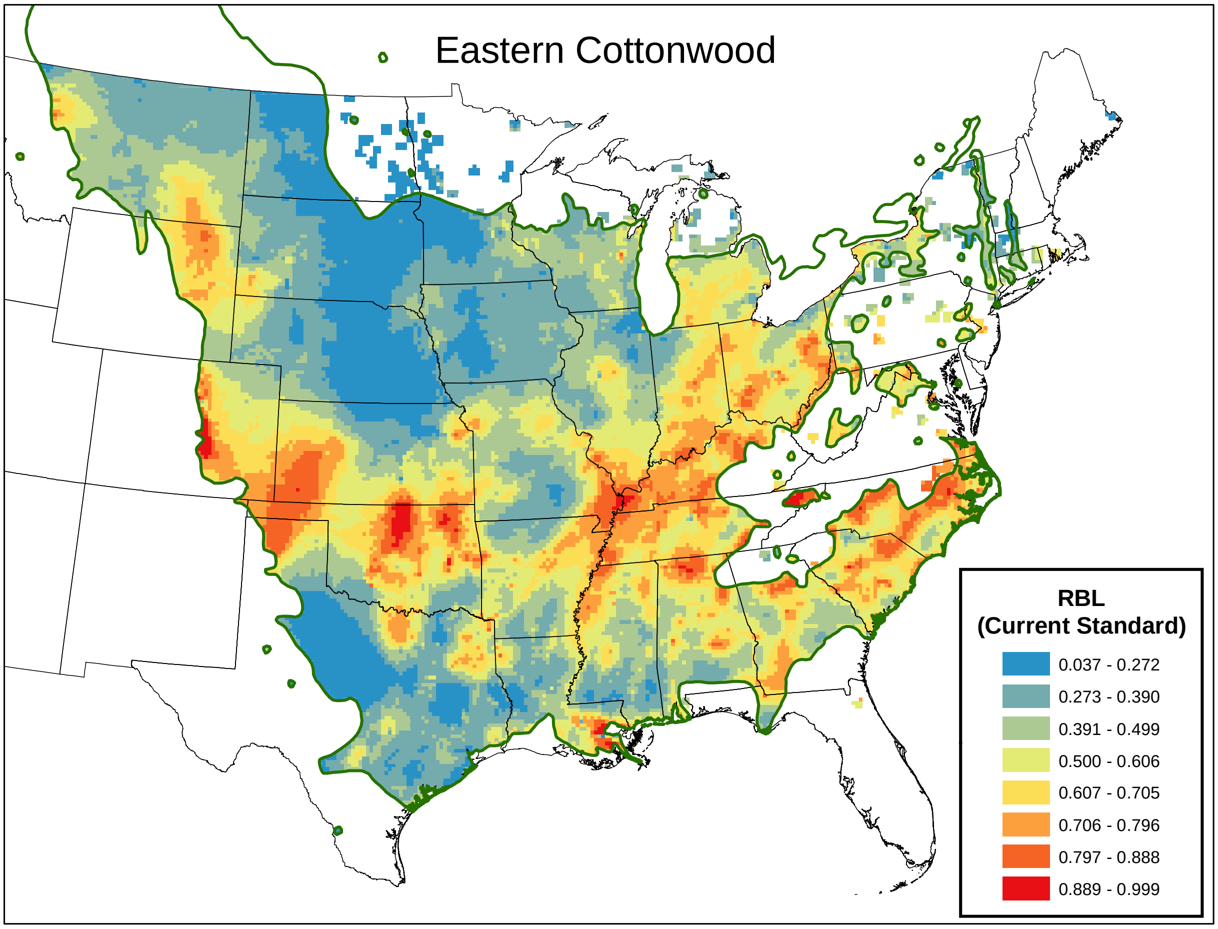


Figure 5A- 41 Relative Biomass Loss for Eastern Cottonwood under the current standard rollback scenario

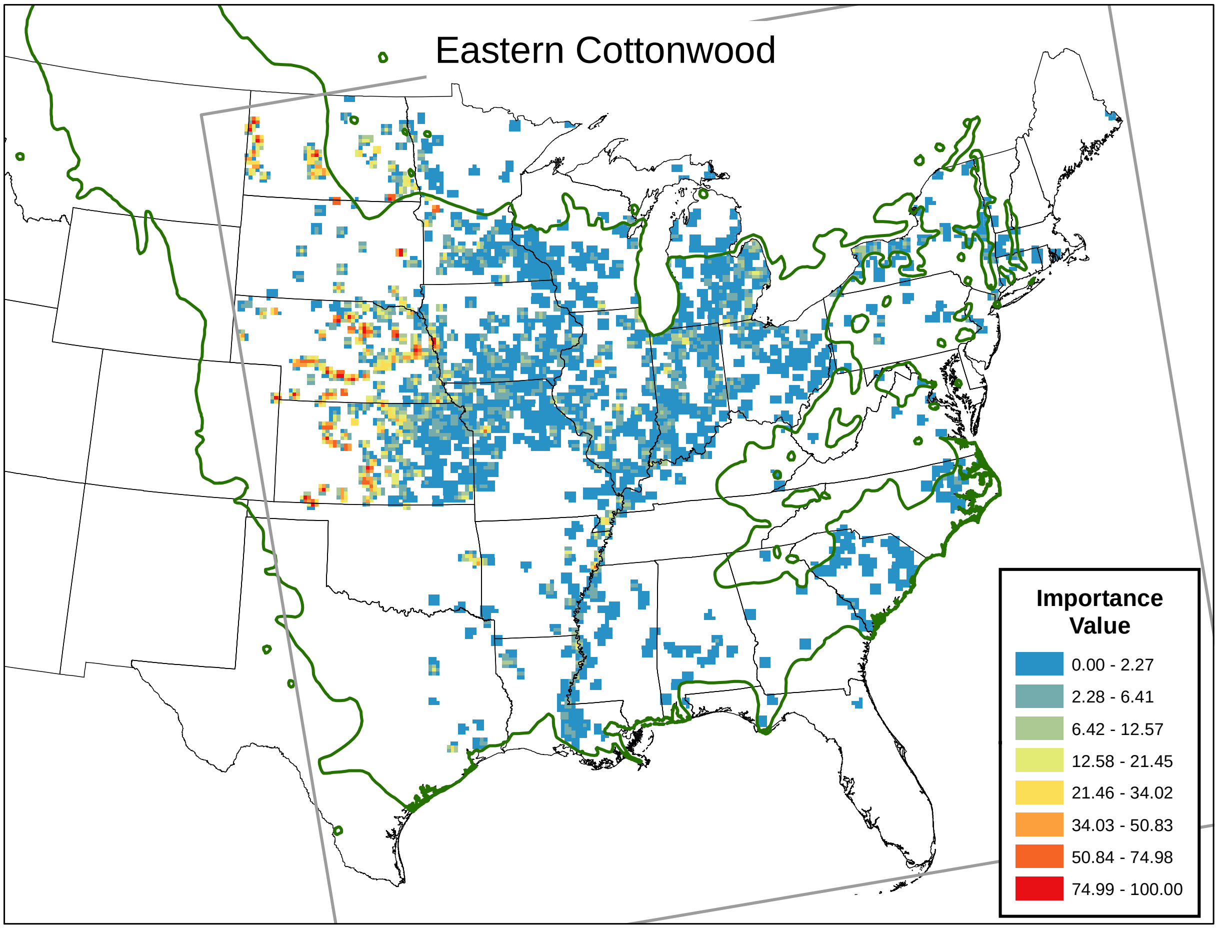


Figure 5A- 42 Importance Values for Eastern Cottonwood. The gray box indicates the extent of the IV data.

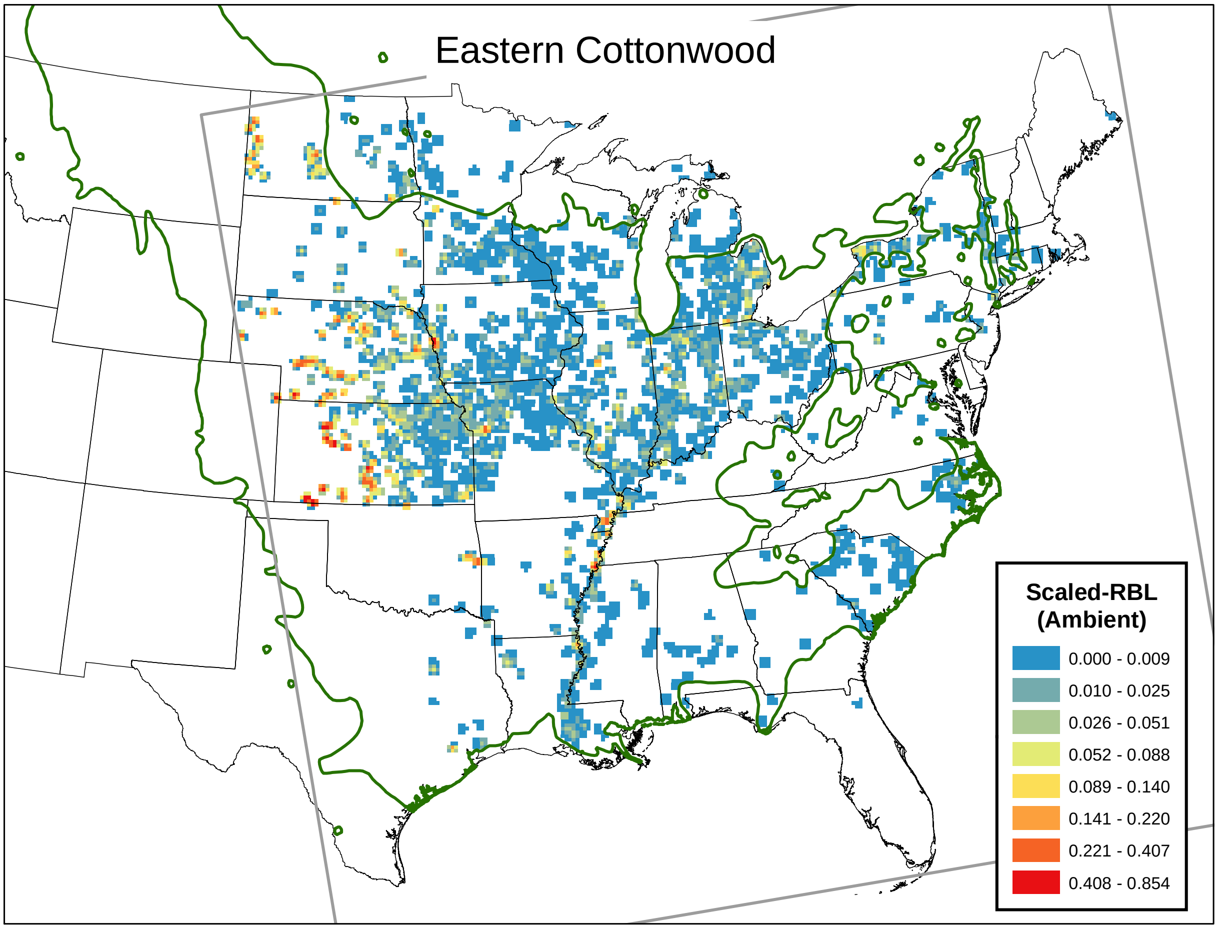


Figure 5A- 43 Scaled Relative Biomass Loss for Eastern Cottonwood under recent ambient conditions

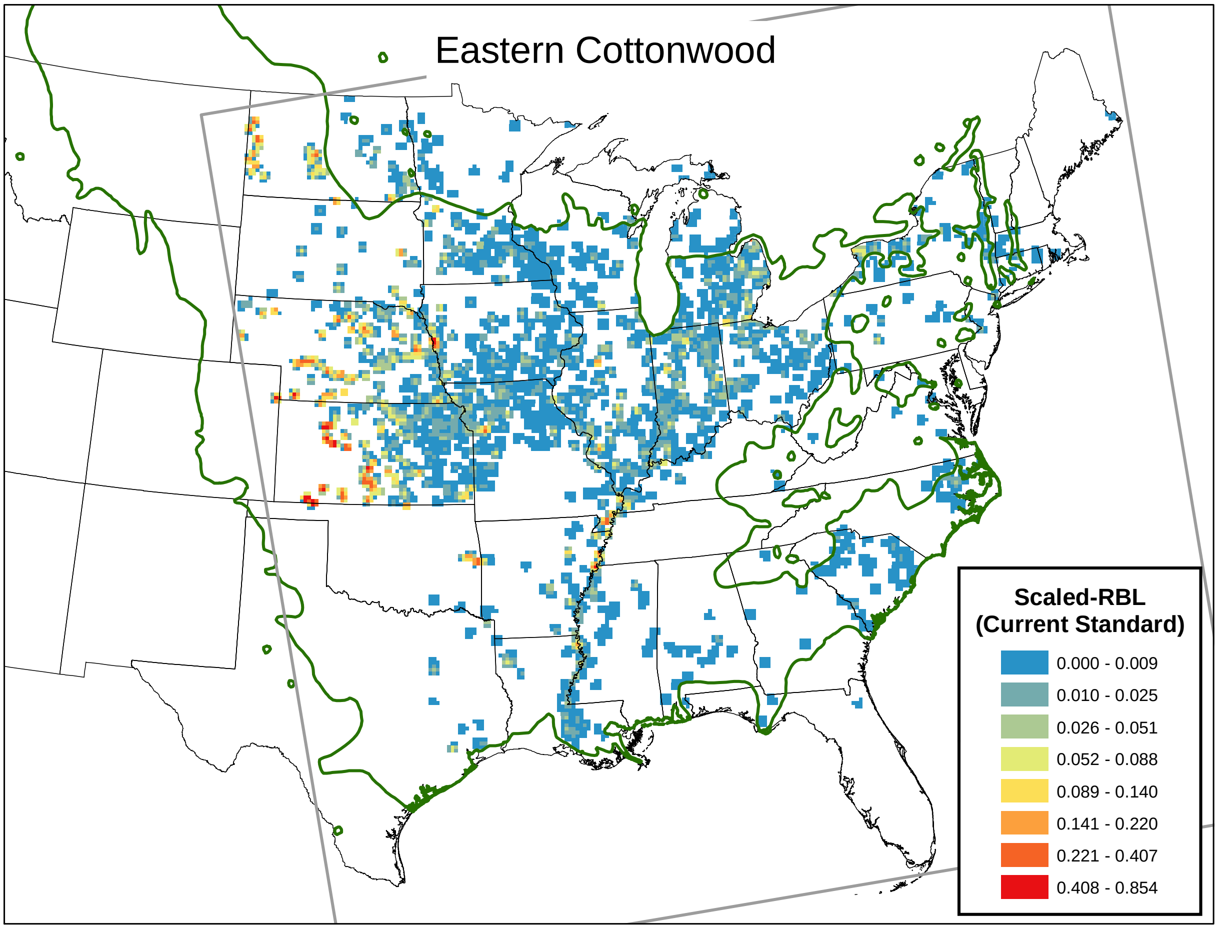


Figure 5A- 44 Scaled Relative Biomass Loss for Eastern Cottonwood under the current standard rollback scenario

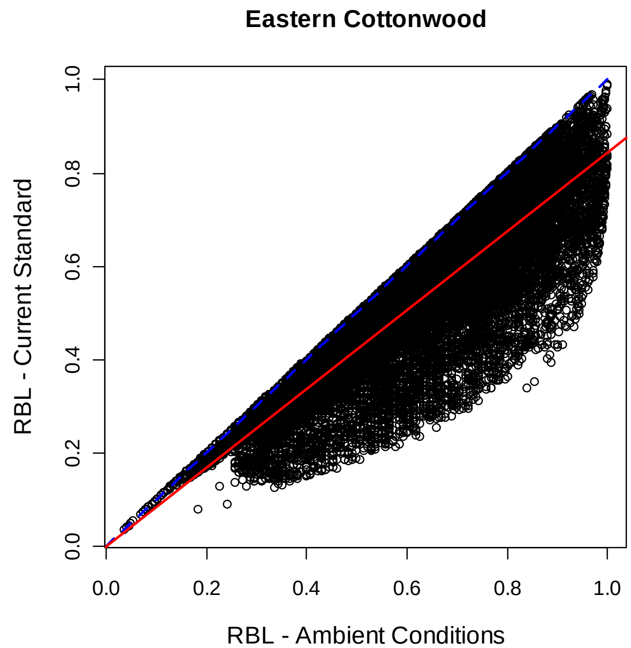


Figure 5A- 45 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Eastern Cottonwood

Table 5A- 9 Summary of Linear Model Results for Eastern Cottonwood

Linear Model Results	Current Standard	Alt A	Alt B
N	26,818		
r-squared	0.9746		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.844		

QUAKING ASPEN

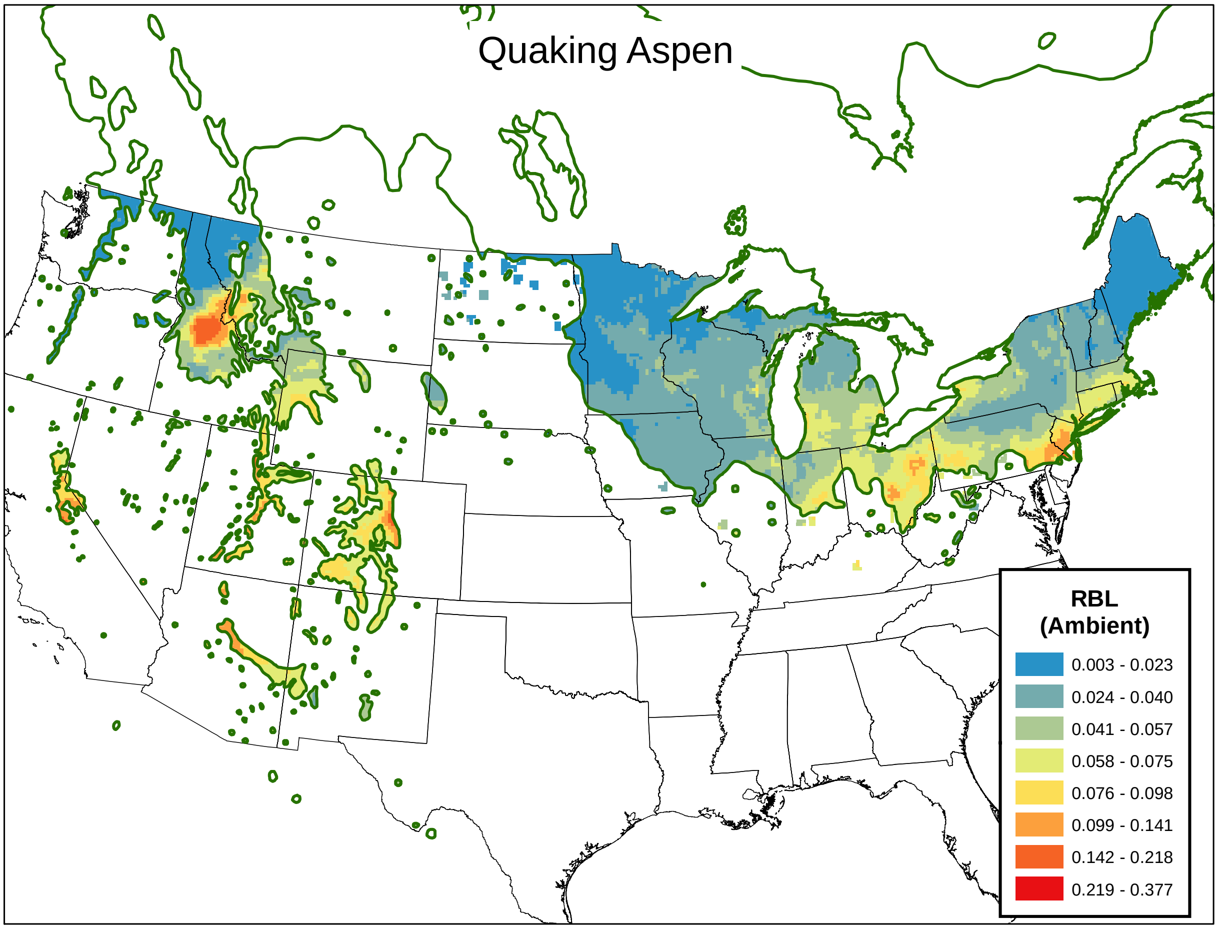


Figure 5A- 46 Relative Biomass Loss for Quaking Aspen under recent ambient conditions

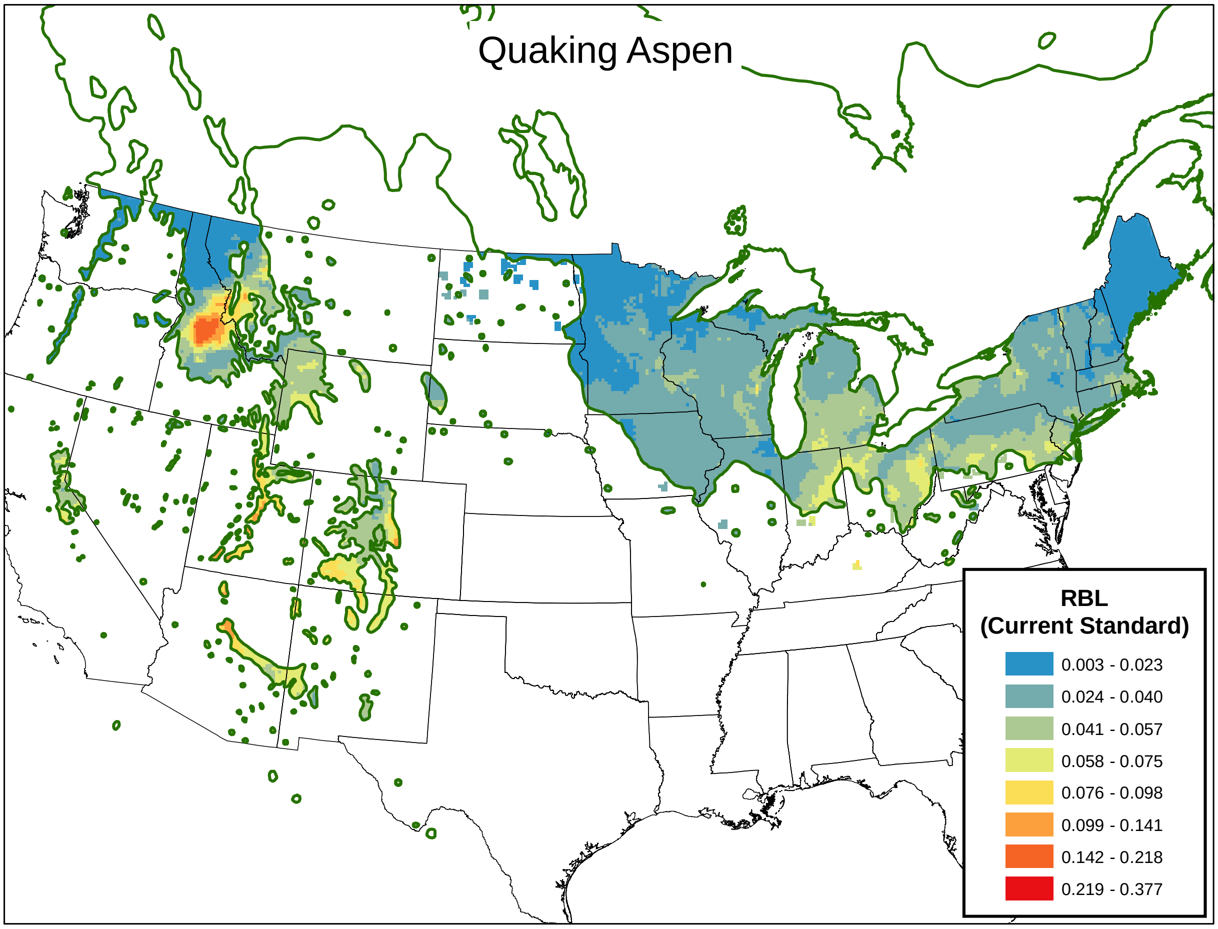


Figure 5A- 47 Relative Biomass Loss for Quaking Aspen under the current standard rollback scenario

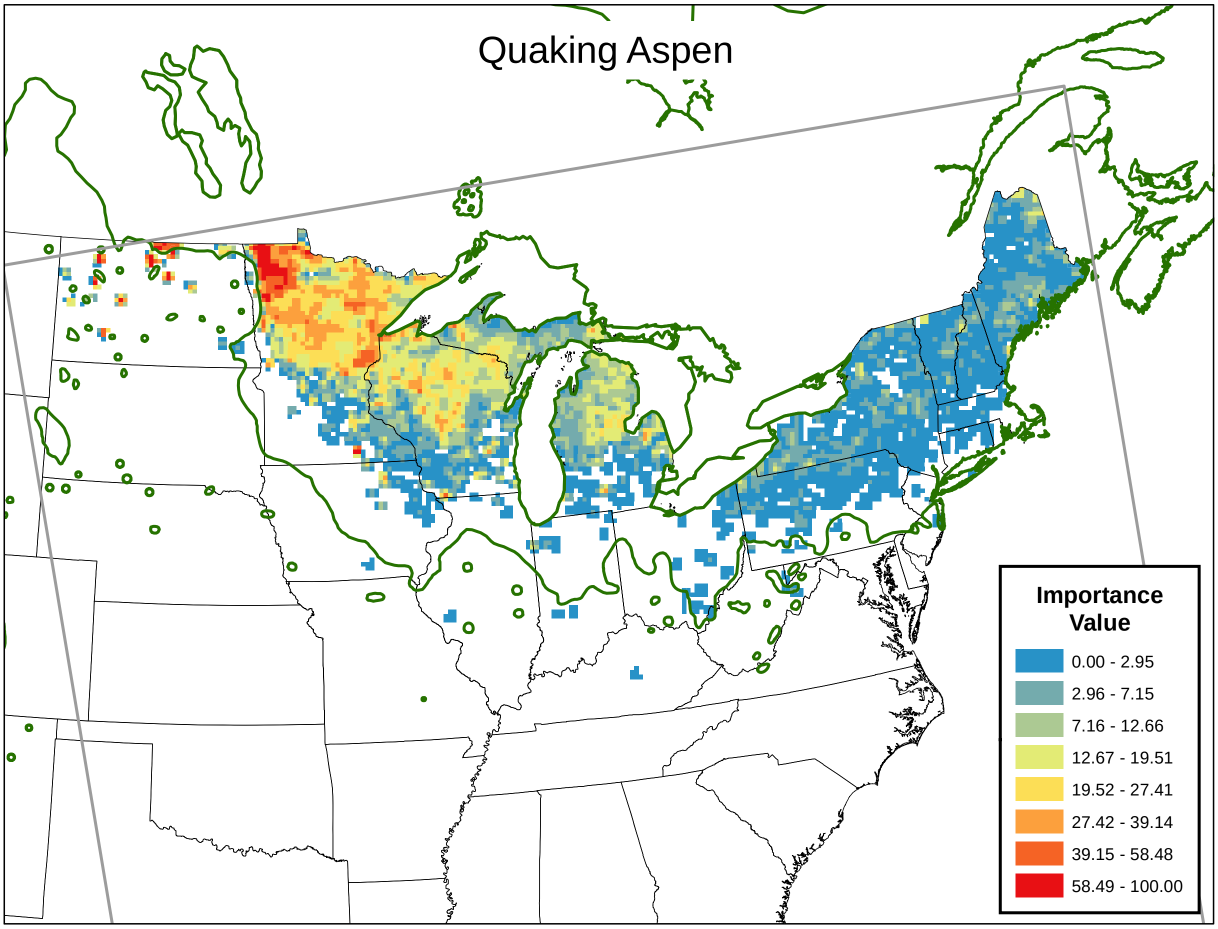


Figure 5A- 48 Importance Values for Quaking Aspen

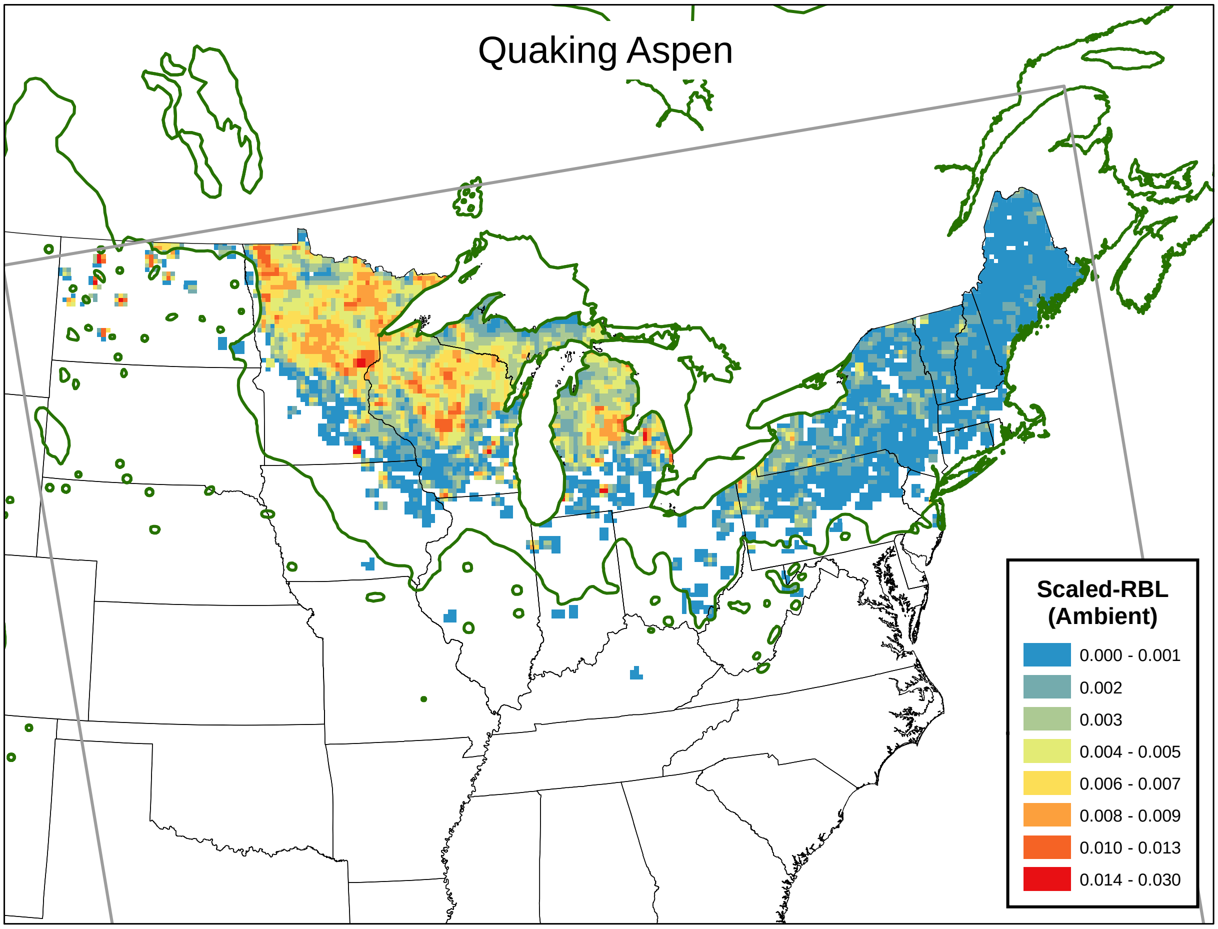


Figure 5A- 49 Scaled Relative Biomass Loss for Quaking Aspen under recent ambient conditions

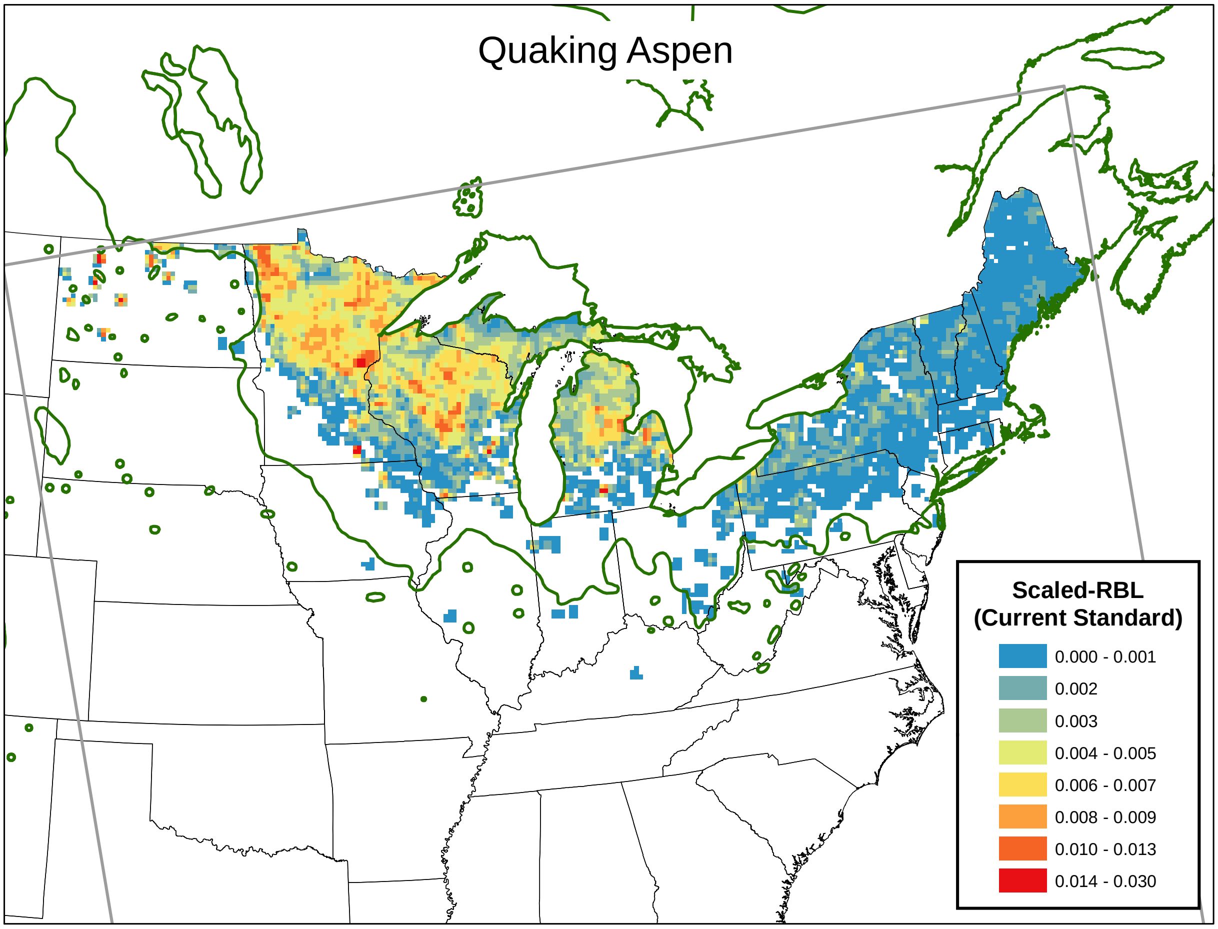


Figure 5A- 50 Scaled Relative Biomass Loss for Quaking Aspen under the current standard rollback scenario

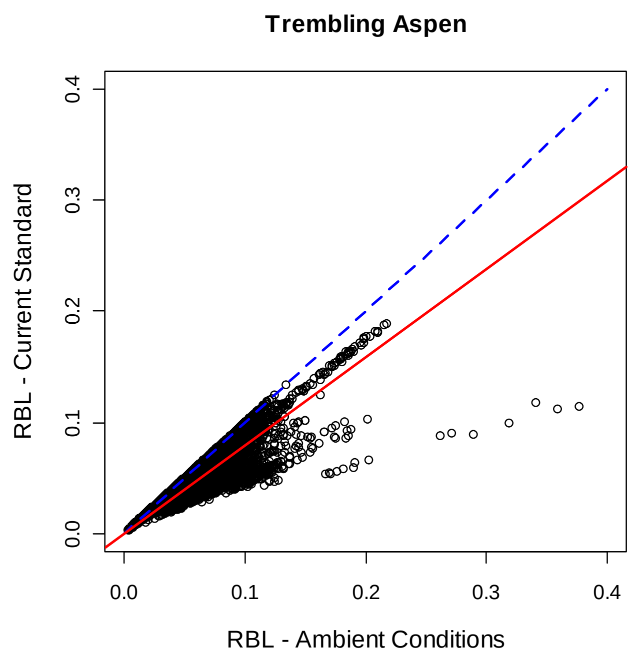


Figure 5A- 51 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Quaking Aspen

Table 5A- 10 Summary of Linear Model Results for Quaking Aspen

Linear Model Results	Current Standard	Alt A	Alt B
N	14,249		
r-squared	0.9508		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.795		

BLACK CHERRY

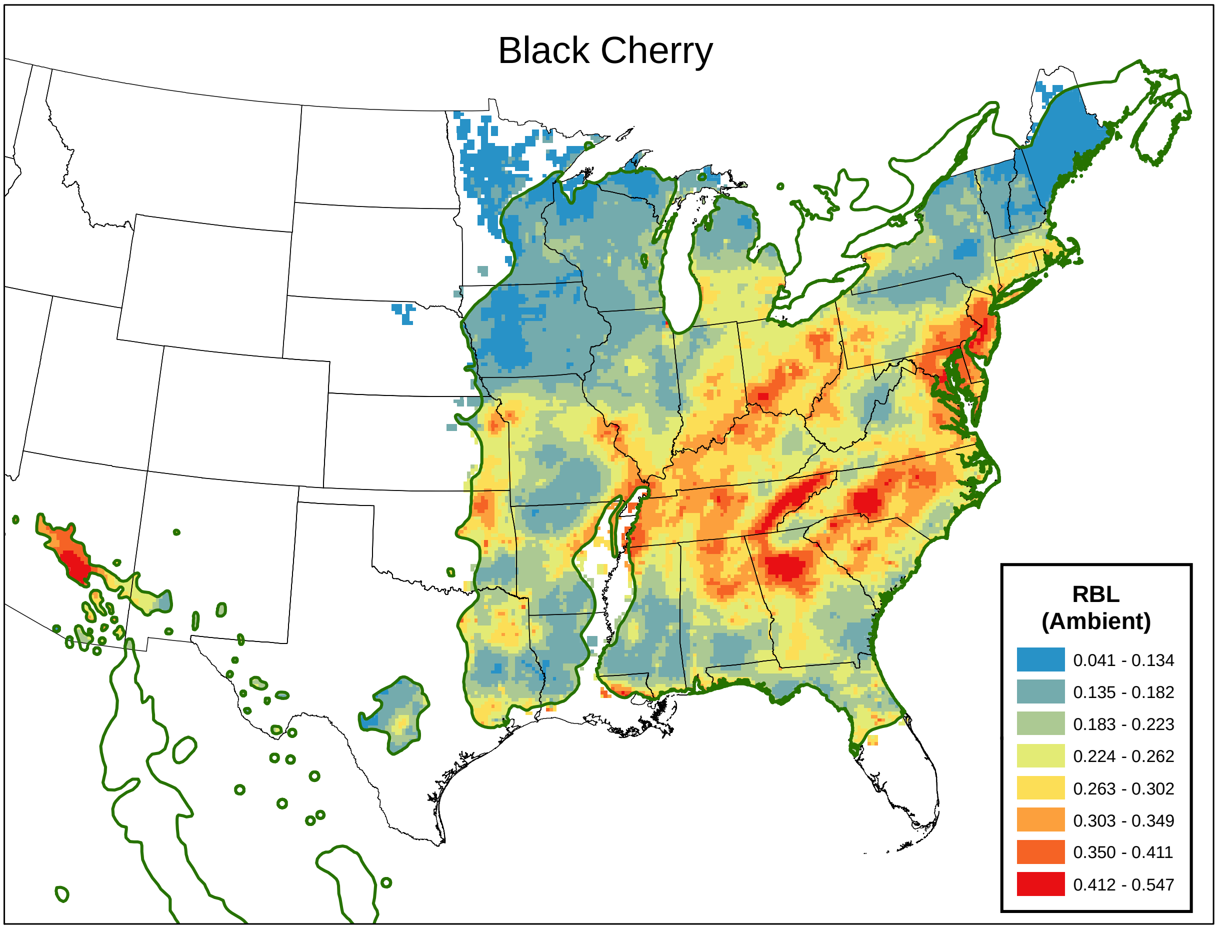


Figure 5A- 52 Relative Biomass Loss for Black Cherry under recent ambient conditions

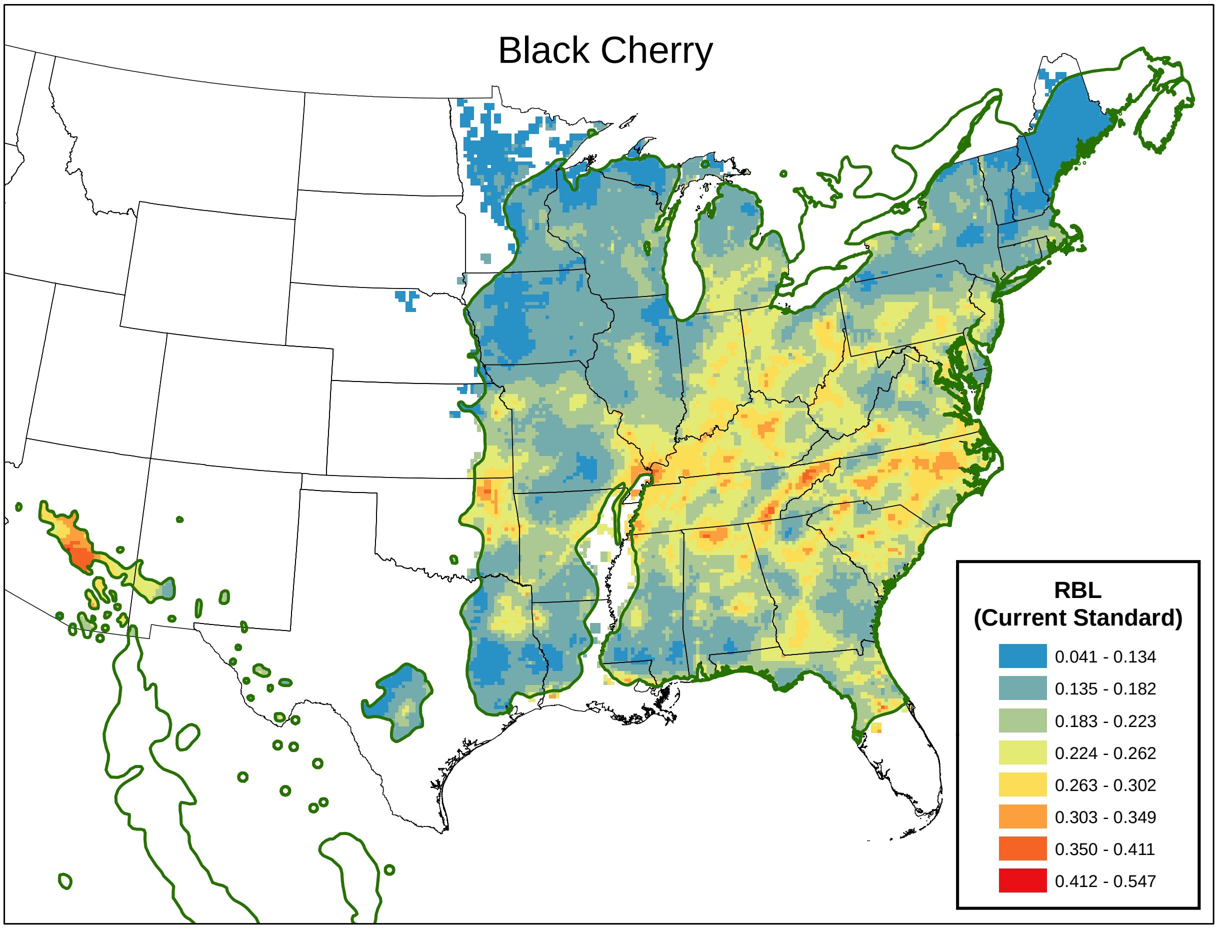


Figure 5A- 53 Relative Biomass Loss for Black Cherry under the current standard rollback scenario

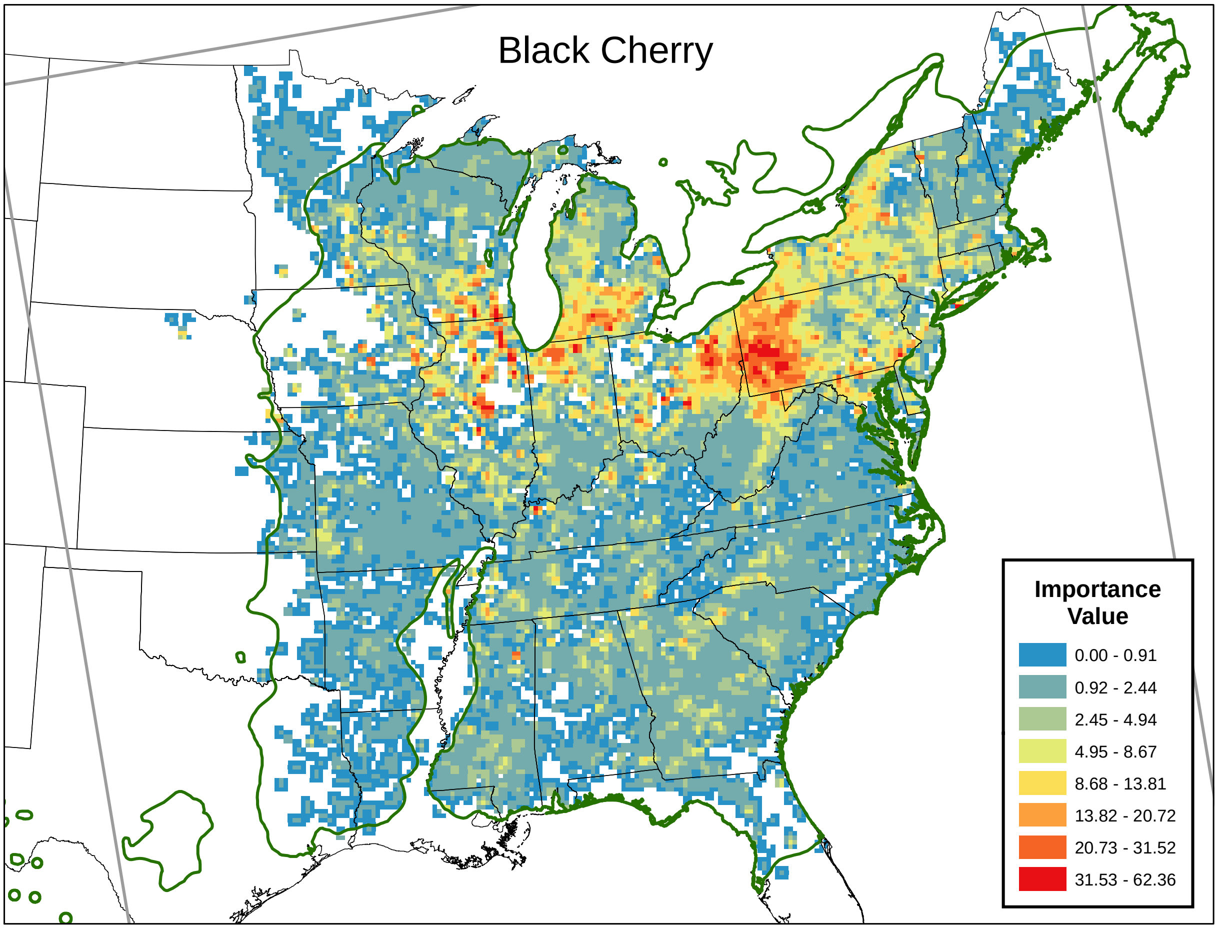


Figure 5A- 54 Importance Values for Black Cherry

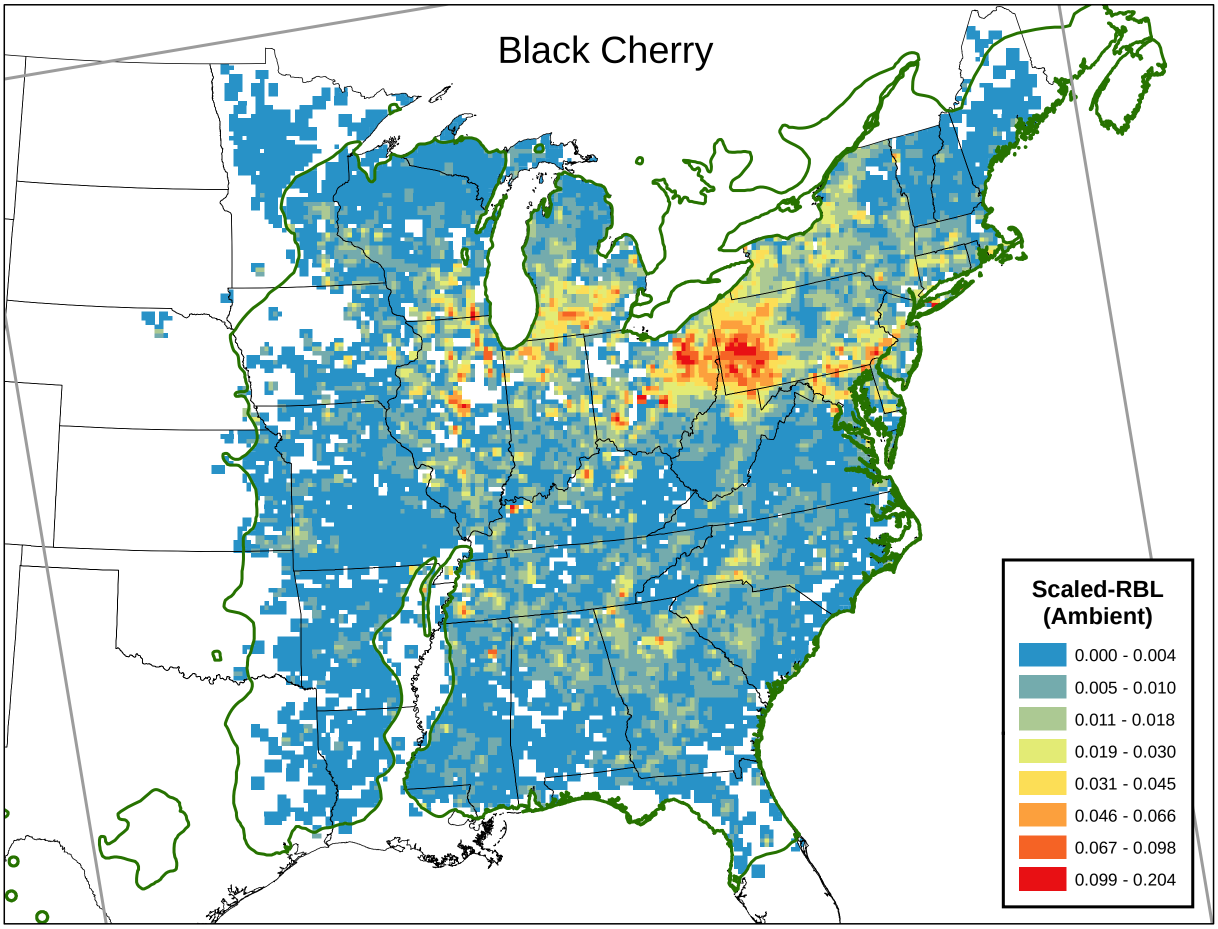


Figure 5A- 55 Scaled Relative Biomass Loss for Black Cherry under recent ambient conditions

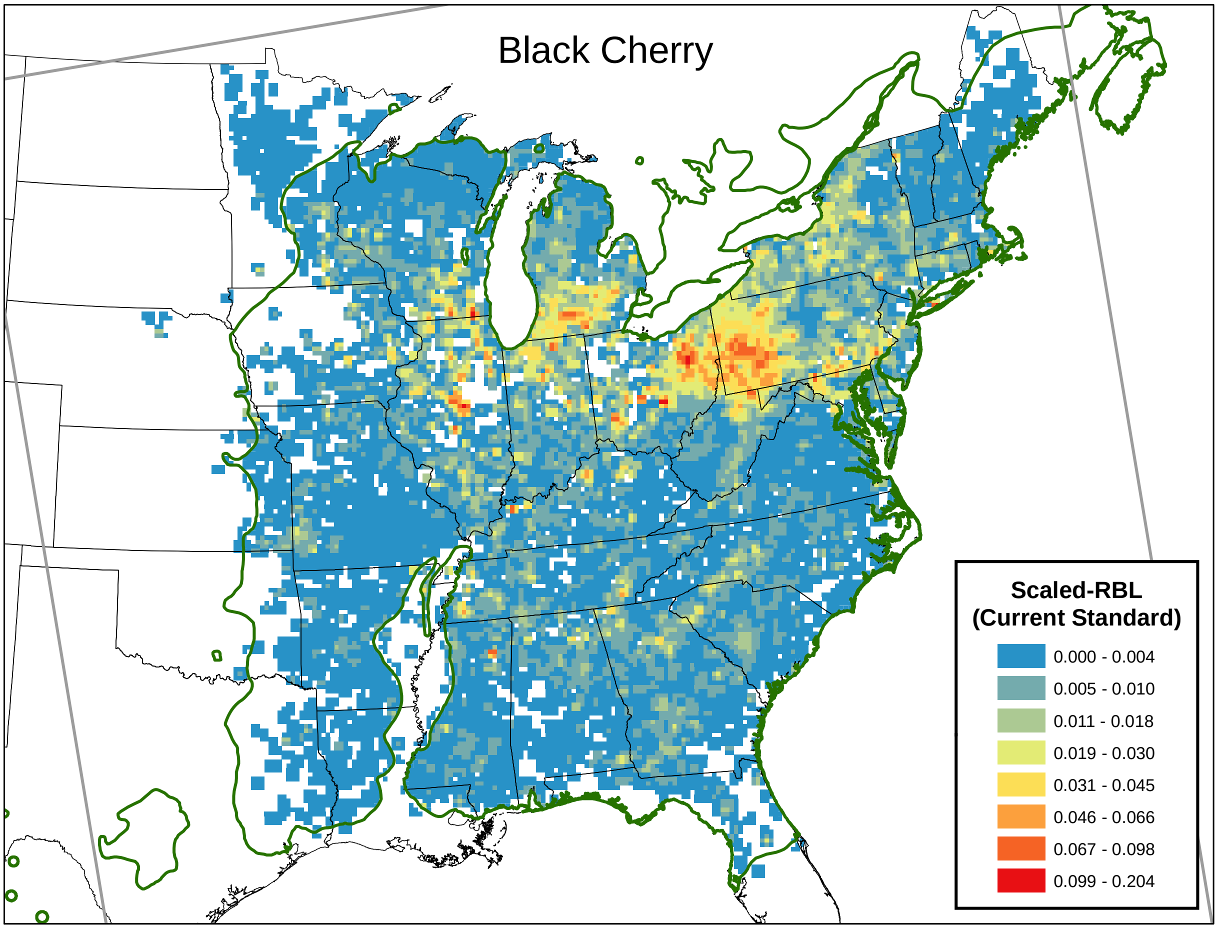


Figure 5A- 56 Scaled Relative Biomass Loss for Black Cherry under the current standard rollback scenario

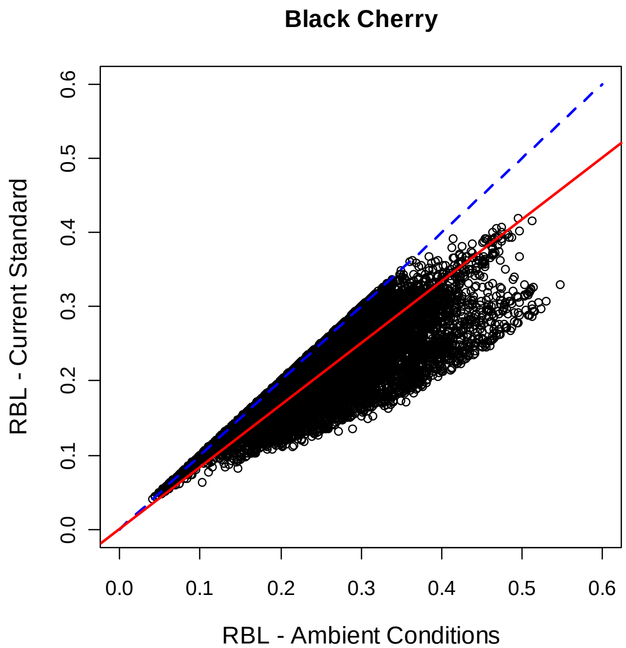


Figure 5A- 57 Linear Model Fit of RBL under a Current Standard Rollback scenario compared to RBL at ambient conditions for Black Cherry

Table 5A- 11 Summary of Linear Model Results for Black Cherry

Linear Model Results	Current Standard	Alt A	Alt B
N	22,504		
r-squared	0.9773		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.834		

APPENDIX 5B: MAPS OF RELATIVE BIOMASS LOSS FOR CLASS I AREAS

This appendix presents the maps and analyses for the 39 Class I areas analyzed in Chapter 5 of this report. Maps of the scaled Relative Biomass Loss (RBL) summed across the 7 eastern tree species (excluding eastern cottonwood) are presented for each area under ambient conditions and current standard rollback scenarios. The results of the linear model analyses are included for each area, when applicable. This includes the test statistics (p-values) for significant differences from zero and goodness of fit metrics, however it is important to note that because the linear model was forced through the origin, the r-squared values cannot be interpreted in the standard manner, however, they may still provide useful information about overall fit.

Acadia National Park

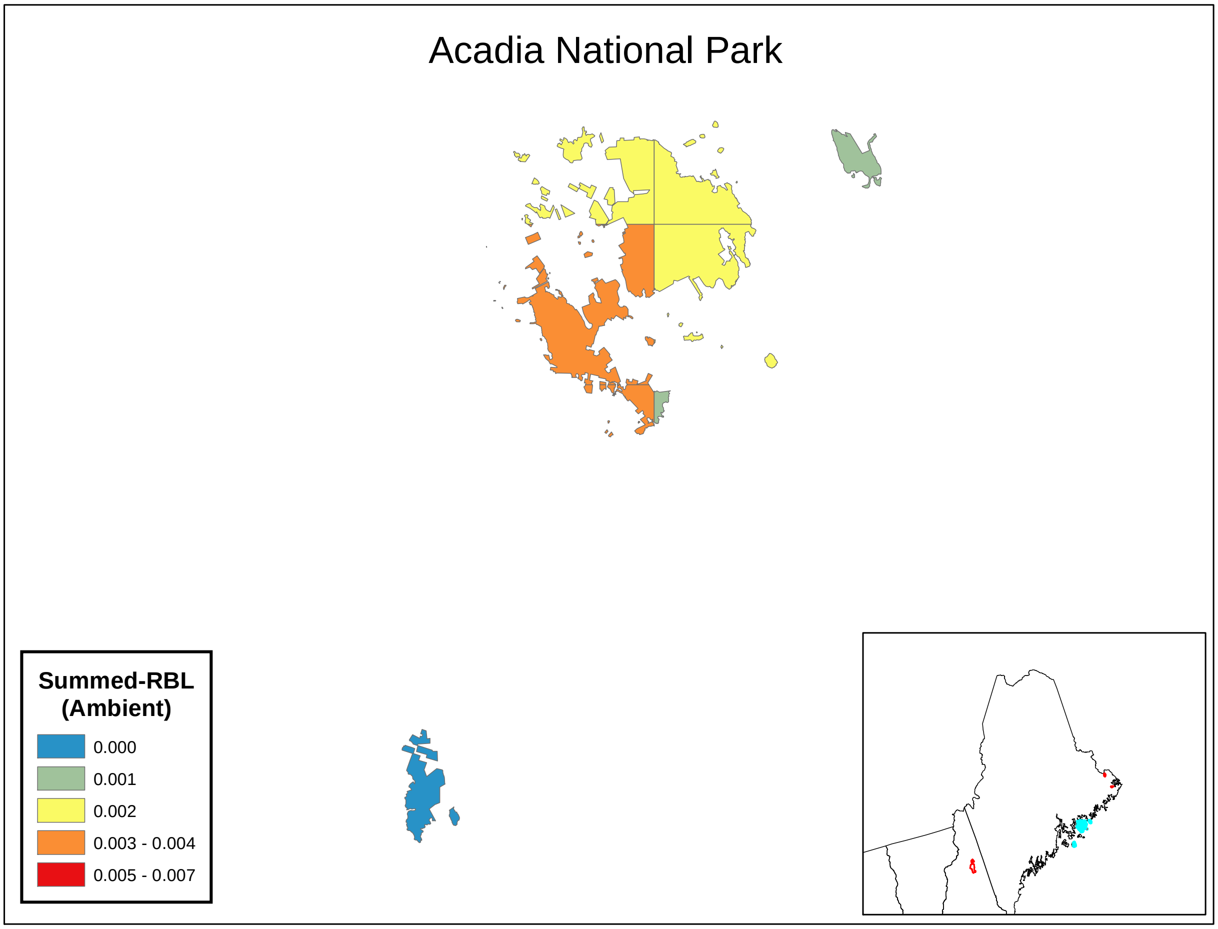


Figure 5B- 1 Scaled Relative Biomass Loss in Acadia National Park under ambient O3 conditions

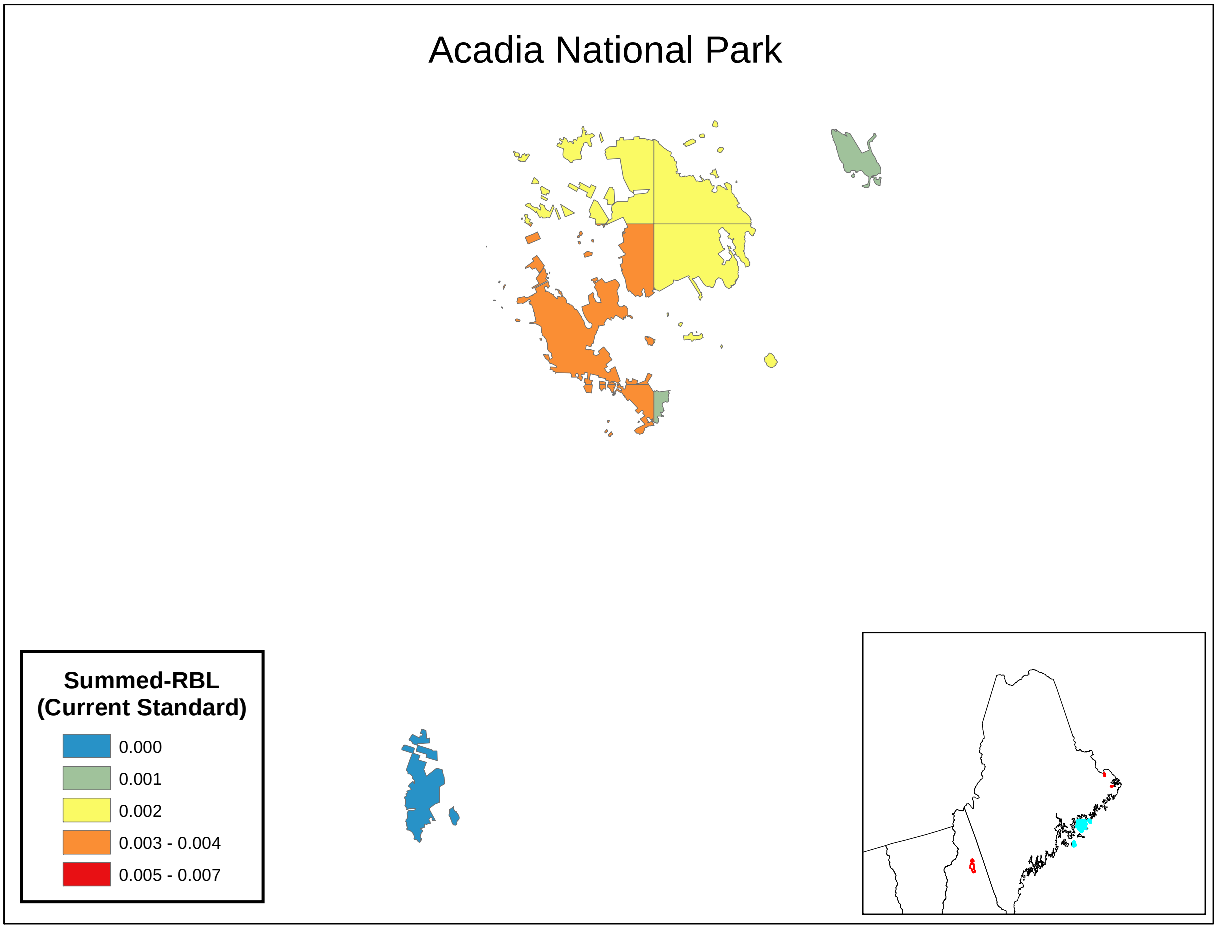


Figure 5B- 2 Scaled RBL in Acadia National Park under the Current Standard rollback scenario

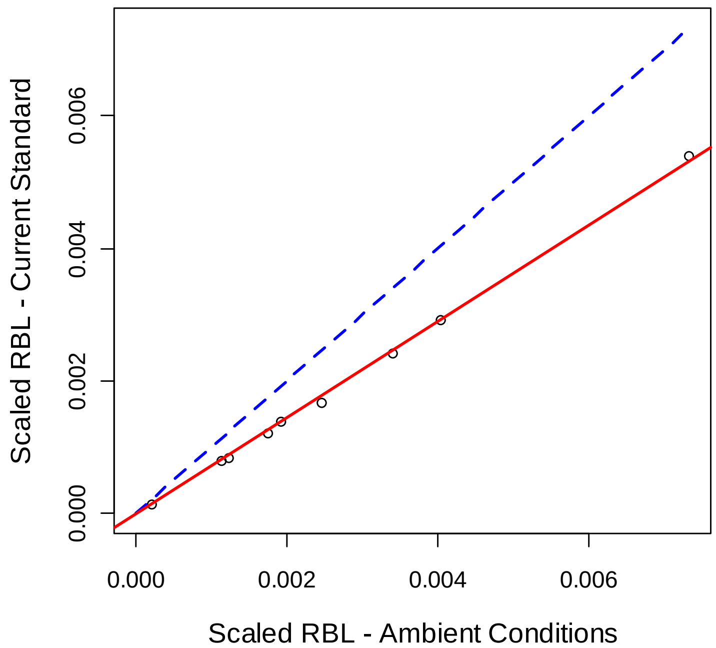


Figure 5B- 3 Linear Model Fit of scaled RBL under the Current Standard Rollback scenario compared to scaled RBL at ambient conditions for Acadia National Park

Table 5B- 1 Summary of Linear Model Results for Acadia National Park

Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	9		
r-squared	0.9993		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.724		
Mean W126 (Ambient is 6.74)	5.24		

BADLANDS/SAGE CREEK WILDERNESS

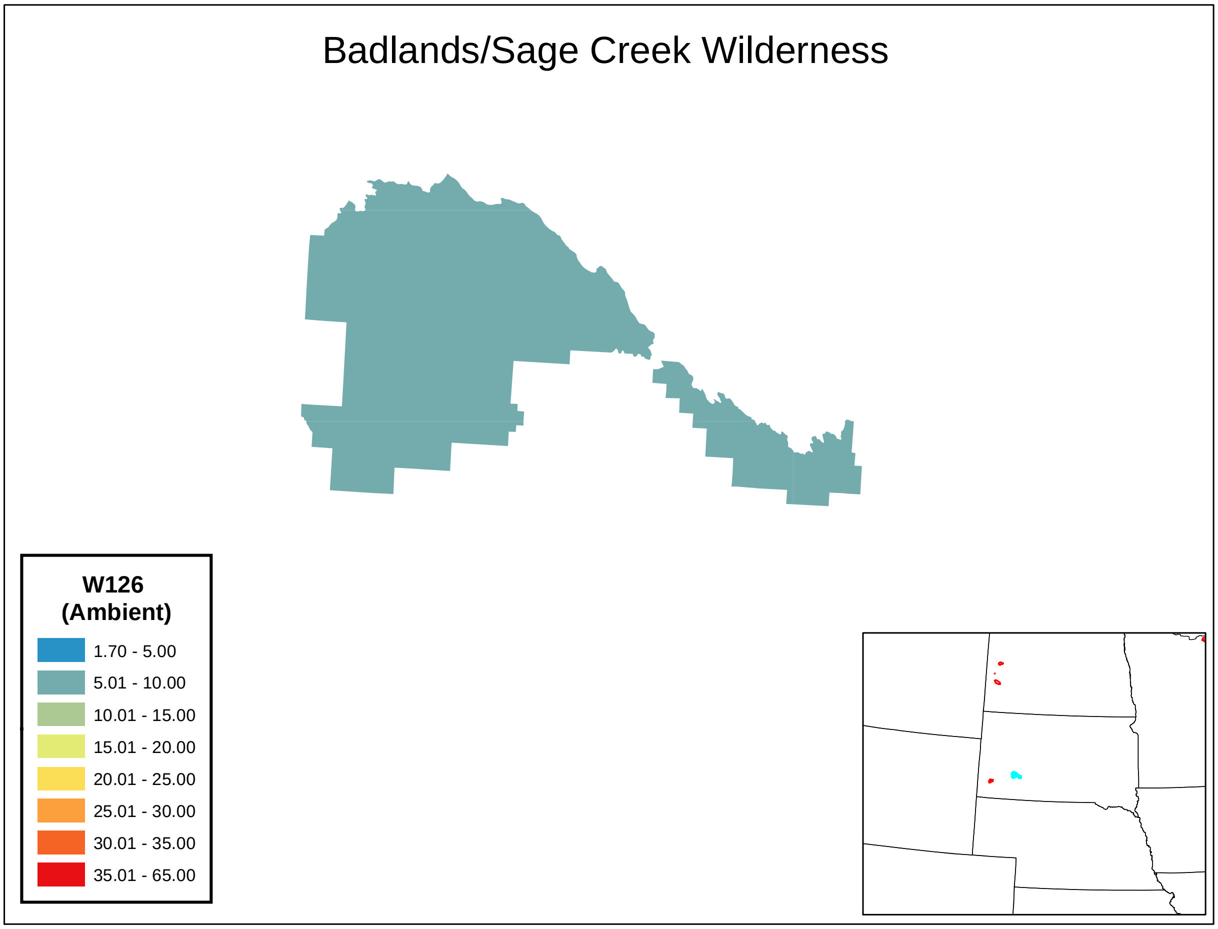
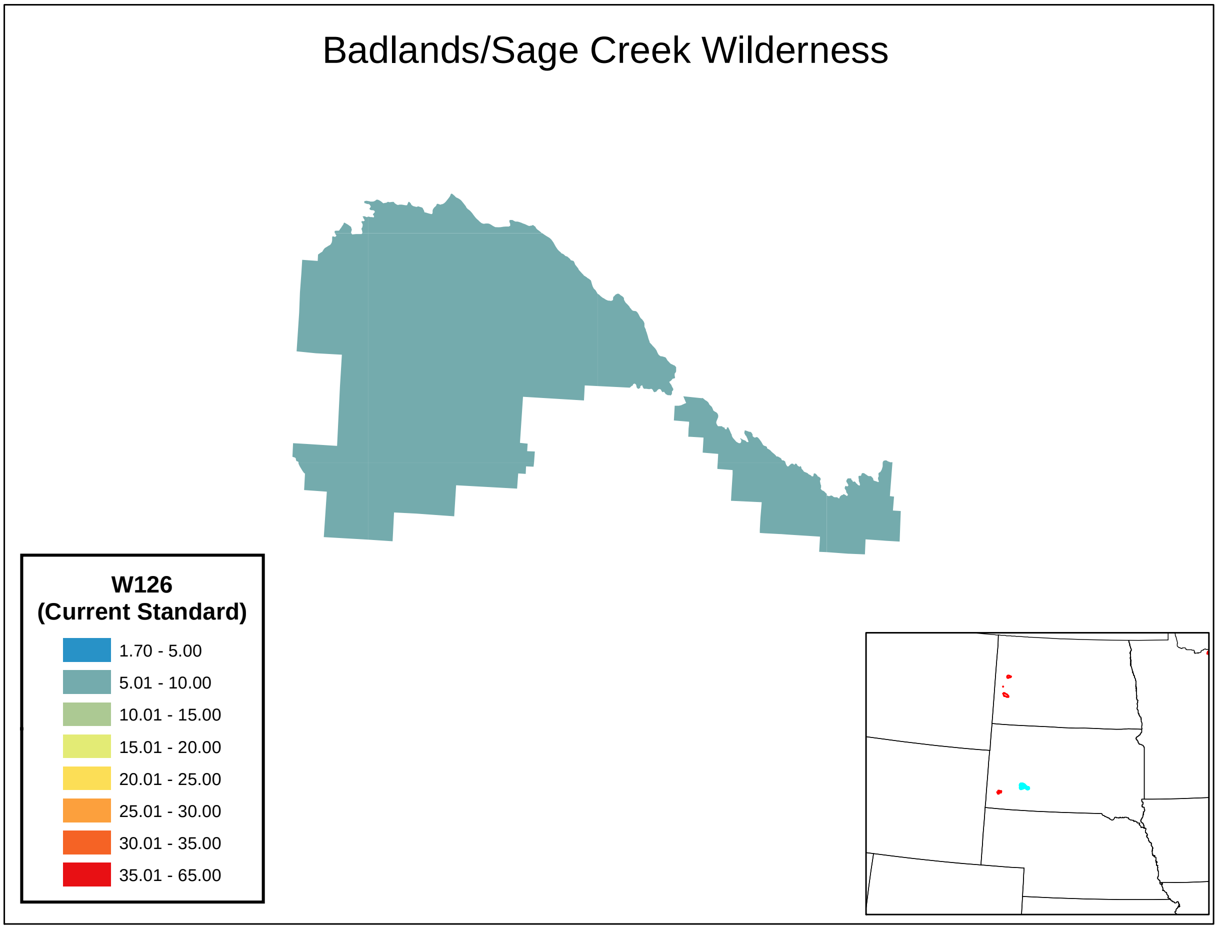
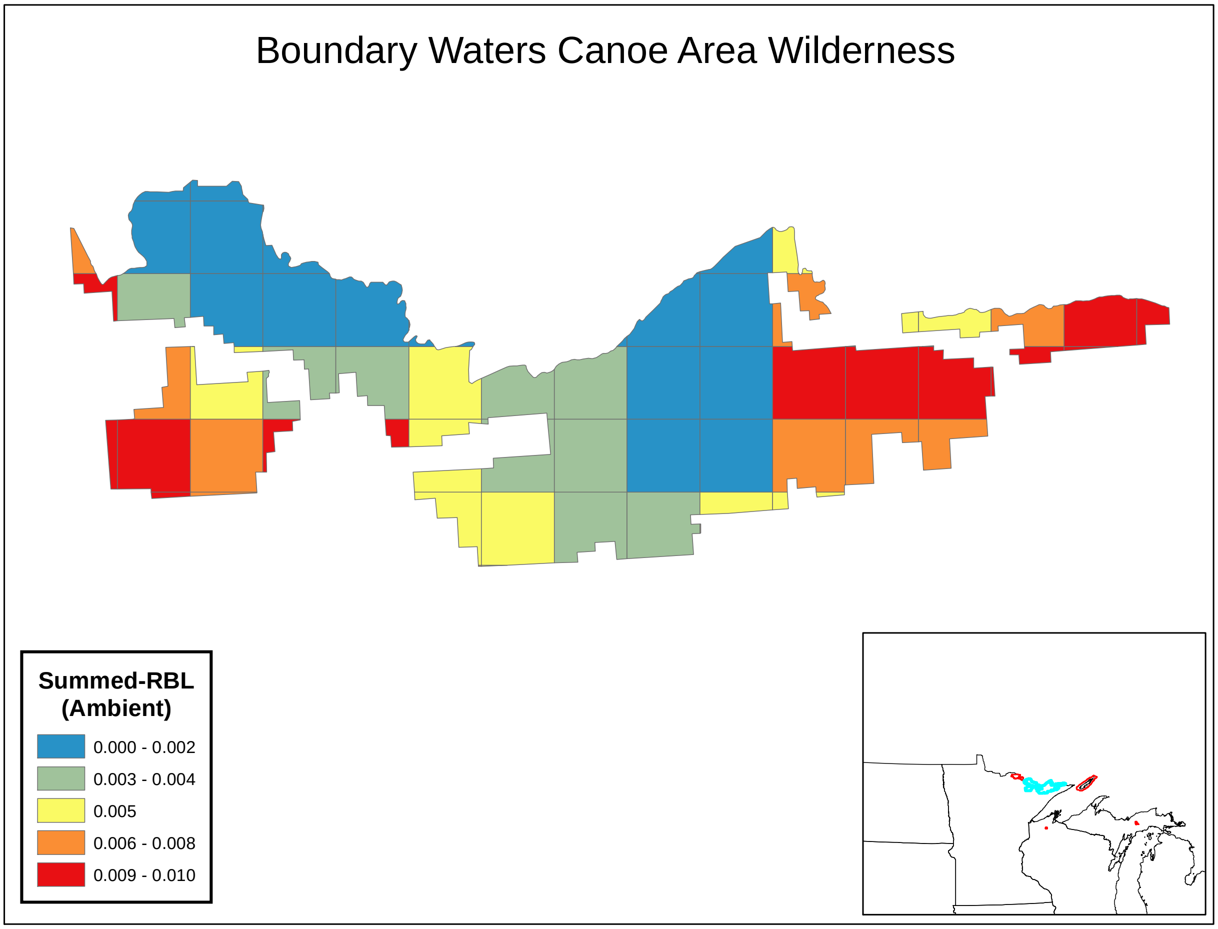


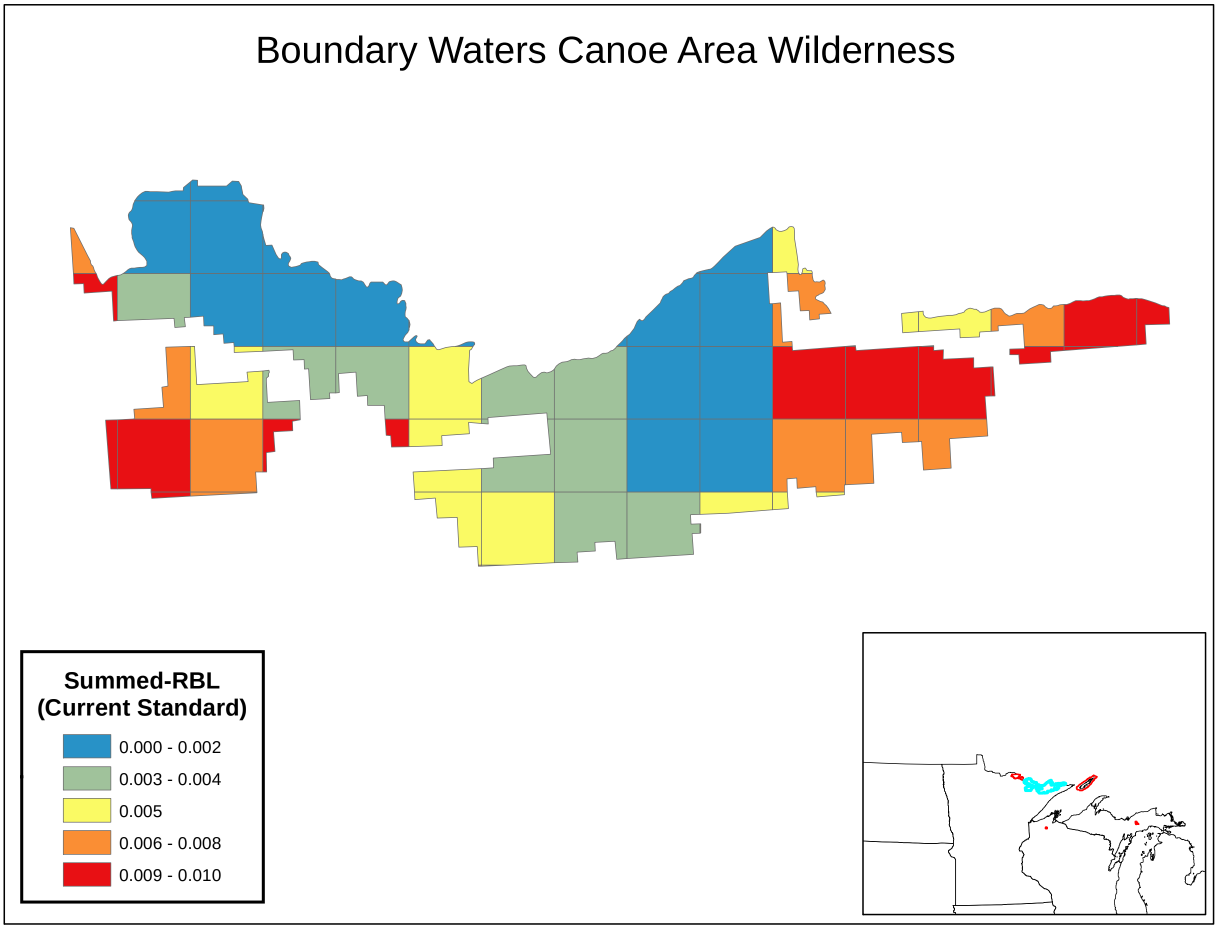
Figure 5B- 4 Ambient W126 Levels in Badlands/Sage Creek Wilderness (11 grid cells, mean W126 = 7.53 PPM)


Badlands/Sage Creek Wilderness
W126
(Current Standard)
1.70 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 - 35.00
35.01 - 65.00

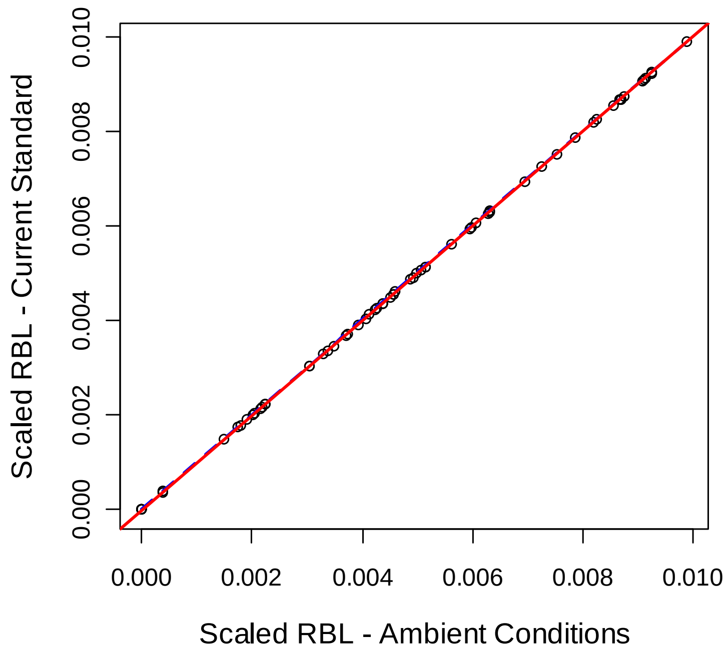
1

BOUNDARY WATERS CANOE AREA WILDERNESS



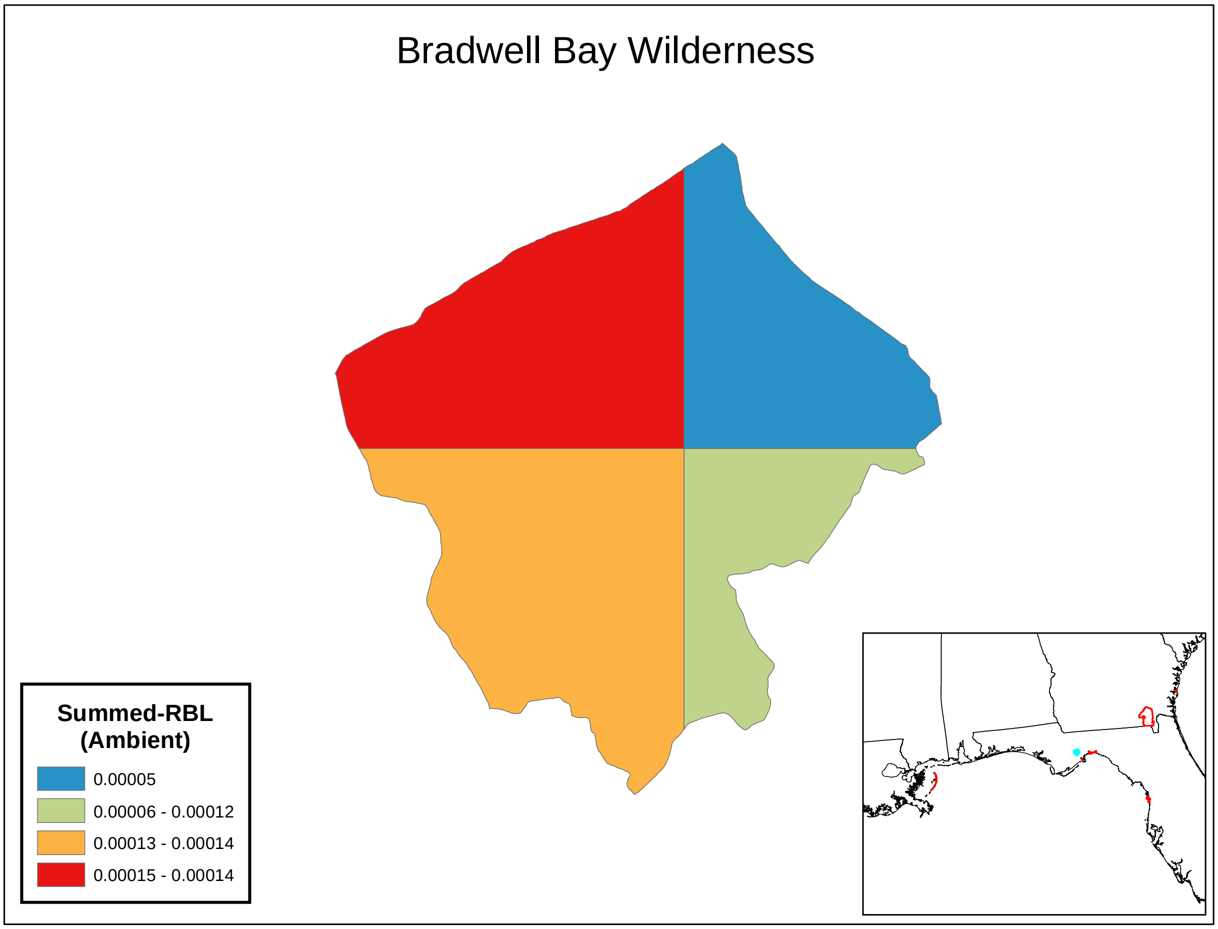

Boundary Waters Canoe Area Wilderness
Summed-RBL
(Current Standard)
0.000 - 0.002
0.003 - 0.004
0.005
0.006 - 0.008
0.009 - 0.010

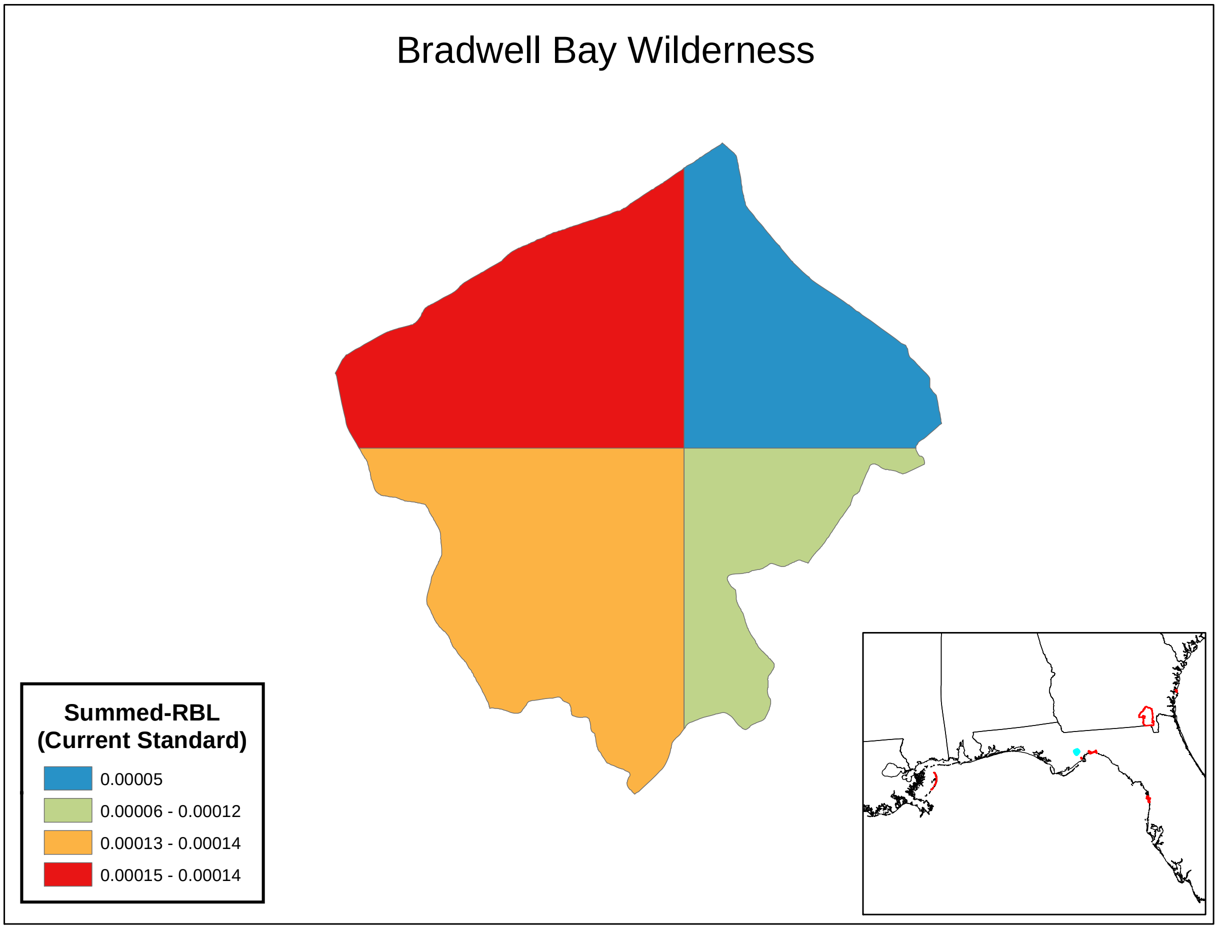
1

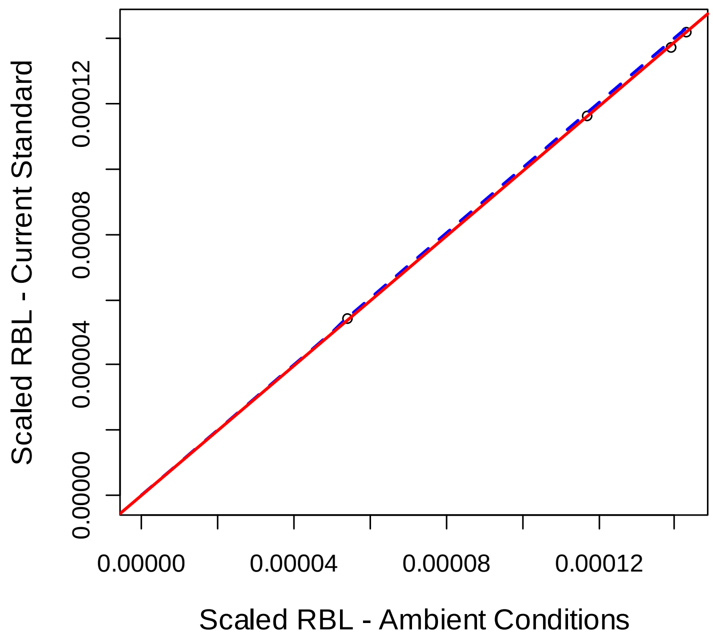


Linear Model Results	Current Standard	Alt A	Alt B
N	67		
r-squared	1		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.000		
Mean W126 (Ambient is 5.24)	5.24		

BRADWELL BAY WILDERNESS

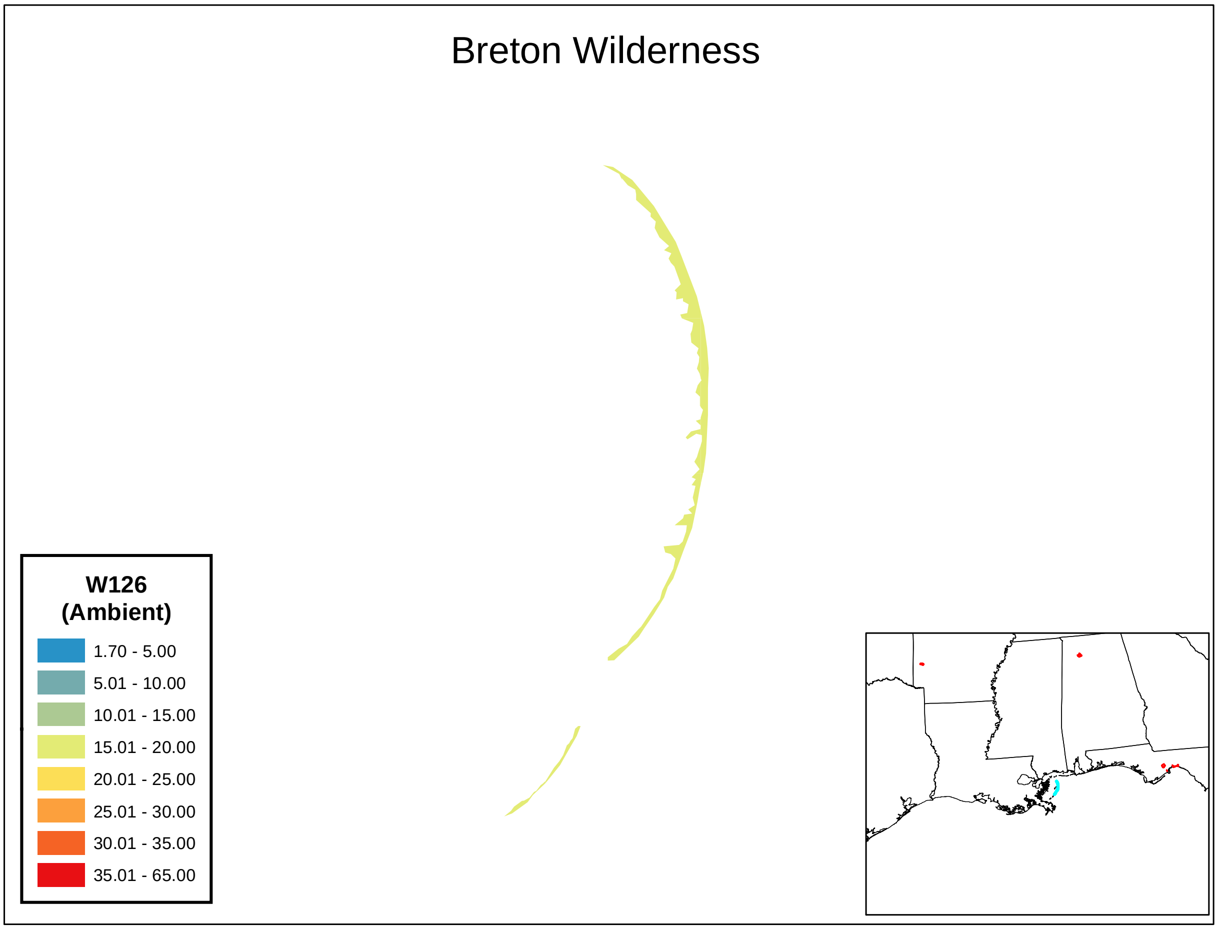



Bradwell Bay Wilderness
Summed-RBL
(Current Standard)
0.00005
0.00006 - 0.00012
0.00013 - 0.00014
0.00015 - 0.00014

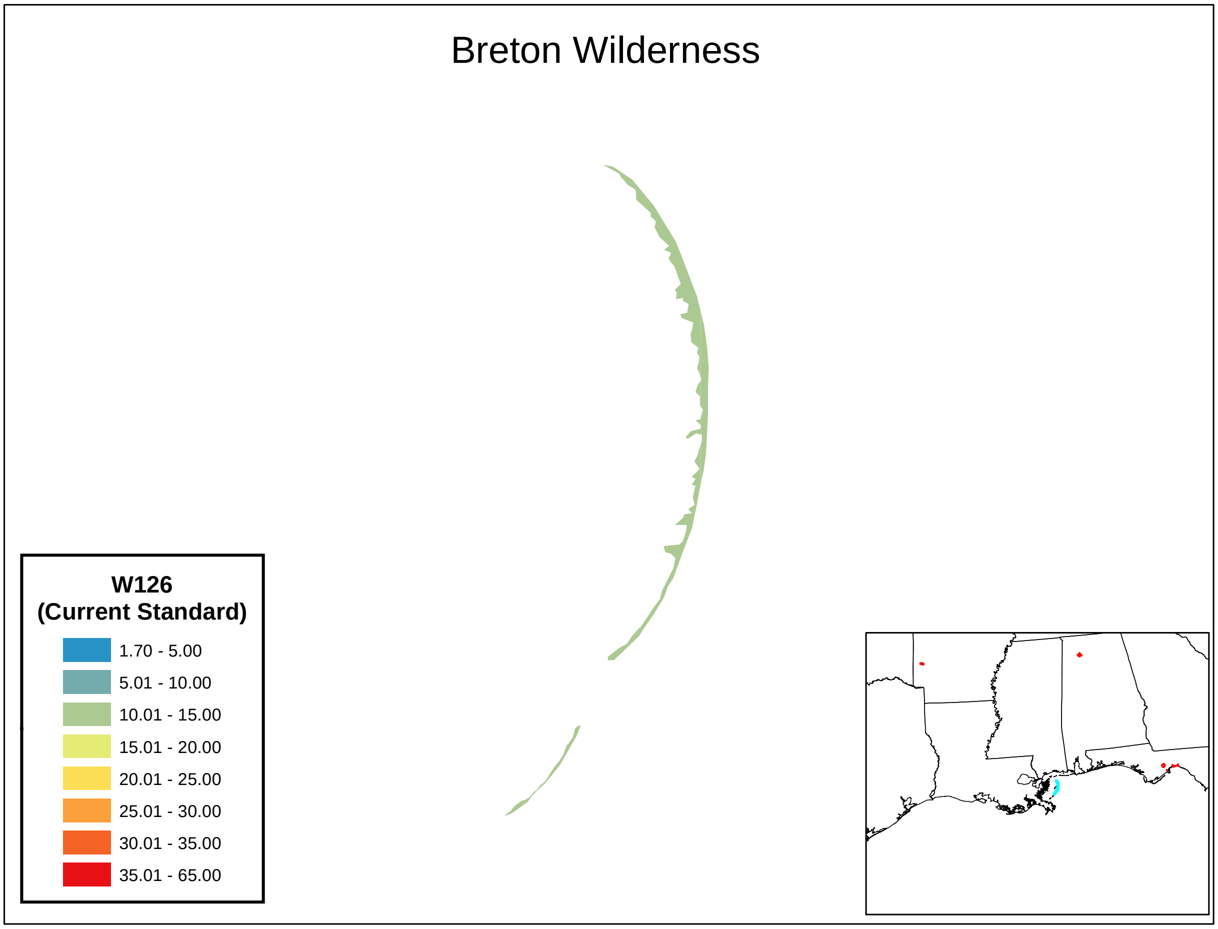


Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	4		
r-squared	1		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.990		
Mean W126 (Ambient = 6.90)	6.86		

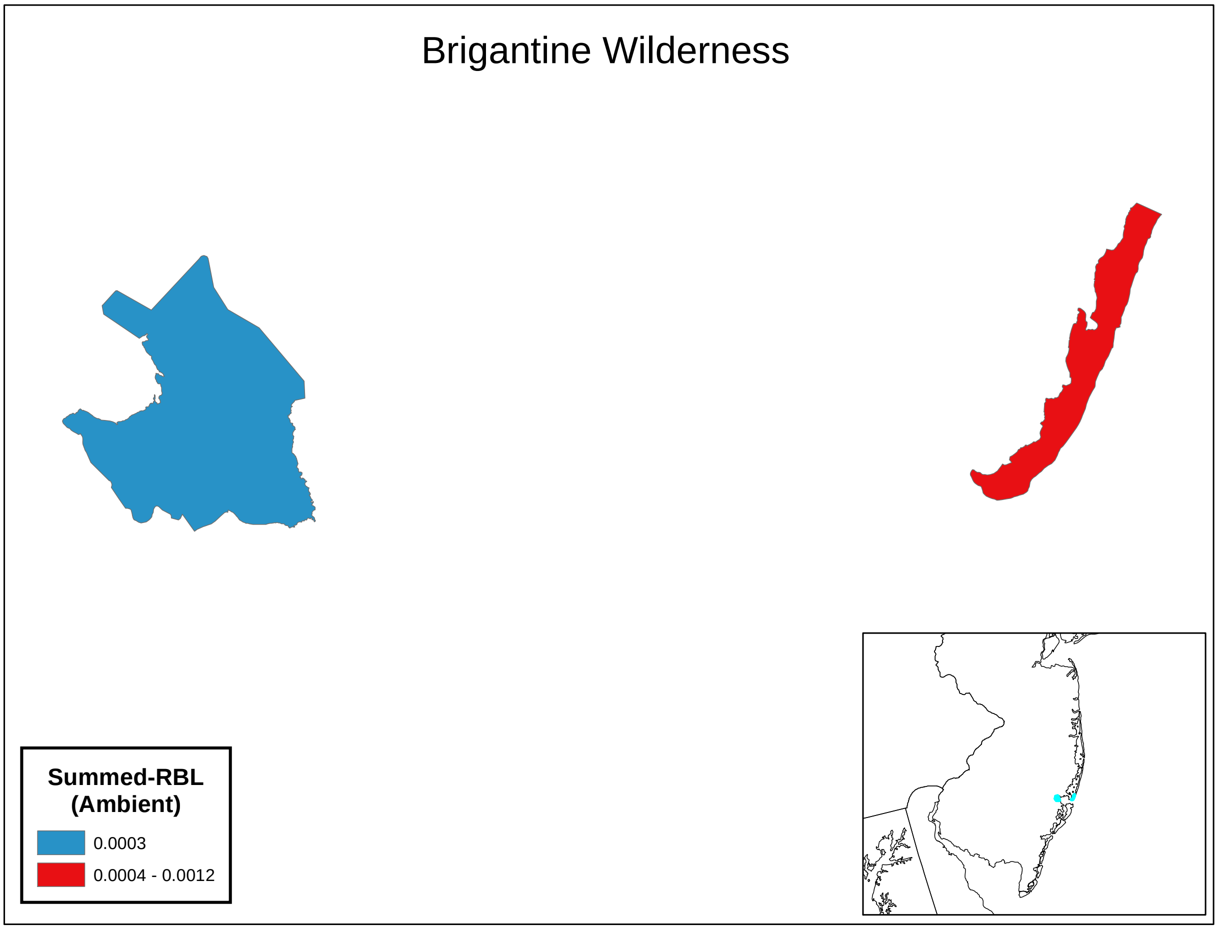
1 **BRETON WILDERNESS**

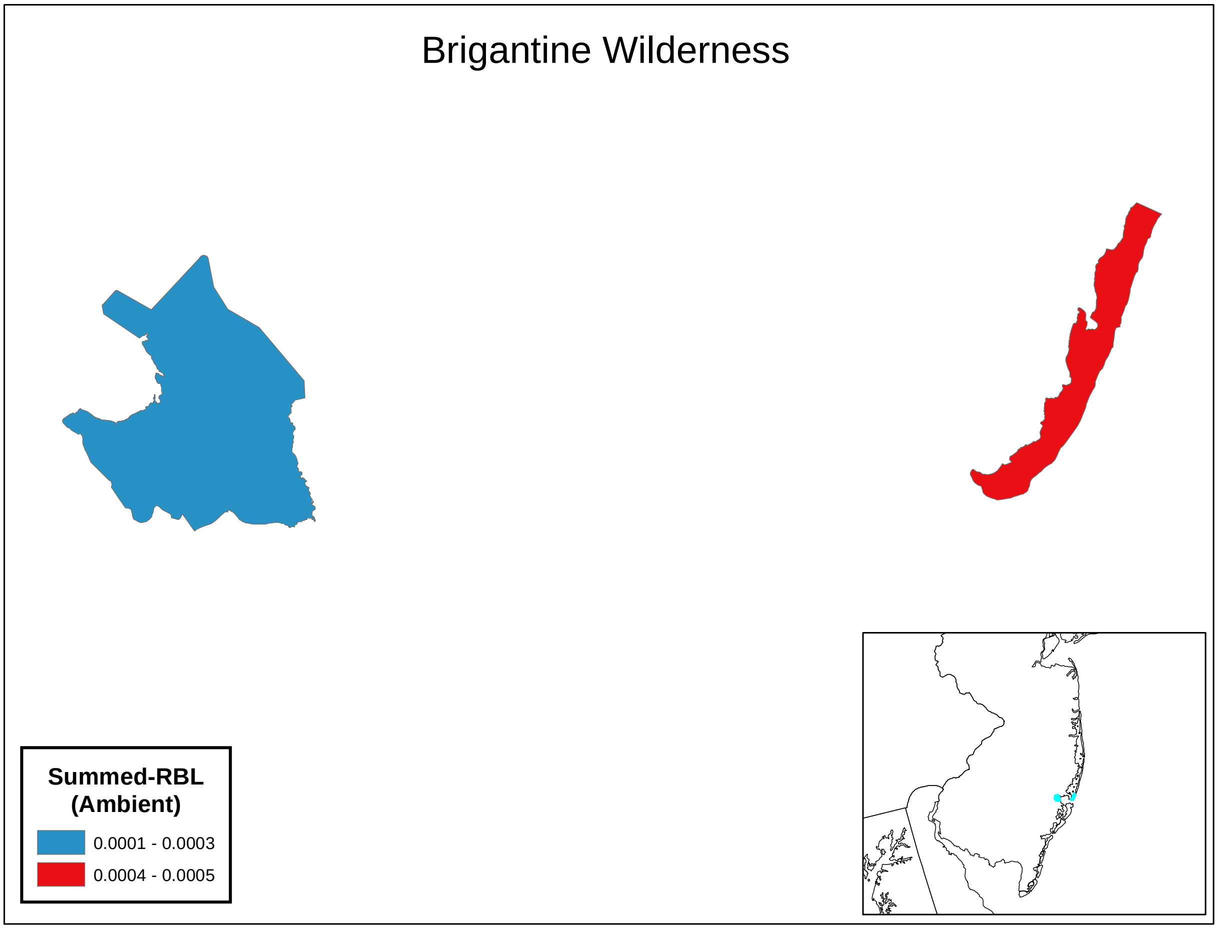


2

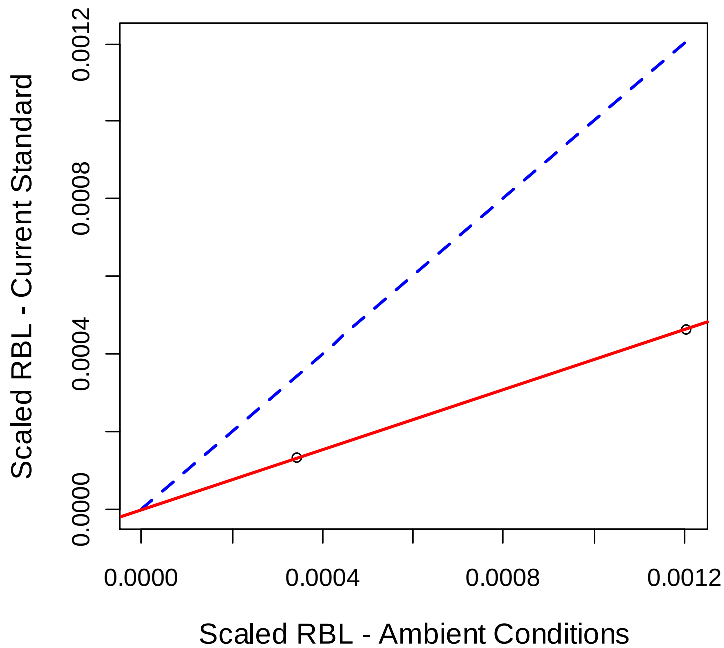

Breton Wilderness
W126
(Current Standard)
1.70 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 - 35.00
35.01 - 65.00

BRIGANTINE WILDERNESS



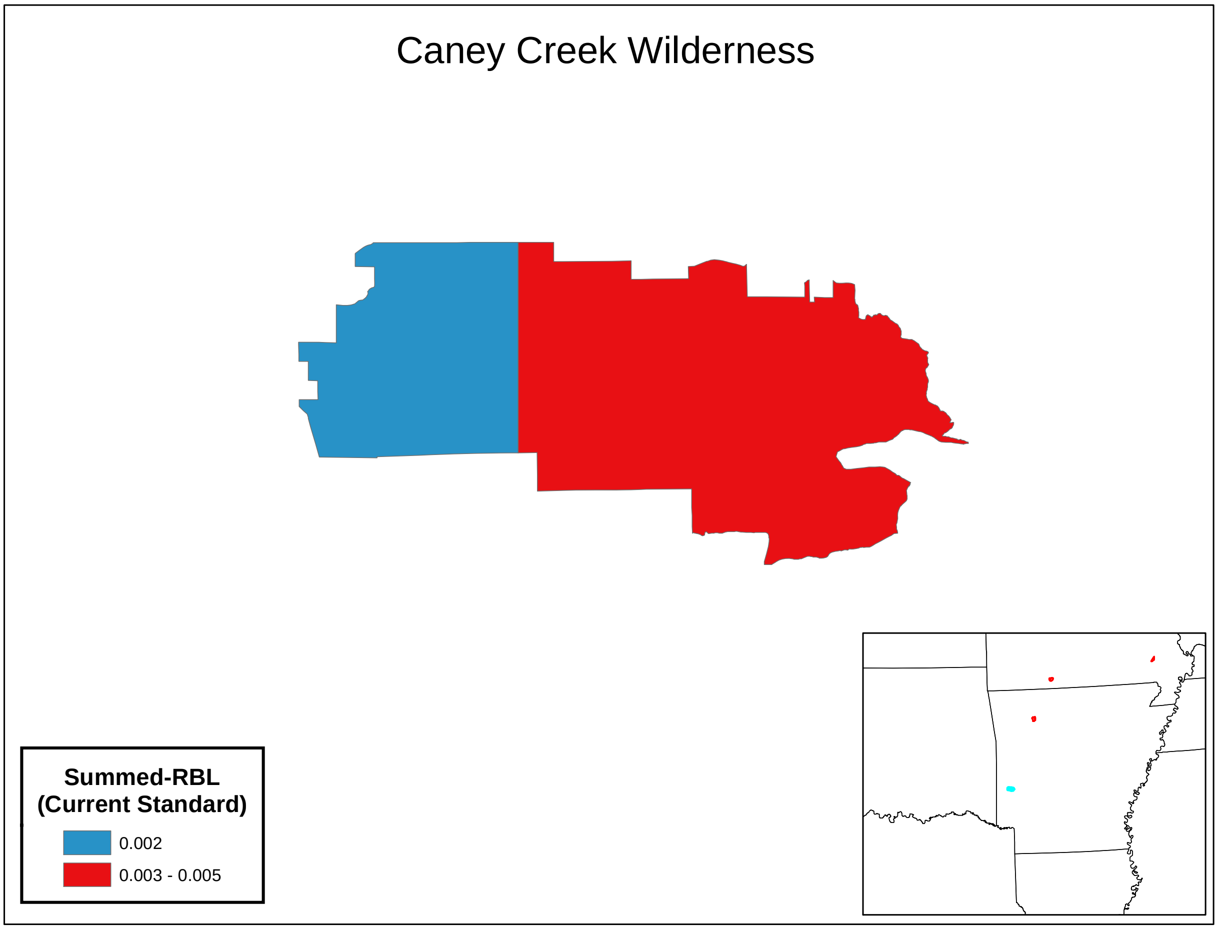

Brigantine Wilderness
Summed-RBL
(Ambient)
0.0001 - 0.0003
0.0004 - 0.0005

1

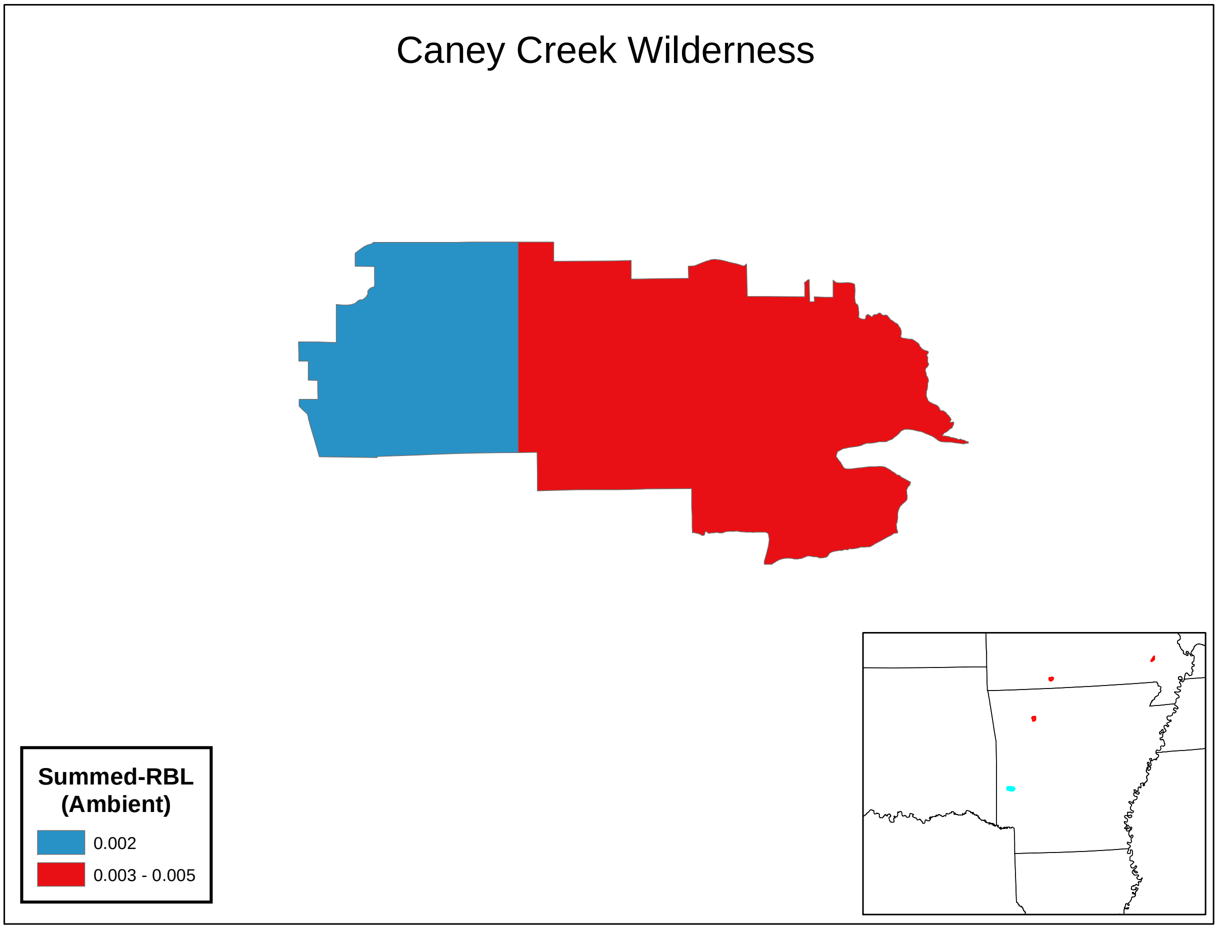


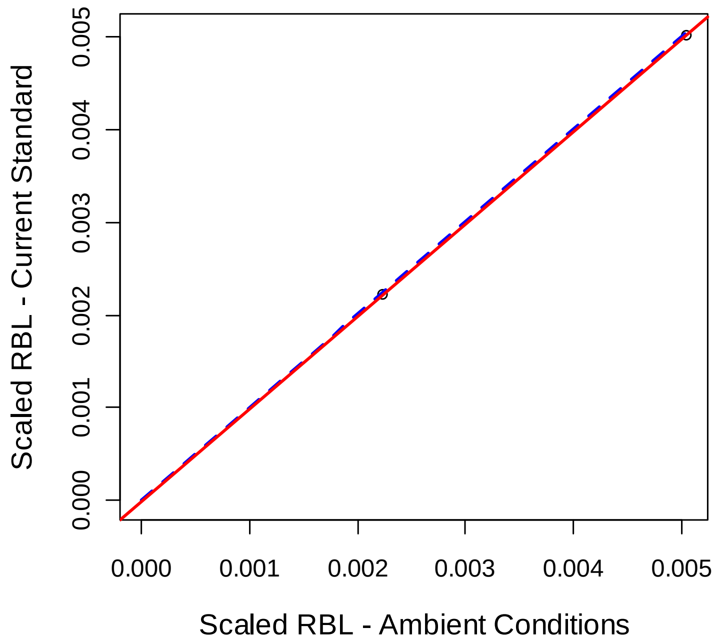
Linear Model Results	Current Standard	Alt A	Alt B
N	2		
r-squared	1		
p-value	0.0031		
Slope (proportion of Ambient RBL)	0.386		
Mean W126 (Ambient = 13.7)	6.79		

CANEY CREEK WILDERNESS



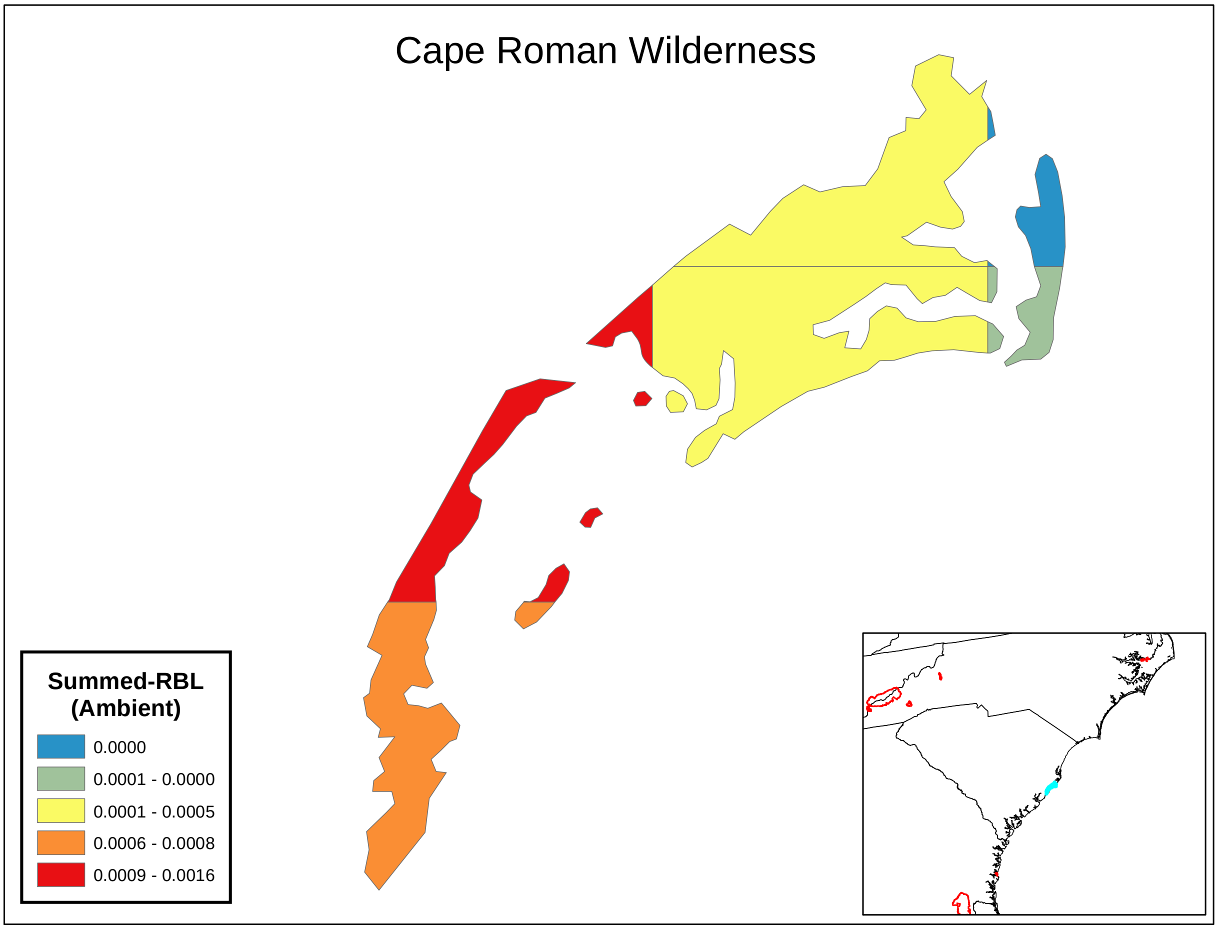
1

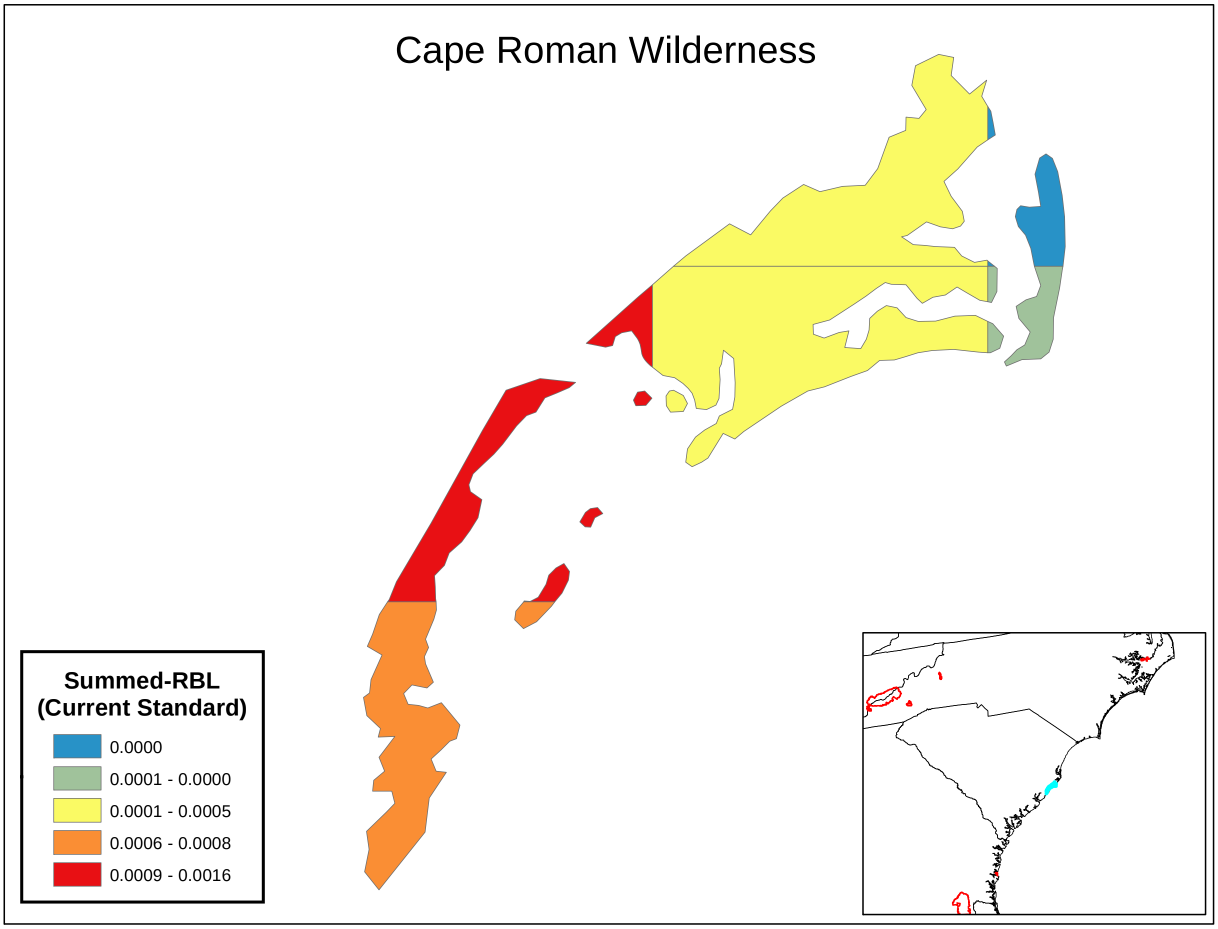


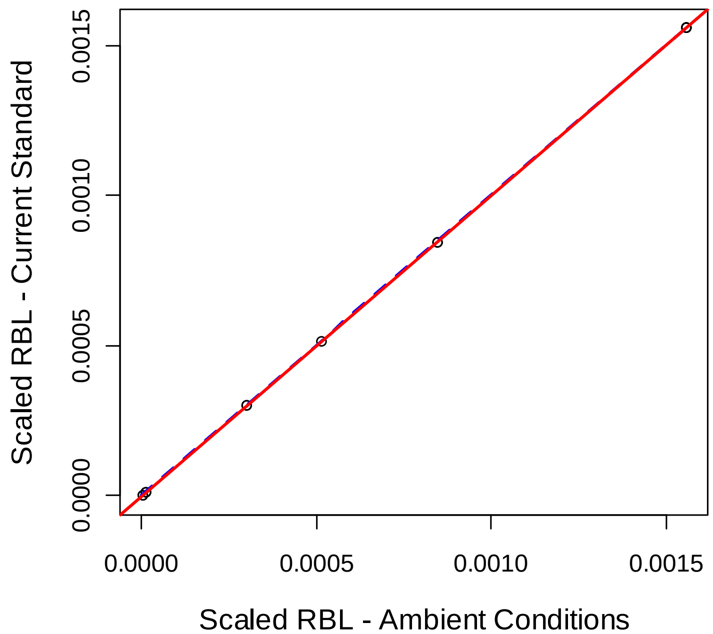


Linear Model Results	Current Standard	Alt A	Alt B
N	2		
r-squared	1		
p-value	0.0008		
Slope (proportion of Ambient RBL)	0.386		
Mean W126 (Ambient = 9.15)	9.11		

CAPE ROMAN WILDERNESS

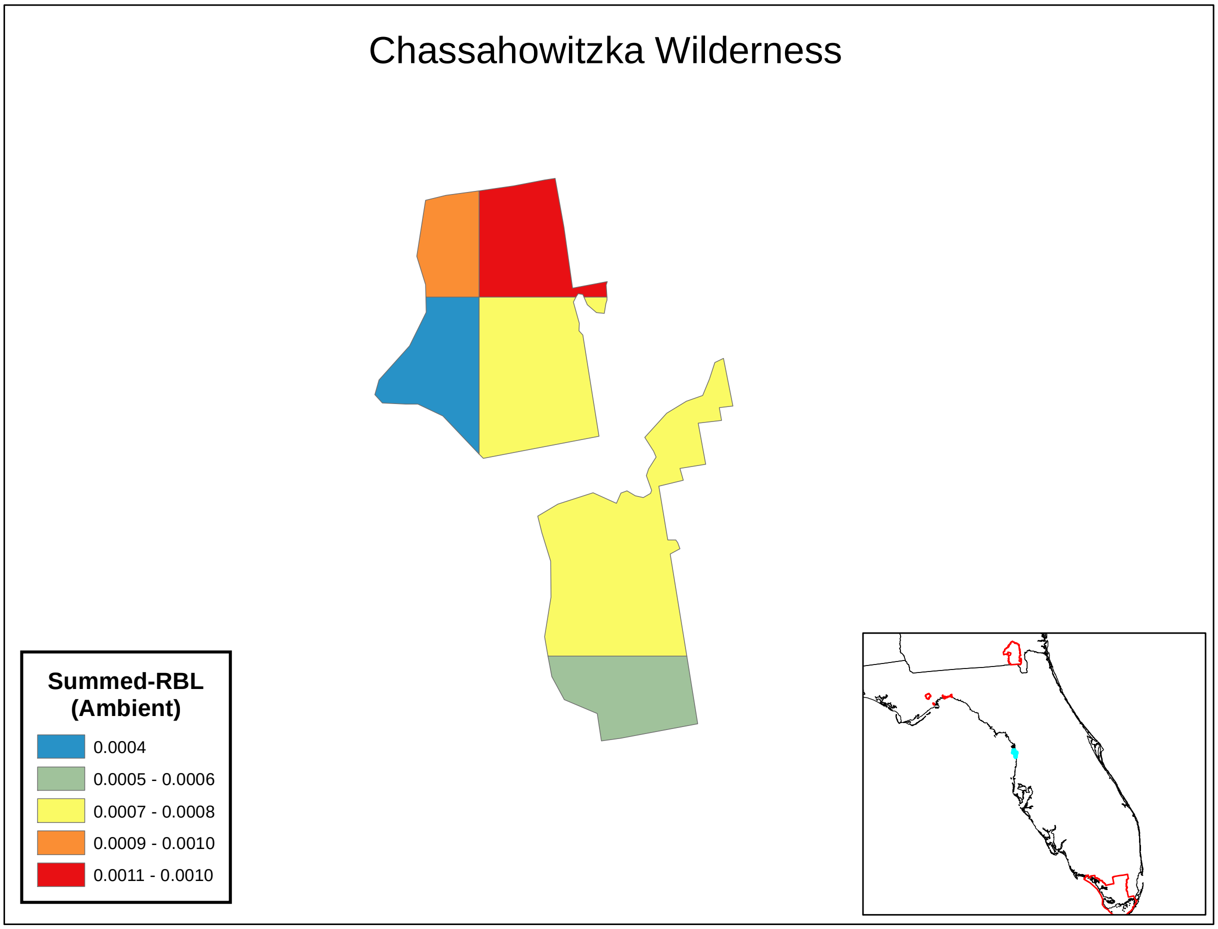


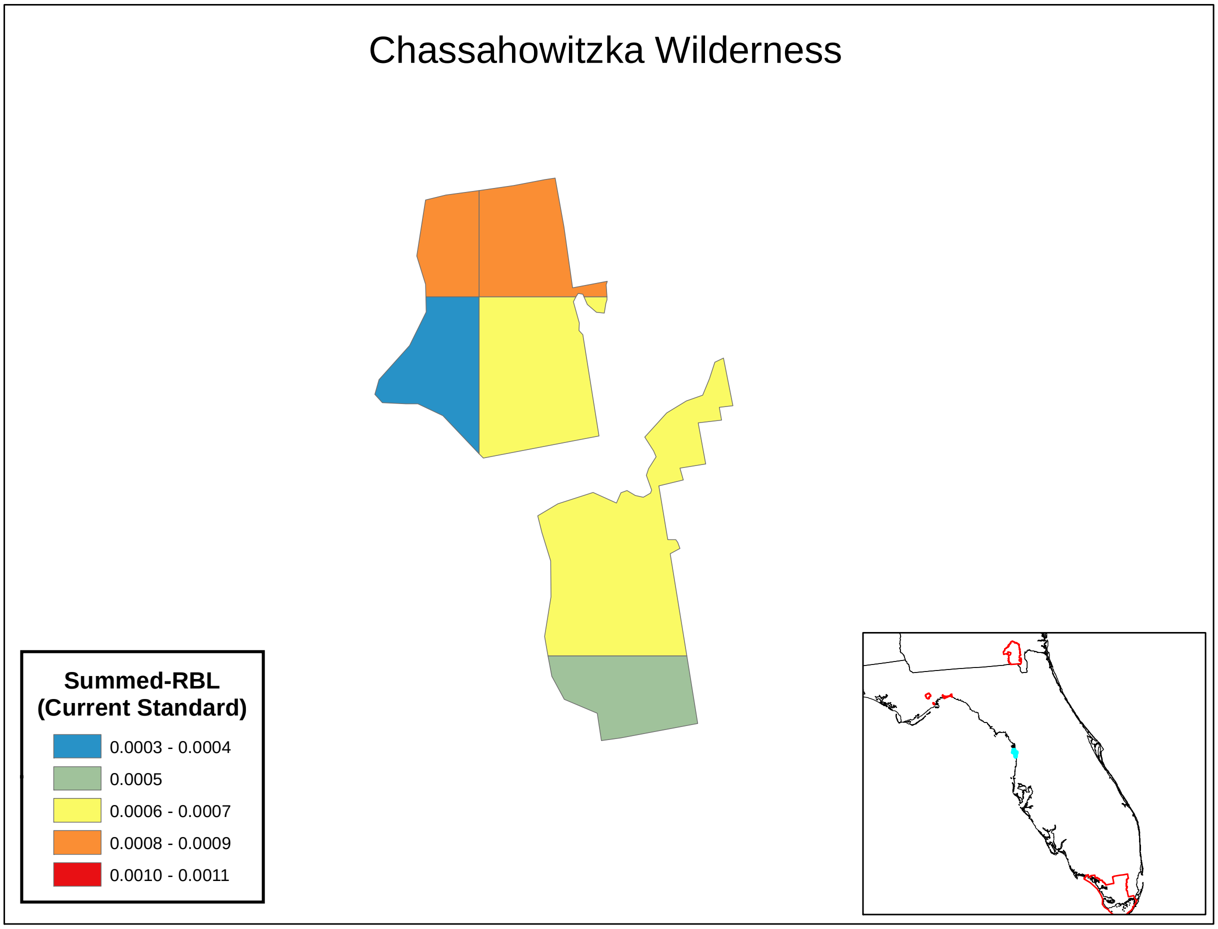

Cape Roman Wilderness
Summed-RBL
(Current Standard)
0.0000
0.0001 - 0.0000
0.0001 - 0.0005
0.0006 - 0.0008
0.0009 - 0.0016

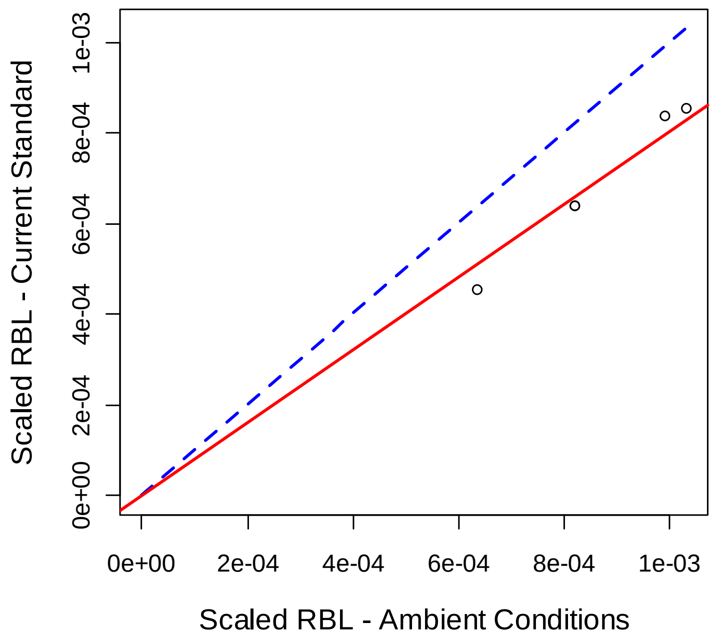


Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	13		
r-squared	1		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.00		
Mean W126 (Ambient = 12.63)	12.62		

CHASSAHOWITZKA WILDERNESS

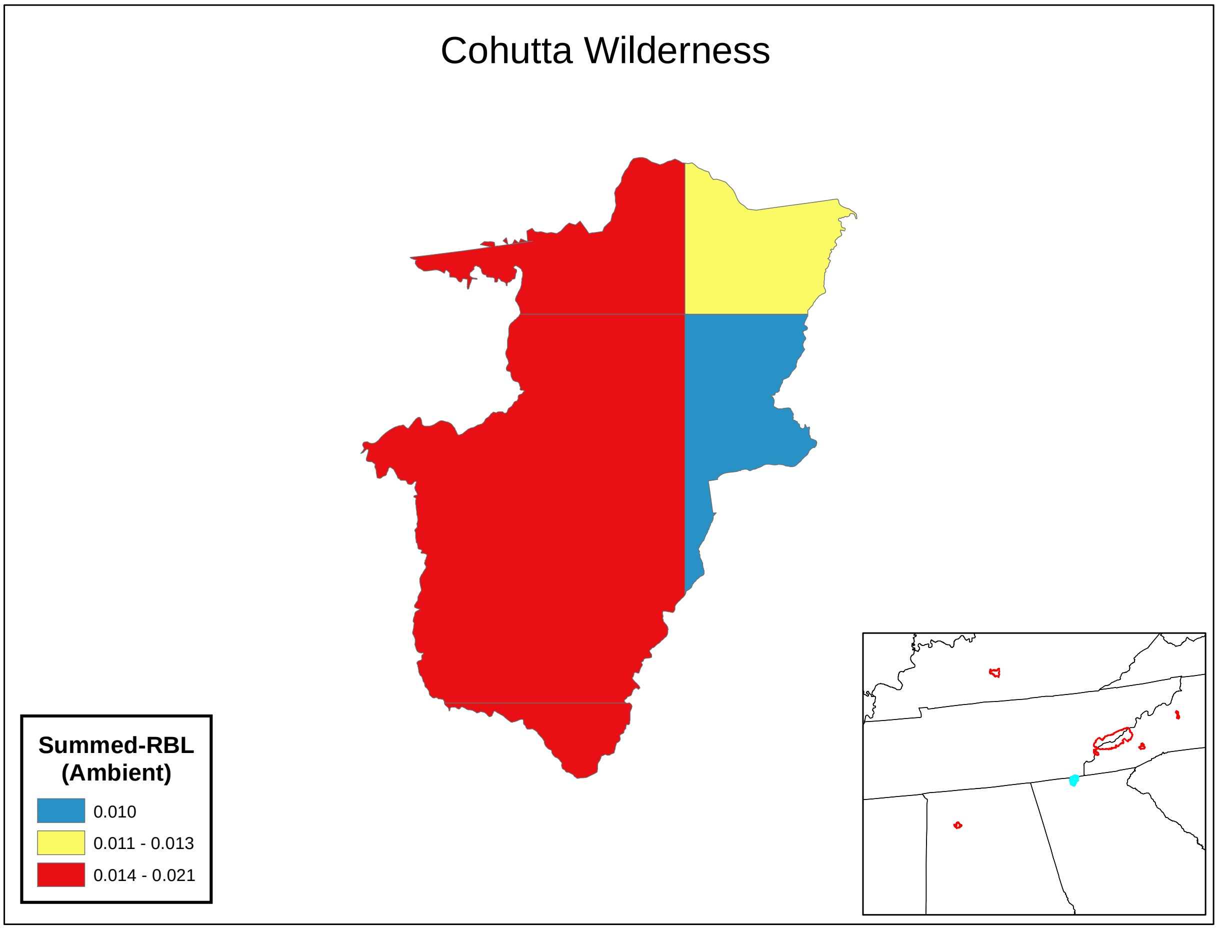


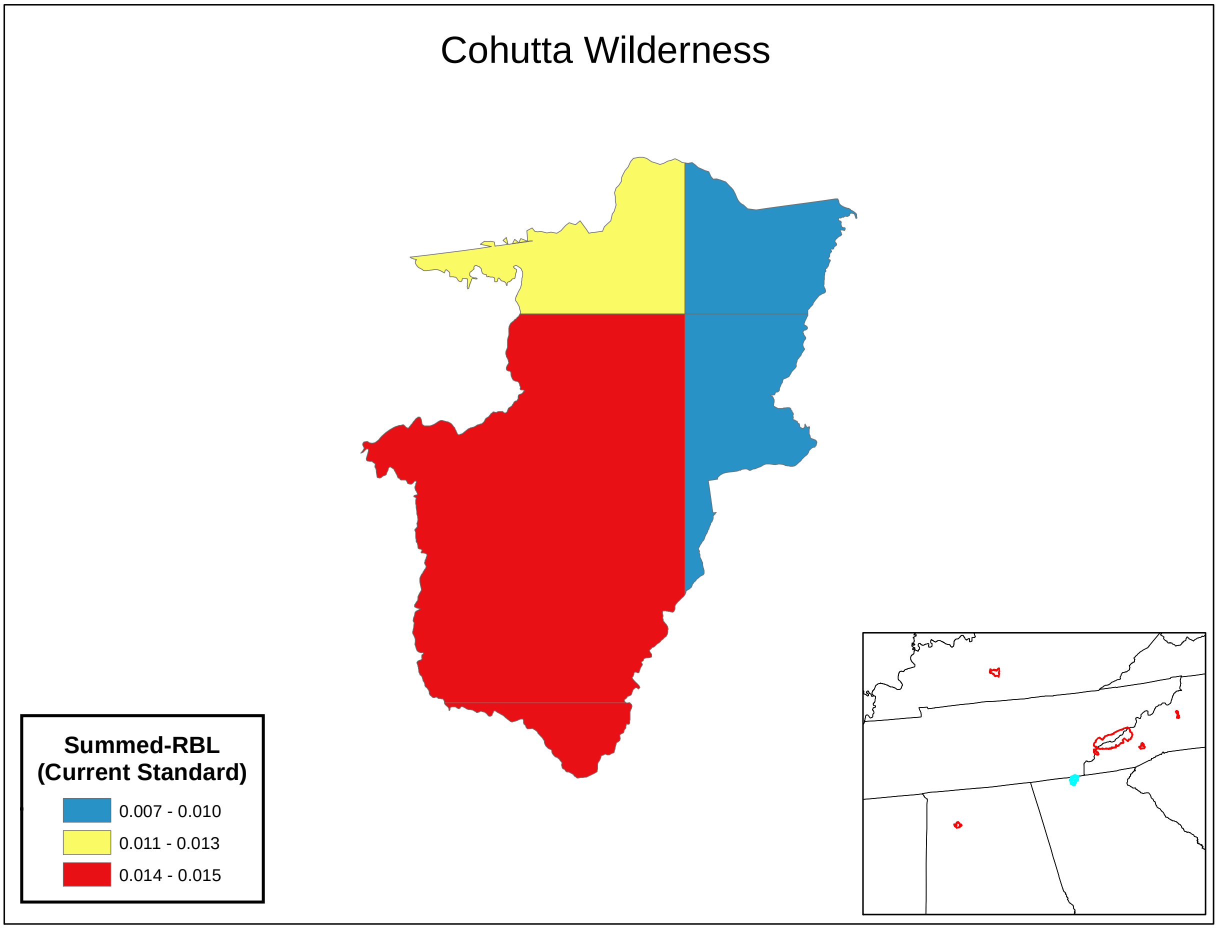

Chassahowitzka Wilderness
Summed-RBL
(Current Standard)
0.0003 - 0.0004
0.0005
0.0006 - 0.0007
0.0008 - 0.0009
0.0010 - 0.0011

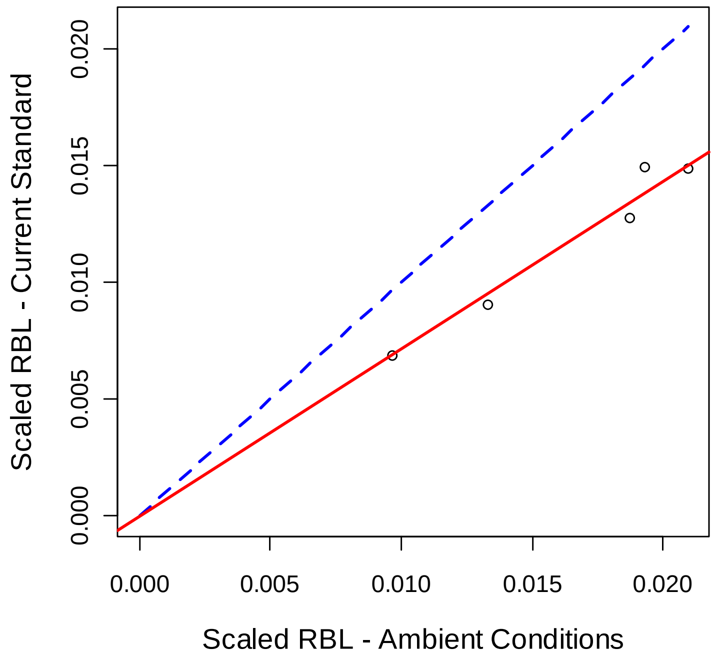


Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	5		
r-squared	0.9968		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.803		
Mean W126 (Ambient = 11.66)	9.75		

COHUTTA WILDERNESS

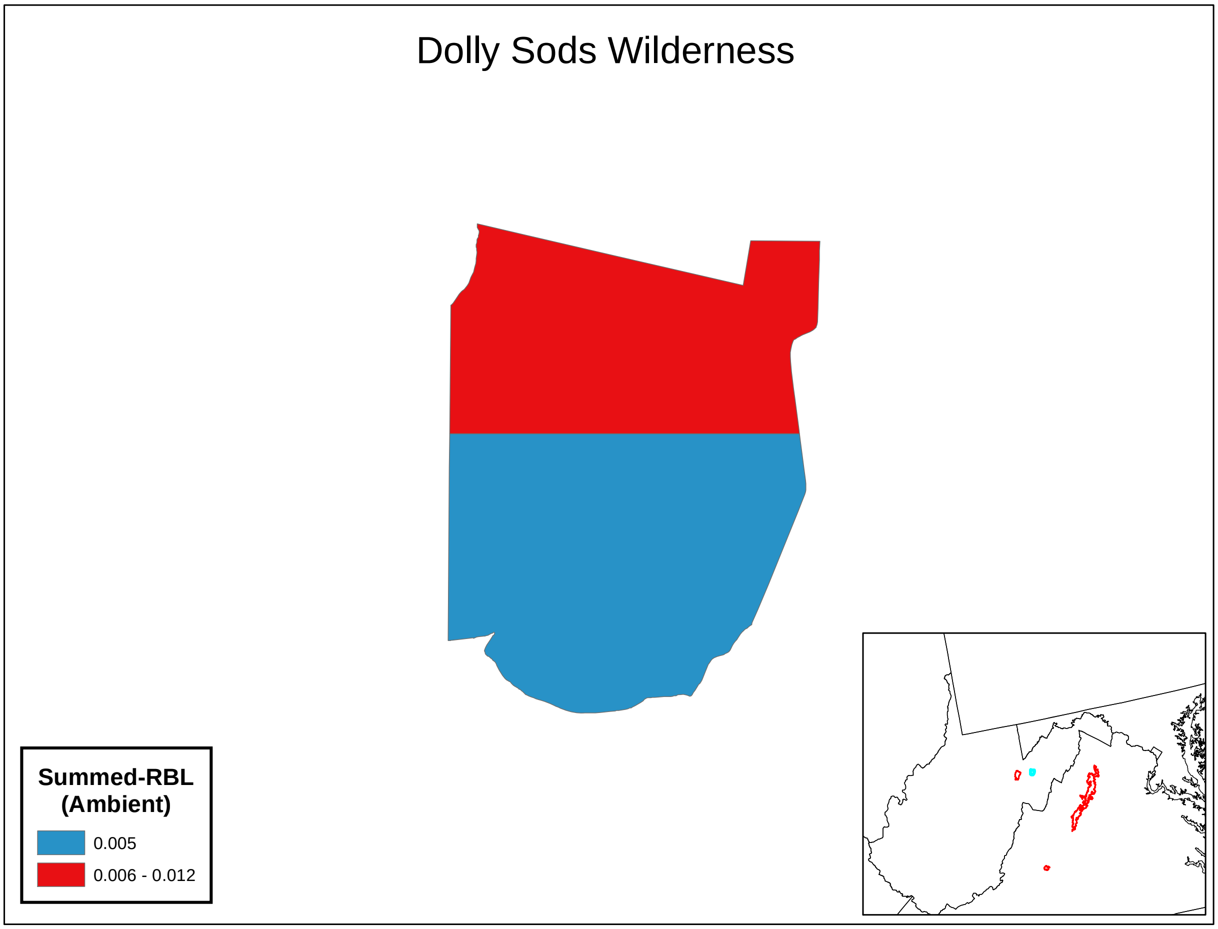



Cohutta Wilderness
Summed-RBL
(Current Standard)
0.007 - 0.010
0.011 - 0.013
0.014 - 0.015

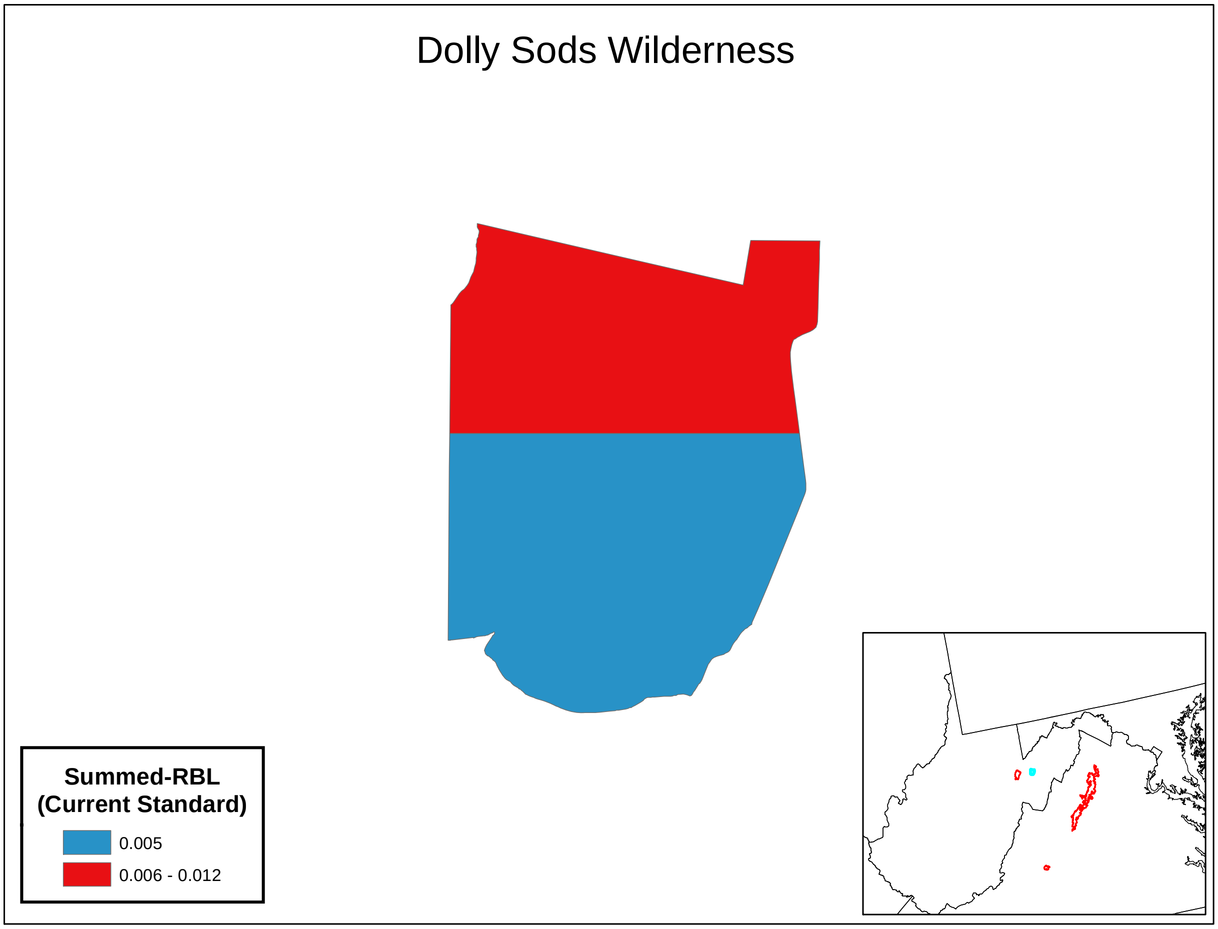


Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	5		
r-squared	0.9967		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.716		
Mean W126 (Ambient = 13.12)	10.40		

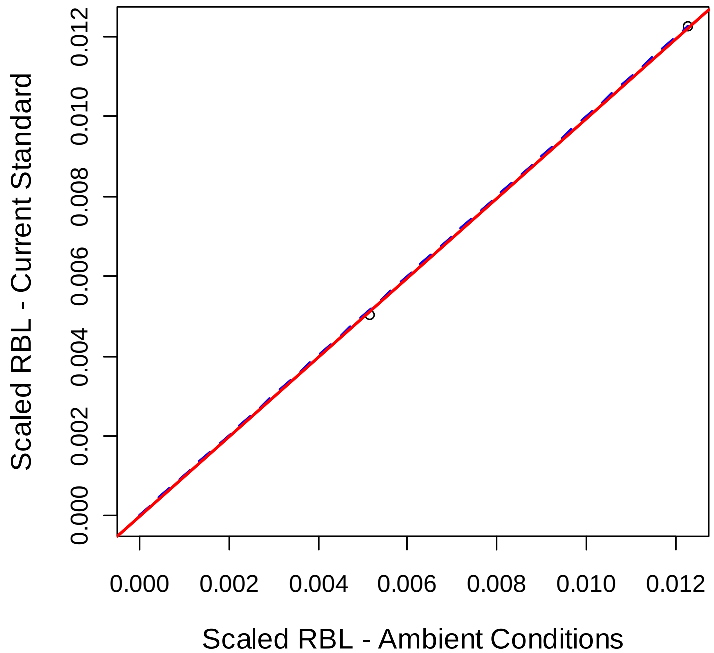
1 **DOLLY SODS WILDERNESS**



2

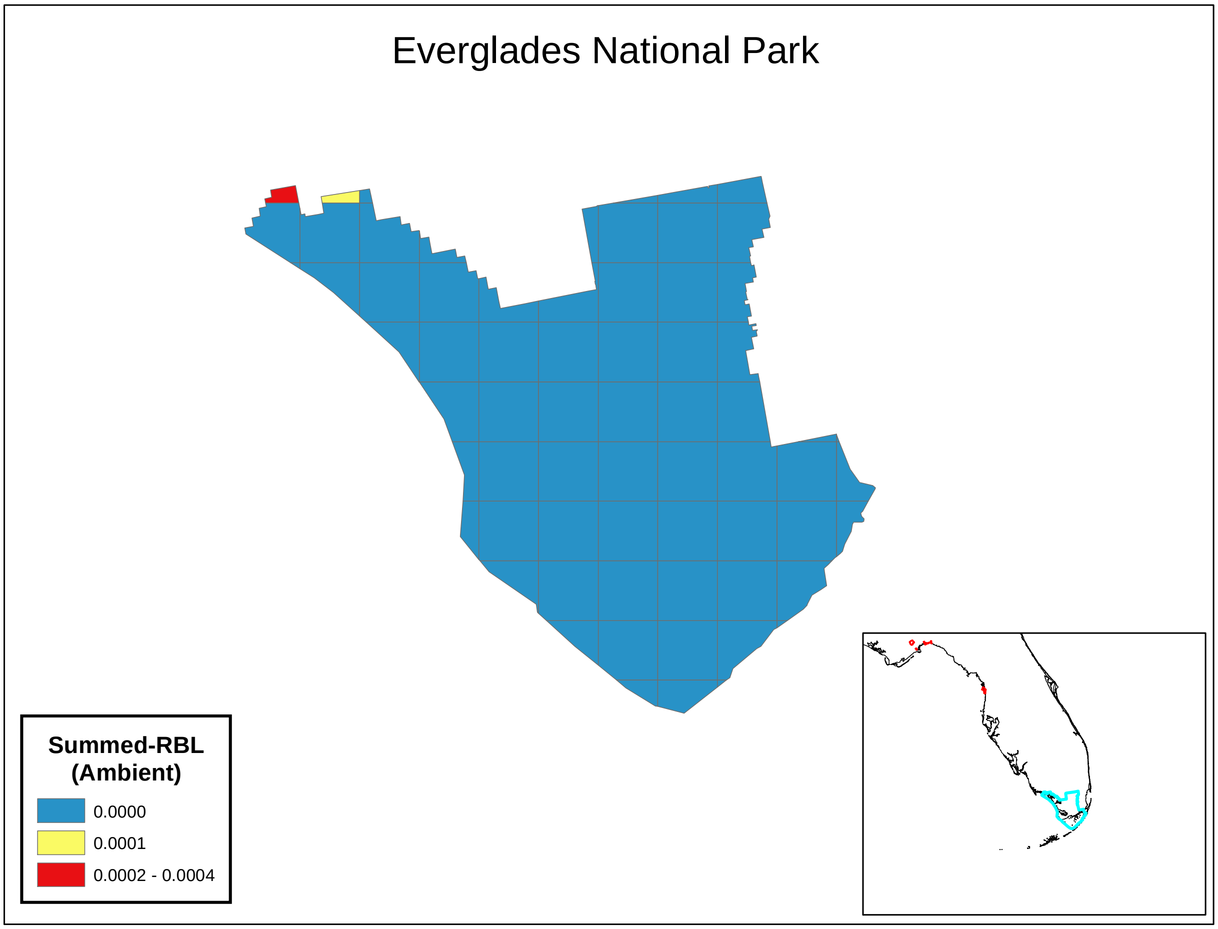

Dolly Sods Wilderness
Summed-RBL
(Current Standard)
0.005
0.006 - 0.012

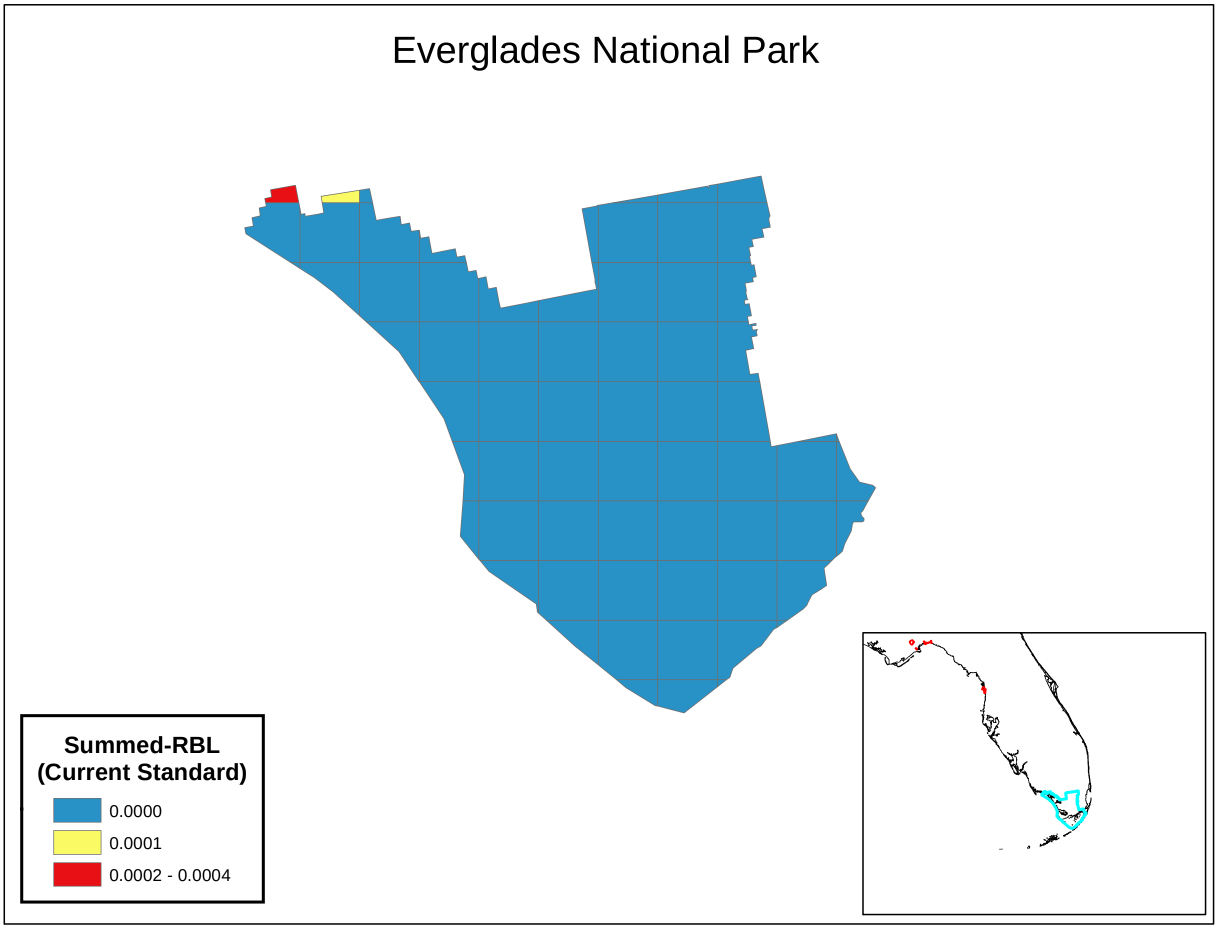
1



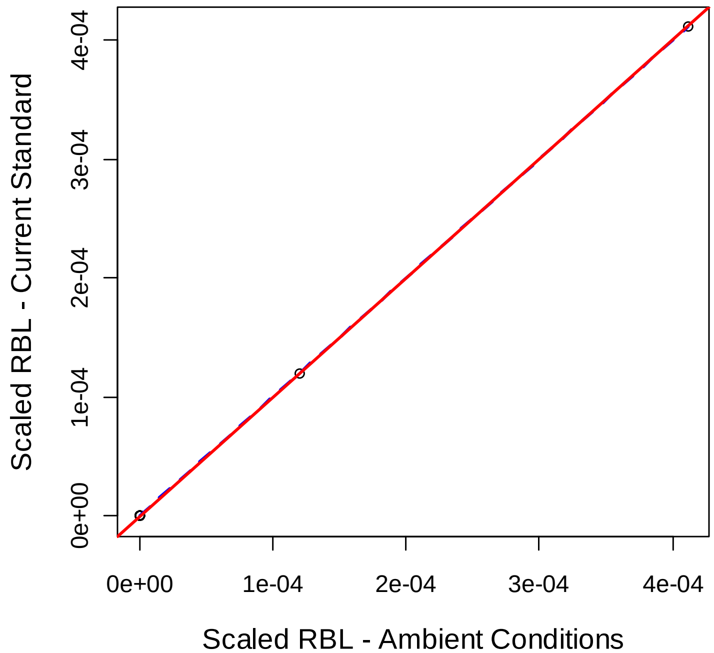
Linear Model Results	Current Standard	Alt A	Alt B
N	2		
r-squared	0.9998		
p-value	0.0059		
Slope (proportion of Ambient RBL)	0.996		
Mean W126 (Ambient = 7.80)	7.71		

EVERGLADES NATIONAL PARK



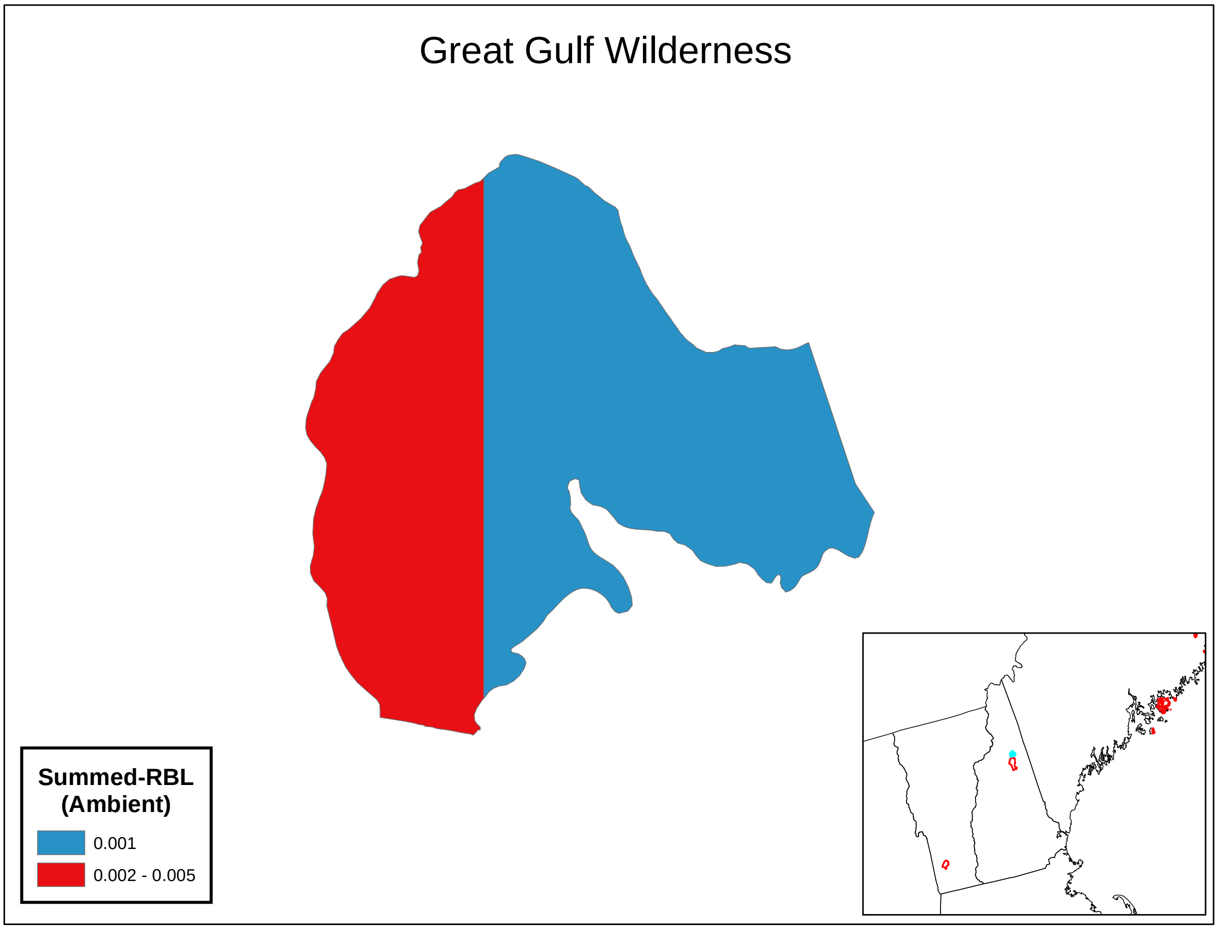

Everglades National Park
Summed-RBL
(Current Standard)
0.0000
0.0001
0.0002 - 0.0004

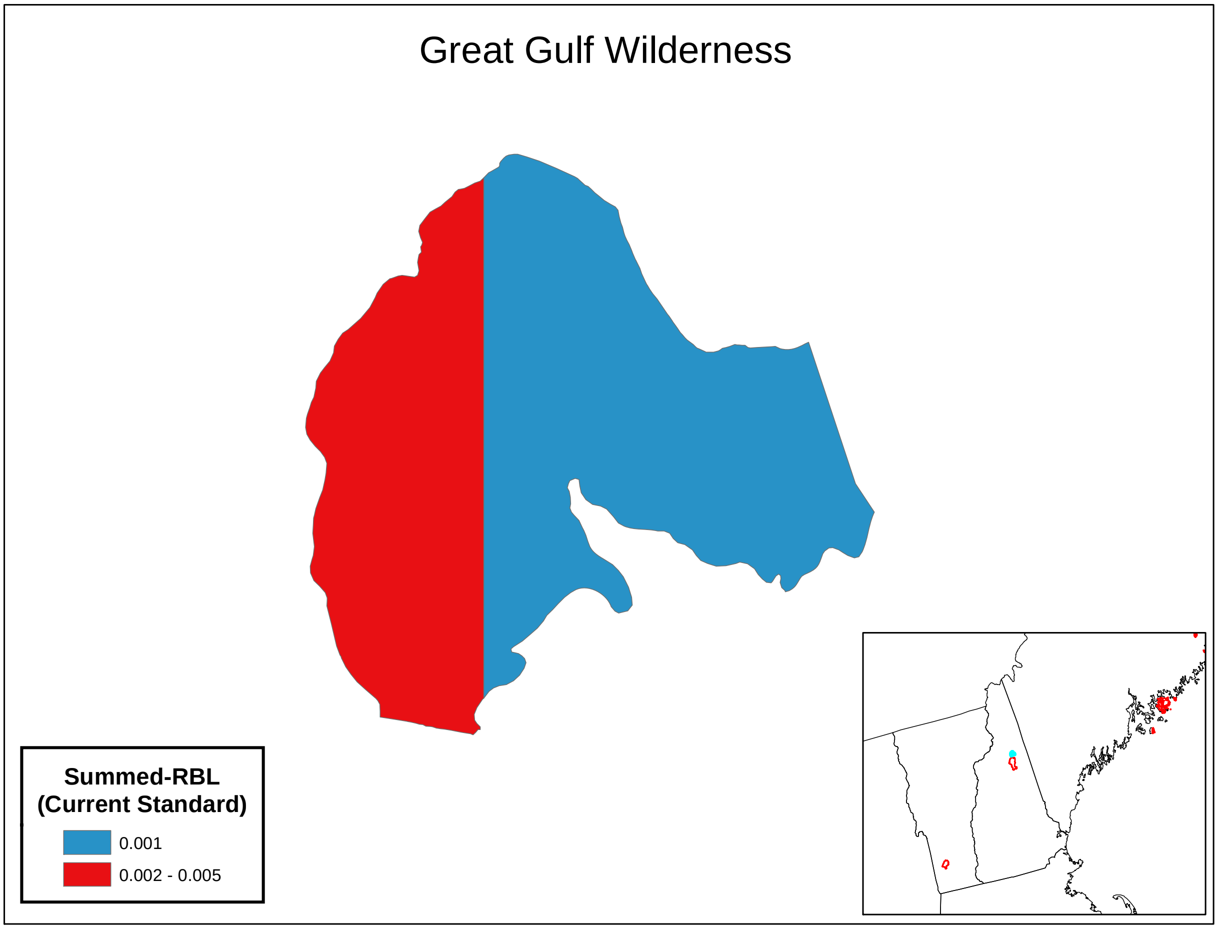
1



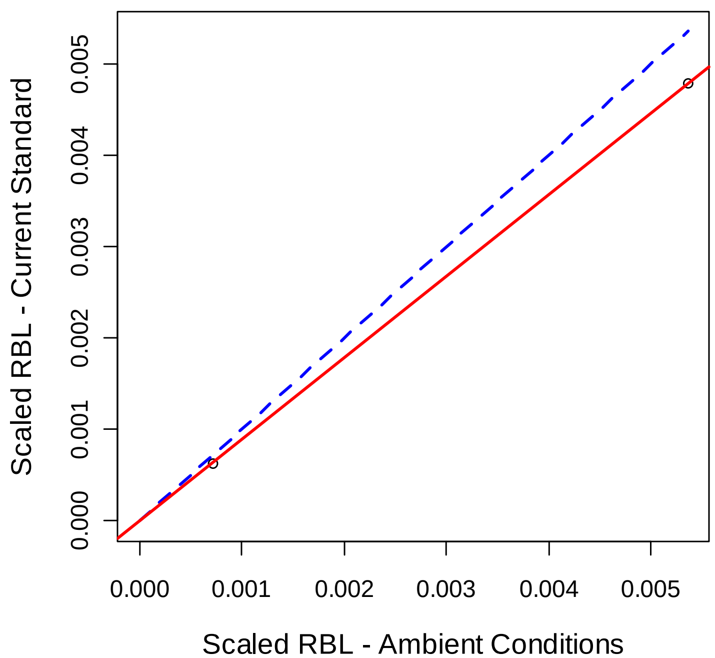
Linear Model Results	Current Standard	Alt A	Alt B
N	62		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.00		
Mean W126 (Ambient = 7.25)	7.25		

GREAT GULF WILDERNESS



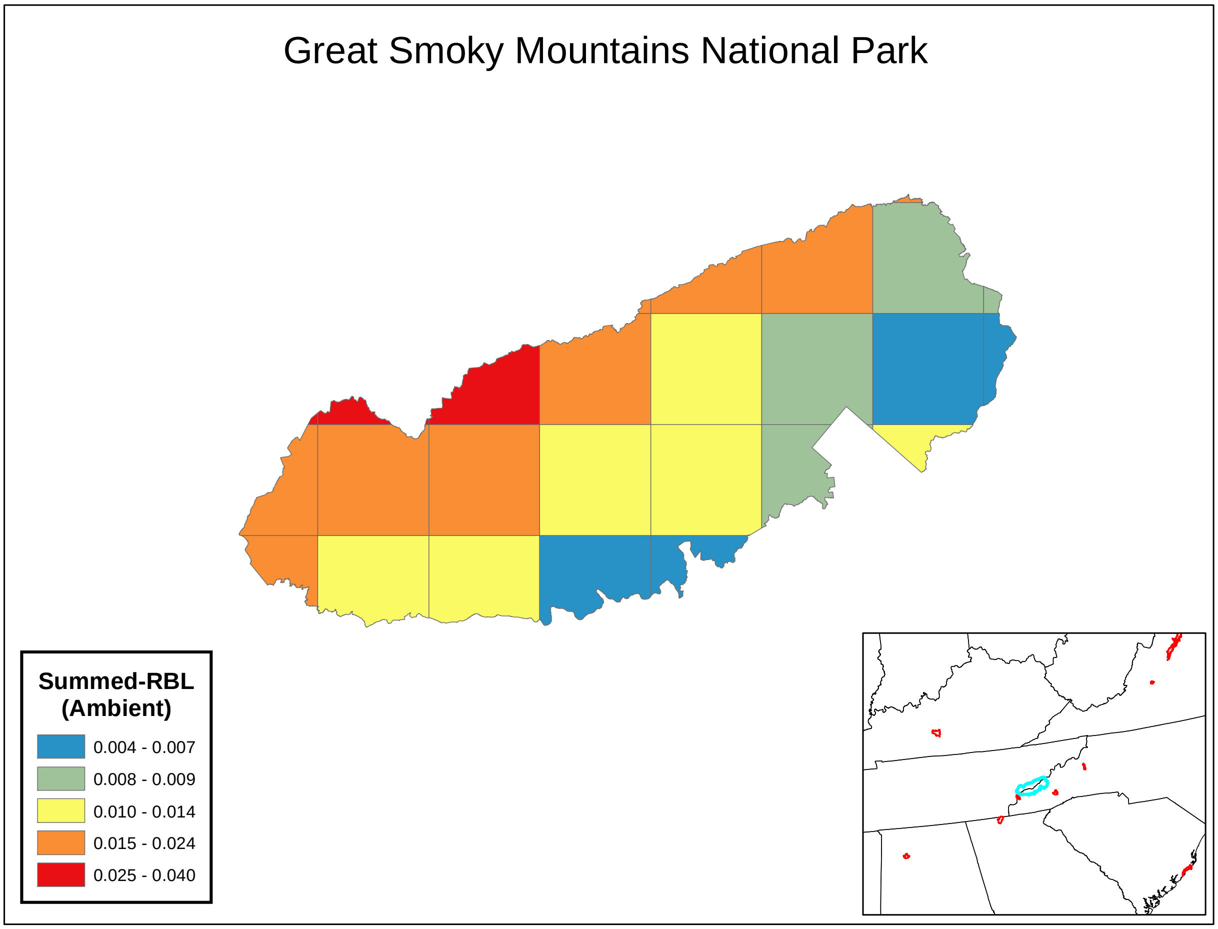

Great Gulf Wilderness
Summed-RBL
(Current Standard)
0.001
0.002 - 0.005

1



Linear Model Results	Current Standard	Alt A	Alt B
N	2		
r-squared	1.000		
p-value	0.0011		
Slope (proportion of Ambient RBL)	0.892		
Mean W126 (Ambient = 7.55)	6.76		

1 **GREAT SMOKY MOUNTAINS NATIONAL PARK**



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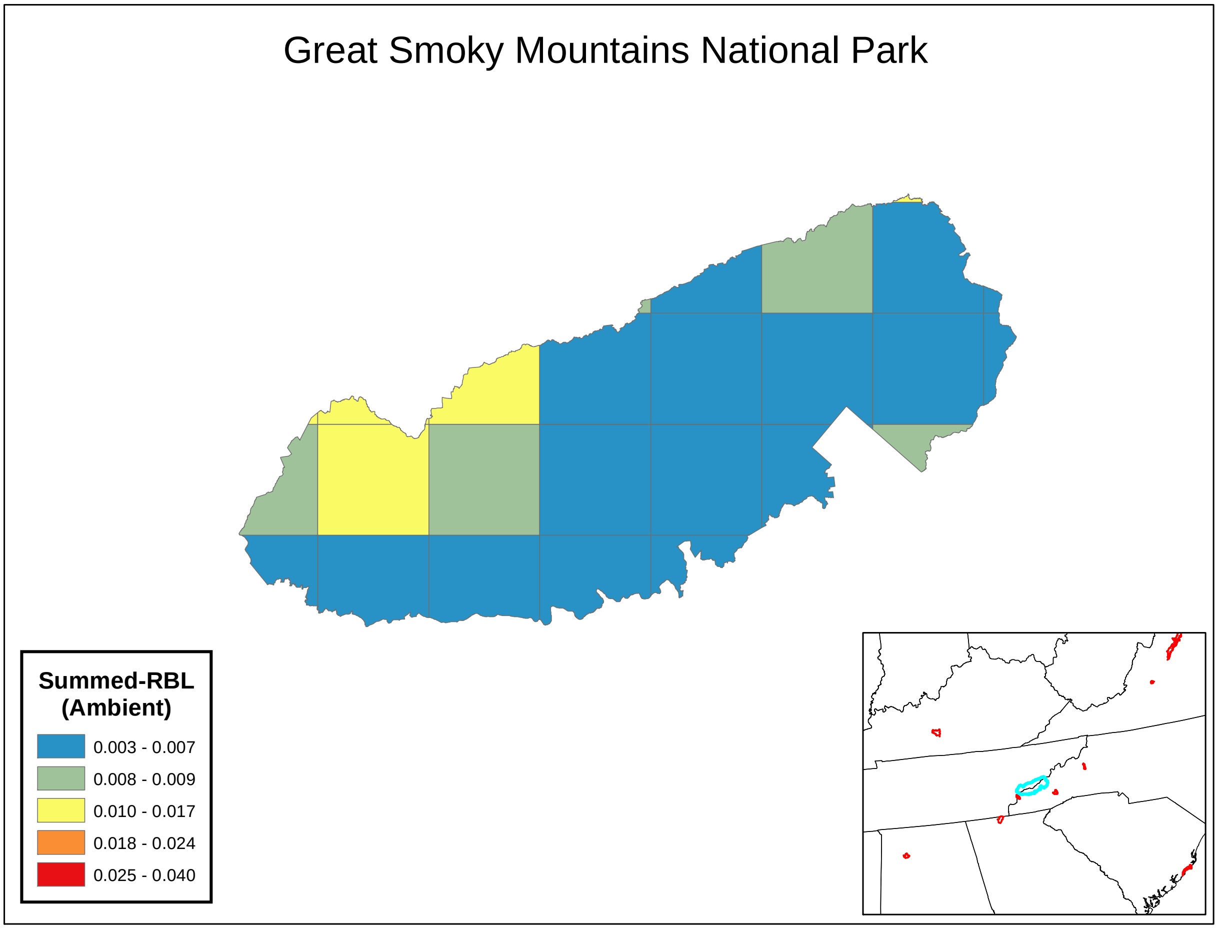
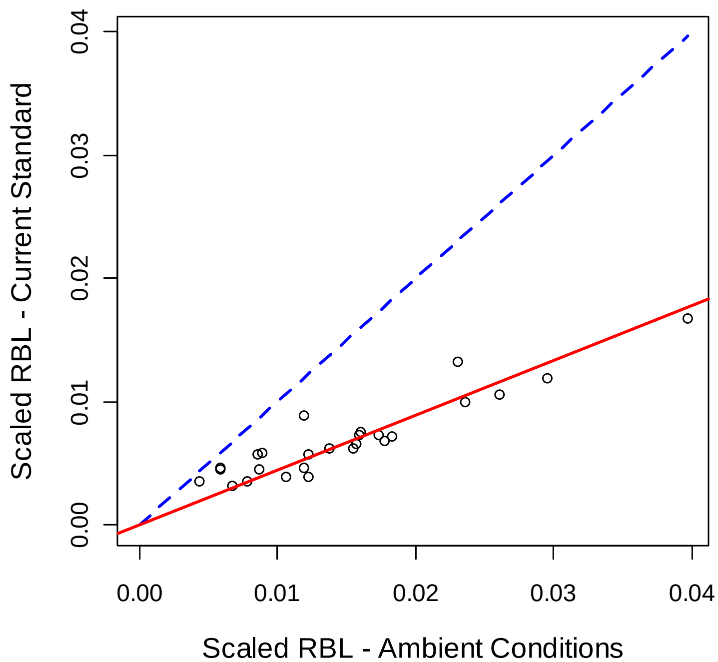
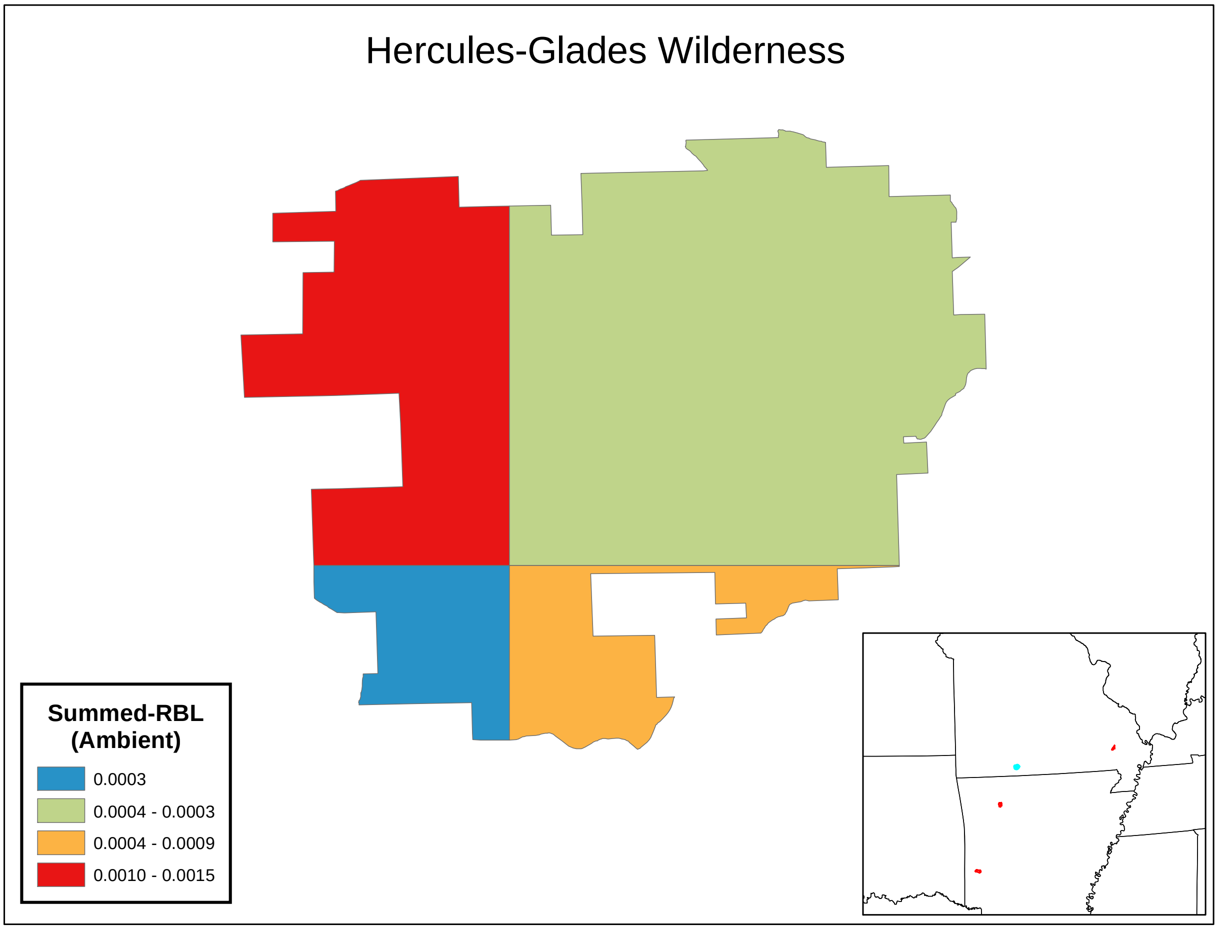

Great Smoky Mountains National Park
Summed-RBL
(Ambient)
0.003 - 0.007
0.008 - 0.009
0.010 - 0.017
0.018 - 0.024
0.025 - 0.040

1



Linear Model Results	Current Standard	Alt A	Alt B
N	26		
r-squared	0.9652		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.445		
Mean W126 (Ambient = 16.64)	10.51		

HERCULES-GLADES WILDERNESS



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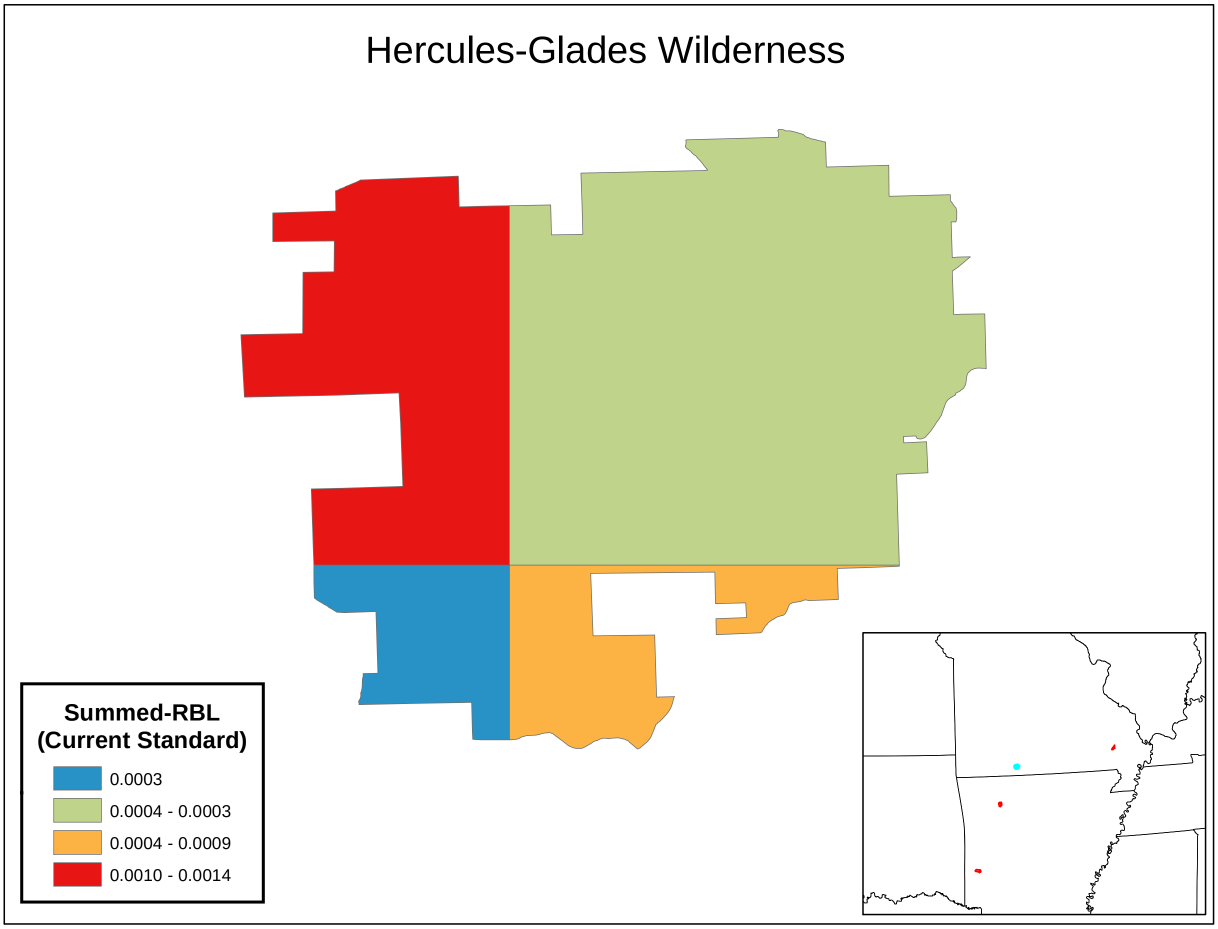
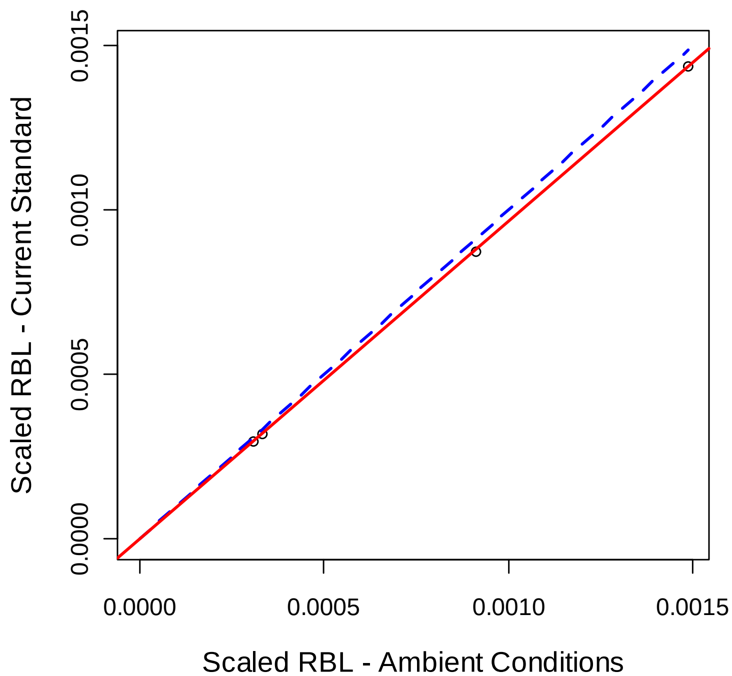
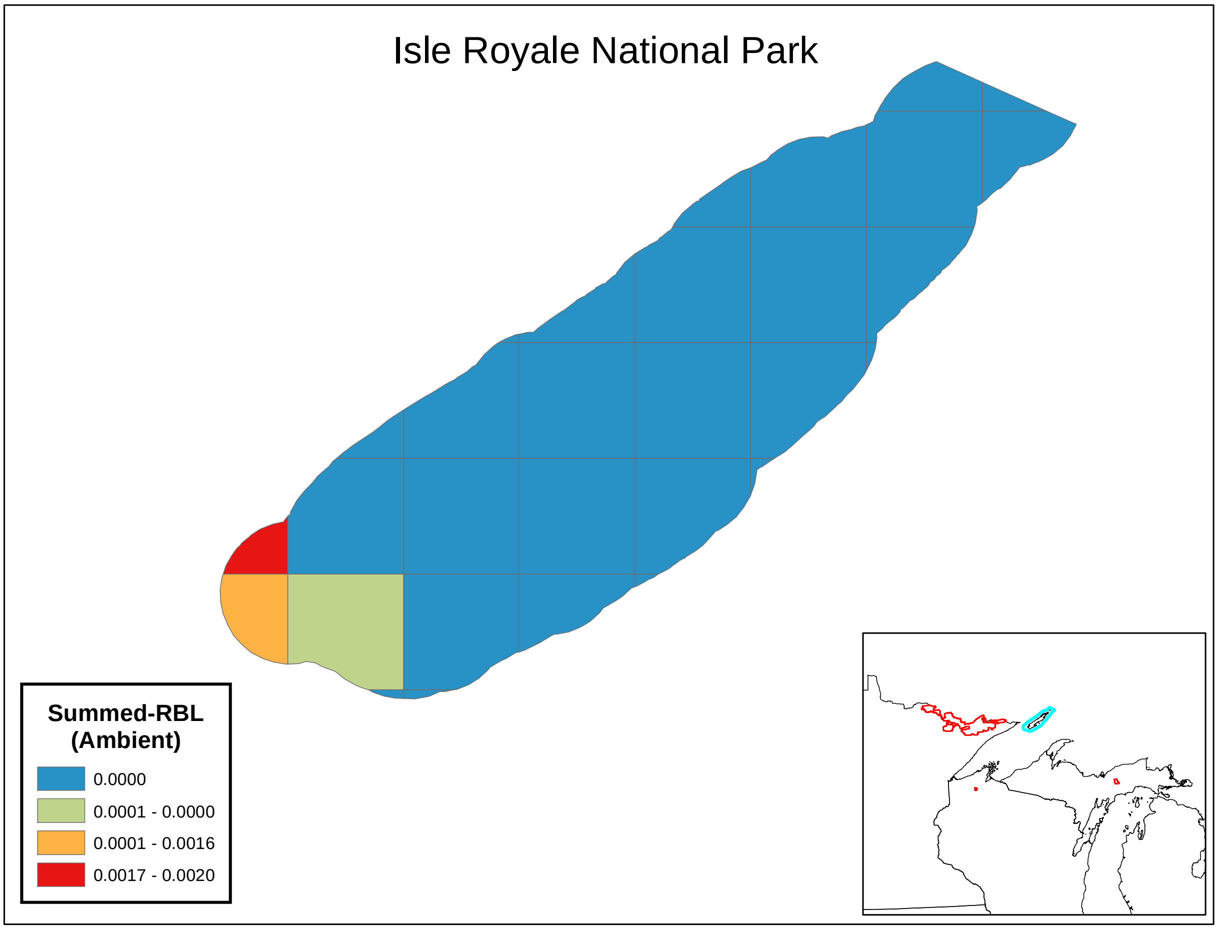
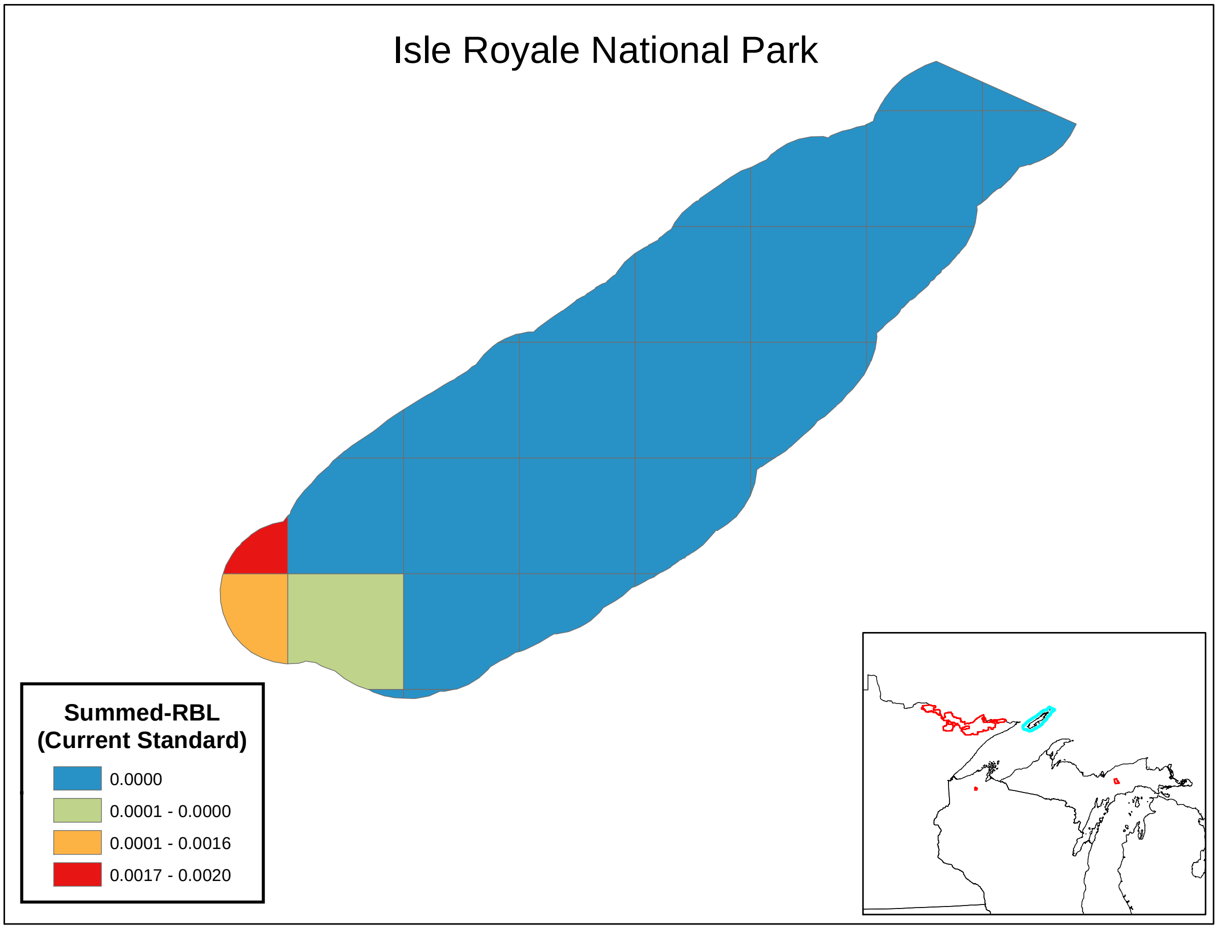

Hercules-Glades Wilderness
Summed-RBL
(Current Standard)
0.0003
0.0004 - 0.0003
0.0004 - 0.0009
0.0010 - 0.0014



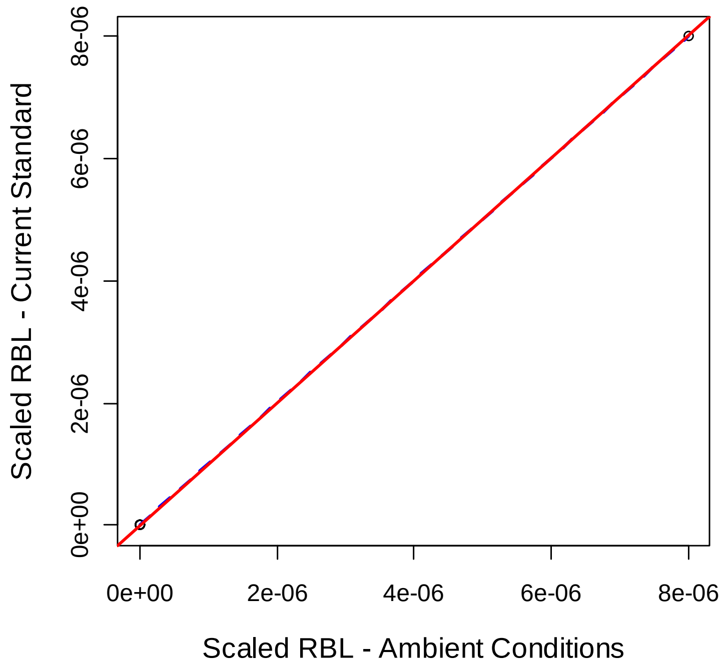
Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	4		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.966		
Mean W126 (Ambient = 6.00)	5.76		

ISLE ROYALE NATIONAL PARK



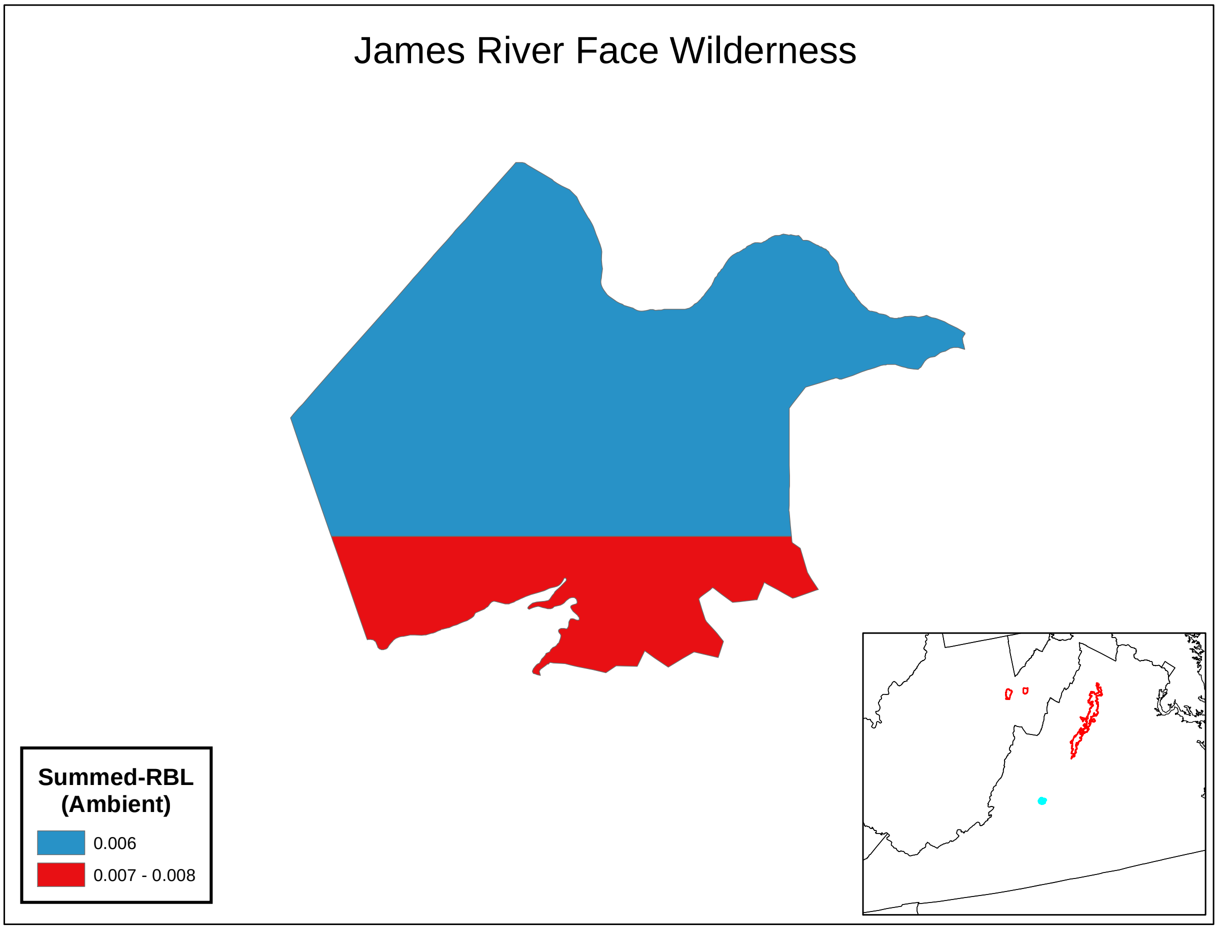

Isle Royale National Park
Summed-RBL
(Current Standard)
0.0000
0.0001 - 0.0000
0.0001 - 0.0016
0.0017 - 0.0020

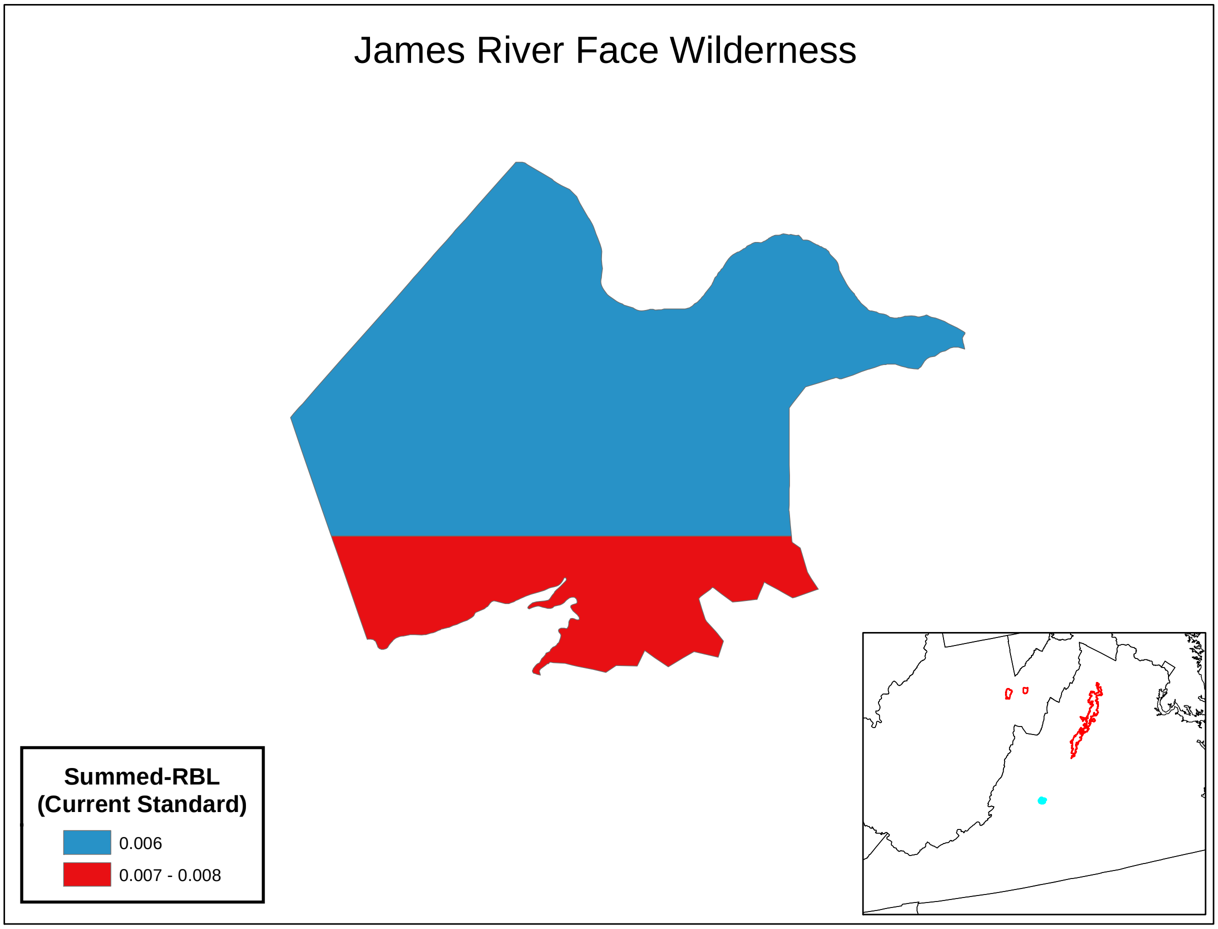
1

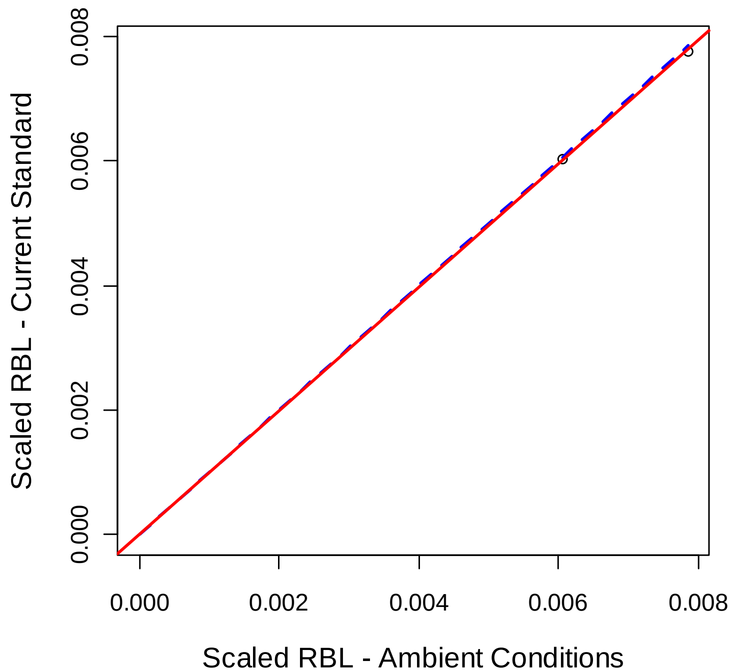


Linear Model Results	Current Standard	Alt A	Alt B
N	16		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.000		
Mean W126 (Ambient = 7.11)	7.11		

JAMES RIVER FACE WILDERNESS

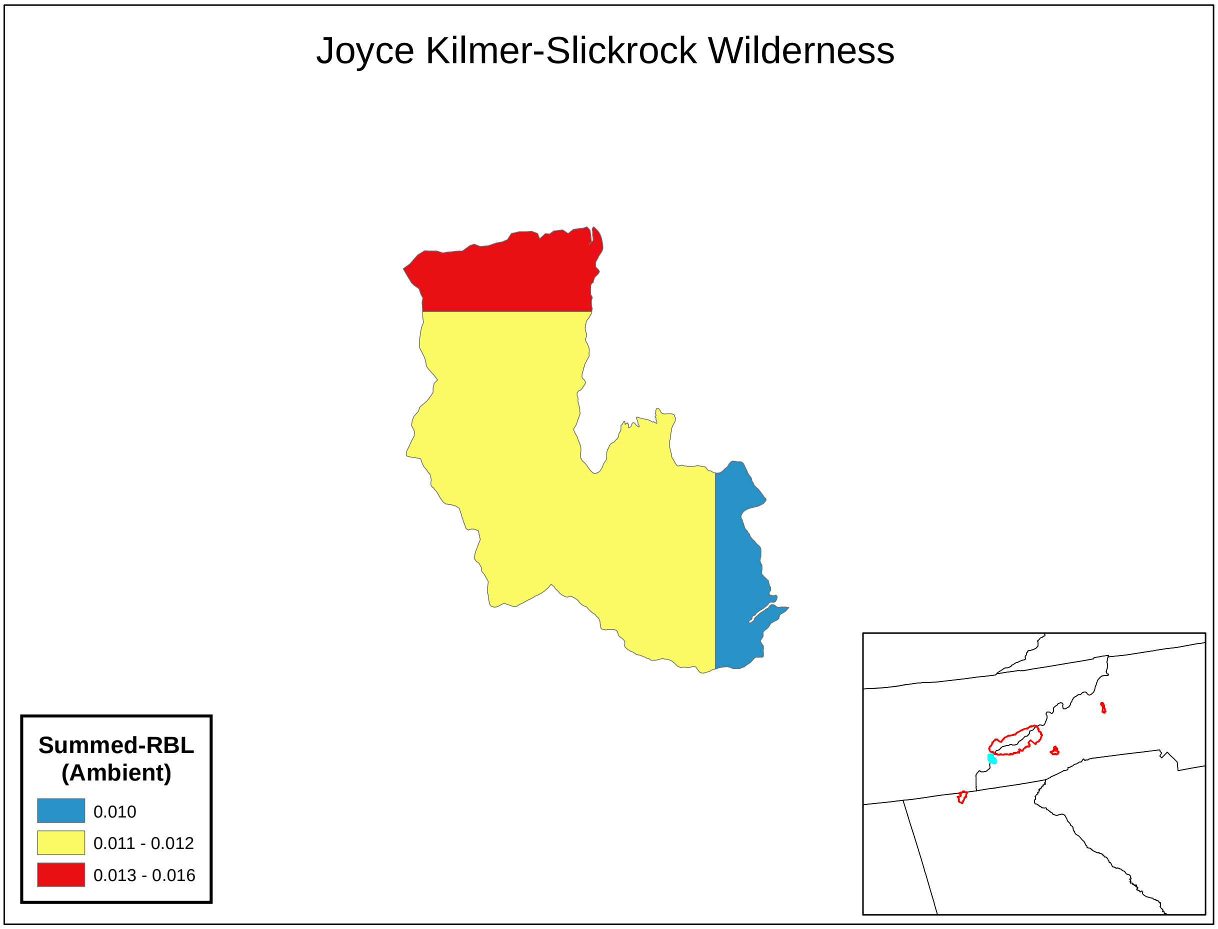


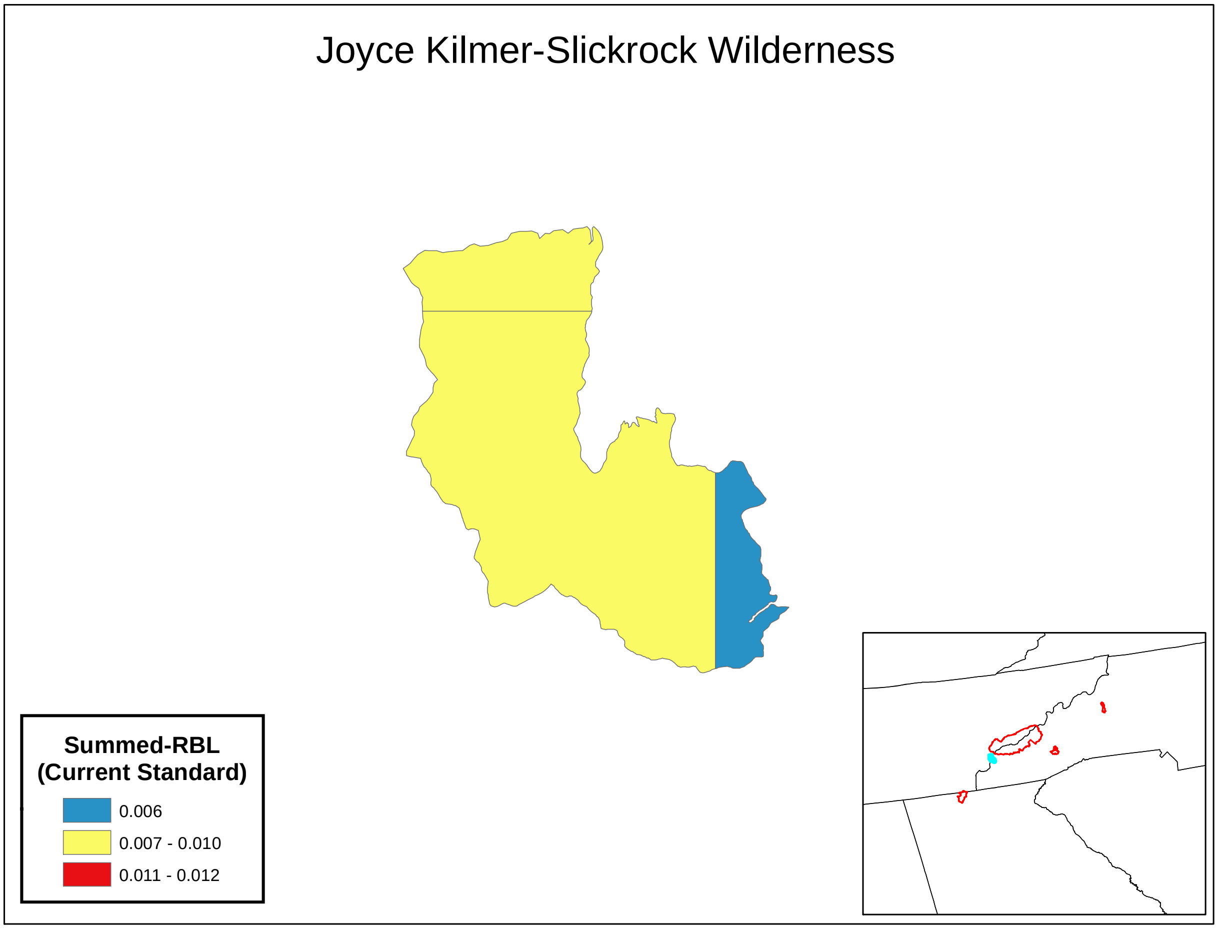

James River Face Wilderness
Summed-RBL
(Current Standard)
0.006
0.007 - 0.008

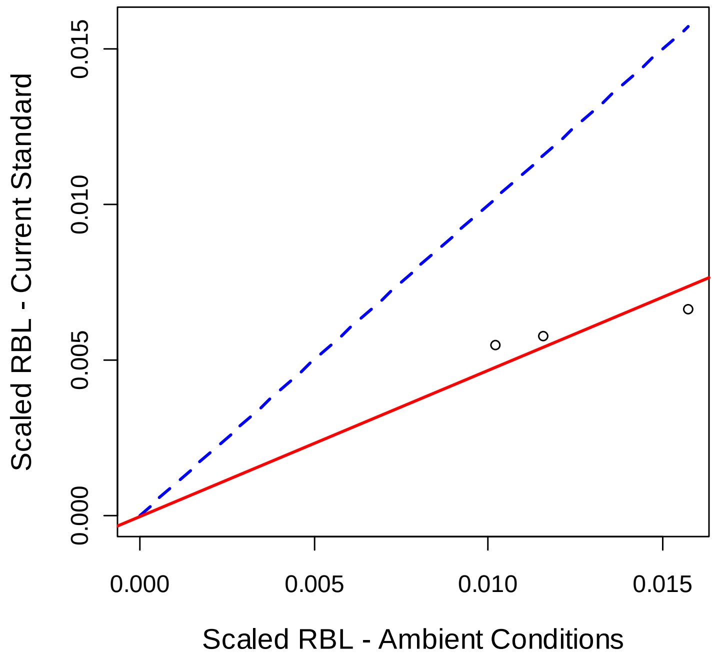


Linear Model Results	Current Standard	Alt A	Alt B
N	2		
r-squared	1.000		
p-value	0.0021		
Slope (proportion of Ambient RBL)	0.992		
Mean W126 (Ambient = 9.10)	9.06		

JOYCE KILMER-SLICKROCK WILDERNESS

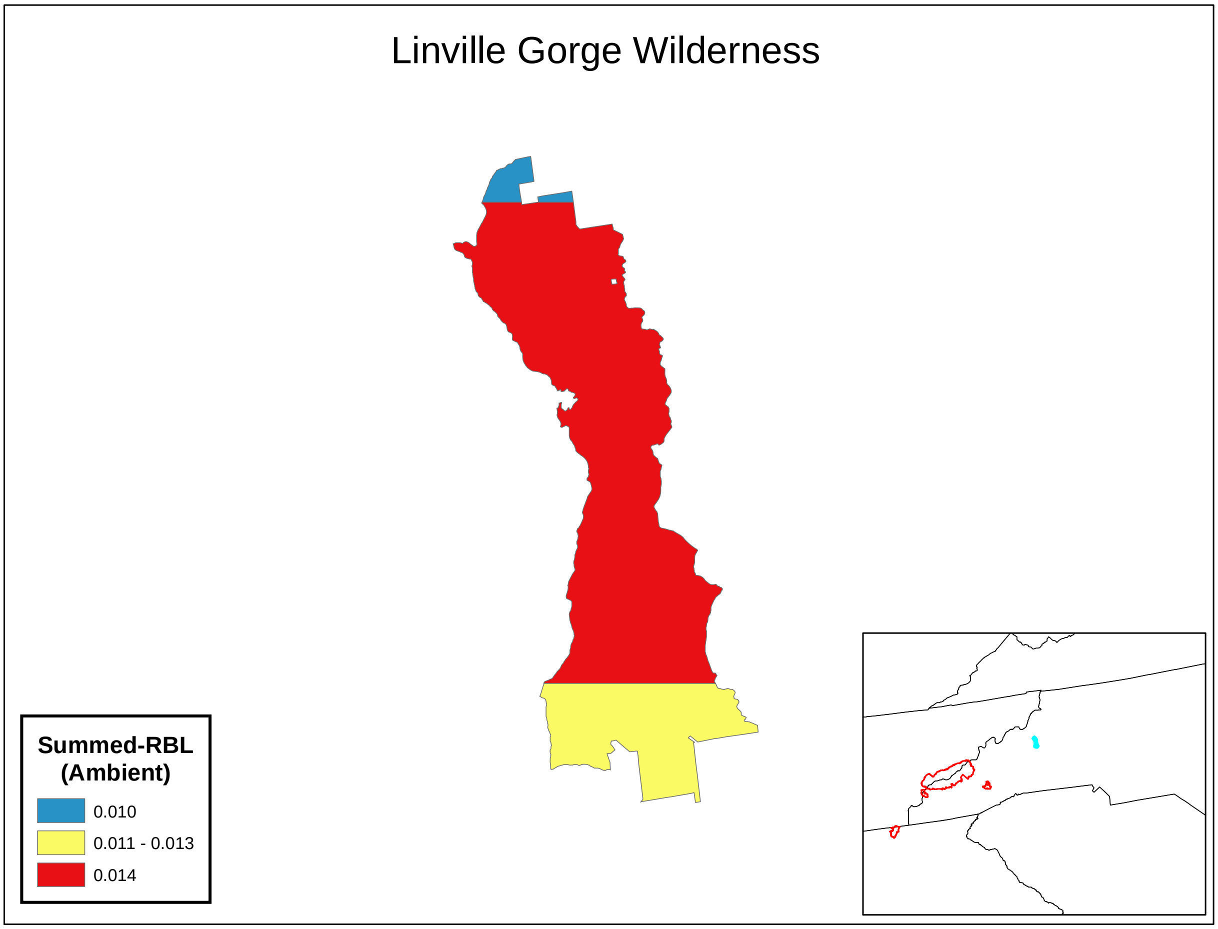


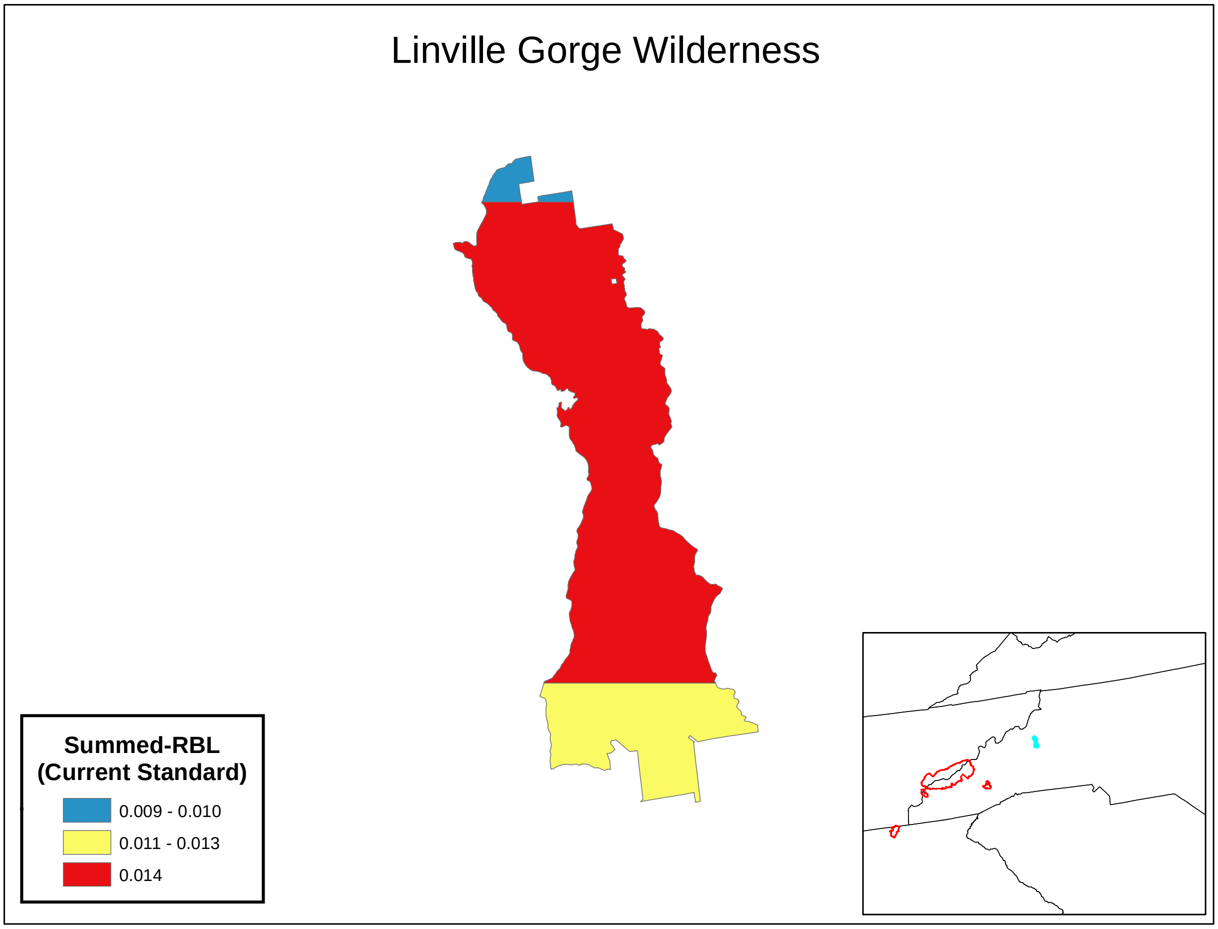

Joyce Kilmer-Slickrock Wilderness
Summed-RBL
(Current Standard)
0.006
0.007 - 0.010
0.011 - 0.012

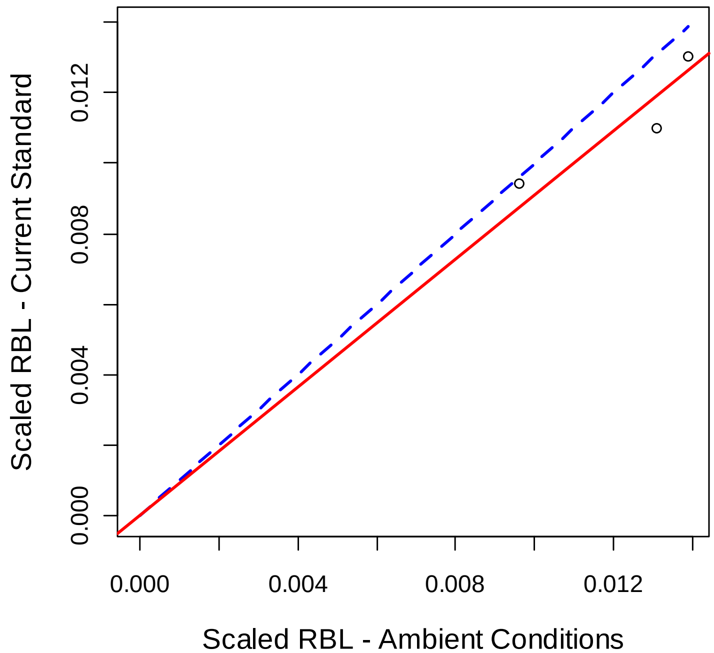


Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	3		
r-squared	0.9837		
p-value	0.0054		
Slope (proportion of Ambient RBL)	0.989		
Mean W126 (Ambient = 14.07)	8.85		

LINVILLE GORGE WILDERNESS

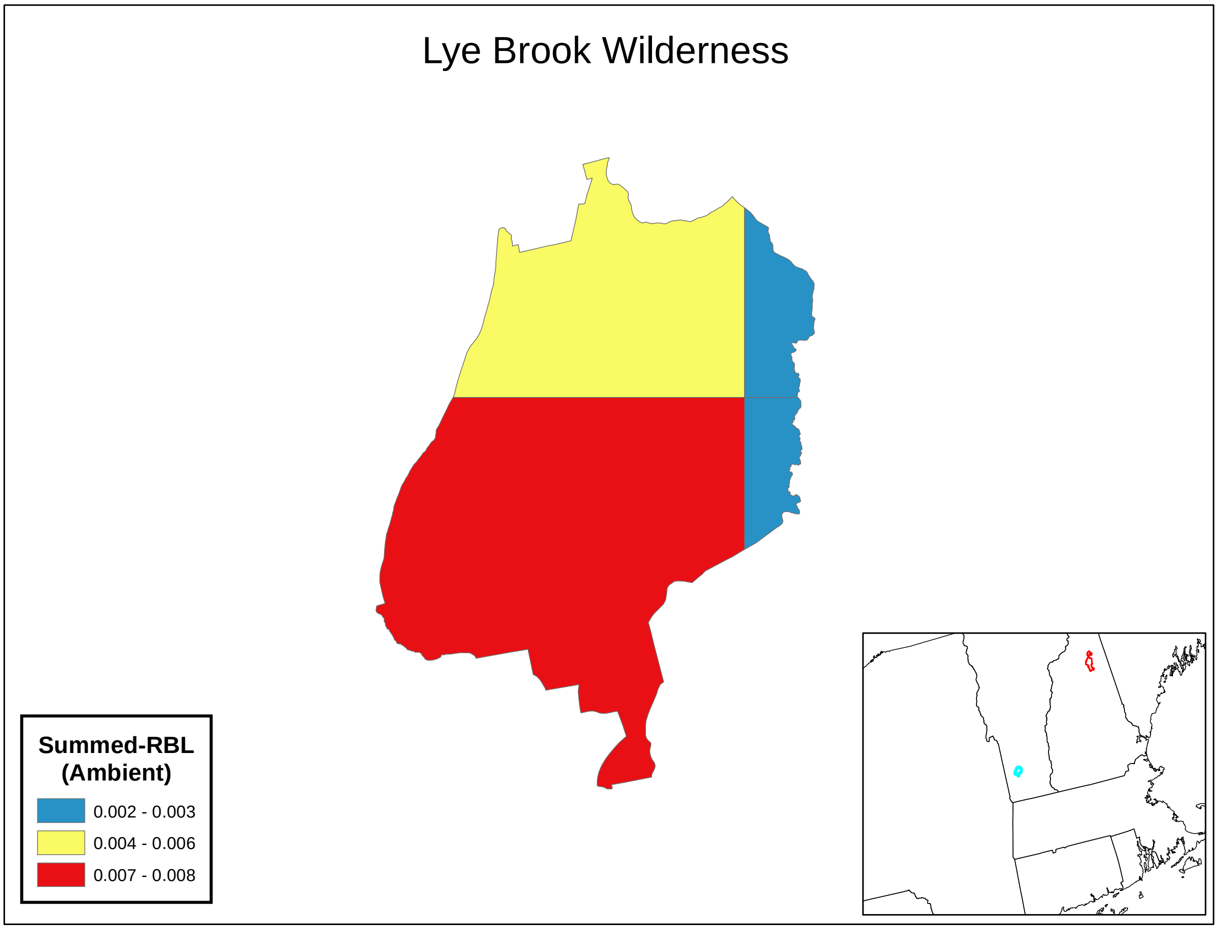


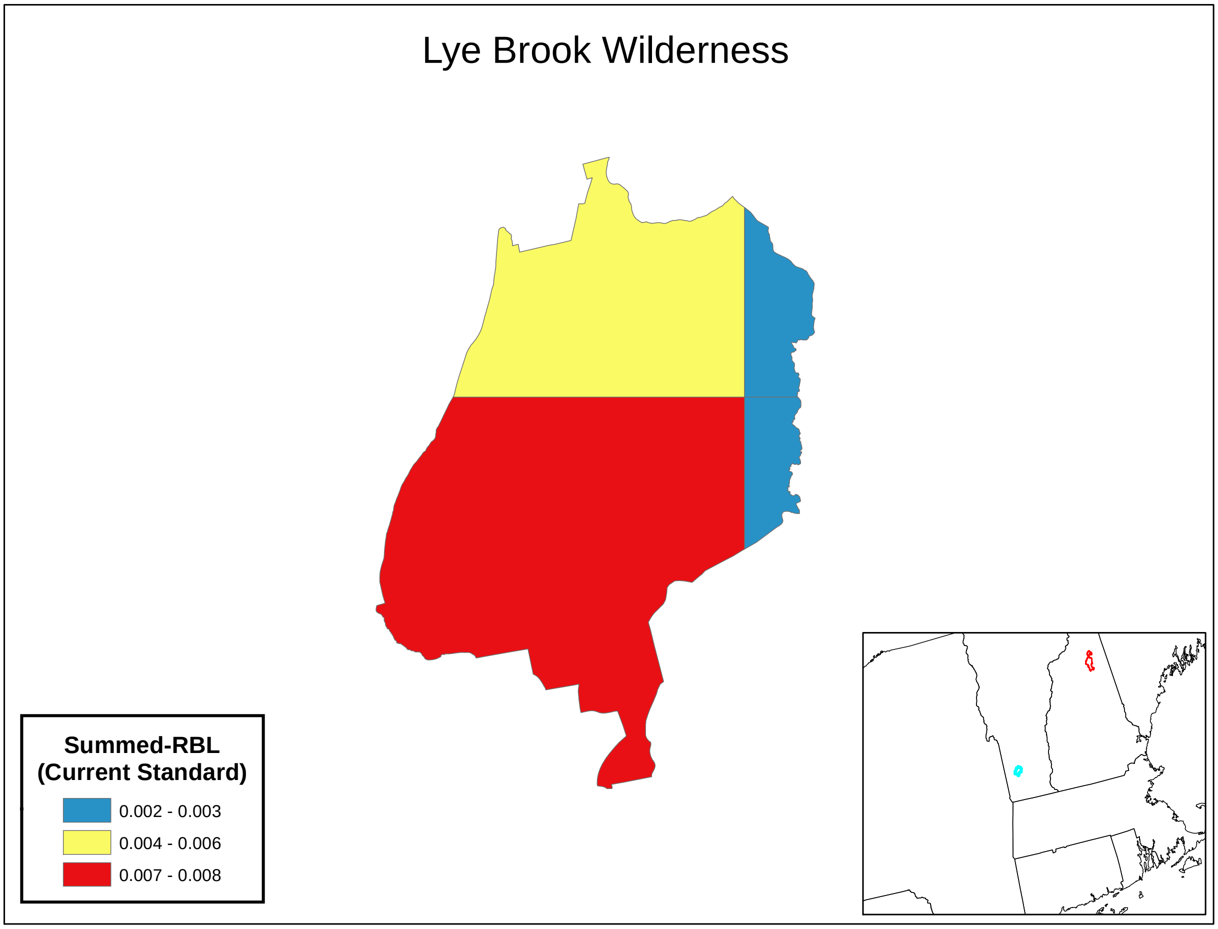

Linville Gorge Wilderness
Summed-RBL
(Current Standard)
0.009 - 0.010
0.011 - 0.013
0.014



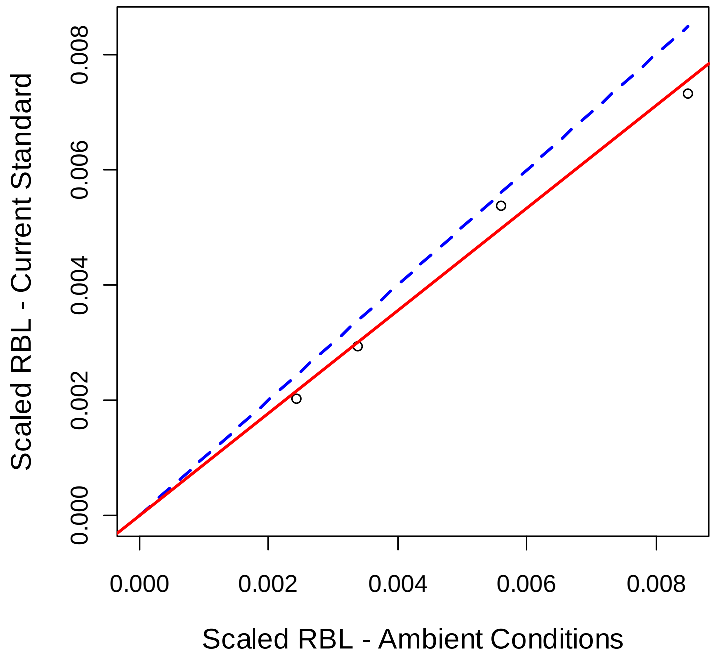
Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	3		
r-squared	0.9941		
p-value	0.0020		
Slope (proportion of Ambient RBL)	0.910		
Mean W126 (Ambient = 10.83)	10.25		

LYE BROOK WILDERNESS



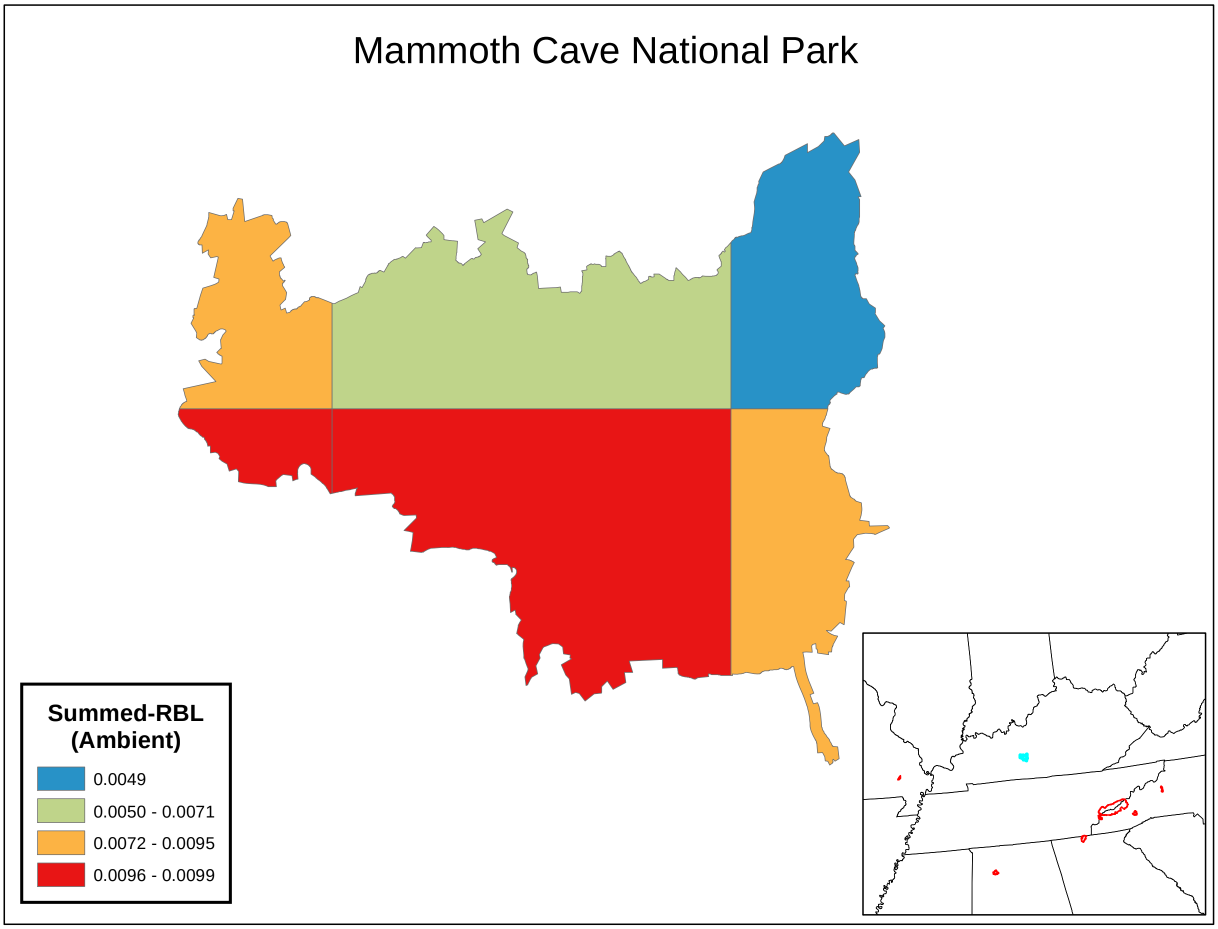

Lye Brook Wilderness
Summed-RBL
(Current Standard)
0.002 - 0.003
0.004 - 0.006
0.007 - 0.008

1



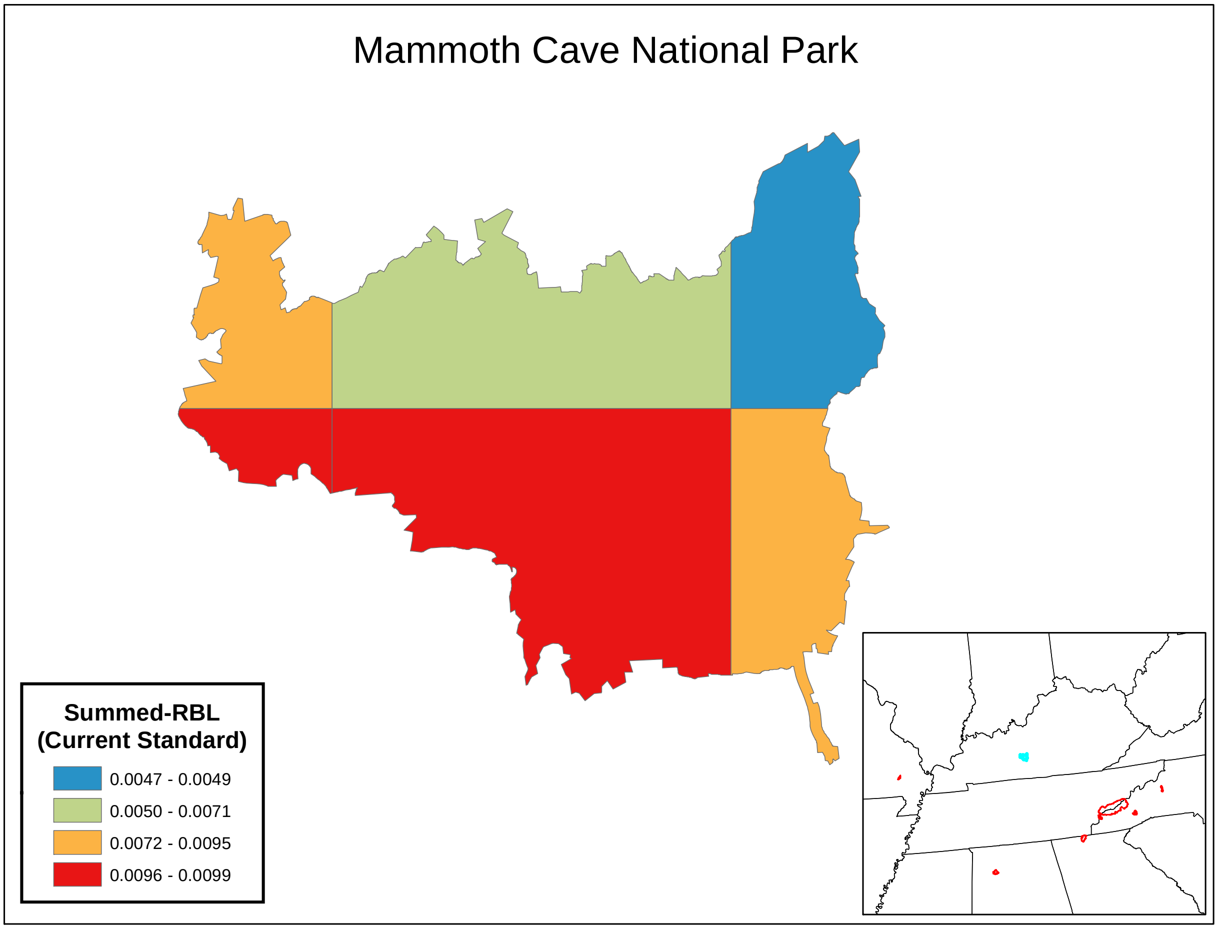
Linear Model Results	Current Standard	Alt A	Alt B
N	4		
r-squared	0.9966		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.889		
Mean W126 (Ambient = 6.83)	6.13		

1 **MAMMOTH CAVE NATIONAL PARK**

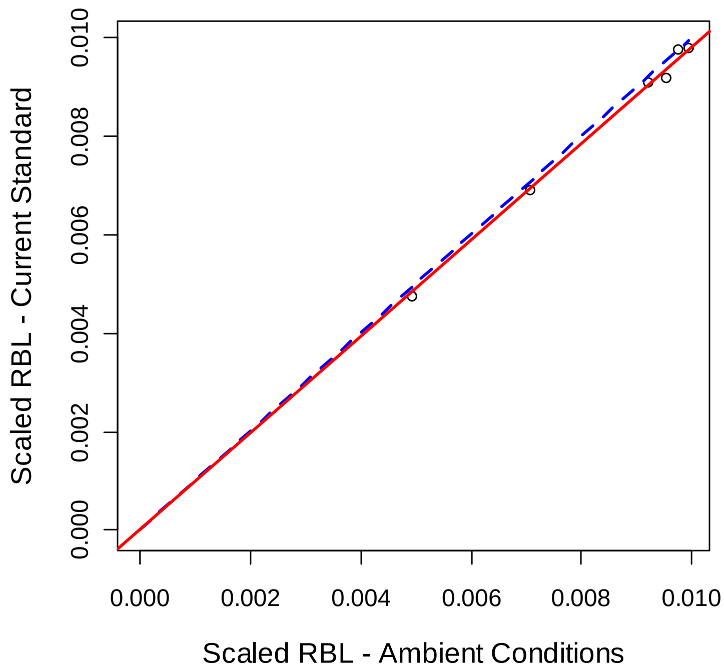


2

1

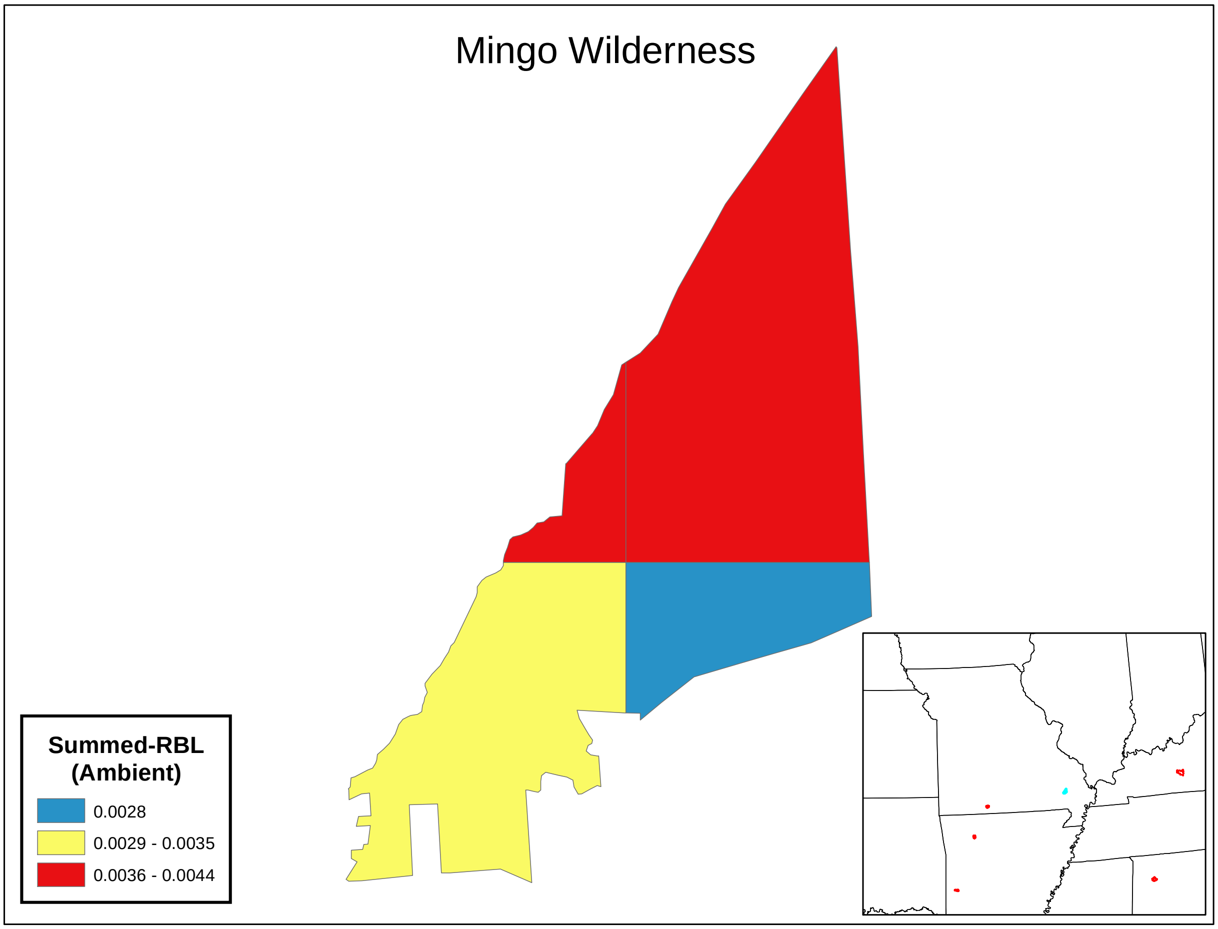


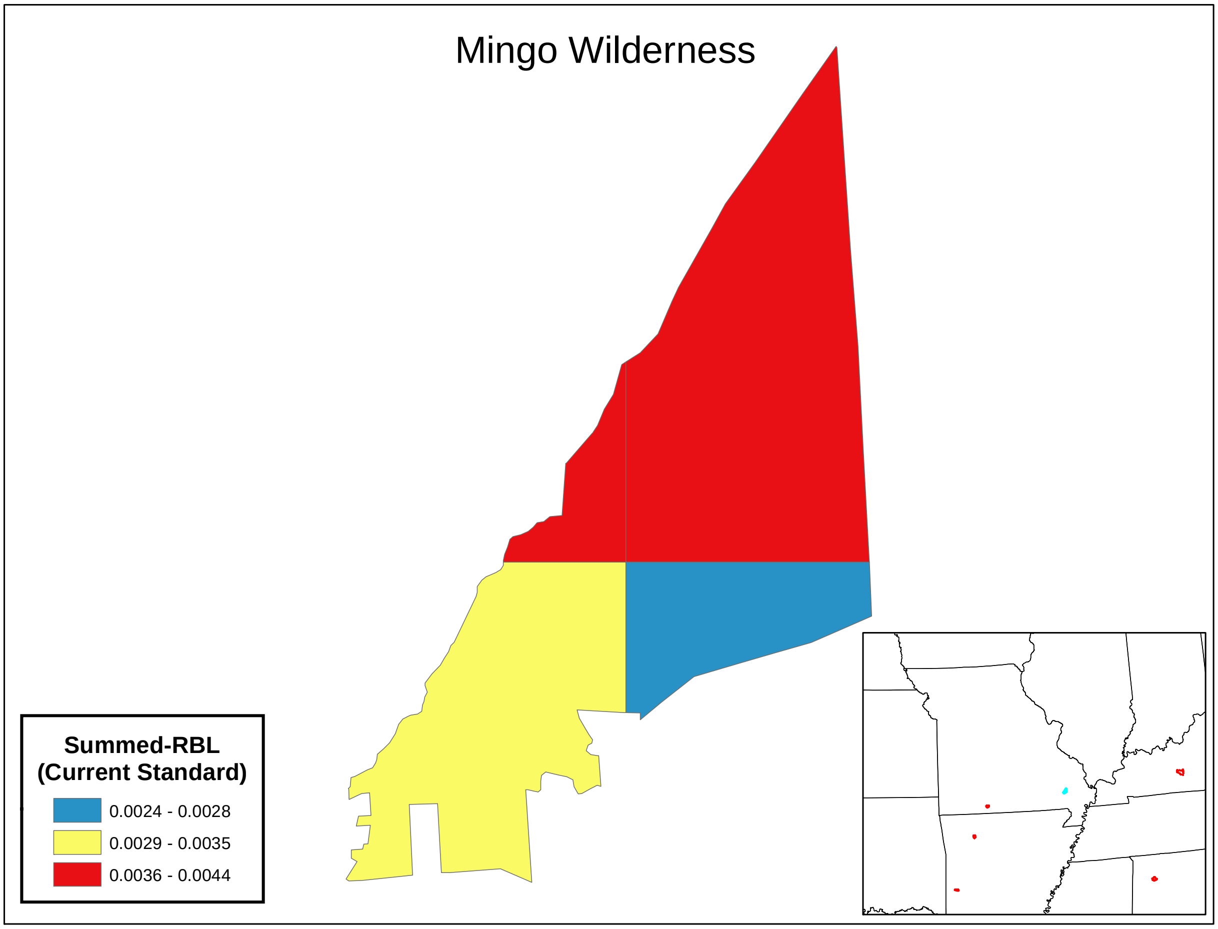
Mammoth Cave National Park
Summed-RBL
(Current Standard)
0.0047 - 0.0049
0.0050 - 0.0071
0.0072 - 0.0095
0.0096 - 0.0099



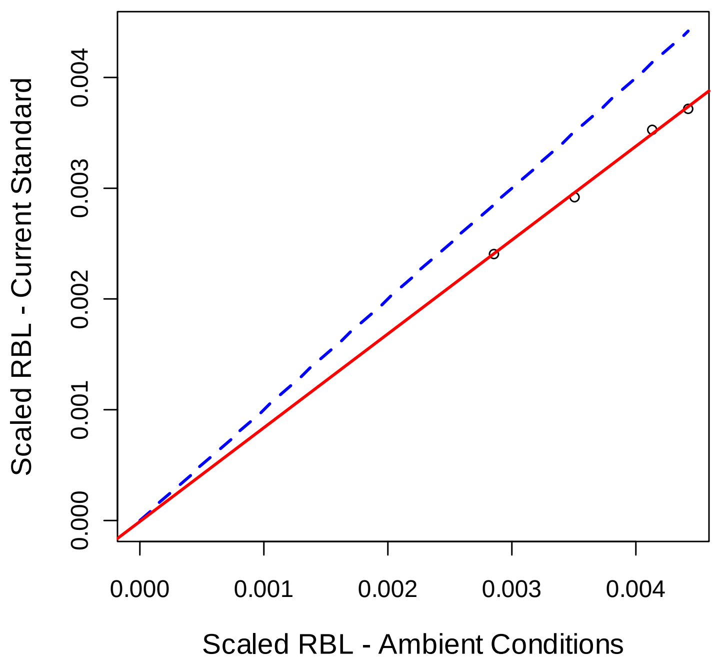
Linear Model Results	Current Standard	Alt A	Alt B
N	6		
r-squared	0.9998		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.981		
Mean W126 (Ambient = 13.53)	13.32		

MINGO WILDERNESS



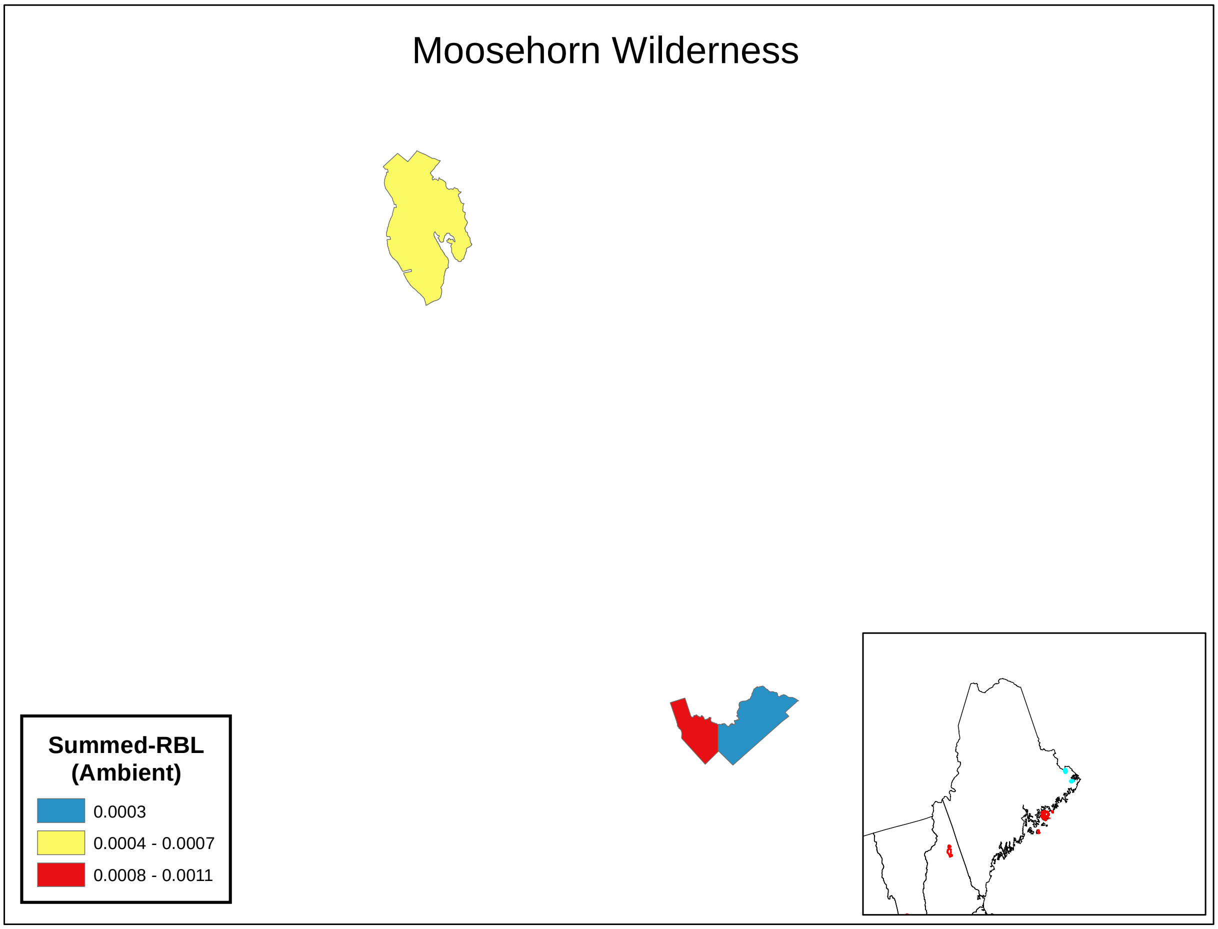
1 

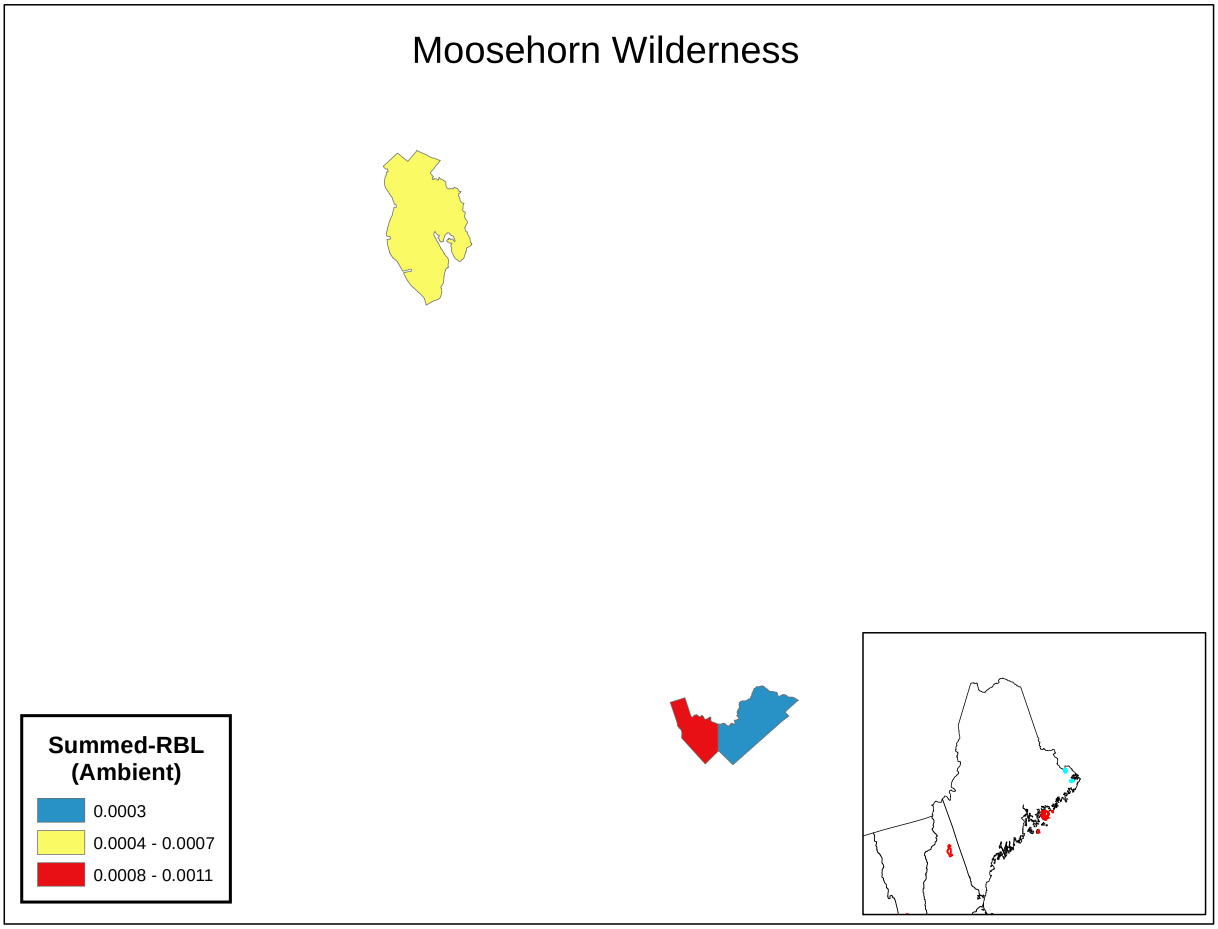
Mingo Wilderness
Summed-RBL
(Current Standard)
0.0024 - 0.0028
0.0029 - 0.0035
0.0036 - 0.0044

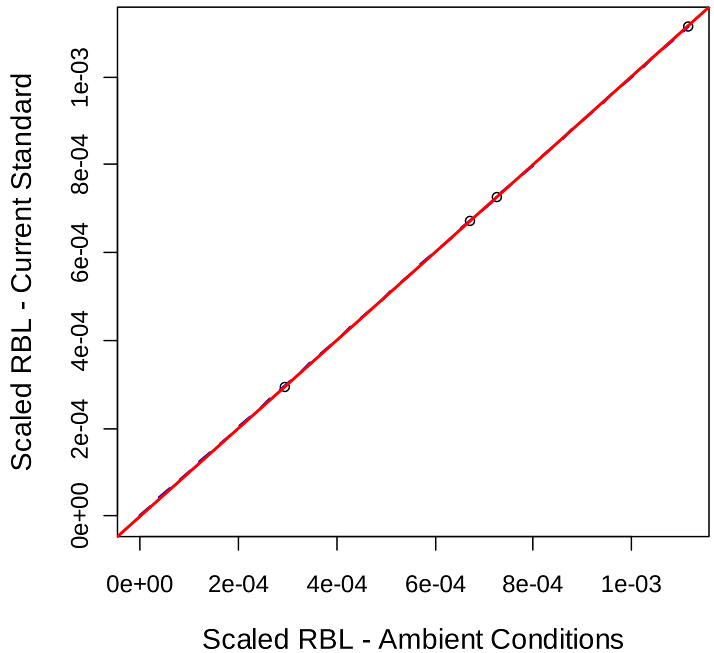


Linear Model Results	Current Standard	Alt A	Alt B
N	4		
r-squared	0.9999		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.845		
Mean W126 (Ambient = 13.60)	11.45		

MOOSEHORN WILDERNESS

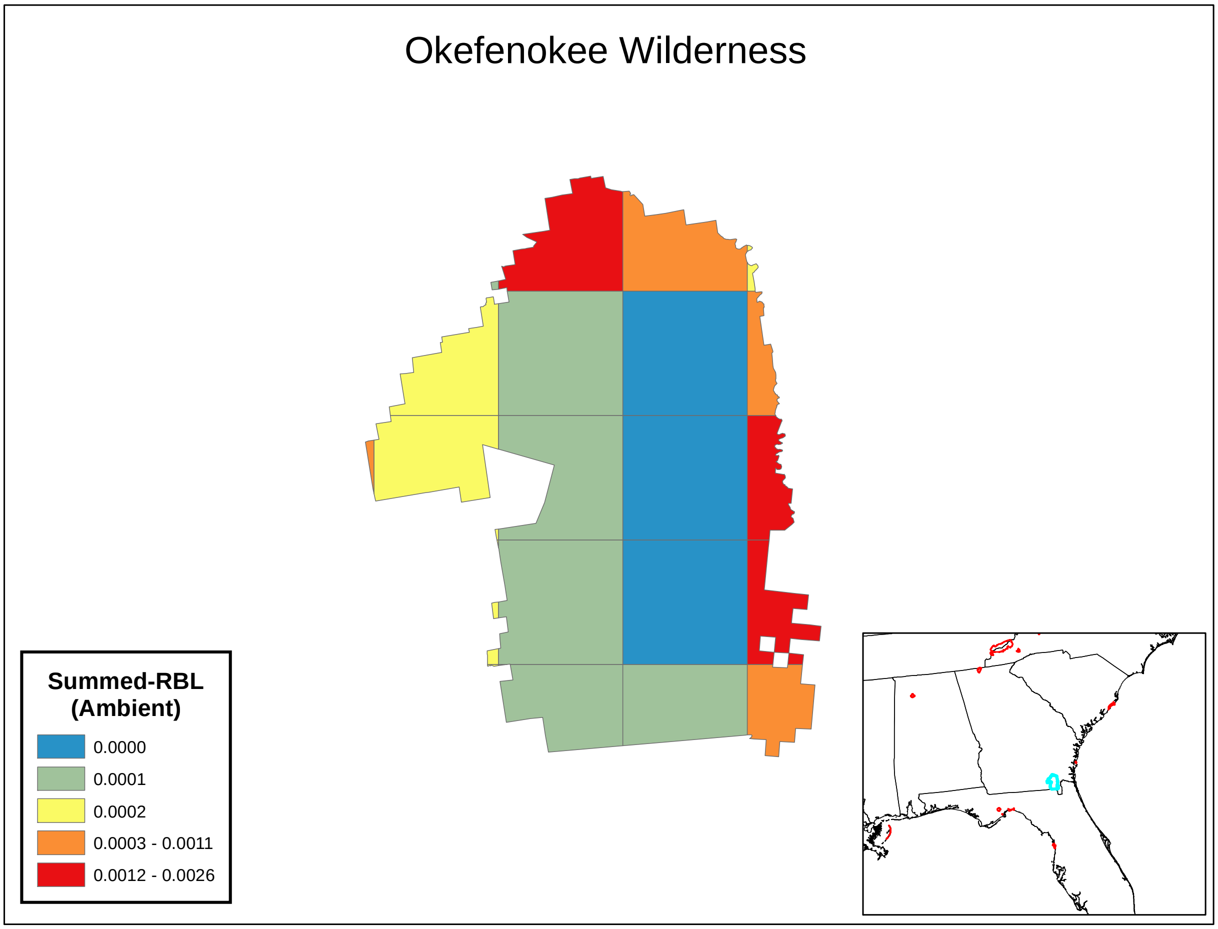



Moosehorn Wilderness
Summed-RBL
(Ambient)
0.0003
0.0004 - 0.0007
0.0008 - 0.0011

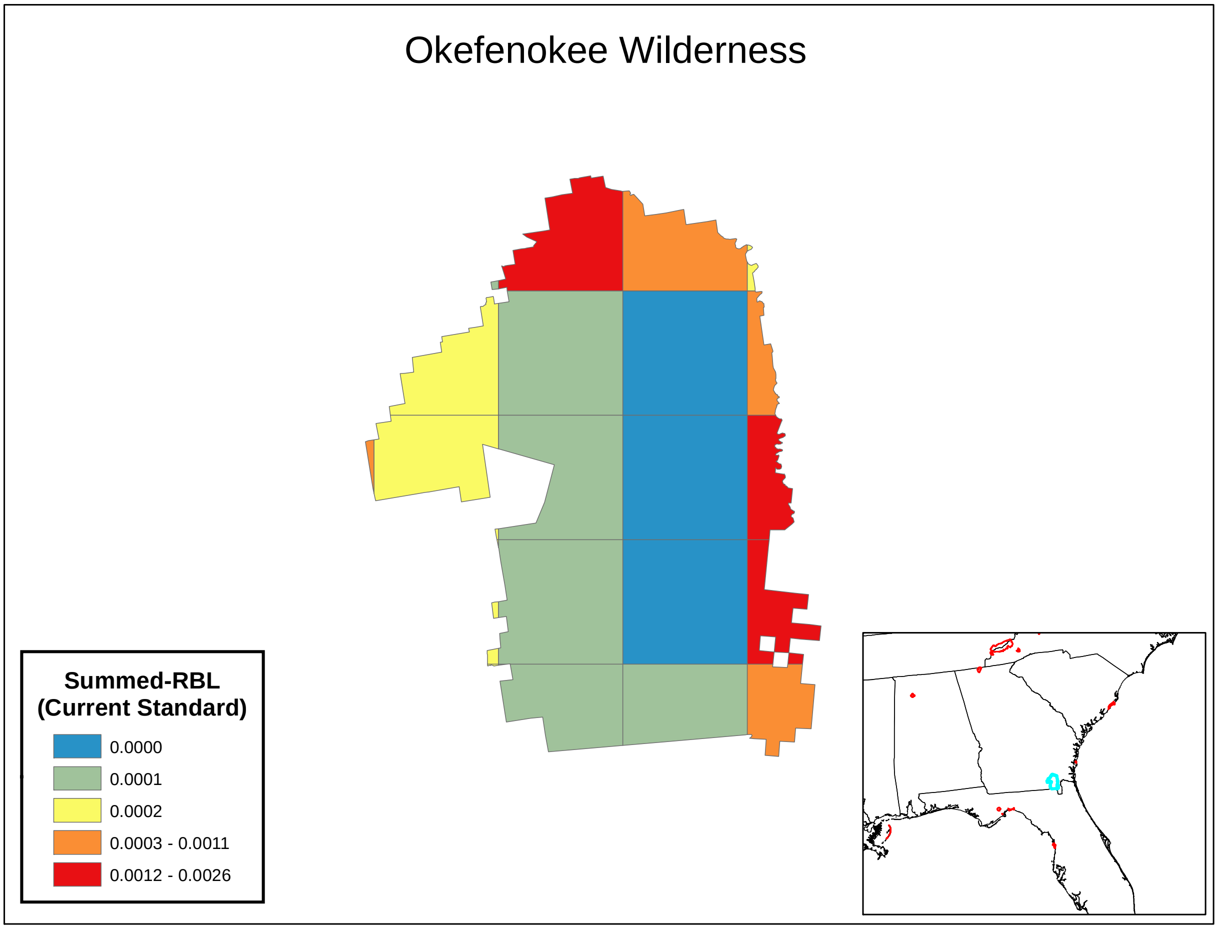


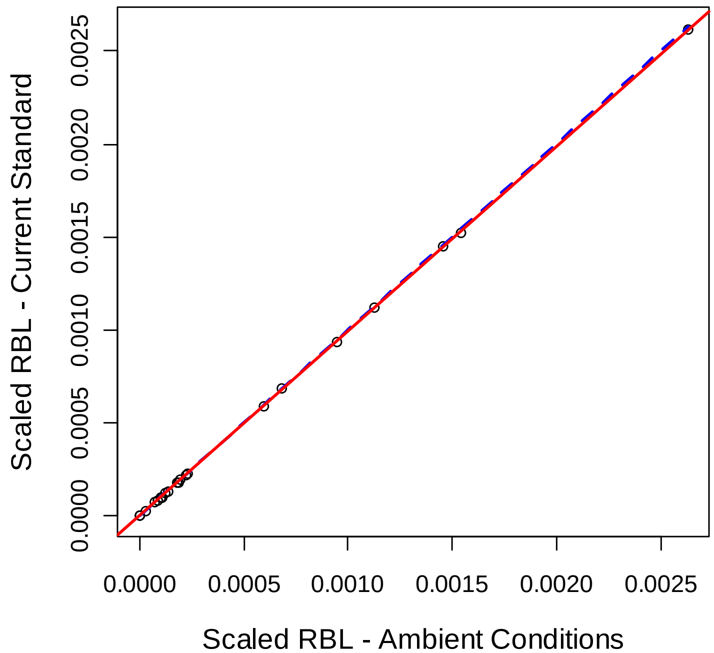
Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	4		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.00		
Mean W126 (Ambient = 1.93)	1.93		

1 **OKEFENOKEE WILDERNESS**



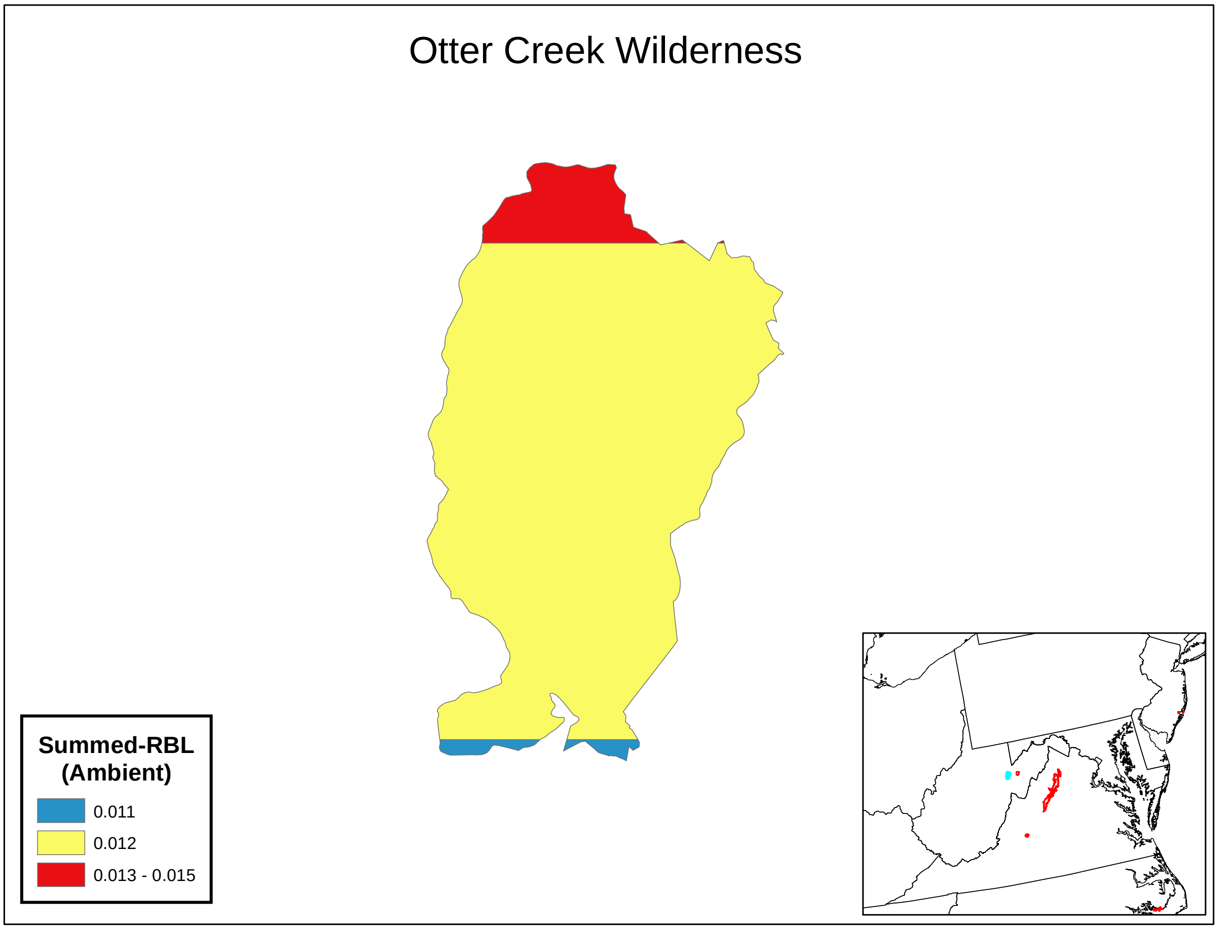
2

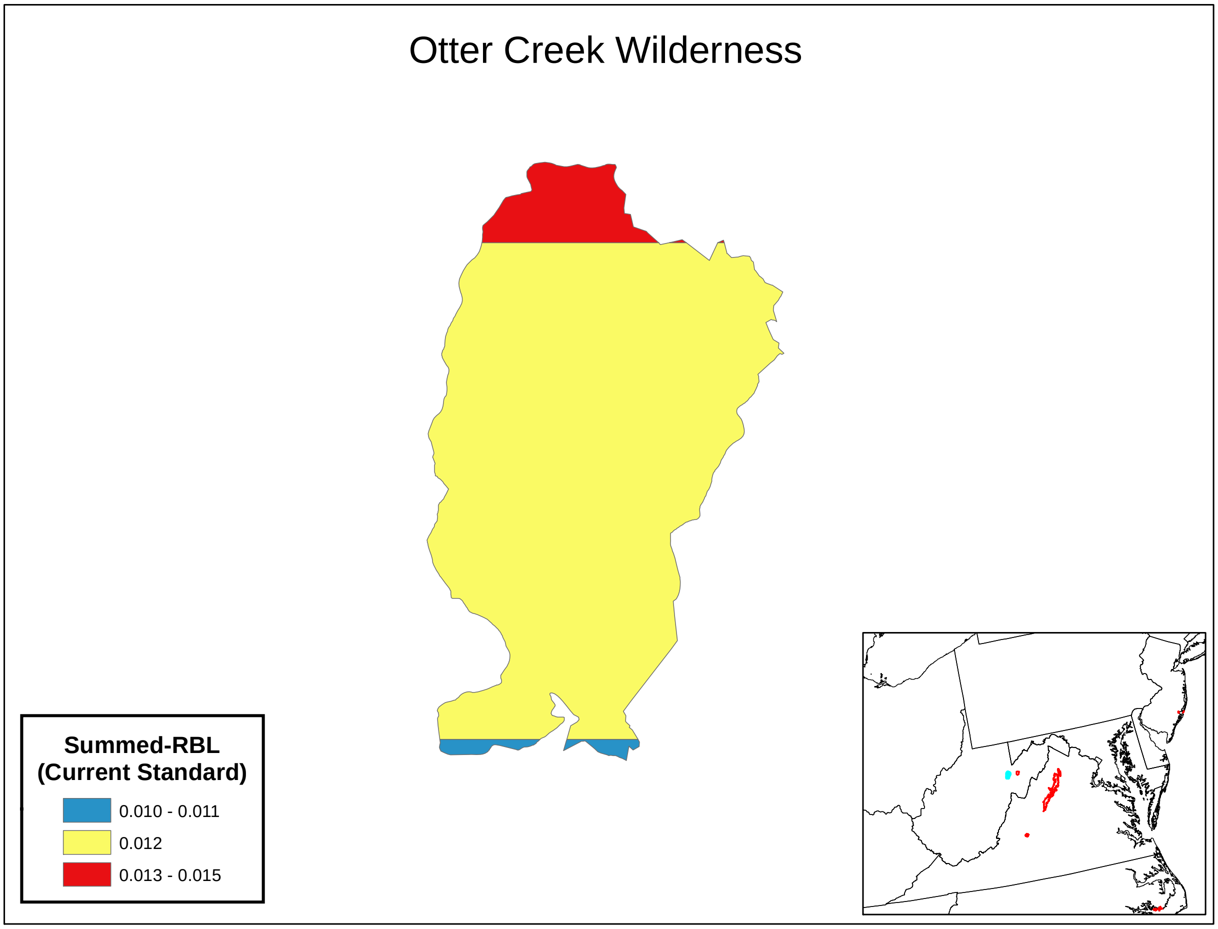
1 
Okefenokee Wilderness
Summed-RBL
(Current Standard)
0.0000
0.0001
0.0002
0.0003 - 0.0011
0.0012 - 0.0026



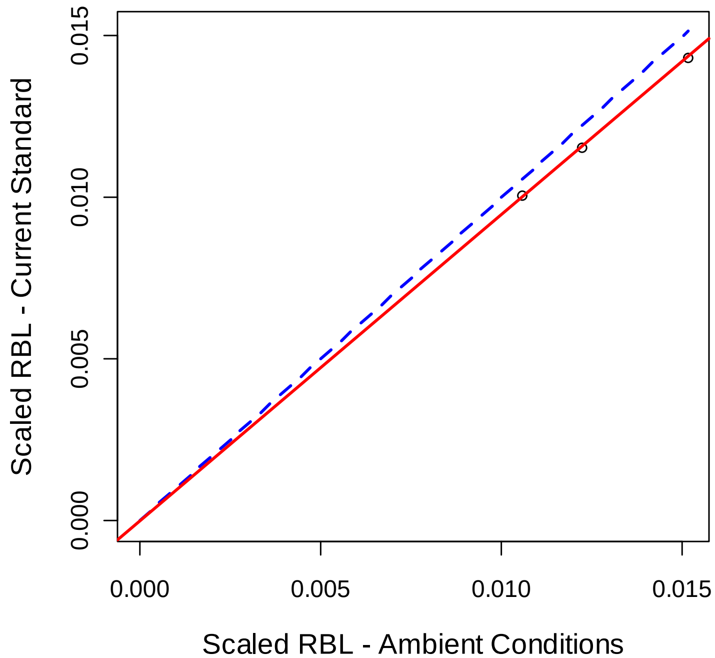
Linear Model Results	Current Standard	Alt A	Alt B
N	21		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.993		
Mean W126 (Ambient = 8.65)	8.59		

OTTER CREEK WILDERNESS



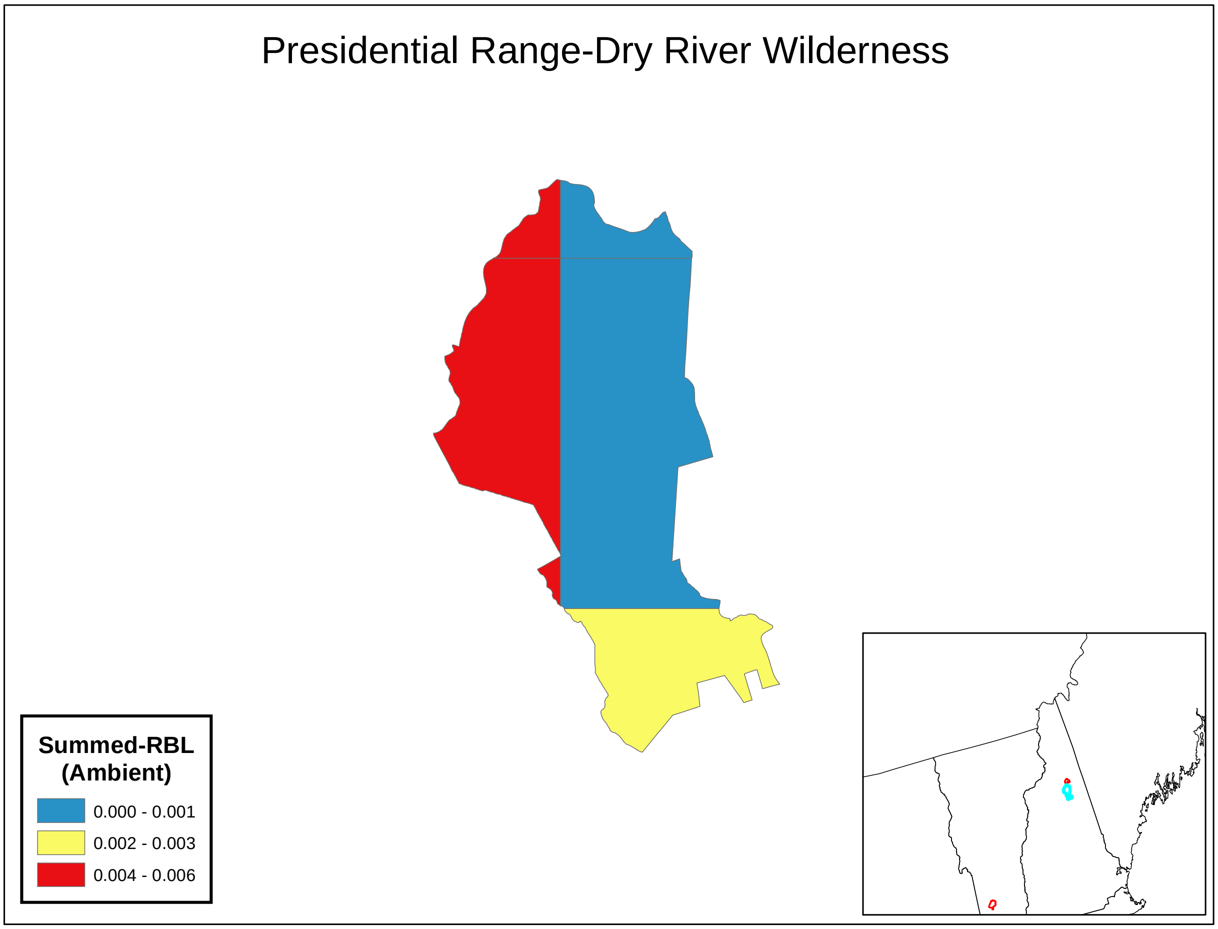

Otter Creek Wilderness
Summed-RBL
(Current Standard)
0.010 - 0.011
0.012
0.013 - 0.015

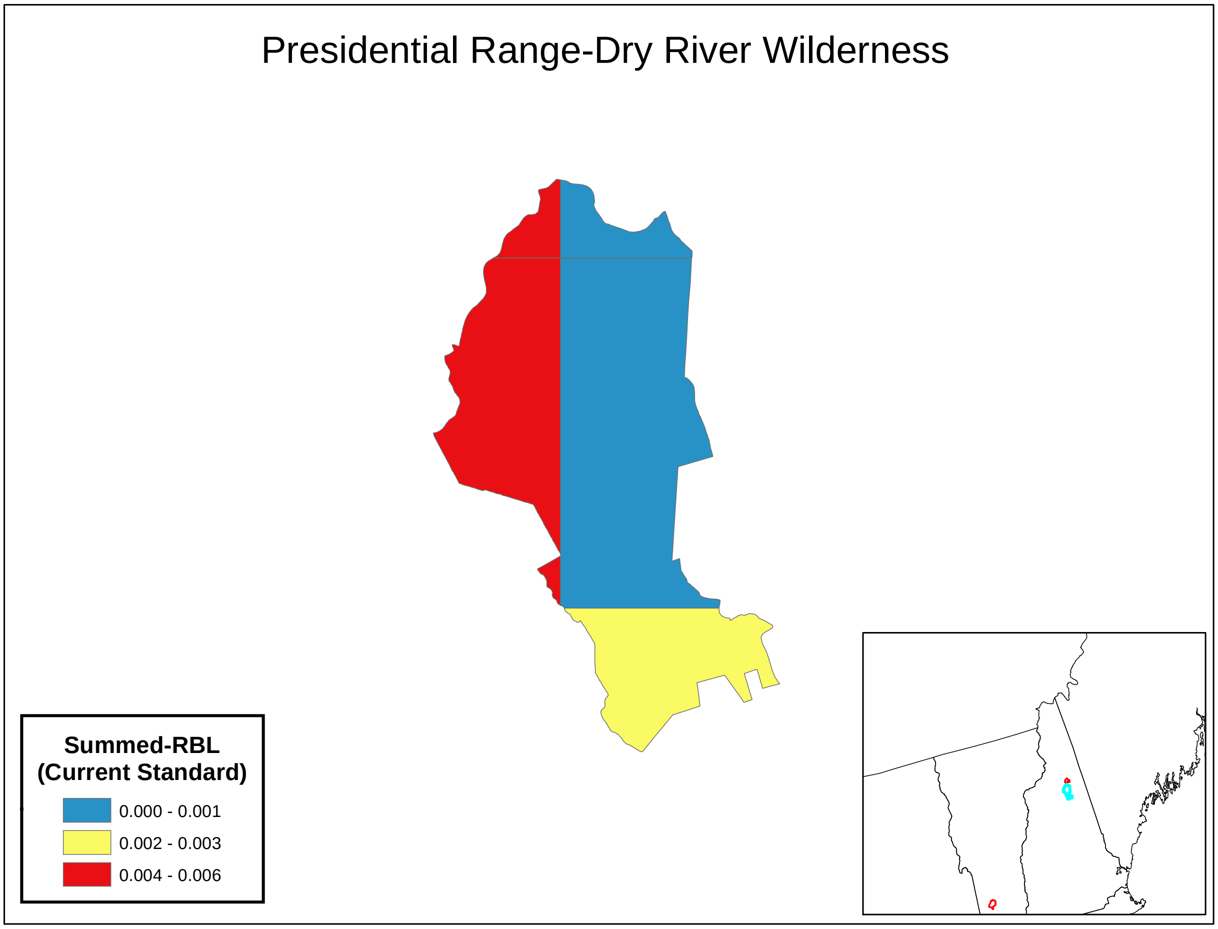
1

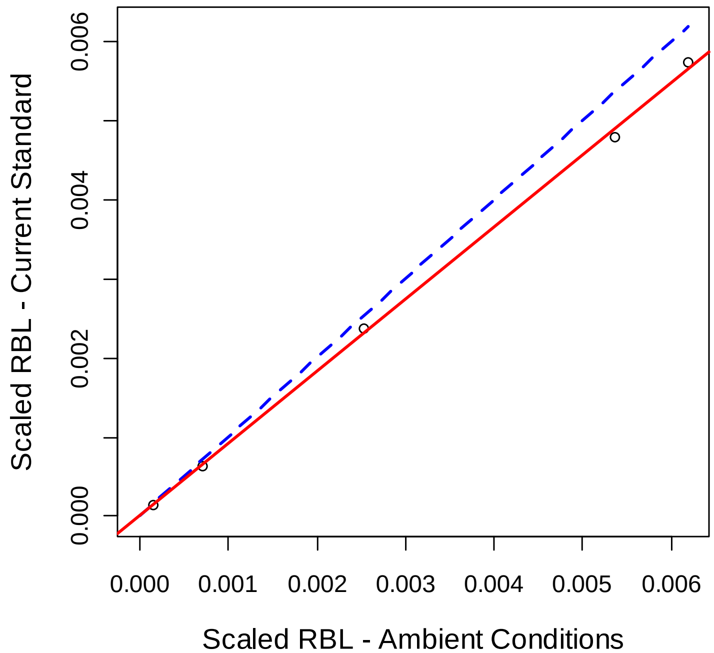


Linear Model Results	Current Standard	Alt A	Alt B
N	3		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.946		
Mean W126 (Ambient = 7.87)	7.46		

PRESIDENTIAL RANGE-DRY RIVER WILDERNESS

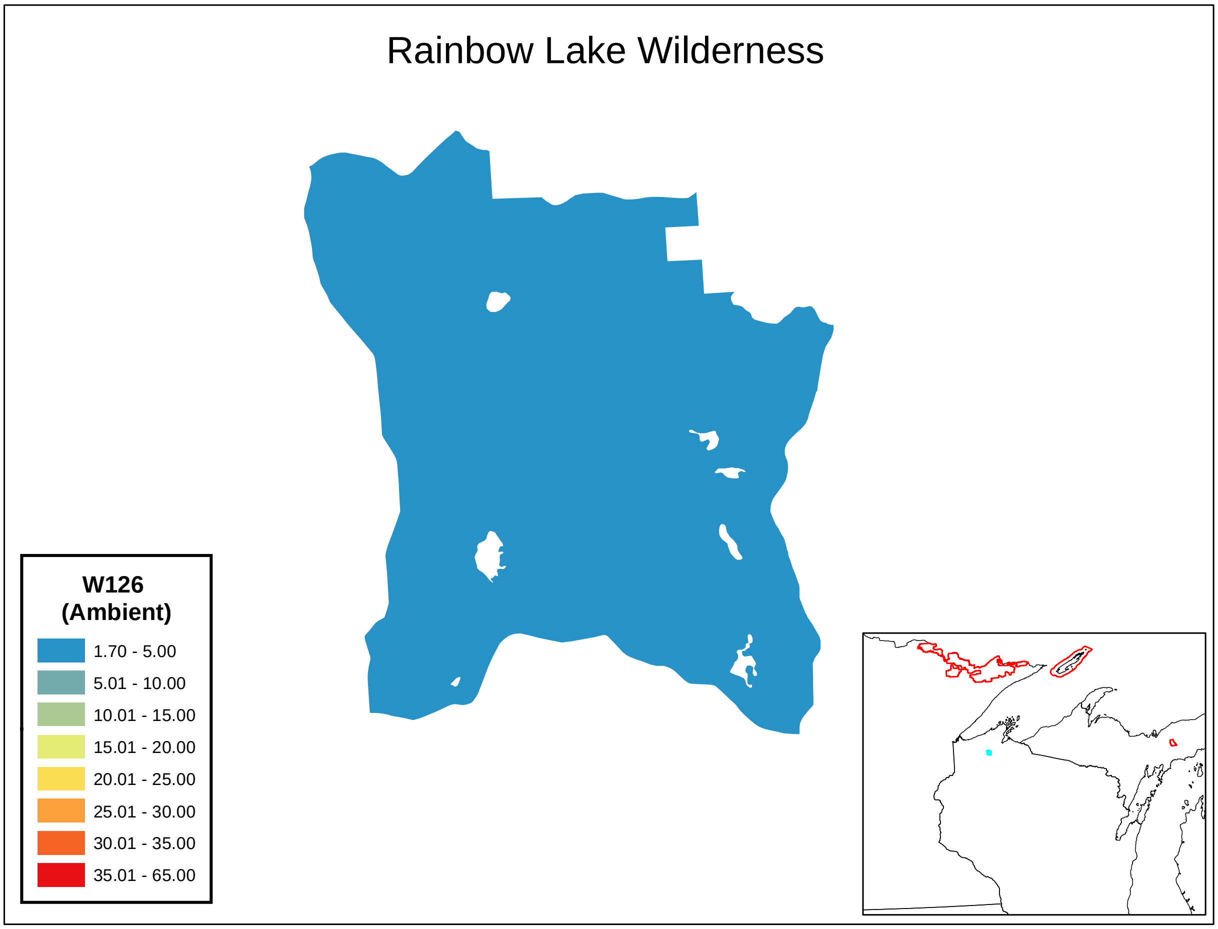


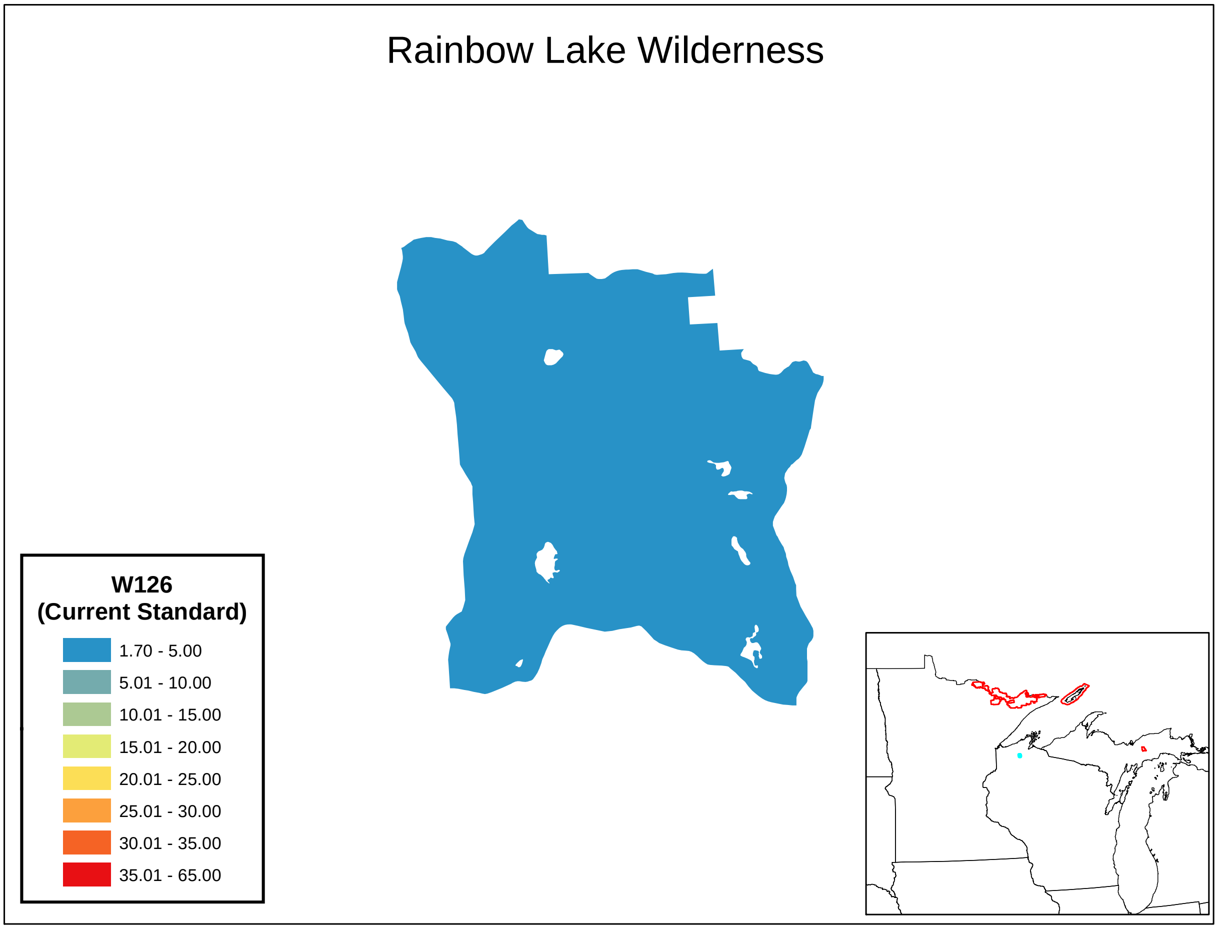

Presidential Range-Dry River Wilderness
Summed-RBL
(Current Standard)
0.000 - 0.001
0.002 - 0.003
0.004 - 0.006



Linear Model Results	Current Standard	Alt A	Alt B
N	5		
r-squared	0.9995		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.914		
Mean W126 (Ambient = 7.52)	6.89		

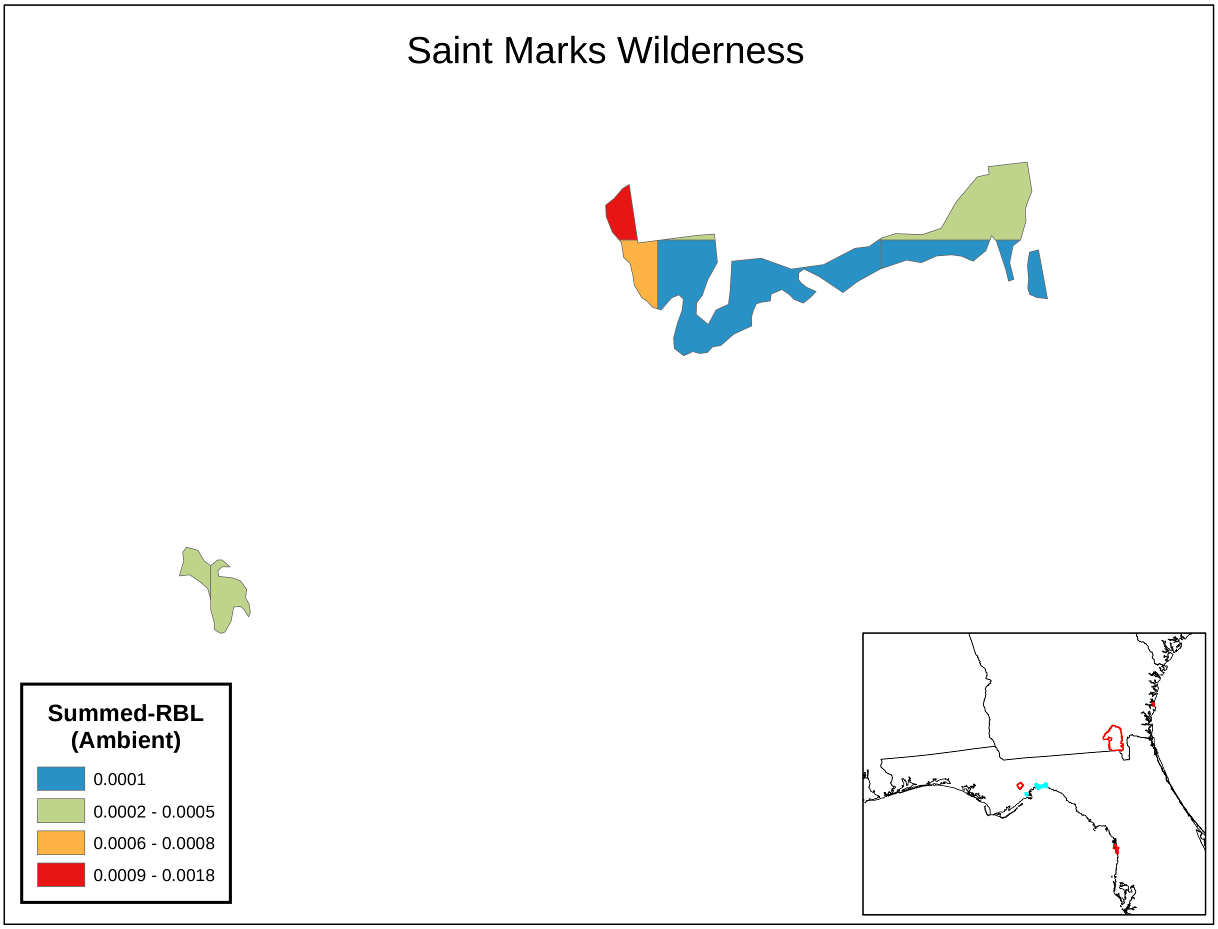
RAINBOW LAKE WILDERNESS

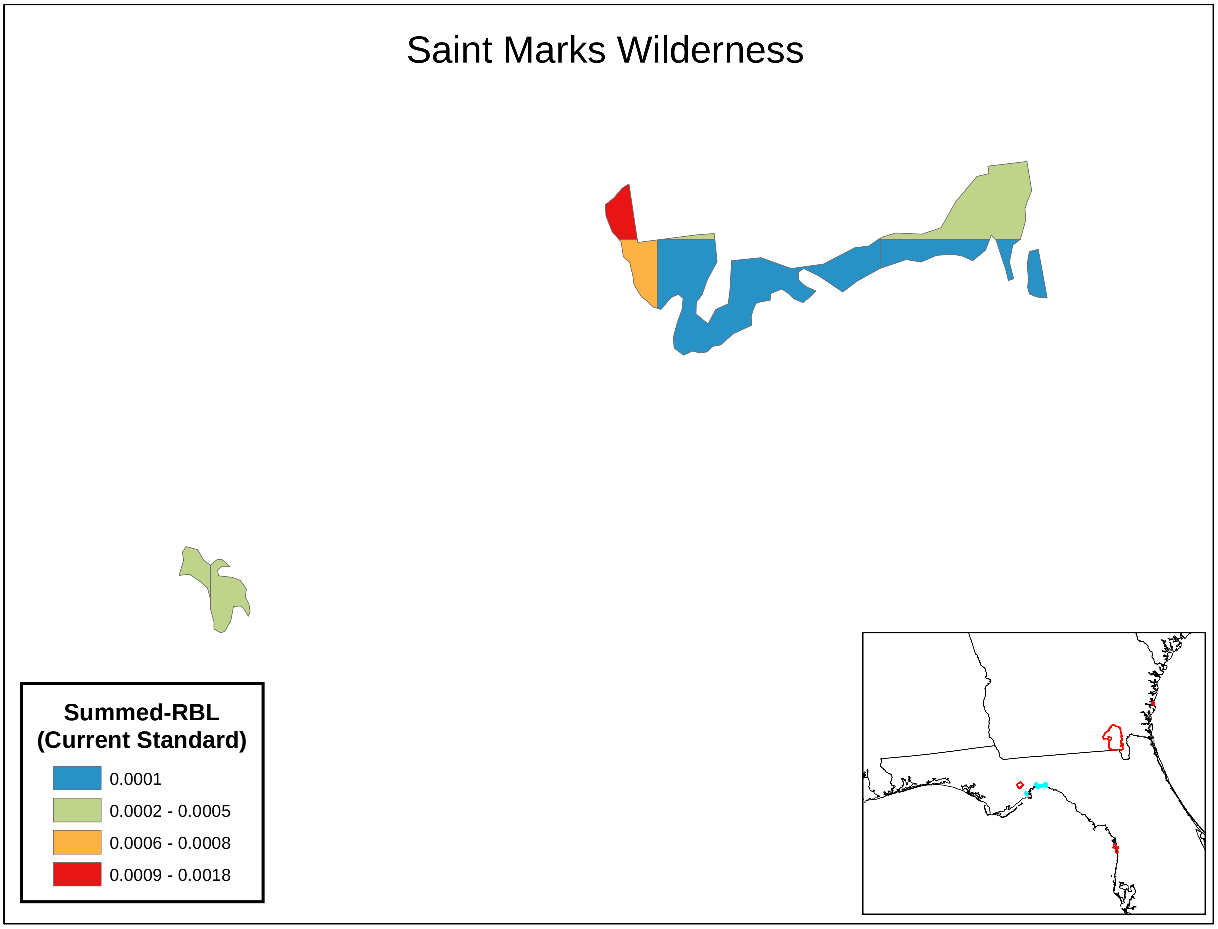


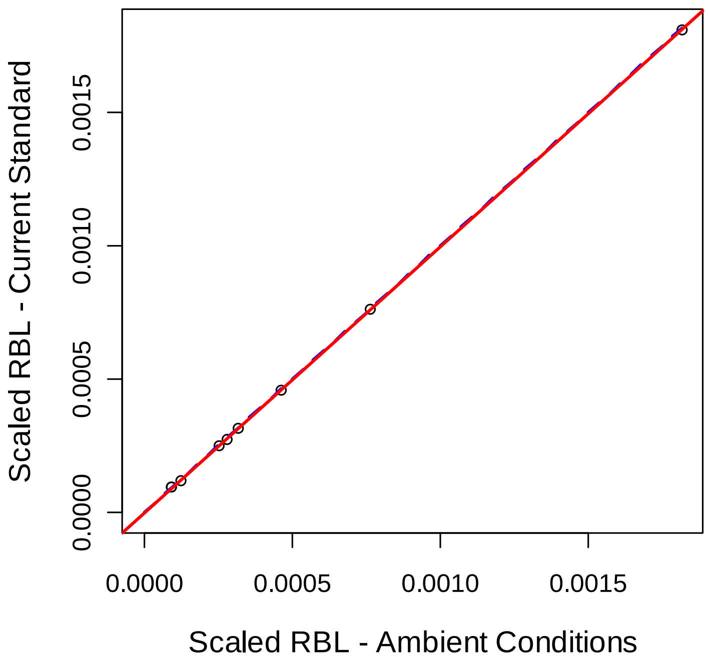

Rainbow Lake Wilderness
W126
(Current Standard)
1.70 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 - 35.00
35.01 - 65.00

1

SAINT MARKS WILDERNESS

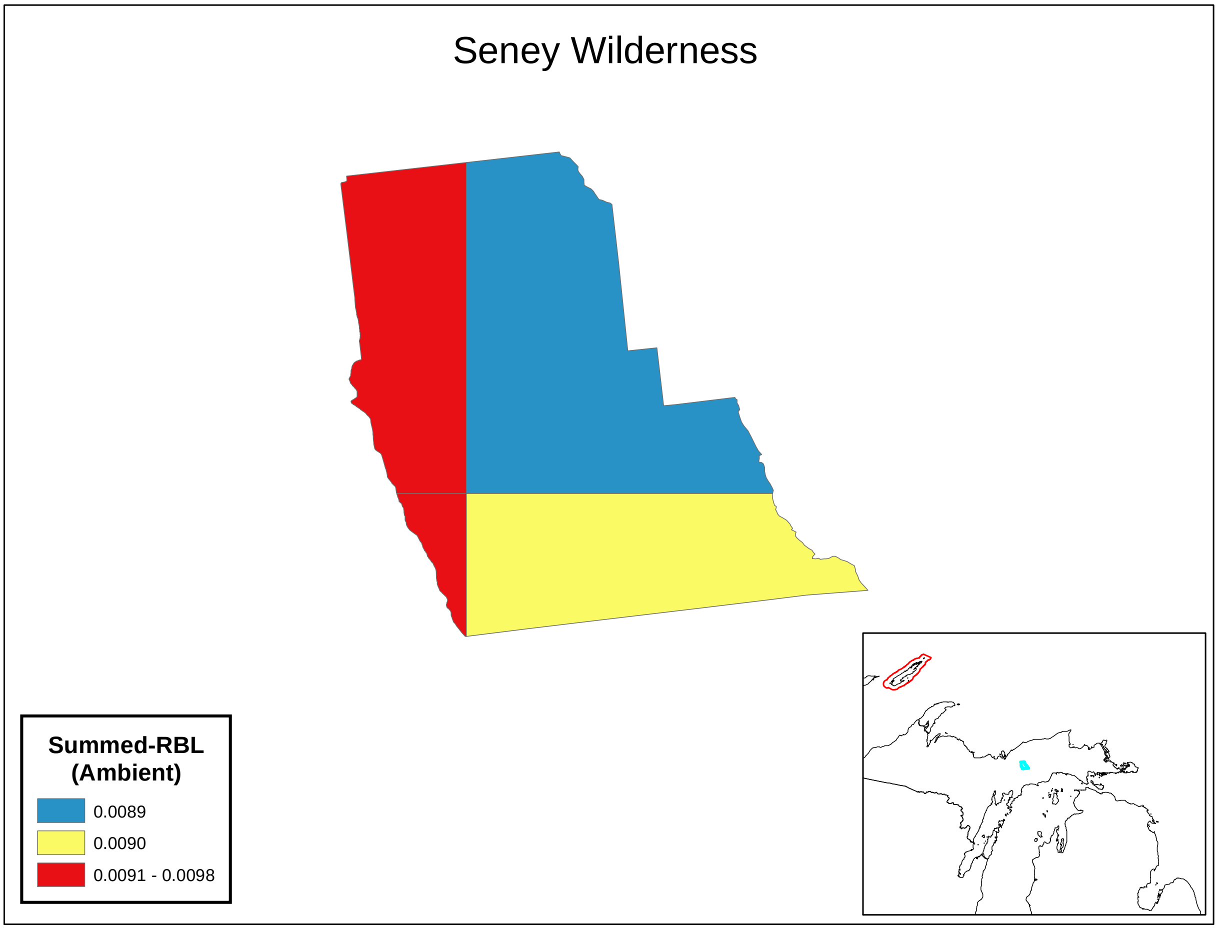


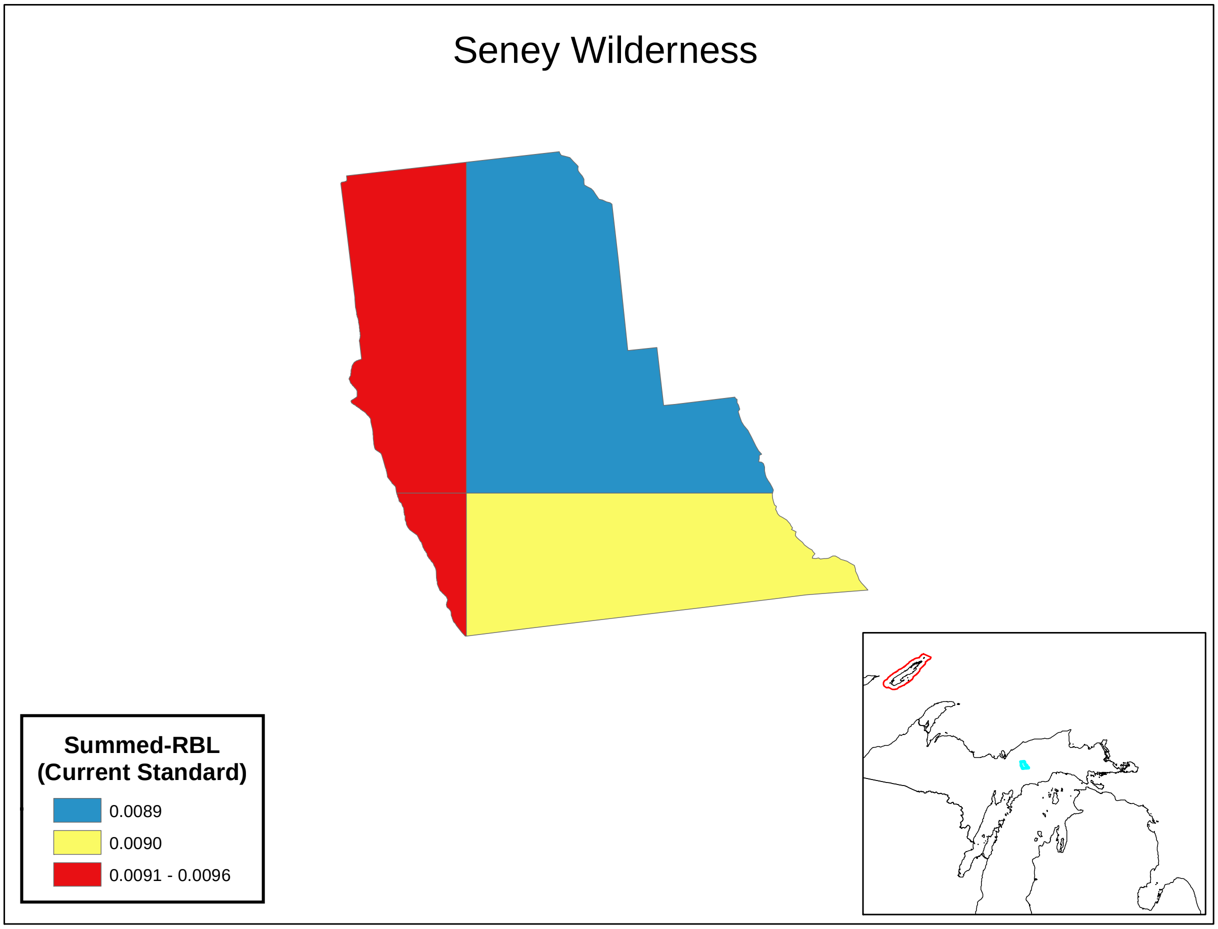
1 
Saint Marks Wilderness
Summed-RBL
(Current Standard)
0.0001
0.0002 - 0.0005
0.0006 - 0.0008
0.0009 - 0.0018

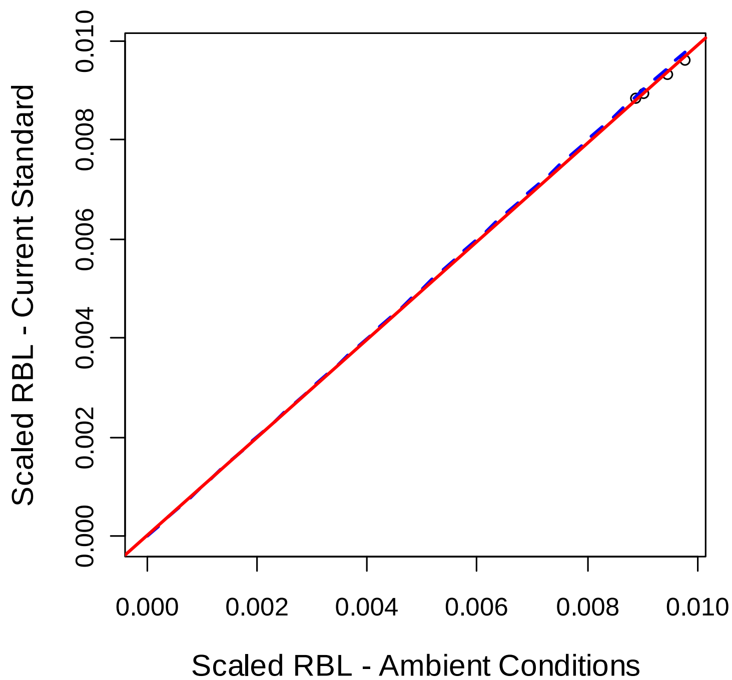


Linear Model Results	Current Standard	Alt A	Alt B
N	9		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.999		
Mean W126 (Ambient = 8.93)	8.92		

SENEY WILDERNESS

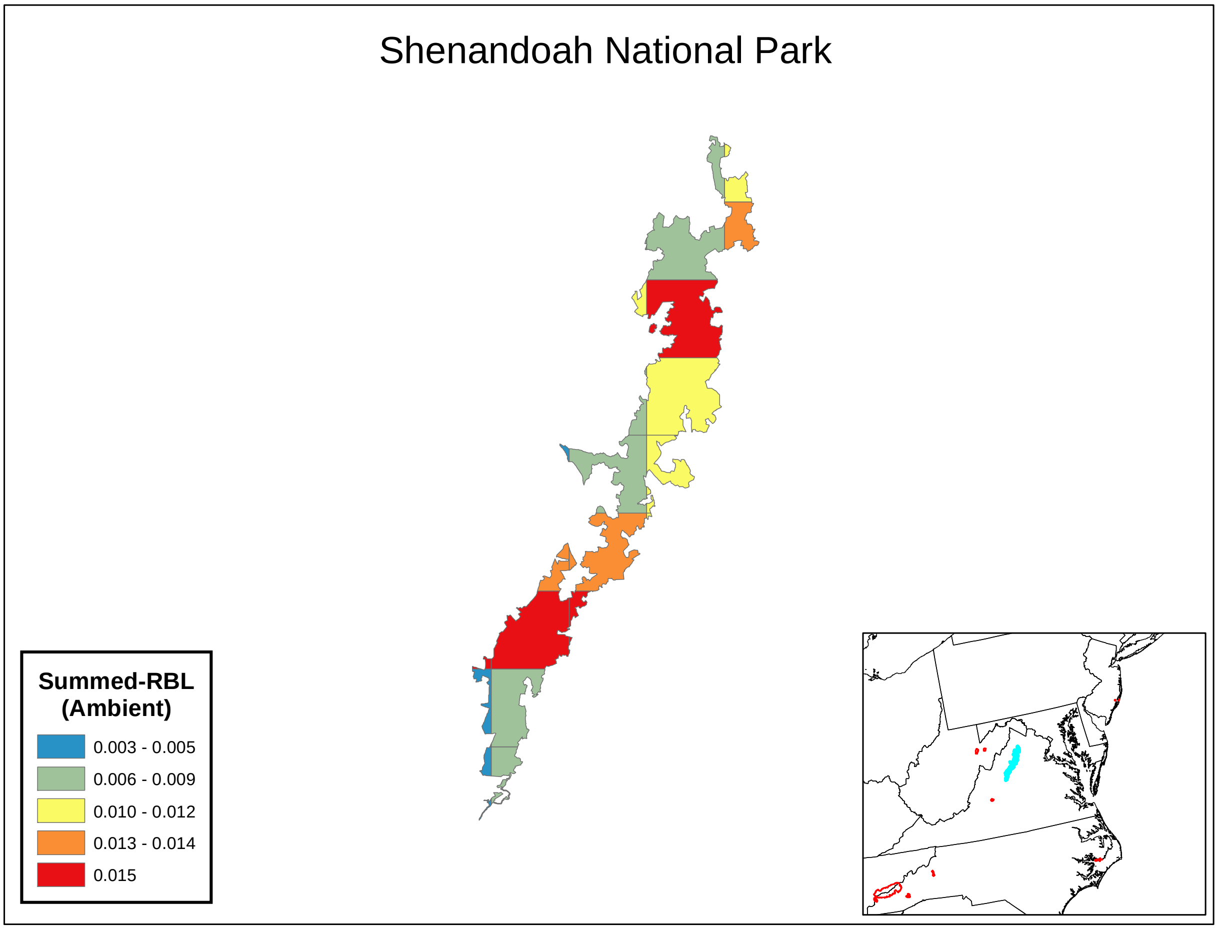



Seney Wilderness
Summed-RBL
(Current Standard)
0.0089
0.0090
0.0091 - 0.0096

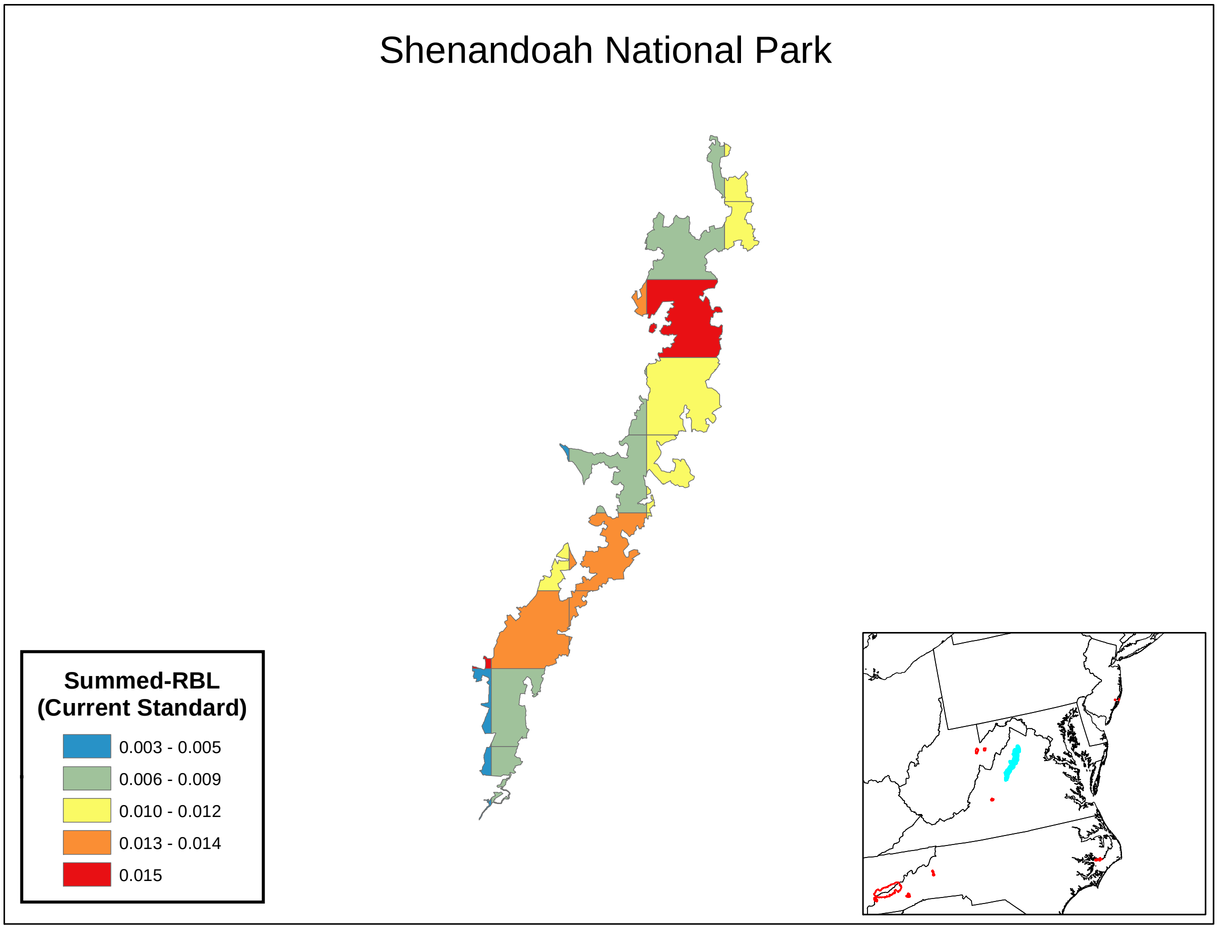


Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	4		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.990		
Mean W126 (Ambient = 7.18)	7.11		

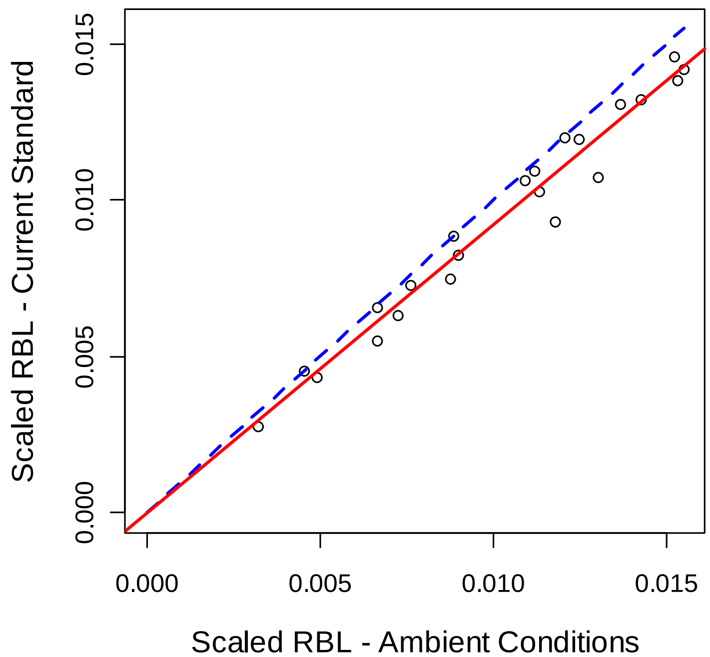
1 **SHENANDOAH NATIONAL PARK**



2

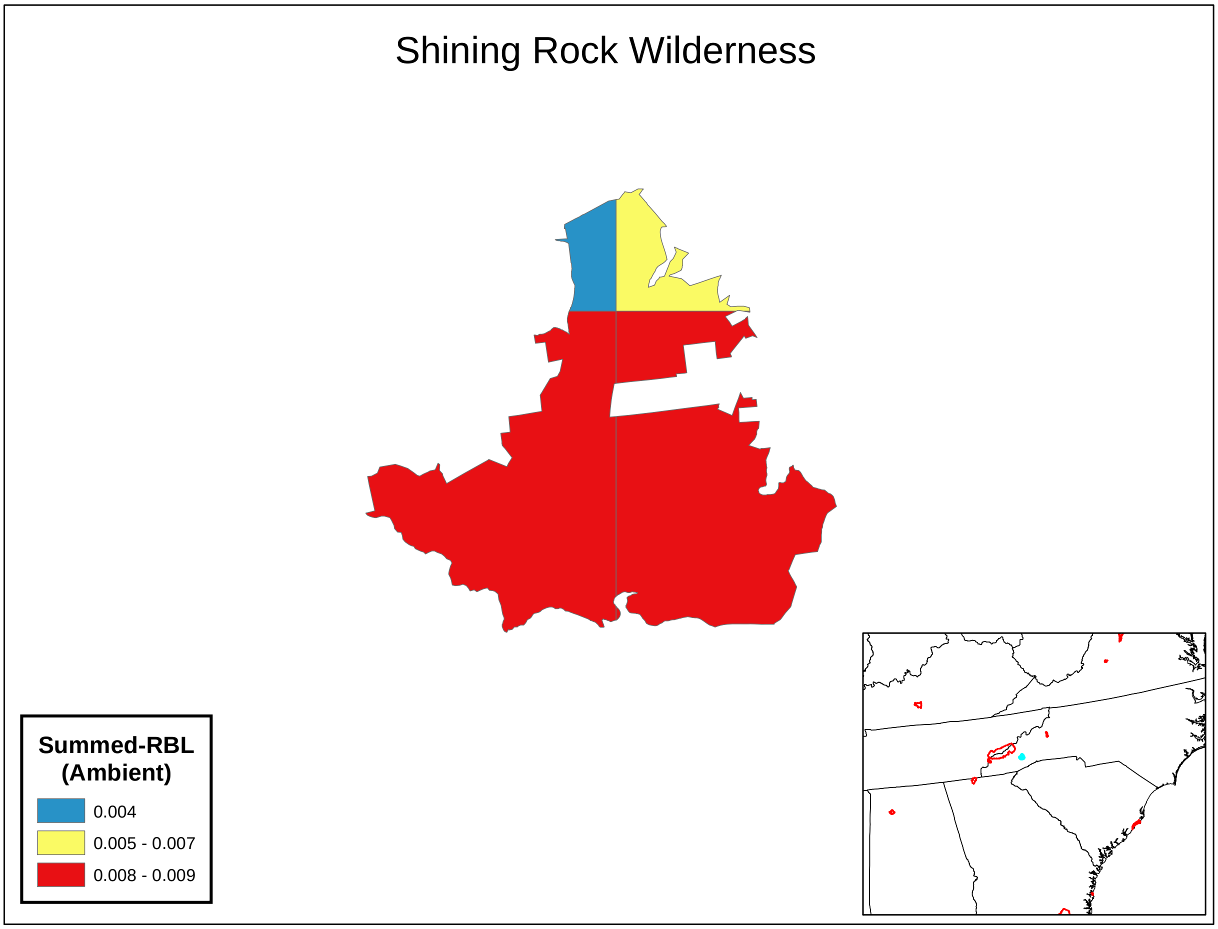

Shenandoah National Park
Summed-RBL
(Current Standard)
0.003 - 0.005
0.006 - 0.009
0.010 - 0.012
0.013 - 0.014
0.015

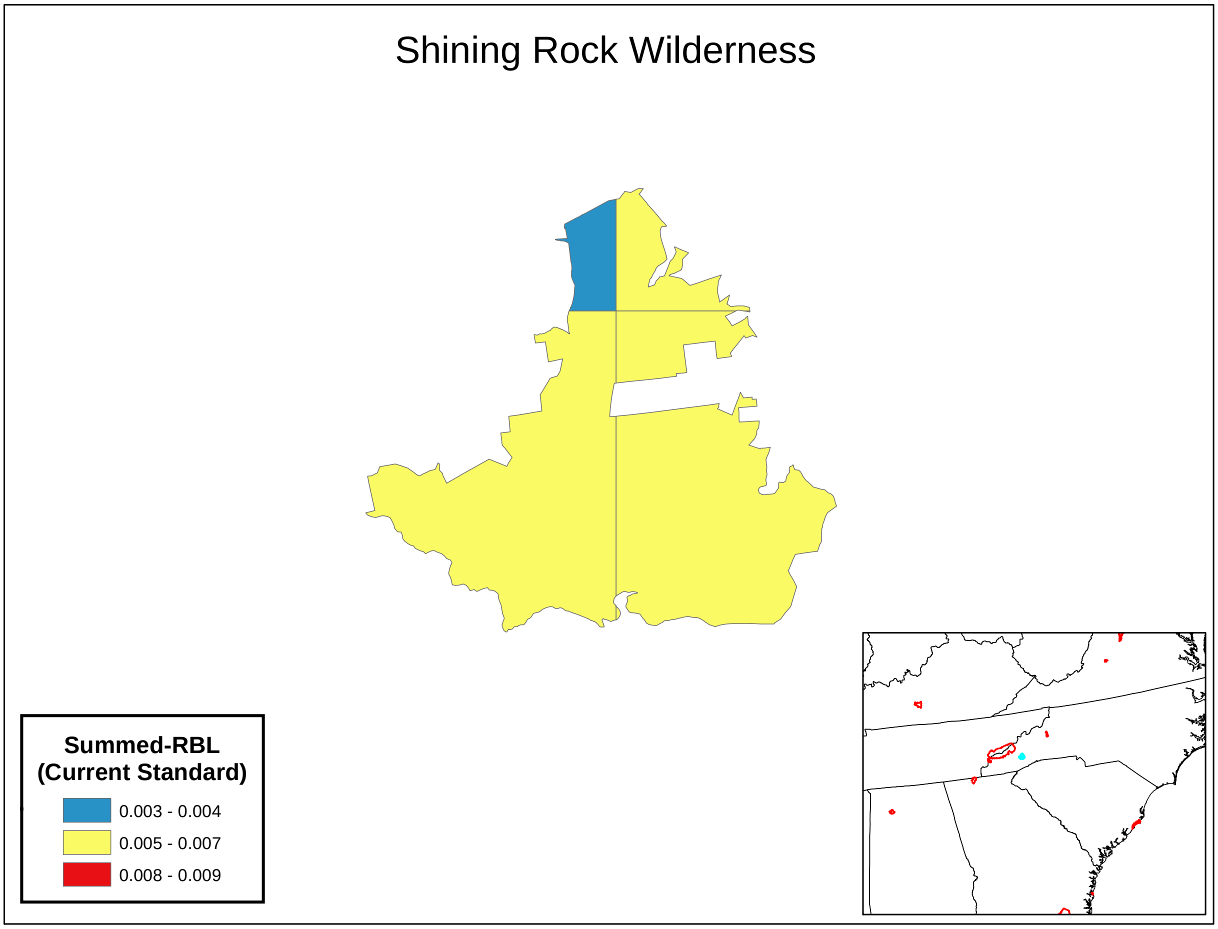
1



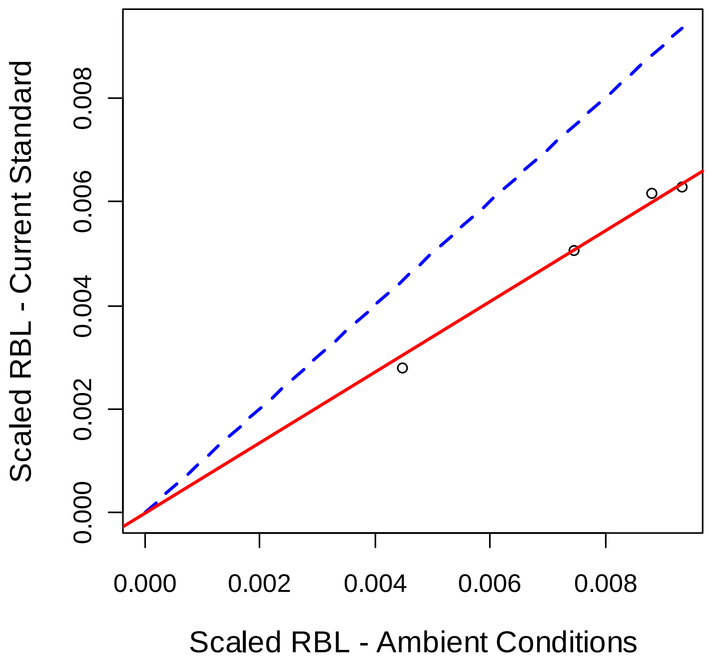
Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	22		
r-squared	0.9961		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.922		
Mean W126 (Ambient = 10.85)	10.25		

SHINING ROCK WILDERNESS



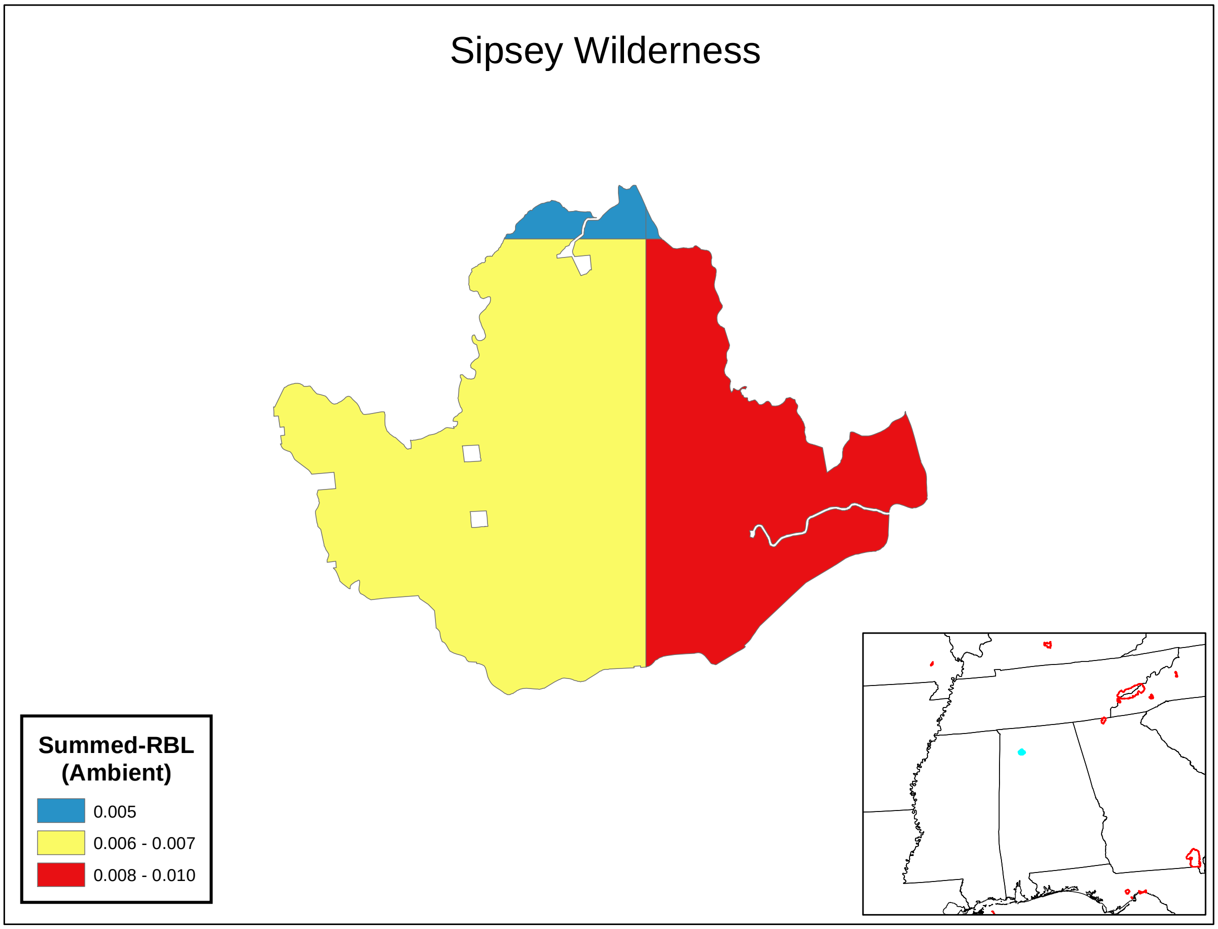

Shining Rock Wilderness
Summed-RBL
(Current Standard)
0.003 - 0.004
0.005 - 0.007
0.008 - 0.009

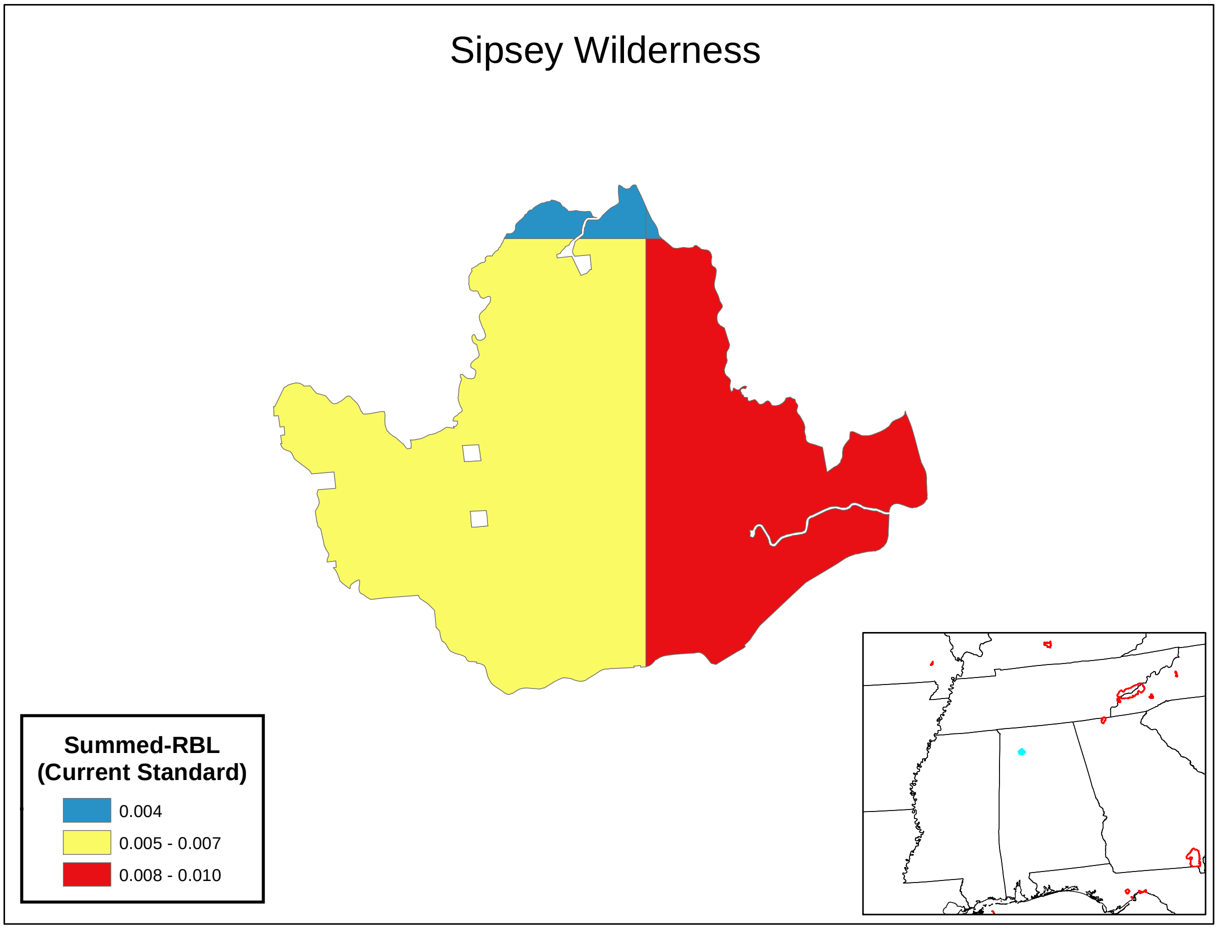
1



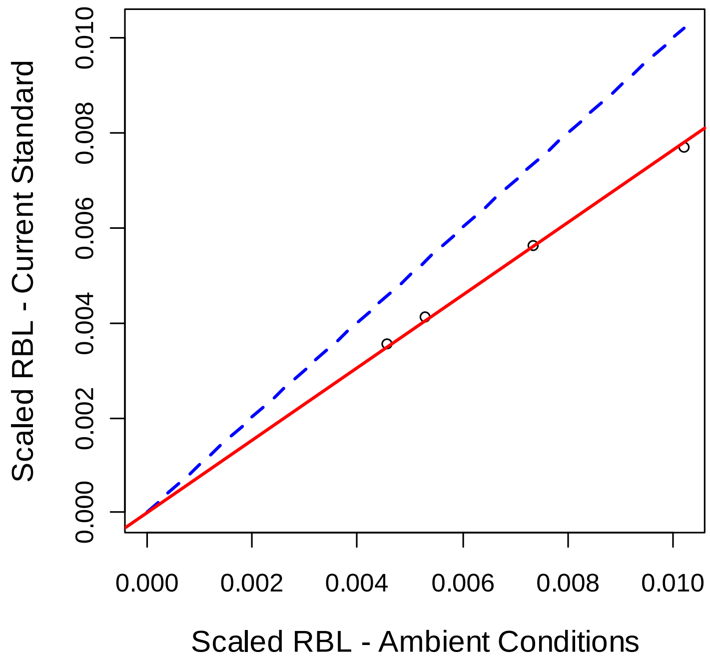
Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	4		
r-squared	0.9989		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.679		
Mean W126 (Ambient = 12.65)	9.88		

SIPSEY WILDERNESS



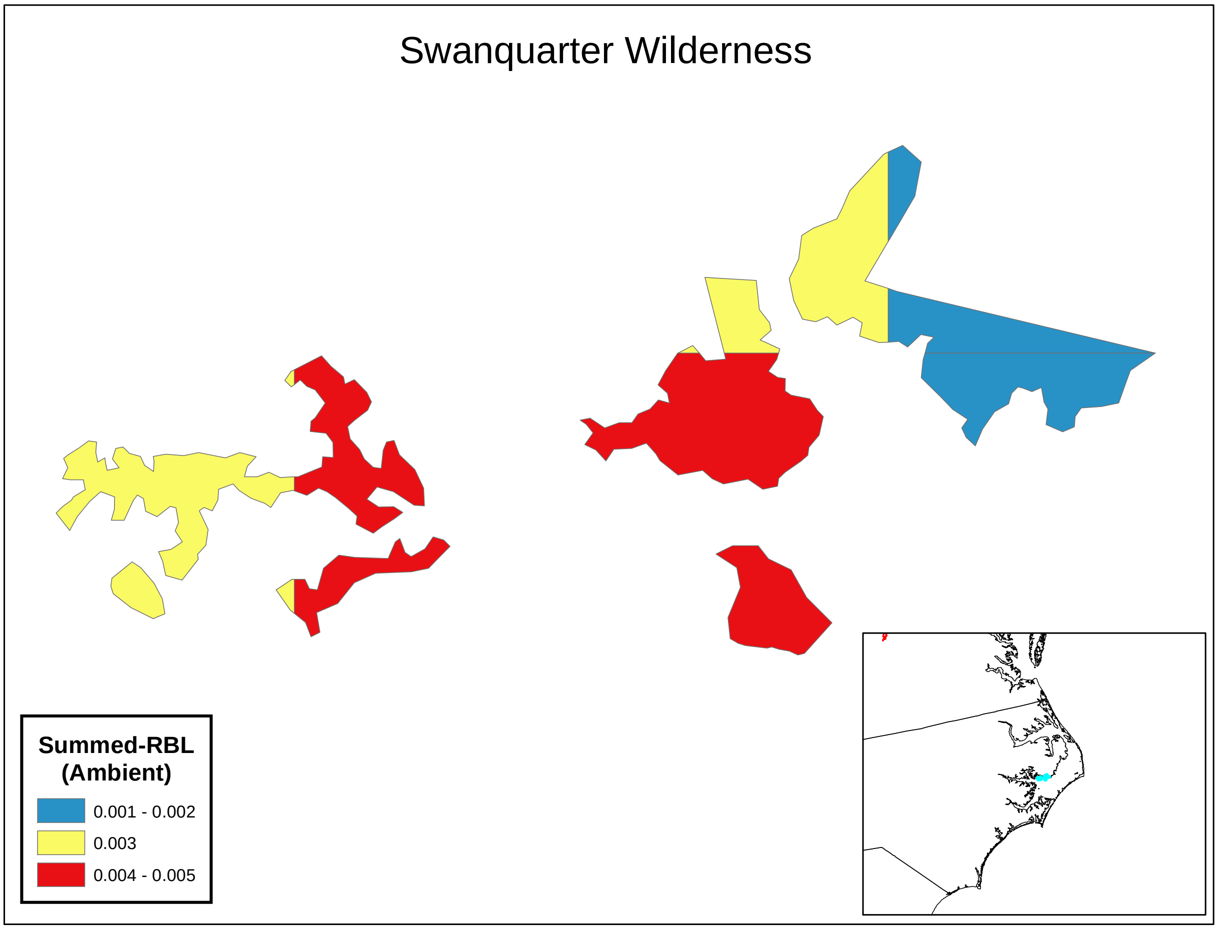

Sipsey Wilderness
Summed-RBL
(Current Standard)
0.004
0.005 - 0.007
0.008 - 0.010

1

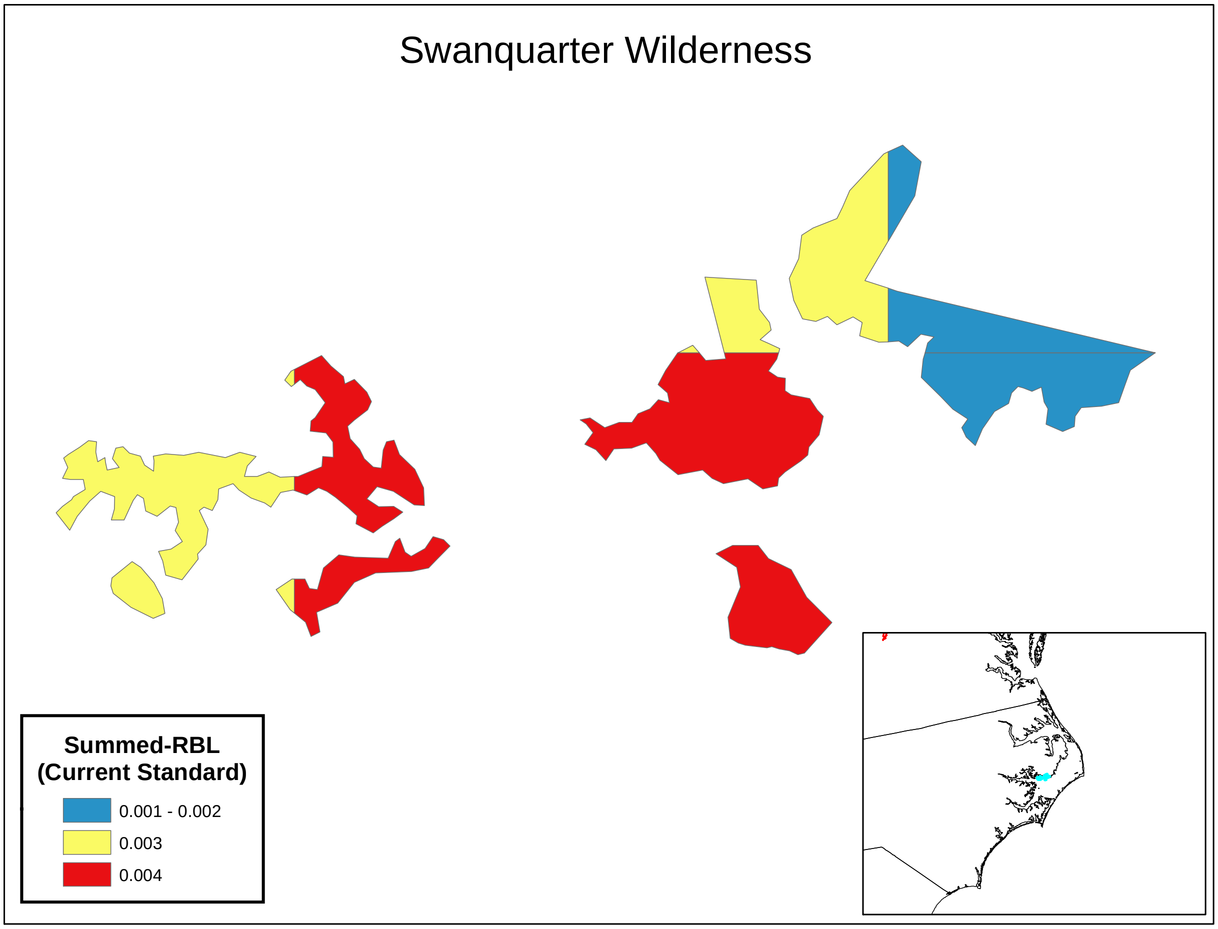


Linear Model Results	Current Standard	Alt A	Alt B
N	4		
r-squared	0.9998		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.765		
Mean W126 (Ambient = 14.53)	12.08		

1 **SWANQUARTER WILDERNESS**

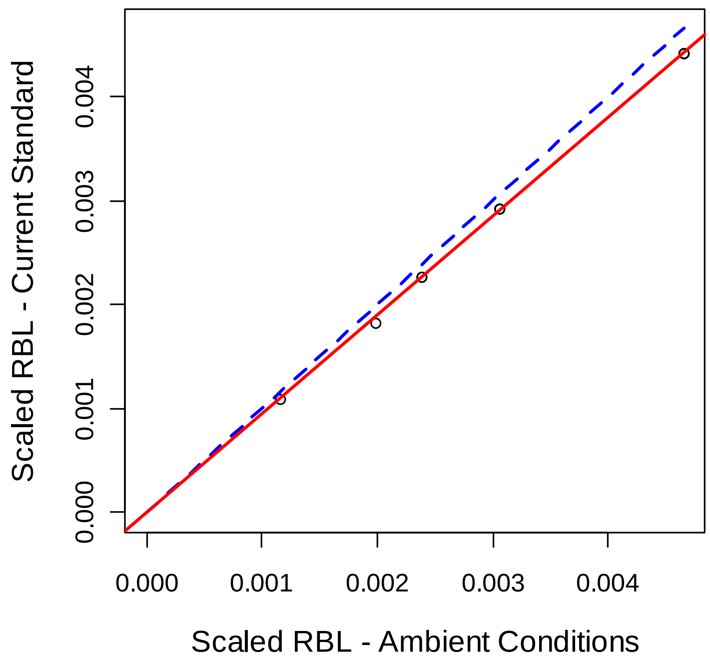


2



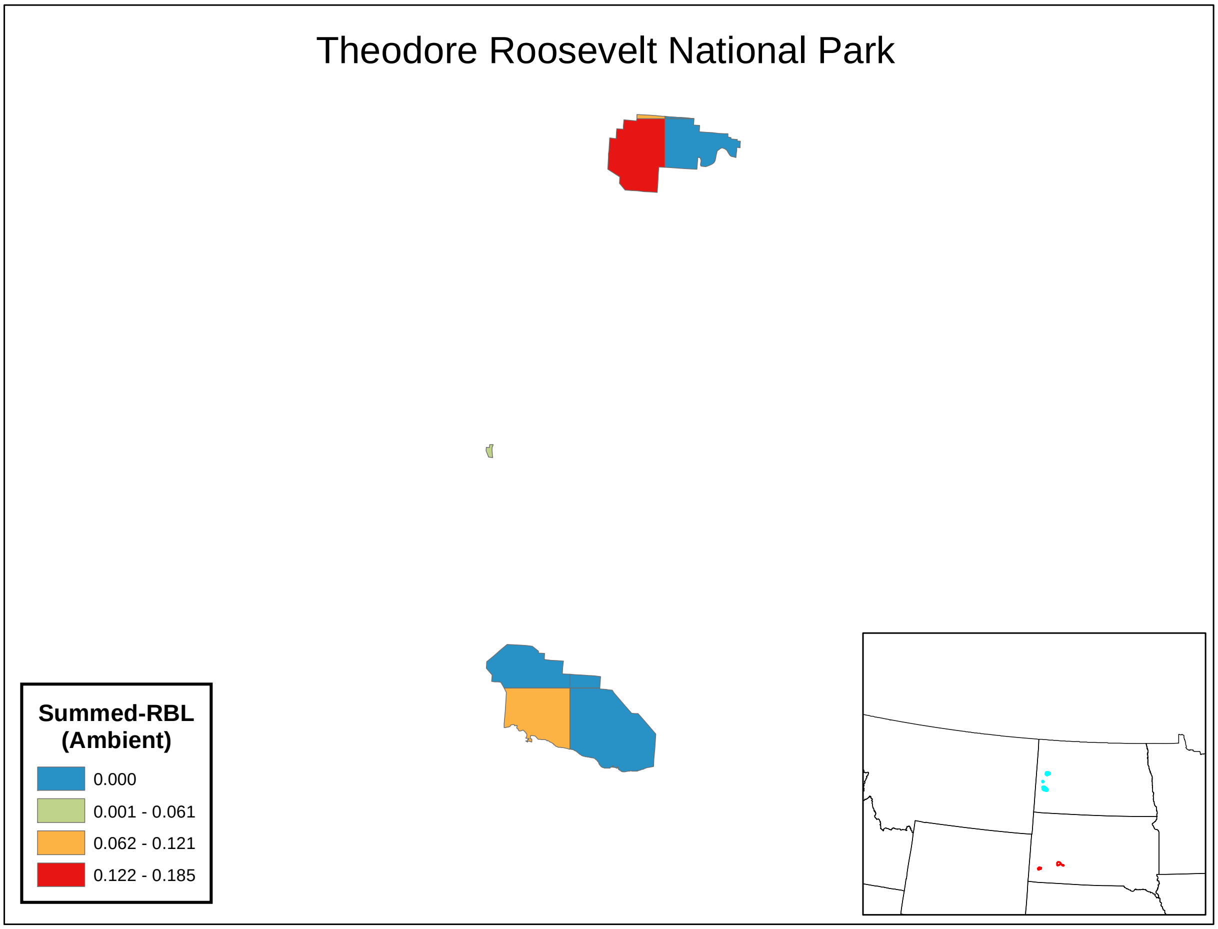
Swanquarter Wilderness
Summed-RBL
(Current Standard)
0.001 - 0.002
0.003
0.004

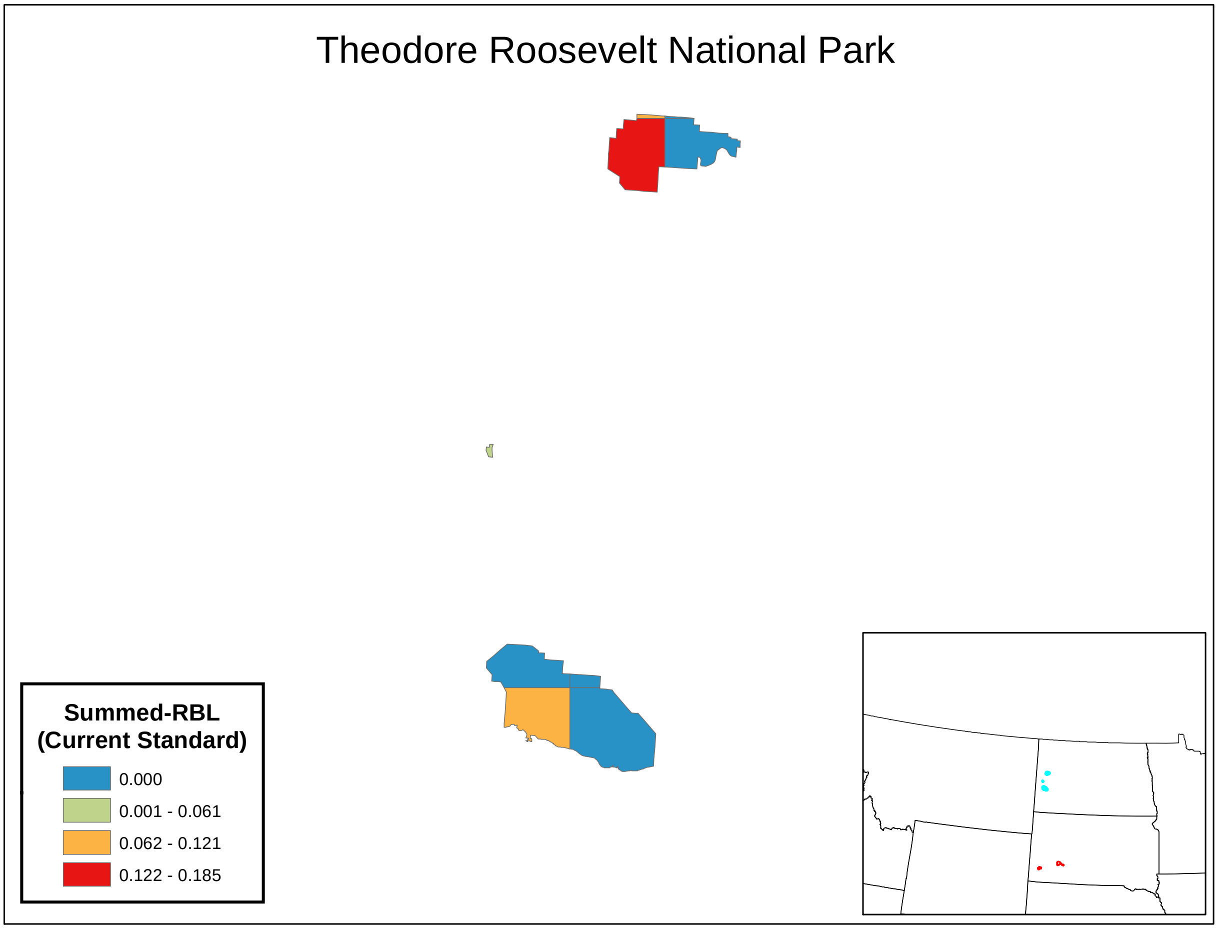
1



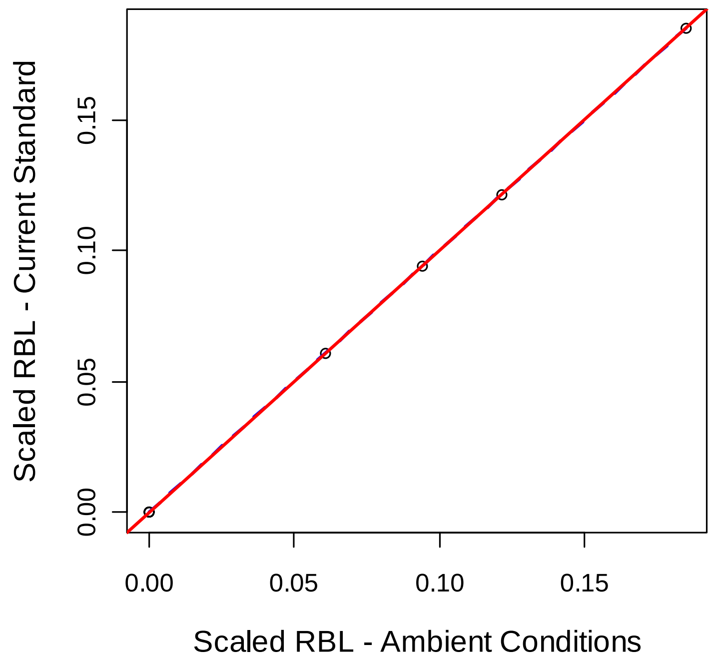
Linear Model Results	Current Standard	Alt A	Alt B
N	4		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.949		
Mean W126 (Ambient = 14.55)	14.00		

THEODORE ROOSEVELT NATIONAL PARK



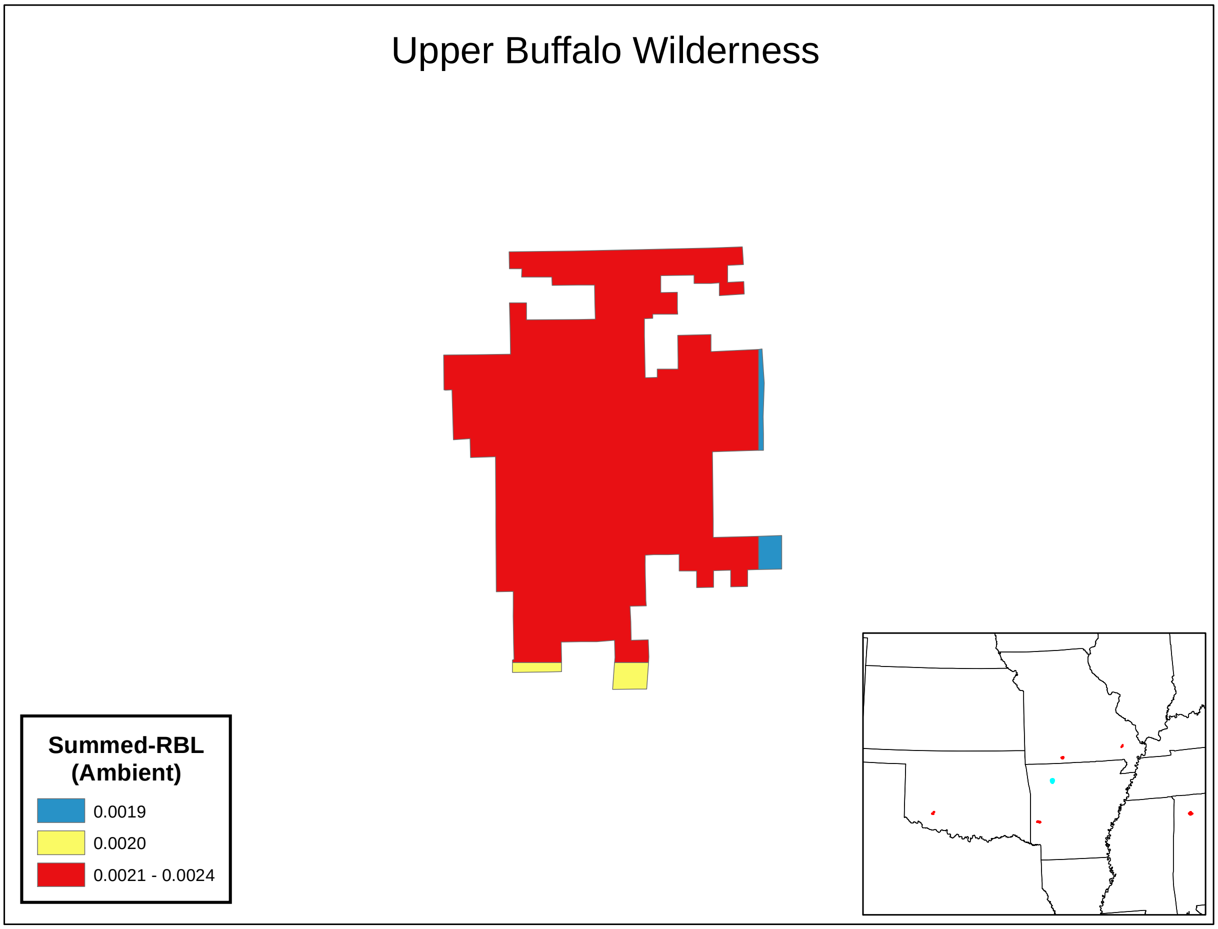

Theodore Roosevelt National Park
Summed-RBL
(Current Standard)
0.000
0.001 - 0.061
0.062 - 0.121
0.122 - 0.185

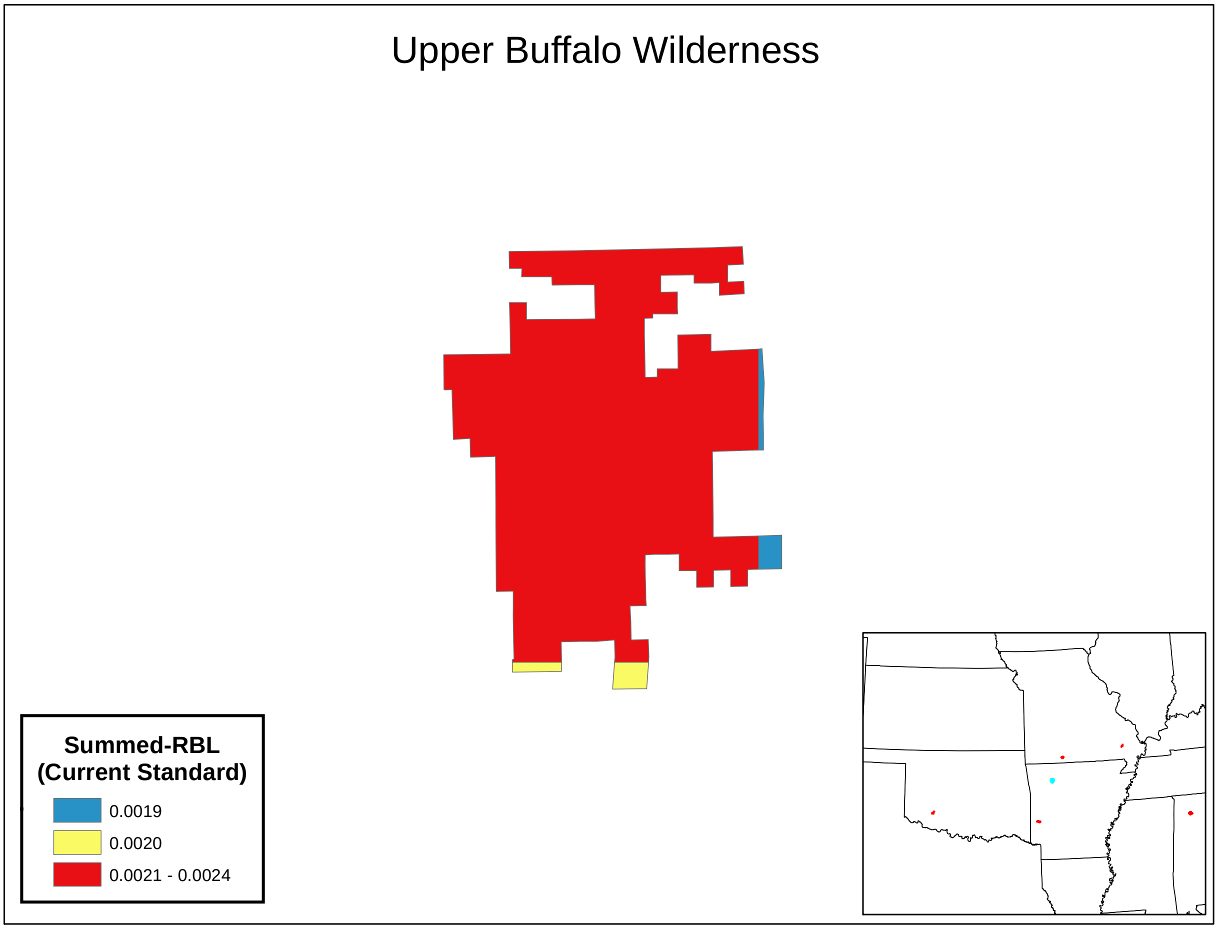
1

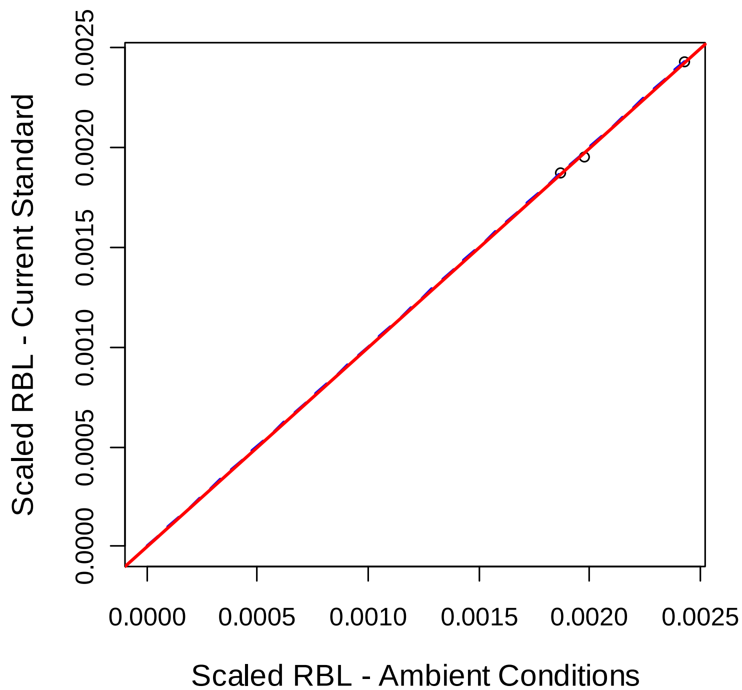


Linear Model Results	Current Standard	Alt A	Alt B
N	9		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.00		
Mean W126 (Ambient = 6.78)	6.78		

UPPER BUFFALO WILDERNESS

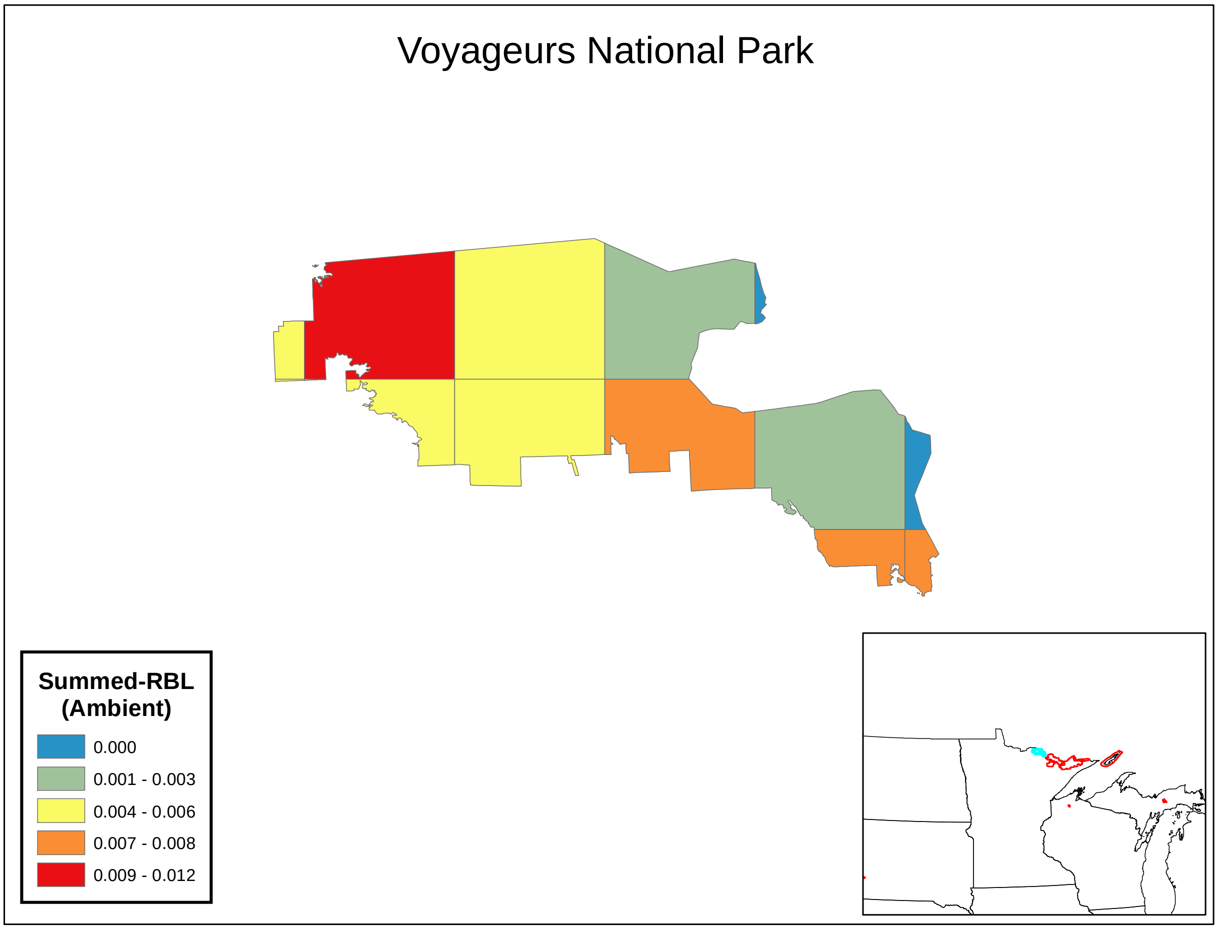


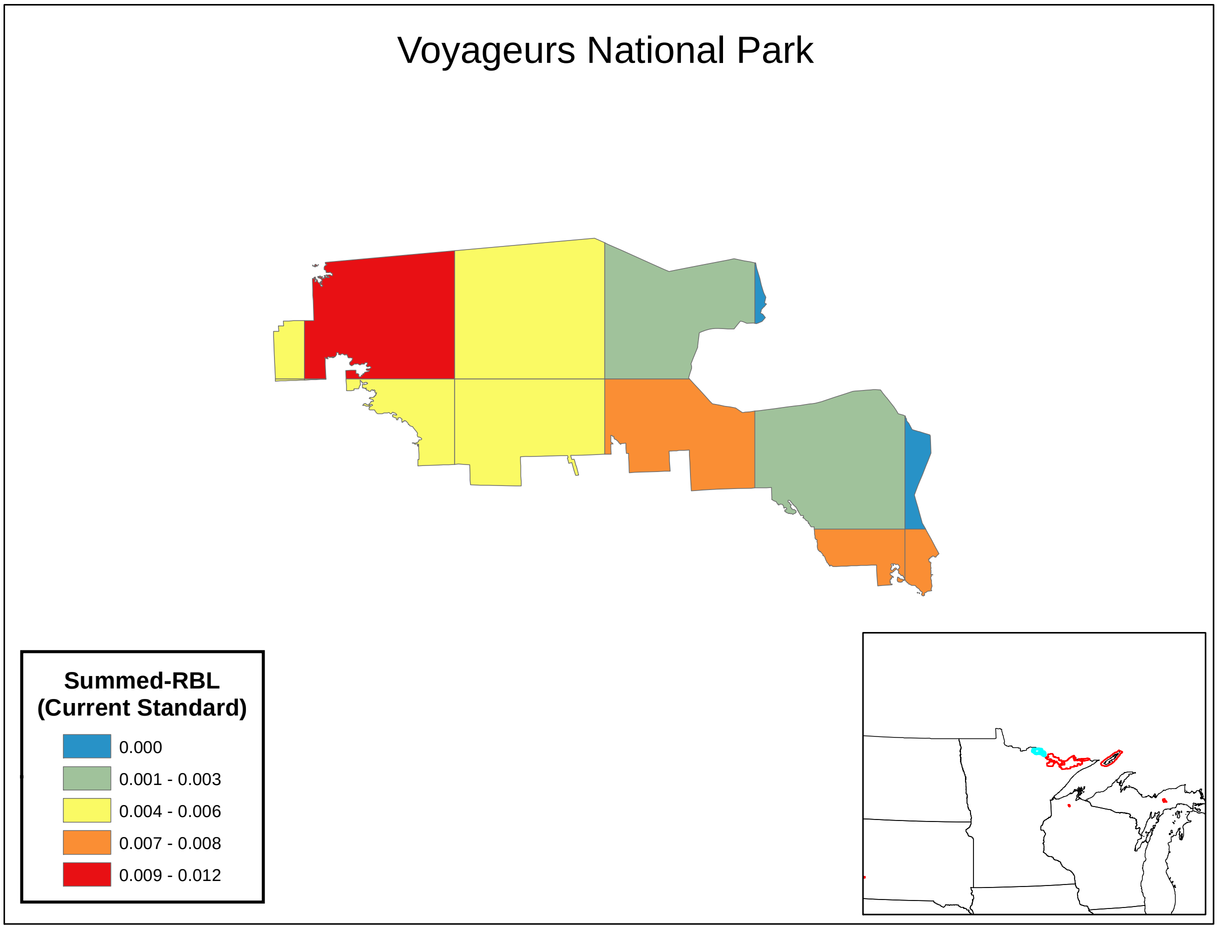

Upper Buffalo Wilderness
Summed-RBL
(Current Standard)
0.0019
0.0020
0.0021 - 0.0024



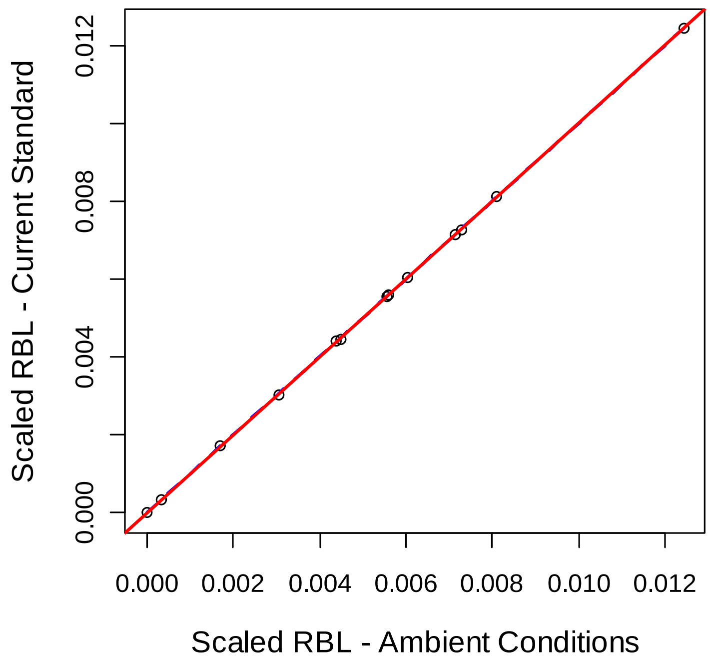
Linear Model Results	Current Standard	Alt A	Alt B
N	3		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.997		
Mean W126 (Ambient = 7.17)	7.14		

VOYAGEURS NATIONAL PARK



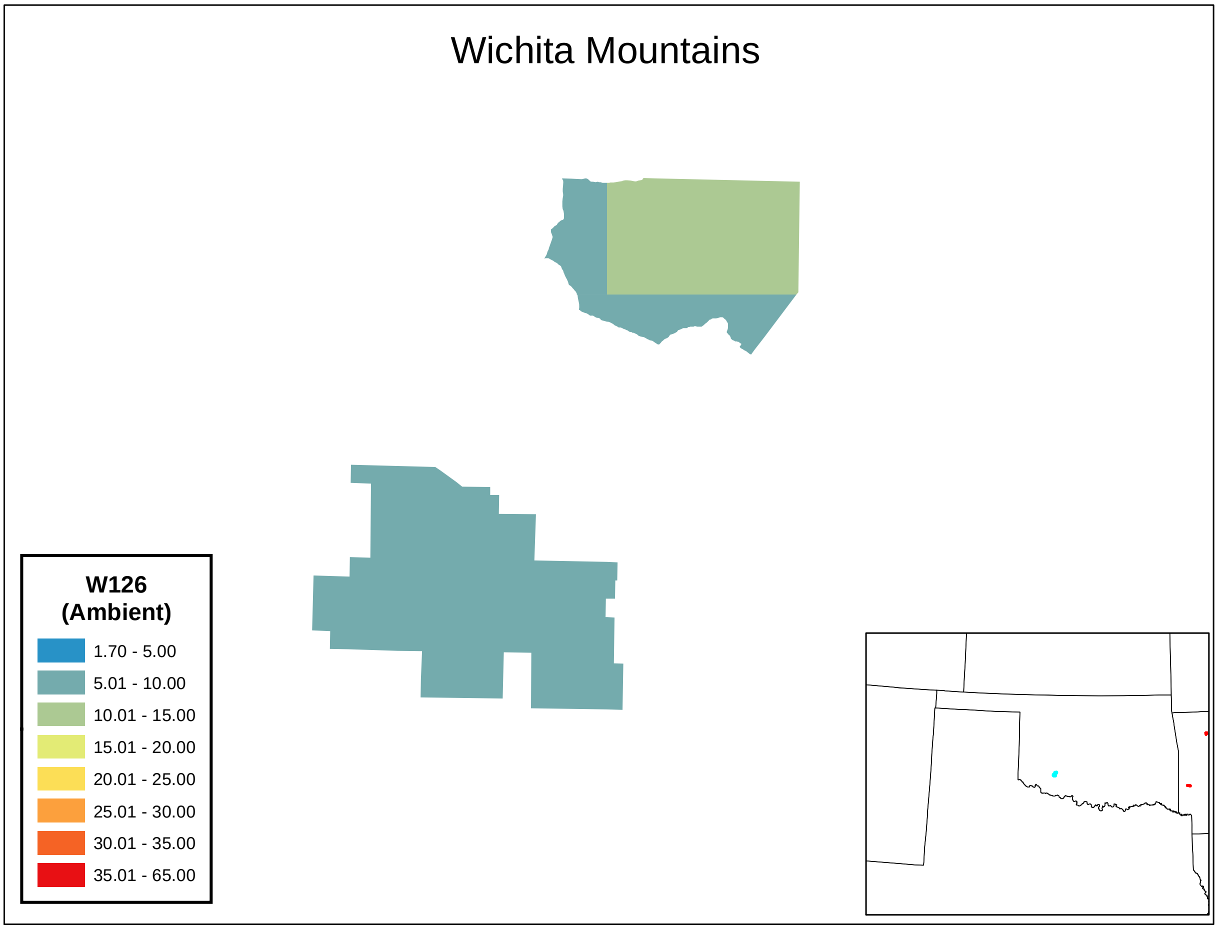

Voyageurs National Park
Summed-RBL
(Current Standard)
0.000
0.001 - 0.003
0.004 - 0.006
0.007 - 0.008
0.009 - 0.012

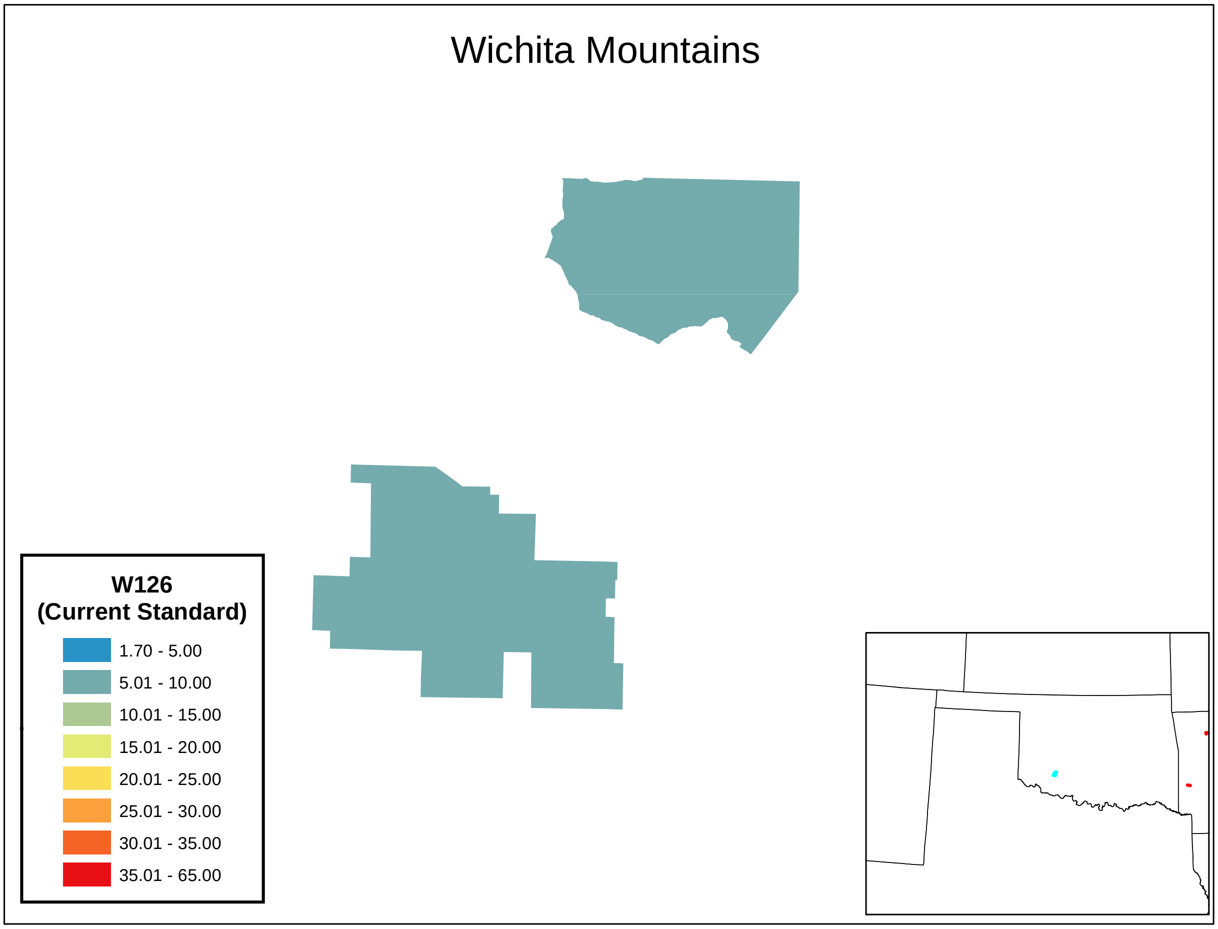
1



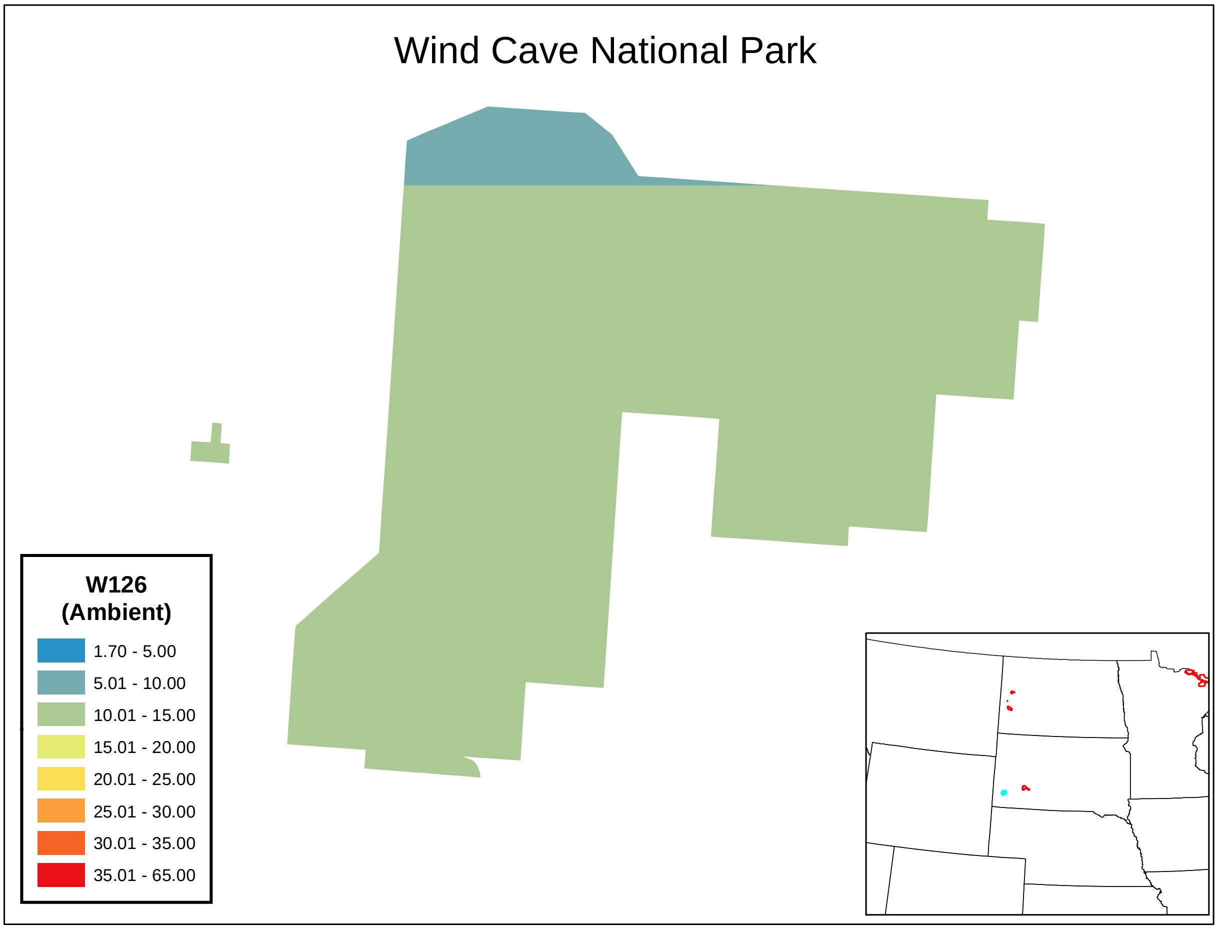
Linear Model Results	**Current Standard**	**Alt A**	**Alt B**
N	13		
r-squared	1.000		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	1.000		
Mean W126 (Ambient = 5.08)	5.08		

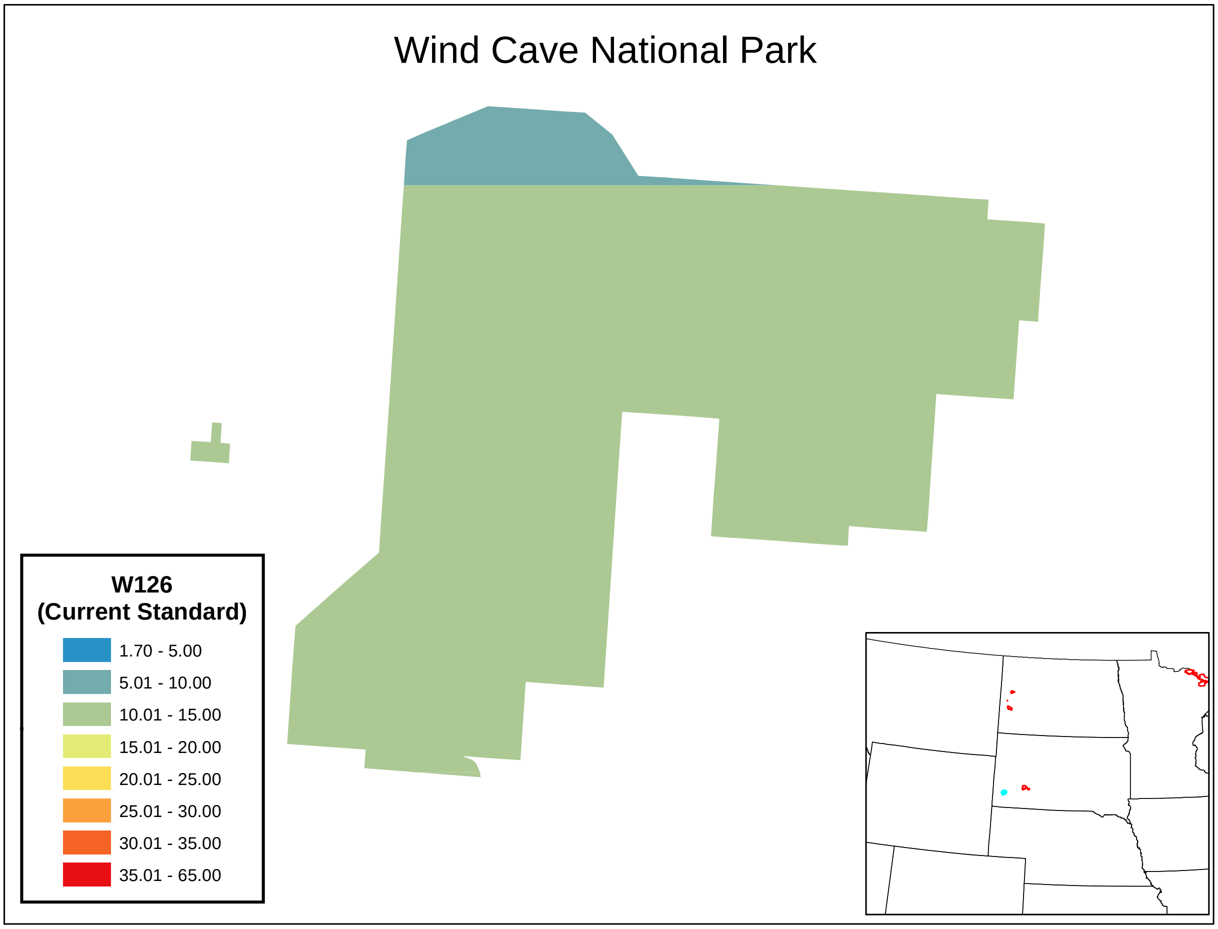
WICHITA MOUNTAINS



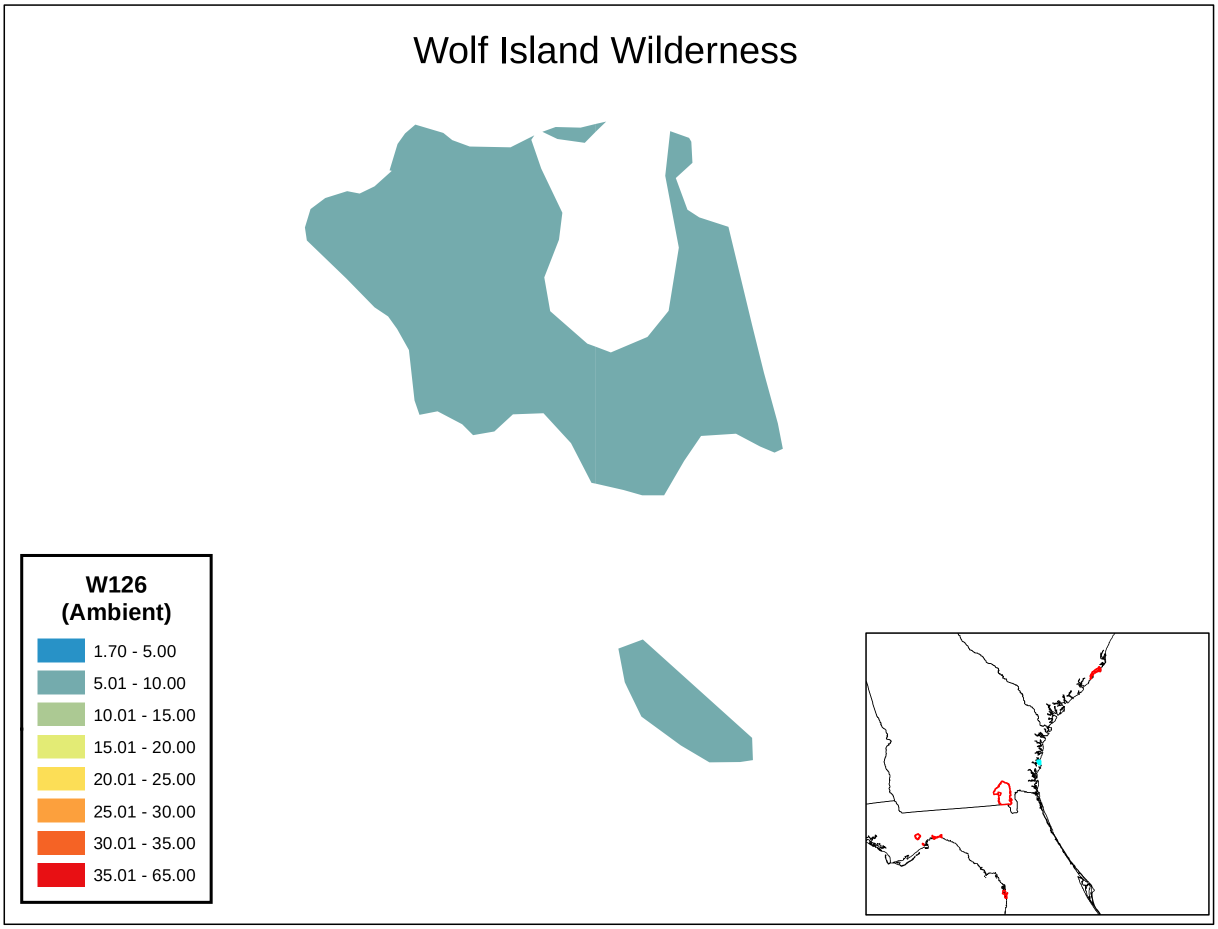

Wichita Mountains
W126
(Current Standard)
1.70 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 - 35.00
35.01 - 65.00

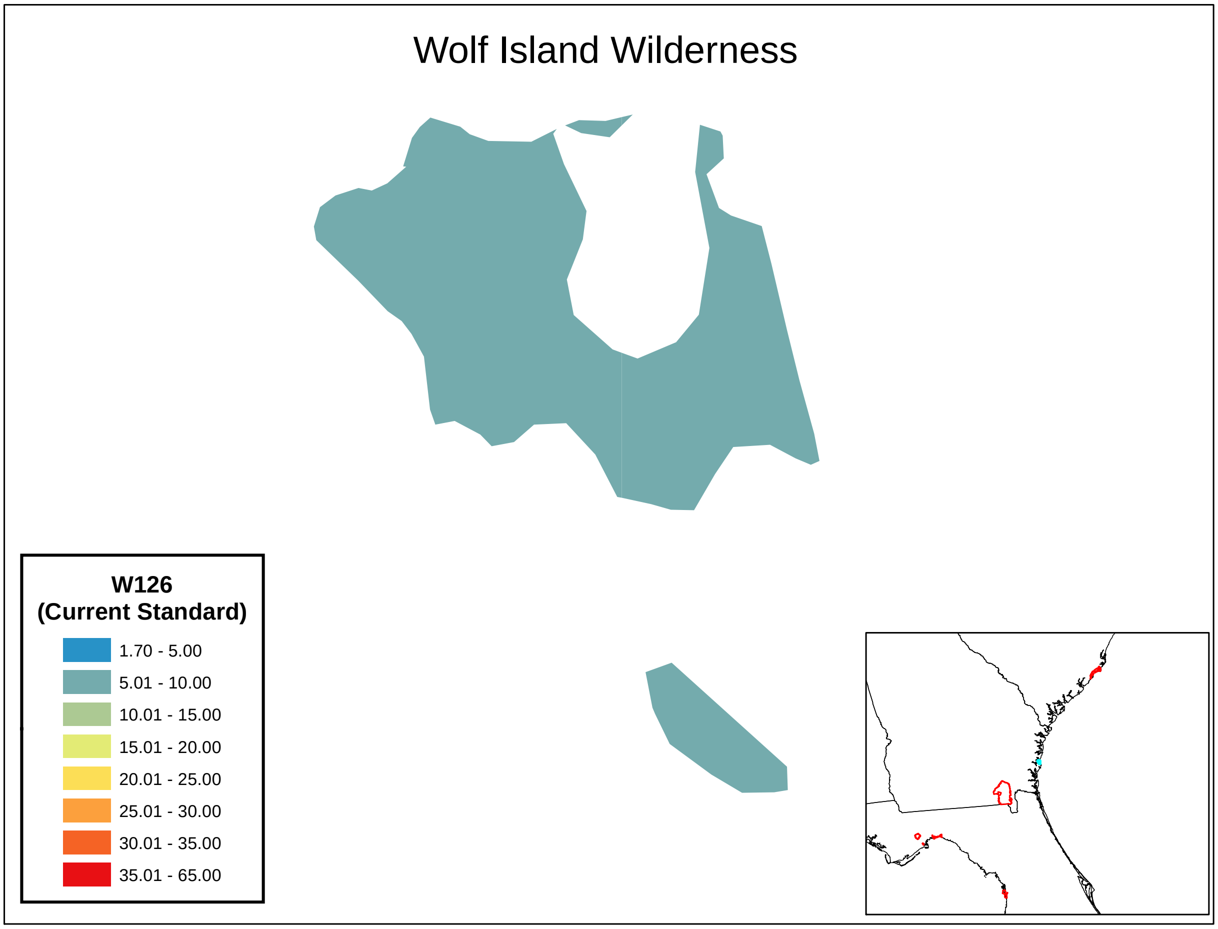
WIND CAVE NATIONAL PARK




Wind Cave National Park
W126
(Current Standard)
1.70 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 - 35.00
35.01 - 65.00

WOLF ISLAND WILDERNESS




Wolf Island Wilderness
W126
(Current Standard)
1.70 - 5.00
5.01 - 10.00
10.01 - 15.00
15.01 - 20.00
20.01 - 25.00
25.01 - 30.00
30.01 - 35.00
35.01 - 65.00

1

APPENDIX 5C: MAPS OF RELATIVE BIOMASS LOSS FOR CRITICAL HABITAT AREAS

This appendix presents the maps and analyses for the 55 Critical Habitat areas analyzed in Chapter 5 of this report. Maps of the summed Relative Biomass Loss (RBL) for the 7 eastern tree species (excluding eastern cottonwood) are presented for each area under recent ambient conditions and current standard scenarios. The results of the linear model analyses are included for each area, when applicable. This includes the test statistics (p-values) for significant differences from zero and goodness of fit metrics, however it is important to note that because the linear model was forced through the origin, the r-squared values cannot be interpreted in the standard manner, however, they may still provide useful information about overall fit. In areas where none of the 7 eastern tree species with RBL data available occurred, a map of the ambient W126 is included.

[For the 2nd Draft REA, this appendix will have summaries for all 54 Critical Habitat areas analyzed in the First draft REA. Of those areas, 26 had tree species present that could be analyzed for changes in summed-RBL and were included in the combined analysis described in Chapter 5. This appendix will follow the same format as Appendix 5B.]

GULF STURGEON (*ACIPER OXYRINCHUS DESOTOI*) CRITICAL HABITAT AREA

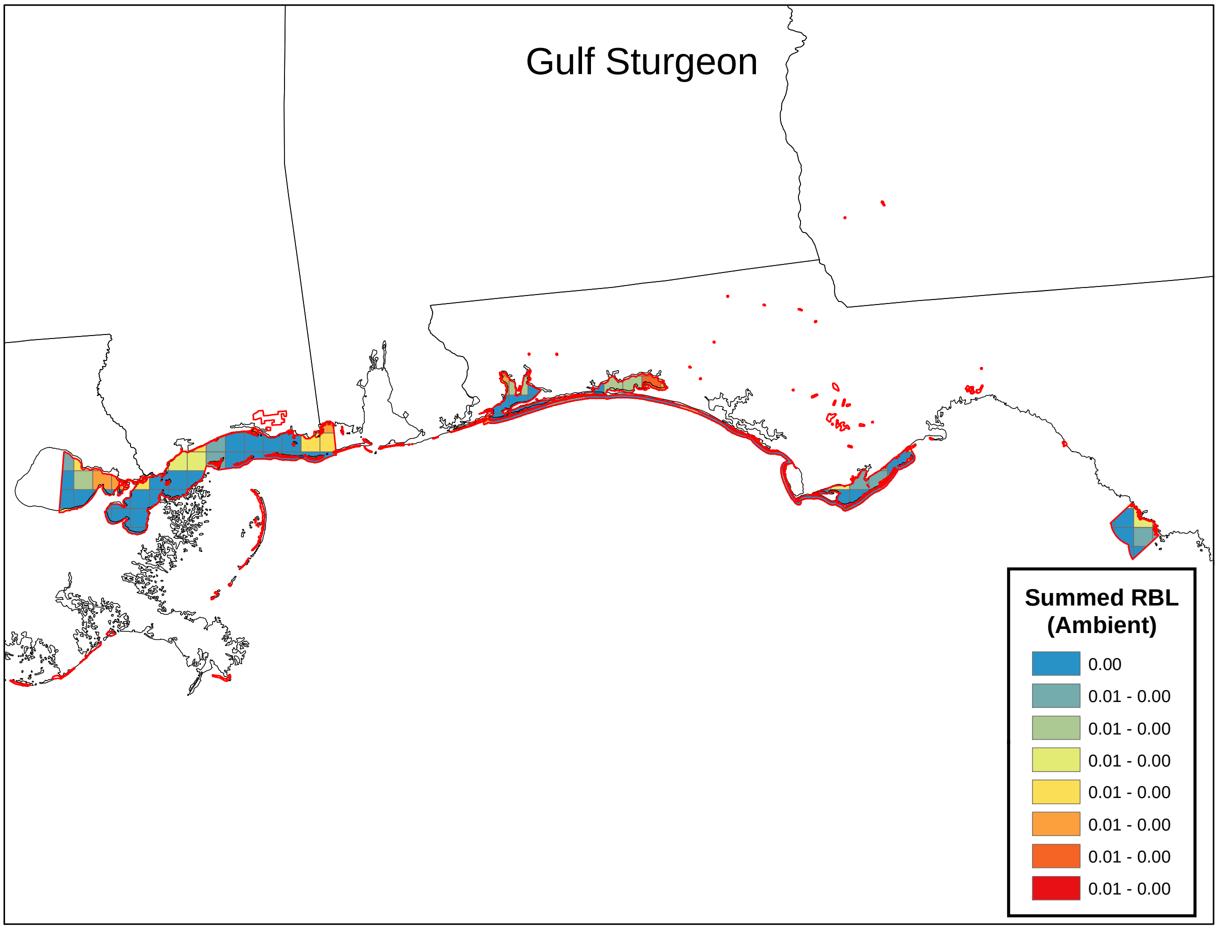


Figure 5C- 1 Summed Relative Biomass Loss (RBL) in the Designated Critical Habitat area for Gulf Sturgeon

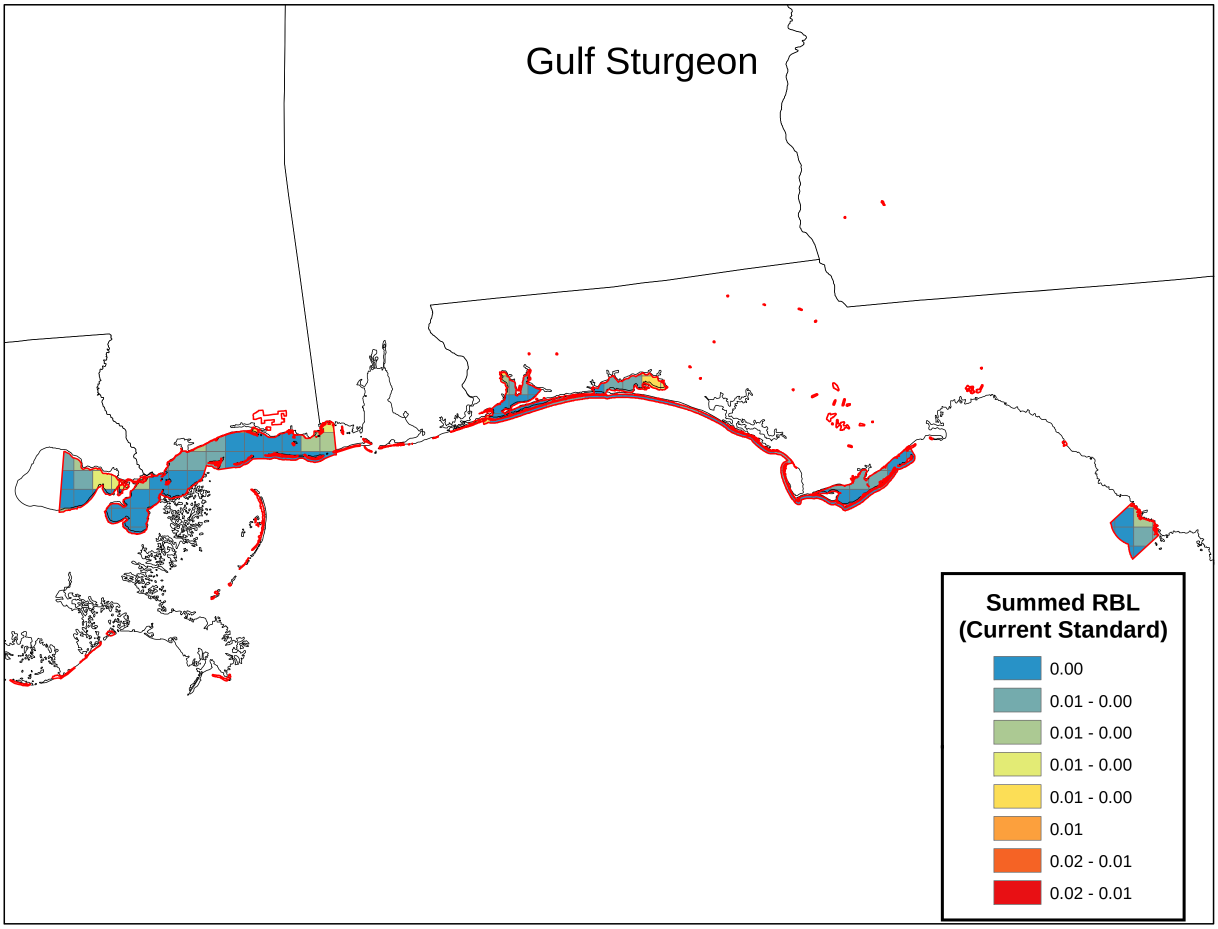


Figure 5C- 2 Scaled RBL in Acadia National Park under the Current Standard rollback scenario

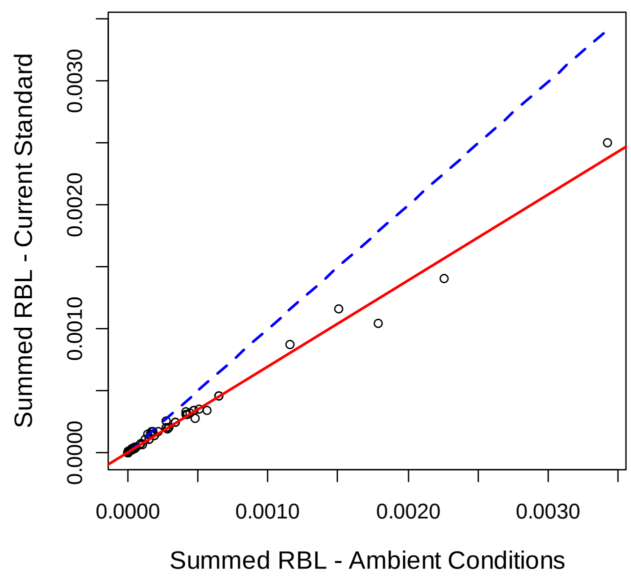


Figure 5C- 3 Linear Model Fit of summed RBL under the Current Standard scenario compared to summed RBL at ambient conditions for the Gulf Sturgeon Critical Habitat Area

Figure 5C- 4 Summary of Linear Model Results for the Gulf Sturgeon Critical Habitat Area

Linear Model Results	Current Standard	Alt A	Alt B
N	116		
r-squared	0.9909		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.695		
Mean W126 (Ambient)	14.69		
Mean summed RBL (Ambient)	0.0002		

APPALACHIAN ELKTOE (*ALASMIDONTA RAVENELIANA*) CRITICAL HABITAT AREA

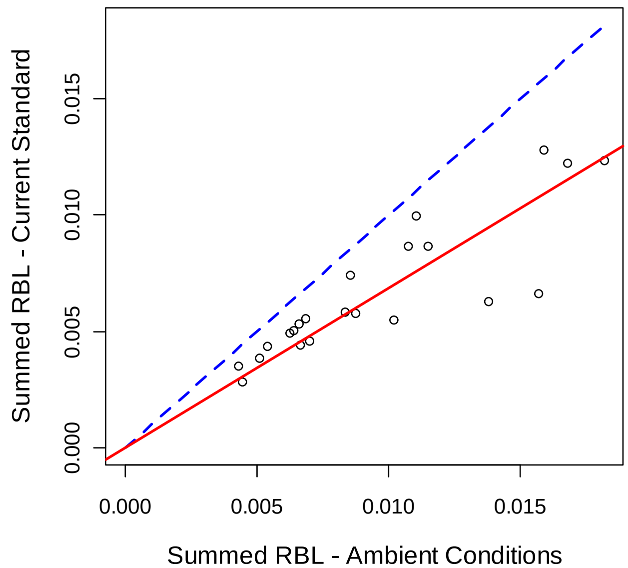


Figure 5C- 5 Summed Relative Biomass Loss (RBL) in the for the Appalachian Elktoe Critical Habitat Area

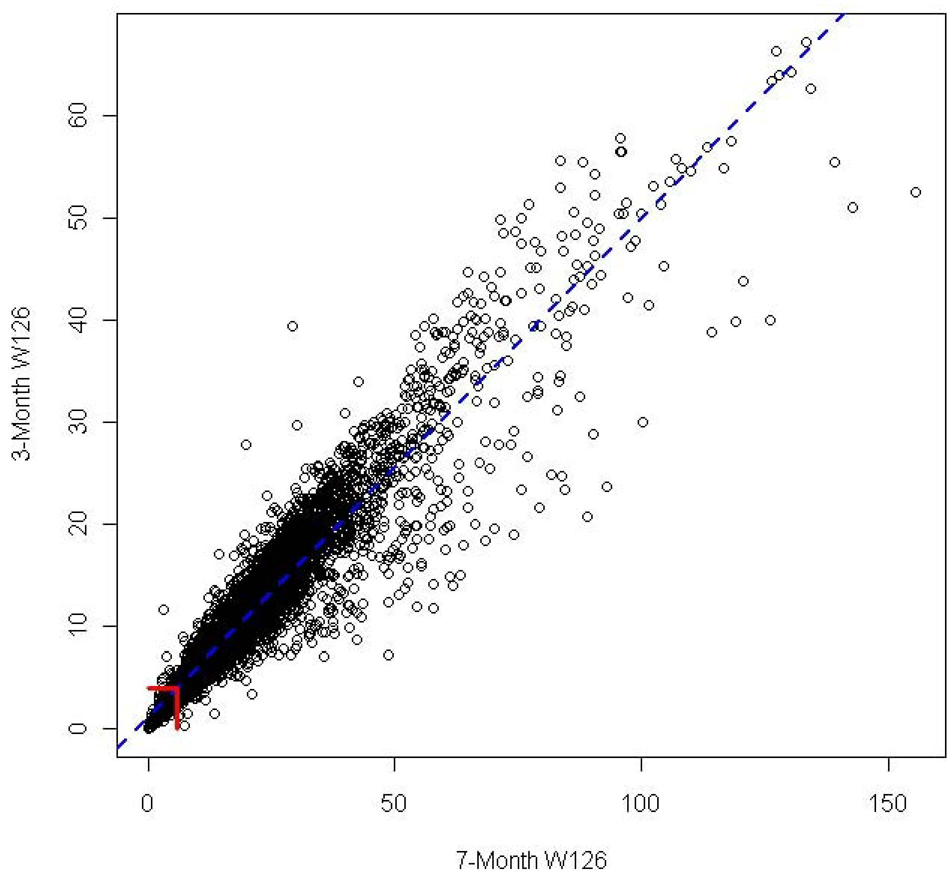
Table 5C- 1 Summary of Linear Model Results for the Appalachian Elktoe Critical Habitat Area

Linear Model Results	Current Standard	Alt A	Alt B
N	22		
r-squared	0.9571		
p-value	<0.0001		
Slope (proportion of Ambient RBL)	0.685		
Mean W126 (Ambient)	11.7		
Mean summed RBL (Ambient)	0.009		

APPENDIX 5D: INPUTS TO THE VISIBILE FOLIAR INJURY RISK ASSESSMENT

This appendix presents the O_3 exposure and soil moisture data used in the assessment of visible foliar injury risk in national parks (Section 5.3.2). In Figure 5D-1, we provide a plot of the relationship between the 3-month and 7-month W126 metrics. Using the slope of this curve, we determined that an O_3 concentration of 5.9 ppm-hrs using the 7-month W126 is equivalent to 4.1 ppm-hrs using the 3-month W126.

In Table 5D-1, we provide the results of the Kohut (2007) assessment and the updated assessment as well as whether the risk criteria were met for each of the 37 park included in this assessment. For the O_3exposure data, we provide seven metrics calculated for each park using 2006 to 2010 monitoring data: SUM06, W126 (3-month and 7-month), N100 (3-month and 7-month), N80 (3-month), and N60 (3-month). We also provide the Palmer Z soil moisture data for April through October for years 2006 to 2010.



3-month W126 = 1.2172 + 7-month W126 * .488515

Figure 5D-1: Maximum 3-month 12-hr W126 plotted against the maximum 7-month 12-hr W126 using data O_3 monitoring data for the years 2006 to 2010.

Table 5D-1 Levels of foliar injury risk in 37 national parks including O_3 exposure data and soil moisture data

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Acadia National Park	Kohut	Moderate	monitored	Sum06	2	1	1	1	1	Apr	-1.69	6.06	0.43	1.97	-3.16
	Updated	Moderate	monitored	W126 (3mo)	10.7	7.9	7.8	7.1	5.3	May	4.93	-0.47	-1.97	0.83	-2.15
	SUM06	not met		N100 (3mo)	2	5	0	0	1	Jun	7.38	-0.11	-0.36	6.40	2.16
	W126/N100 (3mo)	not met		N80 (3mo)	21	28	7	7	13	Jul	3.47	0.74	0.87	5.98	2.03
	W126/N100 (7mo)	met (1 year)		N60 (3mo)	182	116	113	60	48	Aug	0.79	0.18	3.54	3.99	0.17
	Indicator species	present		W126 (7mo)	25.6	27.3	22.1	15.3	16.8	Sep	0.12	-0.42	8.66	-0.71	0.90
	Soil moisture	no relation		N100 (7mo)	3	6	0	0	1	Oct	5.39	1.53	0.37	3.35	3.99
Badlands National Park	Kohut	Low	kriged	Sum06	2	0	0	0	0	Apr	0.42	-0.91	-1.03	3.89	3.36
	Updated	Low	monitored	W126 (3mo)	16.7	8.1	2.2	2.5	3.9	May	-2.31	-0.71	4.89	-1.58	3.91
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-3.80	-2.99	2.30	1.82	2.81
	W126/N100 (3mo)	not met		N80 (3mo)	0	0	0	0	0	Jul	-3.46	-4.31	2.80	3.26	2.75
	W126/N100 (7mo)	not met		N60 (3mo)	341	114	0	0	0	Aug	-0.13	1.52	0.46	3.46	1.67
	Indicator species	present		W126 (7mo)	29.3	16.0	5.2	6.0	8.9	Sep	2.95	-1.36	0.68	0.00	0.76
	Soil moisture	inverse		N100 (7mo)	0	0	0	0	0	Oct	-0.41	1.03	1.30	6.96	0.07
Big Bend National Park	Kohut	Low	monitored	Sum06	1	1	0	0	0	Apr	-2.00	2.04	-1.80	-1.20	2.13
	Updated	Low	monitored	W126 (3mo)	11.7	10.6	10.6	8.6	8.5	May	-3.41	3.54	-2.00	0.04	-1.40
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.59	2.10	-1.51	2.50	0.01
	W126/N100 (3mo)	not met		N80 (3mo)	0	0	0	0	0	Jul	-0.89	2.38	2.94	-0.08	5.99
	W126/N100 (7mo)	not met		N60 (3mo)	179	161	124	74	80	Aug	5.62	0.14	2.04	-1.05	-0.25
	Indicator species	present		W126 (7mo)	25.3	25.0	23.7	20.0	21.1	Sep	-0.23	-0.45	2.54	-1.22	-1.14
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	-0.19	-2.52	-0.48	-0.31	-2.70
Blue Ridge Parkway	Kohut	Low	kriged	Sum06	1	1	1	0	1	Apr	-0.20	-1.49	-1.02	-0.42	-1.47
	Updated	Low	monitored	W126 (3mo)	10.0	11.5	8.8	4.7	8.2	May	-1.37	-2.96	-1.57	4.04	0.00
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	0.98	-0.94	-2.69	0.21	-0.72
	W126/N100 (3mo)	not met		N80 (3mo)	0	3	4	0	1	Jul	-1.12	-0.93	-1.92	-0.84	-2.01
	W126/N100 (7mo)	not met		N60 (3mo)	156	195	118	42	145	Aug	-0.17	-3.27	0.36	0.23	-1.27
	Indicator species	present		W126 (7mo)	15.3	19.6	16.5	7.4	15.9	Sep	3.47	-2.20	-1.54	5.28	0.03
	Soil moisture	inverse		N100 (7mo)	0	0	0	0	0	Oct	0.81	-1.16	-1.31	1.75	-0.29

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Canyonlands National Park	Kohut	Low	monitored	Sum06	2	2	2	1	1	Apr	-1.67	0.03	-0.60	-1.30	0.01
	Updated	Low	monitored	W126 (3mo)	18.0	17.0	17.1	12.2	13.2	May	-3.74	0.18	0.97	0.77	0.54
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.68	-1.09	1.21	-0.05	1.73
	W126/N100 (3mo)	not met		N80 (3mo)	0	1	0	0	0	Jul	-1.29	-0.85	-1.08	-2.54	0.54
	W126/N100 (7mo)	not met		N60 (3mo)	364	301	340	136	201	Aug	0.01	0.38	-0.26	-3.23	2.05
	Indicator species	present		W126 (7mo)	50.2	51.2	50.5	40.9	39.5	Sep	1.35	1.14	-1.78	-1.18	-1.17
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	8.18	-1.36	-1.55	-1.09	1.80
Cape Cod National Seashore	Kohut	High	monitored	Sum06	3	3	2	1	1	Apr	-1.93	4.63	-0.26	1.10	-2.96
	Updated	Moderate	monitored	W126 (3mo)	13.5	13.2	12.9	5.3	7.0	May	7.91	-0.23	-0.70	-0.38	-1.23
	SUM06	not met		N100 (3mo)	7	3	5	0	1	Jun	7.90	-1.17	-0.61	1.78	-1.06
	W126/N100 (3mo)	met (1 year)		N80 (3mo)	46	55	24	9	12	Jul	0.31	0.59	2.79	6.05	-0.88
	W126/N100 (7mo)	met (1 year)		N60 (3mo)	249	203	200	62	103	Aug	-0.04	-2.83	-0.09	1.73	1.21
	Indicator species	present		W126 (7mo)	33.1	27.6	25.9	14.5	17.2	Sep	-0.96	-1.87	4.96	0.56	-1.23
	Soil moisture	no relation		N100 (7mo)	11	3	5	0	1	Oct	1.06	-1.98	-0.39	4.69	1.30
Carlsbad Caverns National Park	Kohut	Low	kriged	Sum06	-	0	2	-	0	Apr	-1.57	1.66	-1.78	-1.56	2.10
	Updated	Low	monitored	W126 (3mo)	-	7.9	14.3	-	7.1	May	-3.11	3.84	-0.88	-1.75	-0.90
	SUM06	not met		N100 (3mo)	-	0	0	-	0	Jun	-1.21	-0.03	-2.41	0.11	0.85
	W126/N100 (3mo)	not met		N80 (3mo)	-	0	3	-	0	Jul	-0.85	0.70	2.72	2.85	5.74
	W126/N100 (7mo)	not met		N60 (3mo)	-	91	265	-	63	Aug	4.37	-1.41	0.28	-3.09	-0.62
	Indicator species	present		W126 (7mo)	-	13.8	31.7	-	14.0	Sep	2.64	0.38	-0.54	-1.31	-0.31
	Soil moisture	no relation		N100 (7mo)	-	0	0	-	0	Oct	1.06	-2.52	0.63	-0.11	-1.56
Colorado National Monument	Kohut	Low	kriged	Sum06	-	1	1	0	0	Apr	-1.95	-0.87	-0.11	0.21	0.72
	Updated	Low	monitored	W126 (3mo)	-	11.6	15.1	4.1	8.6	May	-2.39	0.23	0.95	1.01	-0.19
	SUM06	not met		N100 (3mo)	-	0	0	0	0	Jun	-2.44	-1.18	-0.35	2.56	-0.10
	W126/N100 (3mo)	not met		N80 (3mo)	-	0	0	0	0	Jul	0.24	-0.50	-0.64	-0.07	-0.57
	W126/N100 (7mo)	not met		N60 (3mo)	-	182	282	13	98	Aug	0.35	-0.22	-0.98	-2.19	1.35
	Indicator species	present		W126 (7mo)	-	15.4	29.0	9.3	19.4	Sep	2.41	2.22	-0.47	-1.18	-1.57
	Soil moisture	no relation		N100 (7mo)	-	0	0	0	0	Oct	4.66	-0.39	-1.65	0.03	0.83

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Congaree Swamp National Monument	Kohut	Low	monitored	Sum06	2	1	1	0	1	Apr	-1.88	-0.02	0.38	-0.21	-2.15
	Updated	Low	monitored	W126 (3mo)	12.3	10.8	9.5	4.0	6.4	May	-1.14	-2.32	0.13	2.28	-1.35
	SUM06	not met		N100 (3mo)	0	2	0	0	0	Jun	3.05	1.06	-1.81	0.41	-1.04
	W126/N100 (3mo)	not met		N80 (3mo)	8	5	7	0	0	Jul	-1.91	-1.43	-0.83	-0.16	-0.42
	W126/N100 (7mo)	not met		N60 (3mo)	227	193	157	36	103	Aug	-0.02	-3.06	2.56	-1.87	0.20
	Indicator species	present		W126 (7mo)	17.9	16.9	12.7	4.7	8.1	Sep	0.09	-2.89	0.06	-2.39	-1.61
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	0.31	-1.14	1.77	2.29	-1.18
Cowpens National Battlefield	Kohut	High	monitored	Sum06	2	1	3	0	1	Apr	-1.65	-1.22	-0.35	-0.31	-1.92
	Updated	Low	monitored	W126 (3mo)	14.4	7.9	16.1	3.2	8.9	May	-1.83	-1.82	-1.55	1.72	0.18
	SUM06	not met		N100 (3mo)	2	0	2	0	0	Jun	2.15	-1.19	-3.60	0.39	-0.46
	W126/N100 (3mo)	not met		N80 (3mo)	24	3	26	0	5	Jul	-1.93	-1.88	-2.66	-1.76	-2.12
	W126/N100 (7mo)	not met		N60 (3mo)	253	125	297	17	157	Aug	0.40	-4.22	0.41	-1.98	-1.37
	Indicator species	present		W126 (7mo)	27.3	16.9	28.1	5.4	22.3	Sep	0.27	-2.94	-2.23	0.28	-1.21
	Soil moisture	no relation		N100 (7mo)	2	0	0	0	0	Oct	0.60	-2.15	-0.62	1.87	-1.92
Craters of the Moon National Historic Place	Kohut	Low	monitored	Sum06	-	0	1	0	0	Apr	3.08	-0.23	-1.11	1.11	1.97
	Updated	Low	monitored	W126 (3mo)	-	10.2	10.9	5.7	7.9	May	-0.36	-3.67	-0.15	-0.79	0.92
	SUM06	not met		N100 (3mo)	-	0	0	0	0	Jun	0.38	-2.47	-2.24	7.57	-0.13
	W126/N100 (3mo)	not met		N80 (3mo)	-	1	2	0	0	Jul	-0.19	-3.92	-2.48	2.67	-1.06
	W126/N100 (7mo)	not met		N60 (3mo)	-	112	153	14	64	Aug	-1.43	-2.24	-2.39	1.07	-0.28
	Indicator species	present		W126 (7mo)	-	18.1	26.7	14.5	0.0	Sep	0.75	0.76	-1.42	-0.71	-1.52
	Soil moisture	no relation		N100 (7mo)	-	0	0	0	0	Oct	2.06	2.76	-0.23	1.72	0.14
Cumberland Gap National Historic Place	Kohut	High	kriged	Sum06	-	3	1	0	1	Apr	0.80	0.53	0.94	0.53	-1.71
	Updated	Low	monitored	W126 (3mo)	-	18.4	10.1	3.6	7.3	May	-0.34	-2.39	0.21	3.38	2.59
	SUM06	not met		N100 (3mo)	-	0	0	0	0	Jun	1.01	-2.17	-0.57	2.57	0.54
	W126/N100 (3mo)	not met		N80 (3mo)	-	12	1	0	0	Jul	-0.60	0.46	-0.08	2.37	0.99
	W126/N100 (7mo)	not met		N60 (3mo)	-	348	159	8	97	Aug	1.06	-3.58	-1.34	0.26	0.96
	Indicator species	present		W126 (7mo)	-	68.5	28.4	11.4	26.5	Sep	5.35	-2.52	-3.35	2.69	-0.57
	Soil moisture	no relation		N100 (7mo)	-	0	0	0	0	Oct	4.09	-0.38	-1.73	2.43	-0.64

(cont.)

Park Name	Risk Overview			O$_3$ Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O$_3$ Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Death Valley National Park	Kohut	Low	monitored	Sum06	5	7	4	2	1	Apr	-0.49	-2.36	-1.78	-2.32	0.06
	Updated	Low	monitored	W126 (3mo)	29.2	32.5	25.5	15.3	12.8	May	-2.68	-2.83	-0.79	-3.11	0.14
	SUM06	not met		N100 (3mo)	0	2	0	0	0	Jun	-2.35	-2.37	-1.23	-1.59	0.63
	W126/N100 (3mo)	not met		N80 (3mo)	40	68	29	6	1	Jul	-1.22	-1.12	-0.32	-1.52	-1.05
	W126/N100 (7mo)	not met		N60 (3mo)	648	650	545	281	202	Aug	-1.23	-1.07	-0.72	-1.53	-1.39
	Indicator species	present		W126 (7mo)	74.2	87.5	69.4	42.4	38.7	Sep	-0.74	0.83	-1.20	-1.46	-1.48
	Soil moisture	slight inverse		N100 (7mo)	0	2	0	0	0	Oct	-0.05	-1.08	-1.16	-0.28	1.81
Devils Tower National Monument	Kohut	Low	kriged	Sum06	-	-	1	0	0	Apr	-0.84	-1.96	-1.39	2.16	0.00
	Updated	Low	monitored	W126 (3mo)	-	-	7.1	5.4	5.4	May	-0.91	1.98	6.76	-1.71	3.45
	SUM06	not met		N100 (3mo)	-	-	0	0	0	Jun	-4.83	-1.58	2.52	0.64	1.12
	W126/N100 (3mo)	not met		N80 (3mo)	-	-	2	0	0	Jul	-5.50	-2.35	2.02	1.84	2.13
	W126/N100 (7mo)	not met		N60 (3mo)	-	-	101	45	38	Aug	-1.20	0.34	0.19	4.67	1.30
	Indicator species	present		W126 (7mo)	-	-	8.8	9.7	8.9	Sep	2.63	-2.39	0.65	-1.63	-1.55
	Soil moisture	no relation		N100 (7mo)	-	-	0	0	0	Oct	0.06	0.13	1.15	2.82	-1.21
Dinosaur National Monument	Kohut	Low	kriged	Sum06	-	0	1	0	1	Apr	-0.94	-2.44	0.03	0.52	0.45
	Updated	Low	monitored	W126 (3mo)	-	11.1	10.4	8.4	13.8	May	-2.67	-1.00	0.83	-1.00	-0.09
	SUM06	not met		N100 (3mo)	-	0	0	0	0	Jun	-2.14	-2.44	2.09	1.31	-0.11
	W126/N100 (3mo)	not met		N80 (3mo)	-	0	0	0	6	Jul	-1.19	-2.33	-0.16	-1.77	-0.97
	W126/N100 (7mo)	not met		N60 (3mo)	-	108	146	61	238	Aug	-0.68	-1.67	-0.89	-1.51	0.48
	Indicator species	present		W126 (7mo)	-	17.4	24.0	14.9	21.0	Sep	2.08	1.48	0.61	-0.39	-2.29
	Soil moisture	no relation		N100 (7mo)	-	0	0	0	0	Oct	5.81	-1.12	-1.12	-0.97	0.94
Glacier National Park	Kohut	Low	monitored	Sum06	0	0	0	0	0	Apr	-0.01	1.95	-0.32	2.24	1.84
	Updated	Low	monitored	W126 (3mo)	2.9	2.3	4.0	4.9	3.9	May	-0.88	1.48	3.63	-1.80	3.86
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-0.83	-1.63	1.55	-1.97	1.39
	W126/N100 (3mo)	not met		N80 (3mo)	0	0	0	0	0	Jul	-4.21	-3.87	-0.74	1.21	1.21
	W126/N100 (7mo)	not met		N60 (3mo)	0	0	0	22	15	Aug	-2.45	-2.72	-1.26	-0.24	2.28
	Indicator species	present		W126 (7mo)	6.5	4.7	5.3	5.5	4.3	Sep	0.17	1.24	1.38	-2.54	1.92
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	2.02	-0.27	-1.06	2.39	-1.84

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Grand Canyon National Park	Kohut	Low	monitored	Sum06	3	3	2	1	2	Apr	3.07	0.75	-0.17	-0.20	-1.77
	Updated	Low	monitored	W126 (3mo)	19.0	20.8	14.2	9.1	15.1	May	0.01	-2.85	-0.56	3.62	1.06
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	0.09	-1.00	-1.84	0.98	-1.26
	W126/N100 (3mo)	not met		N80 (3mo)	14	28	7	0	12	Jul	-1.12	0.26	0.06	2.15	-1.20
	W126/N100 (7mo)	not met		N60 (3mo)	358	437	254	126	292	Aug	0.97	-4.57	0.15	1.63	-0.21
	Indicator species	present		W126 (7mo)	59.2	56.8	45.3	33.8	40.8	Sep	3.66	-2.21	-1.94	5.29	0.39
	Soil moisture	slight inverse		N100 (7mo)	0	0	0	0	0	Oct	2.82	-1.72	-1.36	3.22	0.95
Great Basin National Park	Kohut	Low	monitored	Sum06	3	2	2	0	1	Apr	-0.89	-2.07	-1.41	-1.37	-0.28
	Updated	Low	monitored	W126 (3mo)	21.8	18.6	17.0	10.1	15.0	May	-3.65	-2.44	1.52	0.86	0.52
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.91	-3.37	0.71	-0.40	0.98
	W126/N100 (3mo)	not met		N80 (3mo)	2	0	0	0	0	Jul	1.33	0.64	1.23	-2.39	2.53
	W126/N100 (7mo)	not met		N60 (3mo)	501	394	319	96	261	Aug	1.37	0.20	0.97	-3.81	-0.05
	Indicator species	present		W126 (7mo)	59.2	56.8	45.3	33.8	40.8	Sep	0.23	-0.63	-1.17	-1.11	-1.52
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	2.09	-2.16	-1.36	-1.60	1.04
Great Smoky Mountains National Park	Kohut	High	monitored	Sum06	1	2	2	0	1	Apr	1.90	-0.90	-1.43	1.27	1.33
	Updated	Low	monitored	W126 (3mo)	15.6	15.9	17.0	10.1	11.4	May	-0.84	-3.20	-1.00	-1.64	1.57
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-0.31	-3.07	-1.72	4.24	-1.41
	W126/N100 (3mo)	not met		N80 (3mo)	0	9	0	0	2	Jul	0.50	-2.88	-2.03	0.32	-0.86
	W126/N100 (7mo)	not met		N60 (3mo)	264	275	342	110	161	Aug	-1.67	-2.09	-2.03	0.16	-1.80
	Indicator species	present		W126 (7mo)	74.1	88.9	57.7	32.6	63.3	Sep	-1.07	-0.44	-1.73	-1.20	-0.57
	Soil moisture	slight inverse		N100 (7mo)	0	1	0	0	0	Oct	0.79	0.17	-1.33	0.93	2.28
Indiana Dunes National Landmark	Kohut	High	monitored	Sum06	1	2	0	0	0	Apr	-0.72	1.27	-0.94	1.04	-1.22
	Updated	Low	monitored	W126 (3mo)	8.8	12.3	3.7	2.4	3.9	May	0.96	-2.46	0.28	0.27	1.02
	SUM06	not met		N100 (3mo)	0	2	0	0	0	Jun	-1.91	-1.62	0.17	0.10	3.74
	W126/N100 (3mo)	not met		N80 (3mo)	6	34	1	0	6	Jul	3.43	1.57	-0.15	0.10	1.78
	W126/N100 (7mo)	not met		N60 (3mo)	144	201	41	14	50	Aug	3.25	5.79	0.93	0.98	-1.28
	Indicator species	present		W126 (7mo)	13.0	20.3	7.1	5.3	6.7	Sep	1.18	-1.58	6.63	-2.18	-0.64
	Soil moisture	no relation		N100 (7mo)	0	2	0	0	0	Oct	2.88	0.60	1.25	4.67	-2.31

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Joshua Tree National Park	Kohut	High	monitored	Sum06	16	15	15	10	11	Apr	-0.49	-2.36	-1.78	-2.32	0.06
	Updated	High	monitored	W126 (3mo)	55.5	52.5	51.1	40.0	43.8	May	-2.68	-2.83	-0.79	-3.11	0.14
	SUM06	met (all years)		N100 (3mo)	62	72	51	17	16	Jun	-2.35	-2.37	-1.23	-1.59	0.63
	W126/N100 (3mo)	met (all years)		N80 (3mo)	307	311	289	170	194	Jul	-1.22	-1.12	-0.32	-1.52	-1.05
	W126/N100 (7mo)	met (all years)		N60 (3mo)	930	848	844	710	789	Aug	-1.23	-1.07	-0.72	-1.53	-1.39
	Indicator species	present		W126 (7mo)	139.2	155.4	142.6	126.1	120.5	Sep	-0.74	0.83	-1.20	-1.46	-1.48
	Soil moisture	no relation		N100 (7mo)	90	81	72	33	18	Oct	-0.05	-1.08	-1.16	-0.28	1.81
Lassen Volcanic National Park	Kohut	Low	monitored	Sum06	3	2	4	0	1	Apr	4.71	-0.66	-2.10	-1.45	3.09
	Updated	Low	monitored	W126 (3mo)	19.1	15.3	19.1	7.7	9.7	May	-0.58	-1.03	-1.42	1.65	1.78
	SUM06	not met		N100 (3mo)	0	0	5	0	0	Jun	-0.92	-1.00	-2.17	1.44	0.45
	W126/N100 (3mo)	not met		N80 (3mo)	11	5	44	0	0	Jul	-1.48	-0.50	-1.98	0.65	0.87
	W126/N100 (7mo)	not met		N60 (3mo)	379	292	321	106	137	Aug	-1.25	-0.91	-1.38	-0.17	-0.11
	Indicator species	present		W126 (7mo)	36.2	35.0	37.9	17.5	21.9	Sep	-1.51	0.14	-1.59	-1.13	-0.86
	Soil moisture	no relation		N100 (7mo)	0	0	5	0	0	Oct	-1.95	0.64	-0.63	1.56	2.55
Mesa Verde National Park	Kohut	Low	monitored	Sum06	3	2	1	1	1	Apr	-1.95	-0.87	-0.11	0.21	0.72
	Updated	Low	monitored	W126 (3mo)	23.4	17.6	13.4	15.1	12.1	May	-2.39	0.23	0.95	1.01	-0.19
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.44	-1.18	-0.35	2.56	-0.10
	W126/N100 (3mo)	not met		N80 (3mo)	7	0	0	0	3	Jul	0.24	-0.50	-0.64	-0.07	-0.57
	W126/N100 (7mo)	not met		N60 (3mo)	560	346	230	262	182	Aug	0.35	-0.22	-0.98	-2.19	1.35
	Indicator species	present		W126 (7mo)	59.3	49.7	32.5	43.5	32.8	Sep	2.41	2.22	-0.47	-1.18	-1.57
	Soil moisture	slight inverse		N100 (7mo)	0	0	0	0	0	Oct	4.66	-0.39	-1.65	0.03	0.83
Mojave National Preservation	Kohut	High	kriged	Sum06	-	-	9	3	3	Apr	-0.49	-2.36	-1.78	-2.32	0.06
	Updated	Moderate	monitored	W126 (3mo)	-	-	38.9	19.9	19.4	May	-2.68	-2.83	-0.79	-3.11	0.14
	SUM06	met (1 year)		N100 (3mo)	-	-	2	0	0	Jun	-2.35	-2.37	-1.23	-1.59	0.63
	W126/N100 (3mo)	not met		N80 (3mo)	-	-	76	30	12	Jul	-1.22	-1.12	-0.32	-1.52	-1.05
	W126/N100 (7mo)	not met		N60 (3mo)	-	-	813	361	382	Aug	-1.23	-1.07	-0.72	-1.53	-1.39
	Indicator species	present		W126 (7mo)	-	-	114.3	57.2	59.8	Sep	-0.74	0.83	-1.20	-1.46	-1.48
	Soil moisture	no relation		N100 (7mo)	-	-	4	0	0	Oct	-0.05	-1.08	-1.16	-0.28	1.81

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Mount Rainier National Park	Kohut	Low	monitored	Sum06	0	0	0	0	0	Apr	-1.32	-1.68	0.37	0.15	3.35
	Updated	Low	monitored	W126 (3mo)	3.2	3.3	1.2	2.2	1.9	May	-0.02	-1.62	-1.55	2.15	5.27
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-0.44	-0.26	0.49	-1.86	2.48
	W126/N100 (3mo)	not met		N80 (3mo)	0	0	0	0	0	Jul	-1.15	-0.55	-0.72	-2.48	-1.03
	W126/N100 (7mo)	not met		N60 (3mo)	28	32	0	16	10	Aug	-2.05	-1.00	2.67	-2.03	-1.34
	Indicator species	present		W126 (7mo)	9.0	9.8	2.6	4.0	5.2	Sep	-1.67	-1.57	-2.15	-1.54	2.70
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	-1.51	1.32	-1.89	1.46	0.05
Petrified Forest National Park	Kohut	Moderate	kriged	Sum06	2	2	2	0	1	Apr	-0.89	-2.07	-1.41	-1.37	-0.28
	Updated	Low	monitored	W126 (3mo)	19.2	16.4	19.5	9.0	12.7	May	-3.65	-2.44	1.52	0.86	0.52
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.91	-3.37	0.71	-0.40	0.98
	W126/N100 (3mo)	not met		N80 (3mo)	5	0	3	0	0	Jul	1.33	0.64	1.23	-2.39	2.53
	W126/N100 (7mo)	not met		N60 (3mo)	368	327	420	68	184	Aug	1.37	0.20	0.97	-3.81	-0.05
	Indicator species	present		W126 (7mo)	29.8	30.6	33.8	23.1	26.8	Sep	0.23	-0.63	-1.17	-1.11	-1.52
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	2.09	-2.16	-1.36	-1.60	1.04
Pinnacles National Monument	Kohut	High	monitored	Sum06	3	2	4	2	1	Apr	5.05	-0.88	-1.84	-1.38	3.13
	Updated	Low	monitored	W126 (3mo)	17.2	14.8	19.8	11.4	9.9	May	1.65	-1.28	-1.64	0.89	1.78
	SUM06	not met		N100 (3mo)	2	0	1	0	0	Jun	1.29	-1.34	-1.39	0.00	1.73
	W126/N100 (3mo)	not met		N80 (3mo)	26	14	64	8	7	Jul	0.59	-0.99	-1.10	-0.05	1.13
	W126/N100 (7mo)	not met		N60 (3mo)	314	286	341	223	171	Aug	-0.27	-0.77	-0.88	-0.16	0.64
	Indicator species	present		W126 (7mo)	30.0	29.7	43.8	20.1	17.2	Sep	-0.79	-0.18	-1.13	-0.33	-0.40
	Soil moisture	no relation		N100 (7mo)	2	0	1	0	0	Oct	-1.14	1.04	-1.38	5.78	0.86
Saguaro National Park	Kohut	Low	monitored	Sum06	3	2	3	1	2	Apr	-2.41	-1.82	-1.72	-1.56	1.45
	Updated	Low	monitored	W126 (3mo)	19.6	17.1	20.2	11.0	15.3	May	-2.43	-1.79	-0.25	-0.82	1.44
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-1.28	-1.70	-1.01	-0.09	0.83
	W126/N100 (3mo)	not met		N80 (3mo)	13	4	8	0	1	Jul	2.41	1.58	5.19	-2.17	0.54
	W126/N100 (7mo)	not met		N60 (3mo)	389	320	399	157	291	Aug	0.20	-0.48	0.92	-2.97	-0.97
	Indicator species	present		W126 (7mo)	36.9	35.9	39.7	25.4	32.0	Sep	2.27	-1.25	-0.17	-1.17	-1.90
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	-0.69	-1.72	-1.63	-1.12	-0.71

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Saratoga National Historic Park	Kohut	Low	kriged	Sum06	1	2	1	1	1	Apr	0.90	5.13	-1.00	-1.79	-2.75
	Updated	Low	monitored	W126 (3mo)	6.8	10.5	9.3	5.4	6.0	May	0.76	-2.59	-1.56	0.66	-2.12
	SUM06	not met		N100 (3mo)	0	1	0	0	0	Jun	6.45	-0.28	0.59	5.50	-0.18
	W126/N100 (3mo)	not met		N80 (3mo)	15	41	14	2	2	Jul	-0.36	1.59	3.14	4.89	-1.23
	W126/N100 (7mo)	not met		N60 (3mo)	107	157	125	57	98	Aug	1.71	-0.91	0.79	2.59	-0.16
	Indicator species	present		W126 (7mo)	13.0	18.7	17.6	9.8	15.8	Sep	1.17	-1.26	1.65	-1.12	-1.52
	Soil moisture	no relation		N100 (7mo)	0	2	0	0	0	Oct	3.61	1.74	2.48	2.63	4.73
Sequoia & Kings Canyon National Park	Kohut	High	monitored	Sum06	21	19	12	17	16	Apr	4.84	-1.27	-2.33	-1.32	3.07
	Updated	High	monitored	W126 (3mo)	66.4	63.4	40.5	55.8	54.2	May	0.90	-2.37	-1.13	0.71	1.05
	SUM06	met (all years)		N100 (3mo)	81	36	51	34	20	Jun	0.54	-2.58	-1.82	0.05	1.51
	W126/N100 (3mo)	met (all years)		N80 (3mo)	507	446	211	372	326	Jul	-0.41	-1.96	-1.34	-0.26	0.42
	W126/N100 (7mo)	met (all years)		N60 (3mo)	944	974	637	866	874	Aug	-0.99	-0.87	-0.98	-0.44	-0.28
	Indicator species	present		W126 (7mo)	127.1	126.4	83.2	106.9	90.6	Sep	-1.23	-0.09	-1.26	-1.11	-1.13
	Soil moisture	no relation		N100 (7mo)	99	56	59	33	21	Oct	-0.76	-0.22	-0.98	2.99	2.49
Shenandoah National Park	Kohut	Moderate	monitored	Sum06	2	2	1	0	1	Apr	-0.68	0.43	2.52	0.50	-2.58
	Updated	Low	monitored	W126 (3mo)	15.8	13.7	11.5	7.3	10.4	May	-1.61	-2.88	3.52	3.56	-0.70
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	5.69	-1.21	0.94	2.38	-2.46
	W126/N100 (3mo)	not met		N80 (3mo)	7	1	4	0	6	Jul	-0.92	-2.70	-0.10	-1.02	-2.32
	W126/N100 (7mo)	not met		N60 (3mo)	303	277	162	108	159	Aug	-3.30	-1.22	-0.80	-0.87	-1.53
	Indicator species	present		W126 (7mo)	52.5	52.1	37.3	20.3	37.4	Sep	3.16	-2.66	1.28	-1.17	-0.09
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	2.12	-0.78	-1.33	0.26	0.33
Theodore Roosevelt National Park	Kohut	Low	monitored	Sum06	1	0	0	0	0	Apr	0.32	-0.28	-2.35	0.04	0.22
	Updated	Low	monitored	W126 (3mo)	9.4	6.3	6.3	4.2	5.2	May	-0.49	5.94	-1.33	1.30	4.89
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-3.01	-1.26	0.37	0.33	2.18
	W126/N100 (3mo)	not met		N80 (3mo)	0	0	0	0	0	Jul	-2.97	-2.39	-2.61	2.25	2.96
	W126/N100 (7mo)	not met		N60 (3mo)	165	87	55	4	49	Aug	0.45	-0.97	-2.52	0.46	2.21
	Indicator species	present		W126 (7mo)	16.6	11.5	10.8	7.0	9.2	Sep	0.56	-1.67	-0.40	-0.69	5.58
	Soil moisture	slight inverse		N100 (7mo)	0	0	0	0	0	Oct	0.65	-1.21	1.14	3.95	0.40

(cont.)

Park Name	Risk Overview			O$_3$ Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O$_3$ Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Tonto National Monument	Kohut	Moderate	kriged	Sum06	5	4	5	1	2	Apr	-1.41	-1.61	-1.04	-0.16	-0.70
	Updated	Low	monitored	W126 (3mo)	26.6	23.3	25.5	13.8	17.0	May	-3.70	-2.52	2.82	1.99	0.25
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-3.51	-3.22	1.14	0.19	0.20
	W126/N100 (3mo)	not met		N80 (3mo)	58	33	38	4	3	Jul	0.28	0.25	3.68	-0.67	2.08
	W126/N100 (7mo)	not met		N60 (3mo)	527	437	518	239	315	Aug	-0.74	-1.05	3.08	-3.60	-1.20
	Indicator species	present		W126 (7mo)	54.0	54.2	56.4	38.7	37.6	Sep	-0.52	-0.65	-1.53	-0.50	0.40
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	0.79	-2.38	-1.27	-1.99	0.42
Voyageurs National Park	Kohut	Low	monitored	Sum06	0	0	0	0	1	Apr	-2.48	0.85	4.01	0.56	-3.74
	Updated	Low	monitored	W126 (3mo)	5.3	5.2	3.3	5.0	7.7	May	0.89	-0.74	0.73	-0.75	-1.21
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.09	-0.72	2.97	-1.59	-0.02
	W126/N100 (3mo)	not met		N80 (3mo)	0	0	0	0	0	Jul	-1.33	-2.65	-0.65	-0.91	0.54
	W126/N100 (7mo)	not met		N60 (3mo)	50	54	16	54	114	Aug	-2.75	-3.66	-2.66	1.06	0.16
	Indicator species	present		W126 (7mo)	12.7	10.9	6.6	9.1	13.2	Sep	-1.99	5.08	0.98	-3.88	1.98
	Soil moisture	no relation		N100 (7mo)	0	0	0	0	0	Oct	-1.17	5.89	0.77	2.04	1.32
Wind Cave National Park	Kohut	Low	kriged	Sum06	3	1	0	0	0	Apr	2.11	-1.03	-0.82	2.52	2.61
	Updated	Low	monitored	W126 (3mo)	20.4	12.3	5.9	5.8	5.6	May	-0.25	0.55	6.44	-1.93	2.77
	SUM06	not met		N100 (3mo)	0	0	0	0	0	Jun	-2.86	-1.04	2.52	0.04	1.22
	W126/N100 (3mo)	not met		N80 (3mo)	4	2	0	0	0	Jul	-2.98	-0.66	2.15	1.45	0.22
	W126/N100 (7mo)	not met		N60 (3mo)	444	195	29	47	26	Aug	0.46	1.54	1.60	2.23	1.10
	Indicator species	present		W126 (7mo)	43.0	25.3	16.0	11.8	13.9	Sep	2.85	-1.13	0.61	0.30	-0.25
	Soil moisture	inverse		N100 (7mo)	0	0	0	0	0	Oct	0.45	-0.03	1.20	5.22	0.50
Yellowstone National Park	Kohut	Low	monitored	Sum06	1	1	0	0	1	Apr	-2.81	-1.45	-0.77	1.33	0.35
	Updated	Low	monitored	W126 (3mo)	13.0	10.0	8.8	7.6	11.6	May	-2.80	-4.14	2.26	-1.51	0.57
	SUM06	not met		N100 (3mo)	0	0	0	3	0	Jun	-3.20	-2.32	-0.68	2.43	0.10
	W126/N100 (3mo)	not met		N80 (3mo)	7	0	0	4	0	Jul	-2.70	-3.23	-0.91	1.23	-1.58
	W126/N100 (7mo)	not met		N60 (3mo)	203	144	114	49	205	Aug	-3.71	-2.16	-2.48	0.64	0.65
	Indicator species	present		W126 (7mo)	35.4	24.3	24.0	17.5	29.6	Sep	-0.84	-1.80	-1.40	-2.83	-2.55
	Soil moisture	slight inverse		N100 (7mo)	0	0	0	3	0	Oct	1.15	2.78	-0.78	2.51	-1.25

(cont.)

Park Name	Risk Overview			O_3 Exposure						Palmer Z Soil Moisture					
	Analysis	Risk Rating	O_3 Data	Metric	2006	2007	2008	2009	2010	Month	2006	2007	2008	2009	2010
Yosemite National Park	Kohut	High	monitored	Sum06	7	6	10	4	5	Apr	4.84	-1.27	-2.33	-1.32	3.07
	Updated	Moderate	monitored	W126 (3mo)	32.8	28.8	41.5	24.9	26.5	May	0.90	-2.37	-1.13	0.71	1.05
	SUM06	met (1 year)		N100 (3mo)	0	0	20	0	0	Jun	0.54	-2.58	-1.82	0.05	1.51
	W126/N100 (3mo)	met (1 year)		N80 (3mo)	89	67	172	35	19	Jul	-0.41	-1.96	-1.34	-0.26	0.42
	W126/N100 (7mo)	met (1 year)		N60 (3mo)	668	573	745	514	601	Aug	-0.99	-0.87	-0.98	-0.44	-0.28
	Indicator species	present		W126 (7mo)	79.1	90.2	101.5	56.8	57.4	Sep	-1.23	-0.09	-1.26	-1.11	-1.13
	Soil moisture	no relation		N100 (7mo)	0	0	23	0	0	Oct	-0.76	-0.22	-0.98	2.99	2.49

Appendix 6-A

Memo from RTI International Documenting FASOMGHG Modeling of Ozone Impacts on the U.S. Forest and Agriculture Sectors

TO: **Christine Davis, EPA**

FROM: **Robert Beach and Wolfgang Zhang**

DATE: **August 7, 2012**

SUBJECT: **FASOMGHG Modeling of Ozone Impacts on the U.S. Forest and Agriculture Sectors**

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1. INTRODUCTION

As one component of the risk and ecosystem services impacts assessment of the effects of ozone, RTI International (RTI) is working with the U.S. Environmental Protection Agency (EPA) to examine the potential forest and agricultural market responses under alternative ambient ozone concentrations as well as the associated effects on consumer and producer welfare. Examining the dynamic effects of policies affecting the forestry and agricultural sectors requires an analytical framework that can simulate the time path of market and environmental impacts. The model we are using to simulate market outcomes under alternative ozone concentrations is the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG).

FASOMGHG is a dynamic nonlinear programming model of the U.S. forest and agricultural sectors. Although public timberland is not explicitly modeled because the focus of the model is on private decision-maker responses to changing incentives, FASOMGHG includes an exogenous timber supply from public forestlands. Harvests from public forestlands are included in the model but are treated as exogenously determined by the government The model solves a constrained dynamic optimization problem that maximizes the net present value of the sum of producer and consumer surplus across the two sectors over time. The model is constrained such that total production is equal to total consumption, technical input/output relationships hold, and total land use must remain constant. FASOMGHG simulates the allocation of land over time to competing activities in both the forest and agricultural sectors and the associated impacts on commodity markets. In addition, the model simulates environmental impacts resulting from changing land allocation and production practices, including detailed accounting for changes in net greenhouse gas (GHG) emissions. The model was developed to evaluate the welfare and market impacts of policies that influence land allocation and alter production activities within these sectors. FASOMGHG has been used in numerous studies to examine issues including the potential impacts of GHG mitigation policy, climate change, timber harvest policy on public lands, federal farm programs, bioenergy production, changes in ozone levels and a variety of other policies affecting the forest and agricultural sectors.

The comprehensive sectoral coverage provided by FASOMGHG is advantageous for analysis of policies impacting the forest and agricultural sectors for a number of reasons. Because the model accounts for land competition between forestry, crop production, and livestock production (pasture) and landowner responses to changing relative prices, FASOMGHG provides a more complete assessment of the net market impacts associated with a policy than models that focus only on direct policy impacts on an individual commodity or subset of alternative land uses. Using FASOMGHG enables determination of secondary impacts, such as crop switching, movements between cropland and pasture, movements between forestland and agricultural land, and changes in equilibrium quantities of forest and agricultural commodities due to changes in relative commodity prices. FASOMGHG also captures changes in the livestock market due to higher feed costs as well as changes in U.S. exports and imports of major agricultural commodities. In addition, the model accounts for changes in the primary agricultural GHGs (carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O]), from the majority of emitting agricultural activities and tracks carbon sequestration and carbon losses over time. The intertemporal dynamics of the economic and biophysical systems allow for an accounting of environmental impacts over time and by region. This allows for a more complete quantification of net impacts, providing additional insights into the numerous important environmental and economic impacts in these sectors.

FASOMGHG simulates a dynamic baseline and changes from that baseline in response to changes in public policy or other factors affecting these sectors. For instance, the model is often used to evaluate the joint economic and biophysical effects of GHG mitigation and/or bioenergy scenarios in U.S. forestry and agriculture. The model has also been used for previous studies of ozone and climate impacts on forests and agriculture. The primary data required for simulations of the impacts of changing ambient ozone concentrations are regionally disaggregated productivity effects of these concentrations for each crop and forest type included within FASOMGHG. These values are incorporated as shifts in the model production functions. Due to changes in the relative returns available for alternative land uses, landowners will alter their land use, crop mix, production practices, and other factors, moving to a new equilibrium.

In the remainder of this memorandum, we provide an overview of the FASOMGHG model and a description of the methodology used to incorporate ozone impacts data into the model for our ongoing FASOMGHG ozone impacts model runs.

2. OVERVIEW OF THE FASOMGHG MODEL[1]

FASOMGHG combines component models of agricultural crop and livestock production, renewable fuels production, livestock feeding, agricultural processing, log production, forest processing, carbon sequestration, GHG emissions, wood product markets, agricultural markets, GHG payments, and land use to systematically capture the rich mix of biophysical and economic processes that will determine the technical, economic, and environmental implications of changes in policies. FASOMGHG covers

[1] See Adams et al. (2005), Beach et al. (2010), and Beach and McCarl (2010) for more detailed documentation of FASOMGHG.

private timberlands (along with an exogenously determined timber supply from public forestlands[2]) and all agricultural activity across the conterminous ("lower 48") United States, broken into 11 market regions. Finally, FASOMGHG tracks approximately 80 forest product categories and more than 2,000 production possibilities for field crops, livestock, and renewable energy feedstocks.

FASOMGHG assumes intertemporal optimizing behavior by economic agents. For instance, the decision to continue growing a stand of timber rather than harvesting it now is based on a comparison of the net present value of timber harvest from a future period versus the net present value of harvesting now and replanting (or not replanting and shifting the land to agricultural use). Similarly, landowners make a decision to keep their land in agriculture versus afforestation based on a comparison of the net present value of returns in agriculture and forestry. Land can also move between cropland and pasture depending on relative returns. This process establishes a land price equilibrium across the sectors (reflecting productivity in alternative uses and land conversion costs) and, given the land base interaction, a link between contemporaneous commodity prices in the two sectors as well.

The model solution portrays simultaneous multi-period, multi-commodity, multi-factor market equilibria, typically over 60 to 100 years on a 5-year time step basis when running the combined forest-agriculture version of the model. Results yield a dynamic simulation of prices, production, management, consumption, GHG effects, and other environmental and economic indicators within these sectors under each scenario defined in the model run.

The key endogenous variables in FASOMGHG include:

- commodity and factor prices;
- production, consumption, and export and import quantities;
- land use allocations between sectors;
- management strategy adoption;
- resource use;
- economic welfare measures;
- producer and consumer surplus;
- transfer payments;
- net welfare effects; and
- environmental impact indicators, such as
  - GHG emission/sequestration of CO_2, CH_4, and N_2O and

[2] In the scenarios modeled for this draft report, we assumed that timber supply from public forestlands remains constant under all scenarios. However, we may revisit this assumption in the future to examine the potential effects of reduced ozone concentrations on public forests and timber supply from public lands.

- total nitrogen and phosphorous applications.

Additional detail on the model and key characteristics are provided in the following subsections.

2.1 Brief History and Previous Applications

The current version of FASOMGHG reflects numerous model enhancements that have been made over time, dating back to the first version of the Agricultural Sector Model (ASM) (Baumes, 1978). Since the initial version of ASM, there have been many changes to the model, including improvements for pesticide analysis by Burton (1982), as reported in Burton and Martin (1987), and a number of model additions to enable more detailed environmental and resource analyses. ASM has been used for analyses of renewable fuels dating back to the late 1970s and 1980s (Tyner et al., 1979; Chattin, 1982; Hickenbotham, 1987). In addition, ASM was applied to study ozone impacts (Hamilton, 1985; Adams, Hamilton, and McCarl, 1984), acid rain (Adams, Callaway, and McCarl, 1986), soil conservation policy (Chang et al., 1994), global climate change impacts (Adams et al., 1988, 1990, 1999, 2001; McCarl, 1999; Reilly et al., 2000, 2002), and GHG mitigation (Adams et al., 1993; McCarl and Schneider, 2001).

One of the drivers behind integrating ASM with forest-sector models to create FASOM was an ASM study examining issues regarding joint forestry and agricultural GHG mitigation (Adams et al., 1993). Attempting to reconcile forestry production possibilities with the static single-year equilibrium representation in ASM led to the recognition that the model did not adequately reflect a number of dynamic issues associated with land allocation between forestry and agriculture. Thus, the initial FASOM was constructed to address these limitations by linking a simple intertemporal model of the forest sector with a version of the ASM in a dynamic framework, allowing some portion of the land base in each sector to be shifted to the alternative use. Land could transfer between sectors based on its marginal profitability in all alternative forest and agricultural uses over the time horizon of the model. Management investment decisions in both sectors, including harvest timing in forestry, were made endogenous, so they too would be based on the expected profitability of an additional dollar spent on expanding future output (both timber and carbon, if valued monetarily).

The basic structure of the forest sector was based on the family of models developed to support the timber assessment component of the U.S. Forest Service's decennial Forest and Rangeland Renewable Resources Planning Act (RPA) assessment process[3]: TAMM (Timber Assessment Market Model) (Adams and Haynes, 1980, 1996; Haynes, 2003), NAPAP (North American Pulp and Paper model) (Ince, 1994; Zhang, Buongiorno, and Ince, 1993, 1996), ATLAS (Aggregate Timberland Assessment System) (Mills and Kincaid, 1992), and AREACHANGE (Alig et al., 2003, 2010a; Alig, Kline, and Lichtenstein, 2004; and Alig and Plantinga, 2007). Timber inventory data and estimates of current and future timber yields were taken in large part from the ATLAS inputs used for the 2000 RPA Timber Assessment (Haynes, 2003) (these data have since been updated with information from the 2005 RPA Update assessment, as described below). The AREACHANGE models provide timberland area and forest type allocations to the ATLAS model. TAMM and NAPAP are "myopic" market projection models (they project ahead one period at a time) of the solid wood and fiber products sectors in the United States and Canada. In ATLAS, harvested lands are regenerated (grown) according to exogenous assumptions

[3] Adams and Haynes (2007) give a complete description of the full modeling system.

regarding the intensity of management and associated yield volume changes. The timberland base is adjusted for gains and losses projected over time by the AREACHANGE models, including afforestation of the area moving from agriculture into forestry. Product demand relations were extracted directly from the latest versions of TAMM and NAPAP, as were product supply relations for the solid wood products and all product conversion coefficients for both solid wood and fiber commodities. Trade between the United States and Canada in all major classes of wood products is endogenous and subject to the full array of potential trade barriers and exchange rates. Timber supply also uses nearly the full set of management intensity options available in ATLAS (e.g., for the South, seven planted pine management intensity classes directly from ATLAS), and the selection of management intensity is endogenous.

In addition, detailed GHG accounting for CO_2 and major non-CO_2 GHGs was added into a model denoted FASOMGHG. The forest carbon accounting component of FASOMGHG is largely derived from the U.S. Forest Service's Forestry Carbon (FORCARB) modeling system, which is an empirical model of forest carbon budgets simulated across regions, forest types, land classes, forest age classes, ownership groups, and carbon pools. The U.S. Forest Service uses FORCARB, in conjunction with its economic forest-sector models (e.g., TAMM, NAPAP, ATLAS, AREACHANGE) to estimate the total amount of carbon stored in U.S. forests over time as part of the Forest Service's ongoing assessment of forest resources in general (i.e., pursuant to the RPA) and forest carbon sequestration potential in particular (Joyce, 1995; Joyce and Birdsey, 2000). Basing the model's forest carbon accounting structure on FORCARB ensures that forest carbon estimates from FASOMGHG can be compared with ongoing efforts by the U.S. Forest Service to estimate and project national forest carbon sequestration.[4] It also enables FASOMGHG to be updated over time as the FORCARB system evolves to incorporate the latest science.

Following the inclusion of forest carbon accounting and some limited coverage of soil carbon changes associated with land use change, work began to widen the coverage of agricultural GHG sources and management possibilities for mitigating GHG. Schneider (2000) and McCarl and Schneider (2001) expanded the model to account for numerous categories of GHGs and to include a detailed set of agricultural-related GHG management possibilities. That work expanded ASM to include changes in tillage, land use exchange between pasture and crops, afforestation, nitrogen fertilization alternatives, enteric fermentation, manure management, renewable fuel offsets, fossil fuel use reduction, and changes in rice cultivation. The resulting model was labeled ASMGHG.

Given the dynamic modeling and forest carbon sequestration coverage included in FASOM and the agricultural coverage in ASMGHG, it was decided to merge the agricultural alternatives into the FASOM structure. This was manifest in the first version of FASOMGHG that was built in the context of Lee (2002). In that work, the agricultural model was expanded to have all the GHG management alternatives in ASMGHG with the additional coverage of dynamics. More recently, model modifications have been made to enhance FASOM's ability to provide detailed analyses of the agricultural and

[4] Note that FASOMGHG forest carbon accounting currently reflects sequestration on private timberland. Because public forest acreage is held constant and public timber supply is exogenous, the model has assumed no change in carbon storage across scenarios. We anticipate revisiting this assumption in future modeling of ozone impacts, though, because the effects of ozone on growth rates of public forests would be expected to affect carbon sequestration on those lands.

environmental impacts of bioenergy production from forest and agricultural feedstocks, both liquid transportation fuels and bioelectricity.

In the following subsections, we provide an overview of the overall scope of FASOMGHG in terms of the commodities included and commodity flows between primary and secondary (processed) products, inputs used in production, U.S. regional disaggregation, land categories and allocation, GHG accounts tracked, other environmental impacts calculated, and treatment of international trade.

2.2 Commodities

FASOMGHG includes several major groupings of agricultural and forest commodities, depending on the sector and whether they are primary commodities, processed, used for bioenergy, or mixed for livestock feed. These commodity groups are:

- raw crop, livestock, forestry, and renewable fuel feedstock primary commodities grown on the land;
- processed, secondary commodities made from the raw crop, livestock, and wood products;
- energy products made from renewable fuel feedstocks; and
- blended feeds for livestock consumption.

Agricultural commodities are quite frequently substitutable in demand. For example, sorghum is a close substitute for corn on a calorie-for-calorie basis in many uses, and beet sugar is essentially a perfect substitute for sugar derived from sugarcane. In addition, a number of feed grains are substitutes in terms of livestock feeding. Similarly, many forestry products are substitutes for one another, such as sawtimber or pulpwood derived from alternative hardwood and softwood species groups. In addition, bioenergy feedstocks derived from individual agricultural and forestry commodities are substitutes for one another (e.g., ethanol can be produced using either crop residues or logging residues, among other potential feedstocks). Thus, the mix of commodities that will be produced in a given model run depends on interactions between numerous related markets.

Primary Commodities

Primary commodity production is derived from allocation decisions based on the set of production possibilities for field crops, livestock, and biofuels. The allocation decisions are based on optimizing across the budgets associated with each production possibility, given prices for outputs and inputs. Budgets are based on using inputs to produce a given level of outputs.

In the model, primary commodities can be used directly or converted to secondary products via processing activities with associated costs (e.g., soybean crushing to meal and oil, livestock to meat and dairy). Primary commodities can go to livestock use, feed mixing, processing, domestic consumption, or exports. A mixture of primary commodities and processed products are supplied to meet national-level demands in each market. Table 1 summarizes the primary commodities currently included within FASOMGHG and their units. There are currently 40 primary crop products (including multiple subcategories of crops such as grapefruit, oranges, and tomatoes), 25 primary livestock products, 12 categories of forest and agricultural residues, and 32 categories of public and private domestic and imported logs included in the model.

Table 1. Primary Commodities

Commodities	Units
Crop Products	
Barley	Barley in bushels
Canola	Canola in hundredweight (cwt)
Corn	Corn in bushels
Cotton	Cotton in 480 lb bales
Grapefruit, fresh (67 lb. box)	Fresh market grapefruit in 1,000 67 pound boxes (CA, AZ)
Grapefruit, fresh (80 lb. box)	Fresh market grapefruit in 1,000 80 pound boxes (TX)
Grapefruit, fresh (85 lb. box)	Fresh market grapefruit in 1,000 85 pound boxes (FL)
Grapefruit, processing (67 lb. box)	Processing market grapefruit in 1,000 67 pound boxes (CA, AZ)
Grapefruit, processing (80 lb. box)	Processing market grapefruit in 1,000 80 pound boxes (TX)
Grapefruit, processing (85 lb. box)	Processing market grapefruit in 1,000 85 pound boxes (FL)
Hay	Hay in U.S. tons
Hybrid poplar	Hybrid poplar in U.S. tons
Miscanthus	Miscanthus in U.S. tons
Oats	Oats in bushels
Orange, fresh (75 lb. box)	Fresh market oranges in 1,000 75 pound boxes (CA, AZ)
Orange, fresh (85 lb. box)	Fresh market oranges in 1,000 85 pound boxes (TX)
Orange, fresh (90 lb. box)	Fresh market oranges in 1,000 90 pound boxes (FL)
Orange, processing (75 lb. box)	Processing market oranges in 1,000 75 pound boxes (CA, AZ)
Orange, processing (85 lb. box)	Processing market oranges in 1,000 85 pound boxes (TX)
Orange, processing (90 lb. box)	Processing market oranges in 1,000 90 pound boxes (FL)
Potatoes	Potatoes in cwt
Rice	Rice in cwt
Rye	Rye in bushels
Silage	Silage in U.S. tons
Sorghum, energy	Energy sorghum in dry metric tons

(continued)

1 **Table 1. Primary Commodities (continued)**

Commodities	Units
Sorghum, grain	Grain sorghum in cwt
Sorghum, sweet	Sweet sorghum in U.S. tons
Sorghum, sweet (ratooned)	Ratooned sweet sorghum in U.S. tons
Soybeans	Soybeans in bushels
Sugarbeets	Sugarbeets in U.S. tons
Sugarcane	Sugarcane in U.S. tons
Switchgrass	Switchgrass in U.S. tons
Tomatoes, fresh	Fresh tomatoes in cwt
Tomatoes, processing	Processing tomatoes in U.S. tons
Wheat, durum	Durum wheat in bushels
Wheat, hard red spring	Hard red spring wheat in bushels
Wheat, hard red winter	Hard red winter wheat in bushels
Wheat, soft red winter	Soft red winter wheat in bushels
Wheat, soft white	Soft white wheat in bushels
Willow	Willow in U.S. tons
Livestock Products	
NonFedSlaughter	100 lbs non fed beef (liveweight)
FeedlotBeefSlaughter	100 lbs fed beef (liveweight)
CalfSlaughter	100 lbs of calf (liveweight)
CullBeefCo	100 lbs of cull beef cow (liveweight)
Milk	100 lbs of raw milk
CullDairyCows	100 lbs of cull dairy cow (liveweight)
HogsforSlaughter	100 lbs of hogs for slaughter (liveweight)
FeederPig	100 lbs feeder pigs (liveweight)
CullSow	100 lbs cull sows (liveweight)
LambSlaugh	100 lbs of slaughter lambs (liveweight)
CullEwes	100 lbs of cull ewes (liveweight)
Wool	Raw wool in lbs
SteerCalve	100 lbs of steer calves (liveweight)
HeifCalve	100 lbs of heifer calves (liveweight)
StockedCalf	100 lbs of calves after first stocker phase ready to feed (liveweight)
StockedHCalf	100 lbs of heifer calves after first stocker phase ready to feed (liveweight)
StockedSCalf	100 lbs of steer calves after first stocker phase ready to feed (liveweight)
DairyCalves	100 lbs of dairy calves (liveweight)
StockedYearling	100 lbs of yearlings after second stocker phase ready to feed (liveweight)

2 (continued)

Table 1. Primary Commodities (continued)

Commodities	Units
StockedHYearl	100 lbs of heifer yearlings after second stocker phase ready to feed (liveweight)
StockedSYearl	100 lbs of steer yearlings after second stocker phase ready to feed (liveweight)
StockedYearling	100 lbs of yearlings after second stocker phase ready to feed (liveweight)
HorsesandMules	Number of horses and mules in head
Eggs	Dozens of eggs at farm level
Broilers	Broilers in 100 lbs (liveweight)
Turkeys	Turkeys in 100 lbs (liveweight)
Forest and Agricultural Residues	
Softwoodres	Softwood logging residues in U.S. tons
Hardwoodres	Hardwood logging residues in U.S. tons
Softmillres	Softwood milling residues in U.S. tons
Hardmillres	Hardwood milling residues in U.S. tons
Cornres	Corn crop residues in U.S. tons
Sorghumres	Sorghum crop residues in U.S. tons
Wheatres	Wheat crop residues in U.S. tons
Oatsres	Oat crop residues in U.S. tons
Barleyres	Barley crop residues in U.S. tons
Riceres	Rice crop residues in U.S. tons
Biomanure, beef	Beef cattle manure for use in bioenergy production in U.S. tons
Biomanure, dairy	Dairy cattle manure for use in bioenergy production in U.S. tons
Logs From Timber Harvest	
PVT_SWSLOG_WOODS	Softwood privately-produced sawlog in 1,000 cu. ft. in the woods
PVT_HWSLOG_WOODS	Hardwood privately-produced sawlog in 1,000 cu. ft. in the woods
PVT_SWPLOG_WOODS	Softwood privately-produced pulplog in 1,000 cu. ft. in the woods
PVT_HWPLOG_WOODS	Hardwood privately-produced pulplog in 1,000 cu. ft. in the woods
PVT_SWFLOG_WOODS	Softwood privately produced fuellog in 1,000 cu. ft. in the woods
PVT_HWFLOG_WOODS	Hardwood privately produced fuellog in 1,000 cu. ft. in the woods
PUB_SWSLOG_WOODS	Softwood publicly produced sawlog in 1,000 cu. ft. in the woods
PUB_HWSLOG_WOODS	Hardwood publicly produced sawlog in 1,000 cu. ft. in the woods
PUB_SWPLOG_WOODS	Softwood publicly produced pulplog in 1,000 cu. ft. in the woods
PUB_HWPLOG_WOODS	Hardwood publicly produced pulplog in 1,000 cu. ft. in the woods
PUB_SWFLOG_WOODS	Softwood publicly produced fuellog in 1,000 cu. ft. in the woods
PUB_HWFLOG_WOODS	Hardwood publicly produced fuellog in 1,000 cu. ft. in the woods

(continued)

Table 1. Primary Commodities (continued)

Commodities	Units
IMP_SWSLOG_WOODS	Imported softwood sawlog in the woods
IMP_HWSLOG_WOODS	Imported hardwood sawlog in the woods
IMP_SWPLOG_WOODS	Imported softwood pulplog in the woods
IMP_HWPLOG_WOODS	Imported hardwood pulplog in the woods
IMP_SWFLOG_WOODS	Imported softwood fuellog in the woods
IMP_HWFLOG_WOODS	Imported hardwood fuellog in the woods
PVT_SWFLOG_MILL	Softwood privately produced fuellog in 1,000 cu. ft. delivered to the mill
PVT_HWFLOG_MILL	Hardwood privately produced fuellog in 1,000 cu. ft. delivered to the mill
PUB_SWSLOG_MILL	Softwood publicly produced sawlog in 1,000 cu. ft. delivered to the mill
PUB_HWSLOG_MILL	Hardwood publicly produced sawlog in 1,000 cu. ft. delivered to the mill
PUB_SWPLOG_MILL	Softwood publicly produced pulplog in 1,000 cu. ft. delivered to the mill
PUB_HWPLOG_MILL	Hardwood publicly produced pulplog in 1,000 cu. ft. delivered to the mill
PUB_SWFLOG_MILL	Softwood publicly produced fuellog in 1,000 cu. ft. delivered to the mill
PUB_HWFLOG_MILL	Hardwood publicly produced fuellog in 1,000 cu. ft. delivered to the mill
IMP_SWSLOG_MILL	Imported softwood sawlog delivered to the mill
IMP_HWSLOG_MILL	Imported hardwood sawlog delivered to the mill
IMP_SWPLOG_MILL	Imported softwood pulplog delivered to the mill
IMP_HWPLOG_MILL	Imported hardwood pulplog delivered to the mill
IMP_SWFLOG_MILL	Imported softwood fuellog delivered to the mill
IMP_HWFLOG_MILL	Imported hardwood fuellog delivered to the mill

Secondary Commodities

As shown in Table 2, FASOMGHG contains a set of processing activities that make secondary commodities using primary commodities and other inputs (included as a processing cost). Secondary commodities are generally included in the model either to represent substitution or to depict demand for components of products. For example, processing possibilities for soybeans are included depicting soybeans being crushed into soybean meal and soybean oil because these secondary commodities frequently flow into different markets. Similar possibilities exist in the forest sector. For instance, paper could be made from pulp logs or from logging residues. Thus, the model reflects a large degree of demand substitution. There are currently 27 crop products, 17 livestock products, 10 processing byproducts, and 40 forestry products included in the model as secondary commodities.

Primary agricultural and forestry products are converted into processed products using processing budgets. These budgets are generally reflective of a somewhat simplified view of the resources used in processing, where the primary factors in the budgets are the use of primary commodities as inputs, the yield of secondary products, and processing costs to convert primary products into processed products. Processing costs for the production of processed agricultural products are usually assumed to equal the observed price differential between the value of the outputs and the value of the inputs based on USDA

Agricultural Statistics.[5] On the forestry side, the nonwood input supply curve provides the cost of processing wood.

Table 2. Secondary (Processed) Commodities

Secondary Products	Units
Crop Products	
Orange juice	Orange juice in 1,000 gallons at 42 brix
Grapefruit juice	Grapefruit juice in 1,000 gallons at single-strength equivalent
Soybean meal	Soybean meal in U.S. tons
Soybean meal equivalent	Soybean meal equivalency in U.S. tons
Soybean oil	Soybean oil in 1,000 lbs of oil
HFCS	High fructose corn syrup (HFCS) in 1,000 gallons
Beverages	Sweetened beverages in 1,000 gallons
Confection	Sweetened confectionaries in 1,000 lbs
Baking	Sweetened baked goods in 1,000 lbs
Canning	Sweetened canned goods in 1,000 gallons
Refined sugar	Refined sugar in U.S. tons
Gluten meal	Gluten meal in 1,000 lbs
Gluten feed	Gluten feed in 1,000 lbs
DG, export	Distillers grains for export in 1,000 lbs
DG, corn	Distillers grains from corn in 1,000 lbs
DG, noncorn	Distillers grains not from corn in 1,000 lbs
DG, corn fractionation	Distillers grains after fractionation in 1,000 lbs
Canola oil	Canola oil in 100 gallons
Canola meal	Canola meal in U.S. tons
Corn starch	Corn starch in 1,000 lbs
Corn oil	Corn oil in 100 gallons
Corn oil, nonfood	Nonfood grade corn oil from DDG extraction in 100 gallons
Corn syrup	Corn syrup in 1,000 gallons
Dextrose	Dextrose in 1,000 lbs
Potatoes, chipped	Potato chips in 100 lbs
Potatoes, dried	Dried potatoes in 100 lbs
Potatoes, frozen	Frozen potatoes in 100 lbs

(continued)

Table 2. Secondary (Processed) Commodities (continued)

Secondary Products	Units
Livestock Products	
Fed beef	Feedlot fed beef in 100 lbs (carcass weight)

[5]U.S. Department of Agriculture, National Agricultural Statistics Service. Various years. USDA Agricultural Statistics (1990–2002). Available at http://www.nass.usda.gov/Publications/Ag_Statistics/.

Nonfed beef	Nonfed (grass-fed) beef in 100 lbs (carcass weight)
Pork	Pork in 100 lbs after dressing
Chicken	Chicken in 100 lbs on ready to cook basis
Turkey	Turkey in 100 lbs on ready to cook basis
Wool, clean	Clean wool in lbs
Fluid milk, whole	Whole fluid milk in 100 lbs
Fluid milk, low-fat	Fat reduced fluid milk in lbs
Skim milk	Skim milk in lbs
Cream	Cream in lbs
Evaporated condensed milk	Evaporated condensed milk in lbs
Nonfat dry milk	Nonfat dry milk in Lbs
Butter	Butter in lbs
American cheese	American cheese in lbs
Other cheese	Other cheese in lbs
Cottage cheese	Cottage cheese in lbs
Ice cream	Ice cream in lbs
Processing Byproducts	
Bagasse	Sugarcane bagasse in tons
Lard	Lard from swine slaughter in U.S. tons
Lignin	Lignin produced from nonwood cellulosic ethanol processes in U.S. tons
Poultry fat	Fat from chicken and turkey slaughter in lbs
Sweet sorghum pulp	Sweet sorghum pulp in U.S. tons
Tallow, edible	Edible tallow from beef cattle slaughter in lbs
Tallow, nonedible	Nonedible tallow from beef cattle slaughter in lbs
Yellow grease	Waste cooking oil in lbs
Wood Products	
SLUM	Softwood lumber in million board feet, lumber tally
SPLY	Softwood plywood in million square feet, 3/8”
OSB	Oriented strand board (OSB) in million square feet, 3/8”
HLUM	Hardwood lumber in million board feet, lumber tally
HPLY	Hardwood plywood in million square feet, 3/8”
SWPANEL	Softwood used in non-OSB reconstituted panel in million square feet, 3/8”
HWPANEL	Hardwood used in non-OSB reconstituted panel in million square feet, 3/8”

(continued)

Table 2. Secondary (Processed) Commodities (continued)

Secondary Products	Units
SWMISC	Softwood miscellaneous products in million cubic feet
HWMISC	Hardwood miscellaneous products in million cubic feet
SRESIDUES	Softwood residues in million cubic meters
HRESIDUES	Hardwood residues in million cubic meters

HWPULP	Hardwood pulp in million cubic meters
SWPULP	Softwood pulp in million cubic meters
Hardwood pulp	Hardwood pulp moved to agricultural component of model for use in cellulosic ethanol production in U.S. tons
Softwood pulp	Softwood pulp moved to agricultural component of model for use in cellulosic ethanol production in U.S. tons
AGFIBERLONG	Agrifiber, long fiber
AGRIFIBERSHORT	Agrifiber, short fiber
OLDNEWSPAPERS	Old newspapers in million metric tons
OLDCORRUGATED	Old corrugated paper in million metric tons
WASTEPAPER	Mixed wastepaper in million metric tons
PULPSUBSTITUTE	Pulp substitutes in million metric tons
HIGDEINKING	Hi-grade deinking in million metric tons
NEWSPRINT	Newsprint in million metric tons
UNCFREESHEET	Uncoated free sheet in million metric tons
CFREESHEET	Coated free sheet in million metric tons
UNCROUNDWOOD	Uncoated roundwood in million metric tons
CROUNDWOOD	Coated roundwood in million metric tons
TISSUE	Tissue and sanitary in million metric tons
SPECIALTYPKG	Specialty packaging in million metric tons
KRAFTPKG	Kraft packaging in million metric tons
LINERBOARD	Linerboard in million metric tons
CORRUGMED	Corrugated medium in million metric tons
SBLBOARD	Solid bl. board in million metric tons
RECBOARD	Recycled board in million metric tons
CONSTPAPER	Construction paper and board in million metric tons
DISPULP	Dissolving pulp in million metric tons
SWKMPULP	Softwood kraft market pulp in million metric tons
HWKMPULP	Hardwood kraft market pulp in million metric tons
RECMPULP	Recycled market pulp in million metric tons
CTMPMPULP	Chemi-thermomechanical market pulp in million metric tons

The processing budgets for wood products are regionalized for all forest products with different data in the nine domestic forest production regions and the Canadian regions. Agricultural processing is regionalized for renewable fuels production, soybean crushing, wet milling, and bioelectricity generation. Processing budgets for other agricultural products are defined at a national level.

Bioenergy Products

Another category of processed product that can be produced in FASOMGHG using a subset of primary and secondary commodities is bioenergy. In addition to the category totals shown in Table 3, the model tracks the quantity of each bioenergy product produced using each individual feedstock. The bioenergy sector is a very important component of the FASOMGHG specification that has received a great deal of enhancement since the last major model update. Given recent policy interest and promulgation of rules greatly expanding renewable energy production and consumption as well as the sizable potential role for bioenergy in GHG mitigation, we have been engaged in a major effort to update this component of the model in recent years. This has included updates to data and parameters as well as incorporation of additional feedstocks.

Table 3. Bioenergy Products

Bioenergy Products	Units
Crop ethanol	Ethanol from crop grains and sugar in 1,000 gallons
Cellulosic ethanol	Ethanol from cellulosic processes in 1,000 gallons
Biodiesel	Biodiesel in 1,000 gallons
TBtus	Bioenergy inputs to electricity production in trillion British thermal units (Btus)

Blended Livestock Feeds

In addition to using the primary and/or secondary commodities identified above directly as livestock feed, FASOMGHG also allows for blending of livestock feeds from a number of different alternative formulas. Table 4 summarizes the categories of blended livestock feeds that can be used to meet livestock feed demand. These blends are defined to meet nutritional requirements of the individual livestock types, but each of the blends identified below can be made using a variety of different mixtures of primary and secondary commodities to deliver the appropriate nutrient levels. These alternative mixtures are defined by feed and feed blending alternative and vary by market region. The actual mixtures that will be used in the market equilibrium will depend on relative prices and availability as well as nutrient requirements. The resultant feeds are supplied for consumption by each livestock type included within the model.

Table 4. Blended Livestock Feeds

Feed Item	Units
StockPro0	Protein feed for stockers in 100 lbs (cwt)
CatGrain0	Blend of grains for cattle in 100 lbs (cwt)
HighProtCa	Protein feed for cattle in 100 lbs (cwt)
CowGrain0	Blend of grains for cow calf operations in 100 lbs (cwt)
CowHiPro0	Protein feed for cow calf operations in 100 lbs (cwt)

FinGrain0	Blend of grains for pig finishing in 100 lbs (cwt)
FinProSwn0	Protein feed for pig finishing in 100 lbs (cwt)
FarGrain0	Blend of grains for farrowing operations in 100 lbs (cwt)
FarProSwn0	Protein feed for farrowing operations in 100 lbs (cwt)
FPGGrain0	Blend of grains for feeder pigs in 100 lbs (cwt)
FPGProSwn0	Protein feed for feeder pigs in 100 lbs (cwt)
DairyCon0	Blend of grains for dairy operations in 100 lbs (cwt)
BroilGrn0	Blend of grains for broilers in 100 lbs (cwt)
BroilPro0	Protein feed for broilers in 100 lbs (cwt)
TurkeyGrn0	Blend of grains for turkeys in 100 lbs (cwt)
TurkeyPro0	Protein feed for turkeys in 100 lbs (cwt)
EggGrain0	Blend of grains for eggs in 100 lbs (cwt)
EggPro0	Protein feed for eggs in 100 lbs (cwt)
SheepGrn0	Blend of grains for sheep in 100 lbs (cwt)
SheepPro0	Protein feed for sheep in 100 lbs (cwt)

2.3 Inputs to Production

The production component includes agricultural crop and livestock operations, as well as forest industry (FI) and nonindustrial private forests (NIPF) forestry operations. FASOMGHG contains an agricultural production model for each of the primary commodities identified above. Production of traditional agricultural crops, bioenergy crops, livestock and forestry compete for suitable land. In addition to land, FASOMGHG depicts the factor supply of other resources, including water, labor, and other agricultural inputs in agriculture, as well as nonwood inputs in the forest sector.

In agricultural production, water and labor availability are specified on a regional basis. Supply curves for both items have a fixed price component and an upward-sloping component, representing rising marginal costs of higher supply quantities. For water, the fixed price is available to a maximum quantity of federally provided agricultural water, while pumped water has an upward-sloping supply curve and is subject to maximum availability. Numerous other inputs (e.g., fossil fuels, capital) are assumed to be infinitely available at a fixed price (i.e., the agricultural sector is a price taker in these markets).

On the forestry side, nonwood inputs are available on an upward-sloping basis and include hauling, harvesting, and product processing costs. Other forest inputs are assumed to be infinitely available at a fixed price.

Budgets are included for all crops included in the model based on data drawn from a variety of USDA and agricultural extension sources. Table 5 summarizes major categories of inputs included within the crop budgets that are defined and tracked in terms of quantities, typically because those quantities provide information on key energy, natural resource, GHG emissions, and other environmental impacts under a policy scenario (not all inputs are included in all crop budgets). The remainder of budget items are defined only in terms of dollars and largely aggregated for the purposes of the model. For each traditional crop, production budgets are differentiated by region, tillage choice (three choices: conventional tillage, conservation tillage, or no-till), and irrigated or dryland. The differentiation included results in thousands of cropping production possibilities (budgets) representing agricultural production in each 5-year period. Energy crop production possibilities are similar, except that irrigation is not an available option in the current FASOMGHG production possibilities; all energy crops are assumed to be produced under nonirrigated conditions and do not compete for irrigation water.

Table 5. Major Categories Included in Crop Budgets in Quantities

Carbon—Fuel Use	Gasoline	Nitrogen
Carbon—Grain Drying	Herbicide	Nitrous Oxide—Residue Burning
Carbon—Fertilizer Production	Insecticide	Nitrous Oxide—Fertilizer
Carbon—Irrigation Water Pumping	Irrigation Water	Nitrous Oxide—Histosol
Carbon—Pesticide Production	Labor	Nitrous Oxide—Leaching
Crop Residue	Land	Nitrous Oxide—Volatilization
Crop Yield	Lime & Gypsum	Phosphorus
Diesel Fuel	Methane—Residue Burning	Potassium
Electricity	Methane—Rice Cultivation	
Fungicide	Natural Gas	

Table 6 summarizes the inputs included in FASOMGHG livestock production budgets in terms of quantities (not all inputs are included in all livestock budgets). A number of categories track manure management systems because they are a key source of emissions for livestock. As for crops, the remainder of the inputs identified in available livestock budgets are included only in dollar terms and aggregated for model purposes. For livestock production, budgets are included that are defined by region, animal type, enteric fermentation management alternative, manure management alternative, and feeding alternative. Hundreds of livestock production possibilities (budgets) represent agricultural production in each 5-year period.

Table 6. Major Categories included in Livestock Budgets in Quantities

Barley	Liquid Volatile Solids Volume	Oats
Biomanure	Livestock Head	Pasture
Blended Feed Requirements	Livestock Product Output	Silage
Corn	Managed Manure Fraction	Soybean Meal
Hay	Methane—Enteric Fermentation	Volatile Solids in Manure

Head in Liquid Systems	Methane—Manure	Wheat
Labor	Nitrous Oxide—Manure	

Supply curves for agricultural products are generated implicitly within the system as the outcome of competitive market forces and market adjustments. This is in contrast to supply curves that are estimated from observed, historical data. This approach is useful here in part because FASOMGHG is often used to simulate conditions that fall well outside the range of historical observation (such as large-scale tree-planting programs or implementation of mandatory GHG mitigation policies).

The forest production component of FASOMGHG depicts the use of existing private timberland as well as the reforestation decision on harvested land. The forest sector relies on a series of forest growth and yield values to grow the forest inventory over time and to convert harvested area into forest products. In addition, forest carbon sequestration is calculated over time based on the inventory characteristics. Timberland is differentiated by region, the age cohort of trees,[6] ownership class, forest type, site condition, management regime, and suitability of the land for agricultural use. Decisions pertaining to timber management investment are endogenous. Actions on the inventory are depicted in a framework that allows timberland owners to institute management activities that alter the inventory consistent with maximizing the net present value of the returns from the activities. The key decision for existing timber stands involves selecting the harvest age. Lands that are harvested and subsequently reforested or lands that are converted from agriculture to forestry (afforested) introduce decisions involving the choice of forest type, management regime, and future harvest age.

Raw agricultural and forestry products are converted into processed products in FASOMGHG using processing budgets. Agricultural processing is regionalized for biofuels production, soybean crushing, wet milling, and bioelectricity generation. Processing budgets for other agricultural products are defined at a national level. These budgets are generally reflective of a somewhat simplified view of the resources used in processing, where the primary factors in the budgets are the use of primary commodities as inputs, the yield of secondary products, and processing costs to convert primary products into processed products. Processing costs for the production of processed agricultural products are usually assumed to equal the observed price differential between the value of the outputs and the value of the inputs based on USDA Agricultural Statistics.[7] For production of bioenergy, the model also calculates net changes in carbon, methane, and nitrous oxide emissions from replacing fossil fuels with biofuels after accounting for emissions associated with hauling and processing bioenergy feedstocks.

On the forestry side, the nonwood input supply curve provides the cost of processing wood. The processing budgets for wood products are regionalized for all forest products with different data in the

[6] Timberlands are grouped in 21 5-year cohorts, 0 to 4 years, 5 to 9, up to 100+ years. Harvesting is assumed to occur at the midyear of the cohort.
[7] U.S. Department of Agriculture, National Agricultural Statistics Service. Various years. USDA Agricultural Statistics (1990–2002). Available at http://www.nass.usda.gov/Publications/Ag_Statistics/.

nine domestic forest production regions and Canadian regions. Carbon sequestered in wood products is also calculated and tracked over time.

2.4 U.S. Regional Disaggregation

FASOMGHG includes all states in the conterminous ("lower 48") United States, broken into 63 subregions for agricultural production and 11 market regions (see Table 7) (forestry production is not disaggregated into the 63 subregions, just the 11 market regions). These regions are graphically displayed in Figure 1. The 11 market regions provide a consolidation of regional definitions that would otherwise differ if the forest and agricultural sectors were treated separately. Forestry production is included in 9 of the market regions (all but Great Plains and Southwest), whereas agricultural production is included in 10 of the market regions (all but Pacific Northwest—West side, "PNWW"). The Great Plains and Southwest regions are kept separate because they reflect important differences in agricultural characteristics. Likewise, there are important differences in the two Pacific Northwest regions (PNWW, PNWE) for forestry production, and the PNWE region is considered a significant producer of agricultural commodities tracked in the model, whereas PNWW is not. Thus, the two model regions that make up the Pacific Northwest are tracked separately. Each of the production regions is uniquely mapped to one of the 11 larger market regions. The majority of production regions are defined at the state level. However, for selected major production areas with significant differences in production conditions within states, the states are broken into subregions.

Table 7. Definition of FASOMGHG Production Regions and Market Regions

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

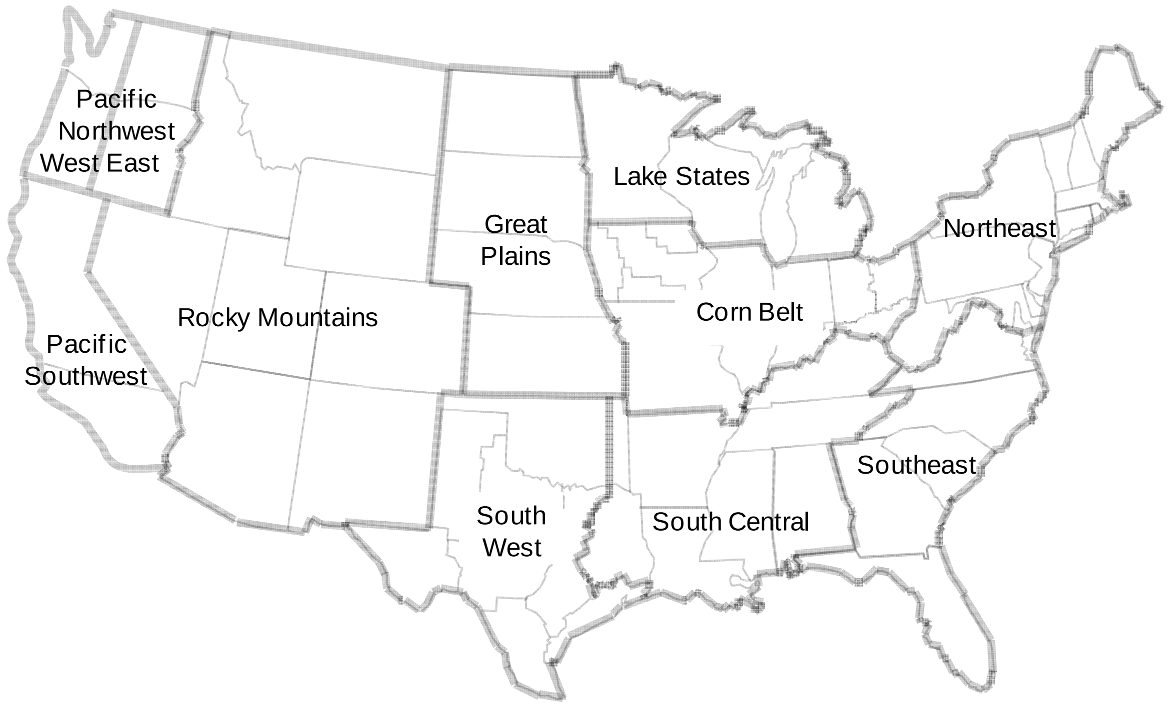

Figure 1. Map of the FASOMGHG Regions

When running the model, one can choose whether to keep the 63 regions or collapse to 11 regions to reduce run time. It is also possible to model agriculture explicitly in all 63 regions for an initial time period to provide maximum regional detail for the near to intermediate term and then collapse to 11 regions at a specified future time period for model size control purposes.

The full FASOMGHG can also be run at the more aggregated regional definition shown in Table 8, although the aggregated version of the model is more typically used for model development and testing. In addition, the wood products production and GHG accounting calculations employ an even more aggregated set of U.S. regions, following the regional definition in the North American Pulp and Paper (NAPAP) model (Zhang et al., 1993, 1996; Ince, 1994). This specification combines the Midwest and Northeast regions into a North region and does not include the Plains region because there are no forests tracked in that region.

Table 8. Aggregated U.S. Regions

Region	FASOMGHG Market Regions Included
Midwest	CB, LS
Northeast	NE
Plains	GP, SW
PNW_West_side	PNWW
Southern_US	SE, SC
Western_US	PNWE, RM, and PSW

Note: CB = Corn Belt; GP = Great Plains; LS = Lake States; NE = Northeast; PNWE = Pacific Northwest—East side; PSW = Pacific Southwest; RM = Rocky Mountains; SC = South Central; SE = Southeast; SW = Southwest

2.5 Land Use Categories

Underlying the commodity production described above and the associated environmental impacts is the decision by landowners on how much, where, and when to allocate land across the two sectors. The inclusion of endogenous land allocation across sectors sets FASOMGHG apart from the majority of other forest and agricultural sector models of the United States. The conceptual foundation for land allocation is described below. In terms of transferability between agriculture and forestry, FASOMGHG includes five land suitability classes.

FASOMGHG includes all cropland, pastureland, rangeland, and private timberland[8] throughout the conterminous United States. The model tracks both area used for production and idled (if any) within each land category. In addition, the model accounts for the movement of forest and agricultural lands into developed uses. We recently updated our land use categorization system to represent a more comprehensive range of land use categories. This process included expanding our coverage of pasturelands to explicitly represent multiple forms of public and private grazing lands (each with different animal unit grazing potential per unit of land). The FASOMGHG land base was developed based on land classifications from multiple sources, with the USDA Economic Research Service Major Land Use (MLU) database (USDA ERS, 2007) and the Natural Resources Inventory (NRI) published by the USDA-Natural Resource Conservation Service serving as our primary data sources.

These databases rely on different sampling methods and define land use categories in separate ways that each have advantages and disadvantages. To maintain consistency with other FASOMGHG input data, we rely on the ERS depiction of cropped acres to define our cropland base. However, the ERS lacks a clear distinction between grassland pasture and rangeland, while the NRI defines these as separate land categories, a distinction that we also wish to maintain given differences in ownership and productivity. Therefore, we make use of both datasets and attempt to avoid overlap between different land use categories as outlined below. This “hybrid” NRI-MLU land categorization system is unique, and we

[8] As noted above, although public timberland is not explicitly modeled because the focus of the model is on private decision-maker responses to changing incentives, FASOMGHG includes an exogenous timber supply from public forestlands.

feel that it provides FASOMGHG with a more realistic representation of public and private grazing lands as well as regional land transition possibilities between alternative uses.

Land categories included in the model are specified as follows:

- **Cropland** is land suitable for crop production that is being used to produce either traditional crops (e.g., corn, soybeans) or dedicated energy crops (e.g., switchgrass). This category includes only cropland from which one or more crops included in FASOMGHG were harvested.[9] Cropland used for livestock grazing before or after crops were harvested is included within this category as long as crops are harvested from the land. Data used to define cropland area are directly from the ERS-MLU (USDA ERS, 2007).

- **Cropland pasture** is managed land suitable for crop production (i.e., relatively high productivity) that is being used as pasture. The ERS-MLU database defines this area as "used only for pasture or grazing that could have been used for crops without additional improvement. Also included were acres of crops hogged or grazed but not harvested prior to grazing." Not requiring additional improvement to be suitable for crop production is a key distinction between cropland pasture and other forms of grassland pasture or rangeland. This land is assumed to be more freely transferable with cropland than other grassland types. State totals for cropland pasture used in the model are drawn directly from the ERS-MLU Web site.

- **Pasture** was defined in an attempt to maintain a consistent definition with the NRI classification of grassland pasture but to eliminate overlap with ERS cropland or cropland pasture as defined above. For each region, we compute the initial stock of "pasture" algebraically as the maximum of 1) ($\text{Cropland}_{\text{NRI}}$ + $\text{Grassland Pasture}_{\text{NRI}}$) – ($\text{Cropland}_{\text{ERS}}$ + $\text{Cropland Pasture}_{\text{ERS}}$) or 2) 0. This procedure is necessary to avoid double counting of pasturelands between the NRI and ERS data.

- **Private grazed forest** is calculated based on woodland areas of farms reported in the Agricultural Census to be used for grazing (woodland pasture).[10] Woodland pasture is defined as "all woodland used for pasture or grazing during the census year. Woodland or forestland pastured under a per-head grazing permit was not counted as land in farms and, therefore, was not included in woodland pastured." These lands are not included in the private timberland areas defined in the model, and there are no forest products harvested from these lands in FASOMGHG. The area in this category is fixed over time and is not allowed to transfer into forestland or other alternative uses.

- **Public grazed forest** is computed as the difference between the ERS-MLU total forest pasture stock and the private portion given by the Agricultural Census as described above.

- **Private rangeland** is defined in FASOMGHG using a combination of NRI and ERS-MLU data. Rangeland is typically unimproved land where a significant portion of the natural vegetation is native grasses and shrubs. The NRI database defines rangeland as "land on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that

[9] Note that FASOMGHG does not include every cropping activity conducted in the United States. For instance, tobacco, vineyards, and most fruits and vegetables are not included within the model.
[10] Data are available at http://www.agcensus.usda.gov/Publications/2002/Volume_1,_Chapter_2_US_State_Level/st99_2_008_008.pdf.

are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and practices, such as deferred grazing, burning, chaining, and rotational grazing, are used with little or no chemicals or fertilizer being applied. Grassland, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain low forb and shrub communities, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland." Thus, rangeland generally has low forage productivity and is unsuitable for cultivation and it is assumed that rangeland cannot be used for crop production or forestland. To calculate rangeland acres while avoiding double-counting, we first use 2003 NRI data to provide a base definition for the rangeland class. States with no reported rangeland acres in the NRI database (USDA NRCS, 2003) are defined to have no rangeland area in FASOMGHG to be consistent with the NRI definition and to limit overlap between the NRI classification of rangeland and the ERS-MLU classification of "grassland pasture and range." Then, to determine the state totals of private rangeland, ERS (2007) data defining regional totals of privately held grazing land by type was used. These regional proportions were multiplied by corresponding state-level totals to define the private rangeland stock by state. For example, the private rangeland stock in Wyoming was calculated by multiplying the total ERS estimate for Wyoming by the proportion of private to total rangeland for the "Mountain" region in which Wyoming is located. In solving for the private rangeland area used in FASOMGHG, it is important to maintain the relationship between all grazing lands for consistency. The ERS defines all privately owned grazing lands to be equal to the sum of cropland pasture, grazed forest, and grassland pasture and range and reports a total of approximately 488 million acres. Following all of our adjustments to develop a consistent land use definition based on both NRI and ERS-MLU data, the total private grazing land base in the baseline is approximately 484 million acres.

- **Public rangeland** was calculated using the proportions described above under private rangeland and totals about 182 million acres. This includes federal, state, and local sources.

- **Forestland** in FASOMGHG refers to private timberland, with a number of subcategories (e.g., different levels of productivity, management practices, age classes) tracked (see below for additional details). The model also reports the number of acres of private forestland existing at the starting point of the model that remains in standing forests (i.e., have not yet been harvested), the number of acres harvested, the number of harvested acres that have been reforested, and the area converted from other land uses (afforested). Public forestland area is not explicitly tracked because it is assumed to remain constant over time. Regional timberland stocks, as well as timber demand, inventory, and additional forestry sector information are drawn from the 2005 RPA Timber Assessment (Adams and Haynes, 2007).

- **Developed** (urban) land is assumed to increase over time at an exogenous rate for each region based on projected changes in population and economic growth. It is assumed that the land value for use in development is sufficiently high that the movement of forest and agricultural land into developed land will not vary between the policy cases analyzed. All private land uses (except CRP and grazed forest) are able to convert to developed land, decreasing the total land base available for forestry and agriculture over time. Land transfer rates vary by land use type over time and are consistent with the national land base assessment by Alig et al. (2010b).

- **Conservation Reserve Program (CRP) land** is specified as land that is voluntarily taken out of crop production and enrolled in the USDA's CRP. Land in the CRP is generally marginal cropland retired from production and converted to vegetative cover, such as grass, trees, or woody vegetation to conserve soil, improve water quality, enhance wildlife habitat, or produce other environmental benefits. State and county-level land area enrolled in the CRP was obtained from the USDA Farm Service Agency (2009).

Figure 2 shows the baseline land allocation in FASOMGHG at the national level across each of the land categories defined above. Land is allowed to move between categories over time subject to restrictions based on productivity and land suitability. The conversion costs of moving between land categories are set at the present value of the difference in the land rental rates between the alternative uses based on the assumed equilibration of land markets (see the subsections below for additional detail on each land use category and its potential conversion to alternative land uses).

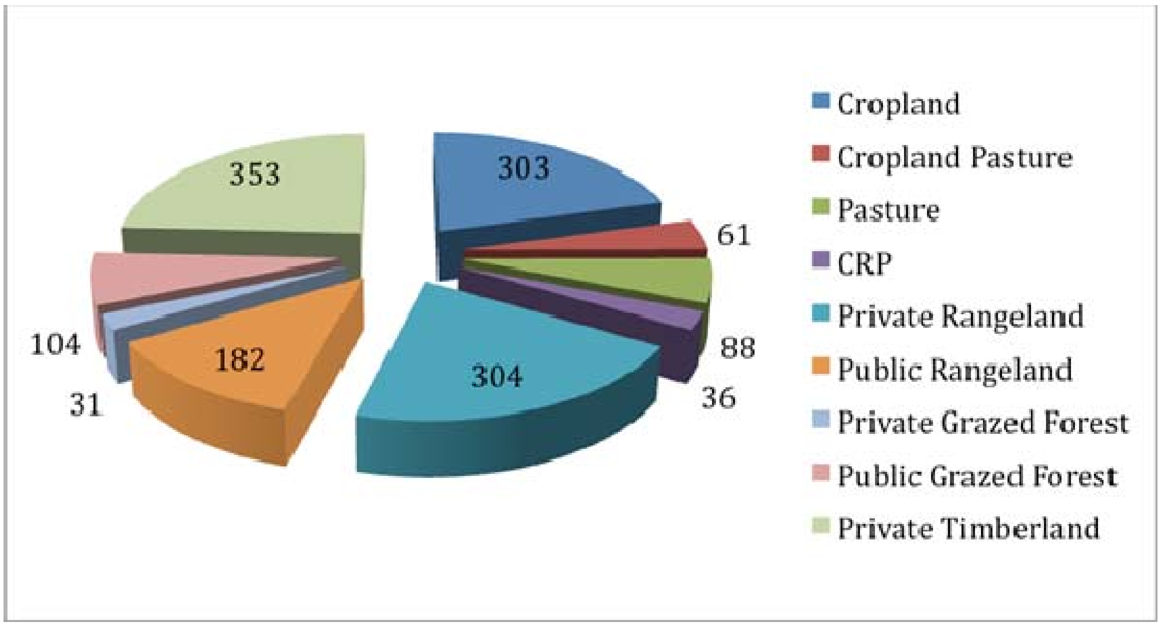

Figure 2. Baseline FASOMGHG U.S. Land Base by Land Use Category (million acres)

Agricultural Land

As described above, cropland is land that is suitable for crop production and can potentially be used in the production of any of the crops included in FASOMGHG for the particular production region being considered. Land in the cropland category is the most productive land available for producing primary agricultural commodities, although cropland in some regions is more productive than in others. Therefore, crop yields vary across regions based on historical data. The total area of baseline cropland is based on ERS-MLU data as described above, with baseline land in production of individual crops based on USDA National Agricultural Statistics Service (NASS) historical data on county-level harvested acreage by crop. Cropland enrolled in the CRP is included under the CRP land category, and cropland used as pasture is implicitly included in the pastureland category in FASOMGHG (i.e., both of these categories of cropland are included in other categories rather than being reported under cropland). The average annual areas of cropland with failed crops[11] are not included in the reported FASOMGHG cropland and are not explicitly tracked in FASOMGHG. Cropland can potentially be converted to cropland pasture or private forestland. In addition to tracking aggregate cropland area, cropland is also tracked by crop tillage system and irrigated/dryland status as well as the duration of time the land has been in such a system[12] to allow tracking of sequestered soil carbon and the transition to a new soil carbon equilibrium following a change in tillage. Also, there are differences in crop yields between irrigated and dryland systems as well as differences in input use, GHG emissions, and other environmental impacts. Different tillage systems also have differences in input usage and environmental impacts in FASOMGHG.

CRP land is cropland that has been enrolled in the Conservation Reserve Program, which is a USDA program providing payments to encourage activities providing conservation and environmental benefits. The land that farmers choose to enroll in the program is typically marginal cropland that farmers have agreed to retire from production for a contracted period. The land is generally converted to vegetative cover such as grass, trees, or woody vegetation to conserve soil, improve water quality, enhance wildlife habitat, or produce other environmental benefits. The area of CRP land in FASOMGHG in the baseline is based on 2007 data on CRP enrollment by state available from the USDA Farm Service Agency (2009). Because landowners can choose to remove their land from the CRP program when their contract expires (or before expiration, subject to a financial penalty), FASOMGHG also tracks the area of CRP land with expiring contracts in each year. As CRP contracts expire, landowners will move land back into agricultural production if the returns to agricultural production exceed the returns associated with maintaining land in the CRP. However, based on the 2008 Farm Bill, which specifies a maximum of 32 million acres in the CRP, and indications from USDA that they plan to provide sufficient funding to maintain that maximum level of 32 million acres in the CRP, FASOMGHG model runs generally place a floor of 32 million acres in CRP land in future years.

Cropland pasture, pasture, and private and public grazed forest are all suitable for livestock grazing (i.e., land that provides sufficient forage to support the needs of grazing livestock within a region), but cropland pasture tends to be more productive. Because it has sufficient quality to be used in crop production, cropland pasture can potentially be converted to crop production within the model. It can also be converted to forestland. Pasture, which is considered less productive, can be converted to forestland but not cropland. Private and public grazed forest refers to land that has varying amounts of

[11] USDA data for planted area exceed the harvested area because there will inevitably be some fraction of planted cropland area that is not harvested due to crop failure associated with poor weather, extreme events, or other conditions. In that case, the cost of harvesting may exceed the value of the crop. Thus, farmers will choose not to harvest those areas.

[12] Crop tillage systems in FASOM include conventional tillage, conservation tillage, and no-till. Conservation tillage and no-till reduce the exposure of carbon in the soil to oxidation and allow larger soil aggregates to form. These practices also leave crop residues on the soil, thereby potentially increasing carbon inputs. Tillage changes from more intensive conventional tillage practices, such as moldboard plowing, to conservation or zero tillage practices will generally increase levels of soil carbon over time. In addition, emission reductions may also result because less-intensive tillage typically involves less direct fossil fuel use for tractors. However, there are also alterations in chemical usage (possibly increases in pesticide usage and alterations in rate of fertilization), which can potentially increase emissions associated with increased manufacture and usage. FASOM has the ability to track these indirectly induced GHG effects associated with changes in tillage.

tree cover but can also be used as pasture. Forage production on these lands tends to be relatively low, however. Neither private nor public grazed forest can be converted to any other uses. As mentioned above, FASOMGHG assumes that no timber is produced from private grazed forest.

Rangeland in FASOMGHG includes both public and private rangeland. Rangeland differs from pastureland primarily in that it is assumed to be generally unimproved land where a significant portion of the land cover is native grasses and shrubs. The productivity of rangeland varies considerably across regions of the United States. Therefore, the area of rangeland required per animal for a given species can be very different across regions. Overall, rangeland provides lower forage production per acre than pastureland and is considered unsuitable for cultivation. In addition, much of the rangeland in the United States is publicly owned. Thus, it is assumed that rangeland cannot be used for crop production or forestland.

The area of pastureland or rangeland required per animal is calculated in FASOMGHG for each combination of livestock type and pasture or rangeland category available in each region. These values are based on forage requirements for each livestock species and estimated forage productivity per acre for each category of pasture in FASOMGHG, defined on a regional basis.[13] The area of pastureland used in livestock production is limited to the pastureland inventory by time period and region. It is possible to have idle pastureland in FASOMGHG and idle pastureland area and associated soil carbon sequestration are tracked in the model. In particular, changes in livestock populations will affect pasture and rangeland used for animal production and could increase or decrease idle land in the model. Changes in animal populations over time and impacts of policies affecting livestock markets, including use of each of the pasture and rangeland categories by each type of livestock, are tracked within FASOMGHG.

Forestland

Timberland refers to productive forestlands able to grow at least 20 cubic feet of growing stock per acre per year and that are not reserved for uses other than timber production (e.g., wilderness use). Lands under forest cover that do not produce at least 20 cubic feet per acre per year, called unproductive forestland, and timberland that is reserved for other uses are not considered part of the U.S. timber base (Haynes et al., 2007) and are therefore not tracked by the model.

In FASOMGHG, endogenous land use modeling is only done for privately held parcels, not publicly owned or publicly managed timberlands. The reason is that management of public lands is largely dictated by government decisions on management, harvesting, and other issues that account for multiple public uses of these lands rather than responses to market conditions. However, an exogenous quantity of timber harvested on U.S. public lands is accounted for within the model. Projected regional public harvest levels are drawn from the assumptions used in the baseline case of the US Forest Service's 2005 RPA Timber Assessment (Haynes et al., 2007). Timber inventory levels for public timberlands are simulated based on these harvest levels.

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[13] The calculation of acres of pasture required by a given type of livestock in a particular region is implicitly based on estimates of AUMs available for each category of pastureland in that region.

Private timberland is tracked by its quality and its transferability between forestry and agricultural use. FASOMGHG includes three different site classes to reflect differences in forestland productivity (these site groups were defined based on ATLAS inputs [Haynes et al., 2007]), where yields vary substantially between groups[14]:

- HIGH—high site productivity group (sites that produce >85 cubic feet of live growing stock per acre per year)
- MEDIUM—medium site productivity group (sites that produce between 50 and 85 cubic feet of live growing stock per acre per year)
- LOW—low site productivity group (sites that produce between 20 and 50 cubic feet of live growing stock per acre per year)

FASOMGHG also tracks land ownership including two private forest owner groups: forest industry (FI) and nonindustrial private forests (NIPF). The traditional definitions are used for these ownership groups: industrial timberland owners possess processing capacity for the timber, and NIPF owners do not. As a result the NIPF group includes lands owned by timber investment management organizations (TIMOs) and real estate investment trusts (REITs).

In addition, FASOMGHG tracks land in terms of the type of timber management practiced, forest type (identified by dominant species), and stand age. As shown in Table 9, across all regions there are 18 management intensity classes defined based on whether thinning, partial cutting, passive management, or other management methods are used. Note that some management intensity classes are only defined for a subset of regions (as identified by the region codes in parentheses) based on regional data and definitions. There are also 25 different forest types, which vary by region (e.g., Douglas-fir and other species types in the West and planted pine, natural pine, and various hardwood types in the South). Stand age is explicitly accounted for in 5-year cohorts, ranging from 0 to 4 years up to 100+ years.

Table 9. Forest Management Intensity Classes (regions of application in parentheses)

MIC Code	Description
AFFOR	Afforestation of bottomland hardwood (SE, SC)
AFFOR_CB	Afforestation of hardwood and softwood forest types (CB)
LO	Natural regeneration (or afforestation) with low management
NAT_REGEN	Natural regeneration with low management (PNWW)
NAT_REGEN_PART_CUT_HI	Partial cutting with high level of management (PNWW)
NAT_REGEN_PART_CUT_LO	Partial cutting with medium level of management (PNWW)
NAT_REGEN_PART_CUT_MED	Partial cutting with low level of management (PNWW)

[14] Changes in ozone concentrations affect the specific forest growth rates for each region/species/management intensity/productivity class, but are assumed not to result in movements between productivity classes. The primary use of the productivity classes in FASOMGHG is to aid in defining potential land use between forestland and other land uses (e.g., only high productivity forestland can be converted to cropland).

NAT_REGEN_THIN	Natural regeneration with a commercial thin (PNWW)
PART_CUT_HI	Partial cutting with medium level of management (SE, SC)
PART_CUT_HI+	Partial cutting with high level of management (SE, SC)
PART_CUT_LO	Partial cutting with low level of management (SE, SC)
PASSIVE	Passive management (minimal amount of management)
PLANT	Plant with no intermediate treatments (PNWW)
PLANT_THIN	Plant with medium level of management (PNWW)
PLANT+	Plant with high level of management (PNWW)
PLNT_HI	Planted pine with high level of management (SE, SC)
PLNT_HI_THIN	Planted pine with commercial thin and high level of management (SE, SC)
PLNT_LO_THIN	Planted pine with commercial thin and no intermediate treatments (SE, SC)
PLNT_MED	Planted pine with medium level of management (SE, SC)
PLNT_MED_THIN	Planted pine with commercial thin and medium level of management (SE, SC)
RESERVED	Reserved from harvest
SHORT_ROTSWDS	Short rotation softwoods with high level of management (SE, SC)
TRAD_PLNT_PINE	Planted pine with no intermediate treatments (SE, SC)

Developed Land

FASOMGHG also accounts for the movement of agricultural and forestland into developed uses. The economic returns to developed land uses typically exceed the returns available to agricultural or forestry land uses. Thus, FASOMGHG assumes an exogenous rate of land conversion into developed uses by region for each of the agricultural and forestland categories included in the model (with the exception of private and public grazed forest pasture and CRP lands) based on projections of future U.S. population and income, with endogenous competition between agriculture and forestry for the remaining land base available for these uses over time. It is assumed that developed land does not convert back to other uses.

Land Allocation

In FASOMGHG, the initial land endowment is fixed. However, because land can move between forests and agriculture, agricultural production faces, in effect, an endogenous excess land supply "equation" from forestry. Forestry production, in turn, effectively faces an endogenous excess land supply "equation" from agriculture.

The conceptual foundation for land allocation is described below. In terms of transferability between agriculture and forestry, FASOMGHG includes five land suitability classes:

- FORONLY—includes timberland acres that cannot be converted to agricultural uses
- FORCROP—includes acres that begin in timberland but can potentially be converted to cropland

- FORPAST—includes acres that begin in timberland but can potentially be converted to pastureland
- CROPFOR—includes acres that begin in cropland but can potentially be converted to timberland
- PASTFOR—includes acres that begin in pasture but can potentially be converted to timberland

Land can flow between the agricultural and forestry sectors or vice versa in the FORCROP, FORPAST, CROPFOR, and PASTFOR land suitability categories. Movements between forestry and cropland are only permitted within the high-quality forest site productivity class. Changes in land allocation involving pastureland occur within the medium-quality forest site productivity class. In addition, land movements in forestry are only allowed in the NIPF owner category, reflecting an assumption (and lengthy historical observation) that land held by the FI ownership group will not be converted from timberland to agriculture.

As mentioned above, the decision to move land between uses depends on the net present value of returns to alternative uses, including the costs of land conversion. Land transfers from forestry to agriculture take place only upon timber harvest and require an investment to clear stumps, level, and otherwise prepare the land for planting agricultural crops. Agricultural land can move to other uses during any of the 5-year model periods, but when afforested it begins in the youngest age cohort of timberland.

In addition to the endogenous land allocation decision, land also moves out of agricultural and forestry uses into developed uses (e.g., shopping centers, housing, and other developed and infrastructural uses) at an exogenous rate. Rates at which forest and agricultural land are converted to developed uses in FASOMGHG are based on land-use modeling for a national land base assessment by the U.S. Forest Service and cooperators. Thus, although land can move between forest, cropland, and pasture, the total land area devoted to agricultural and forestry production is trending downward over time as more land is shifted to developed uses.

An additional potential source of land is CRP land moving back into production. There are, however, environmental benefits associated with land in CRP and plans to retain some portion of that land in the program. In recent analyses, FASOMGHG has generally been applied allowing CRP land to convert back to cropland under the constraint that a minimum of 32 million acres of land remains in the CRP. This is consistent with the 2008 Farm Bill and information provided by USDA on their intentions to maintain that level of CRP acreage.

2.6 Market Modeling

FASOMGHG uses commodity supply and demand curves for the U.S. market that are calibrated to historic price and production data with constant price differentials between regional and national prices for some crops. In addition, the model includes supply and demand data for major commodities traded on world markets such as corn, wheat, soybeans, rice, and sorghum (see Section 2.7 for additional discussion of international trade modeling and foreign regions included). Transportation costs clearly influence equilibrium exports and FASOMGHG includes data on transportation costs to all regions included within the model and between foreign regions for those commodities where trade is explicitly modeled.

The model solution requires that all markets are in equilibrium (i.e., quantity supplied is equal to the quantity demanded in every market modeled at the set of market prices in the model solution). The demand and supply curves included within the model that need to be in equilibrium in each 5-year period include:

- regional product supply;
- national raw product demand;
- regional or national processed commodity demand;
- regional or national supply of processed commodities;
- regional or national (depending on commodity) export demand;
- regional or national (depending on commodity) import supply;
- regional feed supply and demand;
- regional direct livestock demand;
- interregional transport perfectly elastic supply;
- international transport perfectly elastic supply; and
- country-specific excess demand and supply of rice, sorghum, corn, soybeans, and the five individual types of wheat modeled.

In the case of forestry products, commodities are typically produced regionally and are then transported to meet a national demand at a fixed regional transport cost. Harvests from public forestlands are included in the model but are treated as exogenously determined by the government. For agricultural products, processed commodities such as soybean meal, gluten feed, starch, and all livestock feeds are manufactured and used on the 11-market region basis but are supplied into a single national domestic market to meet export demand.

2.7 International Trade

FASOMGHG accounts for international trade in both forestry and agricultural products, with the commodities included in the trade component and their treatment varying based on the importance of trade to the U.S. market and available data.

Forestry

For the forest sector, forest products trade with Canada and softwood lumber trade with the rest of the world are endogenous. These are the largest (by volume or weight) US forest products trade flows. All other product movements are exogenous and, in the baseline case, follow projections derived from the Forest Service's 2005 RPA Timber Assessment Update (Haynes et al., 2007).

Product movements from Canadian producing regions to the United States are endogenous and subject to appropriate transport costs, exchange rates, and tariffs. Supplies of logs in Canada derive primarily from public lands ("Crown" lands) governed by individual provinces, with small volumes from private lands. Harvests from these lands vary over time based on provincial policies, extraction and delivery costs and market prices for logs. These supplies are represented by a set of (log price sensitive) delivered log supply equations for both sawlogs and pulpwood in each Canadian region.

Softwood lumber imports into the United States from non-Canadian sources are based on a linear import supply function drawn from the 2005 RPA Timber Assessment Update (Haynes et al., 2007), which shifts over time to correspond to the base scenario in the Update.

Agriculture

Three types of agricultural commodity trade arrangements are represented. Agricultural primary and secondary commodities may be portrayed:

- with trade occurring in explicit international markets using a Takayama and Judge (1973) style, spatial equilibrium submodel that portrays country/region level excess demand on behalf of a set of foreign countries/regions, excess supply on behalf of a set of foreign countries/regions and interregional trade between the foreign countries/regions themselves and with the United States;

- with the United States facing a single excess supply and/or excess demand relationship on behalf of the ROW; or

- without being subject to international trade.

FASOMGHG has explicit trade functions between the United States and 29 distinct foreign trading partners for agricultural commodities with detailed trade data available. For the remaining commodities traded internationally, excess supply/demand functions are specified to capture net trade flows with the rest of the world as one composite trade region. Demand levels are parameterized based on the USDA Static World Policy Simulation Model (SWOPSIM) database and USDA annual statistics.

International regions are generally defined in a more simple way than domestic regions, with individual region-level supply and demand curves specified only for the commodities with the largest trade volumes, such as corn, wheat, soybeans, sorghum, and rice. In addition, only certain regions are defined for exporters and importers of a given commodity. In cases where commodities are traded in markets with spatial equilibrium submodels defined, the regions that can supply and demand that commodity in the model can either export them to the United States or to another region. Similarly, demand in a region can be met through imports from the United States or from other countries. The model solves for the spatial market equilibrium and trading patterns for these heavily traded commodities.

For many other commodities (e.g., cotton, oats, barley, beef, pork, poultry), trade is modeled as total excess import supply and export demand functions for the ROW) facing the United States rather than individual region supply and demand. In these cases, there are single curves representing the import supply and export demand facing the United States. In addition, there are many commodities without any explicit opportunities for international trade, such as hay, silage, energy crops, livestock, and many processed commodities. Generally, trade is not explicitly modeled for commodities where international trade volumes for the United States are small or the commodity is not actively traded.

When commodities are subject to explicit spatial interregional trade with spatial equilibrium submodels, then trading is portrayed among the 29 individual countries/foreign regions currently included in FASOMGHG. In those countries/foreign regions that are major importers or exporters of an explicitly traded commodity, explicit supply and demand functions are defined. Table 10 presents the commodities that are traded and the countries/regions that supply and demand them in the model. Note that when a country supplies certain commodities, it can either export them to another explicitly defined country/foreign region or to the United States. Similarly, demand in a country/region can be met from imports from other countries or from the United States.

Table 10. Explicitly Traded Commodities and Countries/Regions Trading with the United States

FASOMGHG Commodity	Exporting Countries	Importing Countries
Canola	Canada	NA
Canola oil	Canada	NA
Canola meal	Canada	NA
Corn	Argentina, Brazil, China, USSR, W-Africa	Canada, Caribbean, E-Mexico, Indonesia, Japan, N-Africa, NC-Euro, Philippines, SE-Asia, S-Korea, Taiwan, W-Asia
Rice	E-Medit, India, Myanmar, N-Africa, Pakistan, Thailand, Vietnam	Bangladesh, Brazil, Caribbean, China, Indonesia, Japan, N-Korea, NC-Euro, Philippines, S-Africa, SE-Asia, Taiwan, USSR, W-Africa, WS-America
Sorghum	Argentina, Australia, China	E-Mexico, Japan, NC-Euro, S-Korea, Taiwan
Soybeans	Argentina, Brazil, Canada, Caribbean, USSR	China, E-Europe, E-Mexico, Indonesia, Japan, N-Africa, NC-Euro, SE-Asia, S-Korea, Taiwan, W-Africa, W-Asia
Wheat, Durum	Canada	Brazil, Indonesia, Japan, N-Africa, Philippines, SE-Asia, S-Korea, Taiwan, USSR
Wheat, Hard Red Spring	Australia, Canada	Brazil, Caribbean, China, Indonesia, Japan, N-Africa, Philippines, SE-Asia, S-Korea, Taiwan, USSR, W-Africa, W-Asia
Wheat, Hard Red Winter	Argentina, Australia, Canada	Brazil, China, E-Mexico, Indonesia, Japan, N-Africa, Philippines, SE-Asia, S-Korea, Taiwan, USSR, W-Africa, W-Asia
Wheat, Soft Red Winter	Argentina, Australia, Canada	Brazil, China, E-Mexico, Indonesia, Japan, N-Africa, Philippines, SE-Asia, S-Korea, Taiwan, USSR, W-Africa, W-Asia
Wheat, Soft White	Australia, Canada, NC-Euro	Brazil, China, E-Mexico, Indonesia, Japan, N-Africa, Philippines, SE-Asia, S-Korea, Taiwan, USSR, W-Africa, W-Asia

For commodities where trade is important to the U.S. market, but data on trade flows with individual countries/foreign regions are more limited, U.S. trade is modeled at an aggregate level with the ROW. When U.S. trade is included in the model with only ROW excess import supply and export demand functions, then the curves represent the sum of ROW exports and imports that are faced at the national U.S. market level. The commodities currently included in the model in this way are listed in Table 11, identifying whether they are included in the import supply and/or export demand functions.

Commodities without explicit trade are generally specified as such because either the trade numbers are small or the commodity is not traded. These include the commodities listed in Table 12 as well as all of the blended feeds.

Table 11. Commodities with Only ROW Export or Import Possibilities

FASOMGHG Commodity	Imported into the United States	Exported from the United States
Canola	Y	N
Canola oil	Y	N
Canola meal	Y	N
Cotton	N	Y
DG	N	Y
Oats	N	N
Barley	Y	Y
Sugarcane	N	N
Potatoes	Y	Y
Tomatoes, fresh	Y	Y
Tomatoes, processed	N	N
Oranges, fresh (75 lb. box)	Y	Y
Grapefruit, fresh (85 lb. box)	Y	Y
Eggs	Y	Y
Orange juice	Y	Y
Grapefruit juice	Y	Y
Soybean meal	N	Y
Soybean oil	N	Y
HFCS	N	Y
Confection	Y	N
Gluten feed	N	Y
Frozen potatoes	Y	Y
Dried potatoes	Y	Y
Chipped potatoes	N	Y
Refined sugar	Y	Y
Fed beef	N	Y
Nonfed beef	Y	N
Feedlot beef slaughter	Y	N
Stocked calf	Y	N
Stocked steer calf	Y	N
Pork	Y	Y
Chicken	N	Y
Turkey	N	Y
Wool, clean	Y	Y
Evaporated condensed milk	Y	Y
Nonfat dry milk	Y	Y
Butter	Y	Y
American cheese	Y	Y
Other cheese	Y	Y

Table 12. Commodities without International Trade Possibilities Modeled

Baking	Feeder pigs	Oranges, processing (75 lb. box)

Beverages	Fluid milk	Oranges, processing (85 lb. box)
Biodiesel	Grapefruit, fresh (67 lb. box)	Oranges, processing (90 lb. box)
Broilers	Grapefruit, fresh (80 lb. box)	Refined sugar
Calf slaughter	Grapefruit, processing (67 lb. box)	Silage
Canning	Grapefruit, processing (80 lb. box)	Skim milk
Corn oil	Grapefruit, processing (85 lb. box)	Steer calves
Corn starch	Hay	Stocked heifer calves
Corn syrup	Heifer calves	Stocked heifer yearlings
Cottage cheese	Hogs for slaughter	Stocked steer yearlings
Cream	Horses and mules	Stocked yearlings
Cull beef cows	Hybrid poplar	Sugarbeet
Cull dairy cows	Ice cream	Switchgrass
Cull ewes	Lamb slaughter	Tbtus
Cull sow	milk	Turkeys
Dairy calves	Nonfed slaughter	Willow
Dextrose	Oranges, fresh (85 lb. box)	Wool
Ethanol	Oranges, fresh (90 lb. box)	

Note: FASOMGHG does not explicitly include ethanol trade, but in applications for biofuels analyses, we have assumed exogenous levels of mandated ethanol volumes would be provided by imports based on information from other models.

2.8 GHG Accounts

FASOMGHG quantifies the stocks of GHGs emitted from and sequestered by agriculture and forestry as well as the carbon stock on lands in the model that are converted to nonagricultural, nonforest developed usage. In addition, the model tracks GHG emission reductions in other sectors caused by mitigation actions in the forest and agricultural sectors.

The GHGs tracked by the model include CO_2, CH_4, and N_2O. Given the multi-GHG impact of the agricultural and forestry sectors, there are multidimensional trade-offs between model variables and net GHG emissions. To consider these trade-offs, all GHGs are converted to carbon or carbon dioxide equivalent basis using 100-year global warming potential (GWP) values for application of GHG incentives.

GWPs compare the abilities of different GHGs to trap heat in the atmosphere. They are based on the radiative forcing (heat-absorbing ability) and decay rate of each gas relative to that of CO_2. The GWP allows one to convert emissions of various GHGs into a common measure, which allows for aggregating the radiative impacts of various GHGs into a single measure denominated in CO_2 or C equivalents. Extensive discussion of GWPs can be found in the documents of the Intergovernmental Panel on Climate Change (IPCC). In 2001, the IPCC updated its estimates of GWPs for key GHGs, but these estimates are still under debate. As a result, the FASOMGHG model continues to use the 1996 GWPs for the GHGs covered by the model:

- $CO_2 = 1$

- CH_4 = 21
- N_2O = 310

When CO_2 equivalent results are converted to a C equivalent basis, a transformation is done based on the molecular weight of C in the CO_2. This means that the CO_2 equivalent quantities of gas are divided by 3.667 to compute the carbon equivalent quantities.

A list of all categories included in the model's GHG accounting appears in Table 13, totaling 57 categories. Brief summaries of the major categories are presented in the subsections below.

Table 13. Categories of GHG Sources and Sinks in FASOMGHG

Forest_SoilSequest	Carbon in forest soil
Forest_LitterUnder	Carbon in litter and understory of forests that remain forests
Forest_ContinueTree	Carbon in trees of forests that remain forests
Forest_AfforestSoilSequest	Carbon in forest soil of afforested forests
Forest_AfforestLitterUnder	Carbon in litter and understory of afforested forests
Forest_AfforestTree	Carbon in trees of afforested forests
Forest_USpvtProduct	Carbon from U.S. private forests consumed producing forest products
Forest_USpubProduct	Carbon from U.S. public forests consumed producing forest products
Forest_CANProduct	Carbon in U.S. consumed but Canadian produced forest products
Forest_USExport	Carbon in U.S. produced but exported forest products
Forest_USImport	Carbon in U.S. consumed but imported from non-Canadian source
Forest_USFuelWood	Carbon in U.S. consumed fuelwood
Forest_USFuelResidue	Carbon in U.S. residue that is burned
Forest_USresidProduct	Carbon from U.S. residues consumed producing forest products
Forest_CANresidProduct	Carbon from Canadian residues consumed producing forest products
Carbon_For_Fuel	Carbon emissions from forest use of fossil fuel
Dev_Land_from_Ag	Carbon on land after it moves from agriculture into developed use
Dev_Land_from_Forest	Carbon on land after it moves from forest into developed use

(continued)

Table 13. Categories of GHG Sources and Sinks in FASOMGHG (continued)

AgSoil_CropSequest_Initial	Carbon in cropped agricultural soil with initial tillage
AgSoil_CropSequest_TillChange	Carbon in cropped agricultural soil with change in tillage
AgSoil_PastureSequest	Carbon in pastureland
Carbon_AgFuel	Carbon emissions from agricultural use of fossil fuels
Carbon_Dryg	Carbon emissions from grain drying
Carbon_Fert	Carbon emissions from fertilizer production
Carbon_Pest	Carbon emissions from pesticide production

Carbon_Irrg	Carbon emissions from water pumping
Carbon_Ethl_Offset	Carbon emission offset by conventional ethanol production
Carbon_Ethl_Haul	Carbon emissions in hauling for conventional ethanol production
Carbon_Ethl_Process	Carbon emissions in processing of conventional ethanol production
Carbon_CEth_Offset	Carbon emission offset by cellulosic ethanol production
Carbon_CEth_Haul	Carbon emissions in hauling for cellulosic ethanol production
Carbon_CEth_Process	Carbon emissions in processing of cellulosic ethanol production
Carbon_BioElec_Offset	Carbon emission offset from bioelecticity production
Carbon_BioElec_Haul	Carbon emissions in hauling for bioelecticity production
Carbon_BioElec_Process	Carbon emissions in processing of for bioelecticity production
Carbon_Biodiesel_Offset	Carbon emission offset from biodiesel production
Carbon_Biodiesel_Process	Carbon emissions in processing of biodiesel production
Methane_Liquidmanagement	Methane from emission savings from improved manure technologies
Methane_EntericFerment	Methane from enteric fermentation
Methane_Manure	Methane from manure management
Methane_RiceCult	Methane from rice cultivation
Methane_AgResid_Burn	Methane from agricultural residue burning
Methane_BioElec	Net change in methane emissions from bioelectricity relative to coal-fired
Methane_Biodiesel	Net change in methane emissions from biodiesel production relative to diesel
Methane_Ethl	Net change in methane emissions from ethanol production relative to gasoline
Methane_CEth	Net change in methane emissions from cellulosic ethanol production relative to gasoline
NitrousOxide_Manure	Livestock manure practices under managed soil categories under AgSoilMgmt
NitrousOxide_BioElec	Net change in nitrous oxide emissions from bioelectricity relative to coal-fired
NitrousOxide_Biodiesel	Net change in nitrous oxide emissions from biodiesel production relative to diesel

(continued)

Table 13. Categories of GHG Sources and Sinks in FASOMGHG (continued)

NitrousOxide_Ethl	Net change in nitrous oxide emissions from non-cellulosic ethanol processing relative to gasoline
NitrousOxide_CEth	Net change in nitrous oxide emissions from cellulosic ethanol processing relative to gasoline
NitrousOxide_Fert	Nitrous oxide emissions from nitrogen inputs including nitrogen fertilizer application practices, crop residue retention, and symbiotic nitrogen fixation under managed soil categories under AgSoilMgmt
NitrousOxide_Pasture	Nitrous oxide emissions from pasture
NitrousOxide_Histosol	Emissions from temperate histosol area
NitrousOxide_Volat	Indirect soils volatilization
NitrousOxide_Leach	Indirect soils leaching runoff
NitrousOxide_AgResid_Burn	Agricultural residue burning

Forest GHG Accounts

As identified in Table 13, forest GHG accounting includes carbon sequestered, carbon emitted, and fossil fuel-related carbon emissions avoided. Sequestration accounting encompasses carbon in standing (live and dead) trees, forest soils, the forest understory vegetation, forest floor including litter and large woody debris, and wood products both in use and in landfills. The sequestration accounting involves both increases and reductions in stocks, with changes in specific accounts to reflect land movement into forest use through afforesation, net growth of forests not of afforestation origin, and placement of products in long-lasting uses or landfills.[15] Reductions arise when land is migrated to agriculture or development and products decay in their current uses.

Forest-related emissions accounting includes GHGs emitted when fossil fuels are used in forest production. Forest-related GHG accounting calculates the estimated amount of fossil fuels (and associated GHG emissions) that are saved when wood products are combusted in place of fossil fuels, particularly when milling residues are burned to provide energy (generally for use at the mill). In addition, woody biomass may be used as a bioenergy feedstock.

Forest carbon accounts also include the carbon content of products imported into, or exported out of, the United States. In particular, there is explicit accounting for products:

- processed in and coming from Canada,
- imported from other countries, and
- exported to other countries.

These categories may or may not be included in an incentive scheme for GHG mitigation, as they will generally be accounted for elsewhere. Nonetheless, the accounts are included in the model in case they are needed for policy analysis.

Agricultural GHG Accounts

On the agricultural side, the categories tracked in the model are also listed in Table 13. Agricultural emissions arise from crop and livestock production, principally from:

- fossil fuel use,
- nitrogen fertilization usage,
- other nitrogen inputs to crop production,
- agricultural residue burning,

[15] In the case of wood product accounts, note that these accounts have increases in C sequestration when more products are made, but the forest carbon accounts are simultaneously reduced to account for C reduced by harvesting.

- rice production,
- enteric fermentation, and
- manure management.

In addition, changes in carbon sequestration are tracked within the model. Agricultural sequestration involves the amount of carbon sequestered in agricultural soils, due principally to choice of tillage, and irrigation along with changes to crop mix choice. Sequestration is also considered in terms of grasslands versus cropland/or mixed usage, where cropland can be moved to pasture use or vice versa. The sequestration accounting can yield either positive or negative quantities, depending on the direction of change in tillage between the three available options (conventional, conservation, or zero tillage) and irrigation choices, along with pasture land (grassland)/cropland conversions and movements between agriculture and forestry. With movements from forestry to agriculture, gains in the agricultural soil carbon account are typically more than offset by losses in the forest soil carbon account (e.g., forest soils typically store more carbon per acre than soils in agricultural uses). When moving from agricultural land uses to forestland, on the other hand, there are typically net increases in soil carbon sequestration.

As with forest products, certain agricultural commodities can also be used as bioenergy feedstocks.

Bioenergy GHG Accounts

Selected agricultural and forestry commodities can be used as feedstocks for biofuel production processes in FASOMGHG, possibly affecting fossil fuel usage and associated GHG emissions after accounting for emissions during hauling and processing of bioenergy feedstocks. Four major forms of bioenergy production are included:

- Biodiesel: usage of canola oil, corn oil, lard, poultry fat, soybean oil, tallow, or yellow grease in the production of biodiesel, which replaces petroleum-based diesel fuel
- Bioelectricity: usage of bagasse, crop residues, energy sorghum, hybrid poplar, lignin, manure, miscanthus, sweet sorghum pulp, switchgrass, willow, wood chips, logging residues, or milling residues as inputs to electric generating power plants in place of coal (through either cofiring or dedicated biomass plants)
- Cellulosic ethanol: usage of bagasse, crop residues, energy sorghum, hybrid poplar, miscanthus, sweet sorghum pulp, switchgrass, willow, wood chips, logging residues, or milling residues to produce cellulosic ethanol, which replaces gasoline
- Starch or sugar-based ethanol: usage of barley, corn, oats, rice, sorghum, sugar, sweet sorghum, or wheat for conversion to ethanol and replacement of gasoline

In all of these cases, the GHG reduction provided by bioenergy production is equal to the GHGs emitted from burning and producing the fossil fuel replaced less the GHG emissions of producing, transporting, and processing the bioenergy feedstock.

Developed Land GHG

FASOMGHG incorporates exogenous data that specify the rate of conversion of agriculture and forestry lands to nonagricultural and nonforestry developed uses. Simplified accounting is employed to estimate the carbon sequestered on these lands.

2.9 Other Environmental Impacts

FASOMGHG considers a number of environmental indicators above and beyond the GHG accounts. The main components are nitrogen and phosphorus application and runoff, soil erosion, irrigation water usage, and a number of descriptions of total resource use and activity within the agricultural and forestry sectors (e.g., total land use, total pasture use, manure load, livestock numbers, total afforestation).

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3. METHODS USED TO DEVELOP ESTIMATES OF OZONE EFFECTS ON CROP AND FOREST PRODUCTIVITY

Incorporating the impacts of different ambient ozone concentration levels into FASOMGHG requires determining crop yield and forest productivity impacts associated with changes in concentrations. Productivity impacts are required for each crop/region and forest type/region combination included within the model. In this section, we describe our methods for calculating relative yield losses (RYL) and relative yield gains (RYG) of crops and tree species under alternative ambient ozone concentration levels.

These data are essential for our market analysis because crop and forest yields play an important role in determining the economic returns to agricultural and forest production activities. Thus, they affect landowner decisions regarding land use, crop mix, forest rotation lengths, and production practices, among others. Alterations in ambient ozone concentration levels will therefore change the supply curves of U.S. agricultural and forest commodities, resulting in new market equilibriums. Because both the changes in ozone concentrations and the distribution of ozone-sensitive crops and tree species vary spatially, there may be substantial differences in the net impacts across regions. There may also be distributional impacts as commodity production shifts between regions in response to changes in relative productivity.

3.1 Ambient Ozone Concentration Data

We are using enhanced Voronoi Neighbor Averaging W126 ozone indices (W126_eVNA) provided by EPA to serve as the baseline for this analysis. These values are assumed to represent current ozone concentration levels. Based on information provided by EPA, the W126_eVNA ozone surface is built based on monitor data fused with Community Multi-scale Air Quality (CMAQ) model-based gradient interpolations. The spatial resolution of the ozone surface in ArcGIS Shapefile format is 12km.

County-level W126_eVNA values were extracted from the W126_eVNA ozone surface using ArcGIS. Only the cropland- and forestland- portions of the latest W126 ozone surface are used to derive the county-level crop and forest W126 ozone levels, respectively. These weighting adjustments were made to better reflect the ozone concentration affecting the specific portions of each county containing forested land or cropland rather than basing county-level exposure on the ozone concentration across the whole county. Data from the 2006 National Land Cover Database (NLCD) are utilized to extract the cropland- and forestland- portions from the ozone surface.

In addition, EPA provided ozone concentration data for a scenario corresponding to reduced ambient ozone standards consistent with meeting the ozone standard (RB_ID2). This scenario is used for comparison purposes to assess the impacts of reducing ambient ozone concentrations. As additional ozone concentration data surfaces become available from EPA, we will use those surfaces in our analyses as well.

3.2 Calculation of Relative Yield Loss

The W126 ozone concentration-response (CR) functions for crops and tree seedlings under the median ozone concentration in the 2007 EPA technical report (Lehrer et al. 2007) are used to calculate the relative yield losses (RYL) for crops and tree species under each ambient ozone concentration scenario used in this analysis.

Relative Yield Loss for Crops

Specifically, for crops, we first calculate the FASOMGHG subregion RYLs for crops that have W126 ozone CR functions using the calculated ozone concentrations in each of the 63 FASOMGHG subregions under each ozone concentration scenario. For those crops that do not have W126 ozone CR functions, we assign them RYLs for each scenario based on the crop proxy mapping shown in Table 14. This crop mapping was based on the authors' judgment and previous experience.[16] In addition, for oranges, rice, and tomatoes, which have ozone CR functions but that are not W126-based (they are defined based on alternative measures of ozone levels), we directly used the median relative yield gain (RYG) values under "13ppm" ozone level reported in Table G-7 of Lehrer et al. (2007). More details on RYG are presented below.

Table 14. Mapping of Ozone Impacts on Crops to FASOMGHG Crops

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

[16] Also, note that FASOMGHG defines short-rotation woody crops such as hybrid poplar and willow as crops. Ozone impacts on short-rotation woody crops were based on ozone RYLs for aspen.

Moreover, for crops that have county-level production data and W126 ozone CR functions (W126 crops), we update their RYLs obtained above by using production-weighted RYLs. The 2007 USDA Census of Agriculture county-level production data for W126 crops – including corn, sorghum, soybeans, cotton, and winter wheat (used for hard red winter wheat and soft red winter wheat) – are utilized to derive the weighted FASOMGHG subregion RYLs, following the formula below.

$$wRYL_{ik} = Ozone\ CR\ Function_k\left(\frac{\sum_j Prod_{ijk} * W126_{ij}}{\sum_j Prod_{ijk}}\right)$$

where *i* denotes FASOMGHG subregion, *j* indicates county, and *k* represents W126 crop. Ozone CR $Function_k$ refers to the ozone concentration response function for crop *k*. $Prod_{ijk}$ represents the county-level production level of crop *k*, and $W126_{ij}$ the cropland-based ozone value for county *j* in subregion *i*. Finally, $wRYL_{ik}$ stands for the weighted FASOMGHG subregion RYL for crop *k*. RYLs are calculated for each ozone concentration level being considered.

Relative Yield Loss for Trees

The ozone CR functions for tree seedlings were utilized to calculate RYLs for FASOMGHG trees over their whole life span. To derive the FASOMGHG region-level RYLs for trees under each ozone concentration scenario, we used FASOMGHG region ozone values and the mapping in Table 15.

Specifically, the FASOMGHG region-level RYLs are first calculated for each tree species listed in first column of Table 15. Then, a simple average of RYLs for each tree species mapped to a FASOMGHG forest type in a given region is calculated. The mapping of tree species to FASOMGHG forest types is based on *"Atlas of United States Trees"* by Elbert L. Little, Jr. (Little, 1971, 1976, 1977, 1978). Note that crop RYLs are generated at the FASOMGHG subregion level, whereas forest RYLs are calculated at the FASOMGHG region-level, consistent with the greatest level of regional disaggregation available for these sectors within FASOMGHG.

Table 15. Mapping of Ozone Impacts on Forests to FASOMGHG Forest Types

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

	Planted Pine	
Virginia Pine, Eastern White Pine	Softwood	NE

3.3 Calculation of Relative Yield Gain

As described in Lehrer et al. (2007), the RYL is the relative yield loss compared with the baseline yield under a “clean air” environment. For implementation within FASOMGHG, we calculate the relative yield gain (RYG) for crops and trees under reduced ambient ozone concentrations. Thus, we need to have RYLs under baseline and alternative concentrations in order to calculate the RYG of improving ozone concentrations.

To obtain the relative yield gain (RYG) for crops and trees under an improved environment, we will need the RYLs under current and improved ambient concentrations. For example, to derive RYG under the “rollback” scenario RB_ID2 relative to current conditions, we use the use the formula below:

$$RYG_{rollback} = \frac{1 - RYL_{rollback}}{1 - RYL_{current}} - 1 = \frac{RYL_{current} - RYL_{rollback}}{1 - RYL_{current}}$$

The FASOMGHG subregion-level crop RYGs and the FASOMGHG region-level tree RYGs under “improved” environments are thus obtained.

3.4 Conducting Model Scenarios in FASOMGHG

The current crop/forest budgets included in FASOMGHG are considered as the budgets under current ambient ozone concentrations. To model the effects of changing ozone concentrations on the agricultural and forest sectors, two primary scenarios were constructed and run through the model:

(1) Base scenario, where no RYGs of crops and trees are considered (assumed to be consistent with current ambient ozone concentration levels);

(2) “rollback” scenario, where crop and forest yields are assumed to increase by the percentages calculated in $RYG_{rollback}$.

The time scope of the FASOMGHG model that has been used to date for these analyses is 2000 – 2050, solved in five-year timesteps. The crop and tree RYGs are introduced into the model starting in period 2010 and they remain constant at those percentage reductions relative to baseline for the rest of the modeling period.

By comparing the market equilibriums under different scenarios, we can calculate the welfare and GHG impacts of proposed ozone standards on U.S. agricultural and forest sector, including changes in consumer and producer welfare, land use, and GHG mitigation potential over time. Additional scenarios will be run as data become available for more ozone concentration surfaces.

4. DATA INPUTS

Data on derived relative yield losses (RYLs) and gains (RYGs) for crops and trees are presented in this section. Table 16 shows the subregion-specific RYL estimates for proxy crops under current and the rollback ozone environments. These RYLs were calculated using the cropland ozone surfaces. Table 14 in Section 3 presents the mapping of proxy crops to FASOMGHG crops and Table 7 in Section 2 provided definitions of FASOMGHG regions. As expected, yield losses are smaller under the rollback scenario.

Table 16. Percentage Relative Yield Loss Estimates for Proxy Crops

‘		Potatoes		Winter	Wheat	Sorghum		Soybeans		Aspen	
Region	SubReg	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
CB	IllinoisN	4.37	3.83	1.10	0.85	0.18	0.14	2.81	2.43	4.11	3.61
	IllinoisS	6.41	5.20	2.32	1.54	0.33	0.23	4.30	3.41	5.98	4.87
	IndianaN	5.93	5.16	1.99	1.51	0.29	0.23	3.94	3.38	5.54	4.83
	IndianaS	7.79	6.13	3.41	2.13	0.45	0.30	5.34	4.09	7.24	5.72
	IowaCent	2.94	2.93	0.50	0.50	0.09	0.09	1.81	1.81	2.77	2.77
	IowaNE	5.89	4.87	1.96	1.36	0.29	0.21	3.91	3.17	5.50	4.57
	IowaS	2.90	2.77	0.49	0.45	0.09	0.08	1.78	1.70	2.74	2.62
	IowaW	2.97	2.96	0.52	0.51	0.09	0.09	1.83	1.82	2.81	2.79
	Missouri	5.78	4.68	1.89	1.25	0.28	0.20	3.83	3.03	5.40	4.39
	OhioNW	8.20	5.38	3.77	1.65	0.49	0.25	5.66	3.54	7.62	5.03
	OhioS	8.79	5.66	4.32	1.82	0.55	0.27	6.11	3.75	8.16	5.29
GP	Kansas	5.79	5.24	1.90	1.56	0.28	0.24	3.84	3.44	5.41	4.90
	Nebraska	2.94	2.50	0.50	0.37	0.09	0.07	1.81	1.51	2.78	2.37
	North Dakota	1.69	1.69	0.17	0.17	0.04	0.04	0.98	0.98	1.61	1.61
	South Dakota	2.26	2.24	0.30	0.30	0.06	0.06	1.35	1.34	2.14	2.13

Table 16. Percentage Relative Yield Loss Estimates for Proxy Crops (continued)

‘		Potatoes		Winter	Wheat	Sorghum		Soybeans		Aspen	

Region	SubReg	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
LS	Michigan	5.55	4.82	1.75	1.33	0.26	0.21	3.66	3.14	5.19	4.52
	Minnesota	2.46	2.46	0.36	0.36	0.07	0.07	1.48	1.48	2.33	2.33
	Wisconsin	3.82	3.73	0.84	0.80	0.14	0.14	2.42	2.36	3.59	3.51
NE	Connecticut	6.83	3.82	2.63	0.84	0.36	0.14	4.62	2.42	6.37	3.59
	Delaware	10.06	4.45	5.65	1.13	0.69	0.18	7.11	2.86	9.32	4.17
	Maine	1.39	1.32	0.12	0.11	0.03	0.03	0.79	0.75	1.33	1.27
	Maryland	11.09	5.86	6.84	1.95	0.81	0.28	7.93	3.89	10.26	5.47
	Massachusetts	5.85	3.58	1.94	0.74	0.28	0.13	3.89	2.25	5.47	3.37
	New Hampshire	2.99	2.58	0.52	0.39	0.10	0.08	1.85	1.56	2.83	2.44
	New Jersey	11.69	5.60	7.59	1.78	0.88	0.26	8.41	3.70	10.81	5.23
	New York	4.68	3.87	1.25	0.87	0.20	0.15	3.03	2.46	4.38	3.64
	Pennsylvania	6.88	4.99	2.67	1.42	0.37	0.22	4.65	3.26	6.41	4.68
	Rhode Island	7.11	4.76	2.85	1.30	0.39	0.20	4.83	3.09	6.63	4.46
	Vermont	3.11	2.96	0.56	0.51	0.10	0.09	1.92	1.83	2.93	2.80
	West Virginia	6.49	5.64	2.38	1.80	0.33	0.27	4.36	3.73	6.05	5.27
PNWE	Oregon	2.28	2.13	0.31	0.27	0.06	0.06	1.37	1.27	2.16	2.03
	Washington	1.94	1.85	0.23	0.20	0.05	0.04	1.14	1.08	1.85	1.76
PSW	CaliforniaN	14.02	5.04	10.86	1.45	1.20	0.22	10.32	3.29	12.94	4.72
	CaliforniaS	12.91	6.32	9.23	2.26	1.05	0.32	9.41	4.23	11.93	5.90
RM	Arizona	7.23	5.68	2.94	1.83	0.40	0.27	4.92	3.76	6.73	5.31
	Colorado	7.69	5.56	3.33	1.75	0.44	0.26	5.27	3.67	7.16	5.19
	Idaho	6.57	5.06	2.44	1.46	0.34	0.22	4.42	3.31	6.13	4.74
	Montana	3.71	3.68	0.80	0.78	0.14	0.13	2.34	2.32	3.49	3.46

Table 16. Percentage Relative Yield Loss Estimates for Proxy Crops (continued)

‘		Potatoes		Winter	Wheat	Sorghum		Soybeans		Aspen	
Region	SubReg	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
RM	Nevada	6.36	5.15	2.28	1.51	0.32	0.23	4.26	3.37	5.93	4.82

	New Mexico	6.93	6.80	2.71	2.61	0.37	0.36	4.69	4.59	6.46	6.34
	Utah	10.31	8.71	5.92	4.25	0.72	0.54	7.31	6.06	9.55	8.09
	Wyoming	6.95	5.12	2.73	1.49	0.37	0.23	4.71	3.35	6.48	4.79
SC	Alabama	6.96	5.70	2.73	1.84	0.38	0.27	4.71	3.77	6.48	5.32
	Arkansas	6.88	5.37	2.67	1.64	0.37	0.25	4.65	3.53	6.41	5.03
	Kentucky	8.37	7.10	3.93	2.84	0.51	0.39	5.79	4.82	7.78	6.62
	Louisiana	5.31	4.57	1.61	1.20	0.24	0.19	3.49	2.95	4.97	4.29
	Mississippi	5.98	5.30	2.02	1.60	0.29	0.24	3.98	3.48	5.58	4.96
	Tennessee	9.88	6.85	5.45	2.65	0.67	0.37	6.97	4.63	9.16	6.39
	Eastern Texas	5.28	3.55	1.59	0.73	0.24	0.13	3.47	2.23	4.94	3.34
SE	Florida	5.50	5.24	1.72	1.56	0.26	0.24	3.63	3.44	5.14	4.90
	Georgia	7.13	5.42	2.87	1.67	0.39	0.25	4.84	3.57	6.64	5.07
	North Carolina	8.78	6.74	4.31	2.56	0.55	0.36	6.11	4.55	8.15	6.28
	South Carolina	7.76	6.22	3.38	2.19	0.45	0.31	5.32	4.16	7.22	5.81
	Virginia	7.27	5.59	2.97	1.77	0.40	0.26	4.95	3.69	6.77	5.23
SW	Oklahoma	7.30	6.24	3.00	2.21	0.41	0.31	4.97	4.18	6.80	5.83
	TX Central Blacklands	5.30	3.20	1.60	0.60	0.24	0.11	3.48	1.99	4.96	3.02
	TX Coastal Bend	4.99	3.30	1.42	0.63	0.22	0.11	3.25	2.06	4.67	3.11
	TX Edwards Plateau	2.98	2.24	0.52	0.30	0.10	0.06	1.84	1.34	2.82	2.13
	TX High Plains	5.57	5.22	1.76	1.55	0.26	0.23	3.67	3.42	5.20	4.88
	TX Rolling Plains	4.21	2.60	1.02	0.40	0.17	0.08	2.70	1.58	3.96	2.46
	TX South	2.44	2.24	0.35	0.30	0.07	0.06	1.48	1.34	2.32	2.13
	TX Trans Pecos	5.88	5.22	1.96	1.55	0.29	0.24	3.91	3.43	5.49	4.89

While the RYLs for proxy crops were calculated for each FASOMGHG subregion so they could be used in calculating the yield losses for other crops that occur in those regions, the weighted RYLs that were used for corn, cotton, winter wheat (hard winter wheat and soft red winter wheat), sorghum, and soybeans in the model scenarios were calculated for their production regions only (see Table 17). The values calculated in all 63 regions were weighted by production for these crops, which eliminated regions with no production.

Table 17. Weighted Percentage Relative Yield Loss Estimates for Select Major Crops

	Corn		Cotton		Winter	Wheat	Sorghum		Soybeans	

Region	SubReg	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
CB	IllinoisN	0.06	0.04			1.09	0.78	0.20	0.15	2.84	2.47
	IllinoisS	0.15	0.08			2.61	1.68	0.36	0.27	4.29	3.38
	IndianaN	0.12	0.08			2.12	1.72	0.18	0.10	3.98	3.42
	IndianaS	0.23	0.13			3.19	1.91	0.37	0.25	5.14	3.97
	IowaCent	0.02	0.02			0.67	0.65	0.11	0.11	1.79	1.78
	IowaNE	0.09	0.06			2.62	1.86	0.47	0.30	4.09	3.30
	IowaS	0.02	0.02			0.67	0.56	0.09	0.09	1.71	1.65
	IowaW	0.02	0.02			0.54	0.52	0.10	0.09	1.84	1.83
	Missouri	0.16	0.09	6.65	4.82	2.75	1.83	0.42	0.30	4.27	3.31
	OhioNW	0.29	0.10			3.45	1.45	0.00	0.00	5.56	3.37
	OhioS	0.41	0.12			4.66	1.77	0.00	0.00	6.87	3.92
GP	Kansas	0.14	0.11	3.86	3.84	1.85	1.62	0.23	0.21	3.25	2.67
	Nebraska	0.02	0.01			0.84	0.53	0.08	0.07	1.39	1.31
	North Dakota	0.00	0.00			0.19	0.19			0.77	0.77
	South Dakota	0.01	0.01			0.31	0.30	0.06	0.06	1.34	1.34
LS	Michigan	0.12	0.09			1.65	1.30	0.31	0.25	3.91	3.33
	Minnesota	0.02	0.02			0.21	0.21	0.00	0.00	1.57	1.57
	Wisconsin	0.05	0.04			1.07	0.94	0.15	0.11	2.51	2.42
NE	Connecticut	0.18	0.04			0.00	0.00			0.00	0.00
	Delaware	0.46	0.06			5.77	1.18	0.61	0.14	7.17	2.91

Table 17. Weighted Percentage Relative Yield Loss Estimates for Select Major Crops (continued)

		Corn		Cotton		Winter	Wheat	Sorghum		Soybeans	
Region	SubReg	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
NE	Maine	0.00	0.00			0.00	0.00			0.60	0.60
	Maryland	0.67	0.12			7.73	1.96	0.85	0.24	8.15	3.74
	Massachusetts	0.10	0.02			0.00	0.00			0.00	0.00
	New Hampshire	0.02	0.01			0.00	0.00				

	New Jersey	0.69	0.12			9.02	1.90	0.85	0.28	9.26	3.94
	New York	0.09	0.05			1.68	1.12	0.17	0.15	3.56	2.85
	Pennsylvania	0.27	0.11			3.85	1.86	0.53	0.27	5.51	3.64
	Rhode Island	0.00	0.00								
	Vermont	0.03	0.02			0.70	0.61	0.00	0.00	2.11	1.97
	West Virginia	0.18	0.12			3.70	2.42	0.00	0.00	5.85	4.49
PNWE	Oregon	0.03	0.02			0.29	0.25	0.00	0.00	0.00	0.00
	Washington	0.01	0.01			0.24	0.22			0.00	0.00
PSW	CaliforniaN	0.73	0.06	13.81	3.14	11.02	1.39	0.60	0.14		
	CaliforniaS	0.00	0.00	10.97	3.62	16.51	2.27	0.00	0.00		
RM	Arizona	0.24	0.22	3.89	2.73	2.79	1.92	0.37	0.24		
	Colorado	0.20	0.08			2.73	1.52	0.41	0.34	4.27	3.02
	Idaho	0.20	0.11			1.60	0.99				
	Montana	0.04	0.04			0.93	0.92			0.00	0.00
	Nevada	0.00	0.00			1.90	1.79	0.00	0.00		
	New Mexico	0.18	0.17	3.93	3.72	2.55	2.53	0.30	0.29	0.00	0.00
	Utah	0.55	0.32			6.61	3.82	0.00	0.00		
	Wyoming	0.19	0.07			2.65	1.46				
SC	Alabama	0.26	0.17	3.91	3.18	3.31	2.29	0.34	0.27	5.56	4.42
	Arkansas	0.23	0.12	4.77	3.22	3.04	1.71	0.45	0.28	5.27	3.78

Table 17. Weighted Percentage Relative Yield Loss Estimates for Select Major Crops (continued)

		Corn		Cotton		Winter	Wheat	Sorghum		Soybeans	
Region	SubReg	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
SC	Kentucky	0.34	0.22			4.62	3.25	0.56	0.42	6.11	4.98
	Louisiana	0.06	0.06	2.13	2.00	1.43	1.03	0.20	0.16	3.49	2.93
	Mississippi	0.14	0.12	3.57	3.11	2.98	2.30	0.46	0.35	4.66	4.16
	Tennessee	0.39	0.19	5.69	3.77	5.01	2.80	0.61	0.39	6.68	4.82
	Eastern Texas	0.10	0.03	2.59	1.29	1.91	1.23	0.22	0.11	4.38	3.59

SE	Florida	0.11	0.09	2.93	2.49	1.78	1.09	0.22	0.17	3.51	3.01
	Georgia	0.14	0.11	3.22	2.92	2.17	1.65	0.29	0.24	3.81	3.15
	North Carolina	0.26	0.17	4.85	4.09	4.21	2.69	0.53	0.38	5.57	4.66
	South Carolina	0.20	0.15	4.07	3.44	3.03	2.31	0.42	0.32	4.73	4.20
	Virginia	0.33	0.13	4.94	3.86	5.22	2.40	0.26	0.21	6.40	4.27
SW	Oklahoma	0.29	0.25	2.57	1.70	2.77	2.07	0.45	0.40	5.58	5.00
	TX Central Blacklands	0.10	0.03	2.57	1.49	2.37	0.63	0.26	0.11	3.97	1.84
	TX Coastal Bend	0.07	0.03	2.11	1.71	1.25	0.74	0.18	0.13	3.18	1.79
	TX Edwards Plateau	0.03	0.02	1.22	0.87	0.48	0.27	0.09	0.06	0.00	0.00
	TX High Plains	0.19	0.17	2.32	2.08	2.74	2.49	0.27	0.24	4.08	3.81
	TX Rolling Plains	0.13	0.04	1.50	1.01	0.82	0.34	0.12	0.06	0.00	0.00
	TX South	0.01	0.01	0.77	0.73	0.20	0.18	0.04	0.04	0.86	0.86
	TX Trans Pecos	0.00	0.00	3.28	2.70	2.41	2.28	0.23	0.20	0.00	0.00

As noted above, to implement scenarios with alternative ozone impacts, we then use the differences in RYLs to calculate RYGs as presented in Tables 18 and 19. Among major crops, winter wheat and soybeans are more sensitive to ambient ozone concentration levels than corn and sorghum, implying that they would benefit more from reductions in ozone concentrations in terms of RYGs.

Table 18. Percentage Relative Yield Gain Estimates for Proxy Crops under Rollback Scenario

Region	Subregion	Potatoes	Winter Wheat	Sorghum	Soybeans	Aspen
CB	IllinoisN	0.56	0.25	0.03	0.39	0.52
	IllinoisS	1.29	0.80	0.09	0.93	1.18
	IndianaN	0.82	0.49	0.06	0.59	0.75
	IndianaS	1.80	1.33	0.15	1.32	1.64
	IowaW	0.01	0.01	0.00	0.01	0.01
	IowaCent	0.00	0.00		0.00	0.00
	IowaNE	1.07	0.62	0.08	0.77	0.99
	IowaS	0.13	0.04	0.01	0.09	0.12
	Missouri	1.16	0.65	0.08	0.83	1.06
	OhioNW	3.07	2.21	0.25	2.24	2.80
	OhioS	3.42	2.61	0.28	2.52	3.12
GP	Kansas	0.59	0.35	0.04	0.42	0.54
	Nebraska	0.46	0.14	0.02	0.30	0.42
	South Dakota	0.02	0.01	0.00	0.01	0.02
LS	Michigan	0.77	0.43	0.05	0.55	0.70
	Wisconsin	0.09	0.04	0.01	0.06	0.08
NE	Connecticut	3.24	1.84	0.22	2.31	2.96
	Delaware	6.24	4.78	0.51	4.57	5.68
	Maine	0.07	0.01	0.00	0.04	0.07
	Maryland	5.88	5.25	0.53	4.38	5.34
	Massachusetts	2.42	1.23	0.16	1.70	2.22
	New Hampshire	0.43	0.13	0.02	0.29	0.40
	New Jersey	6.90	6.29	0.63	5.15	6.25
	New York	0.84	0.39	0.05	0.59	0.77
	Pennsylvania	2.02	1.28	0.15	1.46	1.85
	RhodeIsland	2.53	1.60	0.19	1.83	2.32
	Vermont	0.15	0.05	0.01	0.10	0.14
	West Virginia	0.91	0.59	0.07	0.66	0.83
RM	Arizona	1.67	1.15	0.13	1.22	1.52
	Colorado	2.31	1.63	0.18	1.69	2.11
	Idaho	1.62	1.00	0.12	1.17	1.48
	Montana	0.04	0.01	0.00	0.03	0.04
	Nevada	1.29	0.79	0.09	0.93	1.18
	New Mexico	0.14	0.10	0.01	0.10	0.13

Table 18. Percentage Relative Yield Gain Estimates for Proxy Crops under Rollback Scenario (continued)

Region	Subregion	Potatoes	Winter Wheat	Sorghum	Soybeans	Aspen
RM	Utah	1.78	1.77	0.17	1.35	1.61
	Wyoming	1.98	1.27	0.15	1.43	1.81
PSW	CaliforniaN	10.45	10.56	0.99	7.84	9.45
	CaliforniaS	7.57	7.68	0.73	5.71	6.84
PNWE	Oregon	0.15	0.04	0.01	0.10	0.14
	Washington	0.09	0.02	0.00	0.06	0.09
SC	Alabama	1.36	0.91	0.10	0.99	1.24
	Arkansas	1.62	1.06	0.12	1.17	1.48
	Kentucky	1.38	1.13	0.12	1.03	1.26
	Louisiana	0.78	0.42	0.05	0.56	0.72
	Mississippi	0.72	0.44	0.05	0.52	0.66
	Tennessee	3.36	2.96	0.31	2.51	3.05
	Eastern Texas	1.83	0.87	0.11	1.28	1.68
SE	Florida	0.28	0.16	0.02	0.20	0.25
	Georgia	1.84	1.23	0.14	1.34	1.69
	North Carolina	2.24	1.83	0.20	1.66	2.04
	South Carolina	1.67	1.23	0.14	1.23	1.52
	Virginia	1.81	1.24	0.14	1.32	1.65
SW	Oklahoma	1.14	0.82	0.09	0.84	1.04
	TX High Plains	0.37	0.21	0.03	0.26	0.34
	TX Rolling Plains	1.68	0.63	0.09	1.15	1.56
	TX Central Blacklands	2.22	1.02	0.14	1.55	2.04
	TX Edwards Plateau	0.76	0.22	0.04	0.51	0.71
	TX Coastal Bend	1.78	0.80	0.11	1.24	1.64
	TX South	0.21	0.05	0.01	0.14	0.19
	TX Trans Pecos	0.70	0.41	0.05	0.50	0.64

Thus, FASOMGHG crops mapped to winter wheat or soybeans as proxy crops tend to have much larger RYGs than other crops, as shown in Table 18.

The magnitude of RYGs essentially depends on two factors: one is the sensitivity of the (proxy) crop to its ambient ozone concentration level, and the other is the difference between the “current” and the “rollback” ozone levels. For subregions Minnesota and North Dakota, the RYG estimates are virtually zero because the room for air quality improvement in these subregions is quite limited.

Table 19 shows the weighted RYGs for crops that have county-level production information under the Rollback scenario. RYGs for California appear to be much larger than other subregions – this largely reflects the significant room for improvement in ozone concentrations in the PSW region. Major crops including corn and sorghum are estimated to incur less positive effects from the improved Rollback environments – due to their relatively moderate sensitivities to ambient ozone concentration levels.

Table 19. Weighted Percentage Relative Yield Gain Estimates for Select Major Crops under Rollback Scenario

Region	Subregion	Corn	Cotton	Winter Wheat	Sorghum	Soybeans
CB	IllinoisN	0.02		0.32	0.04	0.38
	IllinoisS	0.07		0.95	0.10	0.95
	IndianaN	0.04		0.42	0.08	0.58
	IndianaS	0.10		1.32	0.12	1.23
	IowaW			0.02	0.01	0.01
	IowaCent			0.02		0.00
	IowaNE	0.03		0.79	0.17	0.82
	IowaS	0.00		0.11		0.07
	Missouri	0.07	1.96	0.95	0.12	1.00
	OhioNW	0.19		2.08		2.33
	OhioS	0.29		3.03		3.17
GP	Kansas	0.03	0.02	0.23	0.02	0.60
	Nebraska	0.00		0.32	0.01	0.08
	South Dakota			0.01	0.01	0.00
LS	Michigan	0.03		0.36	0.06	0.61
	Wisconsin	0.00		0.12	0.04	0.10
NE	Connecticut	0.14				
	Delaware	0.41		4.87	0.47	4.59
	Maine					0.00
	Maryland	0.55		6.25	0.61	4.80
	Massachusetts	0.08				
	New Hampshire	0.01				
	New Jersey	0.57		7.83	0.56	5.86
	New York	0.03		0.57	0.02	0.73
	Pennsylvania	0.16		2.07	0.25	1.98
	Vermont	0.00		0.09		0.14
	West Virginia	0.06		1.32		1.44

Table 19. Weighted Percentage Relative Yield Gain Estimates for Select Major Crops under Rollback Scenario (continued)

Region	Subregion	Corn	Cotton	Winter Wheat	Sorghum	Soybeans
RM	Arizona	0.02	1.21	0.90	0.14	
	Colorado	0.11		1.25	0.08	1.30
	Idaho	0.09		0.63		
	Montana	0.00		0.01		
	Nevada			0.11		
	New Mexico	0.00	0.22	0.02	0.01	
	Utah	0.24		2.98		
	Wyoming	0.11		1.22		
PSW	CaliforniaN	0.67	12.38	10.82	0.46	
	CaliforniaS		8.26	17.05		
PNWE	Oregon	0.01		0.04		
	Washington	0.00		0.02		
SC	Alabama	0.09	0.75	1.05	0.07	1.20
	Arkansas	0.11	1.63	1.37	0.18	1.57
	Kentucky	0.12		1.44	0.14	1.21
	Louisiana	0.01	0.13	0.41	0.04	0.58
	Mississippi	0.02	0.48	0.70	0.10	0.53
	Tennessee	0.20	2.04	2.33	0.22	1.99
	Eastern Texas	0.07	1.34	0.69	0.11	0.82
SE	Florida	0.02	0.45	0.71	0.05	0.52
	Georgia	0.03	0.30	0.54	0.05	0.69
	North Carolina	0.09	0.80	1.59	0.15	0.96
	South Carolina	0.05	0.66	0.74	0.10	0.55
	Virginia	0.20	1.13	2.97	0.05	2.28
SW	Oklahoma	0.04	0.89	0.72	0.05	0.61
	TX High Plains	0.02	0.24	0.25	0.03	0.28
	TX Rolling Plains	0.09	0.50	0.49	0.06	
	TX Central	0.07	1.11	1.78	0.15	2.21
	TX Edwards Plateau	0.01	0.36	0.21	0.03	
	TX Coastal Bend	0.04	0.41	0.51	0.05	1.43
	TX South	0.00	0.04	0.02	0.00	0.00
	TX Trans Pecos		0.60	0.13	0.03	

The region-specific RYLs for softwood and hardwood tree species upon which the RYGs for FASOMGHG forest types were derived are presented in Tables 20 and 21, respectively. Black Cherry is the most sensitive of the tree species examined.

Table 20. Percentage Relative Yield Loss Estimates for Softwood Tree Species by Region

	Douglas Fir		Eastern White Pine		Ponderosa Pine		Virginia Pine	
Region	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
CB			4.97	3.56				
LS			2.19	2.08				
NE			3.50	2.57			0.49	0.41
PNWE					1.10	1.04		
PNWW	0.00	0.00			1.16	1.09		
PSW					5.22	2.71		
RM					4.64	4.04		
SC							0.62	0.52
SE			6.45	4.37			0.72	0.56

Table 21. Percentage Relative Yield Loss Estimates for Hardwood Tree Species by Region

	Black Cherry		Tulip Poplar		Quaking Aspen		Red Maple		Sugar Maple		Red Alder	
Region	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback	Current	Rollback
CB	23.86	19.95	3.56	2.34	5.55	4.35	0.91	0.69	0.08	0.02		
LS	15.25	14.84	1.26	1.18	3.04	2.94	0.46	0.44	0.00	0.00		
NE	19.74	16.69	2.28	1.55	4.29	3.43	0.68	0.52	0.02	0.01		
PNWE											0.79	0.75
PNWW											0.85	0.79
PSW											4.05	2.04
RM					6.72	5.83						
SC	24.30	20.65	3.72	2.53			0.94	0.73				
SE	27.40	22.28	4.96	3.03			1.14	0.82				

The derived RYL and RYG estimates for FASOMGHG forest types are presented in Table 22. The upland hardwood forest in the South Central and the South West regions appear to have the largest RYGs among the various forest types. In addition, softwood and hardwood forests in the PSW region would incur relatively larger yield increases than other forest types.

Table 22. Percentage Relative Yield Loss and Gain Estimates for FASOMGHG Forest Types by Region

Forest Type	Region	RYL		RYG
		Current	Rollback	Rollback
Softwood				
Douglas Fir	PNWW	0.00	0.00	0.00
Natural Pine	SC	0.62	0.52	0.11
Natural Pine	SE	3.51	2.41	1.17
Oak-Pine	SC	0.62	0.52	0.11
Oak-Pine	SE	3.58	2.47	1.19
Other Softwood	PNWW	1.16	1.09	0.07
Planted Pine	SC	0.62	0.52	0.11
Planted Pine	SE	3.58	2.47	1.19
Softwood	CB	4.97	3.56	1.48
Softwood	LS	2.19	2.08	0.11
Softwood	NE	1.99	1.49	0.52
Softwood	RM	4.64	4.04	0.63
Softwood	PSW	5.22	2.71	2.65
Softwood	PNWE	1.10	1.04	0.06
Hardwood				
Bottomland Hardwood	SC	0.94	0.73	0.21
Bottomland Hardwood	SE	1.14	0.82	0.32
Hardwood	CB	6.79	5.47	1.59
Hardwood	LS	4.00	3.88	0.14
Hardwood	NE	5.40	4.44	1.12
Hardwood	RM	6.72	5.83	0.95
Hardwood	PSW	4.05	2.04	2.09
Hardwood	PNWW	0.85	0.79	0.05
Hardwood	PNWE	0.79	0.75	0.04
Upland Hardwood	SC	14.01	11.59	3.03
Upland Hardwood	SE	16.18	12.66	4.54

5. MODEL RESULTS

This section presents the model results reporting on changes in U.S. agricultural and forestry welfare, economic activities, land utilization, and GHG mitigation potential.

5.1 Welfare

Table 23 below shows the estimated welfare changes brought about by the Rollback scenario. Consumer and producer surplus in the forest sector are more affected by the Rollback environments than in the agricultural sector. In general, consumer surplus increases in both the forest and agricultural sectors as higher productivity tends to increase total production and reduce market prices. Because demand for most forestry and agricultural commodities is inelastic, producer surplus tends to decline with higher productivity as the effect of falling prices on profits more than outweighs the effects of higher production levels. Additional detail on the market effects is provided in the sections below.

Table 23. Changes in Welfare under the Rollback Scenario w.r.t. Base (Million $2004 U.S. Dollars)

Sector	Welfare Category	2010	2020	2030	2040
Forest	Consumer Surplus	1,804	1,977	3,567	4,082
Forest	Producer Surplus	-2,289	-1,917	-4,090	-4,503
Agriculture	Consumer Surplus	465	104	656	507
Agriculture	Producer Surplus	-2,221	0	-1,177	-26

5.2 Agricultural Sector

Changes in U.S. agricultural production and prices measured using Fisher Indices under the Rollback Scenario are presented in Table 24. As shown in the first half of the table, both (primary) crop and livestock production levels are projected to increase over the modeling periods, whereas their prices would decrease in general. The price index for all farm production including crop and livestock turns out to follow the crop price index more closely than the livestock price index, indicating the greater share of crop production in total value of farm production.

The second part of Table 24 displays the “secondary” production and price indices, covering crop and milk-based processed products (processed), crop-based feed mixes (mixed feeds), and meat products (meats). Again, in general the “secondary” production expands compared to the base case and prices fall.

Table 24. Agricultural Production and Price Fisher Indices under the Rollback Scenario (Base = 100)

	Production/Price	2010	2020	2030	2040
All Farm Products	Production	100.17	100.16	100.26	100.23

All Farm Products	Price	98.99	99.78	99.42	99.29
Crops	Production	100.35	100.30	100.36	100.38
Crops	Price	98.99	99.78	99.42	99.29
Livestock	Production	100.00	100.01	100.16	100.11
Livestock	Price	98.89	98.34	99.43	100.18
Processed	Production	100.03	100.03	100.04	100.07
Processed	Price	99.44	99.48	99.12	99.26
Mixed Feeds	Production	99.99	100.05	100.27	100.08
Mixed Feeds	Price	99.57	97.91	97.78	96.29
Meats	Production	99.98	100.03	100.29	100.10
Meats	Price	100.01	99.96	99.98	99.77

Table 25 shows the changes in crop acres under the Rollback scenario. Overall, there tends to be some reallocation of land from cotton and wheat to corn and soybeans, with small changes in either direction for other crops. In addition, compared with the base case, the estimated total cropped area is slightly smaller initially and larger in 2040. Intuitively, decreases in cropped area would be expected as the Rollback environment would induce crop yield increases and thus less cropland would be needed to meet the agricultural demand. However, land allocation also depends on relative returns across various uses and is also influenced by forest harvest timing. There is additional discussion of the changes in land allocation included later in this section.

Note that the sum of the crop-specific changes will not necessarily equal the total changes shown in Table 25 because there is some double-cropping reflected in the model (e.g., soybeans and winter barley).

Table 25. Changes in Crop Acreage under the Rollback Scenario w.r.t. Base, in Million Acres

Crop	2010	2020	2030	2040
Cotton	-0.12	-0.14	-0.14	-0.21
Corn	-0.04	0.23	0.02	0.03
Soybeans	0.37	0.37	0.21	0.43
Wheat, Soft White	0.05	-0.02	0.00	0.02
Wheat, Hard Red Winter	-0.10	-0.30	-0.29	-0.14
Wheat, Soft Red Winter	0.01	0.03	0.04	0.00
Wheat, Durum	-0.06	-0.12	0.01	0.05
Wheat, Hard Red Spring	0.05	-0.16	0.00	0.02

Table 25. Changes in Crop Acreage under the Rollback Scenario w.r.t. Base, in Million Acres (continued)

Sorghum	-0.04	-0.01	0.15	-0.03
Rice	0.01	-0.02	-0.01	0.04
Oats	0.00	-0.05	-0.02	0.05
Barley, Winter	0.00	0.05	-0.05	-0.04

Barley, Spring	-0.07	-0.21	-0.03	0.02
Rye	-0.01	-0.11	-0.06	0.00
Canola	-0.03	0.00	0.00	0.01
Silage	0.00	-0.02	-0.01	0.00
Hay	0.10	-0.11	0.20	0.10
Sugarcane	0.00	0.00	0.00	0.00
Sugarbeet	0.01	0.00	0.00	0.00
Potatoes	-0.01	-0.01	-0.01	-0.01
Tomato, Fresh	0.00	0.00	0.00	0.00
Tomato, Processing	0.00	0.00	0.00	0.00
SwitchGrass	0.00	0.00	0.01	0.00
HybrdPoplar	-0.06	0.00	0.00	0.00
SweetSorghum	0.00	0.00	0.00	0.00
Orange, Fresh	0.00	-0.01	-0.01	-0.01
Orange, Processing	0.00	-0.01	-0.01	0.00
Grapefruit, Fresh	0.00	0.00	0.00	0.00
Grapefruit, Processing	0.00	0.00	0.00	0.00
Wheat Grazing	-0.07	-0.08	-0.03	-0.12
Total	-0.03	-0.70	-0.05	0.20

5.2 Forest Sector

The effects of the Rollback scenario on U.S. timber market are presented in Table 26. Compared to the base case, timber harvests generally increase and prices tend to decline. Hardwood log prices would experience significant drops, while softwood log prices would see moderate decreases.

Unlike the sawtimber production and prices that exemplify the usual price-versus-quantity relationships, pulpwood price estimates show decreases in periods 2030 and 2040 when its harvest volumes also decrease. This implies that some sawtimber would be used as pulpwood for manufacturing (thus on effect the supply of pulpwood becomes larger), which could occur when the value of sawtimber is driven down to equal the value of pulpwood. The assumed RYGs for forest types under the Rollback scenario may have made this transformation of saw logs into pulp logs possible by increasing the supply of sawtimber – especially in later periods when the forests have been under the reduced ozone environments for two decades.

Table 26. Percentage Changes in National Timber Harvests and Prices under the Rollback Scenario

		2010	2020	2030	2040
Hardwood Pulplog	Harvest	2.9	1.0	-2.6	-8.0
	Price	-25.6	-19.0	-31.0	-39.0
Hardwood Sawlog	Harvest	-0.1	0.3	3.0	4.6
	Price	-17.3	-20.9	-32.7	-44.8
Softwood Pulplog	Harvest	0.8	1.4	0.5	-2.7
	Price	-6.5	-8.2	-8.4	-8.8

Softwood Sawlog	Harvest	0.1	1.0	0.2	1.0
	Price	-2.4	-4.4	-6.1	-6.2

Table 27 displays the Rollback-induced changes in distribution of harvested acres across forest types. For softwood production, significant increases in pine harvests are projected to occur in 2010 and 2040, and for hardwood production, bottomland hardwood harvests are estimated to expand in those periods. Moreover, the harvested area of upland hardwood would experience some decreases. This reflects that the impacts of the Rollback scenario would be largely demonstrated in the South, where softwood pines, upland and bottomland hardwoods are located.

Table 27. Percentage Changes in Harvested Acres by Forest Type under the Rollback Scenario

Forest Type	2010	2020	2030	2040
Douglas Fir	0.1	1.6	1.5	0.2
Natural Pine	-1.3	-9.7	3.7	15.4
Oak-Pine	37.8	-0.9	-6.7	4.2
Softwood (PNWW)	0.0	-17.3	0.0	0.0
Planted Pine	-2.2	-2.1	-1.8	-9.5
Softwood	3.6	2.6	-6.0	-6.4
Total Softwood	***3.3***	***-1.2***	***-2.7***	***-2.5***
Bottomland Hardwood	42.2	2.6	-35.3	25.4
Hardwood	-3.5	-3.0	-2.0	-11.5
Upland Hardwood	0.0	-6.7	2.3	-16.1
Total Hardwood	***5.1***	***-3.3***	***-5.5***	***-6.1***
Total	3.9	-2.1	-4.0	-4.1

Also, it appears that the softwood harvest expansion would focus on forest types having relatively larger RYGs, whereas the hardwood harvest increase would rely on forest types with smaller RYGs – which may be explained by their differed economic potentials. In addition, in general, the harvested forest area would decrease under the Rollback scenario.

Table 28 presents the percentage changes in softwood and hardwood inventories. Overall, both hardwood and softwood inventories would increase, with hardwood having greater inventories on existing stands that outpace the decreases on new stands. The majority of the increases in softwood inventories would occur on existing stands.

Table 28. Percentage Changes in Timber Inventories under Rollback Scenario

		2010	2020	2030	2040
Existing	softwood	0.8	2.8	4.6	7.9

Existing	hardwood	1.7	4.9	9.6	15.8
New	softwood	0.4	0.6	0.1	-0.9
New	hardwood	0.8	-5.4	-7.5	-8.8
Total	softwood	0.8	2.2	2.5	3.3
Total	hardwood	1.7	4.5	8.3	13.0

5.3 Land Use

Accompanying the projected increases in forest inventories shown in Table 28 are the decreases in overall forestland estimates. Table 29 shows that the decreases in forestland area are principally due to decreases in new forestland areas, which include afforested and reforested forestlands. As a result of faster growth and higher inventories decreasing the prices of forest products and returns to forestland, there is less reforestation and afforestation than under baseline conditions.

Table 29. Changes in Land Use by Land Category under the Rollback Scenario in Thousand Acres

	2010	2020	2030	2040
All Forest	-405	-1,655	-1,343	-2,803
Existing	-227	56	999	3,360
Reforested	-59	-318	-1,487	-3,577
Afforested	-119	-1,393	-855	-2,586
Cropland	-22	-700	113	1,218
Pasture	181	339	338	278
Cropland Pasture	224	1,968	844	1,259
Rangeland	0	0	0	0
CRP Retained	22	48	48	48

Under the Rollback scenario, the area of grassland including pasture and cropland pasture would increase and more CRP land would remain as CRP land rather than being converted to cropland.

The area of cropland would initially decrease; yet as time advances, it would increase instead – as the forestland shrinks and consequently the relatively more profitable cropland alternative expands onto the former forestland.

Recall Table 25 that shows increases in crop acres in 2040, especially for soybeans. The area available for cropland expansion brought on by declines in forest area makes increases in feed supply possible, and in turn contributes to the wider occurrence of livestock production activities.

5.4 GHG Mitigation Potential

The impacts of the Rollback scenario on GHG mitigation potential in U.S. forest and agricultural sectors are presented in Table 30, where positive numbers indicate more emissions/less sequestration, and negative numbers imply the opposite.

As shown in the table, much greater GHG changes are projected in the forest sector than in the agricultural sector. The soil-based changes, driven by land use change, turn out to play a peripheral role in GHG mitigation, such as the reductions in afforestation-related GHG sequestration. The vast majority of the enhanced GHG mitigation potential under the Rollback scenario lies in the forest biomass as the Rollback-induced yield increases accruing to forests accumulate over time.

5.5 Summary

In summary, the Rollback scenario provides benefits to consumers who would experience reduced prices for agricultural and forest products in general. On the other hand, producers would see decreases in profits, though production volumes would expand.

The forest sector would be more affected by the Rollback reduced ozone environments, and as time moves forward, the accumulated benefits of biomass yield increases for forest inventories and biomass per acre could lead to forestland contraction. Along with the contraction in forest would be grassland and cropland expansion.

Though the agricultural land use changes are noteworthy, the GHG mitigation potential associated with them would be much smaller than that lies in forest management – most of the sequestration would occur via the Rollback-induced increases in forest inventories.

Table 30. Changes in GHG Stock Compared with Base in Million Tons of CO_2eq

GHG Category	2010	2020	2030	2040
Afforestation	1	95	84	248
Existing Forest Soil	15	9	34	-1
Afforested Forest Soil	6	160	128	235
Forest Management	-289	-736	-1,553	-2,253
Forest Product	-13	-31	-35	-55
Canada Forest Product	3	2	3	3
Export Forest Product	0	0	0	0
Import Forest Product	0	0	0	0
Forest Fuel	0	0	0	0
Total Forest	-278	-500	-1,340	-1,823
Agricultural Soil	-11	-47	-23	-87
Ag Fuel Use	0	0	1	3
Fertilizer Manufacture	0	-1	0	0
Fertilizer N_2O	0	-1	0	0
Pasture N_2O	0	3	5	7
Pesticide Manufacture	0	1	1	1
Biodiesel Offset	0	0	0	0
Grain Ethanol Offset	0	0	0	0
Cellulosic Ethanol Offset	0	0	0	0
Bio-Electricity Offset	-2	-17	-18	-20
Manure Emissions	0	1	1	2
Enteric Fermentation	1	0	0	1
Rice Emissions	0	0	-1	0
Miscellaneous	0	0	0	0
Total Agriculture	-12	-62	-34	-92
All Total	-289	-562	-1,375	-1,915

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APPENDIX 6-B: DETAILS FOR ECONOMIC VALUATION ANALYSES

6-B.1 COMMERCIAL NTFP MARKEY ESTIMATES

The USDA estimates the proportion of the national supply of NTFP represented by U.S. FS and BLM lands is approximately 10%. From this estimate values for first point of sale for permit harvested NTFPs was $272,900,000 dollars ($2007). Extrapolating to wholesale value assuming that first point of sale value is 40% of whole sale yields wholesale estimates of $682,400,000. Finally assuming that the retail mark-up is 50% yields retail values for NTFPs harvested on Forest Service and Bureau of Land Management lands is approximately $1,364,800,000. 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 ozone those losses are already embedded within the harvest and values reported here.

6-B.2 IMPLAN

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 that was reviewed by an expert panel and is available at http://www.outdoorfoundation.org/pdf/ResearchRecreationEconomyTechnicalReport.pdf. The Outdoor Industry Foundation is a non-profit group dedicated to increasing outdoor recreation activity and is partnered with the Outdoor Industry Association a trade group for companies in the active outdoor recreation business.

The 2006 FHWAR provides estimates of trip and equipment related annual expenditures for wildlife watching activities in the United States. According to the survey 37% of all money spent in 2006 for all wildlife-related recreation went to wildlife watching activities and 79% of wildlife watchers spent money on this activity. These recreationists spent approximately $13.9 billion on trips and another $27.0 billion on equipment purchases including binoculars, cameras, and special apparel. Auxiliary equipment such as tents and backpacking equipment added another $1.1 billion and special equipment such as off-road vehicles, campers, and boats added $13.3 billion to the total expenses of wildlife watchers. Other miscellaneous expenses contributed $10.4 billion. See Table A-1 for details of these expenses by category.

Also in 2006 the Outdoor Industry Foundation (OIF) sponsored a study 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 ozone related damages. According to the report The Economic Contribution of Active Outdoor Recreation – Technical Report on Methods and Findings (2006) nationally trial and camping related expenditures accounted for $154.5 billion dollars of the approximately $256 billion dollars spent on the recreation activities surveyed for the report. Trip related expenses for trail-based recreation, which for this study included trail running, day hiking, backpacking, and climbing ice or natural rock, were $32.4 billion of the total and equipment and services accounted for about $3.5 billion dollars. Camping contributed $11.7 billion dollars in trip-related expenses and another $118.2 billion dollars in equipment purchases. See Table 6B-1 for details of these expenses by category.

The impact of these expenditures has a multiplier effect through the economy as a whole which was estimated by OIF using the IMPLAN® model a commercially available model developed by the Minnesota IMPLAN Group, Inc. of Stillwater, Minnesota. The model estimates the flow of goods and money through the economy at scales from local to national. The model is based on a matrix organized by the U.S. Census Bureau surveys of industry and commerce that track where their expenditures are made. 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.

Statistics regarding the precision of the final economic impacts were not produced by OIF due to feasibility issues. The statistics for the Harris Interactive survey results are provided in Appendix II of the OIF report, however, to produce the national statistics several parameters from the Harris data such as number of participants, mean expenditures per trip-related items and mean annual trips, are combined. Additionally outside data from the Census population estimates and IMPLAN multipliers were used. Each source of data has an associated uncertainty and error. As these data are combined it was not practically possible for the authors to develop precision estimates.

Table 6B-1 Expenditures for Wildlife-Watching, Trail, and Camp Related Recreation[a]

Trip-Related:	**Wildlife-Watching[b]**	**Trail[c]**	**Camp[c]**	**Total[c]**
Food & lodging	8.1	14.4	48.4	70.9
Transportation	4.8	10.1	35.2	50.1
Other trip costs	1.0			1.0
Recreation, entertainment, & activities	N/R	4.2	16.6	20.8
Souvenirs, gifts, & other miscellaneous		3.1	8.4	11.5
Totals	13.9	31.8	108.6	153.3
Equipment & Services:	**Wildlife-Watching[b]**	**Trail[c]**	**Camp[c]**	**Total[c]**
Equipment & apparel	10.7	2.4	5.8	18.9
Auxiliary equipment	1.0	N/R	N/R	1.0
Special equipment	13.3	N/R	N/R	13.3
Accessories		0.8	1.9	2.7
Services		0.4	1.6	2.0
Totals	25.0	3.6	9.3	37.9
Other Expenditures	**Wildlife Watching[b]**	**Trail[c]**	**Camp[c]**	**Total**
Land leasing and owning	7.1	N/R	N/R	7.1
Plantings for wildlife	1.7	N/R	N/R	1.7
Memberships, dues, and contributions	1.2	N/R	N/R	1.2
Magazines and books	0.4	N/R	N/R	0.4
Total				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

APPENDIX 6-C: i-TREE MODEL AND METHODOLOGY

6-C.1 MODEL

6-C.1.1 i-Tree Model Components

i-Tree version 4.0 offers several urban forest assessment applications including i-Tree Eco, previously known as UFORE. The Urban Forest Effects (UFORE) model was developed to aid in assessing urban forest structure, functions, and values (Nowak and Crane 2000). This model contains protocols to measure and monitor urban forests as well as estimate ecosystem functions and values.

The basic premise behind the UFORE model is that urban forest structure affects forest functions and values. By having an accurate assessment of urban forest structure, better estimates of functions and values can be produced. The model uses a sampling procedure to estimate various measured structural attributes about the forest (e.g., species composition, number of trees, diameter distribution) within a known sampling error. The model uses the measured structural information to estimate other structural attributes (e.g., leaf area, tree and leaf biomass) and incorporates local environmental data to estimate several functional attributes (e.g., air pollution removal, carbon sequestration, building energy effects). Economic data from the literature are used to estimate the value of some of the functions. The model includes the following modules descriptions of which are excerpted from Nowak, 2008.

6-C.1.2 Urban Forest Structure

Urban forest structure is the spatial arrangement and characteristics of vegetation in relation to other objects (e.g., buildings) within urban areas (e.g., Nowak 1994a). This module quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass), value, diversity, and potential risk to pests.

Urban Forest Effect model assessments have used two basic types of sampling to quantify urban forest structure: randomized grid and stratified random sampling. With the randomized grid sampling, the study area is divided into equal-area grid cells based on the desired number of plots and then one plot is randomly located within each grid cell. The study area can then be subdivided into smaller units of analysis (i.e., strata) after the plots are distributed (poststratification). Plot distribution among the strata will be proportional to the strata area. This random sampling approach allows for relatively easy assessment of changes through future measurements (urban forest monitoring), but likely at the cost of increased variance (uncertainty) of the population estimates. With stratified random sampling, the study area is stratified before distributing the plots and plots are randomly distributed within each stratum (e.g., land use). This process allows the user to distribute the plots among the strata to potentially decrease the overall variance of the population estimate. For example, because tree effects are often the primary focus of sampling, the user can distribute more plots into strata that have more trees. The disadvantage of this approach is that it makes long-term change assessments more difficult as a result of the potential for strata to change through time. There is no significant difference in cost or time to establish plots regardless of sampling methods for a fixed number of plots. However, there are likely differences in estimate precision. Prestratification, if done properly, can reduce overall variance because it can focus more plots in areas of higher variability. Any plot size can be used in UFORE, but the typical plot size used is 0.04 ha (0.1 ac). The number and size of plots will affect total cost of the data collection as well as the variance of the estimates (Nowak et al. 2008).

6-C.1.3 Data Collection Variables

There are four general types of data collected on a UFORE plot: 1) general plot information (Table 1) used to identify the plot and its general characteristics; 2) shrub information (Table 2) used to estimate shrub leaf area/biomass, pollution removal, and volatile organic compound (VOC) emissions by shrubs; 3) tree information (Table 3) used to estimate forest structural attributes, pollution removal, VOC emissions, carbon storage and sequestration, energy conservation effects, and potential pest impacts of trees; and 4) ground cover data used to estimate the amount and distribution of various ground cover types in the study area. Typically, shrubs are defined as woody material with a diameter at breast height (dbh; height at 1.37 m [4.5 ft]) less than 2.54 cm (1 in), whereas trees have a dbh greater than or equal to 2.54 cm (1 in). Trees and shrubs can also be differentiated by species (i.e., certain species are always a tree or always a shrub) or with a different dbh minimum threshold. For example, in densely forested areas, increasing the minimum dbh to 12.7 cm (5 in) can substantially reduce the field work by decreasing the number of trees measured, but less information on trees will be attained. Woody plants that are not 30.5 cm (12 in) in height are considered herbaceous cover (e.g., seedlings). Shrub masses within each plot are divided into groups of same species and size, and for each group, appropriate data are collected (Table 2). Tree variables (Table 3) are collected on every measured tree. Field data are collected during the in-leaf season to help assess crown parameters and health. More detailed information on plot data collection methods and equipment can be found in the i-Tree User's Manual (i-Tree 2008).

6-C.1.4 Leaf Area and Leaf Biomass

Leaf area and leaf biomass of individual open-grown trees (crown light exposure [CLE] of 4 to 5) are calculated using regression equations for deciduous urban species (Nowak 1996). If shading coefficients (percent light intensity intercepted by foliated tree crowns) used in the regression did not exist for an individual species, genus or hardwood averages are used. For deciduous trees that are too large to be used directly in the regression equation, average leaf area index (LAI: m2 leaf area per m2 projected ground area of canopy) is calculated by the regression equation for the maximum tree size based on the appropriate height–width ratio and shading coefficient class of the tree. This LAI is applied to the ground area (m2) projected by the tree's crown to calculate leaf area (m2). For deciduous trees with height-to-width ratios that are too large or too small to be used directly in the regression equations, tree height or width is scaled downward to allow the crown to the reach maximum (2) or minimum (0.5) height-to-width ratio. Leaf area is calculated using the regression equation with the maximum or minimum ratio; leaf area is then scaled back proportionally to reach the original crown volume. For conifer trees (excluding pines), average LAI per height to-width ratio class for deciduous trees with a shading coefficient of 0.91 is applied to the tree's ground area to calculate leaf area. The 0.91 shading coefficient class is believed to be the best class to represent conifers because conifer forests typically have approximately 1.5 times more LAI than deciduous forests (Barbour et al. 1980) and 1.5 times the average shading coefficient for deciduous trees (0.83; see Nowak 1996) is equivalent to LAI of the 0.91 shading coefficient. Because pines have lower LAI than other conifers and LAI that are comparable to hardwoods (e.g., Jarvis and Leverenz 1983; Leverenz and Hinckley 1990), the average shading coefficient (0.83) is used to estimate pine leaf area.

Leaf biomass is calculated by converting leaf area estimates using species-specific measurements of grams of leaf dry weight/m2 of leaf area. Shrub leaf biomass is calculated as the product of the crown volume occupied by leaves (m3) and measured leaf biomass factors (g/m3) for individual species (e.g., Winer et al. 1983; Nowak 1991). Shrub leaf area is calculated by converting leaf biomass to leaf area based on measured species conversion ratios (m2/g). As a result of limitations in estimating shrub leaf area by the crown-volume approach, shrub leaf area is not allowed to exceed a LAI of 18. If there are no leaf-biomass to-area or leaf-biomass-to-crown-volume conversion factors for an individual species, genus or hardwood/conifer averages are used. For trees in more forest stand conditions (higher plant competition), LAI for more closed canopy positions (CLE _ 0–1) is calculated using a forest leaf area formula based on the Beer-Lambert Law:

$$LAI = \ln(I\_Io)\_-k$$

where I _ light intensity beneath canopy; Io _ light intensity above canopy; and k _ light extinction coefficient (Smith et al. 1991). The light extinction coefficients are 0.52 for conifers and 0.65 for hardwoods (Jarvis and Leverenz 1983). To estimate the tree leaf area (LA):

$$LA = [\ln(1 - xs)\_-k] \times \_r2$$

where xs is average shading coefficient of the species and r is the crown radius. For CLE _ 2–3: LA is calculated as the average of leaf area from the open-grown (CLE _ 4–5) and closed canopy equations (CLE _ 0–1). Estimates of LA and leaf biomass are adjusted downward based on crown leaf dieback (tree condition). Trees are assigned to one of seven condition classes: excellent (less than 1% dieback); good (1% to 10% dieback); fair (11% to 25% dieback); poor (26% to 50% dieback); critical (51% to 75% dieback); dying (76% to 99% dieback); and dead (100% dieback). Condition ratings range between 1 indicating no dieback and 0 indicating 100% dieback (dead tree). Each class between excellent and dead is given a rating between 1 and 0 based on the midvalue of the class (e.g., fair _ 11% to 25% dieback is given a rating of 0.82 or 82% healthy crown). Tree leaf area is multiplied by the tree condition factor to produce the final LA estimate.

6-C.1.5 Carbon Storage and Annual Sequestration

This module calculates total stored carbon and gross and net carbon sequestered annually by the urban forest. Biomass for each measured tree is calculated using allometric equations from the literature (see Nowak 1994c; Nowak et al. 2002b). Equations that predict aboveground biomass are converted to whole tree biomass based on a root-to-shoot ratio of 0.26 (Cairns et al. 1997). Equations that compute fresh weight biomass are multiplied by species- or genus-specific conversion factors to yield dry weight biomass. These conversion factors, derived from average moisture contents of species given in the literature, averaged 0.48 for conifers and 0.56 for hardwoods (see Nowak et al. 2002b). Open-grown, maintained trees tend to have less aboveground biomass than predicted by forest-derived biomass equations for trees of the same dbh (Nowak 1994c). To adjust for this difference, biomass results for urban trees are multiplied by a factor of 0.8 (Nowak 1994c). No adjustment is made for trees found in more natural stand conditions (e.g., on vacant lands or in forest preserves). Because deciduous trees drop their leaves annually, only carbon stored in wood biomass is calculated for these trees. Total tree dry weight biomass is converted to total stored carbon by multiplying by 0.5 (Forest Products Laboratory 1952; Chow and Rolfe 1989). The multiple equations used for individual species were combined to produce one predictive equation for a wide range of diameters for individual species. The process of combining the individual formulas (with limited diameter ranges) into one more general species formula produced results that were typically within 2% of the original estimates for total carbon storage of the urban forest (i.e., the estimates using the multiple equations). Formulas were combined to prevent disjointed sequestration estimates that can occur when calculations switch between individual biomass equations. If no allometric equation could be found for an individual species, the average of results from equations of the same genus is used. If no genus equations are found, the average of results from all broadleaf or conifer equations is used

6-C.1.6 Urban Tree Growth and Carbon Sequestration

To determine a base growth rate based on length of growing season, urban street tree (Fleming 1988; Frelich 1992; Nowak 1994c), park tree (deVries 1987), and forest growth estimates (Smith and Shifley 1984) were standardized to growth rates for 153 frost-free days based on: standardized growth _ measured growth × (153/number of frost-free days of measurement). Average standardized growth rates for street (open-grown) trees were 0.83 cm/year (0.33 in/year). Growth rates of trees of the same species or genera were then compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Park growth averaged 1.78 times less than street trees, and forest growth averaged 2.29 times less than street tree growth. Crown light exposure measurements of 0 to 1 were used to represent forest growth conditions; 2 to 3 for park conditions; and 4 to 5 for open-grown conditions. Thus, the standardized growth equations are:

Standardized growth (SG) _ 0.83 cm/year (0.33 in/year) × number of frost free days/153 and for: CLE 0–1: Base growth_SG/2.26; CLE 2–3: base growth_SG /1.78; and CLE 4–5: base growth _ SG. Base growth rates are adjusted based on tree condition. For trees in fair to excellent condition, base growth rates are multiplied by 1 (no adjustment), poor trees' growth rates are multiplied by 0.76, critical trees by 0.42, dying trees by 0.15, and dead trees by 0. Adjustment factors are based on percent crown dieback and the assumption that less than 25% crown dieback had a limited effect on dbh growth rates. The difference in estimates of carbon storage between year *x* and year *x* + 1 is the gross amount of carbon sequestered annually.

6-C.1.7 Air Pollution Removal

This module quantifies the hourly amount of pollution removed by the urban forest, its value, and associated percent improvement in air quality throughout a year. Pollution removal and percent air quality improvement are calculated based on field, pollution concentration, and meteorologic data. This module is used to estimate dry deposition of air pollution (i.e., pollution removal during nonprecipitation periods) to trees and shrubs (Nowak et al. 1998, 2000). This module calculates the hourly dry deposition of ozone (O3), sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter less than 10 _m (PM10) to tree and shrub canopies throughout the year based on tree-cover data, hourly NCDC weather data, and U.S. Environmental Protection Agency pollution concentration monitoring data. The pollutant flux (F; in g/m2/s) is calculated as the product of the deposition velocity (Vd; in m/s) and the pollutant concentration (C; in g/m3):

$$F = Vd \times C$$

Deposition velocity is calculated as the inverse of the sum of the aerodynamic (Ra), quasilaminar boundary layer (Rb), and canopy (Rc) resistances (Baldocchi et al. 1987):

$$Vd = (Ra + Rb + Rc)-1$$

Hourly meteorologic data from the closest weather station (usually airport weather stations) are used in estimating Ra and Rb. In-leaf, hourly tree canopy resistances for O3, SO2, and NO2 are calculated based on a modified hybrid of big leaf and multilayer canopy deposition models (Baldocchi et al. 1987; Baldocchi 1988). Because CO and removal of particulate matter by vegetation are not directly related to transpiration, Rc for CO is set to a constant for in-leaf season (50,000 sec/m [15,240 sec/ft]) and leaf-off season (1,000,000 sec/m [304,800 sec/ft]) based on data from Bidwell and Fraser (1972). For particles, the median deposition velocity from the literature (Lovett 1994) is 0.0128 m/s (0.042 ft/s) for the in-leaf season. Base particle Vd is set to 0.064 m/s (0.021 ft/s) based on a LAI of 6 and a 50% resuspension rate of particles back to the atmosphere (Zinke 1967). The base Vd is adjusted according to actual LAI and in-leaf versus leaf-off season parameters. Bounds of total tree removal of O3, NO2, SO2, and PM10 are estimated using the typical range of published in-leaf dry deposition velocities (Lovett 1994). Percent air quality improvement is estimated by incorporating local or regional boundary layer height data (height of the pollutant mixing layer). More detailed methods on this module can be found in Nowak et al. (2006a).

6-C.1.8 i-Tree Forecast Prototype Model Methods and Results

The i-Tree Forecast Prototype Model was built to simulate future forest structure (e.g., number of trees and sizes) and various ecosystem services based on annual projections of the current forest structure data. There are 3 main components of the model:

1) Tree growth – simulates tree growth to annually project tree diameter, crown size and leaf area for each tree

2) Tree mortality – annually removes trees from the projections based on user defined mortality rates

3) Tree establishment – annually adds new trees to the projection. These inputs can be used to illustrate the effect of the new trees or determine how many new trees need to be added annually to sustain a certain level of tree cover or benefits.

6-C.1.9 Tree Growth

Annual tree diameter growth is estimated for the region based on: 1) the length of growing season, 2) species average growth rates, 3) tree competition, 4) tree condition, and 5) current tree height relative to maximum tree height.

To determine a base growth rate based on length of growing season, urban street tree, park tree, and forest growth estimates were standardized to growth rates for 153 frost free days based on: Standardized growth = measured growth x (153/ number of frost free days of measurement).[3] Growth rates of trees of the same species or genera were also compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Park growth averaged 1.78 times less than street trees, and forest growth averaged 2.29 times less than street tree growth.

For this study, average standardized growth rates for open-grown (street) trees was input as 0.26 in/yr for slow growing species, 0.39 in/yr for moderate growing species and 0.52 in/yr for fast growing species. Crown light exposure (CLE) measurements of 0-1 were used to represent forest growth conditions; 2-3 for park conditions; and 4-5 for open-grown conditions. Thus, for: CLE 0-1: Base growth = Standardized growth (SG) / 2.26; CLE 2-3: Base growth = SG / 1.78; and CLE 4-5: Base growth = SG. However, as the percent canopy cover increased or decreased, the CLE correction factors were adjusted proportionally to the amount of available greenspace (i.e., as tree cover dropped and available greenspace increased – the CLE adjustment factor dropped; as tree cover increased and available greenspace dropped – the CLE adjustment factor increased).

Base growth rates are also adjusted based on tree condition. For trees in fair to excellent condition, base growth rates are multiplied by 1 (no adjustment), Trees in poor condition by 0.76, critical trees by 0.42, dying trees by 0.15, and dead trees by 0. Adjustment factors are based on percent crown dieback and the assumption that less than 25-percent crown dieback had a limited effect on dbh growth rates.

As trees approach their estimated maximum height, growth rates are reduced. Thus the species growth rates as described above were adjusted based on the ratio between the current height of the tree and the average height at maturity for the species. When a tree's height is over 80% of its average height at maturity, the amount of annual dbh growth is proportionally reduced from full growth at 80% of height to ½ growth rate at height at maturity. The growth rate is maintained at ½ growth until the tree is 125% past maximum height, when the growth rate is then reduced to 0 in/yr.

Tree height, crown width, crown height and leaf area were then estimated based on tree diameter each year. Height, crown height and crown width are calculated using species, genus, order and family specific equations that were derived from measurements from urban tree data (publication in preparation). If there was no equation for a particular species, then genus equation was used, followed by the family and order equations if necessary. If no order equation could be used, one average equation for all trees was used to estimate these parameters. Leaf area was calculated from the crown height, tree height and crown width estimates based on standard i-Tree methods[3].

Total canopy cover was calculated by summing the crown area of each tree in the population. This estimate of crown area was adjusted to attain the actual tree cover of the study area based on photo-interpretation. As trees often have overlapping crown, the sum of the crown areas will often over estimate total tree cover as determined by aerial estimates. Thus the crown overlap can be determined by comparing the two estimates:

% crown overlap = (sum of crown area – actual tree cover area) / sum of crown area

When future projections predicted an increase in percent canopy cover, the percent crown overlap was held constant However, when 100% canopy cover was attained all new canopy added was considered as overlapping canopy. When there was a projected decrease in percent canopy cover, the percent crown overlap decreased in proportion to the increase in the amount of available greenspace (i.e., as tree cover dropped and available greenspace increased – the crown overlap decreased).

6-C.1.10 Tree Mortality Rate

Canopy dieback is the first determinant for tree mortality with trees 50 – 75% dieback having a mortality rate of 13.1% annual mortality rate; trees with 76-99% dieback having a 50% annual mortality rate, and trees with 100% dieback having a 100% annual mortality rate.[43] Trees with less than 50% dieback have a user defined mortality rate that is adjusted based on the tree size class and the current tree dbh.

Trees are placed into species size classes where small trees have an average height at maturity of less than or equal to 40 ft (maximum dbh class = 20+ inches), medium trees have mature tree height of 41- 60 ft (maximum dbh = 30 inches), and large trees have a mature height of greater than 60 ft (maximum dbh = 40 inches). Each size class has a unique set of 7 DBH ranges to which base mortality rates area assigned based on measured tree mortality by dbh class.[43] The same distribution of mortality by dbh class was used for all tree size classes, but the range of the dbh classes differed by size class. The actual mortality rate for each dbh class was adjusted so that the overall average mortality rate for the base population equaled the mortality rates assigned by user. That is, the relative curve of mortality stayed the same among dbh classes, but the actual values would change based on the user defined overall average rate.

6-C.1.11 Tree Establishment

Based on the desired canopy cover level and the number of years desired to reach that canopy level, the program calculates the number of trees needed to be established annually to reach that goal given the model growth and mortality rate. In adding new trees to the model each year, the species composition of new trees was assumed to be proportional to the current species composition. Crown light exposure of newly established trees was also assumed to be proportional to the current growth structure of the canopy. Newly established trees were input with a starting dbh of 1 inch.

6-C.2 OZONE EFFECTS ANALYSIS METHODS

For this Risk and Exposure Assessment the U.S. Forest Service developed the methodology and ran the iTree model to project the impact of ozone on carbon sequestration and air pollution removal in selected urban areas. EPA provided CMAQ model generated W126 results for current ambient ozone concentrations and for a rollback scenario that just meets the current standard. These methods are described in Chapter 4 Air Quality Considerations. For the effects of ozone, we used the concentration-response functions for the 11 tree species analyzed in Chapter 5 to reduce the growth of the trees over a 25 period and compared base model estimates (full-growth) with ozone effected results (reduced growth). Tree growth was only reduced in analyzed cities for the 11 species that had W126 equations.

We used a new forecast model (Nowak, 2012) components of which are described above in the sections on tree growth, mortality, and establishment. This model simulated tree growth, tree influx and mortality annually to estimate annual changes in number of trees, tree cover and stored carbon. For these scenarios, we adjusted the annual mortality (3 or 4%) and influx rate (between 1 and 6 trees / ha / yr) to keep canopy cover as close to current values as possible after 25 years. These base assumptions were consistent in both runs (full and reduced growth). Species composition of new trees added annually was proportional to the current species population.

Carbon estimates: total carbon storage at the end of the 25 year period was contrasted between the model runs to estimate the impact of reduced growth due to ozone. Differences in number of trees and tree sizes at the end of 25 years will affect the carbon estimate.

Pollution removal: pollution removal was based calculating the average tons of air pollutants removed. The forecast model was then used to project differences in estimated tree cover (m2) between the model runs for each of the 25 years. These annual tons of pollutants removed were summed to estimate the total impact over 25 years.

All model runs use the same assumptions, so difference in the estimates are due to reduced growth. However, the magnitude of the impact over 25 years will be affected by the assumptions. As you change the mortality and influx rates, the magnitude of the differences between the model runs will differ. We tried to use reasonable estimates based on limited data on mortality and influx rates. We used Nowak (2012, in press) to help estimate an influx rate and the attached paper on tree mortality to estimate a mortality rate, but we reduced the rate to 3-4% as forest stands are around 1% and the mortality in this paper was around 6%. We have limited mortality data for urban trees, but based on the data and our experience, we believe 3-4% to be reasonable, but it likely varies somewhere between 1% and 5%.

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Appendix 6-Ca: Itree City Comparison

Table shows tree species in each city for which C-R functions are available and the rank of each tree in terms of abundance in the city

Species for which C-R functions are available

- Ponderosa Pine
- Red Alder
- Black Cherry
- Tulip Poplar
- Sugar Maple
- Eastern White Pine
- Red Maple
- Douglas Fir
- Quaking Aspen
- Virginia Pine
- Eastern Cottonwood

Study Area					
	Baltimore09	**Syracuse09**	**ChicagoRegion**	**Atlanta**	**Tennessee**
1					
2		Sugar maple			Virginia Pine
3		Black cherry			
4			Black cherry		
5					
6	Black cherry				
7			Sugar maple	Black cherry	
8					Red Maple
9	Red maple	Eastern cottonwood		Red maple	
10					
% of top10	8.5	18.5	7.7	6.6	9.3
% of total	11.2	20.2	10.5	8.9	17.4

TOP 10 MOST COMMON SPECIES

American beech	European buckthorn	European buckthorn	Sweetgum	Chinese privet
Black locust	Sugar maple	Green ash	Loblolly pine	Virginia pine
American elm	Black cherry	Boxelder	Flowering dogwood	Eastern redcedar
Tree of heaven	Boxelder	Black cherry	Tulip tree	Hackberry
White ash	Norway maple	Hardwood	Water oak	Flowering dogwood
Black cherry	Northern white cedar	American elm	Boxelder	Amur honeysuckle
White mulberry	Norway spruce	Sugar maple	Black cherry	Winged elm
Northern red oak	Staghorn sumac	White ash	White oak	red maple
Red maple	Eastern cottonwood	Amur honeysuckle	Red maple	balck tupelo
White oak	Eastern hophornbeam	Silver maple	Southern red oak	American beech

Appendix 6-Cb1: iTree Results for Air Pollution Removals

Summary: Data from 5 urban areas were simulated to estimate the effect of ozone (based on the W126 index) on tree ecosystem services of carbon storage and air pollution removal
The prototype i-Tree Forecast model was used to estimate growth and ecosystem services by trees over a 25 year period
Tree data from the urban areas were loaded in the Forecast model as a base case scenario and simulated for 25 years
The tree growth was then adjusted downward based on the reduced growth factors for 11 species using the W126 protocal and equations (only W126 species had reduced
The differences between the two scenario are then contrasted (Standard = base case; O3 adjusted = W126 reduced growth) for the 25 year period.
Model assumed an annual influx of between 1-6 trees/ha/yr and a 3-4% annual morrtality rate
These values are updated based on new adjusted RYL values

Ponderosa Pine
Red Alder
Black Cherry
Tulip Poplar
Sugar Maple
Eastern White Pine
Red Maple
Douglas Fir
Quaking Aspen
Virginia Pine

Region	**Area (ha)**	**% Canopy Cover after 25yrs**	**Ozone Adjusted % Canopy after 25yrs**	**Rolled Back RYL Index**	**Regeneration Rate (trees per ha)**
Atlanta	34,139	51.92	45.13	11.04	2
Baltimore	20,917	29.22	27.26	5.85	2
Chicago Region	993,036	20.91	18.98	5.39	1
Syracuse	6,501	27.76	24.34	7.26	6
Tennessee (Urban Are	630,614	37.56	35.25	11.93	1

	Pollution Removal Metric tons Standard 25 yrs total	Recent Ozone Conditions (Column D cover) Removal (metric tons) 25 yrs total	Difference w/ Std	Just Meeting Standards (Column E Cover) Removal (metric tons) 25 yrs total	Difference w/ std	DIFFERENCE BETWEEN RECENT CONDITIONS AND JUST MEETING STANDARDS Removal (metric tons) 25 yrs total
CO						
Atlanta	1,482	1,312	-170	1,386	-96	74
Baltimore	186	176	-10	180	-6	4
Chicago Region	8,620	7,863	-757	7,969	-651	106
Syracuse	55	49	-6	49	-6	0
Tennessee	12,854	11,825	-1,029	12,217	-637	392
NO2						
Atlanta	6,852	6,067	-785	6,409	-443	342
Baltimore	1,968	1,863	-105	1,905	-63	43
Chicago Region	104,247	95,093	-9,153	96,375	-7,871	1,282
Syracuse	50	45	-6	45	-6	0
Tennessee	54,381	50,028	-4,353	51,688	-2,693	1,660
O3						
Atlanta	25,495	22,574	-2,922	23,848	-1,647	1,274
Baltimore	6,262	5,927	-335	6,063	-199	136
Chicago Region	243,701	222,304	-21,398	225,301	-18,401	2,997
Syracuse	1,544	1,370	-175	1,370	-175	0
Tennessee	393,205	361,729	-31,475	373,730	-19,474	12,001
SO2						
Atlanta	3,380	2,992	-387	3,161	-218	169
Baltimore	852	806	-46	825	-27	18
Chicago Region	29,675	27,070	-2,606	27,435	-2,241	365
Syracuse	71	63	-8	63	-8	0
Tennessee	59,371	54,618	-4,753	56,430	-2,940	1,812
Total						
Atlanta	37,209	32,946	-4,264	34,805	-2,404	1,860
Baltimore	9,268	8,772	-496	8,973	-295	201
Chicago Region	386,243	352,330	-33,913	357,079	-29,163	4,750
Syracuse	1,721	1,526	-195	1,526	-195	0
Tennessee	519,810	478,200	-41,610	494,066	-25,745	15,865

Note: for Syracuse there is no difference between recent ozone conditions and after simulating just meeting the current standards because the recent conditions are close to meeting the standar growth)

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Appendix 6-Cb2: iTree Results for Carbon Sequestration

Carbon Storage (metric tons) after 25 years

	Current Carbon Storage	**Standard Growth Rates**	**Recent Ozone Response Adjusted Growth Rates**	**Just Meeting the Standards Ozone Response Adjusted Growth Rates**	Recent Ozone Response Adjusted Growth Rates	Just Meeting the Standards Ozone Response Adjusted Growth Rates	
	(metric tonnes)	**Carbon Storage (metric tonnes)**	**Carbon Storage (metric tonnes)**	**Carbon Storage (metric tonnes)**	**Difference compared with standards growth rates**	**Difference compared with standards growth rates**	**Difference between recent ozone and ozone just meeting the current standards**
Atlanta	1,331,096	1,426,626	1,214,522	1,251,089	-212,105	-175,537	36,567
Baltimore	598,533	577,824	508,248	535,080	-69,577	-42,744	26,832
Chicago Region	17,480,805	19,560,361	16,869,139	17,017,363	-2,691,223	-2,542,999	148,224
Syracuse	181,382	169,356	141,308	141,313	-28,048	-28,043	5
Tennessee	17,020,383	20,568,155	18,314,030	18,859,868	-2,254,125	-1,708,288	545,838

Note: for Syracuse there is no difference between recent ozone conditions and after simulating just meeting the current standards because the recent conditions are close to meeting the standards.

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