



Ozone Sensitive Plant Species on National Park Service Lands

Natural Resource Report NPS/WASO/NRR—2020/2062



ON THE COVER

(left) Emmi Felker-Quinn and Johnathan Jernigan conduct foliar injury survey at Ninety Six National Historic Site (NPS/DENESIA CHEEK); (top right) Ozone injury to milkweed leaf (NPS/JOHNATHAN JERNIGAN); (bottom right) Ozone injury to ponderosa pine needles, (NPS/DAN DURISCOE); (bottom middle) Ozone injury to green ash leaflet (©JOHN SKELLY)

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Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Executive Summary

Tropospheric ozone is formed by atmospheric reactions between sunlight and atmospheric pollutants including NO_x and volatile organic compounds. Ozone is a significant phytotoxic pollutant that damages vegetation by entering leaves through the stomata and altering cellular function, resulting in visible leaf damage, decreased growth and reproduction, or early leaf senescence. While peak ozone concentrations are decreasing nationally, total ozone exposure in some regions is still above the threshold to cause damage to vegetation. Each plant species has a varying level of tolerance to ozone based on leaf chemistry, timing and rate of gas exchange, and environmental conditions. Community effects can lead to shifts in dominant species, change in light dynamics in the understory, or slowing succession rates post-disturbance. The National Park Service is responsible for identifying Air Quality Related Values that are impacted by ozone.

The National Park Service (NPS) convened a workshop in June 2003 to review and update lists used by the NPS and the U.S. Fish and Wildlife Service (FWS) to identify ozone sensitive plant species. At the workshop, ozone effects scientists made recommendations for the lists; subsequent to the workshop, an additional group of scientists provided review and comments to the lists. Since the workshop, many scientific studies have been completed to measure the ozone sensitivity of additional plant species. This document is an update to the report *Ozone Sensitive Plant Species on National Park Service and U.S. Fish and Wildlife Service Lands: Results of a June 24-25 2003 Workshop* (Porter 2003). Peer reviewed documents published after June 2003 were reviewed to determine if vegetation showed negative growth affects or visible damage under expected levels of ozone exposure. Additionally, this list updates the taxonomic nomenclature of the original list based on the Integrated Taxonomic Information System (www.ITIS.gov).

The species within this report are those that have a visible physical response (e.g., chlorotic mottle, leaf stipple) to ozone exposure. While additional physiological responses have been measured in other species, the listed species allow managers and scientists to visually evaluate where ozone impacts are occurring.

Description of types of ozone sensitivity

Sensitive Species: Species that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one expert observer.

Biological Indicator: A subset of ozone sensitive species that exhibit foliar symptoms that can be easily recognized as ozone injury by subject matter experts at ambient ozone concentrations. Biological indicators are widely distributed regionally and are easily identified in the field. Additionally, the ozone sensitivity of these species have been confirmed at realistic ozone concentrations in controlled laboratory conditions.

Suspect Species: There is some evidence for sensitivity; however they do not meet the criteria listed above. For example, suspect species may have shown foliar injury in fumigations at unrealistically high ozone concentrations or in very limited field observations, or they may be species for which evidence from different observers is conflicting. Suspect species should not be included on park or refuge lists of ozone sensitive species; however, researchers may want to consider suspect species as potential candidates for future investigations.

Background

Human created air pollutants such as ozone, nitrogen, and sulfur have broad negative impacts on the vegetation communities (Fenn et al. 2011, Pardo et al. 2011, Weigel et al. 2015). Tropospheric ozone is one of the most widespread air pollutants and is known to harm human health as well as vegetation (EPA 2013). Ozone is a secondary pollutant as it is not emitted directly from smokestacks or vehicles. Ozone forms when other pollutants, primarily nitrogen oxides (NO_x) and volatile organic compounds (VOCs), react in the atmosphere in the presence of sunlight, usually during the warm summer months (EPA 2013). The National Park Service is responsible for identifying and protecting resources on their lands that may be affected by all types of air pollution. These air quality related values (AQRVs) include vegetation, wildlife, water, soils, and visibility, and are monitored by the NPS Air Resources Division.

Ozone effects on natural vegetation have been documented throughout the country, particularly in many areas of the eastern U.S. and in California. While many national park units exceed ozone levels where damage may occur, a relatively small number of national parks and national wildlife refuges have been surveyed for ozone injury. As a result, injury has been documented in Acadia National Park, Carl Sandburg Home National Historic Site, Cowpens National Battlefield, Cumberland Gap National Historical Park, Great Smoky Mountains National Park, Guilford Courthouse National Military Park, Shenandoah National Park, Lassen Volcanic National Park, Little River Canyon National Preserve, Mammoth Cave National Park, Rocky Mountain National Park, Russell Cave National Monument, Sequoia/Kings Canyon National Park, Shiloh National Military Park, and Yosemite National Park (Eckert et al. 1999, Jernigan et al. 2009, Jeringan et al. 2010, U.S. Forest Service 2010, Jernigan et al. 2011, Kohut et al. 2012, Jernigan et al. 2013, Jernigan et al. 2014, Jernigan 2019); and Edwin B. Forsythe, Cape Romain, Moosehorn, Seney, and Mingo National Wildlife Refuges (Davis and Orendovici 2006, Davis 2007a, b, 2009, 2011). As surveys are resource intensive, the NPS developed ozone risk assessments for all National Park Service Class I areas to identify parks that may have species sensitive to ozone damage (Kohut 2007, National Park Service 2013).

Ozone causes considerable damage to vegetation by entering plants through the leaf stomata and oxidizing plant tissue, which causes changes in biochemical and physiological process (Weigel et al. 2015). Ozone effects include visible foliar injury (e.g., stipple and chlorosis), changes in growth (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights), or changes in reproduction (e.g., number or mass of fruit or seeds) in sensitive species (Skelly 2000, Leisner and Ainsworth 2012). In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stressors (Kohut et al. 2012).

Plant exposure to ozone differs in key ways from human exposure to ozone, and the use of multiple metrics for ozone exposure reflects these differences. Humans suffer near-immediate health effects when hourly ozone concentrations are high, and the metric commonly used to assess human exposure is the 8 hour average of ozone concentrations. Plants accumulate increasing ozone damage when

hourly ozone concentrations range from moderate to high during daylight hours over the course of the growing season, and the metric commonly used to assess plant exposure is the 90-day W126 sum (Lefohn et al. 1988, Taylor 2017). In its last review of the National Ambient Air Quality Standards (NAAQS) for ozone, EPA staff recommended that a secondary standard for ozone be set using the W126 at a level between 7 and 17 ppm-hrs to prevent biomass loss in trees (EPA 2014). In reviewing EPA's analyses, the Clean Air Science Advisory Committee advised that the standard be set to W126 between 7 and 15 ppm-hrs to protect trees, annual plants, and agriculture (EPA 2014). NPS argued for a stricter standard, requesting that the secondary standard be set to W126 of 7-9 ppm-hrs to protect against ozone effects of foliar injury as well as biomass loss in natural vegetation. In October 2015, the EPA Administrator set the ozone primary and secondary NAAQS at the 4th highest 8 hour average of 0.070 ppm averaged over 3 years, arguing that this single standard would provide sufficient protection to human health and public welfare without utilizing the W126 metric (80 FR 65292). NPS uses the W126 to evaluate trends and conditions of ozone concentrations in parks with respect to ozone effects upon plants, and currently considers parks with W126 <7 ppm-hrs to be in good condition, with W126 7-13 ppm-hrs warranting moderate concern, and W126 >13 ppm-hrs warranting significant concern (Taylor 2017).

Development of the Sensitive Species List

In the 1990s, NPS and FWS developed lists of ozone sensitive plant species for many parks and refuges and in 2000 published these lists in the Federal Land Managers' Air Quality Related Values Workgroup (FLAG) report (U.S. Forest Service 2010). As new information became available, NPS and FWS recognized a need to review, revise, and update the lists of sensitive plant species. In June 2003, NPS sponsored a workshop in Baltimore, Maryland, for this purpose. Workshop participants had extensive experience in ozone field surveys and ozone fumigation experiments conducted with species that occur on NPS and FWS lands. Participants reviewed the existing NPS and FWS lists of sensitive species and, using expert judgement based on knowledge of scientific literature, fumigation experiments, and field experience, revised and updated the list (Porter 2003). In the process, sensitive species were sorted into three lists: Sensitive Species, Biological Indicators, and Suspect Species (Box 1).

Lists were limited in number of species because relatively few species from natural ecosystems have been fumigated in chambers or examined in the field for ozone symptoms. The lists also include a small number of exotic species, e.g., *Ailanthus altissima*, which, while preferably would not be present in the park, can act as an indicator of possible ozone injury to native species and therefore be useful to resource managers.

In 2019, this list was updated based on research performed between 2003 and 2019. Species were only considered if they had undergone fumigation treatments and visible effects of ozone had been viewed under natural conditions. Species added from the literature were evaluated by some of the original attendees of the meeting. Many of the species added to the list in 2019 are exotic species to the National Parks due to the fact that much of the research that has been performed in European countries.

One of the main uses of the 2003 report has been to identify ozone sensitive species within a National Park through the NPSpecies database. This process links a park's plant inventory to the ozone sensitive species list and pulls out matching records. Since taxonomic nomenclature of sensitive species may have changed since the report, we updated all previously identified species with their current species names (as of 10/1/2019) based on the Integrated Taxonomic Information System (www.ITIS.gov). Additionally, we recommend that synonyms of sensitive species should be extracted from the ITIS database and be compared to park species lists, since many parks do not have the capacity to update their list with every ITIS nomenclature update. Lastly, for species that have been divided into subspecies since the original research was completed, both the original species name (e.g., *Prunus serotina*) and the autonym (e.g., *Prunus serotina* var *serotina*) are included in the list. An autonym is the species name given to the original description of a species when a subspecies has been identified. If the autonym of a species was included on the original list or in subsequent research, the parent of that species was also included on the list. These steps were done to capture a species presence if a park had not split a species into subtaxa.

Use of the Sensitive Species List

The list of sensitive species will enable parks and refuges to identify their AQRVs that are potentially sensitive to ozone. As noted in the introduction, vegetation damage can be dependent on multiple factors including ozone dose, environmental conditions such as rainfall and soil moisture, and elevation (Kohut et al. 2012). Just because a species is present within a park does not make the individual at risk of ozone damage. It is recommended that the first step a park takes is to use the NPS ARD Air Quality Conditions and Trends page¹ to identify if their park experiences ozone doses high enough to damage and inhibit growth of vegetation.

The NPS is currently using the lists in their foundation documents to highlight AQRVs within a park. Park-specific ozone sensitive species lists are a work in progress. Lists build on information currently in the NPSpecies data system where records are continually being added or updated by National Park Service staff.

¹<https://www.nps.gov/subjects/air/park-conditions-trends.htm>

Ozone Sensitive Species

Sensitive Species

Species that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one expert observer (Table 1).

Table 1. A list of plant species with known sensitivity to ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Acer pseudoplatanus</i>	sycamore maple	Non-Native	Orendovici et al. 2003
<i>Acer rubrum</i>	red maple	Native	Eckert et al. 1999
<i>Acer rubrum</i> var. <i>rubrum</i>	red maple	Native	Autonym
<i>Acer saccharinum</i>	silver maple	Native	Orendovici et al. 2003
<i>Achillea millefolium</i>	common yarrow	Native	Scebba et al. 2006
<i>Aesculus flava</i> *	yellow buckeye	Native	Porter 2003
<i>Alnus viridis</i> ssp. <i>sinuata</i>	green alder	Native	Scebba et al. 2006
<i>Amelanchier alnifolia</i>	saskatoon serviceberry	Native	Porter 2003
<i>Amelanchier arborea</i>	common serviceberry	Native	Scebba et al. 2006
<i>Apocynum cannabinum</i>	Indian hemp	Native	Porter 2003
<i>Aralia nudicaulis</i>	wild sarsaparilla	Native	Scebba et al. 2006
<i>Asclepias incarnata</i>	swamp milkweed	Native	Porter 2003
<i>Betula alleghaniensis</i>	yellow birch	Native	Scebba et al. 2006
<i>Betula papyrifera</i>	paper birch	Native	Scebba et al. 2006
<i>Betula pendula</i> *	European white birch	Non-Native	Mortensen and Skre 1990, Mortensen 1999
<i>Betula pubescens</i>	downy birch	Non-Native	Mortensen and Skre 1990, Mortensen 1999
<i>Betula pubescens</i> ssp. <i>pubescens</i>	downy birch	Non-Native	Autonym
<i>Catalpa speciosa</i>	northern catalpa	Native	Orendovici et al. 2003
<i>Cerantia siliqua</i>	St. John's bread	Non-Native	Orendovici et al. 2003

* Species nomenclature updated since publication of Porter 2003.

Table 1 (continued). A list of plant species with known sensitivity to ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Clematis virginiana</i>	virgin's bower	Native	Porter 2003
<i>Clematis vitalba</i>	old-man's-beard	Non-Native	Orendovici et al. 2003
<i>Eupatorium perfoliatum</i>	common boneset	Native	Orendovici et al 2003
<i>Fraxinus excelsior</i>	European ash	Non-Native	Novak et al. 2003, Orendovici et al. 2003
<i>Fraxinus nigra</i>	black ash	Native	Krupa et al. 1998
<i>Fraxinus pennsylvanica</i>	green ash	Native	Porter 2003
<i>Helianthus hirsutus</i>	hairy sunflower	Native	Orendovici et al. 2003
<i>Krigia montana</i>	mountain dwarf dandelion	Native	Porter 2003
<i>Liquidambar styraciflua</i>	sweetgum	Native	Porter 2003
<i>Morus nigra</i>	black mulberry	Non-Native	VanderHeyden et al. 2001
<i>Osmorhiza brachypoda</i>	California sweet-cicely	Native	Peterson et al. 1992
<i>Osmorhiza claytonii</i>	hairy sweet-cicely	Native	Lefohn and Musselman 2012
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Native	Porter 2003
<i>Philadelphus coronarius</i>	sweet mock orange	Non-Native	Porter 2003
<i>Pinus banksiana</i>	black pine	Native	Porter 2003
<i>Pinus pungens</i>	hickory pine	Native	Porter 2003
<i>Pinus radiata</i>	Monterey pine	Non-Native	Porter 2003
<i>Pinus rigida</i>	pitch pine	Native	Porter 2003
<i>Pinus strobus</i>	eastern white pine	Native	Krupa et al. 1998
<i>Pinus taeda</i>	loblolly pine	Non-Native	Porter 2003
<i>Pinus virginiana</i>	Virginia pine	Native	Porter 2003
<i>Poa pratensis</i>	Kentucky bluegrass	Native	Scebba et al. 2006
<i>Poa pratensis</i> ssp. <i>pratensis</i>	Kentucky bluegrass	Native	Autonym
<i>Populus balsamifera</i>	balsam poplar	Native	Krupa et al 1998
<i>Populus deltoides</i>	eastern cottonwood	Native	Krupa et al 1998
<i>Populus deltoides</i> ssp. <i>deltoides</i>	eastern cottonwood	Native	Autonym
<i>Populus grandidentata</i>	bigtooth aspen	Native	Krupa and Manning 1988
<i>Prunus americana</i>	American plum	Native	Orendovici et al. 2003

* Species nomenclature updated since publication of Porter 2003.

Table 1 (continued). A list of plant species with known sensitivity to ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Prunus avium</i>	sweet cherry	Non-Native	Novak et al. 2003
<i>Prunus virginiana</i>	common chokecherry	Native	Porter 2003
<i>Prunus virginiana</i> var. <i>virginiana</i> *	chokecherry	Native	Autonym
<i>Quercus kelloggii</i>	California black oak	Native	Porter 2003
<i>Rhamnus cathartica</i>	European buckthorn	Non-Native	VanderHeyden et al. 2001
<i>Rhus copallinum</i> *	dwarf sumac	Native	Porter 2003
<i>Robinia pseudoacacia</i>	black locust	Native	Porter 2003
<i>Rubus cuneifolius</i>	sand blackberry	Native	Porter 2003
<i>Rubus parviflorus</i>	western thimbleberry	Native	Porter 2003
<i>Salix discolor</i>	pussy willow	Native	Kline et al. 2008
<i>Salix exigua</i>	desert willow	Native	Kline et al. 2008
<i>Salix exigua</i> var. <i>exigua</i>	coyote willow	Native	Autonym
<i>Salix gooddingii</i>	Goodding's willow	Native	Porter 2003
<i>Salix lucida</i>	shining willow	Native	Kline et al. 2008
<i>Salix nigra</i>	black willow	Native	Kline et al. 2008
<i>Salix purpurea</i>	purple willow	Native	Kline et al. 2008
<i>Salix sericea</i>	silky willow	Native	Kline et al. 2008
<i>Salix viminalis</i>	basket willow	Non-Native	VanderHeyden et al. 2001
<i>Salix x cotteti</i>	willow	Native	Kline et al. 2008
<i>Sambucus ebulus</i>	dwarf elder	Native	Kline et al. 2008
<i>Sassafras albidum</i>	sassafras	Native	Porter 2003
<i>Silphium perfoliatum</i>	cup plant	Native	Orendovici et al. 2003
<i>Solidago altissima</i>	Canada goldenrod	Native	Porter 2003
<i>Solidago altissima</i> ssp. <i>altissima</i>	Canada goldenrod	Native	Autonym
<i>Spartina alterniflora</i>	smooth cordgrass	Native	Porter 2003
<i>Teucrium scorodonia</i>	woodland germander	Non-Native	Orendovici et al. 2003
<i>Tilia cordata</i>	littleleaf linden	Non-Native	Novak et al 2003
<i>Tilia platyphyllos</i>	largeleaf linden	Non-Native	Novak et al 2003

* Species nomenclature updated since publication of Porter 2003.

Table 1 (continued). A list of plant species with known sensitivity to ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Vernonia noveboracensis</i>	New York ironweed	Native	Orendovici et al. 2003
<i>Veronica chamaedrys</i>	germander speedwell	Non-Native	Scebba et al. 2006
<i>Viburnum lentago</i>	nannyberry	Native	Orendovici et al. 2003

* Species nomenclature updated since publication of Porter 2003.

Biological Indicators

A subset of ozone sensitive species in which leaf damage from ambient ozone concentrations can be easily recognized as ozone injury by subject matter experts. Biological indicators are widely distributed regionally and are easily identified in the field. Additionally, the ozone sensitivity of these species has been confirmed at realistic ozone concentrations under controlled laboratory conditions (Table 2).

Table 2. A list of plant species with known to be bioindicators of tropospheric ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Ageratina altissima</i>	white snakeroot	Native	Parent
<i>Ageratina altissima</i> var. <i>altissima</i> *	white snakeroot	Native	Porter 2003
<i>Ailanthus altissima</i>	Tree of Heaven	Non-Native	Porter 2003
<i>Alnus incana</i>	gray alder	Native	Manning et al. 2002, Manning and Godzik 2004
<i>Alnus incana</i> ssp. <i>incana</i>	gray alder	Native	Autonym
<i>Alnus incana</i> ssp. <i>rugosa</i> *	speckled alder	Native	Porter 2003
<i>Alnus rubra</i>	red alder	Native	Porter 2003
<i>Apios americana</i>	American Groundnut	Native	Porter 2003
<i>Apocynum androsaemifolium</i>	spreading dogbane	Native	Porter 2003
<i>Artemisia douglasiana</i>	Douglas' sagewort	Native	Porter 2003
<i>Artemisia ludoviciana</i>	white sagebrush	Native	Porter 2003
<i>Asclepias exaltata</i>	poke milkweed	Native	Porter 2003

* Species on the 2003 list that have had their nomenclature updated according to ITIS

Table 2 (continued). A list of plant species with known to be bioindicators of tropospheric ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Asclepias syriaca</i>	broadleaf milkweed	Non-Native	Porter 2003
<i>Campsis radicans</i>	common trumpet creeper	Native	Orendovici et al 2003
<i>Centaurea nigra</i>	lesser knapweed	Non-Native	Manning and Godzik 2004
<i>Centaurea scabiosa</i>	greater knapweed	Non-Native	Manning and Godzik 2004
<i>Cephalanthus occidentalis</i>	buttonbush	Native	Kline et al. 2008
<i>Cercis canadensis</i>	eastern redbud	Native	Porter 2003
<i>Colutea arborescens</i>	bladder senna	Non-Native	Orendovici et al 2003
<i>Cornus florida</i>	flowering dogwood	Native	Kline et al. 2008
<i>Corylus americana</i>	American hazelnut	Native	Porter 2003
<i>Corylus cornuta</i>	beaked hazelnut	Native	Davis 2007
<i>Corylus cornuta</i> ssp. <i>cornuta</i>	beaked hazelnut	Native	Autonym
<i>Crataegus monogyna</i>	oneseed hawthorn	Non-Native	Novak et al 2003
<i>Crataegus monogyna</i> var. <i>monogyna</i>	oneseed hawthorn	Non-Native	Autonym
<i>Eurybia macrophylla</i> *	bigleaf aster	Native	Porter 2003
<i>Fraxinus americana</i>	white ash	Native	Porter 2003
<i>Gaylussacia baccata</i>	black huckleberry	Native	Porter 2003
<i>Humulus lupulus</i>	common hop	Native	Manning and Godzik 2004
<i>Liriodendron tulipifera</i>	tulip poplar	Native	Porter 2003
<i>Lonicera involucrata</i>	twinberry honeysuckle	Native	Brace et al. 1999
<i>Lonicera involucrata</i> var. <i>involucrata</i>	twinberry honeysuckle	Native	Autonym
<i>Lyonia ligustrina</i>	maleberry	Native	Porter 2003
<i>Lyonia ligustrina</i> var. <i>ligustrina</i>	maleberry	Native	Autonym
<i>Mentzelia albicaulis</i>	white-stemmed evening-star	Native	Thompson et al. 1984
<i>Oclemena acuminata</i> *	whorled wood aster	Native	Porter 2003
<i>Oenothera elata</i>	Hooker's evening-primrose	Native	Porter 2003
<i>Oenothera elata</i> ssp. <i>hookeri</i>	Hooker's evening primrose	Native	Porter 2003
<i>Physocarpus capitatus</i>	Pacific ninebark	Native	Porter 2003
<i>Physocarpus malvaceus</i>	mallow ninebark	Native	Porter 2003

* Species on the 2003 list that have had their nomenclature updated according to ITIS

Table 2 (continued). A list of plant species with known to be bioindicators of tropospheric ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Pinus jeffreyi</i>	Jeffrey pine	Native	Porter 2003
<i>Pinus ponderosa</i>	ponderosa pine	Native	Porter 2003
<i>Pinus ponderosa</i> var. <i>ponderosa</i>	ponderosa pine	Native	Autonym
<i>Platanus occidentalis</i>	American sycamore	Native	Porter 2003
<i>Populus nigra</i>	black cottonwood	Non-Native	Novak et al 2003
<i>Populus tremuloides</i>	quaking aspen	Native	Porter 2003
<i>Prunus pensylvanica</i>	pin cherry	Native	Davis 2007
<i>Prunus serotina</i>	black cherry	Native	Porter 2003
<i>Prunus serotina</i> var. <i>serotina</i> *	black cherry	Native	Autonym
<i>Rhus aromatica</i> *	fragrant sumac	Native	Porter 2003
<i>Rhus aromatica</i> var. <i>aromatica</i>	fragrant sumac	Native	Autonym
<i>Rhus copallinum</i> var. <i>copallinum</i> *	winged sumac	Native	Kline et al. 2008
<i>Rubus allegheniensis</i>	common blackberry	Native	Porter 2003
<i>Rubus canadensis</i>	smooth blackberry	Native	Porter 2003
<i>Rudbeckia laciniata</i>	cut-leaf coneflower	Native	Porter 2003
<i>Rudbeckia laciniata</i> var. <i>ampla</i>	cut-leaf coneflower	Native	Kohut et al. 2012, Neufeld et al 2018
<i>Rudbeckia laciniata</i> var. <i>humulis</i>	cut-leaf coneflower	Native	Neufeld et al 2018
<i>Rudbeckia laciniata</i> var. <i>laciniata</i>	cut-leaf coneflower	Native	Autonym
<i>Rumex acetosa</i>	garden sorrel	Non-Native	Manning and Godzik 2004
<i>Salix alba</i>	golden willow	Non-Native	Novak et al. 2003
<i>Salix scouleriana</i>	Scouler's willow	Native	Porter 2003
<i>Sambucus nigra</i> ssp. <i>canadensis</i> *	blue elderberry	Native	Porter 2003
<i>Sambucus racemosa</i>	red elderberry	Native	Porter 2003
<i>Sambucus racemosa</i> ssp. <i>racemosa</i> *	red elderberry	Native	Autonym
<i>Sorbus aucuparia</i>	rowan	Non-Native	Manning and Godzik 2004
<i>Symphoricarpos albus</i>	common snowberry	Non-Native	Porter 2003
<i>Symphoricarpos albus</i> var. <i>albus</i>	common snowberry	Non-Native	Autonym

* Species on the 2003 list that have had their nomenclature updated according to ITIS

Table 2 (continued). A list of plant species with known to be bioindicators of tropospheric ozone. Species new to the list are linked to the reference for which they were identified. Updated taxonomic nomenclature is listed as Autonym or Parent.

Species Name	Common Name	Nativity	Source
<i>Triadica sebifera</i> *	tallowtree	Non-Native	Porter 2003
<i>Ulmus procera</i> *	English elm	Non-Native	Orendovici et al 2003
<i>Vaccinium membranaceum</i>	thinleaf huckleberry	Native	Porter 2003
<i>Verbesina occidentalis</i>	yellow crownbeard	Native	Porter 2003
<i>Viburnum lantana</i>	wayfaring tree	Non-Native	Novak et al 2003, Orendovici et al 2003
<i>Viburnum nudum</i> var. <i>cassinoides</i>	with-rod	Native	Davis 2007
<i>Viburnum opulus</i>	European cranberrybush	Non-Native	Novak et al 2003
<i>Viburnum opulus</i> var. <i>opulus</i>	European cranberrybush	Non-Native	Autonym
<i>Vitis labrusca</i>	fox grape	Native	Porter 2003
<i>Vitis vinifera</i> ssp. <i>sylvestris</i> *	wild grape	Non-Native	Porter 2003

* Species on the 2003 list that have had their nomenclature updated according to ITIS

Suspect Species

Species suspected of being sensitive to ozone are species for which there is some evidence of sensitivity, but species does not meet criteria for sensitive species (i.e., sensitive species typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one observer). Suspect species are also those species for which evidence from different observers is conflicting (Table 3). NOTE: THIS LIST SHOULD NOT BE USED TO IDENTIFY OZONE-SENSITIVE SPECIES IN PARKS. IT CAN BE USED TO IDENTIFY SPECIES OF INTEREST FOR FUTURE RESEARCH.

Table 3. A list of plant species suspected to be sensitive to tropospheric ozone, but have conflicting evidence.

Scientific Name	Common Name	Category
<i>Acer macrophyllum</i>	Bigleaf maple	Suspect
<i>Acer negundo</i>	Boxelder	Suspect
<i>Aconitum uncinatum</i>	Wild monkshood	Suspect (GRSM*)
<i>Aesculus glabra</i>	Ohio buckeye	Suspect
<i>Amelanchier laevis</i>	Allegheny serviceberry	Suspect (GRSM*)

* GRSM – injury noted in Great Smoky Mountains NP (Hacker and Renfro 1992).

Table 4 (continued). A list of plant species suspected to be sensitive to tropospheric ozone, but have conflicting evidence.

Scientific Name	Common Name	Category
<i>Anemone quinquefolia</i>	Wood anemone	Suspect (GRSM*)
<i>Anemone virginiana</i>	Thimbleweed	Suspect (GRSM*)
<i>Aristolochia durior</i>	Dutchman's pipe	Suspect (GRSM*)
<i>Asclepias quadrifolia</i>	Four-leaved milkweed	Suspect
<i>Aster curtisii</i>	Curtis's aster	Suspect (GRSM*)
<i>Aster divaricatus</i>	White-wood aster	Suspect (GRSM*)
<i>Aster engelmannii</i>	Engelmann's aster	Suspect
<i>Aster infirmus</i>	Entire- leaved aster	Suspect (GRSM*)
<i>Aster puniceus</i>	Purple-stemmed aster	Suspect
<i>Aster umbellatus</i>	Flat-toppped aster	Suspect
<i>Betula populifolia</i>	Gray birch	Suspect
<i>Bidens frondosa</i>	Beggar-ticks	Suspect (GRSM*)
<i>Bromus tectorum</i>	Cheatgrass	Suspect
<i>Calycanthus floridus</i>	Sweet-shrub	Suspect (GRSM*)
<i>Cladrastis lutea</i>	Yellowwood	Suspect
<i>Clitoria mariana</i>	Butterfly pea	Suspect (GRSM*)
<i>Diervilla sessilifolia</i>	Bush-honeysuckle	Suspect (GRSM*)
<i>Gaylussacia ursina</i>	Bear huckleberry	Suspect (GRSM*)
<i>Gentiana amarella</i>	Northern gentian	Suspect
<i>Geum radiatum</i>	Mountain avens	Suspect (GRSM*)
<i>Gillenia trifoliata</i>	Bowman's-root	Suspect (GRSM*)
<i>Glyceria nubigena</i>	Manna grass	Suspect
<i>Hamamelis virginiana</i>	Witch-hazel	Suspect (GRSM*)
<i>Helianthus divaricatus</i>	Woodland sunflower	Suspect
<i>Helianthus glaucophyllus</i>	White- leaf sunflower	Suspect (GRSM*)
<i>Helianthus microcephalus</i>	Small wood sunflower	Suspect (GRSM*)
<i>Helianthus strumosus</i>	Paleleaf woodland sunflower	Suspect
<i>Hexastylis arifolia</i>	Heartleaf	Suspect (GRSM*)
<i>Hieracium paniculatum</i>	Panicled hawkweed	Suspect (GRSM*)

* GRSM – injury noted in Great Smoky Mountains NP (Hacker and Renfro 1992).

Table 3 (continued). A list of plant species suspected to be sensitive to tropospheric ozone, but have conflicting evidence.

Scientific Name	Common Name	Category
<i>Impatiens capensis</i>	Spotted touch-me- not	Suspect (GRSM*)
<i>Larix decidua</i>	European larch	Suspect
<i>Larix leptolepis</i>	Japanese larch	Suspect
<i>Lindera benzoin</i>	Spicebush	Suspect
<i>Menziesia pilosa</i>	Minnie-bush	Suspect (GRSM*)
<i>Oxydendrum arboreum</i>	Sourwood	Suspect (GRSM*)
<i>Pinus nigra</i>	Austrian pine	Suspect
<i>Prenanthes altissima</i>	Rattlesnake root	Suspect (GRSM*)
<i>Rhamnus alnifolia</i>	Alder-leaved buckthorn	Suspect (GRSM*)
<i>Rhododendron bakeri</i>	Cumberland azalea	Suspect (GRSM*)
<i>Rhododendron calendulaceum</i>	Flame azalea	Suspect (GRSM*)
<i>Rhododendron catawbiense</i>	Catawba rhododendron	Suspect (GRSM*)
<i>Rhus glabra</i>	Smooth sumac	Suspect
<i>Rhus typhina</i>	Staghorn sumac	Suspect
<i>Rubus argutus</i>	Highbush blackberry	Suspect
<i>Rubus idaeus</i>	Red raspberry	Suspect
<i>Rudbeckia hirta</i>	Black-eyed susan	Suspect
<i>Rugelia nudicaulis</i>	Rugel's ragwort	Suspect
<i>Saxifraga arguta</i>	Saxifrage	Suspect
<i>Senecio serra</i>	Tall butterweed	Suspect
<i>Silphium asteriscus</i>	Rosin-weed	Suspect (GRSM*)
<i>Smilax glauca</i>	Glaucous catbrier	Suspect (GRSM*)
<i>Smilax rotundifolia</i>	Greenbrier	Suspect (GRSM*)
<i>Solidago roanensis</i>	Roan's goldenrod	Suspect (GRSM*)
<i>Spiraea x vanhouttei</i>	Vanhoutte spirea	Suspect
<i>Spiraea x vanhouttei</i>	Vanhoutte spirea	Suspect
<i>Stachys clingmanii</i>	Clingman's hedge-nettle	Suspect (GRSM*)
<i>Stewartia ovata</i>	Mountain stewartia	Suspect (GRSM*)
<i>Syringa vulgaris</i>	Common lilac	Suspect

* GRSM – injury noted in Great Smoky Mountains NP (Hacker and Renfro 1992).

Table 3 (continued). A list of plant species suspected to be sensitive to tropospheric ozone, but have conflicting evidence.

Scientific Name	Common Name	Category
<i>Syringa x chinensis</i>	Chinese lilac	Suspect
<i>Tilia americana</i>	American basswood	Suspect
<i>Tilia euchlora</i>	Crimean linden	Suspect
<i>Tilia heterophylla</i>	White basswood	Suspect (GRSM*)
<i>Toxicodendron radicans</i>	Poison-ivy	Suspect
<i>Trautvetteria caroliniensis</i>	Tassel- rue; False bugbane	Suspect (GRSM*)
<i>Vitis aestivalis</i>	Summer grape	Suspect (GRSM*)
<i>Vitis riparia</i>	Riverbank grape	Suspect
<i>Vitis vulpina</i>	Frost grape	Suspect (GRSM*)

* GRSM – injury noted in Great Smoky Mountains NP (Hacker and Renfro 1992).

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