2. Overview of Ozone Effects on Vegetation

Ozone is one of the most phytotoxic air pollutants, and causes considerable damage to vegetation throughout the world. Data have shown that plants are more sensitive to ozone than are humans (U.S. Environmental Protection Agency 1996). Although most ozone effects research has been on crops, and large economic losses have been documented for U.S. agriculture, many native plants in natural ecosystems are sensitive to ozone (U.S. Environmental Protection Agency 1996).

Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. The injured plant cells eventually die, resulting in visible foliar injury. In the case of broadleaf plants, this injury is visible as a small black or brown interveinal necrotic lesion on the upper surface of the leaf, called "oxidant stipple". In conifers, ozone injury appears as yellow or chlorotic spots on needles.

Ozone also causes premature leaf loss; reduced photosynthesis; and reduced leaf, root, and total dry weights in sensitive plant species. These physiological changes can occur in the absence of foliar injury, and vice versa. 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 stresses.

Geographic Extent of Ozone Effects:

In the past few years, there have been a number of attempts to evaluate the geographic extent, and environmental consequences, of ozone exposure. All of these efforts have focused on the eastern United States. The Southern Appalachian Mountains Initiative (SAMI), with funding from the EPA, initiated a series of projects evaluating the effects of current, increased, and decreased ozone concentrations on vegetation found in the Southern Appalachian Mountains (Nicholas et al. 2000). Chappelka and Samuelson (1998) and Chappelka et al. (1996) summarized previous ozone effects work in the area and concluded 1) ozone-induced foliar injury has been documented on a number of tree species throughout much of the eastern United States, and 2) growth losses at ambient ozone levels in the eastern United States tend to be in the range of zero to ten percent per year. Laurence et al. (in press) linked TREGRO, a mechanistic model of an individual tree, to ZELIG, a forest stand model, to examine the responses of loblolly pine (*Pinus taeda*) and tulip poplar (*Liriodendron tulipifera*) to various ozone exposure regimes. The authors found that even moderate levels of ozone can have a significant effect on tree and forest response if adequate soil moisture is available. The models predicted substantial changes in basal area of both species in small areas of their range. Others have also examined the interacting effects of ozone exposure and soil moisture in the Southern Appalachian Mountains and concluded that in a small number of areas, sensitive species, such as black cherry (*Prunus serotina),* could experience growth losses (Lefohn 1998, Lefohn et al. 1997, Patterson et al. 2000, Southern Appalachian Man and the Biosphere 1996) (figure 1). Hogsett et al. (1997) used a geographical information system (GIS) to prepare a spatially based risk assessment for the eastern United States. They concluded that for sensitive species such as black cherry and aspen (*Populus tremuloides*), there could be a 14 to 33 percent biomass loss over 50 percent of their distribution due to current ozone concentrations.

The NPS and FWS have conducted ozone injury surveys in a limited number of areas. Studies conducted in some of those Class I air quality areas are discussed in detail below. Heck and Cowling (1997) recommended 3-month, 8:00 a.m. to 8:00 p.m., SUM06 (the sum of hourly average ozone concentrations greater than or equal to 60 ppb) effects endpoints for natural vegetation, i.e., 8 to12 ppm-hrs for foliar injury to natural ecosystems and 10 to 15 ppm-hrs for growth effects on tree seedlings in natural forest stands. The NPS Air Resources Division (ARD) used these endpoints to evaluate 1995-1999 maximum ozone concentrations monitored in NPS and FWS areas (figure 2). The results indicate current ozone concentrations in a number of NPS and FWS areas are high enough to cause foliar injury and/or growth loss in sensitive species. Moreover, based on trend analyses, it appears that ozone concentrations are increasing in many of these areas (figure 3). The ARD, in collaboration with the University of Denver, used ozone data collected at federal- and state-run monitors to interpolate ozone values for the rural United States (figure 4). A confidence analysis indicates large portions of California, Arizona, and the eastern United States could have maximum 3-month, 8:00 a.m. to 8:00 p.m., SUM06 ozone concentrations greater than 10 ppm-hrs (figure 5).

Shenandoah National Park, Virginia:

Field plots and open-top chambers were established in Big Meadows in Shenandoah NP in 1979 to investigate the effects of ozone on tree species. Studies conducted from 1979 to 1981 showed that ambient levels of ozone caused foliar injury of tulip poplar, green ash (*Fraxinus pennsylvanica*), and sweetgum (*Liquidambar styraciflua*), as well as reduced average height growth of tulip poplar, green ash, black locust (*Robinia pseudoacacia*), Virginia pine (*Pinus virginiana*), Eastern white pine (*Pinus strobus*), table mountain pine, (*Pinus pungens*), and Eastern hemlock (*Tsuga canadensis*) (Duchelle et al. 1982). A concurrent study found that ambient ozone concentrations reduced aboveground biomass production of native vegetation compared to charcoal-filtered air (Duchelle et al. 1983). Foliar injury surveys were conducted on five native plant species in Shenandoah NP in 1982. Three of the five species, i.e., virgin's bower (*Clematis virginiana*), black locust, and wild grape (*Vitis* sp.) displayed increased injury with increased elevation (Winner et al. 1989).

In 1991, trend plots of three ozone-sensitive hardwoods, i.e., tulip poplar, black cherry, and white ash (*Fraxinus americana*), were established near the ambient ozone monitors at Dickey Ridge, Big Meadows, and Sawmill Run in Shenandoah NP. Marked trees in each plot were evaluated for ozone injury in 1991, 1992, and 1993 (Hildebrand et al. 1996). Black cherry and white ash exhibited increased foliar injury with increased ozone exposure across all three sites and at each site across all years of study. While the amount of foliar injury on tulip poplar at Dickey Ridge corresponded well with ozone exposure, there was no correlation at the Big Meadows or Sawmill Run sites. The authors speculated the lack of correlation for tulip poplar at Big Meadows and Sawmill Run may have been due to extremes in moisture availability at the two sites. Hildebrand et al. (1996) concluded that cumulative ozone statistics, such as SUM06 and W126 (the sum of hourly average ozone concentrations using a sigmoidal weighting function), best represented foliar injury observations, particularly for black cherry, during the period of study.

Ambient ozone data collected by the NPS indicate maximum 3-month, 8:00 a.m. to 8:00 p.m., ozone concentrations ranged between 9 and 32 ppm-hrs during the years the trend plots were evaluated. Subsequent data show ozone concentrations have been increasing since 1993, which suggests ozone injury has continued in Shenandoah NP (figure 6).

In summary, ozone-induced foliar injury has been observed on a number of species in Shenandoah NP since the early 1980s. The amount of foliar injury on black cherry, in particular, correlated well with cumulative ozone exposures.

Great Smoky Mountains National Park, North Carolina and Tennessee:
Based on reports in the late 1970s of foliar symptoms consistent with ozone injury in Great Smoky Mountains NP, an ozone fumigation facility was established in the park, at Twin Creeks, in 1987. The purpose of the fumigations was to evaluate the effects of ambient and elevated ozone concentrations on species found in the park and to verify if foliar symptoms observed in the field were due to ozone. Between 1987 and 1991, 39 species were tested in the fumigation chambers. Visible injury similar to that in the field was observed on 25 of the 39 species (Neufeld et al. 1992). Subsequent work identified five additional species with confirmed ozone-induced foliar injury (Jim Renfro, Great Smoky Mountains NP, personal communication).

For some of the fumigated species, biomass loss increased with ozone exposure (Neufeld et al. 1992). Black cherry seedlings were particularly sensitive to ozone concentrations typical of high elevation sites in Great Smoky Mountains NP (Neufeld et al. 1995). Of the parameters examined, ozone-induced reductions in leaf and root biomass were most significant. Neufeld et al. (1995) concluded that while annual growth reduction of black cherry might be minor, large cumulative reductions could occur over the long lifespan of a tree. This is even more likely given that Samuelson and Kelly (1997) found that ozone uptake is much higher for mature black cherry trees than for seedlings and saplings. The conclusions about black cherry sensitivity to ozone in Great Smoky Mountains NP are supported by work conducted in other places which indicates ozone can reduce photosynthesis (Samuelson 1994) and accelerate leaf senescence (Pell et al. 1999) in this species.

Table mountain pine, Virginia pine, and Eastern hemlock were fumigated over one to three seasons at the Twin Creeks facility using ozone profiles based on data from a nearby ozone monitor. None of the species exhibited growth effects, even in the chambers with highest ozone exposure (Neufeld et al. 2000). These results conflict with those reported by Duchelle et al. (1982) in Shenandoah NP. In the Twin Creeks fumigation chambers, Table mountain pine and Virginia pine displayed foliar injury, but there was a great deal of variability between years and among plants. Neufeld et al. (2000) speculated the differences might have been due to different ozone exposure regimes or interactions with weather. These results underscore the difficulty in making definitive conclusions about the ozone sensitivity of particular species. They also highlight the need to consider the role of other environmental factors when determining ozone concentrations that are protective of native vegetation.

Concurrent with the trend plot work in Shenandoah NP discussed above, plots were established near ozone monitors at Cove Mountain, Look Rock, and Twin Creeks in Great Smoky Mountains NP. Black cherry, tulip poplar, and sassafras (*Sassafras albidum*) trees were examined in 1991, 1992, and 1993 (Chappelka et al. 1999). Foliar injury was observed on trees of all species at all locations during all years of the study. Ozone injury on black cherry and sassafras was greatest at Cove Mountain, the highest elevation site, which also had the highest ozone concentrations. Concurrent tree coring indicated tulip poplar and black cherry trees exhibiting ozone-induced foliar injury also had reduced radial growth (Somers et al. 1998). For black cherry, the cores showed a 12 percent reduction over 5 years and an 8 percent reduction over 10 years. Results were even more dramatic for tulip poplar, with the cores showing a 43 percent reduction over 5 years and a 30 percent reduction over 10 years. Chappelka et al. (1999) examined the combined data from the Great Smoky Mountains NP and Shenandoah NP trend plots. They found a clear correlation between elevational gradients of ozone exposure and foliar injury of black cherry, with higher ozone concentrations, and a greater percent of trees injured, at higher elevations (figure 7). The correlation was particularly strong for the Great Smoky Mountains NP data. A similar correlation, although not as strong, was found for sassafras (figure 8). The authors concluded that higher ozone exposures are more important than lower exposures in eliciting symptoms on sensitive trees.

In addition to the trend plots, foliar injury surveys were conducted along hiking trails in Great Smoky Mountains NP. In 1992, black cherry and tall milkweed (*Asclepias exaltata*) along 500 km of trail were examined for ozone-induced foliar injury. Injured plants were widely distributed throughout the park and the percent of injured plants was quite high, i.e., 47 percent of the black cherry trees exhibited ozone-induced foliar injury and 74 percent of the milkweed plants were injured (Chappelka et al. 1994).

Ambient ozone data collected by the NPS indicate maximum 3-month, 8:00 a.m. to 8:00 p.m., ozone concentrations ranged between 11 and 34 ppm-hrs during the years the trend plots were evaluated. Subsequent data show ozone concentrations have been increasing significantly since 1993, which suggests ozone injury has continued in Great Smoky Mountains NP (figure 9).

In summary, both fumigation studies and foliar injury surveys have shown that there are a number of species in Great Smoky Mountains NP that are sensitive to ozone. The fumigation studies showed that in addition to foliar injury, ozone concentrations typical of higher elevations in the park are sufficient to cause biomass loss in sensitive species.

Sierra Nevada Mountains, California:

Ozone injury symptoms were diagnosed on ponderosa pine (*Pinus ponderosa*) and Jeffrey pine (*Pinus jeffreyi*) in the Sierra Nevada Mountains of California in the early 1970s. A series of field surveys in the 1980s and 1990s documented the extent and severity of injury in selected locations (Miller 1996). For example, between 1980 and 1982, a network of monitoring plots was established in Sequoia/Kings Canyon NPs. Ponderosa and Jeffrey pines in the plots were examined for ozone-induced foliar injury and other health-related parameters. The plots were re-surveyed in 1984 and 1989. Although there was no significant increase in ozone concentrations, there was a significant increase in both the number of injured trees and the average amount of injury per tree between the 1980/1982 and 1989 surveys (Ewell and Gay 1993). Studies of plants in open-top chambers show that, in addition to ozone concentration, plant genotype, drought stress, and exposure to other atmospheric pollutants can influence the amount of ozone-induced foliar injury (Temple et al. 1992, Miller 1996).

In 1990-1991, a collaborative effort was initiated among the NPS, U.S.D.A. Forest Service, and California Air Resources Board to monitor ozone concentrations and foliar injury on ponderosa and Jeffrey pines in the Sierra Nevada. This effort, the Forest Ozone Response Study (FOREST), resulted in the establishment of 33 field plots, containing a total of 1700 trees, along the extent of the Sierra Nevada Mountains (Arbaugh et al. 1998). Sites were established in Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite NPs, as well as in the Tahoe, El Dorado, Stanislaus, Sierra, Sequoia, and San Bernardino National Forests (NF). Data were collected in most plots from 1991 to 1994 (1992 to 1994 in Lassen Volcanic NP and 1992 to 1995 in the San Bernardino NF). In general, the FOREST results indicated the number of injured trees, as well as ozone concentrations, increased from the northern Sierra Nevada to the southern Sierra Nevada (Arbaugh et al. 1998, Salardino and Carroll 1998) (see figure 10 for summary ozone and injury data for plots in National Parks).

Ambient ozone data collected by the NPS indicate maximum 3-month, 8:00 a.m. to 8:00 p.m., ozone concentrations ranged between 11 and 87 ppm-hrs during the years the plots were evaluated. Subsequent data show ozone concentrations have not decreased significantly at any of the parks since 1994, which suggests ozone injury has continued (figures 11, 12, and 13).

Because ponderosa and Jeffrey pine are such good bioindicators for ozone, few studies have examined ozone effects on other species found in the Sierra Nevada. Duriscoe and Temple (1996) performed a preliminary survey of ozone injury on a handful of understory species in the Sequoia NF and Sequoia/Kings Canyon NPs. The authors found a small amount of injury on mugwort (*Artemisia douglasiana*) and Mexican elder (*Sambucus mexicana*) that they attributed to ozone. Grulke and Miller (1994) examined the response of current-year, 2-, 5-, 20-, 125-, and greater than 2,000-year-old giant sequoias (*Sequoiadendron giganteum*) to ozone using fumigation chambers. Current-year seedlings exposed to 150 percent ambient ozone concentrations had visible foliar injury, whereas seedlings grown in charcoal-filtered air did not. Based on carbon exchange rate and other physiological parameters, the authors concluded that giant sequoias are particularly sensitive to ozone until they are about five years old.

In summary, foliar injury surveys conducted in the Sierra Nevada Mountains since the early 1980s have consistently documented the occurrence of ozone-induced foliar injury at ambient concentrations. While most studies have focused on ponderosa and Jeffrey pines, limited information indicates other species can be injured by ozone as well. Further studies are needed to clarify whether ambient ozone concentrations are affecting sensitive species so significantly that within-species genetic variability or overall plant community composition is being affected.

Edwin B. Forsythe National Wildlife Refuge, New Jersey:

Vegetation surveys were conducted by FWS from 1993 to1996 to evaluate ozone injury in Edwin B. Forsythe National Wildlife Refuge (NWR). Edwin B. Forsythe NWR encompasses the Brigantine Wilderness, a Class I air quality area, and is located on the Atlantic Coast in southeastern New Jersey. The refuge is also designated in the “List of Wetlands of International Importance” under the United Nations Ramsar Convention.

In 1993, ten sites were established at Edwin B. Forsythe NWR in locations that contained a variety of ozone-sensitive indicator species, including black cherry, wild grape, common milkweed (*Asclepias syriaca*), Virginia creeper (*Parthenocissus quinquefolia*), and winged sumac (*Rhus copallina*). In 1993 and 1994, surveys were conducted in both August and September. In 1995 and 1996, surveys were conducted in late August. During each survey, approximately 600-700 plants were examined and rated for amount and severity of injury.

In 1993, 81 percent of the common milkweeds examined and 69 percent of the wild grapes exhibited ozone injury symptoms. In 1994, 41 percent of common milkweeds and 67 percent of wild grapes exhibited injury. In 1995, 23 percent of common milkweeds and 18 percent of wild grapes exhibited injury. And in 1996, 70 percent of common milkweeds and 47 percent of wild grapes exhibited injury. In addition, several other species showed typical ozone injury symptoms during the surveys, including black cherry, Virginia creeper, and winged sumac (Davis 1995; Davis 1996a; Davis 1996b).

Ambient ozone concentrations in Edwin B. Forsythe NWR are monitored by the New Jersey Department of Environmental Protection (figure 14). From 1993 to1996, the maximum 3-month, 8:00 a.m. to 8:00 p.m., SUM06 varied from 24 to 39 ppm-hrs. Ozone injury was documented during all those years. Surveys have not been conducted since 1996; however, because ozone levels have remained considerably higher (31 to 36 ppm-hrs) from 1997 to 1999 than the lowest level at which injury was observed (24 ppm-hrs), it is likely that ozone injury has occurred every year since surveys were done.

In summary, certain species of plants at Edwin B. Forsythe NWR displayed considerable symptoms of ozone injury during the years of the surveys. Common milkweed and wild grape were particularly affected, with 23-81 percent of common milkweeds affected and 18-69 percent of wild grapes affected. Other species had foliar ozone injury symptoms as well. Because ozone levels have remained high in the area, it is likely that vegetation continues to be injured at Edwin B. Forsythe NWR.

Cape Romain National Wildlife Refuge, South Carolina:

Vegetation surveys were conducted by FWS from 1996 to1998 to evaluate ozone injury in Cape Romain NWR, located on the Atlantic Coast near Charleston, South Carolina. The refuge encompasses the Cape Romain Wilderness, a Class I air quality area.

In 1996, general survey locations containing ozone-sensitive indicator species were identified in the refuge, both on the mainland and an offshore island. Indicator species present included wild grape, winged sumac, black cherry, loblolly pine, sweetgum, and Virginia creeper. Surveys were conducted in August of each year. During each survey, approximately 300-400 plants were examined and rated for amount and severity of injury.

Injury at the mainland survey location was generally higher than at the island location. On the mainland in 1996, 25 percent of wild grapes examined and 20 percent of winged sumac exhibited ozone injury symptoms (Davis 1997). In 1997, 48 percent of wild grapes and 24 percent of winged sumac exhibited injury (Davis 1998). In 1998, 44 percent of wild grapes exhibited injury (winged sumac could not be evaluated in 1998) (Davis 1999a).

Ambient ozone concentrations in Cape Romain NWR are monitored at the mainland survey location by the South Carolina Department of Health and Environmental Control (figure 15). From 1996 to1998, the maximum 3-month, 8 a.m. to 8 p.m., SUM06 varied from 7 to14 ppm-hrs. Ozone injury was documented during all those years. Surveys have not been conducted since 1998; however, because ozone levels increased in 1999 (15 ppm-hrs), it is likely that ozone injury also occurred in 1999.

In summary, certain species of plants at Cape Romain NWR displayed considerable symptoms of ozone injury during the years of the surveys. Wild grape and winged sumac were particularly affected, with 25-48 percent of wild grapes affected and 20-24 percent of winged sumac affected. Ozone injury was induced at levels as low as 7 ppm-hrs (maximum 3-month, 8 a.m. to 8 p.m., SUM06. Ozone levels in 1999, the year following the survey, increased to 15 ppm-hrs, making it likely that ozone injury occurred in that year also.

Other National Wildlife Refuges:

FWS has conducted vegetation surveys and documented ozone injury symptoms at several other national wildlife refuges as well. Surveys conducted in Mingo NWR in Missouri from 1998 to 2000 found ozone injury on ash (*Fraxinus spp*.), black cherry, common milkweed, cucumbertree (*Magnolia acuminata*), dogwood (*Cornus florida*), wild grape, sassafras, and sweet gum (Davis 1999b; Davis 2000a). Surveys in Moosehorn NWR in Maine from 1998-2000 found ozone injury to ash, aspen, black cherry, spreading dogbane (*Apocynum androsaemifolium*), pin cherry (*Prunus pennsylvanica*), and serviceberry (*Amelanchier laevis*) (Davis 1999c; Davis 2000b). Surveys in Seney NWR in Michigan in 1999 found ozone injury to black cherry, common milkweed, and spreading dogbane (Davis 2000c).

Ozone Recommendations:

In EPA's July 18, 1997, *Federal Register* notice regarding the ozone NAAQS, it recognized that the 8-hour primary standard of 80 ppb, while more protective than the previous 1-hour standard, might not protect vegetation in Class I air quality areas. There is still some debate among ozone effects experts regarding the correct form of a potential secondary standard, however, it appears from the literature cited above that all of the experts favor a standard based on cumulative concentration, and most recommend that the exposure be accumulated over both a 24-hour period and the growing season. Cumulative ozone statistics, such as SUM06 and W126 (the sum of hourly average ozone concentrations using a sigmoidal weighting function), best represent foliar injury observations.

An analysis of ozone monitoring data in several parks and wilderness areas shows that cumulative ozone exposure in excess of levels known to injure vegetation occurs in areas where the 8-hour standard is not likely to be exceeded (figure 16). Therefore, we urge EPA to develop a secondary ozone standard that is truly protective of natural vegetation. Even if EPA promulgates a secondary ozone standard that is more appropriate and protective than the current one, it is possible that the standard might not be sufficient to protect certain sensitive species. In those cases, the recommended AQRV protection regulation would provide Federal Land Managers an avenue for protecting areas against ozone-related effects on vegetation.

It must also be recognized that rural ozone production and transport are somewhat different from the urban situations that have been studied more extensively. However, regional research studies have the potential to provide the information needed if the rural context is considered in the analysis. In the eastern US, the abundance of biogenic VOC and its high reactivity leads to a NO_x-limited scenario. Sources that are 3 to 20 hours upwind from parks seem to have the highest potential for transport of ozone to the parks because of their continued production of ozone during transport. Underneath the plume production of ozone is the background defined by natural processes of stratosphere to troposphere O_3 transport and oxidation of background levels of CO and CH_4. The CO and CH_4 concentrations are increasing above natural levels in the Northern Hemisphere from anthropogenic sources, much of it mobile sources. We see that NO_x and CO controls are likely to be the best measures to reduce rural ozone. Certainly, more attention should be directed at how to reduce rural levels of ozone during ozone control discussions and modeling efforts. An approach that considers areas of influence and broad regions as the sources and transport of ozone pollution is needed if effective control and reductions in ozone are to be accomplished.

We recommend that EPA consider the need to develop ozone and precursor monitoring and to develop modeling programs that better characterize and quantitate the rural ozone concentrations and trends. Control strategies based on influence areas need to be put into place that also protect the most sensitive rural areas.

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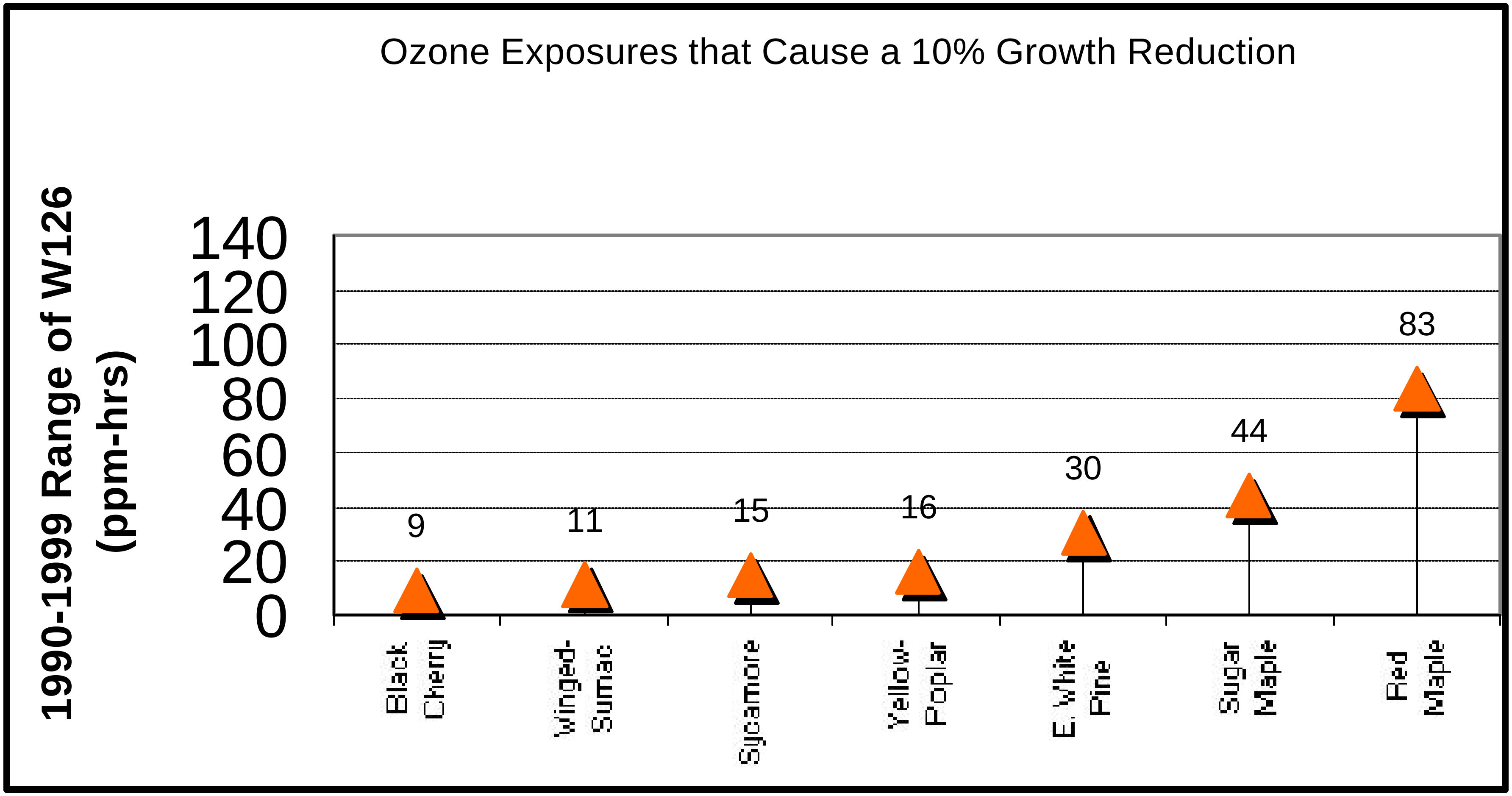

Ozone Exposures that Cause a 10% Growth Reduction
1990-1999 Range of W126
(ppm-hrs)
140
120
100
80
60
40
20
0
9
11
15
16
30
44
83
Black Cherry
Winged-Sumac
Sycamore
Yellow-Poplar
E. White Pine
Sugar Maple
Red Maple

Figure 1.

Maximum 3-Month 8am-8pm SUM06 During the Period 1995-1999
(ppm-hr)

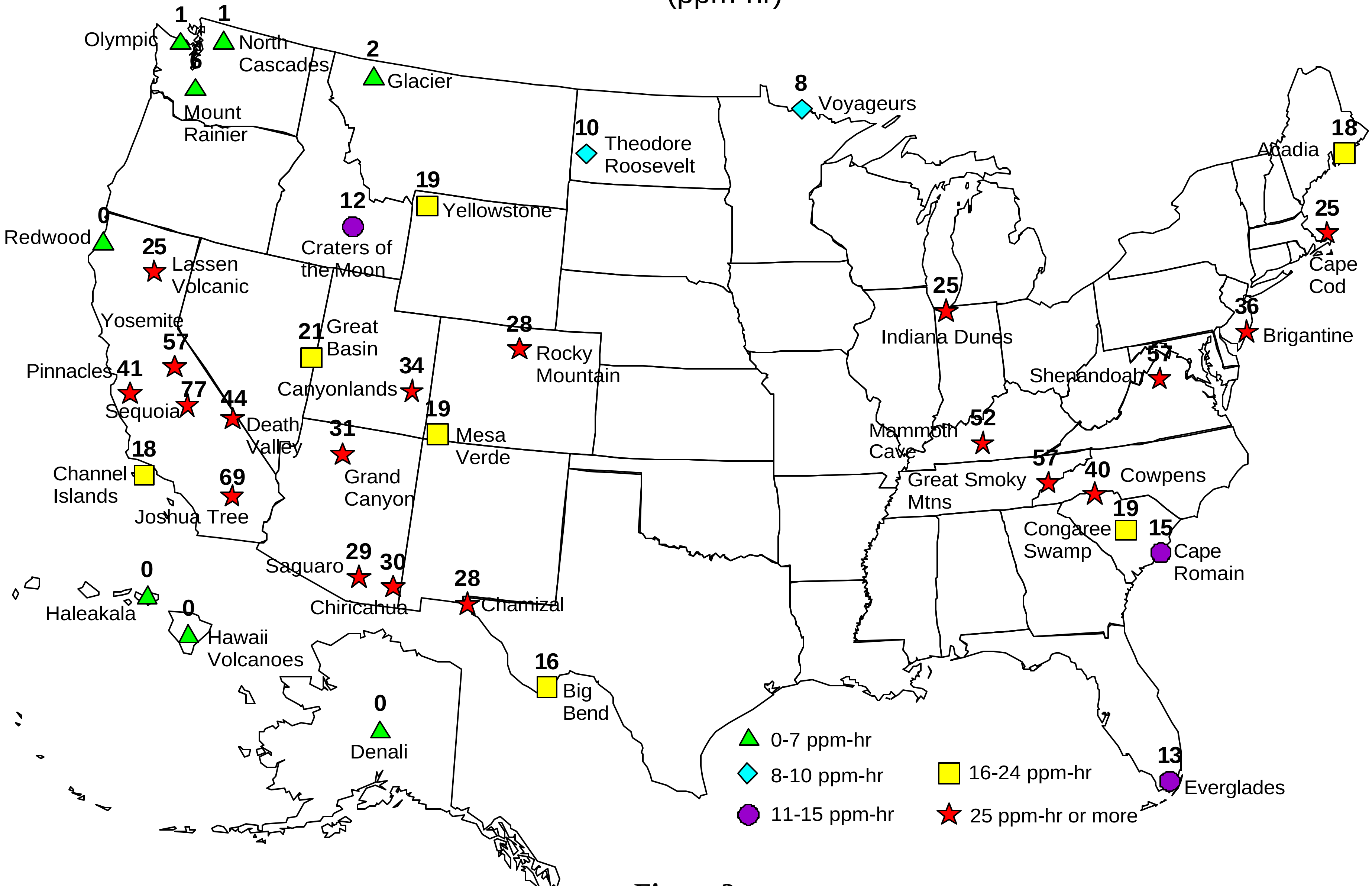


Figure 2.

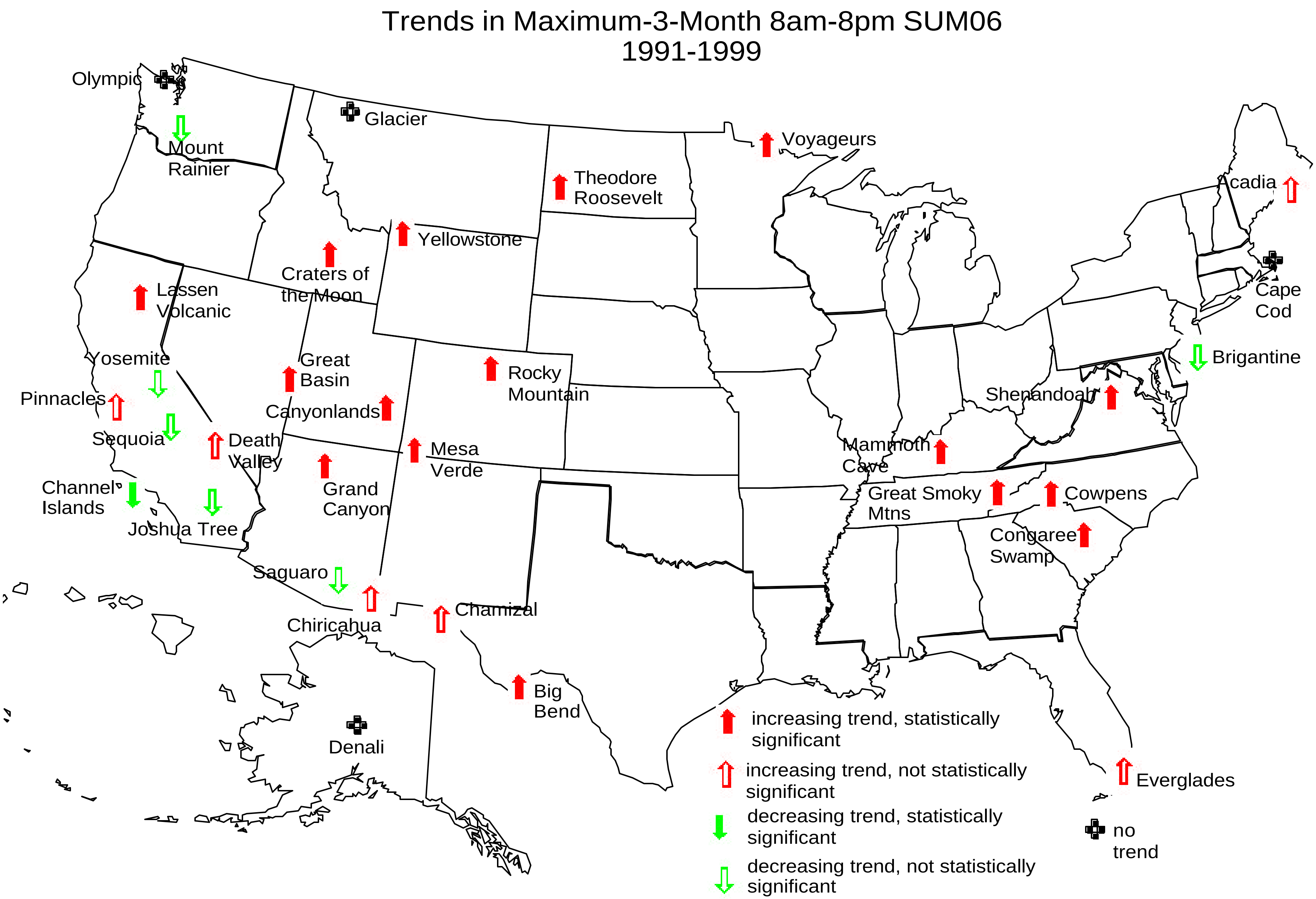

Trends in Maximum-3-Month 8am-8pm SUM06
1991-1999
Olympic
Glacier
Voyageurs
Mount Rainier
Theodore Roosevelt
Acadia
Yellowstone
Craters of the Moon
Lassen Volcanic
Cape Cod
Yosemite
Great Basin
Rocky Mountain
Brigantine
Pinnacles
Canyonlands
Shenandoah
Sequoia
Death Valley
Mesa Verde
Mammoth Cave
Channel Islands
Grand Canyon
Great Smoky Mtns
Cowpens
Joshua Tree
Congaree Swamp
Saguaro
Chiricahua
Chamizal
Big Bend
Denali
Everglades
increasing trend, statistically significant
increasing trend, not statistically significant
decreasing trend, statistically significant
decreasing trend, not statistically significant
no trend

Figure 3.

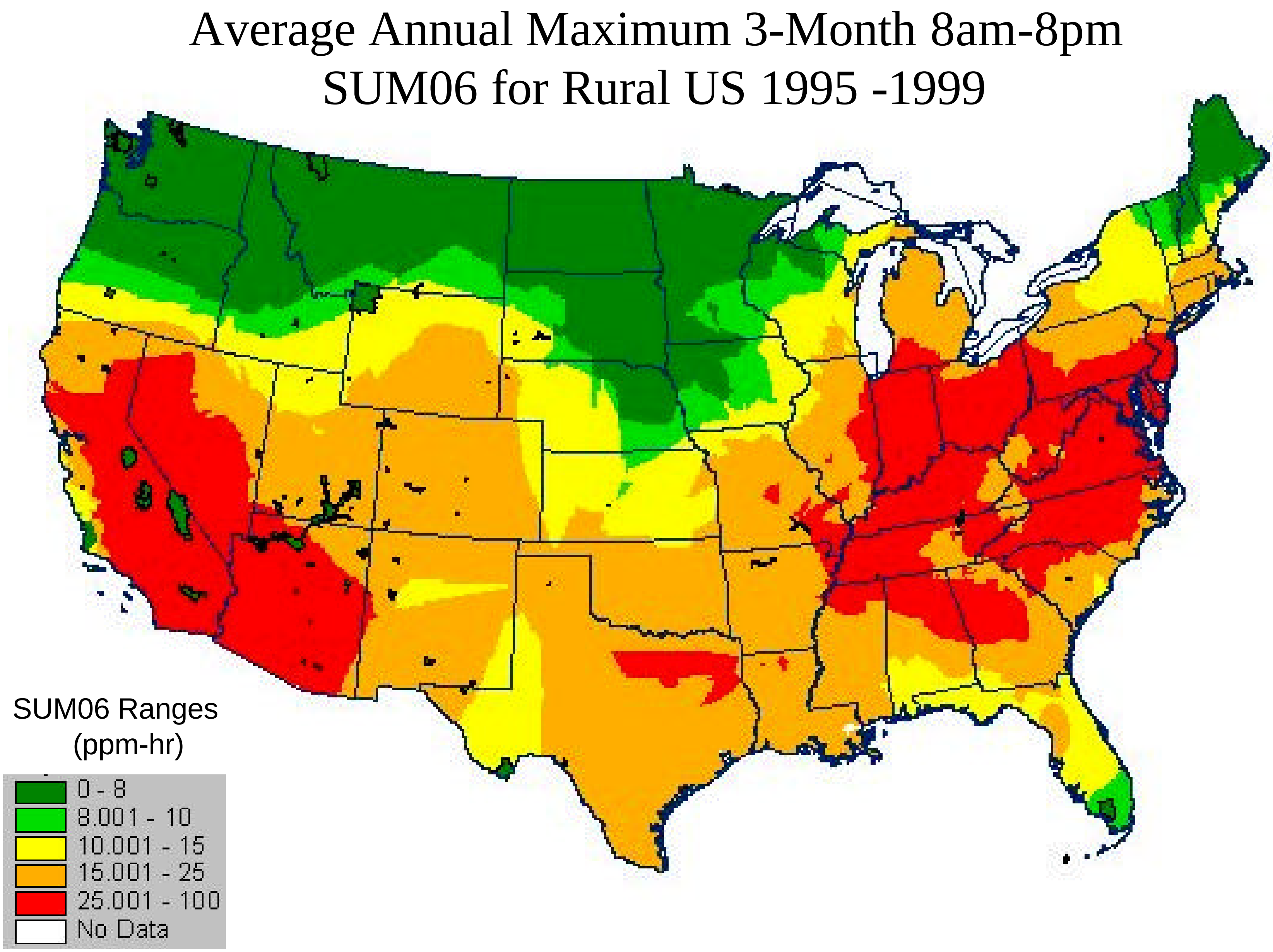

Average Annual Maximum 3-Month 8am-8pm
SUM06 for Rural US 1995 -1999
SUM06 Ranges
(ppm-hr)
0 - 8
8.001 - 10
10.001 - 15
15.001 - 25
25.001 - 100
No Data

Figure 4.

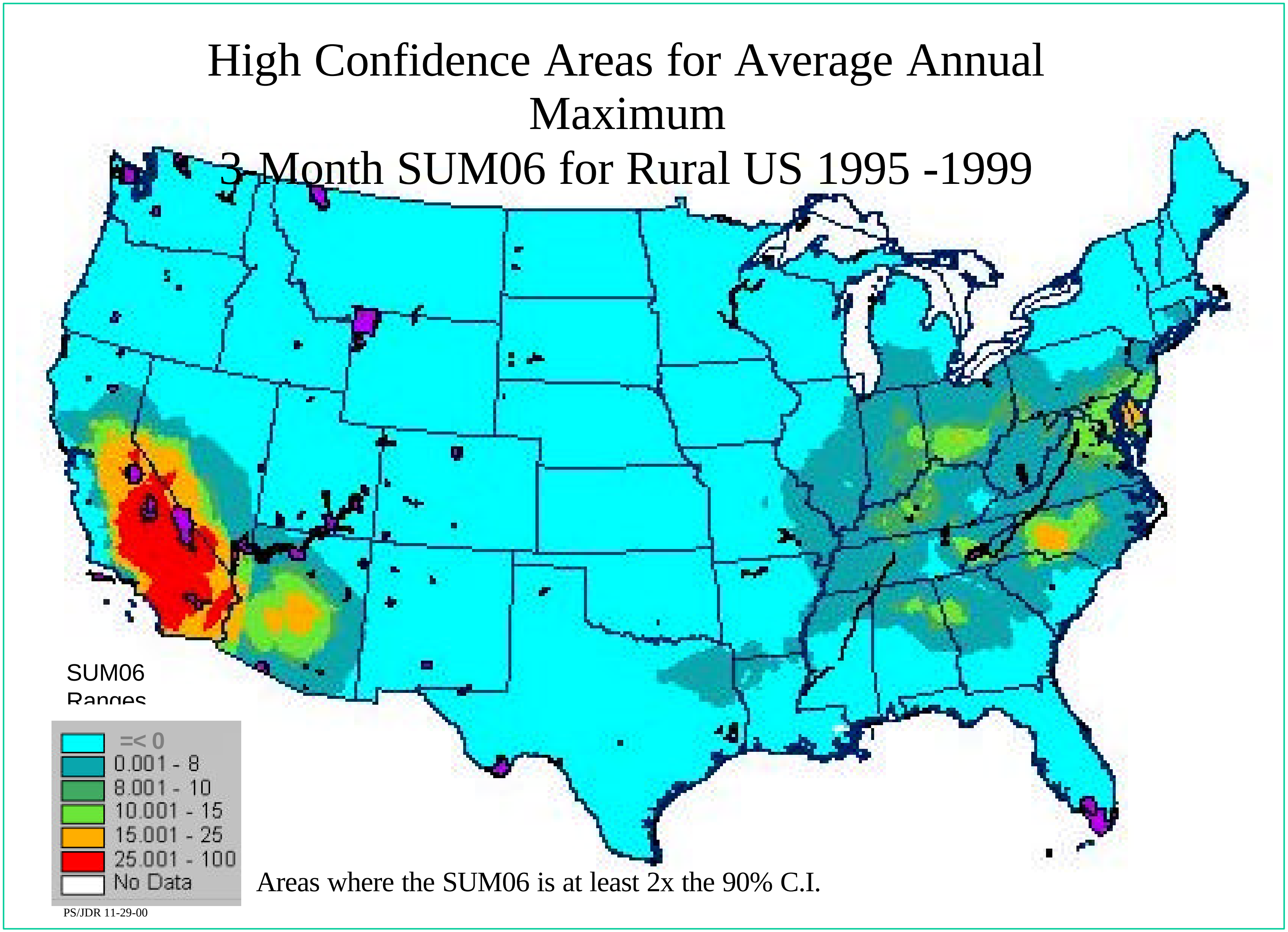

High Confidence Areas for Average Annual
Maximum
3-Month SUM06 for Rural US 1995 -1999
SUM06
Ranges
=< 0
0.001 - 8
8.001 - 10
10.001 - 15
15.001 - 25
25.001 - 100
No Data
Areas where the SUM06 is at least 2x the 90% C.I.
PS/JDR 11-29-00

Figure 5.

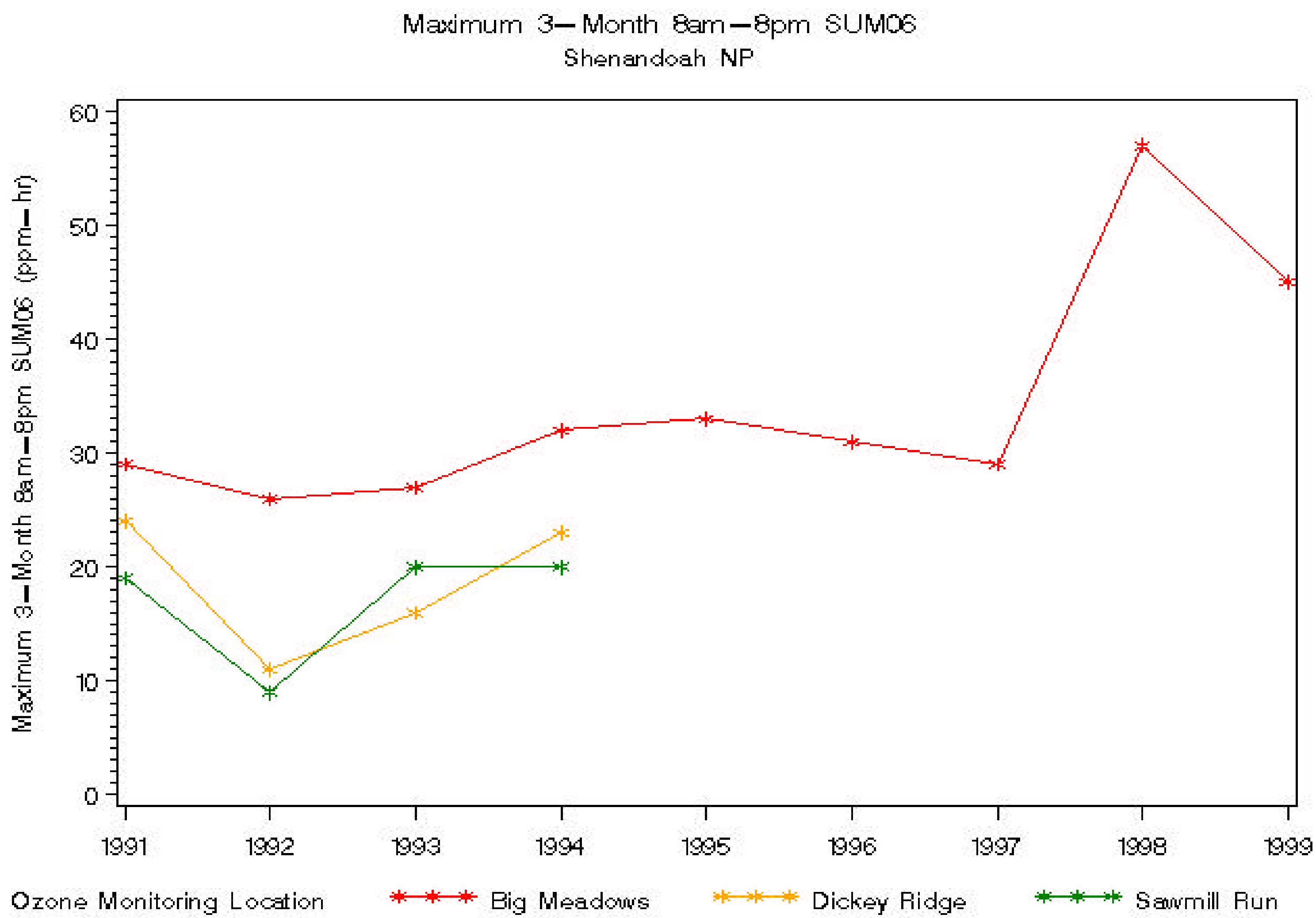

Maximum 3—Month 8am—8pm SUM06
Shenandoah NP
Maximum 3—Month 8am—8pm SUM06 (ppm—hr)
0
10
20
30
40
50
60
1991
1992
1993
1994
1995
1996
1997
1998
1999
Ozone Monitoring Location
Big Meadows
Dickey Ridge
Sawmill Run

Figure 6.

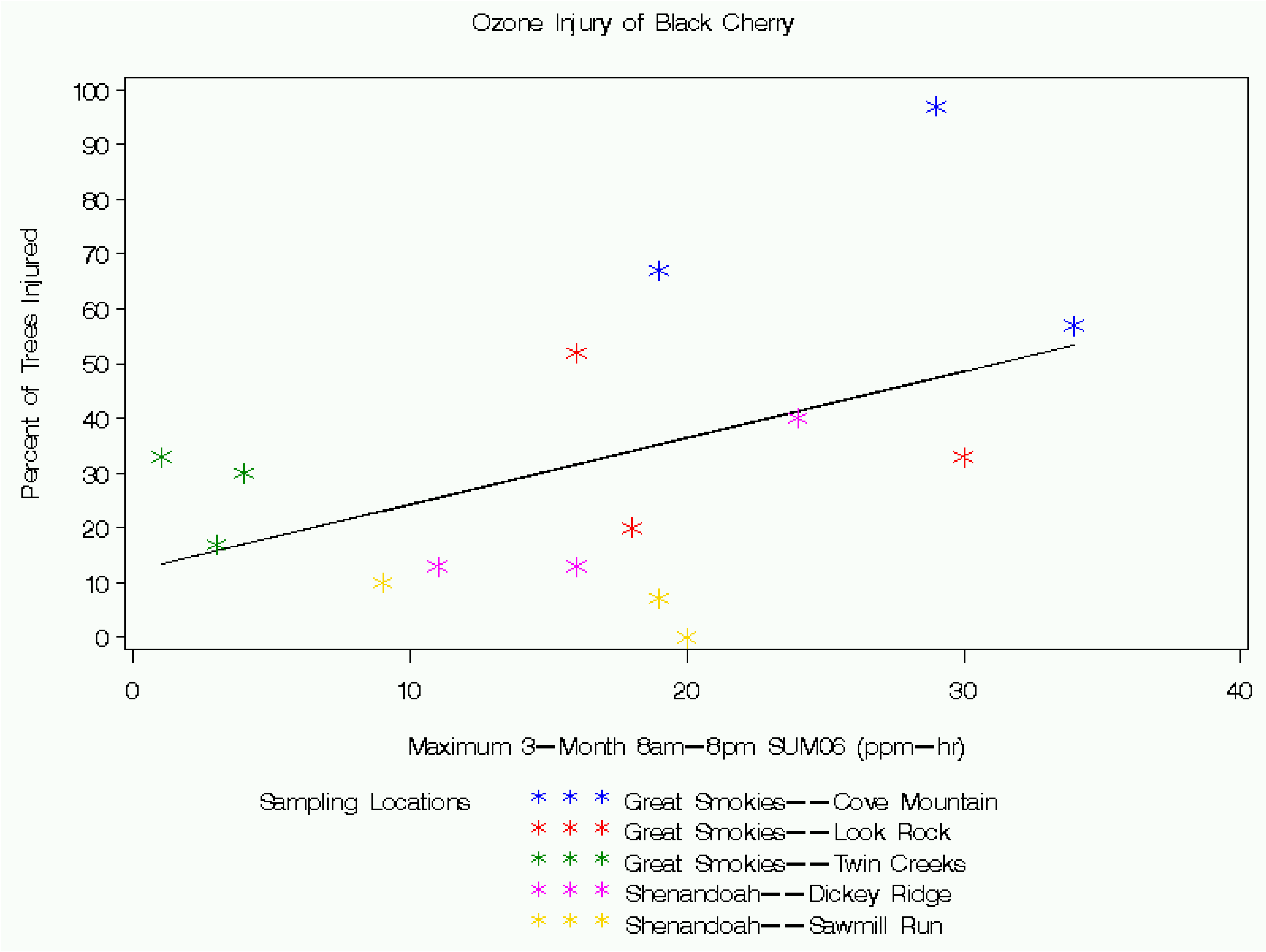

Ozone Injury of Black Cherry
Percent of Trees Injured
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
Maximum 3-Month 8am-8pm SUM06 (ppm-hr)
Sampling Locations
Great Smokies--Cove Mountain
Great Smokies--Look Rock
Great Smokies--Twin Creeks
Shenandoah--Dickey Ridge
Shenandoah--Sawmill Run

Figure 7.

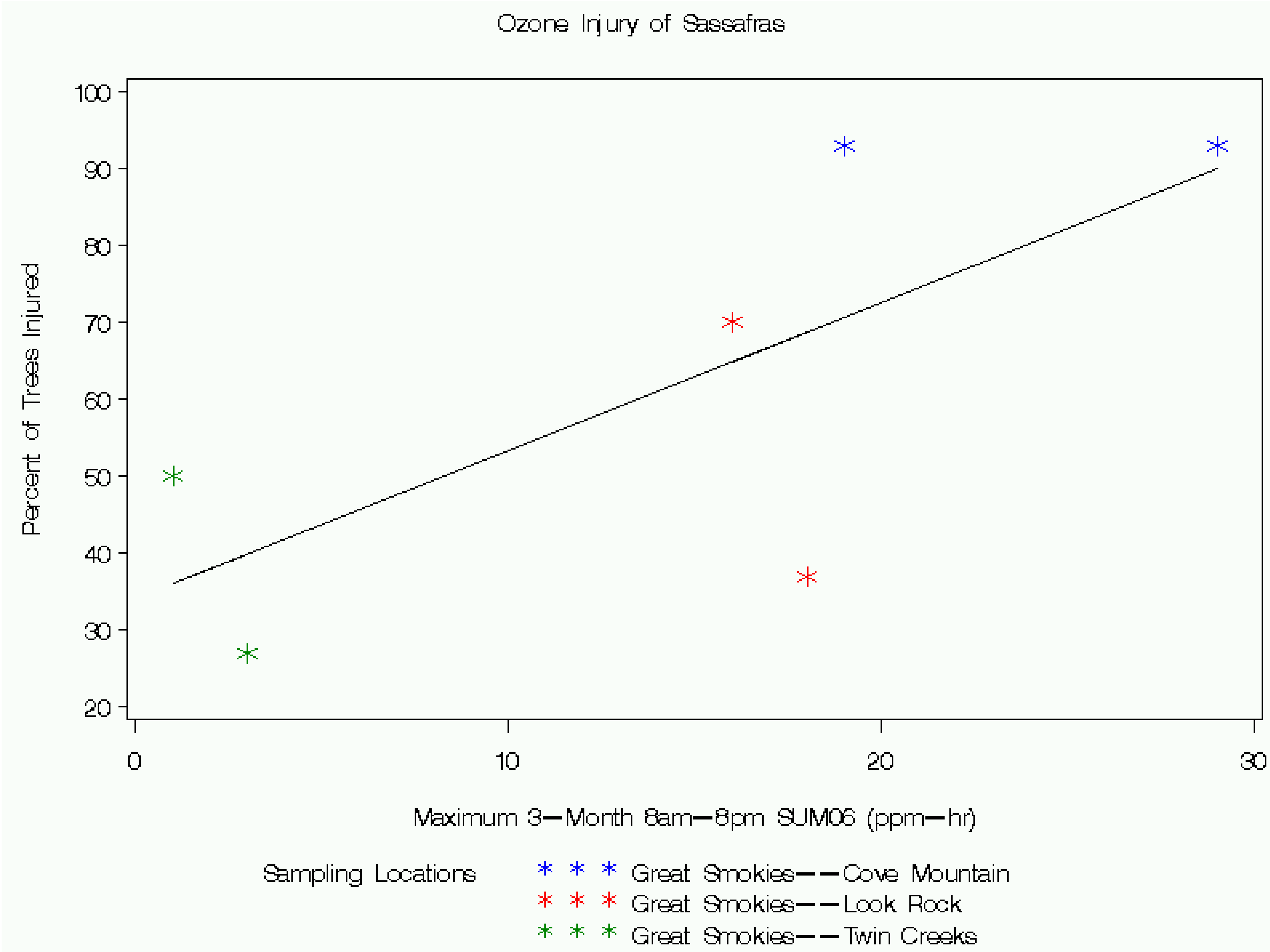

Ozone Injury of Sassafras
Percent of Trees Injured
100
90
80
70
60
50
40
30
20
0
10
20
30
Maximum 3-Month 8am-8pm SUM06 (ppm-hr)
Sampling Locations
Great Smokies--Cove Mountain
Great Smokies--Look Rock
Great Smokies--Twin Creeks

Figure 8.

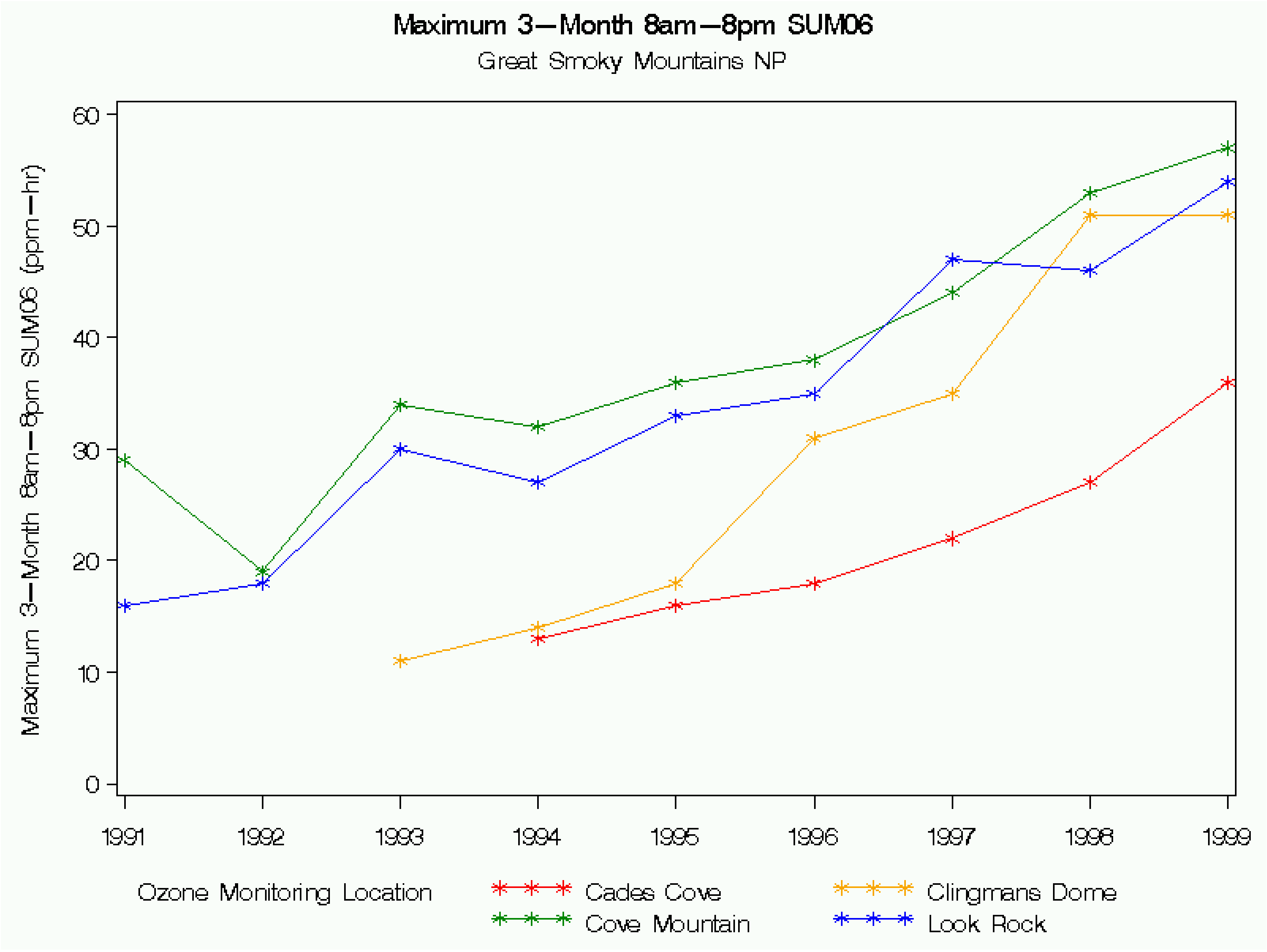
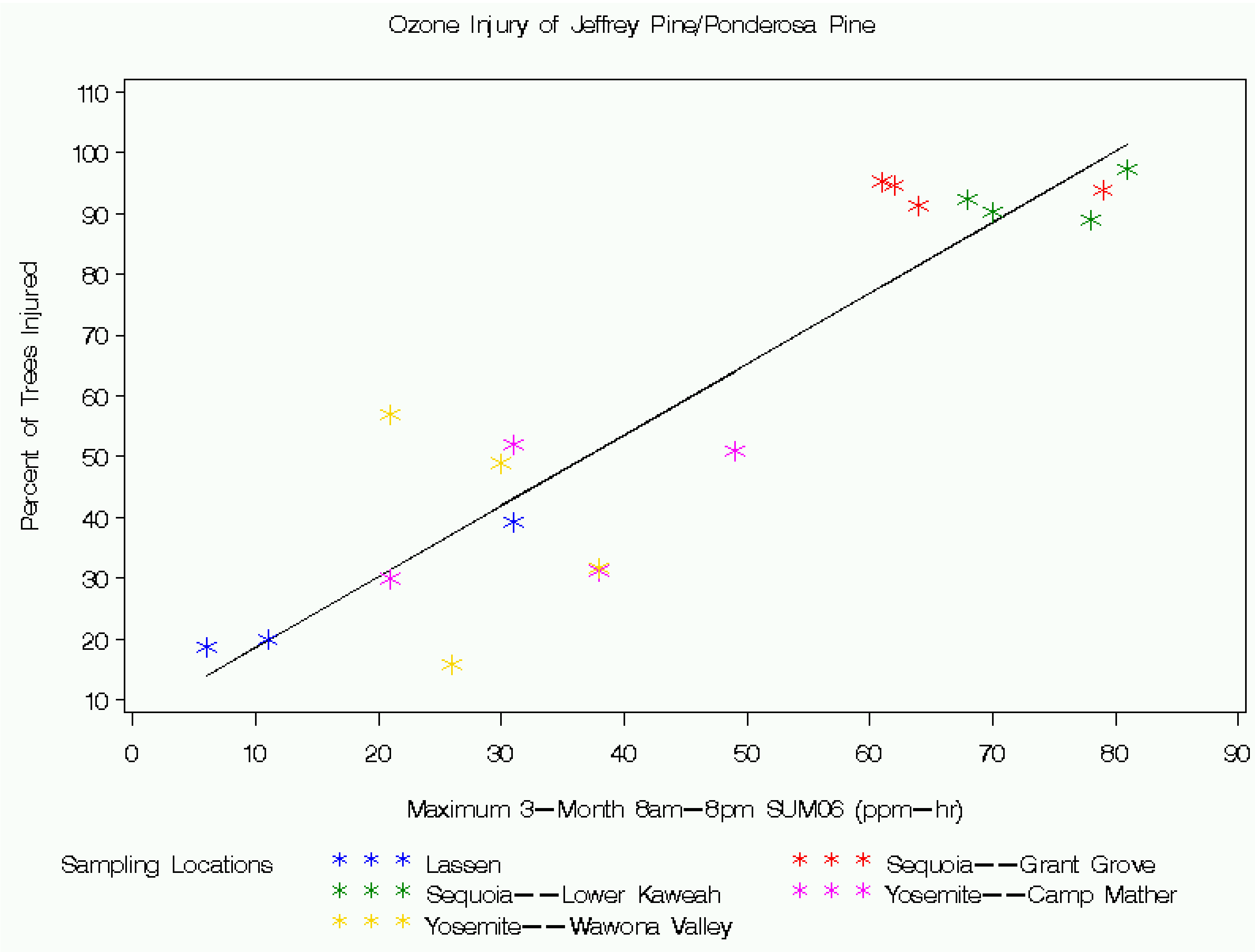

Maximum 3—Month 8am—8pm SUM06
Great Smoky Mountains NP
Maximum 3—Month 8am—8pm SUM06 (ppm—hr)
0
10
20
30
40
50
60
1991
1992
1993
1994
1995
1996
1997
1998
1999
Ozone Monitoring Location
Cades Cove
Clingmans Dome
Cove Mountain
Look Rock

Figure 9.



Ozone Injury of Jeffrey Pine/Ponderosa Pine
Percent of Trees Injured
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
Maximum 3−Month 8am−8pm SUM06 (ppm−hr)
Sampling Locations
Lassen
Sequoia−−Lower Kaweah
Yosemite−−Wawona Valley
Sequoia−−Grant Grove
Yosemite−−Camp Mather

Figure 10.

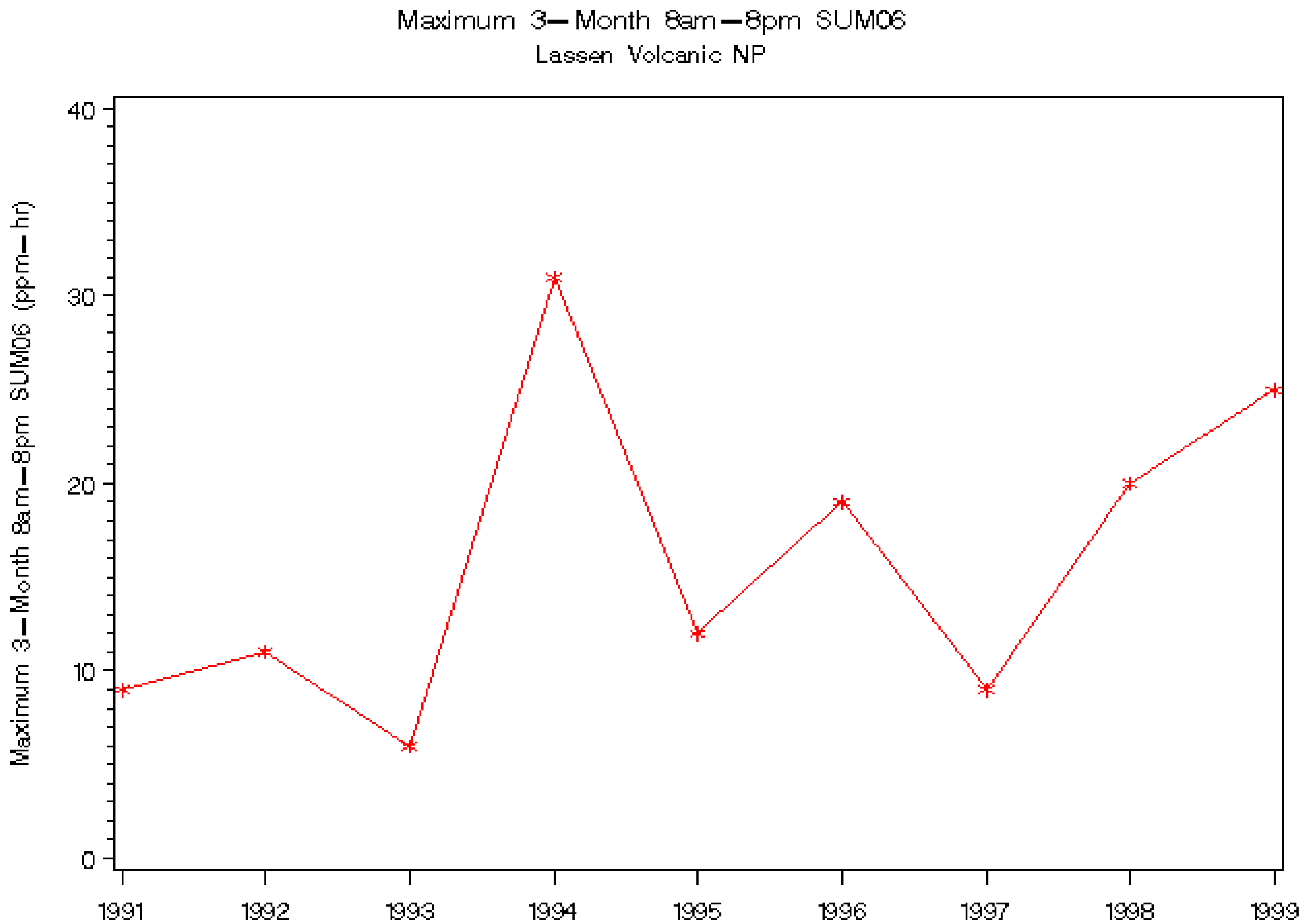

Maximum 3—Month 8am—8pm SUM06
Lassen Volcanic NP
Maximum 3—Month 8am—8pm SUM06 (ppm—hr)
40
30
20
10
0
1991
1992
1993
1994
1995
1996
1997
1998
1999

Figure 11.

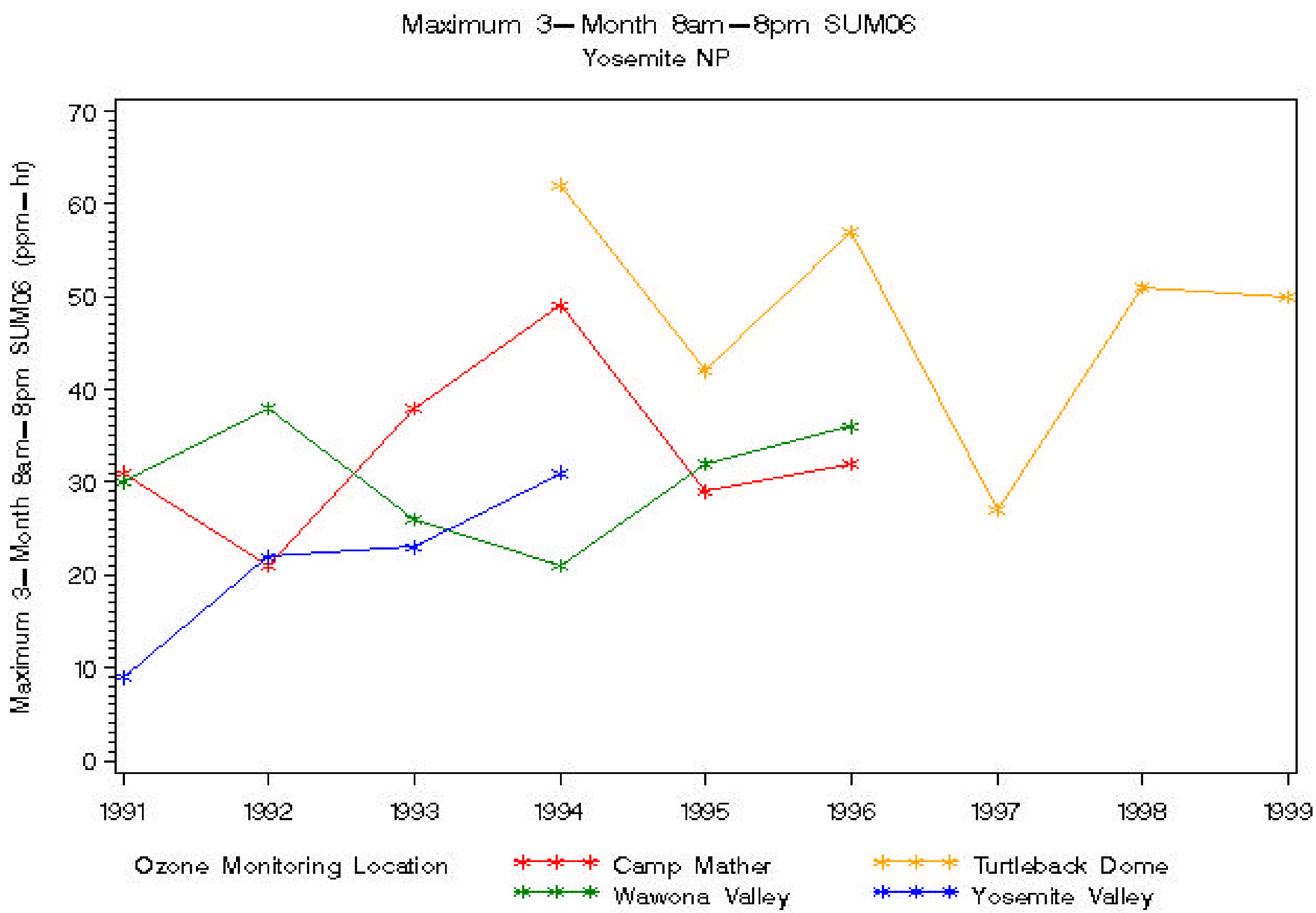

Maximum 3-Month 8am-8pm SUM06
Yosemite NP
Maximum 3-Month 8am-8pm SUM06 (ppm-hr)
0
10
20
30
40
50
60
70
1991
1992
1993
1994
1995
1996
1997
1998
1999
Ozone Monitoring Location
Camp Mather
Wawona Valley
Turtleback Dome
Yosemite Valley

Figure 12.

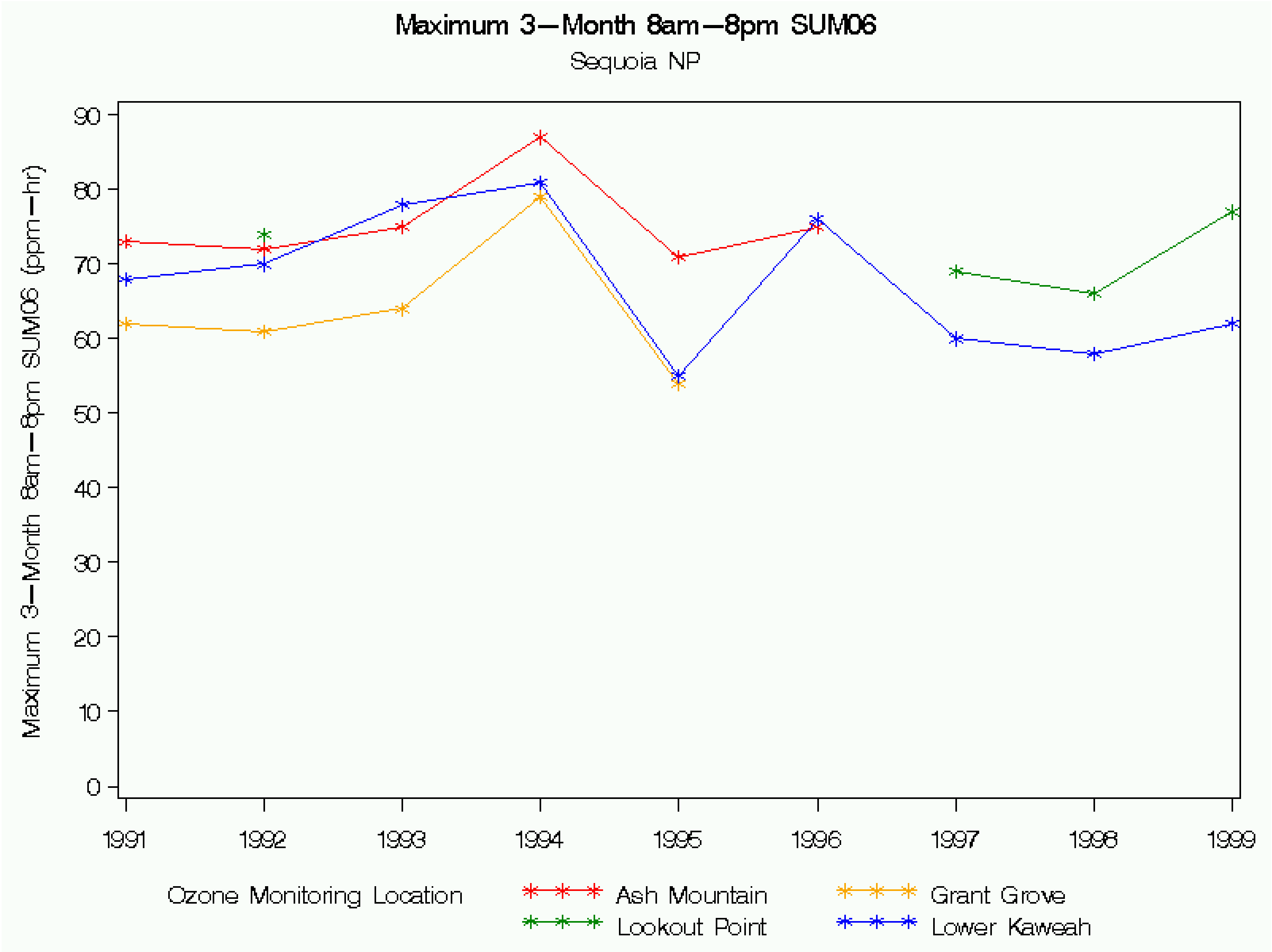

Maximum 3—Month 8am—8pm SUM06
Sequoia NP
Maximum 3—Month 8am—8pm SUM06 (ppm—hr)
0
10
20
30
40
50
60
70
80
90
1991
1992
1993
1994
1995
1996
1997
1998
1999
Ozone Monitoring Location
Ash Mountain
Grant Grove
Lookout Point
Lower Kaweah

Figure 13.

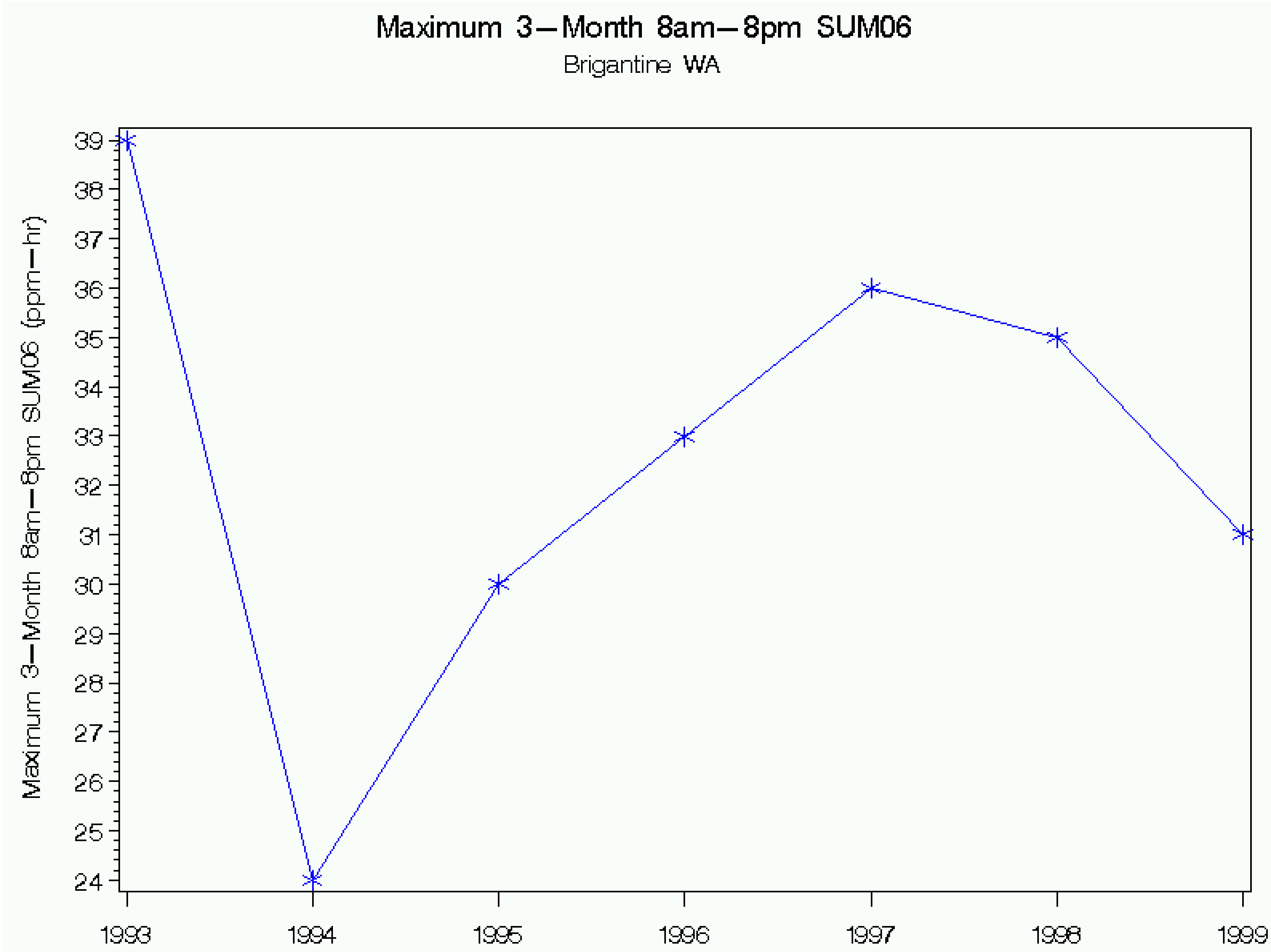

Maximum 3—Month 8am—8pm SUM06
Brigantine WA
Maximum 3—Month 8am—8pm SUM06 (ppm—hr)
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
1993
1994
1995
1996
1997
1998
1999

Figure 14.

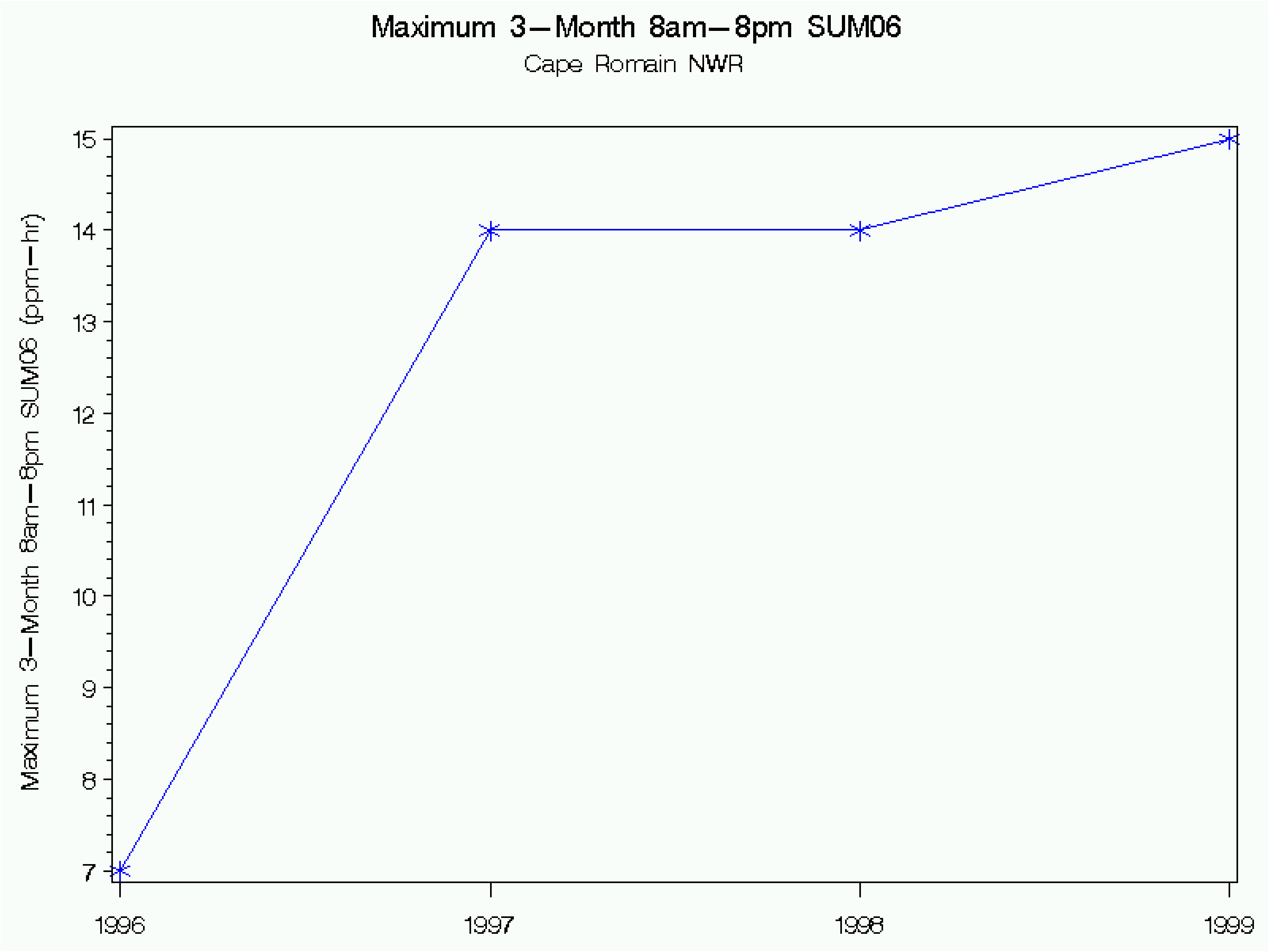
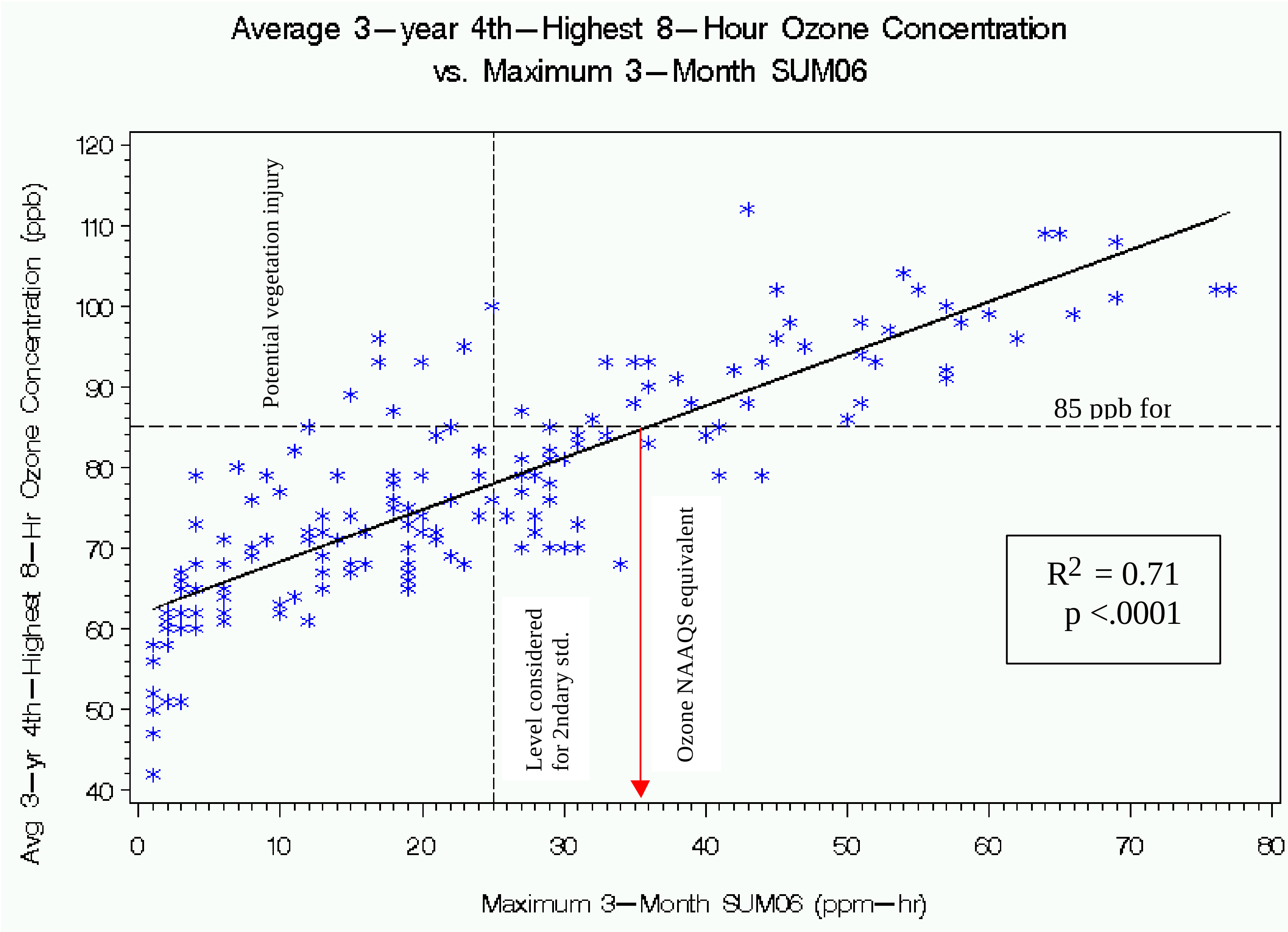

Maximum 3—Month 8am—8pm SUM06
Cape Romain NWR
Maximum 3—Month 8am—8pm SUM06 (ppm—hr)
15
14
13
12
11
10
9
8
7
1996
1997
1998
1999

Figure 15.



Average 3—year 4th—Highest 8—Hour Ozone Concentration
vs. Maximum 3—Month SUM06
Avg 3—yr 4th—Highest 8—Hr Ozone Concentration (ppb)
Maximum 3—Month SUM06 (ppm—hr)
Potential vegetation injury
Level considered
for 2ndary std.
Ozone NAAQS equivalent
85 ppb for
R2 = 0.71
p <.0001
120
110
100
90
80
70
60
50
40
0
10
20
30
40
50
60
70
80

Figure 16.