# Evaluation of Ozone Injury
# to Vegetation in the
# Wichita Mountains National Wildlife Refuge
# Oklahoma

**2001 Observations**

Submitted to

**The U.S. Fish and Wildlife Service**
**Branch of Air Quality**
**Denver, CO**

Donald D. Davis, Ph.D.

October 30, 2002

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# INTRODUCTION

## General

The Wichita Mountains National Wildlife Refuge (NWR), located in southwestern Oklahoma, is one of more than 500 Refuges in the National Wildlife Refuge System (NWRS) administered by the U.S. Fish and Wildlife Service (FWS). The NWRS is a network of lands and waters managed specifically for the protection of wildlife and wildlife habitat and represents the most comprehensive wildlife management program in the world. Units of the system stretch across the United States from northern Alaska to the Florida Keys and include small islands in the Caribbean and South Pacific. The character of the Refuges is as diverse as the nation itself.

By proclamation on July 4, 1901, President McKinley withheld from settlement and designated the acres that now are Wichita Mountains NWR as a forest reserve. In 1905, by Executive Order of President Theodore Roosevelt, a game preserve was created on these lands when Congress appropriated $15,000 to enclose 8,000 acres, and the modern history of the Wichita Mountains NWR began (Figure 1). Thus, the Wichita Mountains area has been a national wildlife refuge since 1905 and as such is the oldest managed unit of the Refuge System, although it did not enter the System officially until 1935. It now encompasses 59,020 acres, 8,570 acres of which are designated wilderness within the National Wilderness Preservation System, thereby granted special protection that will insure the preservation of its wilderness character.

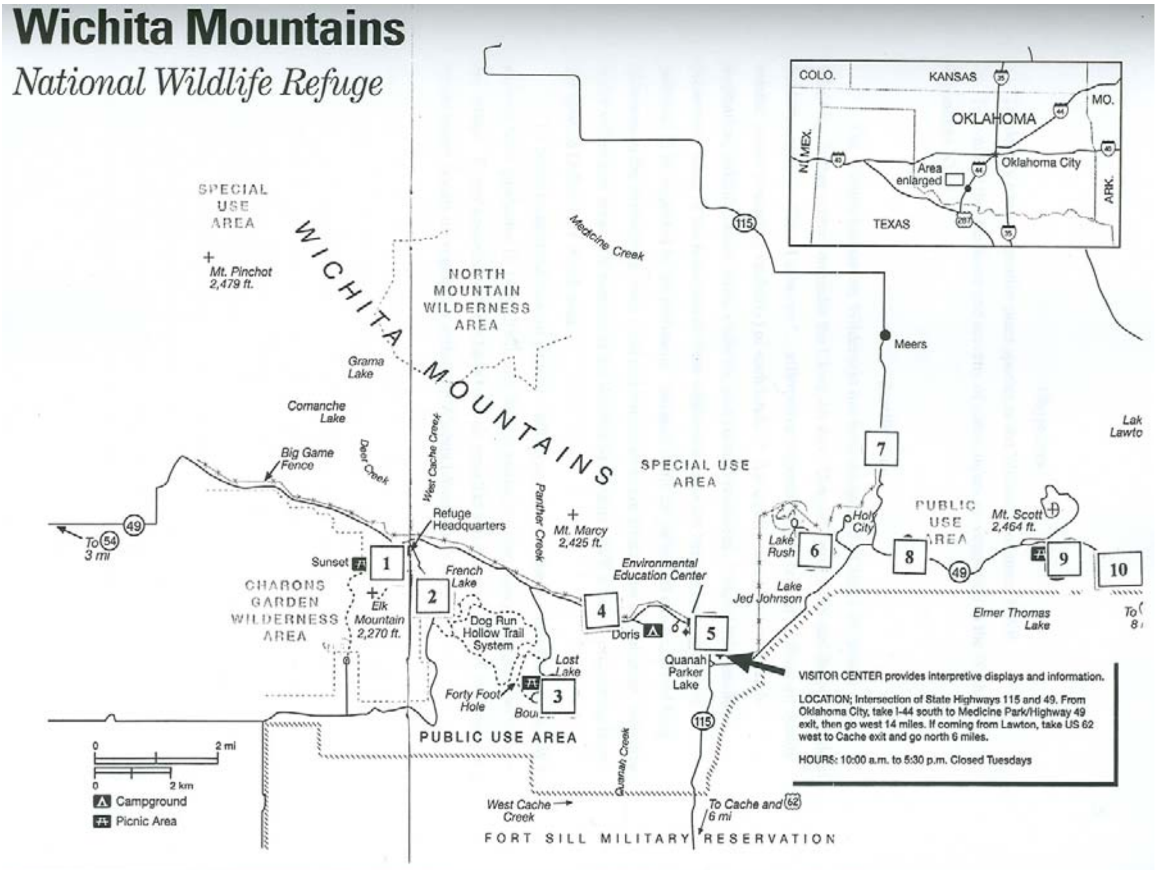


Figure 1. General map of the Wichita Mountains NWR. Numbers in square boxes denote approximate location of survey sites.

## Objectives

1). To identify ozone–sensitive plant species in the Wichita Mountains NWR

2). To evaluate the incidence and severity of ozone injury on vegetation in the Wichita Mountains NWR

## Justification

The Wichita Mountains Wilderness has been designated a Class I air quality area, receiving further protection under the Clean Air Act. Congress gave FWS and the other Federal land managers for Class I areas an "…affirmative responsibility to protect all those air quality related values (including visibility) of such lands..." Air quality related values include vegetation, wildlife, water, soils, visibility, and cultural resources. Despite this special protection, many of the resources in these wilderness areas are being impacted or have the potential to be impacted by air pollutants. Because many air pollutants can be carried long distances in the atmosphere, even rural and remote areas are affected by air pollution, including many wilderness areas. Of concern at the Wichita Mountains NWR is ozone originating from the upwind Dallas-Fort Worth area.

To better understand how air pollution affects resources at the Wichita Mountains NWR, surveys were conducted in 1999, 2000, and 2001 to evaluate ozone injury to vegetation within the refuge. To my knowledge, there have been no recorded surveys prior to 1999 to document if ozone injury occurs on vegetation within the Wichita Mountains NWR.

**Diagnosis of Air Pollution Injury on Plants**

Although many gaseous air pollutants are emitted into the atmosphere, only certain ones are phytotoxic and capable of injuring plants and inducing symptoms readily apparent during field surveys. The most important of these gaseous, phytotoxic air pollutants are ozone, sulfur dioxide, and fluorides. These pollutants are taken into the plant leaf, along with the normal constituents of the air, through the stomata. Once inside the leaf, the pollutant or its breakdown products react with cellular components, mainly cellular membranes, causing injury or death of tissues.

The resulting macroscopic symptoms, which are visible on the leaf surface, are classified as chronic or acute depending upon the severity of injury. Chronic symptoms imply tissue injury, whereas acute injury signifies tissue death. Chronic symptoms on foliage usually result from exposure of a plant to low levels of pollution for a long time, or occur when a plant is somewhat resistant to a pollutant. Visible ozone injury is usually considered to be chronic injury. Acute injury is observed following a short-term, high concentration of pollution, or occurs when a plant is in a very sensitive condition. Sulfur dioxide injury as observed in the field is often acute. Fluoride injury may be either.

Macroscopic leaf injury caused by air pollutants often represents an intermediate step between initial physiological events and decreases in productivity. Decreases in productivity (Pye 1988) may result in ecological changes, such as reduced diversity (Rosenberg et al. 1979). Visible leaf symptoms induced by phytotoxic pollutants serve as important diagnostic tools that allow observers to identify specific air pollutants as causal agents of vegetation damage (Davis 1984; Skelly et al. 1987). This knowledge can be used in the air pollution emissions permitting process for siting new industries (i.e. Prevention of Significant Deterioration Program), assessment of the secondary air quality standards, assessing the presence of air pollution injury in Class I areas, and in litigation involving air pollution injury.

Although ozone was the air pollutant of concern in this survey, it should be recognized that phytotoxic levels of primary pollutants such as sulfur dioxide and fluorides may occur near industrial sources. Likewise, metals may be found in excessive levels in vegetation growing in areas downwind from industrial or urban sources (Davis et al. 1984, Davis et al. 2001, ). Toxic metals such as arsenic, mercury, and lead may be especially important in areas being managed for wildlife such as a NWR. Although such compounds are of more interest in mammalian and avian toxicity as compared to phytotoxicity, vegetation may absorb or adsorb such contaminants and become part of the contaminated food chain (Davis 2002). However, the presence of excessive metals, as well as organic biohazards such as dioxins and furans, is determined with laboratory analysis of foliage, not with surveys dealing with macroscopic foliar injury.

**Ozone**

Ozone is probably the most important and widespread phytotoxic air pollutant in the United States, and is the air pollutant most likely to have an easily recognizable impact on vegetation within a NWR. Background levels of ozone exist naturally in the lower atmosphere, possibly originating from vertical downdrafts of ozone from the stratosphere or from lightning, but more likely from chemical reactions of naturally occurring compounds. However, the major sources of precursors leading to phytotoxic levels of ozone occur within urban areas. In those areas, hydrocarbons and oxides of nitrogen are emitted into the atmosphere from various sources, the most important being automobile exhaust. These compounds undergo photochemical reactions in the presence of sunlight forming photochemical smog, of which ozone is a major component. Smog, ozone, or its precursors may travel downwind for hundreds of miles during long-range transport, as influenced by wind direction and movement of weather fronts. Thus, ozone impinging on refuges may originate in urban areas many miles upwind from the refuge. Concentrations of ozone are often greater in rural areas downwind from urban areas, as compared to within the urban area itself, due to the presence of reactive pollutants in the urban air which scavenge the ozone.

There are certain bioindicator plants that are very sensitive to ozone (Anderson et al. 1989, Davis and Coppolino 1976, Davis and Skelly 1992, Davis et al. 1981, Davis and Wilhour 1976, and Jensen and Dochinger 1989). The principal investigator in this survey routinely uses the following broad-leaved bioindicator species for evaluating ozone injury: black cherry (Prunus serotina), common elder (Sambucus canadensis), common milkweed (Asclepias syriaca), grape (Vitis spp), white ash (Fraxinus americana), and yellow-poplar (Liriodendron tulipifera). The investigator also uses, but less commonly, Virginia creeper (Parthenocissus quinquefolia) and Viburnum spp. Many of these ozone-sensitive species occur in our refuges in eastern United States.

On broadleaved bioindicators, ozone-induced symptoms usually appear as small, 1 to 2 mm diameter "stipples" of pigmented, black or reddish-purple tissue on the adaxial surface of mature leaves (see Skelly 2000, Skelly et al. 1987). The pigmented tissue is usually restricted by the veinlets. Immature leaves seldom exhibit symptoms, whereas premature defoliation of mature leaves may occur on sensitive species. To the casual observer, these symptoms are similar to those induced by other stresses (e.g., nutrient deficiency, fall coloration, insects, and certain diseases). However, the pigmented, adaxial stipple on plants of known sensitivity (i.e., black cherry or grape) is a reliable diagnostic symptom of ozone injury.

On eastern conifers, the most reliable symptom (current-year needles only) induced by ozone is a chlorotic mottle, which consists of small patches of chlorotic tissue interspersed within the green, healthy needle tissue. The mottle usually has a “soft edge” (as opposed to a sharply defined edge) to the individual mottled areas. An extremely sensitive plant may exhibit needle tip browning. However, this symptom is common to many stresses and not a reliable diagnostic symptom. Conifer needles older than current-year needles are not useful as monitors, since over-wintering may produce symptoms similar to that caused by ozone. Ozone injury to monocots, such as grasses (i.e., Spartina sp.), is very difficult to diagnose in the field, as there are many causal agents that can result in tipburn and chlorotic mottle on grasses. August and early September are the best times to survey for ozone-induced injury in the Northeast (Davis and Skelly 1992).

**Description of Refuge**

SOURCE: Wichita Mountains Wildlife Refuge. 1973. Refuge brochure. Department of the Interior, U.S. Fish and Wildlife Service RF-2351700-1

For three-quarters of a century, the Wichita Mountains NWR in southwest Oklahoma has been a wildlife and wildlands treasure house. When this area of Oklahoma was opened for homesteading in 1901, a sizable portion in the heart of the Wichita Mountains range was protected from settlement. The refuge was originally established to protect all species of wildlife, especially those in danger of extinction. Through efforts of the New York Zoological Society and the American Bison Society, 15 buffalo (bison) were brought here in 1907. Elk and wild turkey were also brought back to their former home. The few deer that found sanctuary in remote sections flourished under protection. Today in this 59,020-acre refuge you can also see longhorn cattle, bobwhite quail, eagles, migratory waterfowl, and many species of small mammals and birds.

Efforts to protect and maintain the native species of wildlife have been amply rewarded. Big game herds have increased many-fold and are no longer endangered. So successful has the big game program been that the goal of simple preservation has been changed to one calling for the maintenance of representative herds, with numbers in keeping with a balanced grassland environment.

**The Refuge Today**

The WNWR today is managed to meet two primary objectives. The first is to maintain a natural wildlife population in a natural environment. The second is to provide an opportunity for the public to observe, study, and enjoy wildlife in this natural setting. The refuge receives well over a million visitors annually.

The refuge is an “island” rising out of the rolling vastness of the Great Plains. Far from being a panorama of colorful vistas and lonely beauty, this island refuge consists of a remarkable variety of environments - rolling grasslands, woody drainage ways and hillsides, rocky surfaces and bare mountaintops, streams and lakes. In each of these environments, animals and plants all interact with one another under the pressures of non-living forces - soil, water and geological changes - that have been active since the

Wichita mountains were formed. When one begins to understand all these creations, the refuge becomes more than a place of color or beauty. It becomes an ever-changing place in which plants, mammals, birds, insects, fish, and other tiny unseen creatures are engaged in a struggle for existence. The best way to understand this "Island in a Prairie Sea" is to learn something about its five distinct environments and appreciate the complexity and inner beauty of the Wichita Mountains NWR.

**The five environments**

**Rocky Outcrops**. The jagged outcrops of rock seen on the Wichita Mountains NWR are mainly of two types: gabbro, which ranges in color from dark gray to black, and red granite. Gabbro is an igneous rock formed millions of years ago by the cooling of hot lava forced to the surface. Red granite, the most common rock on the refuge, was also formed from hot lava, but at a later geological time than gabbro. Mt. Scott is composed of this granite. Because trees grow on the gabbro, but not on the red granite, contact between these two types of rock can be detected by the tree line.

**Stony Rocklands.** The mountains of the Wichita Mountains NWR were formed 300 million years ago, created by a tremendous uplift accompanied by large folds and faults. Those mountains were much higher than the ones you see today. Erosion - caused by water, wind, and temperature - has stripped off the upper parts and deposited this material in valleys, creating stony rocklands. As erosion wears away the granite, rock boulders are formed. Hardy types of vegetation gain a foothold in this environment and accelerate the breakdown of the rocks, thus helping to produce soil.

**Prairie Grasslands.** Prairies result from erosion and adaptation to climate, especially rainfall. Here on the dry plains, trees seldom gain a roothold; if they do, they rarely survive the periodic droughts. But hardy native grasses, adapted to long periods of dormancy, flourish and thus conserve the land at their roots. The grass mat insulates the soil, conserving moisture and preventing soil erosion by wind and water. The dominant feature of this environment is the variety of native grasses such as little bluestem, big bluestem, buffalo grass, sideoats grama, and Indian grass.

**Woodlands.** In some areas trees have gained a roothold on the prairie. The post oak and blackjack oak are among the few species that can do this, being drought-resistant and sun-loving. In moist years, seedlings sprout and the woodlands advance onto the prairie.  In dry years, the seedlings are stunted or die and the hardier prairie grasses push back, reclaiming their former territory.

**Water.** Although it may seem arid, the Wichita Mountains NWR actually contains numerous aquatic environments.  Streams, springs, and man-made lakes supply water - the basis of life for the wildlife and vegetation of the refuge.  Rainfall runs off by way of streams and filters through the soil.  Some of the water is collected and stored in the man-made lakes.  Many species of animals make their homes in these aquatic areas.  Some of the more abundant are frogs, crayfish, mussels, and fresh water sponges.  Fish also flourish in the numerous lakes of the refuge.  Unique types of vegetation also abound in this watery environment, including cattails, water primrose, American lotus (lily pads), bullrushes, and water milfoil.

**Wildlife and the Land**

When buffalo were returned to this area, perhaps fewer than 300 of these mighty creatures could be found in the United States out of the millions that once roamed the plains.  Extinction seemed imminent.  Now, through careful management, the Wichita Mountains NWR herd alone numbers over 600.  America's most authentic herd of longhorn cattle grazes at the refuge.  These longhorns are descended from 27 animals placed on the refuge by the Forest Service in 1927.  Elk were exterminated here about 1875.  Today's herd of more than 300 is a result of 17 transplanted from Jackson Hole, Wyoming.  The native whitetail deer, the most common big game animal of the southern United States, is found in all sections of the refuge.  Fox squirrels, raccoons, opossums, skunks, and smaller animals are also common.

Observers have identified more than 240 species of both eastern and western birds on the refuge.  The scissor-tailed flycatcher, Oklahoma's state bird, nests on the refuge.  Bobwhites, roadrunners, and great horned owls are among the many permanent residents.  The refuge's 20-odd lakes are host to migratory waterfowl during spring and fall flights.  Both the bald and golden eagles winter among the refuge's crags.

**Man and the Land**

Although named for the Wichita Indians, the lands of today’s refuge were once the hunting grounds of other tribes.  Kiowas, Apaches, and Comanches roamed the mountains.  Many peaks, lakes, and streams bear their names. Quanah Parker, a famous chief of the Comanches, chose the Wichita Mountains as a place to build his home, which stood for many years just south of the refuge boundary. In the 19th century, these mountains were the scene of frenzied, and unsuccessful, searches for gold and silver. All that remain today are prospect holes and colorful legends about lost mines and caches of treasure.

## METHODS

### General Survey Areas

It had been predetermined that survey sites had to occur in open-areas (such as those occurring along roads or trails, or in fields) where ozone-sensitive plant species were found in sunlight and exposed to unrestricted air movement (Anderson et al. 1989; USDA Forest Service, 1990). Immediately prior to the initial (1999) survey, the investigator met with refuge personnel at the Wichita Mountains NWR headquarters. During this time, refuge maps were viewed and discussed, which aided selection of preliminary survey areas. Based on these initial discussions, tentative survey areas were selected, visited, and suitability determined. This process resulted in 10 general areas deemed suitable for surveys (Figure 1). These 10 areas, with modification, were used in the 1999, 2000 and 2001 surveys.

### Preliminary Selection of Bioindicator Species

A list of refuge flora was furnished by FWS personnel (Appendix). Prior to the 1999 field survey, an initial selection of potential bioindicators that might exhibit ozone injury in the survey area had been selected from this list, as well as by talking to refuge personnel. Plant species or genera on the list tentatively selected as bioindicators included: various milkweeds (Asclepias spp.), eastern redbud (Cercis canadensis), green ash (Fraxinus pennsylvanica), morning glory (Ipomoea spp.), Virginia creeper (Parthenocissus quinquefolia), poison-ivy (Toxicodendron radicans), fragrant sumac (Rhus aromatica), smooth sumac (Rhus glabra), Prunus spp., and Rubus spp. Of course, many of the species listed grow in scattered localities through the NWR, and may not be present at designated survey areas; they may only be found with the help of local botanists.

### Air Quality

Ozone monitoring data are useful to complement the visual injury surveys. In general, one may assume that more ozone-induced stipple is likely to occur in years with greater ozone concentrations. However, this is not always the case. More long-term, ambient ozone monitoring is needed to further understand the relationship between foliar symptoms, ambient ozone, and environmental conditions (e.g. droughts) in our parks and refuges.

Ozone has been monitored at Lawton, Oklahoma, approximately 15 km (9 mi.) southeast of the refuge, at an EPA ozone-monitoring site (EPA AIRS #40-031-0647) since 1998. In this report, ambient ozone levels are expressed as “cumsum60”, the cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb. In other studies, we have found that this ozone statistic correlates fairly well with plant damage. During 1998, prior to the first survey, ambient ozone concentrations attained a value of about 45,000 ppb.hrs by September 1 (data not shown). The 1998 ozone levels during the growing season were considered to be above the threshold limit for inducing ozone injury on sensitive plants, and indicated that an ozone-injury survey in the Wichita Mountains NWR would be worthwhile.

At time of survey each year, approximate cumsum60 ozone levels were as follows: August 11-15, 1999 (20,000 ppb.hrs), July 13-16, 2000 (22,000 ppb.hrs), and August 4-7, 2001 (30,000 ppb.hrs) (Figure 2). For the annual growing seasons, ambient ozone concentrations were lowest in 1999. In 1999, ozone levels were very low through the end of July, but then rapidly rising during August and reaching a plateau of about 40,000 ppb.hrs by mid- to late-September. In years 2000 and 2001, ozone concentrations were slightly greater than those monitored in 1999; ozone levels were very similar between these two years until about 1 September, at which time the ozone levels in year 2000 increased more rapidly, peaking at nearly 60,000 ppb.hrs in October. These annual ambient ozone concentrations monitored near the Wichita Mountains NWR in 1998 - 2001 were quite high, but were still lower than the excessive levels observed at the Mingo NWR in Missouri and the Edwin B. Forsythe NWR near Brigantine, New Jersey.

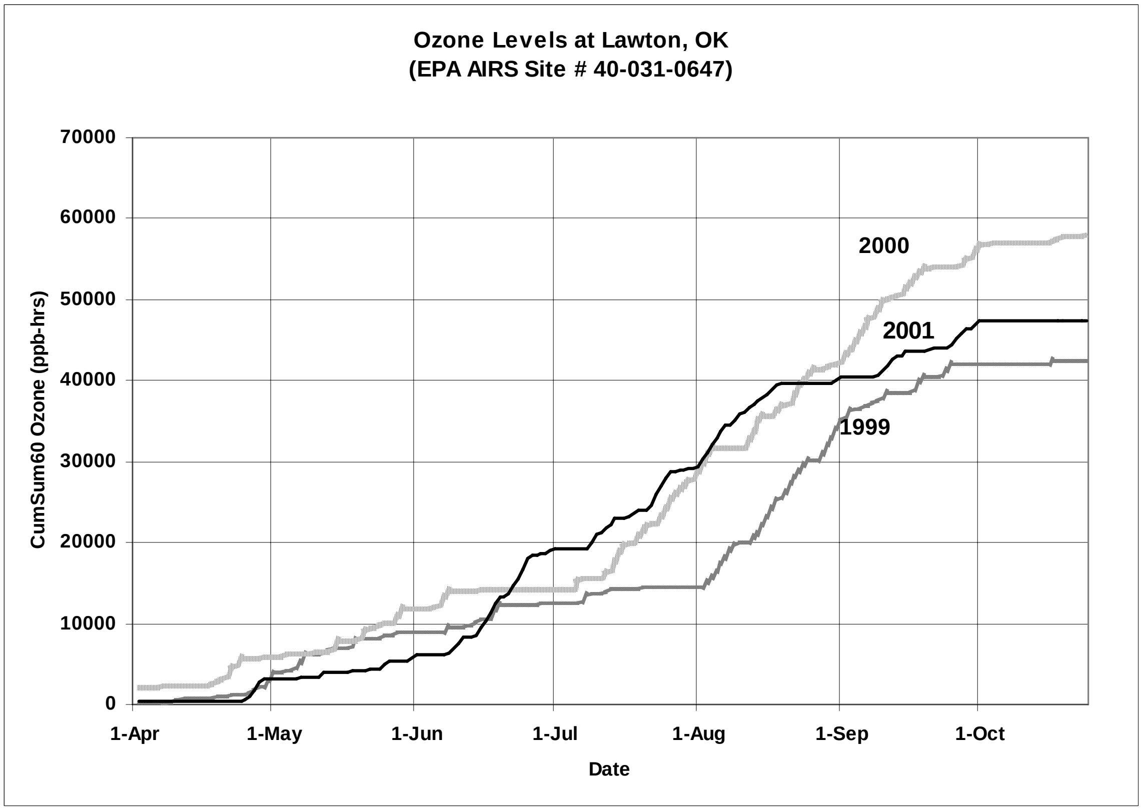


Figure 2. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumsum60, ppb.hrs) monitored at Lawton, OK (EPA AIRS Site # 40-031-0647) during 1999 - 2001; units are ppb.hrs. The monitoring station is located approximately 15 km (9 mi.) southeast of the refuge.

## Survey Dates

In 1999 the Wichita Mountains NWR was surveyed on August 5-8. During this 1999 survey, the refuge was very hot and very dry, conditions that would inhibit gas uptake, including ozone, by vegetation and therefore inhibit foliar ozone injury. Therefore, in 2000 it was decided to survey the refuge earlier, in an attempt to evaluate vegetation prior to the onset of hot, dry weather. (Of course, a confounding factor is that high levels of ozone usually accompany high temperatures; the highest ozone concentrations often occur later in the hottest (and driest) part of the summer). Refuge personnel indicated that the weather had been relatively wet and fairly cool prior to the tentative survey date of 2000, and that vegetation should be in good condition for gas uptake. Therefore, in 2000 the refuge was surveyed earlier, during July 13-16. However, during the survey the temperature still reached or exceeded $100^{o}$ F nearly every day, which was the onset of an extremely hot, dry period, and severe drought that extended for several months. In 2001 the survey was conducted during August 4-7, again during very hot, dry weather.

## Survey Areas

As described earlier, tentative locations for survey areas were based on the 1999 discussions with the refuge personnel, examination of maps, and the 1999 observations made on-site. Ten survey areas had been deemed suitable for the 1999 survey, based on openness, accessibility, and presence of bio-indicators (Figure 1). All 10 areas, as well as several adjacent areas, were visited again in 2000 and 2001, although data were not necessarily taken at all sites. In addition to these specific areas, vegetation was observed as the investigator traveled from location to location during the 2001 survey. This is a very large refuge, and many other potential areas could be visited, but many of the other areas (i.e., in the "back country" of the refuge) also appeared to be very arid and dry. This survey was concentrated in the less arid parts of the refuge, to enhance the possibility of finding ozone injury, except when evaluating milkweed plants, which were often found in the middle of hot, dry grasslands. Whenever possible, survey areas in 2001 were limited to riparian vegetation growing immediately adjacent to streams or lakes.

## Severity Rating

Each broadleaved plant evaluated for ambient ozone injury had to have foliage within reach; that is, trees were not climbed nor were pole-pruners used. The ForestHealth Expert System had been used to train the investigator in estimating the amount of stipple on a leaf. The following procedure has been developed by the investigator for such surveys. For broadleaved tree species, the percentage of ozone injury is estimated on the oldest leaf on each of four branches, and the average value recorded. Then, the next oldest leaf is evaluated, and so on, until the five oldest leaves have been rated. For each herbaceous plant, each of the five (if present) oldest (basal) leaves of the plant is examined and the average percent stipple recorded. Each of the oldest five leaves on the current woody growth (canes) of vines is rated and the average percent stipple recorded. On all species, only adaxial leaf surfaces are evaluated. Symptom severity on the adaxial surface of each leaf evaluated is estimated by assigning severity classes, based on the percentage of surface injured, of 0, 5, 10, 20, 40, 60, 80, 90, 95 and 100 %.

Photographs (slides) were taken and originals (with corresponding captions) were sent to the FWS Branch of Air Quality in Denver, CO.

## RESULTS AND DISCUSSION

### Final Selection of Bioindicator Species

Final selection of bioindicator species or genera (plants regarded as being sensitive to ozone) was made on-site during each year of the survey. The expanded list of potential bioindicators consisted of grape (Vitis spp.), various milkweeds, eastern redbud, green ash, morning glory, Virginia creeper, poison-ivy, fragrant sumac, smooth sumac, Prunus spp., and Rubus spp. These were among the most common ozone-sensitive plants in the refuge, and usually occurred in open areas. Not all species/genera listed were present at all sites. Giant ragweed (Ambrosia trifida) was selected as an indicator for sulfur dioxide injury, along with Rubus spp. However, since there was no point source of $SO_2$ readily evident, emphasis was placed on the ozone-sensitive bioindicators.

In all 3 years, vegetation growing in the drier parts of the refuge were not thoroughly evaluated, as it was attempted to survey plants along the moist seeps, streams, and lakes. However, initial 2000 field observations indicated that two milkweed species were very common in the refuge, although occurring in the drier grasslands. Milkweeds (Asclepias spp.) in general are very sensitive to ozone. The Visitors Center and Headquarters each had a copy of an excellent, large notebook compiled by local FWS botanists containing photographs and scientific descriptions of many of the plants growing on the refuge. This notebook was examined several times by the investigator during the 2000 and 2001 surveys. Based on this notebook, the two milkweeds appeared to be Asclepias asperula and Asclepias viridis. Special attempts were made in 2000 and 2001 to include these two milkweed species in the survey.

### Foliar Symptoms

As in 1999 and 2000, extremely light ozone-induced injury was observed in the Wichita Mountains NWR during the 2001 survey (Table 1). Again, ozone-sensitive bioindicator plant species were not plentiful. During the August 1999 survey, plants were often wilted, which precluded gas uptake and ozone injury during that year. In July 2000 plants were not wilted, but were more green and fresh as compared to 1999, apparently due to a more favorable moisture regime in June. However, heat stress (i.e. leaf rolling and chlorosis) was beginning to occur in 2000 on some plant species. In 2001, heat stress was again quite prevalent. Again, heat stress likely limited resulted in stomatal closure, and reduced uptake of ozone. The very light level of ozone-induced symptoms observed in 2001within the Wichita Mountains NWR was attributed to the relatively low levels of ambient ozone in 2001 at time of survey (Figure 2), confounded by hot weather and associated reduced stomatal uptake prior to the survey.

The ambient ozone levels that occurred at the Wichita Mountains NWR in the early summer (prior to August) were somewhat similar to levels experienced by other refuges having relatively low ozone concentrations, such as the Okefenokee, Moosehorn, and Seney NWRs. However, during the long, hot summer at the Wichita Mountains NWR, ambient ozone levels continued to rise until October, resulting in ozone exposures for a longer time as compared to many refuges. During 2000 for example, plants in the refuge were exposed to ozone from February 9 until October 24, a period of approximately 260 days. Probably only the hot, dry weather in late summer (and corresponding lack of gas exchange) saved the plants within the Wichita Mountains NWR from suffering severe ozone injury by late summer

In summary, during all 3 years, ambient ozone concentrations monitored near the Wichita Mountains NWR were near phytotoxic levels, capable of causing injury on ozone-sensitive species of vegetation except during hot, dry periods. However, when the 1999 survey was conducted (in early August), ozone levels were barely at phytotoxic levels. In addition, the weather was hot and dry, and little ozone injury occurred. In the year 2000, the refuge was surveyed earlier, during mid-July, in an attempt to survey under more ideal moisture conditions. Moisture levels appeared to be lightly better in 2000 (for gas uptake). However, again, ozone levels at time of survey were low, being similar to 1999 levels. In 2001, ozone levels were higher than in the other 2 years, but once more, the weather was very hot and dry. Many plants were brown and/or wilted, and gas uptake (including ozone) was likely to be minimal. These low ozone levels and dry conditions, in addition to the scarcity of ozone-sensitive plant species in the refuge, combined to yield little ozone injury data during the 3 years of survey.

## Observations at Specific Survey Sites

For report purposes, the initial mileage was recorded as 0.0 miles at the extreme western boundary line of the refuge. Grass throughout the refuge was brown and crunchy at time of survey.

**Site 1 (Sunset Picnic Area at 3.9 mi).** This survey site consisted mainly of a large clump of smooth sumac plants growing adjacent to the stream and small CCC impoundment. Ozone-induced injury was not observed on 50 sumac plants, nor on 5 wild grape plants (Table 1). Leaflets of the sumac plants were drooping and wilting, and were beginning to turn red. Grape leaves exhibited light spotting, on the leaf surface as well as on the veins and veinlets; this appeared to be insect injury, and was not classic ozone-induced stipple. Classic stipple was present on 2 of 30 poison-ivy plants; however, foliage of this species also exhibited general reddening. Although the stipple on poison-ivy may be induced by ozone, the effects of ozone on poison-ivy have not been thoroughly studied, and this result must be treated with caution.

Ozone-induced stipple was observed on 1 of 10 Virginia creeper plants. An important observation was that classic ozone injury was noted on a species tentatively identified as Atlantic pigeonwing (Clitoria mariana) growing on the stream bank within 1 m of the water. Stipple was present on leaflets of 1 of 10 of these pigeonwing plants growing at this location. This species has not been studied with regard to ozone sensitivity, but is likely a new ozone bioindicator for the Wichita Mountains NWR. However, more observations are needed in areas containing more individuals of this species.

Table 1. Summary of observations made during the 1999, 2000, and 2001 surveys at the Wichita Mountains National Wildlife Refuge. Numbers in table refer to number of plants with ozone-induced injury as compared to the total number of plants evaluated for that species, and expressed as percentages.

| Date/Site | Ash | Grape | Asclepias viridis | Asclepias asperula | Poison-ivy | Redbud | Smooth Sumac | Black Walnut | Virginia Creeper |
|---|---|---|---|---|---|---|---|---|---|
| **Aug 11-15, 1999 Total** | 1/50 | 1/13 | | | 0/80 | | 0/235 | 0/10 | 0/40 |
| **Aug 11-15, 1999%** | 2.0% | 7.7% | | | 0.0% | | 0.0% | 0.0% | 0.0% |
| **July 13-16, 2000 Total** | 0/90 | 0/19 | 1/60 | 0/70 | 0/60 | 0/5 | 0/105 | 0/10 | 3/65 |
| **July 13-16, 2000%** | 0.0% | 0.0% | 1.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 4.6% |
| **August 4-7, 2001** | | | | | | | | | |
| **1 (Sunset Picnic Area)** | | 0/5 | | | 2/30 | | 0/40 | | 1/10 |
| **1a (Hdq)** | | | | | | | | | |
| **2 (French Lake)** | | 0/5 | | | 0/10 | | 0/10 | 0/10 | 0/10 |
| **3 (Lost Lake)** | 1/50 | 0/10 | | | 0/200 | 0/1 | | | 0/20 |
| **4 (Gate)** | 0/10 | | | | 0/10 | | 0/20 | | 0/15 |
| **4a (Burfurd Lake)** | | | | | 0/200 | | | | 0/10 |
| **4b (Corral)** | | | | | | | | | |
| **5 (Q Parker Ed Ctr)** | 2/30 | | 0/4 | | 0/10 | | | | 1/10 |
| **5a (Visitor Ctr)** | | | 0/15 | | | | | | |
| **6 (Ned Johnson)** | | | 0/30 | | | | | | |
| **7 (Meers Boundary)** | | | | | | | | | |
| **8 (Hole Along Road)** | | | | | | | | | |
| **9 (Mt Scott Picnic Area)** | | | | | | | 0/20 | | 0/3 |
| **10 (Elmer Lake)** | | | | | | | | | |
| **10a** | | | | | | | | | |
| **August 4-7, 2001 Total** | 3/90 | 0/20 | 0/49 | * | 2/460** | 0/1*** | 0/90 | 0/10 | 2/78 |
| **August 4-7, 2001%** | 3.3% | 0.0% | 0.0% | | 0.4% | 0.0% | 0.0% | 0.0% | 2.6% |

*this species was brown and completely dried at the time of the 2001 survey
**poison-ivy leaves were turning red, possibly due to heat stress, ozone, or both
***most redbud leaves in the refuge were severely stressed and could not be evaluated

**Site 1a (Refuge Headquarters Building).** This survey site consisted of vegetation growing in the vicinity of the headquarters building and personnel houses. There was no ozone injury on wild grape, eastern redbud, or Virginia creeper at this location (Table 1).

**Site 2 (French Lake @ 6.1 mi).** Ozone injury was not observed on 5 wild grape, 10 Virginia creeper, 10 poison-ivy, 10 walnut, or 10 smooth sumac plants growing along the streambank at this site. However, the stream was completely dry at time of the 2001 survey (there had been water in the stream at time of 1999 and 2000 surveys) indicating the droughty condition of the area. The complete understory , comprised mainly of coralberry (Symphorocarpus, sp.), was brown, dry, and crunchy.

**Site 3 (Lost Lake, Picnic Area @ 20.4 mi).** This site was one of the better survey sites in terms of bio-indicators present, and was located on the bank of a lake. However, ozone injury was not observed on leaves of the 50 ash seedlings/sprouts, 10 wild grape, 200 poison-ivy, 1 redbud, or 20 Virginia creeper plants at this location. The understory vegetation, comprised mainly of Symphorocarpus, sp., was brown, dry, and crunchy.

**Site 4 (Gate @ 24.6 mi).** Ozone injury was not observed on 10 ash, 10 poison-ivy, 20 smooth sumac or 15 Virginia creeper plants at this fairly dry, non-riparian site. Plants were very dry.

**Site 4a (Burford Lake.).** Ten Virginia creeper and approximately 200 poison-ivy plants were examined in the moist areas immediately adjacent to Burford Lake. Ozone injury was not observed.

**Site 4b (Cobblestone House).** Ozone injury was not observed on 15 Asclepias asperula milkweed plants growing in the open, dry fields near the abandoned cobblestone house. Plants were very dry, but each clump of milkweeds usually had one plant with intact leaves that were evaluated.

**Site 4b (Near Corral).** Ozone injury was not observed on numerous Asclepias asperula milkweed plants growing in the open, dry fields near this corral. Plants were very dry.

**Site 5 (Quanah Parker Environmental Education Center).** Ozone injury was not observed 10 poison-ivy plants, 10 Virginia creeper vines, 4 milkweeds, or 1 elderberry growing beside the concrete walkway along the edge of the lake. Ozone-induced stipple was present on 2 of 30 ash seedlings. Most milkweed plants were only present as dried, collapsed clumps of brown vegetation, difficult to identify as to species, and were not evaluated.

**Site 5a (Visitors Center).** All Asclepias viridis milkweed plants growing in the open, dry fields near the Visitors Center had collapsed, were brown or bleached white, and could not be rated.

**Site 6 (Lake Rush, Jed Johnson Entrance Road).** Few Asclepias viridis milkweeds were still maintaining an upright posture on the dry hillsides surrounding the lake. A total of 30 of these individuals were examined, and ozone injury was not observed. However, the plants were likely too far collapsed to exhibit ozone injury. In addition, 15 plants tentatively identified as whorled milkweed (Asclepias verticillata) were examined, but they likewise were very chlorotic and/or collapsed; ozone injury was not observed.

**Site 7 (Northern Refuge Boundary on Meers Road).** The numerous Asclepias viridis milkweeds growing on a dry site near the northern refuge boundary were collapsed, dead, and bleached white. Plants could not be evaluated for ozone injury.

**Site 8 (Beside Water Hole Along Highway).** Did not evaluate smooth sumacs at this highway location.

**Site 9 (Mt. Scott Picnic Area).** Ozone injury was not observed on 3 Virginia creeper or 20 smooth sumac plants growing at this dry site near the picnic area. Most plants were brown or wilted.

**Site 10 (Lake Elmer).** Did not evaluate smooth sumacs at this dry hillside overlooking the lake.

**Site 10a (East Gate).** Ozone injury was not observed on smooth sumac plants growing at this dry site near the refuge sign at the boundary.

## SUMMARY

As in 1999 and 2000, the results of this 2001 survey revealed that extremely light ("trace") amounts of ozone injury occurred on vegetation within the boundaries of the Wichita Mountains NWR, a portion of which is a Class I air quality area. The cumsum60 ozone levels at time of survey (August 4 – 7) was 30,000 ppb.hrs (Figure 2), a value that may be considered phytotoxic in mesic areas. However, these ozone levels are barely phytotoxic for dry regions that routinely suffer from droughty conditions. During droughts, of course, many types of plants close their stomata to conserve water. In doing so, they also limit uptake of gases, including ozone. The investigator observed widespread wilting and drought injury on refuge plants in 2001. The dry nature of this refuge is likely the main contributing factor for little ozone injury being observed, in spite of potentially damaging ambient ozone levels.

Nevertheless, slight amounts of ozone-induced stipple were observed on the leaves of several plants (Table 1). Atlantic pigeonwing showed classic ozone-induced stipple, and may prove to be the best ozone bioindicator at the refuge. However, more populations of this plant species need to be identified and examined for classic stipple by refuge biologists throughout the summer. The two milkweed plants (Asclepias asperula and Asclepias viridis) may prove to be good bioindicators for detecting ozone injury, but only earlier in the season under adequate moisture levels.

Surveying Wichita Mountains NWR for ozone injury on vegetation presents a dilemma. At time of surveys in 1999 - 2001, approximate cumsum60 ozone levels were as follows: August 11-15, 1999 (20,000 ppb.hrs), July 13-16, 2000 (22,000 ppb.hrs), and August 4-7, 2001 (30,000 ppb.hrs) (Figure 2). These levels of ambient ozone are barely phytotoxic for dry areas. The highest ozone levels at this refuge occur later, during the hot, dry period of the summer. As shown in Figure 2, ozone levels at this refuge rise rapidly during August and early September, peaking at phytotoxic levels of 40,000 to 50,000 ppb.hrs in late September. However, by late summer the plants are often in a wilted or collapsed state, do not take in ozone, and subsequently do not exhibit ozone injury. This was why the refuge was surveyed earlier in 2000 (July 13-16) in an attempt to avoid the hot, dry weather of August. However, even at this time, little ozone injury was observed, and a prolonged drought was just beginning.

Based on these 3 years of survey, future surveys might be conducted much earlier in the year, perhaps in mid- to late-June. However, the ozone database at Lawton (as well as weather records) should be examined immediately prior to any planned surveys, to determine if potentially phytotoxic levels of ozone have occurred, and if the environment has been conducive for gas uptake. Emphasis during future surveys should be on riparian vegetation, possibly spring bioindicators, various milkweeds, and Atlantic pigeonwing. Bioindicators that may be only present in the spring should be examined for ozone-induced stipple.

Results of this and future surveys should prove useful to the FWS when making air quality management decisions, including those related to the review of Prevention of Significant Deterioration (PSD) permits.

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# APPENDIX

## Vegetation List for Wichita Mountains Wildlife Refuge

## (Furnished by the US FWS)

| CODE | Scientific Name | Common Name |
|---|---|---|
| ACLA5 | Achillea lanulosa Nutt. | (Achillea millefolium var. occidentalis) |
| ACSA3 | Acer saccharum Marsh. | (sugar maple) |
| AGLA8 | Agave lata Shinners | (Manfreda virginica) |
| ALCA3 | Allium canadense L. | (meadow garlic) |
| ALDR | Allium drummondii Regel | (Drummond's onion) |
| ALST | Allium stellatum Nutt. ex Ker-Gawl. | (autumn onion) |
| AMCA6 | Amorpha canescens Pursh | (leadplant) |
| AMCIT2 | Amsonia ciliata var. texana (Gray) Coult. | (Texas bluestar) |
| ANCO9 | Androstephium coeruleum (Scheele) Greene | (blue funnellily) |
| ANSA5 | Andropogon saccharoides Sw. | (Bothriochloa saccharoides) |
| ANSC10 | Andropogon scoparius Michx. | (Schizachyrium scoparium ssp. scoparium) |
| ARDR3 | Arisaema dracontium (L.) Schott | (greendragon) |
| ARPA27 | Arenaria patula Michx. | (Minuartia patula) |
| ARPO2 | Argemone polyanthemos (Fedde) G.B. Ownbey | (crested pricklypoppy) |
| ASAR | Asclepias arenaria Torr. | (sand milkweed) |
| ASASD | Asclepias asperula var. decumbens (Nutt.) Shinners | (Asclepias asperula ssp. capricornu) |
| ASCR2 | Astragalus crassicarpus Nutt. | (groundplum milkvetch) |
| ASER3 | Aster ericoides L. | (heath aster) |
| ASST | Asclepias stenophylla Gray | (slimleaf milkweed) |
| ASSU5 | Aster subulatus Michx. | (annual saltmarsh aster) |
| ASTU | Asclepias tuberosa L. | (butterfly milkweed) |
| ASVE | Asclepias verticillata L. | (whorled milkweed) |
| ASVI2 | Asclepias viridis Walt. | (green antelopehorn) |
| BAAUM | Baptisia australis var. minor (Lehm.) Fern. | (blue wild indigo) |
| BALE3 | Baptisia leucophaea Nutt. | (Baptisia bracteata var. leucophaea) |
| BASP | Baptisia sphaerocarpa Nutt. | (yellow wild indigo) |
| BOCU | Bouteloua curtipendula (Michx.) Torr. | (sideoats grama) |
| BOHI2 | Bouteloua hirsuta Lag. | (hairy grama) |
| BRJA | Bromus japonicus Thunb. ex Murr. | (Japanese brome) |
| BRTE | Bromus tectorum L. | (cheatgrass) |
| CACI8 | Castilleja citrina Pennell | (Castilleja purpurea var. citrina) |
| CAFA | Cassia fasciculata Michx. | (Chamaecrista fasciculata) |
| CAIN2 | Callirhoe involucrata (Torr. & Gray) Gray | (purple poppymallow) |
| CALE2 | Callirhoe leiocarpa R.F. Martin | (tall poppymallow) |
| CASC5 | Camassia scilloides (Raf.) Cory | (Atlantic camas) |
| CASP8 | Catalpa speciosa (Warder) Warder ex Engelm. | (northern catalpa) |
| CEAM2 | Centaurea americana Nutt. | (American star thistle) |
| CECA4 | Cercis canadensis L. | (eastern redbud) |
| CECY2 | Centaurea cyanus L. | (garden cornflower) |
| CEOC2 | Cephalanthus occidentalis L. | (common buttonbush) |
| CEPA12 | Cenchrus pauciflorus Benth. | (Cenchrus incertus) |
| CHAS | Chaetopappa asteroides Nutt. ex DC. | (Arkansas leastdaisy) |
| CHPI6 | Chrysopsis pilosa (Walt.) Britt., | |
| CHVE2 | Chloris verticillata Nutt. | (tumble windmill grass) |

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|---|---|---|
| CHVI4 | Chloris virgata Sw. | (feather fingergrass) |
| CIMA2 | Cicuta maculata L. | (spotted water hemlock) |
| CIUN | Cirsium undulatum (Nutt.) Spreng. | (wavyleaf thistle) |
| CLMA4 | Clitoria mariana L. | (Atlantic pigeonwings) |
| CLVI3 | Claytonia virginica L. | (Virginia springbeauty) |
| COAR4 | Convolvulus arvensis L. | (field bindweed) |
| CODR | Cornus drummondii C.A. Mey. | (roughleaf dogwood) |
| COERA | Commelina erecta var. angustifolia (Michx.) Fern. | (whitemouth dayflower) |
| COGRL | Coreopsis grandiflora var. longipes (Hook.) Torr. & Gray | (largeflower tickseed) |
| COTI3 | Coreopsis tinctoria Nutt. | (golden tickseed) |
| COVI2 | Collinsia violacea Nutt. | (violet blue eyed Mary) |
| CRCA6 | Croton capitatus Michx. | (hogwort) |
| CUFO | Cucurbita foetidissima Kunth | (Missouri gourd) |
| CUSCU | Cuscuta L. | (dodder) |
| DAAU | Dalea aurea Nutt. ex Pursh | (golden prairieclover) |
| DAPU3 | Daucus pusillus Michx. | (American wild carrot) |
| DAPU5 | Dalea purpurea Vent. | (purple prairieclover) |
| DEIL | Desmanthus illinoensis (Michx.) MacM. ex B.L. Robins. & Fern. | (prairie bundleflower) |
| DESE | Desmodium sessilifolium (Torr.) Torr. & Gray | (sessileleaf ticktrefoil) |
| DEVI | Delphinium virescens Nutt. | (Delphinium carolinianum ssp. virescens) |
| DRCU | Draba cuneifolia Nutt. ex Torr. & Gray | (wedgeleaf whitlowgrass) |
| ECPA | Echinacea pallida (Nutt.) Nutt. | (pale purple coneflower) |
| ECRE | Echinocereus reichenbachii (Terscheck ex Walp.) Haage f. | (lace hedgehog cactus) |
| ELCA4 | Elymus canadensis L. | (Canada wildrye) |
| ENPI | Engelmannia pinnatifida Gray ex Nutt. | (Engelmann's daisy) |
| ERAM5 | Erythronium americanum Ker-Gawl. | (American troutlily) |
| ERCA14 | Erysimum capitatum (Dougl. ex Hook.) Greene | (sanddune wallflower) |
| ERCI6 | Erodium cicutarium (L.) L'Her. ex Ait. | (redstem stork's bill) |
| ERLE11 | Eryngium leavenworthii Torr. & Gray | (Leavenworth's eryngo) |
| ERST3 | Erigeron strigosus Muhl. ex Willd. | (prairie fleabane) |
| EUCO10 | Euphorbia corollata L. | (flowering spurge) |
| EUGR4 | Eustoma grandiflorum (Raf.) Shinners | (Eustoma russellianum) |
| EUMA8 | Euphorbia marginata Pursh | (snow on the mountain) |
| FRPEP | Fraxinus pennsylvanica var. pennsylvanica Marshall | (green ash) |
| GACO5 | Gaura coccinea Nutt. ex Pursh | (scarlet beeblossom) |
| GAPU | Gaillardia pulchella Foug. | (firewheel) |
| GASI | Gaura sinuata Nutt. ex Ser. | (wavyleaf beeblossom) |
| GASU | Gaillardia suavis (Gray & Engelm.) Britt. & Rusby | (perfumeballs) |
| GIRU3 | Gilia rubra (L.) Heller | (Ipomopsis rubra) |
| GRSQN | Grindelia squarrosa var. nuda (Wood) Gray | (Grindelia nuda var. nuda) |
| GRSQS2 | Grindelia squarrosa var. squarrosa (Pursh) Dunal | (curlycup gumweed) |
| HASP3 | Haplopappus spinulosus (Pursh) DC. | (Machaeranthera pinnatifida ssp. pinnatifida) |
| HEAMB2 | Helenium amarum var. badium (Gray ex S. Wats.) Waterfall | (yellowdicks) |
| HEAN3 | Helianthus annuus L. | (common sunflower) |
| HECR9 | Hedyotis crassifolia Raf. | (Houstonia pusilla) |
| HEHI2 | Helianthus hirsutus Raf. | (hairy sunflower) |
| HEMA2 | Helianthus maximiliani Schrad. | (Maximilian sunflower) |
| HENI4 | Hedyotis nigricans (Lam.) Fosberg | (diamondflowers) |
| HEPE | Helianthus petiolaris Nutt. | (prairie sunflower) |
| HYLI7 | Hymenoxys linearifolia Hook. | (Tetraneuris linearifolia var. linearifolia) |
| HYSC | Hymenopappus scabiosaeus L'Her. | (Carolina woollywhite) |
| INMI | Indigofera miniata Ortega | (coastal indigo) |

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|---|---|---|
| IPSH | Ipomoea shumardiana (Torr.) Shinners | (narrowleaf morningglory) |
| IVCI2 | Iva ciliata Willd. | (Iva annua var. annua) |
| JUAM | Justicia americana (L.) Vahl | (American waterwillow) |
| JURE6 | Jussiaea repens L. | (Ludwigia peploides ssp. glabrescens) |
| JUVI | Juniperus virginiana L. | (eastern redcedar) |
| KRDA | Krigia dandelion (L.) Nutt. | (potato dwarfdandelion) |
| KRSE | Krameria secundiflora auct. non DC. | (Krameria lanceolata) |
| LAAM | Lamium amplexicaule L. | (henbit deadnettle) |
| LASE | Lactuca serriola L. | (prickly lettuce) |
| LEGR2 | Lesquerella gracilis (Hook.) S. Wats. | (spreading bladderpod) |
| LEIN2 | Lespedeza intermedia (S. Wats.) Britt. | (intermediate lespedeza) |
| LEOB | Lepidium oblongum Small | (veiny pepperweed) |
| LEOVA2 | Lesquerella ovalifolia var. alba Goodman | (Lesquerella ovalifolia ssp. alba) |
| LEVI3 | Lepidium virginicum L. | (Virginia pepperweed) |
| LIAS | Liatris aspera Michx. | (tall gayfeather) |
| LICA6 | Linaria canadensis (L.) Chaz. | (Nuttallanthus canadensis) |
| LIIN2 | Lithospermum incisum Lehm. | (narrowleaf gromwell) |
| LIPU | Liatris punctata Hook. | (dotted gayfeather) |
| LIRIR | Linum rigidum var. rigidum Pursh | (largeflower yellow flax) |
| LISU4 | Linum sulcatum Riddell | (grooved flax) |
| LOAM5 | Lotus americanus (Nutt.) Bisch., | |
| LYAL4 | Lythrum alatum Pursh | (winged lythrum) |
| MEOL | Mentzelia oligosperma Nutt. ex Sims | (chickenthief) |
| MILI3 | Mirabilis linearis (Pursh) Heimerl | (narrowleaf four o'clock) |
| MINY | Mirabilis nyctaginea (Michx.) MacM. | (heartleaf four o'clock) |
| MOCI | Monarda citriodora Cerv. ex Lag. | (lemon beebalm) |
| MOFI | Monarda fistulosa L. | (wildbergamot beebalm) |
| MOPU | Monarda punctata L. | (spotted beebalm) |
| NELU | Nelumbo lutea Willd. | (American lotus) |
| NELU2 | Neptunia lutea (Leavenworth) Benth. | (yellow puff) |
| NOBI2 | Nothoscordum bivalve (L.) Britt. | (crowpoison) |
| OELAG2 | Oenothera laciniata var. grandiflora (S. Wats.) B.L. Robins. | (Oenothera grandis) |
| OEMA | Oenothera macrocarpa Nutt. | (bigfruit eveningprimrose) |
| OESE3 | Oenothera serrulata Nutt. | (Calylophus serrulatus) |
| OESP2 | Oenothera speciosa Nutt. | (pinkladies) |
| OPCO10 | Opuntia compressa J.F. Macbr. | (Opuntia ficus-indica) |
| OXST | Oxalis stricta L. | (common yellow oxalis) |
| OXVI | Oxalis violacea L. | (violet woodsorrel) |
| PAQU2 | Parthenocissus quinquefolia (L.) Planch. | (Virginia creeper) |
| PAVI2 | Panicum virgatum L. | (switchgrass) |
| PECO4 | Penstemon cobaea Nutt. | (cobaea beardtongue) |
| PEOK | Penstemon oklahomensis Pennell | (Oklahoma beardtongue) |
| PHAM4 | Phytolacca americana L. | (American pokeweed) |
| PHLO9 | Physalis lobata Torr. | (Quincula lobata) |
| PHSE9 | Phoradendron serotinum (Raf.) M.C. Johnston | (Phoradendron leucarpum) |
| PHVI17 | Physalis viscosa L. | (starhair groundcherry) |
| PLAR3 | Plantago aristata Michx. | (largebracted plantain) |
| PLVI | Plantago virginica L. | (Virginia plantain) |
| PLWR | Plantago wrightiana Dcne. | (Wright's plantain) |
| POAL4 | Polygala alba Nutt. | (white milkwort) |
| PODE3 | Populus deltoides Bartr. ex Marsh. | (eastern cottonwood) |
| PODO3 | Polanisia dodecandra (L.) DC. | (roughseed clammyweed) |
| PONU4 | Polytaenia nuttallii DC. | (Nuttall's prairie parsley) |
| PRAN3 | Prunus angustifolia Marsh. | (Chickasaw plum) |

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|---|---|---|
| PRJU | Prosopis juliflora auct. p.p. non (Sw.) DC. | (Prosopis glandulosa var. glandulosa) |
| PRME | Prunus mexicana S. Wats. | (Mexican plum) |
| PRPE3 | Prunus persica (L.) Batsch | (peach) |
| PSCU | Psoralea cuspidata Pursh | (Pediomelum cuspidatum) |
| PYCA2 | Pyrrhopappus carolinianus (Walt.) DC. | (Carolina desertchicory) |
| PYSC | Pyrrhopappus scaposus DC. | (Pyrrhopappus grandiflorus) |
| QUMA3 | Quercus marilandica Muenchh. | (blackjack oak) |
| QUST | Quercus stellata Wangenh. | (post oak) |
| RACO3 | Ratibida columnifera (Nutt.) Woot. & Standl. | (upright prairie coneflower) |
| RHAR4 | Rhus aromatica Ait. | (fragrant sumac) |
| RHGL | Rhus glabra L. | (smooth sumac) |
| RHTO8 | Rhus toxicodendron L. | (Toxicodendron pubescens) |
| RIOD | Ribes odoratum H. Wendl. | (Ribes aureum var. villosum) |
| ROMU | Rosa multiflora Thunb. ex Murr. | (multiflora rose) |
| ROPS | Robinia pseudoacacia L. | (black locust) |
| RUCR | Rumex crispus L. | (curly dock) |
| RUGR | Rudbeckia grandiflora (D. Don) J.F. Gmel. ex DC. | (rough coneflower) |
| RUHI2 | Rudbeckia hirta L. | (blackeyed Susan) |
| RUHU | Ruellia humilis Nutt. | (fringeleaf wild petunia) |
| RUPE4 | Ruellia pedunculata Torr. ex Gray | (stalked wild petunia) |
| RUTR | Rubus trivialis Michx. | (southern dewberry) |
| SAAZ | Salvia azurea Michx. ex Lam. | (azure blue sage) |
| SACA3 | Sabatia campestris Nutt. | (Texas star) |
| SANI | Salix nigra Marsh. | (black willow) |
| SCNU | Schrankia nuttallii (DC.) Standl. | (Mimosa nuttallii) |
| SENU | Sedum nuttallianum Raf. | (yellow stonecrop) |
| SEPL | Senecio plattensis Nutt. | (prairie groundsel) |
| SEVI4 | Setaria viridis (L.) Beauv. | (green bristlegrass) |
| SIAN3 | Sisyrinchium angustifolium P. Mill. | (narrowleaf blueeyed grass) |
| SILA3 | Silphium laciniatum L. | (compassplant) |
| SMBO2 | Smilax bona-nox L. | (saw greenbrier) |
| SOCA3 | Solanum carolinense L. | (Carolina horsenettle) |
| SOEL | Solanum elaeagnifolium Cav. | (silverleaf nightshade) |
| SOHA | Sorghum halepense (L.) Pers. | (Johnsongrass) |
| SOMI2 | Solidago missouriensis Nutt. | (Missouri goldenrod) |
| SONU2 | Sorghastrum nutans (L.) Nash | (yellow Indiangrass) |
| SORO | Solanum rostratum Dunal | (buffalobur nightshade) |
| SPCE | Spiranthes cernua (L.) L.C. Rich. | (nodding ladiestresses) |
| SPCO | Sphaeralcea coccinea (Nutt.) Rydb. | (scarlet globemallow) |
| SPLE2 | Specularia leptocarpa (Nutt.) Gray | (Triodanis leptocarpa) |
| SPPE5 | Specularia perfoliata (L.) A. DC. | (Triodanis perfoliata var. perfoliata) |
| STVI11 | Stenosiphon virgatus Spach | (Stenosiphon linifolius) |
| SYOR | Symphoricarpos orbiculatus Moench | (coralberry) |
| TAOF | Taraxacum officinale G.H. Weber ex Wiggers | (common dandelion) |
| TAPA3 | Talinum parviflorum Nutt. | (sunbright) |
| THFI | Thelesperma filifolium (Hook.) Gray | (stiff greenthread) |
| TOAR | Torilis arvensis (Huds.) Link | (spreading hedgeparsley) |
| TRCA5 | Trifolium campestre Schreb. | (field clover) |
| TRMA9 | Tragopogon major Jacq. | (Tragopogon dubius) |
| TROC | Tradescantia occidentalis (Britt.) Smyth | (prairie spiderwort) |
| TROH | Tradescantia ohiensis Raf. | (bluejacket) |
| TRTH | Tradescantia tharpii E.S. Anderson & Woods. | (Tharp's spiderwort) |
| TYLA | Typha latifolia L. | (broadleaf cattail) |
| ULRU | Ulmus rubra Muhl. | (slippery elm) |

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| VEAR | Veronica arvensis L. | (corn speedwell) |
| VEBA | Vernonia baldwinii Torr. | (Balwin's ironweed) |
| VEBI | Verbena bipinnatifida Nutt. | (Glandularia bipinnatifida var. bipinnatifida) |
| VECA4 | Verbena canadensis (L.) Britt. | (Glandularia canadensis) |
| VEPU | Verbena pumila Rydb. | (Glandularia pumila) |
| VEUR | Verbena urticifolia L. | (white vervain) |
| VEVI3 | Verbesina virginica L. | (white crownbeard) |
| VIBI | Viola bicolor Pursh | (field pansy) |
| XADR | Xanthocephalum dracunculoides (DC.) Shinners | (Amphiachyris dracunculoides) |
| XAST | Xanthium strumarium L. | (rough cockleburr) |
| YUGL | Yucca glauca Nutt. | (small soapweed) |
| ZEBR | Zephyranthes brazosensis (Herbert) Traub | (Cooperia drummondii) |
| _ANCAC | Anemone caroliniana fo. caroliniana | |
| _ANCAV | Anemone caroliniana fo. violacea | |
| _OXLA | Oxytropis lamberti | |
| _PECA3 | Petalostemum candidum | |