Evaluation of Ozone Injury
on Vegetation within the
Edwin B. Forsythe National Wildlife Refuge
Brigantine, New Jersey

2004 Observations

Submitted to

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

Donald D. Davis, Ph.D.

April 15, 2005

TABLE OF CONTENTS

Page

TABLE OF CONTENTS 2
INTRODUCTION 3
General 3
Objectives 5
Justification 5
Diagnosis of Air Pollution Injury 5
Description of Refuge 8
METHODS 11
General Survey Areas 11
Preliminary Selection of Bioindicator Species 12
Air Quality 13
Survey Dates and Sites 18
Severity Rating 19
RESULTS AND DISCUSSION 20
Final Selection of Bioindicator Species 20
Foliar Symptoms 20
DISCUSSION 29
SUMMARY 33
RELATED LITERATURE 34
APPENDIX (Vegetation list) 36

INTRODUCTION

General

The Edwin B. Forsythe National Wildlife Refuge (NWR) 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.

The Forsythe NWR, located on the Atlantic Ocean in southeastern New Jersey (Figure 1), was created to provide feeding, nesting, and resting habitat for a variety of waterfowl, other water birds, and several threatened or endangered bird species. This NWR is one of the original four United States wetlands designated in the "List of Wetlands of International Importance" under the United Nations Convention on Wetlands of International Importance, also known as the Ramsar Convention. The Forsythe NWR contains the Brigantine Wilderness Area, a Class I air quality area.

Air pollutants have been monitored by the State of New Jersey within the Forsythe NWR since 1989. The primary air pollutant of concern is ozone, and monitored concentrations of ozone found within this refuge are considered to be very high and at phytotoxic levels during most, if not all, years. Botanical surveys conducted in or near the refuge have recorded plant species known to be sensitive to ozone. However, no surveys were conducted in the NWR prior to 1993 regarding foliar injury caused by ambient ozone.

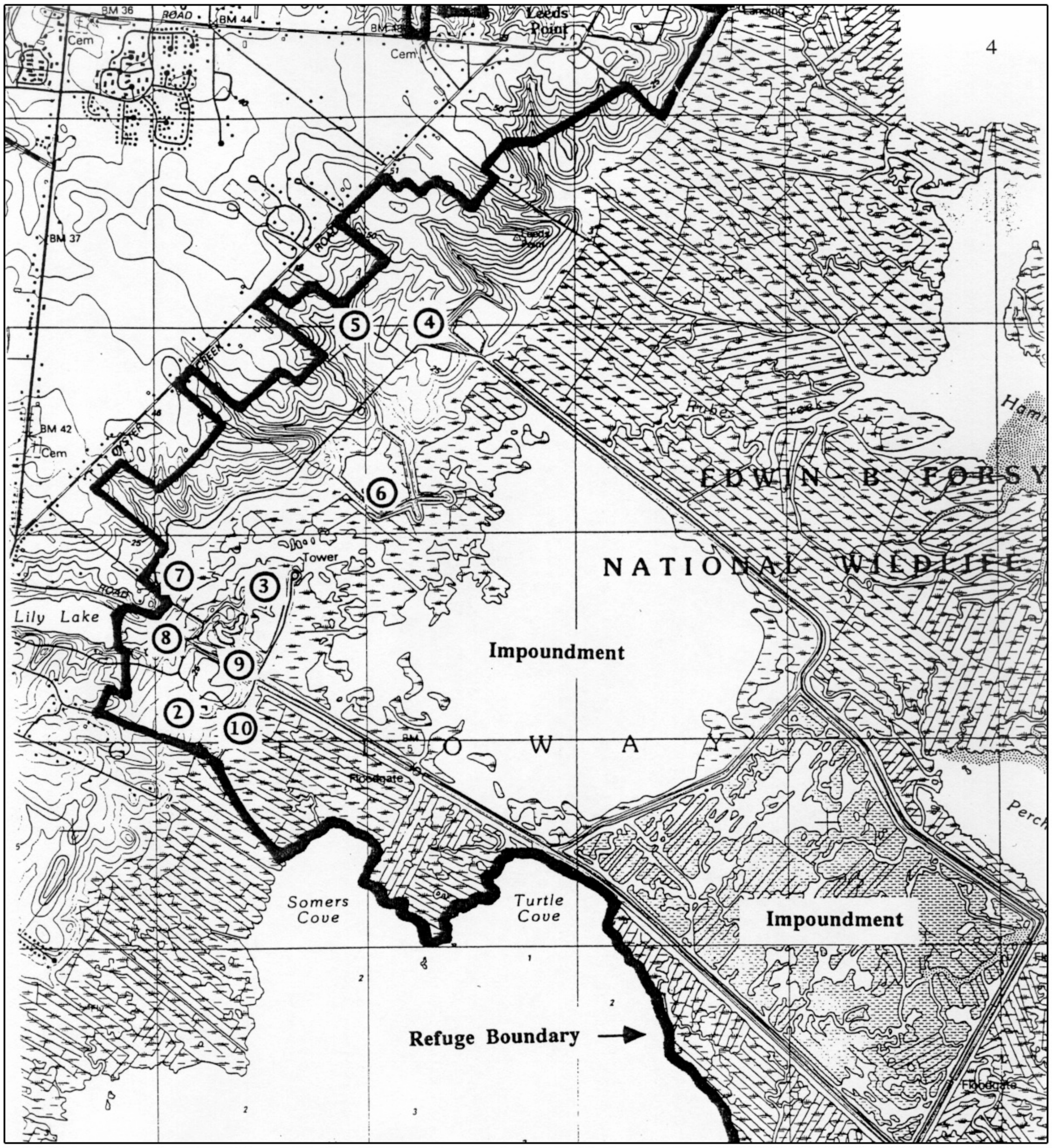

Figure 1. Location of the Edwin B. Forsythe National Wildlife Refuge in southeastern New Jersey. Circled numbers indicate approximate location of survey sites.

Objectives

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

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

Justification

The Forsythe NWR contains a designated Class I air quality area, which receives protection under the Clean Air Act. Congress charged the FWS and the other Federal land managers for Class I areas to have 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 air pollutants can be carried long distances in the atmosphere, even remote wilderness areas can be affected by air pollution.

To better understand how air pollution affects resources at the Forsythe NWR, annual surveys were conducted in 1993 – 1996 and 2001 - 2004 to evaluate ozone injury to vegetation within the refuge.

Diagnosis of Air Pollution Injury on Plants

Although many gaseous air pollutants are emitted into the atmosphere, only certain ones are phytotoxic and induce characteristic leaf symptoms that are useful during field surveys. The most important of these gaseous, phytotoxic air pollutants are ozone, sulfur dioxide, and fluorides. These pollutants, along with the normal constituents of the air, are taken into the plant leaf through the stomata. Once inside the leaf, the pollutant or its breakdown products react with cellular components causing tissue injury or death.

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 a plant's exposure to low levels of pollution for an extended time, or occur when a plant is somewhat resistant to a pollutant. Visible ozone injury is usually considered to be chronic injury. Acute injury may be 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.

Macroscopic leaf injury caused by air pollutants often represents an intermediate step between initial physiological events and decreases in plant productivity. Decreases in plant 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, Skelly 2000). 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 air primary pollutants such as sulfur dioxide and fluorides might occur near industrial sources. Likewise, trace elements including 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 elements such as arsenic, mercury (Davis et al. 2002), selenium, and lead may be especially important in areas being managed for wildlife. Although such compounds are of more interest in mammalian and avian toxicity as compared to phytotoxicity, vegetation may sorb such contaminants and become part of the contaminated food chain. However, the presence of excessive trace elements such as 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, lightning, or chemical reactions of naturally occurring precursors. However, in many areas, precursors leading to phytotoxic levels of ozone originate from upwind urban areas. In those areas, hydrocarbons and oxides of nitrogen are emitted into the atmosphere from various industrial sources and automobiles. These compounds undergo photochemical reactions in the presence of sunlight forming photochemical smog, of which ozone is a major component. 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 areas many miles upwind from the refuge. In fact, concentrations of ozone are often greater in rural areas downwind from urban areas, as compared to within an upwind urban area, due to the presence of reactive pollutants in the urban air that scavenge the ozone.

There are certain bioindicator plants in the East that are very sensitive to ozone and exhibit characteristic symptoms when exposed 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.

Ozone-induced symptoms on broadleaved bioindicators usually appear as small 1 - 2 mm diameter "stipples" of pigmented, black or reddish-purple tissue, restricted by the veinlets, on the adaxial surface of mature leaves (see Skelly 2000, Skelly et al. 1987). Immature leaves seldom exhibit symptoms, whereas mature leaves of sensitive species may show severe symptoms. To the casual observer, ozone-induced symptoms are similar to those induced by other stresses (e.g., moisture stress, nutrient deficiency, fall coloration, heat stress, as well as certain insects, and diseases). However, the pigmented, adaxial stipple on plants of known ozone-sensitivity (i.e., black cherry or grape) is a reliable diagnostic symptom that can be used to evaluate 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 also exhibit needle tip browning. However, this latter symptom can be caused by many stresses and is not a reliable diagnostic symptom. Conifer needles older than current-growing season needles are not useful as monitors, since over-wintering and multi-year insect injuries may produce confounding symptoms. Ozone injury on monocots such as grasses (i.e., *Spartina* sp.) is also very difficult to diagnose in the field, as there are many causal agents that can result in tipburn and chlorotic mottle on grasses.

Description of Edwin B. Forsythe NWR
(Adapted from NWR brochures)

General

The Forsythe NWR is located within the Atlantic Coastal Plain in southeastern New Jersey, extending from Barnegat south to Absecon (Figure 1). The Brigantine Refuge was established in 1939 under the authority of the Migratory Bird Conservation Act to preserve estuarine habitats important to the Atlantic brant (*Branta bernicla*) and to provide nesting habitats for black ducks (*Anas rubripes*) and rails. The Barnegat NWR was established in 1967 under the same authority, with the basic purpose of preserving estuarine feeding and resting habitat for ducks and brant. These two refuges were combined in 1984, forming the Edwin B. Forsythe NWR, named in honor of the late conservationist Congressman from New Jersey. The former Brigantine and Barnegat refuges are now considered as divisions of the Edwin B. Forsythe NWR.

The approved boundary of the Forsythe NWR contains 47,800 acres, of which about 80% (38,214 acres) has been acquired. This refuge is one of the original four United States wetlands designated in the "List of Wetlands of International Importance" under the United Nations Convention on Wetlands of International Importance, also known as the Ramsar Convention.

Two large (1,415 acres) impoundments are managed as marsh habitat for wildlife in the Brigantine Division. One, fed by Doughty Creek and associated springs, is managed as a fresh water impoundment, whereas the other is managed as a brackish impoundment. These diversified wetlands were created to attract and support a wider variety of wildlife than could salt marsh alone. Additional fresh water areas at Brigantine include a spring-fed experimental pool, a sand-borrow pit, and a gravel pit. Three fresh water "stop ditch" impoundments are located on the Barnegat Division. These ditches, totaling about 100 acres, were formed by plugging old mosquito control ditches and channels, and are fed by upland streams.

The Holgate Unit, Little Beach Island, and the unaltered salt marsh areas of the refuge comprise the 6,603-acre Brigantine Wilderness, a Class I air quality area.

Vegetation

Many different plant species are found within the Forsythe NWR, from the salt marshes to the uplands forests. Estuarine marsh, dominated by salt marsh cordgrass (*Spartina alterniflora*) and salt meadow cordgrass (*S. patens*), is the most abundant habitat. Most of the marsh had been ditched in the past for mosquito control, and traces of ditches are readily observed. Palustrine forested wetlands on the Barnegat Division are dominated by red maple (*Acer rubrum*), oaks (*Quercus* spp.), black gum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), and occasional stands of Atlantic white cedar (*Chamaecyparis thyoides*). Grasslands occur mainly at the interface between the salt marsh and woodlands. Upland woodlands are dominated by pitch pine (*Pinus rigida*), red maple, and various oaks, while reverting grasslands contain forbs and grasses interspersed with sassafras, eastern red cedar (*Juniperus virginiana*), and winged sumac (*Rhus copallina*). In addition to native plant species, introduced plants occur throughout the Forsythe refuge.

Wildlife

The Forsythe NWR supports 33 of the 72 fish and wildlife species or groups of species designated as National Species of Special Emphasis, as well as several other species designated as Regional Species of Special Emphasis. At this NWR, more than 39,000 acres of southern New Jersey coastal habitats are actively protected and managed for migratory birds. The impoundments and the other wetlands at the Forsythe NWR provide important feeding, nesting, and resting habitat for a variety of waterfowl, other water birds, and several federal or state threatened or endangered species. The refuge provides wintering habitat for approximately 10% of the Atlantic Flyway's black duck population and approximately 15% of the flyway's Atlantic brant population. A much greater portion of the flyway's population of these two species utilizes the refuge during fall and spring migration. The refuge also provides significant wintering habitat for mallards (*Anas platyrhynchos*), American widgeon (*A. americana*), canvasbacks (*Aythya valisineria*), and greater scaup (*A. marila*), as well as nesting habitat for mallards and black ducks.

Federal or state threatened or endangered species important at the Forsythe NWR include the piping plover (*Charadrius melodus*), peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), least tern (*Sterna antillarum*), and black skimmer (*Rynchops niger*). Piping plovers nest on the Holgate Unit of the Barnegat Division and on Little Beach Island at the Brigantine Division. Peregrine falcons are not native to the refuge, but use artificial nesting structures within the refuge. They can be seen at this NWR throughout the year and each division has an active peregrine nest. Ospreys nest on both divisions. Bald eagles are occasional visitors to the refuge. Least terns and black skimmers nest on the Holgate Unit and use other parts of the refuge for feeding and resting.

Public Use

Public use is an important aspect of the management program at the Forsythe NWR because of the recreational and educational opportunities it affords and its impacts on wildlife. The public use facilities are located at the Brigantine Division headquarters area in Oceanville. An 8-mile Wildlife Drive and two short foot trails provide excellent wildlife viewing and photo opportunities. Numerous groups from educational institutions visit the refuge each year to study and learn about the refuge natural resources. Approximately 200,000 visits are made to the refuge each year for varied activities such as wildlife interpretation and observation, education, fishing, clamming, crabbing, waterfowl hunting, archery and gun hunting for deer, trapping, beach activities, and wildlands appreciation. Approximately 40% (14,000 acres) of the Forsythe refuge is open to waterfowl hunting and approximately 10% (upland and wooded areas) are open to deer hunting.

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 are exposed to sunlight and unrestricted air movement (Anderson et al. 1989; USDA Forest Service, 1990). Immediately prior to the initial (1993) survey, the investigator met with Forsythe NWR personnel at refuge headquarters. During this time, maps were viewed to help select potential survey areas.

Two general areas were selected in the field in 1993 to determine if ambient ozone injury was occurring on vegetation within the refuge. One area was Little Beach Island, located within the Brigantine Wilderness Class I air quality area, and accessed only by boat. Elevations on the island range from sea level to 10 feet. Initial observations in 1993 revealed that the island contained few bioindicator species. The second survey area consisted mainly of higher ground located near the NWR headquarters, and a few sites along the auto tour route. The higher ground was a long, narrow stretch of land that extended from Lily Lake (near Oceanville) to Scott Landing, bounded by the Oyster Creek Road on the northwest and the West Pool on the southeast (Figure 1). Elevations in this area ranged from sea level to 50 feet.

The upland area contained more bioindicator species than did Little Beach Island, and was considered to be superior in terms of potential to detect quantifiable ozone injury. Exact location of survey sites were further refined in the field during each visit. The upland area was surveyed during 1993–1996 and 2001–2004. Little Beach Island was surveyed only during 1993 (August and September), 1994 (September), and 1996 (August). To the best of my knowledge, there were no recorded surveys, prior to my initial survey in 1993, to document the level of ozone injury occurring to vegetation within the refuge.

Preliminary Selection of Bioindicator Species

Vegetation in or near the Forsythe NWR had been classified by Stalter (1989) and Anderson (1990). Prior to my first visit in 1993, potential ozone-sensitive bioindicators were selected from the lists of these botanists. Stalter (1989) classified vegetation on Little Beach Island into three main plant communities: beach and swale community, salt marsh, and immature maritime forest. Black cherry was the only ozone-sensitive species listed in the beach and swale community. Poison-ivy (*Toxicodendron radicans*), a species that often exhibits macroscopic foliar symptoms in the field similar to those caused by ozone, was also present in this community. However, the sensitivity of poison-ivy to ozone has not been studied under controlled conditions, and its foliage often turns red under stress. These factors make poison-ivy less valuable as a bioindicator.

Anderson (1990) conducted a survey of vascular plants along Doughty Creek, a stream that flows into Lily Lake near the upland survey area. Among the plant species that he listed were several known to be sensitive to ambient ozone, including: black cherry, common elderberry, common milkweed, grape, red maple, sassafras, sweet gum, Virginia creeper, and winged sumac.

A summary list of the vegetation known to exist at the refuge was constructed by the FWS from these two reports (Appendix).

It is recognized that ozone-sensitivity among plant species varies from area to area, depending upon genetics and local environmental factors. Nevertheless, it was apparent from the previous botanical surveys that an adequate number of ozone-sensitive species existed in the survey area. Tentatively, it was decided in 1993 to use black cherry, wild grape, common milkweed, sassafras, Virginia creeper, and winged sumac as potential indicators. During the surveys, tree-of-heaven (*Ailanthus altissima*) and salt marsh cordgrass were added to the list based on field observations. These species formed the basis for surveys conducted in 1993–1996 and 2001-2003.

Many of the plant species listed in the Appendix grow in scattered localities through the NWR, and were not present at desired survey areas; they may only be found with the help of local botanists or refuge biologists. Also, most plant species growing in the more wet areas of the refuge have not been studied with regard to ozone-induced macroscopic symptoms. That is, the ozone-sensitivity of most wetland species, as determined by controlled exposures of ozone, is generally unknown. Likewise, the ozone-sensitivity of spring ephemerals is largely unknown.

Air Quality

Ambient ozone monitoring data are useful to complement visual injury surveys. In general, when soil moisture is adequate, the amount of ozone-induced stipple may be positively correlated with ambient ozone concentrations during the growing season. However, more consistent and long-term monitoring datasets are needed to further understand the interactions between foliar symptoms and factors such as ambient ozone, plant species, time of year, and environmental conditions such droughts in our national wildlife refuges.

Ozone data used in this report were monitored at EPA AIRS site #34-001-0005, located within the Forsythe NWR and operated by the state of New Jersey. Ambient ozone levels are expressed as “cumSUM60”, the cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb, expressed as ppb.hrs. In other studies, we have found that this ozone statistic correlates with plant injury induced by ozone.

Ozone has been monitored at the Forsythe NWR annually since 1989. Ozone levels at the end of August during this period were greatest in 1991, reaching 70,000 ppb.hrs, and least in 2004, reaching only 18,000 ppb.hrs (Figure 2). In 2004 ambient ozone levels throughout the northeastern U.S. were at record lows, related at least partially to the very cool wet weather of that year. During the years of survey (1993–1996 and 2001–2004), cumSUM60 ozone levels by the end of August were greatest in 1993 and 1996, with levels exceeding 45,000 ppb.hrs. Ambient ozone levels were low in 1994 and 2003, slightly exceeding 25,000 ppb.hrs. Ozone levels were intermediate in 1995, 2001, and 2002, reaching approximately 34,000 to 40,000 ppb.hrs.

During the entire time period that encompassed the surveys, ozone levels were greatest during the non-survey years of 1997 and 1998, approaching 55,000 ppb.hrs by the end of August (Figure 2), and were greatest the “high ozone” year of 1991. During that hot, dry year of 1991, cumSUM60 ozone values actually exceeded 80,000 ppb.hrs by September 30 (data not shown).

Figures 3 and 4 illustrate the pattern of ozone accumulation during the growing seasons of 1993–1996 and 2001–2004, respectively. These figures allow a visual evaluation of the total ozone that a plant has experienced for various portions of the summer. It is interesting to note that ozone levels within this refuge exceeded 10,000 ppb.hrs during June of 2001 and 2002, likely exceeding phytotoxic levels by this early date. This indicates that the potential exists for ozone-induced plant damage to occur in this refuge (and perhaps other refuges), on plants such as spring ephemerals, as many of these species are still present by June. To my knowledge, the impact of ambient ozone on spring ephemerals has not been reported.

The ozone levels monitored within the Forsythe NWR are generally greater than those experienced by more rural refuges such as the Moosehorn NWR in Maine, Okefenokee NWR in Georgia/Florida, and Seney NWR in Michigan. Ozone levels at Forsythe NWR are generally comparable to those observed at the Mingo NWR in Missouri. As stated earlier, the ozone levels at the Edwin B. Forsythe NWR reached about 80,000 ppb.hrs by the end of September in 1991, and often approach 40,000 ppb.hrs by August 31 (Figure 2). Similarly, ozone levels at the Mingo NWR also reached 80,000 ppb.hrs by fall of 1999.

Based on these historically high levels of ambient ozone (Figure 2), ozone-induced leaf injury is likely to occur on sensitive species of vegetation within the Edwin B. Forsythe NWR and the associated Class I wilderness area during most, if not all, years.

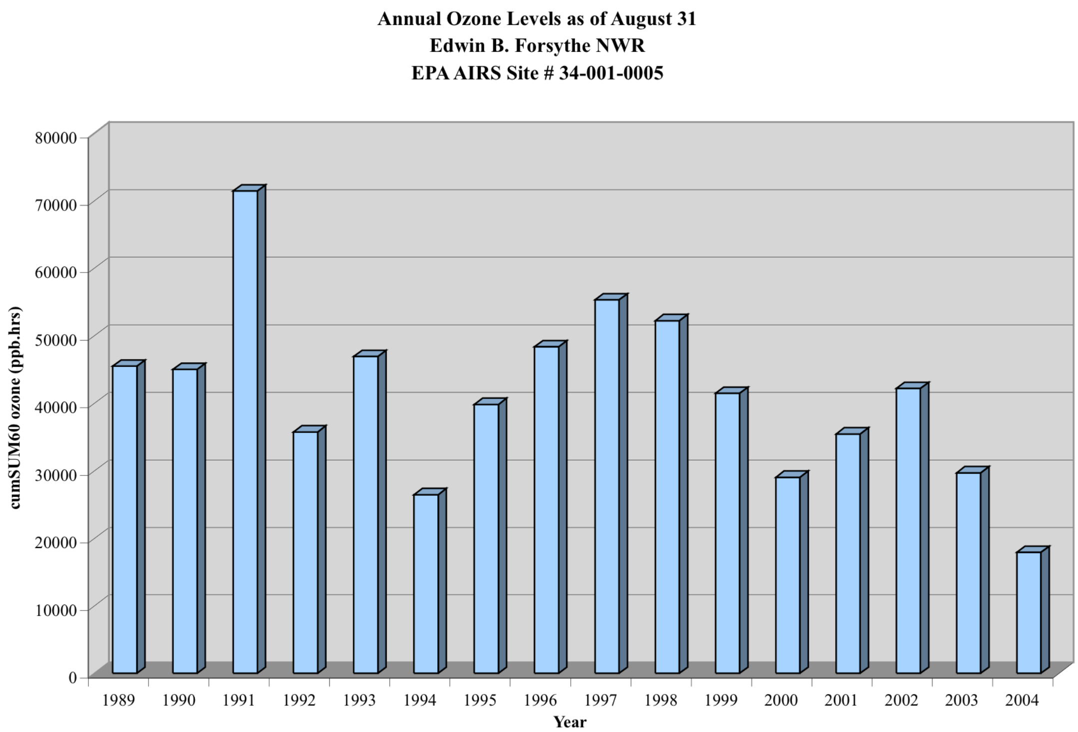

Figure 2. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumSUM60, ppb.hrs) as of August 31 within the Edwin B. Forsythe NWR at EPA AIRS Site # 34-001-0005 during 1989–2004.

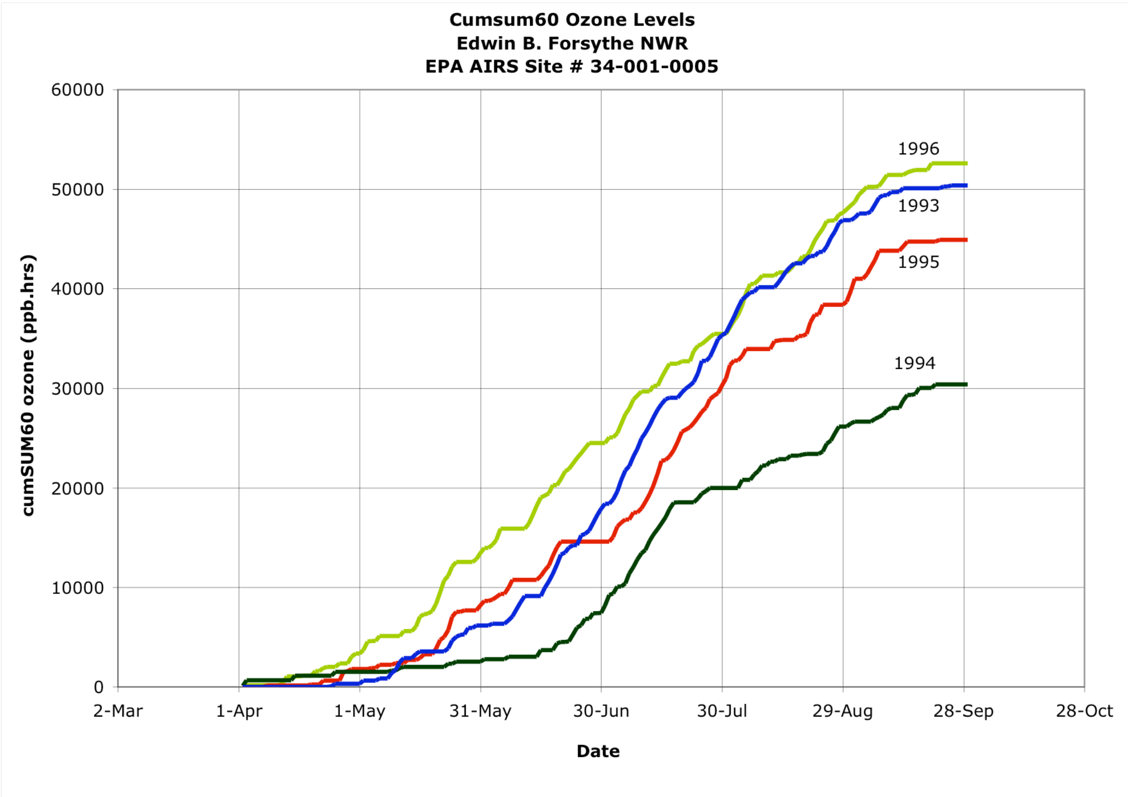

Figure 3. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumSUM60, ppb.hrs) during the 1993-1996 years of survey within the Edwin B. Forsythe NWR as monitored at EPA AIRS Site # 34-001-0005.

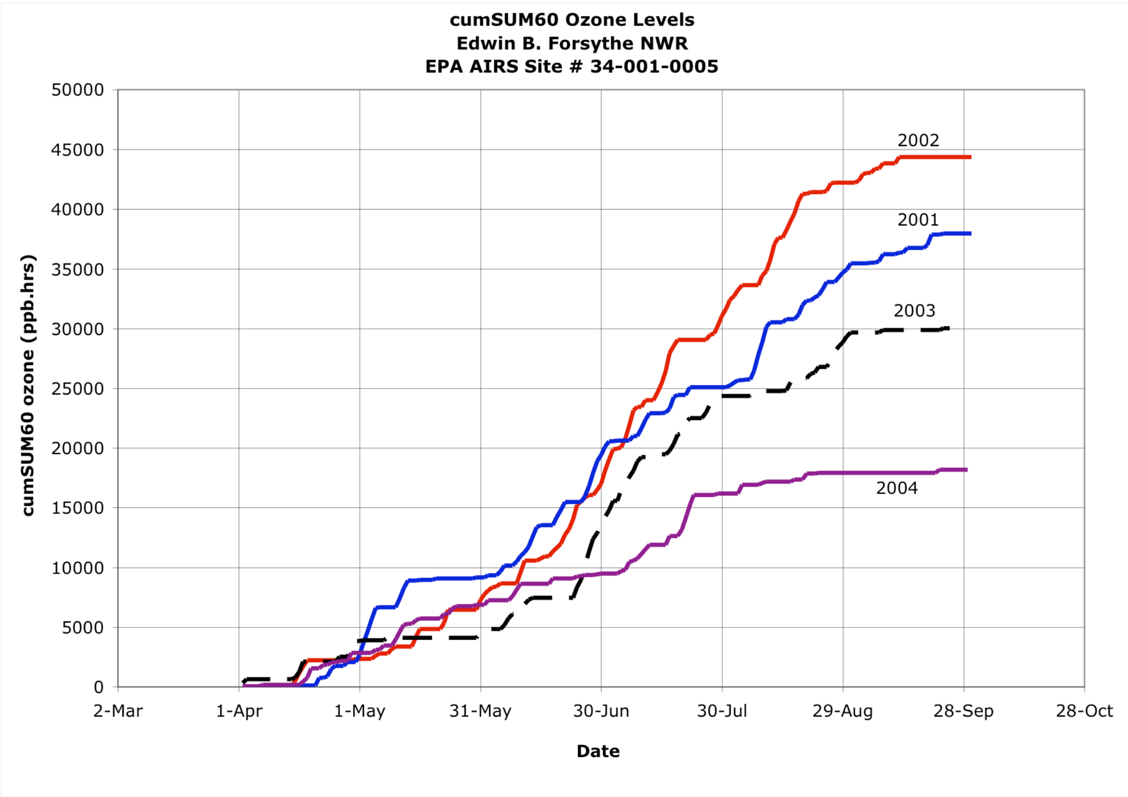

Figure 4. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumSUM60, ppb.hrs) monitored during the 2001-2004 years of survey within the Edwin B. Forsythe NWR at EPA AIRS Site # 34-001-0005.

Surveys Dates

During 1993 and 1994, two surveys were conducted each year, one in August and one in September. In 1993 sites were visited during 2-6 August and 13-16 September. The 1994 surveys were conducted during 7-12 August and 18-21 September. In 1995-1996 and 2001-2004 only one survey per year was conducted. Plants were examined in 25-29 August 1995, 26-30 August 1996, 25-28 August 2001, 7–10 August 2002, 4–6 August 2003, and 9-10 August 2004.

Surveys Sites

As previously stated, in 1993 the FWS and the author selected the two general areas to be surveyed during 1993-1996: Little Beach Island and higher elevation areas near the refuge headquarters. It had been determined that specific survey sites must occur in open-areas (such as along roads 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). On the island, most plants were exposed to full sunlight and unrestricted air movement, so location of the specific survey sites was determined by the presence or absence of ozone-sensitive plant species. However, the upland area was heavily wooded with a full canopy, and survey sites were restricted to the roadsides and fields along the automobile route. However, the specific survey location was again dictated by presence or absence of ozone-sensitive species.

Ten specific survey sites, including the island as one site, were visited during the 1993–1994 and 1996 surveys. (The island could not be accessed in 1995 and was not surveyed in that year). These early surveys revealed that the island site contained few bioindicators, and subsequently was not visited in 2001-2004. Nine areas (Figure 1) were deemed suitable for ozone injury surveys, based on openness, accessibility, and presence of bioindicators, and were visited in 2004. In addition to these specific areas, vegetation was observed in a general manner as the investigator traveled from location to location during the survey.

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 main dataset taken was the number of plants (expressed as a percentage) within a species that exhibited stipple, as compared to the total number of plants evaluated for that species. In addition, severity of injury (percentage of leaf tissue injured by ozone) was estimated on one or two selected bioindicators.

The ForestHealth Expert System had been used to train the investigator in estimating the amount of stipple on a leaf. The following evaluation system was utilized. For broadleaved tree species, the percentage of ozone injury was estimated on the oldest leaf on each of four branches, and the average value recorded. Then, the next oldest leaf was evaluated, and so on, until the five oldest leaves had been rated. For each herbaceous plant, each of the five (if present) oldest (basal) leaves of the plant was examined and the average percent stipple recorded. Each of the oldest five leaves on the current woody growth (canes) of vines, such as grapes, was rated and the average percent stipple recorded. On all species, only adaxial leaf surfaces were evaluated. Symptom severity on the adaxial surface of each leaf evaluated was estimated by assigning severity classes, based on the percentage of surface injured, of 0, 5, 10, 20, 40, 60, 80, 90, 95 and 100 %.

Slides or digital images were taken, if suitable subjects were observed, and sent to the FWS Air Quality Branch in Denver.

RESULTS AND DISCUSSION

Selection of Bioindicator Species

The selection of bioindicator species to be used was revised each year. Over the years, the list of potential bioindicators was narrowed to include black cherry, common milkweed, sassafras, sweet gum, tree-of-heaven, Virginia creeper, wild grape, and winged sumac. These species occurred commonly within the refuge, usually occurred in open areas, and formed the basis for the 2004 survey. Not all species/genera listed were present at all sites. Raspberry and blackberry were selected as indicators for sulfur dioxide (SO_2) injury. However, since there was no point source of SO_2 readily evident, emphasis was placed on ozone-sensitive bioindicators.

Foliar Symptoms

In 2004 the main survey sites were located on the narrow stretch of higher land that extends approximately from Lily Lake (near Oceanville) to Scott Landing, approximately bounded by the Oyster Creek Road on the northwest and the West Pool Impoundment on the southeast (Figure 1). Elevations in this area range from sea level to 50 feet. Prior to the 2004 visit, coastal New Jersey had plentiful rainfall, and adequate soil moisture, in contrast to the extreme drought of 2002 (Figure 5).

Only approximate percentages (no decimal points) are given in the following text for incidence of injury prior to 2004.

Site 1. This former survey site, Little Beach Island, had been surveyed in 1993–1994 and 1996. Due to the lack of bioindicators on the island, and time required to survey it, the island has not been visited since and was not surveyed in 2004.

Site 2. This survey site is located on the grounds immediately adjacent to the refuge headquarters building. Vegetation was examined along both sides of the macadam road leading to the headquarters building, near the gate, adjacent to the parking areas in back of the building, and along the lanes and walks leading to the building.

In 2004 ozone-induced stipple was observed on 10 of 53 (18.9%) wild grapes and 3 of 23 (13.0%) winged sumacs (Table 1). Symptoms on winged sumac were present only on older, chlorotic foliage of unhealthy plants. Ozone injury was not observed on 51 arrow-wood viburnums, 61 black cherry trees, 21 common milkweed plants, 13 sassafras saplings, 9 serviceberry saplings, 20 smooth sumacs, 18 Virginia creeper vines, or 20 wisteria vines in 2004.

Reddening of foliage, somewhat resembling stipple, was noted on one arrow-wood Viburnum. There was no SO_2 injury on raspberry or blackberry plants, at this or at any other location in the refuge in 2004. This finding was expected, since there were no apparent point sources of SO_2 immediately upwind from the refuge.

The leaves of most Virginia creeper and winged sumac plants, and many grapes, were generally dark green in 2004, with very little reddening. This healthy-appearing condition was likely related to the low levels of ambient ozone, cool temperatures, and adequate soil moisture. However, some foliar symptoms commonly associated with cool, wet weather were noted in 2004 (as well as in 2003). Such wet-weather diseases included oak leaf blister and oak anthracnose, as well as leafspots on black cherry, grapes, and other broadleaved species. Common insect disorders were observed at this site, and throughout the refuge. For example, plant foliage exhibited insect disorders caused by tent caterpillars, various chewing insects, leafhoppers, and gall-forming insects. However, the incidence and severity of insect disorders were generally low, as in 2003, possibly due to the wet weather (which does not favor insect disorders).

In 2003, a wet cool year with low ozone levels, stipple had been noted only on one wild grape (3%) at this location, and not on any other bioindicators examined. In 2002, many plants had wilted from the severe drought, but ozone-induced injury was still observed on 5.7% of the wild grapes examined. Injury had not been observed on black cherry, common milkweed, sassafras, winged sumac, Virginia creeper, arrow-wood viburnum, and wisteria vines in 2002. (Ozone stipple had been noted on Wisteria leaves in the past). In 2001, which was less droughty than 2002 and had more ambient ozone than 2003, ozone stipple had been observed on approximately 58% of the grapevines, 14% of the winged sumac shrubs, 11% of the Virginia creeper plants, and 9% of the sassafras saplings.

Site 3. Site 3 is located along the west side of the road leading to the observation tower next to "Gull Pond". In 2004 ozone injury was only noted the one grapevine that was examined. Injury was not observed on 20 arrow-wood viburnum plants, 22 black cherry saplings, 10 Virginia creeper vines, or 10 winged sumac shrubs (Table 1). Winged sumac plants were not red in 2004 (or 2003), as they often are at this time of year, probably due to the cool temperatures, low ozone, and adequate soil moisture. However, one Virginia creeper vine was red. Arrow-wood viburnum leaves exhibited small dark spots, somewhat resembling ozone injury, but this was not recorded as stipple.

In 2003 ozone injury had not been observed on 1 grapevine, 10 winged sumac shrubs, 33 black cherry saplings, 11 Virginia creeper vines, or 30 arrow-wood viburnum plants.. In 2002 ozone injury was not observed on grape, winged sumac, or black cherry at this site.

Site 4. Site 4 is a low area located near the parking area ("Jen's Trail") at the northernmost corner of the automobile route. In 2004 ozone stipple was noted on 2 of 12 (16.7%) of the grape plants examined. Ozone injury was not observed on 16 black cherry saplings or 20 winged sumac shrubs (Table 1).

In 2003 ozone stipple had been observed on 14% of the grape plants. Ozone injury was not observed on 20 black cherry saplings, 6 winged sumacs, or 6 winged sumac shrubs. Webworm infestations occurred in the area in 2003.

In 2002, ozone injury had not been observed on black cherry or winged sumac shrubs.

Site 5. Site 5 is located along the former construction road that led from the automobile route to Oyster Creek Road. This road was now greatly overgrown, becoming very shaded, and many tree-of-heaven plants had invaded the roadside. In 2004 ozone injury was not observed on 10 arrow-wood viburnums, 5 black cherry saplings, 11 grapevines, 1 sassafras sapling, 10 winged sumacs, or 10 wisteria vines (Table 1). In 2004, as in 2003, all tree-of-heaven sprouts and saplings examined had a moderate to severe chlorotic mottle. The cause of this disorder is unknown. Tree-of-heaven also exhibited defoliation from webworms, as in past years. In the future, only the beginning of this plot should be surveyed because of the increasing shade.

In 2003 ozone injury was noted on only one (9%) of the grape plants. Ozone injury was not observed on 9 arrow-wood Viburnums, 5 black cherry saplings, 3 common milkweed plants, 3 lilacs, 13 sassafras saplings, 6 winged sumacs, or 10 wisteria vines in 2003. All 30 tree-of-heaven sprouts and saplings examined in 2003 had a moderate to severe chlorotic mottle, but did not exhibit classic ozone stipple. Grapes had a severe leafspot and lilacs had powdery mildew infections.

In 2002 ozone injury had been noted on 3% of the grapes and 3% of the tree-of-heaven saplings. Ozone injury had not been observed on black cherry, common milkweed, sassafras, or winged sumac shrubs in 2002.

Site 6. Site 6 is located near the construction storage area, along the sandy access road extending out into the impoundment. In 2004, 5 of 30 (16.7%) of the grapevines had ozone injury (Table 1). Ozone injury was not observed on 20 arrow-wood plants, 40 black cherry saplings, or 5 winged sumac shrubs. Leafspots were common.

In 2003, only one (17%) of the winged sumac shrubs had ozone injury. Ozone injury was not observed on 30 arrow-wood plants, 50 black cherry saplings, 30 grapevines, or 6 sassafras plants. Black cherry and grape foliage had severe Cercospora-type leafspots and chlorotic mottle in 2003, likely related to the very wet weather. Grape leaves also had severe leafspots, but exhibited little ozone injury in 2003.

In 2002, ozone injury had not been observed on grape or black cherry at this site.

Site 7. Site 7 is located along the edge of the large field near the easternmost corner of the automobile route. Each year, the common milkweed plants are being replaced by woody plants and a vetch-like vine as natural succession takes place. In 2004 ozone injury was observed on 3 of 33 (9.1%) common milkweed plants and on none of 20 black cherry saplings (Table 1). Common milkweed plants had severe aphid infestation, and severe defoliation. If present, the lower leaves were very chlorotic.

In 2003 ozone injury had been observed on 3% of the common milkweed plants and on none of 50 black cherry saplings.

In 2002 ozone injury had not been observed on milkweed or black cherry at this site.

Site 8. Site 8 is located at the small bridge. Many of the common milkweeds examined at this location in past years were not longer present. In 2004 ozone injury was not noted on 32 common milkweeds, which were dark green and maintained most of their leaves. However, this site is also becoming very shaded and probably should be abandoned.

In 2003 ozone injury was not observed on 24 common milkweeds, which were dark green and maintained most of their leaves.

In 2002, ozone injury had not been observed on any common milkweed plants.

Site 9. Site 9 is located along the grassy woods road leading from “the treadles” in the road, which prevented cars from backing up and returning to the automobile route to the refuge. In 2004, ozone injury was not observed on 25 common milkweed plants examined. However, this plot is also becoming very shaded.

In 2003, ozone injury was not observed on 28 common milkweed plants examined. In 2002 ozone injury had not been observed on milkweed.

Site 10. Site 10 is located along the “Leeds Eco-trail”. In 2004 ozone injury was noted only on 1 of 34 (2.9%) common milkweed plants (Table 1). Ozone injury was not observed on 20 arrow-wood viburnums, 17 black cherry saplings, 3 grapevines, 2 sassafras saplings, 13 Virginia creeper vines, and 5 winged sumac shrubs. Tree-of-heaven had a severe chlorotic mottle. This site was much more shaded in 2003-2004 than in 1993-1996. However, the site immediately adjacent to the small parking area is not shaded and is suitable for survey.

In 2003 ozone injury occurred on 11.1% of the tree-of-heavens and 7.1% of the Virginia creeper vines. Ozone injury was not observed on 20 arrow-wood viburnums, 15 black cherry saplings, 4 grapevines, 31 common milkweed plants, 1 sassafras sapling, and 4 winged sumac shrubs in 2003. In 2002 ozone injury had not been observed on black cherry, grape, common milkweed, sassafras, winged sumac, tree-of-heaven, or Virginia creeper.

Foliar Symptoms: Summary for 1993 – 2004

Table 1 illustrates the findings of the 2004 survey, and also shows a comparison of ozone injury observed during each year of survey. Observations for each year of survey are summarized as follows.

1993: In early August of 1993, ozone injury had occurred on 1.9% of the black cherry trees examined and on 13.2% of the grape plants evaluated (Table 1). By mid-September of 1993, 3.1% of the black cherry observed trees exhibited ozone injury, and 69.0% of the grape plants evaluated had foliar injury caused by ambient ozone. In addition, 81.8% of the common milkweeds showed ozone injury, and 56.2% of the tree-of-heaven plants had foliar injury induced by ambient ozone. Remaining bioindicator species did not exhibit ozone injury during 1993. Ozone injury was most severe on grape, milkweed, and tree-of-heaven.

1994: In early August of 1994, ozone injury was not present on any of the black cherry trees examined, but occurred on 28.7% the grape plants and 9.6% of the common milkweeds evaluated (Table 1). By mid-September of 1994, 1.0% of the black cherry trees exhibited ozone injury, and 66.7% of the grape plants had foliar injury caused by ambient ozone. In addition, 41.0% of the common milkweeds showed ozone injury. Tree-of-heaven plant foliage was senescing and was not evaluated in September 1994. Ozone injury was most severe on grape and milkweed. Remaining bioindicator species did not exhibit ozone injury in 1994.

1995: In 1995, only visit was made, during the last week of August. At the time of survey, ozone injury occurred on 2.4% of the black cherry trees and 17.8% of the grape plants evaluated (Table 1). In addition, 22.7% of the common milkweeds showed ozone injury, and 17.9% of the tree-of-heaven plants had foliar injury induced by ambient ozone. Virginia creeper exhibited foliar symptoms, but the symptoms were confounded by early fall coloration. Sassafras and winged sumac did not exhibit ozone injury in 1995. Ozone injury was most severe on grape, milkweed, and tree-of-heaven.

1996: Only one visit was made in 1996, during the last week of August. In 1996, ozone injury occurred on 3.4% of the black cherry trees, 46.7% of the grape plants, 70.2% of the common milkweeds, and 21.8% of the winged sumac plants (Table 1). Sassafras did not exhibit ozone-induced symptoms. Tree-of-heaven plant foliage was senescing and was not evaluated. Virginia creeper exhibited foliar symptoms, but the symptoms were confounded by early fall coloration on this species. Ozone injury was most severe on grape and milkweed in 1996.

2001: As generally observed in past years, the percentage of plants exhibiting ozone injury in 2001 was greatest for wild grape (45.1%) and common milkweed (31.9%) (Table 1). Tree-of-heaven at this location was also quite sensitive to ozone (14.0%), followed by Virginia creeper (9.3%), winged sumac (7.4%), and sassafras (3.2%). Among the bioindicators, only black cherry showed no ozone-induced stipple. As observed in past years, ozone-induced injury in 2001 was light in severity (Table 2).

2002: Apparently due to the extremely severe drought along the coast of New Jersey (Figure 5), there was very little ozone injury on sensitive bioindicators. The only two species to exhibit stipple were grape and tree-of-heaven (Table 1). Only 3 of 86 (3.5%) of the grapes showed ozone injury, and only 1 of 43 (2.3%) tree-of-heaven saplings exhibited stipple. This is a much lower incidence of symptomatic plants as compared to previous surveys. In addition, the severity of the injury was extremely light in 2002 (Table 2).

2003: Due to the very low ambient ozone levels, and the cool wet weather in 2003, there was little ozone injury on refuge vegetation during 2003. Only 4.2% of the grape plants had ozone injury, and only 1.3% of the common milkweeds exhibited ozone injury. In addition, only 1 smooth sumac, 1 winged sumac, and 1 Virginia creeper showed ozone injury in 2003.

2004: Due to the second year in a row of very low ambient ozone levels and cool wet weather, there were fairly low levels of ozone injury on refuge vegetation during 2004 (Table 1). However, a total of 18 of 110 (16.4%) grape plants had ozone injury, 4 of 145 (2.8%) of the common milkweeds exhibited ozone injury, 3 of 83 (3.6%) of the winged sumac had possible ozone injury, and 1 of 13 (3.2%) Virginia creeper vines showed ozone injury.

Table 1. Summary of observations made at specific sites during the 2004 survey at the Edwin B. Forsythe NWR. Numbers in table refer to number of plants with ozone-induced stipple as compared to the total number of plants evaluated for that species; data also expressed as percentages. For comparison, summaries of 1993-1996, and 2001-2003 data are also presented.

Site	Black Cherry	Grape	Common Milkweed	Sassafras	Winged Sumac	Tree-of-Heaven	Virginia Creeper
2	0/61	10/53	0/21	0/13	3/33		0/18
3	0/22	1/1			0/10		
4	0/26	2/12			0/20		
5	0/5	0/11		0/1	0/10		
6	0/40	5/30			0/5		
7	0/20		3/33				
8			0/32				
9			0/25				
10	0/17	0/3	1/34	0/2	0/5		1/13
Aug 9-10, 2004 Total **Aug 9-10, 2004 %**	0/191 0.0%	18/110 16.4%	4/145 2.8%	0/16 0.0%	3/83 3.6%		1/31 3.2%
Aug 4-6, 2003 Total **Aug 4-6, 2003%**	0/219 0.0%	4/94 4.2%	2/148 1.3%	0/31 0.0%	1/52 1.9%		1/48 2.1%
Aug 7-10, 2002 Total **Aug 7-10, 2002%**	0/220 0.0%	3/86 3.5%	0/81 0.0%	0/26 0.0%	0/75 0.0%	1/43 2.3%	0/25 0.0%
Aug 25-28, 2001 Total **Aug 25-28, 2001%**	0/204 0.0%	41/91 45.1%	22/69 31.9%	1/31 3.2%	7/95 7.4%	4/29 14.0%	5/54 9.3%
Aug 26-30, 1996 Total **Aug 26-30, 1996%**	11/327 3.4%	43/92 46.7%	113/161 70.2%	0/35 0.0%	24/110 21.8%		
Aug 25-29, 1995 Total **Aug 25-29, 1995%**	6/250 2.4%	13/73 17.8%	34/150 22.7%	0/35 0.0%	0/85 0.0%	10/56 17.9%	6/30 20.0%
Sept 18-21, 1994 Total **Sept 18-21, 1994%**	8/330 2.4%	52/78 66.7%	25/61 41.0%	0/21 0.0%	0/92 0.0%	4/20 20.0%	
Aug 7-12, 1994 Total **Aug 7-12, 1994%**	0/290 0.0%	27/94 28.7%	7/65 10.8%	0/21 0.0%	0/92 0.0%	4/20 20.0%	0/54 0.0%
Sept 13-16, 1993 Total **Sept 13-16, 1993%**	12/384 3.1%	58/84 69.0%	18/22 81.8%	0/9 0.0%	0/10 0.0%	9/16 56.2%	0/66 0.0%
Aug 2-6, 1993 Total **Aug 2-6, 1993%**	7/369 1.9%	10/76 13.2%	0/97 0.0%	0/21 0.0%	0/102 0.0%		0/66 0.0%

Table 2. Severity of ozone-induced stipple on leaves of symptomatic grape plants.

			Leaf Number				
Species	**Site No.**	**Plant No.**	1*	2	3	4	5
Grape	**2**	**1**	10**	10	10	5	5
		2	5	5	5	0	0
		3	5	0	0	0	0
		4	10	10	5	5	5
		5	5	5	5	0	0
		6	0	0	5	5	0
		7	5	0	0	0	0
		8	10	10	10	5	0
		9	10	20	0	0	0
		10	5	0	0	0	0
	3	**1**	5	5	0	0	0
	4	**1**	5	0	0	0	0
		2	5	5	5	5	0
	6	**1**	40	40	10	5	5
		2	20	20	20	10	5
		3	10	10	5	5	5
		4	5	5	0	0	0
		5	5	5	5	5	5

*Oldest leaf of the 5 leaves evaluated.

**Severity values = 0, 5, 10, 20, 40, 60, 80, 90, 95, and 100% of leaf tissue injured.

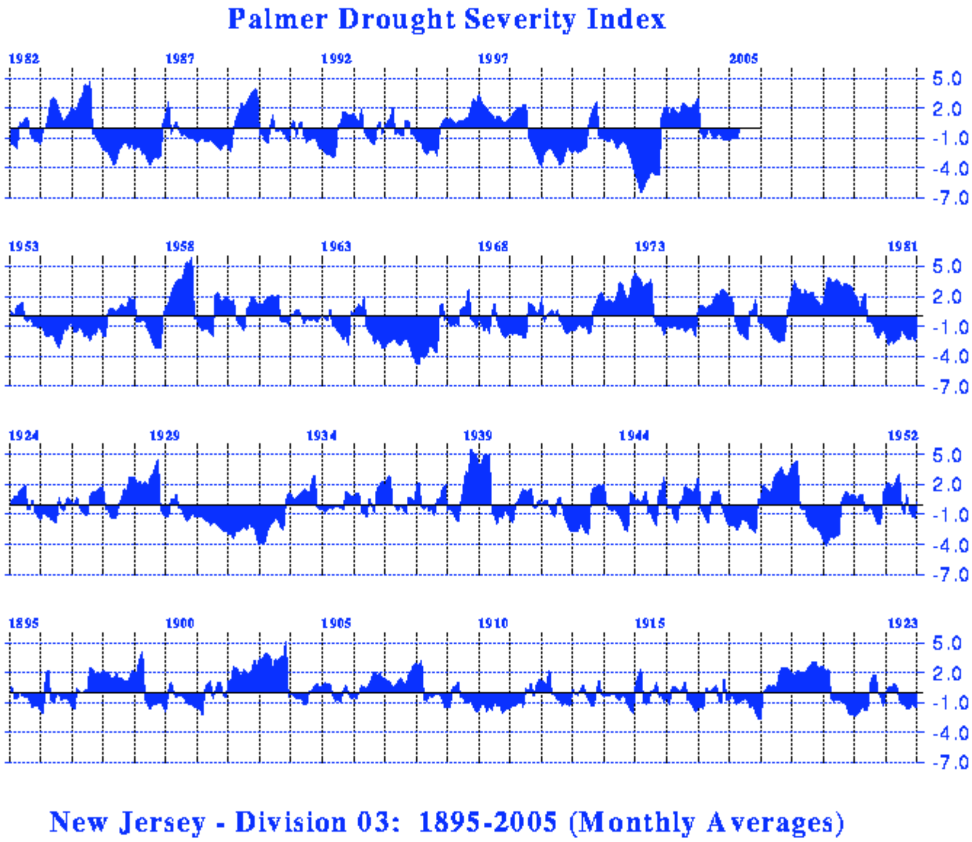

Figure 5. Palmer Drought Severity Index (PDSI) for coastal New Jersey, including the Edwin B. Forsythe National Wildlife Refuge (NWR), during 1895-2004. The horizontal line at "0" is considered normal moisture levels. Areas above the line represent adequate moisture for normal plant functioning, whereas areas below the line represent water stress. A drought severity index of -3 is considered to be a severe drought, likely causing wilting, closing stomata, and subsequently reducing ozone uptake. Moisture was adequate in 2004. Note the severe drought that encompassed coastal New Jersey in 2002.

DISCUSSION

Usefulness of bioindicators

During all years of survey at the Edwin B. Forsythe NWR, the bioindicators that proved to be most useful were wild grape (probably *Vitis labrusca*), common milkweed, and tree-of-heaven (Table 1). These three species have been recognized as being very sensitive to ozone, and have been used by the investigator as bioindicators in other ozone-injury surveys in the East.

It was surprising that black cherry showed so little ozone injury, and has not been a useful bioindicator species for demonstrating the presence or absence of ozone injury within this refuge. Apparently, the populations of grape, milkweed, and tree-of-heaven were genetically more sensitive to ozone than were the populations of black cherry at this location. Also, most of the ozone injury observed on the black cherry was restricted to Little Beach Island, which was surveyed only during 1993–1994 and 1996. It's possible that the isolated population of black cherry on the island may be more sensitive to ozone than the black cherry population on the mainland. The cherry population on the island may not have been selected for ozone resistance, since the island is likely subjected to sea breezes lower in ozone than on the mainland.

Sassafras was not a good biomonitor at this location. In general, sassafras is not sensitive to ozone. Virginia creeper and winged sumac were variable in their response, and often exhibited fall reddening (possibly induced in part by ozone), which confounded evaluation of ozone injury. Tree-of-heaven, although a good bioindicator, tended to defoliate prematurely, possibly due to ozone, and showed a chlorotic mottle in some years that may or may not be related to ozone.

Other Confounding Factors

In addition to variability among species in sensitivity to ozone, other factors confound the results of such field surveys. For example, milkweed plants growing along roads were often cut during roadside mowing and could not be evaluated year-to-year in a consistent manner. Milkweeds growing in fields away from the roads were at times defoliated by caterpillars, and/or were often overgrown and replaced or shaded as the old fields in the refuge underwent natural succession. Also, common milkweeds usually grow in vegetative clones, in which the individual plants are all of the same genetic sensitivity to ozone. This latter characteristic requires that survey sites be spaced properly, so as not to rate only individuals of the same clone. The invasive tree-of-heaven plants, which were small saplings in 1993, were rapidly reaching tree size in the refuge by 2004, which may or may not affect their sensitivity to ozone. In addition, some sites in which the tree-of-heaven saplings were growing were becoming very shaded.

Nevertheless, as long as one considers all these factors, it is still possible to use bioindicators such as grape or common milkweed in ozone-injury surveys. The wild grape plants were judged to be the most valuable ozone bioindicator plants at the Forsythe NWR. However, the species of grape was not determined. Further studies on the use of wild grapes as biomonitors are warranted for this refuge, as well as other areas.

In general, one might assume that greater ozone-induced stipple would be manifested in years with greater ambient ozone concentrations. However, these general relationships can be completely overshadowed by extreme environmental conditions, such as in 1988, 1991, and 2002 when severe droughts occurred. For example, observing only the ambient ozone data in 1988, one might have concluded that severe ozone injury probably occurred on sensitive plant species 1n 1988 in the Northeast. However, in reality the severe drought and resultant water stress caused in stomatal closure in plants, very little uptake of ozone, and very little foliar injury in 1988 in the East. Likewise, the investigator observed widespread drought stress and very little ozone injury within the Forsythe NWR in 2002. This is compounded by the fact that most of the survey sites within this refuge are on sandy soils, which have low moisture-holding capacity, and are therefore drought-prone.

Little is known regarding the sensitivity of salt marsh plants to ozone. Salt marsh cordgrass (*Spartina alterniflora*) has been exposed to ozone in open-top chambers at Penn State (Taylor et al. 2002). Symptoms similar to those caused by ozone in artificial exposures were noted on salt marsh cordgrass and salt meadow cordgrass (*S. patens*) in the field at the NWR, but were not quantified since there are many other stress factors that can cause chlorotic mottle symptoms. Likewise, little is known about the ozone sensitivity of “spring ephemerals”. Since the ozone levels at the Forsythe NWR are usually quite high by June, it is possible that unnoticed ozone injury occurs on ozone-sensitive plants that emerge and complete their life cycle by early summer within the refuge.

SUMMARY

The results of this 2004 survey (Table 1), as well as results of previous years' surveys, revealed that ozone injury was present on vegetation within the boundaries of the Edwin B. Forsythe NWR, a portion of which contains a Class I air quality area. It is likely that ozone injury occurs on sensitive vegetation annually in the refuge, as well as within the Class I area. Prior to the 2004 visit, this part of New Jersey experienced very low levels of ambient ozone (Figure 4) and, generally the overall incidence and severity of ozone injury was light. Soil moisture was adequate within the refuge in 2003-2004, both of which were very wet years in general (Figure 5).

There are several excellent bioindicator plants present in the Forsythe NWR. Wild grape and common milkweed are good bioindicators to evaluate terrestrial effects of ozone in the East. Because of the wide difference in ozone levels among the survey years (Figures 2-4), this NWR should be continued to be surveyed annually to document the presence or absence of ozone-induced injury on vegetation over time. It is recommended that surveys take place in early to mid-August to continue the excellent database that has been collected at this refuge.

These results 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.

RELATED LITERATURE

Anderson, R. L., C. M. Huber, R. P. Belanger, J. Knighten, T. McCartney, and B. Book. 1989. Recommended survey procedures for assessing on bioindicator plants in Region 8 Class 1 Wilderness areas. USDA Forest Service, Forest Pest Management, Asheville Field Office Report 89-1-36, 6 pp.

Anderson, K. 1990. Doughty Creek drainage – survey of vascular plants seen. Unpub. Report from a survey conducted in the Brigantine Unit, Edwin B, Forsythe N.W.R. – on May 22 and June 7, 1989; and June 5 and 29, 1990, by Karl Anderson, New Jersey Audubon Society.

Conkling, B. L. and G. E. Byers (eds.). 1993. Forest Health Monitoring Field Methods Guide. Internal Report. US EPA, Las Vegas, NV.

Davis, D. D. 1984. Description of leaf injury caused by gaseous air pollutants. pp 77-82 In: Davis, et al. (ed.). Proc. Sym. Air Pollut. and Productivity of the Forest, Wash., DC. Oct. 4-5, 1983. Pub. by Izaac Walton League, Wash., DC, 344 pp. .

Davis, D. D. and J. B. Coppolino. 1976. Ozone susceptibility of selected woody shrubs and vines. Plant Dis. Rptr. 60:876-878.

Davis, D. D. and J. M. Skelly. 1992. Foliar sensitivity of eight eastern hardwood tree species to ozone. J. Water, Air, Soil Pollut. 62:269-277.

Davis, D. D. and R. G. Wilhour. 1976. Susceptibility of woody plants to sulfur dioxide and photochemical oxidants. E.P.A. Ecol. Res. Series EPA 600/3-76-102, 70 pp.

Davis, D. D., J. R. McClenahen, and R. J. Hutnik. 2001. Use of an epiphytic moss to biomonitor pollutant levels in southwestern Pennsylvania. Northeastern Naturalist 8:379-392.

Davis, D. D., J. R. McClenahen, and R. J. Hutnik. 2002. Selection of a biomonitor to evaluate mercury levels in forests of Pennsylvania. Northeastern Naturalist 9:183-192.

Davis, D. D., A. Millen, and L. Dochinger (ed.). 1984. Air pollution and productivity of the forest. Proc. Sym. Air Pollut. and Productivity of the Forest, Wash., DC. Oct. 4-5, 1983. Pub. by Izaac Walton League, Wash., DC, 344 pp.

Davis, D. D., J. M. Skelly, and B. L. Nash. 1995. Major and trace element concentrations in red oak, white oak, and red maple foliage across an atmospheric deposition gradient in Pennsylvania. Proc. Tenth Annual Centr. Hdwd. Conf. Morgantown, WVA, USDA Forest Service Tech. Bull. pp 188-195.

Davis, D. D., D. M. Umbach, and J. B. Coppolino. 1981. Susceptibility of tree and shrub species and response of black cherry foliage to ozone. Plant Dis. 65: 904-907.

Davis, D. D., F. A. Wood, R. J. Hutnik, G. C. Weidersum, and W. R. Rossman. 1984. Observations around coal-fired power plants in Pennsylvania. Forest Wissen. Centralblatt 103:61-73.

Jensen, K. F. and L. S. Dochinger. 1989. Response of eastern hardwood species to ozone, sulfur dioxide, and acidic precipitation. J. Air Pollut. Control Assoc. 39:852.

Pye, J. M. 1988. Impact of ozone on the growth and yield of trees: A review. J. Environ. Qual. 17:347-360.

Rosenberg, C. R., R. J. Hutnik, and D. D. Davis. 1979. Forest composition at varying distances from a coal-burning power plant. Environ. Pollut. 19:307-317.

Skelly, J. M. 2000. Tropospheric ozone and its importance to forests and natural plant communities of the northeastern United States. Northeastern Naturalist 7:221-236.

Skelly, J. M., D. D. Davis, W. Merrill, and E. A. Cameron (Eds.). 1987. Diagnosing injury to eastern forest trees. College of Agric., Penn State Univ., 122 pp.

Stalter, R. 1989. The vegetation of Little Beach Island, New Jersey. USFWS File Copy of Unpub. Report by Prof. Richard Stalter, St. John's University, Jamaica, NY. Survey conducted from May 3, 1989 to November 6, 1989.

Taylor, M.D., J.P. Sinn, D.D. Davis, and E.J. Pell. 2002. The impact of ozone on a salt marsh cordgrass (Spartina alterniflora). Environ. Pollut. 120:701-705.

Umbach, D. M. and D. D. Davis. 1984. Severity and frequency of SO_2-induced leaf necrosis on seedlings of 57 tree species. For. Sci. 30:587-596.

van Haut, H. and H. Stratmann. 1969. Color-plate atlas of the effects of sulfur dioxide on plants. Verlag W. Girardet, Essen, W. Germany, 206 pp.

Wood, F. A., R. J. Hutnik, D. D. Davis, G. C. Weidersum, and W. R. Rossman. 1982. Effects of large coal-burning power plants on vegetation in western Pennsylvania. Pres. 75th Annu. Meet. APCA, New Orleans, Preprint No. 82-67.7.

APPENDIX

The following attached vegetation list was compiled by US FWS personnel, mainly from the following two references:

Anderson, K. 1990. Doughty Creek drainage – survey of vascular plants seen. Unpub. Report from a survey conducted in the Brigantine Unit, Edwin B, Forsythe N.W.R. – on May 22 and June 7, 1989; and June 5 and 29, 1990, by Karl Anderson, New Jersey Audubon Society.

Stalter, R. 1989. The vegetation of Little Beach Island, New Jersey. USFWS File Copy of Unpub. Report by Prof. Richard Stalter, St. John's University, Jamaica, NY. Survey conducted from May 3, 1989 to November 6, 1989.

Appendix – Vegetation List

Code	Scientific name	Common name
ACMI2	Achillea millefolium L.	(common yarrow)
ACNE2	Acer negundo L.	(boxelder)
ACRU	Acer rubrum L.	(red maple)
AICA	Aira caryophyllea L.	(silver hairgrass)
AIPR	Aira praecox L.	(yellow hairgrass)
ALSE2	Alnus serrulata (Ait.) Willd.	(hazel alder)
ALVI	Allium vineale L.	(wild garlic)
AMAR2	Ambrosia artemisiifolia L.	(annual ragweed)
AMBR	Ammophila breviligulata Fern.	(American beachgrass)
AMCA4	Amelanchier canadensis (L.) Medik.	(Canadian serviceberry)
ANCO2	Anthemis cotula L.	(stinking chamomile)
ANOD	Anthoxanthum odoratum L.	(sweet vernalgrass)
ANPL	Antennaria plantaginifolia (L.) Richards.	(woman's tobacco)
ANSC10	Andropogon scoparius Michx.	(Schizachyrium scoparium ssp. scoparium)
APAM	Apios americana Medik.	(groundnut)
APCA	Apocynum cannabinum L.	(Indianhemp)
ARCTI	Arctium L.	(burrdock)
ARSE2	Arenaria serpyllifolia L.	(thymeleaf sandwort)
ARTH	Arabidopsis thaliana (L.) Heynh.	(mouseear cress)
ARTR	Arisaema triphyllum (L.) Schott	(Jack in the pulpit)
ASDU	Aster dumosus L.	(rice button aster)
ASNO2	Aster novi-belgii L.	(New Belgium aster)
ASPA5	Aster patens Ait.	(late purple aster)
ASSU5	Aster subulatus Michx.	(annual saltmarsh aster)
ASSY	Asclepias syriaca L.	(common milkweed)
ASTE2	Aster tenuifolius L.	(saline aster)
ASTU	Asclepias tuberosa L.	(butterfly milkweed)
ATAR	Atriplex arenaria Nutt.	(Atriplex pentandra)
ATPAH2	Atriplex patula var. hastata auct. non (L.) Gray	(Atriplex prostrata)
BAHA	Baccharis halimifolia L.	(eastern baccharis)
BAHI3	Bassia hirsuta (L.) Aschers.	(hairy smotherweed)
BAVE	Barbarea verna (P. Mill.) Aschers.	(early yellowrocket)
BAVU	Barbarea vulgaris Ait. f.	(garden yellowrocket)
BICO	Bidens coronata (L.) Britt.	(crowned beggarticks)
BOCY	Boehmeria cylindrica (L.) Sw.	(smallspike false nettle)
BRIN2	Bromus inermis Leyss.	(smooth brome)
BRJA	Bromus japonicus Thunb. ex Murr.	(Japanese brome)
BRSC	Brasenia schreberi J.F. Gmel.	(watershield)
BRTE	Bromus tectorum L.	(cheatgrass)
CAAT4	Carex atlantica Bailey	(prickly bog sedge)
CABL	Carex blanda Dewey	(eastern woodland sedge)
CAED	Cakile edentula (Bigelow) Hook.	(American searocket)
CAHO10	Carex howei Mackenzie	(Carex atlantica ssp. capillacea)
CALA30	Carex lanuginosa Michx.	(woolly sedge)
CALU5	Carex lurida Wahlenb.	(shallow sedge)
CARYA	Carya Nutt.	(hickory)

CASE13	Calystegia sepium (L.) R. Br.	(hedge false bindweed)
CASI6	Carex silicea Olney	(beach sedge)
CAST5	Carex stipata Muhl. ex Willd.	(owlfruit sedge)
CAST8	Carex stricta Lam.	(uptight sedge)
CASW	Carex swanii (Fern.) Mackenzie	(Swan's sedge)
CEFO2	Cerastium fontanum Baumg.	(common chickweed)
CEMA4	Centaurea maculosa auct. non Lam.	(Centaurea biebersteinii)
CEOC	Celtis occidentalis L.	(common hackberry)
CEOR7	Celastrus orbiculatus Thunb.	(oriental bittersweet)
CETR	Cenchrus tribuloides L.	(sanddune sandbur)
CHAL7	Chenopodium album L.	(lambsquarters)
CHAM	Chenopodium ambrosioides L.	(Mexican tea)
CHJU	Chondrilla juncea L.	(hogbite)
CHLA6	Chasmanthium laxum (L.) Yates	(slender woodoats)
CHLE80	Chrysanthemum leucanthemum L.	(Leucanthemum vulgare)
CHMA3	Chimaphila maculata (L.) Pursh	(striped prince's pine)
CHTH2	Chamaecyparis thyoides (L.) B.S.P.	(Atlantic white cedar)
CIAR4	Cirsium arvense (L.) Scop.	(Canadian thistle)
CIIN	Cichorium intybus L.	(chicory)
CIMA2	Cicuta maculata L.	(spotted water hemlock)
CIVU	Cirsium vulgare (Savi) Ten.	(bull thistle)
CLAL3	Clethra alnifolia L.	(coastal sweetpepperbush)
CLMA	Cladium mariscoides (Muhl.) Torr.	(smooth sawgrass)
CLTE4	Clematis terniflora DC.	(sweet autumn virginsbower)
COAM2	Cornus amomum P. Mill.	(silky dogwood)
COCA5	Conyza canadensis (L.) Cronq.	(Canadian horseweed)
COSE14	Convolvulus sepium L.	(Calystegia sepium ssp. sepium)
COVA2	Coronilla varia L.	(purple crownvetch)
CUGR	Cuscuta gronovii Willd. ex J.A. Schultes	(scaldweed)
CUSCU	Cuscuta L.	(dodder)
CYAC3	Cypripedium acaule Ait.	(pink lady's slipper)
CYFI	Cyperus filicinus Vahl	(Cyperus polystachyos var. filicinus)
CYST	Cyperus strigosus L.	(strawcolored flatsedge)
DACA6	Daucus carota L.	(Queen Anne's lace)
DAGL	Dactylis glomerata L.	(orchardgrass)
DASP2	Danthonia spicata (L.) Beauv. ex Roemer & J.A. Schultes	(poverty danthonia)
DEVE	Decodon verticillatus (L.) Ell.	(swamp loosestrife)
DIAR	Dianthus armeria L.	(Deptford pink)
DICL	Dichanthelium clandestinum (L.) Gould	(deertongue panicgrass)
DISA	Digitaria sanguinalis (L.) Scop.	(hairy crabgrass)
DISP	Distichlis spicata (L.) Greene	(inland saltgrass)
DITE2	Diodia teres Walt.	(poorjoe)
DIVI5	Diospyros virginiana L.	(common persimmon)
DRIN3	Drosera intermedia Hayne	(spoonleaf sundew)
DRRO	Drosera rotundifolia L.	(roundleaf sundew)
DUAR3	Dulichium arundinaceum (L.) Britt.	(threeway sedge)
ECWA	Echinochloa walteri (Pursh) Heller	(coast cockspur)
ELEOC	Eleocharis R. Br.	(spikerush)
ELPA5	Eleocharis parvula (Roemer & J.A. Schultes) Link ex Bluff	(,)

ELUM	Elaeagnus umbellata Thunb.	(autumn olive)
ERAN	Erigeron annuus (L.) Pers.	(eastern daisy fleabane)
ERCI6	Erodium cicutarium (L.) L'Her. ex Ait.	(redstem stork's bill)
ERCU2	Eragrostis curvula (Schrad.) Nees	(weeping lovegrass)
ERDE5	Eriocaulon decangulare L.	(tenangle pipewort)
ERIGE2	Erigeron L.	(fleabane)
ERSP	Eragrostis spectabilis (Pursh) Steud.	(purple lovegrass)
EUAL2	Eupatorium album L.	(white thoroughwort)
EUCY2	Euphorbia cyparissias L.	(cypress spurge)
EUHY	Eupatorium hyssopifolium L.	(hyssopleaf thoroughwort)
EUPE3	Eupatorium perfoliatum L.	(common boneset)
EUPO4	Euphorbia polygonifolia L.	(Chamaesyce polygonifolia)
FEEL	Festuca elatior L. p.p.	(Lolium pratense)
FRVI	Fragaria virginiana Duchesne	(Virginia strawberry)
GAAP2	Galium aparine L.	(stickywilly)
GABA	Gaylussacia baccata (Wangenh.) K. Koch	(black huckleberry)
GABO2	Galium boreale L.	(northern bedstraw)
GAFR2	Gaylussacia frondosa (L.) Torr. & Gray ex Torr.	(blue huckleberry)
GAPR2	Gaultheria procumbens L.	(eastern teaberry)
GECA5	Geranium carolinianum L.	(Carolina geranium)
GECA7	Geum canadense Jacq.	(white avens)
GLHE2	Glechoma hederacea L.	(groundivy)
GLOB	Glyceria obtusa (Muhl.) Trin.	(Atlantic mannagrass)
GLST	Glyceria striata (Lam.) A.S. Hitchc.	(fowl mannagrass)
GNOB	Gnaphalium obtusifolium L.	(Pseudognaphalium obtusifolium ssp. obtusifol
HEFU	Hemerocallis fulva (L.) L.	(orange daylily)
HESU3	Heterotheca subaxillaris (Lam.) Britt. & Rusby	(camphorweed)
HICA10	Hieracium caespitosum Dumort.	(meadow hawkweed)
HIMO	Hibiscus moscheutos L.	(crimsoneyed rosemallow)
HIPA6	Hibiscus palustris L.	(Hibiscus moscheutos ssp. moscheutos)
HIPI	Hieracium pilosella L.	(mouseear hawkweed)
HOPE	Honckenya peploides (L.) Ehrh.	(seaside sandplant)
HOPER2	Honckenya peploides ssp. robusta (Fern.) Hulten	(seaside sandplant)
HULU	Humulus lupulus L.	(common hop)
HUTO	Hudsonia tomentosa Nutt.	(woolly beachheather)
HYDRO2	Hydrocotyle L.	(hydrocotyle)
HYPE	Hypericum perforatum L.	(common St. Johnswort)
HYVI4	Hypericum virginicum L.	(Triadenum virginicum)
ILGL	Ilex glabra (L.) Gray	(inkberry)
ILOP	Ilex opaca Ait.	(American holly)
ILVE	Ilex verticillata (L.) Gray	(common winterberry)
IMCA	Impatiens capensis Meerb.	(jewelweed)
IPOMO	Ipomoea L.	(morningglory)
IRVE2	Iris versicolor L.	(harlequin blueflag)
IVFR	Iva frutescens L.	(bigleaf sumpweed)
JUCA3	Juncus canadensis J. Gay ex Laharpe	(Canadian rush)
JUEF	Juncus effusus L.	(common rush)
JUTE	Juncus tenuis Willd.	(poverty rush)
JUVI	Juniperus virginiana L.	(eastern redcedar)

KOVI	Kosteletzkya virginica (L.) K. Presl ex Gray	(Virginia saltmarsh willow)
KRVI	Krigia virginica (L.) Willd.	(Virginia dwarfdandelion)
LACA	Lactuca canadensis L.	(Canada lettuce)
LECA5	Lepidium campestre (L.) Ait. f.	(field pepperweed)
LECU	Lespedeza cuneata (Dum.-Cours.) G. Don	(Chinese lespedeza)
LEMA	Lechea maritima Leggett ex B.S.P.	(beach pinweed)
LERA4	Leucothoe racemosa (L.) Gray	(swamp doghobble)
LEVI3	Lepidium virginicum L.	(Virginia pepperweed)
LEVU	Leucanthemum vulgare Lam.	(oxeyedaisy)
LICA17	Limonium carolinianum (Walt.) Britt.	(Carolina sealavender)
LICA6	Linaria canadensis (L.) Chaz.	(Nuttallanthus canadensis)
LILIU	Lilium L.	(lily)
LIMON	Limonium P. Mill.	(sealavender)
LIST2	Liquidambar styraciflua L.	(sweetgum)
LIVU	Ligustrum vulgare L.	(European privet)
LIVU2	Linaria vulgaris P. Mill.	(butter and eggs)
LOJA	Lonicera japonica Thunb.	(Japanese honeysuckle)
LOPE	Lolium perenne L.	(perennial ryegrass)
LYAL	Lychnis alba P. Mill.	(Silene latifolia ssp. alba)
LYAM	Lycopus americanus Muhl. ex W. Bart.	(American waterhorehound)
LYCO	Lychnis coronaria (L.) Desr.	(rose campion)
LYCOP2	Lycopodium L.	(clubmoss)
LYDI3	Lycopodium digitatum Dill. ex A. Braun	(fan clubmoss)
LYHY2	Lythrum hyssopifolia L.	(hyssop loosestrife)
LYVI4	Lycopus virginicus L.	(Virginia waterhorehound)
MAPU	Malus pumila P. Mill.	(cultivated apple)
MAVI2	Magnolia virginiana L.	(sweetbay)
MEAL12	Melilotus alba Medikus	(white sweetclover)
MEOF	Melilotus officinalis (L.) Lam.	(yellow sweetclover)
MIRE	Mitchella repens L.	(partridgeberry)
MISC	Mikania scandens (L.) Willd.	(climbing hempvine)
MOAL	Morus alba L.	(white mulberry)
MYPE2	Myrica pensylvanica Loisel.	(northern bayberry)
MYST2	Myosotis stricta Link ex Roemer & J.A. Schultes	(strict forget me not)
NYOD	Nymphaea odorata Ait.	(American white waterlily)
NYSY	Nyssa sylvatica Marsh.	(blackgum)
OEBI	Oenothera biennis L.	(common eveningprimrose)
OEFR	Oenothera fruticosa L.	(narrowleaf eveningprimrose)
ONSE	Onoclea sensibilis L.	(sensitive fern)
ORUM	Ornithogalum umbellatum L.	(sleepydick)
OSCI	Osmunda cinnamomea L.	(cinnamon fern)
OSRE	Osmunda regalis L.	(royal fern)
OXRI	Oxypolis rigidior (L.) Raf.	(stiff cowbane)
OXST	Oxalis stricta L.	(common yellow oxalis)
PAAM2	Panicum amarum Ell.	(bitter panicgrass)
PAQU2	Parthenocissus quinquefolia (L.) Planch.	(Virginia creeper)
PAVI2	Panicum virgatum L.	(switchgrass)
PEVI	Peltandra virginica (L.) Schott	(green arrow arum)
PHAM4	Phytolacca americana L.	(American pokeweed)

PHAR3	Phalaris arundinacea L.	(reed canarygrass)
PHAU7	Phragmites australis (Cav.) Trin. ex Steud.	(common reed)
PHCO15	Phragmites communis Trin.	(Phragmites australis)
PHPR3	Phleum pratense L.	(timothy)
PIEC2	Pinus echinata P. Mill.	(shortleaf pine)
PIRI	Pinus rigida P. Mill.	(pitch pine)
PITH2	Pinus thunbergii Parl.	(Pinus thunbergiana)
PLAR3	Plantago aristata Michx.	(largebracted plantain)
PLCL	Platanthera clavellata (Michx.) Luer	(green woodland orchid)
PLLA	Plantago lanceolata L.	(narrowleaf plantain)
PLMA2	Plantago major L.	(common plantain)
PLMA3	Plantago maritima L.	(goose tongue)
PLMAJ2	Plantago maritima ssp. juncoides (Lam.) Hulten	(Plantago maritima var. juncoides)
PLPU2	Pluchea purpurascens (Sw.) DC.	(Pluchea odorata var. odorata)
POAN	Poa annua L.	(annual bluegrass)
POAR4	Polygonella articulata (L.) Meisn.	(coastal jointweed)
POAR6	Polygonum arifolium L.	(halberdleaf tearthumb)
POAR8	Potentilla argentea L.	(silver cinquefoil)
POCA17	Potentilla canadensis L.	(dwarf cinquefoil)
POCO	Poa compressa L.	(Canada bluegrass)
POLYG4	Polygonum L.	(knotweed)
POPE2	Polygonum pensylvanicum L.	(Pennsylvania smartweed)
POPR	Poa pratensis L.	(Kentucky bluegrass)
POPU5	Polygonum punctatum Ell.	(dotted smartweed)
PORE5	Potentilla recta L.	(sulphur cinquefoil)
POSA5	Polygonum sagittatum L.	(arrowleaf tearthumb)
POSC3	Polygonum scandens L.	(climbing false buckwheat)
POSI2	Potentilla simplex Michx.	(common cinquefoil)
PRMA2	Prunus maritima Marsh.	(beach plum)
PRSE2	Prunus serotina Ehrh.	(black cherry)
PTCA	Ptilimnium capillaceum (Michx.) Raf.	(herbwilliam)
PYMU	Pycnanthemum muticum (Michx.) Pers.	(clustered mountainmint)
QUAL	Quercus alba L.	(white oak)
QUFA	Quercus falcata Michx.	(southern red oak)
QUIL	Quercus ilicifolia Wangenh.	(bear oak)
QUPA2	Quercus palustris Muenchh.	(pin oak)
QUPR4	Quercus prinus auct. p.p. non L.	(Quercus michauxii)
QUST	Quercus stellata Wangenh.	(post oak)
QUVE	Quercus velutina Lam.	(black oak)
RHCO13	Rhus copallina L.	(dwarf sumac)
RHVI2	Rhododendron viscosum (L.) Torr.	(swamp azalea)
ROCA4	Rosa carolina L.	(Carolina rose)
ROHI	Robinia hispida L.	(bristly locust)
ROMU	Rosa multiflora Thunb. ex Murr.	(multiflora rose)
ROPA	Rosa palustris Marsh.	(swamp rose)
RORU	Rosa rugosa Thunb.	(rugosa rose)
RUAC3	Rumex acetosella L.	(common sheep sorrel)
RUAL	Rubus allegheniensis Porter	(Allegheny blackberry)
RUCR	Rumex crispus L.	(curly dock)

RUCU	Rubus cuneifolius Pursh	(sand blackberry)
RUFL	Rubus flagellaris Willd.	(northern dewberry)
RUHI	Rubus hispidus L.	(bristly dewberry)
RUMA5	Ruppia maritima L.	(widgeongrass)
SAAL5	Sassafras albidum (Nutt.) Nees	(sassafras)
SABI	Salicornia bigelovii Torr.	(dwarf saltwort)
SACA12	Sambucus canadensis L.	(Sambucus nigra ssp. canadensis)
SAEU	Salicornia europaea auct. non L.	(Salicornia maritima)
SAGR6	Sanicula gregaria Bickn.	(Sanicula odorata)
SAKA	Salsola kali L.	(prickly Russian thistle)
SALIC	Salicornia L.	(pickleweed)
SANI	Salix nigra Marsh.	(black willow)
SAOF4	Saponaria officinalis L.	(bouncingbet)
SAST5	Sabatia stellaris Pursh	(rose of Plymouth)
SAVI	Salicornia virginica L.	(Virginia glasswort)
SCAM2	Scirpus americanus Pers.	(Schoenoplectus americanus)
SCCY	Scirpus cyperinus (L.) Kunth	(woolgrass)
SCPU3	Scirpus pungens Vahl	(Schoenoplectus pungens var. pungens)
SCRO	Scirpus robustus Pursh	(Bolboschoenus robustus)
SCSC	Schizachyrium scoparium (Michx.) Nash	(little bluestem)
SEMA3	Sesuvium maritimum (Walt.) B.S.P.	(slender seapurslane)
SIAL12	Silene alba (P. Mill.) Krause	(Silene latifolia ssp. alba)
SISYR	Sisyrinchium L.	(blue-eyed grass)
SMGL	Smilax glauca Walt.	(cat greenbrier)
SMRO	Smilax rotundifolia L.	(roundleaf greenbrier)
SOAS	Sonchus asper (L.) Hill	(spiny sowthistle)
SOGR8	Solidago graminifolia (L.) Salisb.	(Euthamia graminifolia var. graminifolia)
SONI4	Solanum nigrum auct. non L.	(Solanum ptychanthum)
SOPS2	Solanum pseudogracile Heiser	(glowing nightshade)
SOSE	Solidago sempervirens L.	(seaside goldenrod)
SPAL	Spartina alterniflora Loisel.	(smooth cordgrass)
SPMA2	Spergularia marina (L.) Griseb.	(Spergularia salina var. salina)
SPPA	Spartina patens (Ait.) Muhl.	(saltmeadow cordgrass)
SPPAM	Spartina patens var. monogyna (M.A. Curtis) Fern.	(Spartina patens)
STME2	Stellaria media (L.) Vill.	(common chickweed)
SULI	Suaeda linearis (Ell.) Moq.	(annual seepweed)
SYVU	Syringa vulgaris L.	(common lilac)
TAOF	Taraxacum officinale G.H. Weber ex Wiggers	(common dandelion)
TECA3	Teucrium canadense L.	(Candad germander)
THNO	Thelypteris noveboracensis (L.) Nieuwl.	(New York fern)
THPA	Thelypteris palustris Schott	(eastern marsh fern)
THPU2	Thalictrum pubescens Pursh	(king of the meadow)
TORA2	Toxicodendron radicans (L.) Kuntze	(eastern poison ivy)
TOVE	Toxicodendron vernix (L.) Kuntze	(poison sumac)
TRAR4	Trifolium arvense L.	(rabbitfoot clover)
TRCA5	Trifolium campestre Schreb.	(field clover)
TRDI2	Trichostema dichotomum L.	(forked bluecurls)
TRDU	Tragopogon dubius Scop.	(yellow salsify)
TRDU2	Trifolium dubium Sibthorp	(suckling clover)

TRPE4	Triodanis perfoliata (L.) Nieuwl.	(clasping Venus' lookingglass)
TRPU4	Triplasis purpurea (Walt.) Chapman	(purple sandgrass)
TRRE3	Trifolium repens L.	(white clover)
TYAN	Typha angustifolia L.	(narrowleaf cattail)
TYLA	Typha latifolia L.	(broadleaf cattail)
UTFI	Utricularia fibrosa Walt.	(fibrous bladderwort)
VAAT	Vaccinium atrococcum (Gray) Heller	(Vaccinium fuscatum)
VACO	Vaccinium corymbosum L.	(highbush blueberry)
VAMA	Vaccinium macrocarpon Ait.	(cranberry)
VEAR	Veronica arvensis L.	(corn speedwell)
VEBL	Verbascum blattaria L.	(moth mullein)
VETH	Verbascum thapsus L.	(common mullein)
VEUR	Verbena urticifolia L.	(white vervain)
VIAN	Vicia angustifolia L.	(Vicia sativa ssp. nigra)
VICR	Vicia cracca L.	(bird vetch)
VIDE	Viburnum dentatum L.	(southern arrowwood)
VILA4	Viola lanceolata L.	(bog white violet)
VIMI2	Vinca minor L.	(common periwinkle)
VINU	Viburnum nudum L.	(possumhaw)
VIOLA	Viola L.	(violet)
VITIS	Vitis L.	(grape)
VUMY	Vulpia myuros (L.) K.C. Gmel.	(rattail fescue)
WOAR	Woodwardia areolata (L.) T. Moore	(netted chainfern)
XAST	Xanthium strumarium L.	(rough cockleburr)
ZOMAS	Zostera marina var. stenophylla Aschers. & Graebn.	(seawrack)
_HYRA	Hypochoeris radicata	()
_JUGE	Juncus gerardi	()
_NULU	Nuphar luteum	()
_VIPR	Viola primulifolia	()