Evaluation of Ozone Injury
On Vegetation in the
Moosehorn National Wildlife Refuge
Maine

2004 Observations

Submitted to

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

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INTRODUCTION

General

Moosehorn 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 their 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. Moosehorn National Wildlife Refuge (MNWR) was established in 1937 as a refuge and breeding ground for migratory birds and other wildlife. It is the first in a chain of migratory bird refuges that extends from Maine to Florida. The Refuge consists of two units. The Baring Unit covers 16,080 acres and is located off U.S. Route 1 southwest of Calais, Maine. The 6,665-acre Edmunds Unit borders the tidal waters of Cobscook Bay near Dennysville, Maine (Figure 1).

Objectives

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

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

Justification

Approximately 4,680 acres of the Baring Unit and 2,780 acres of the Edmunds Unit were set aside by Congress as Wilderness Areas and named the "Moosehorn Wilderness". In 1978, Moosehorn Wilderness was designated a Class I air quality area, receiving further protection under the Clean Air Act. Congress gave the 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 transported long distances in the atmosphere, even remote areas (including wilderness areas) can be affected by air pollution. To better understand how air pollution affects resources at the Moosehorn NWR, surveys were conducted in 1998-2000 and 2000-2004 to evaluate ozone injury to vegetation within the refuge.

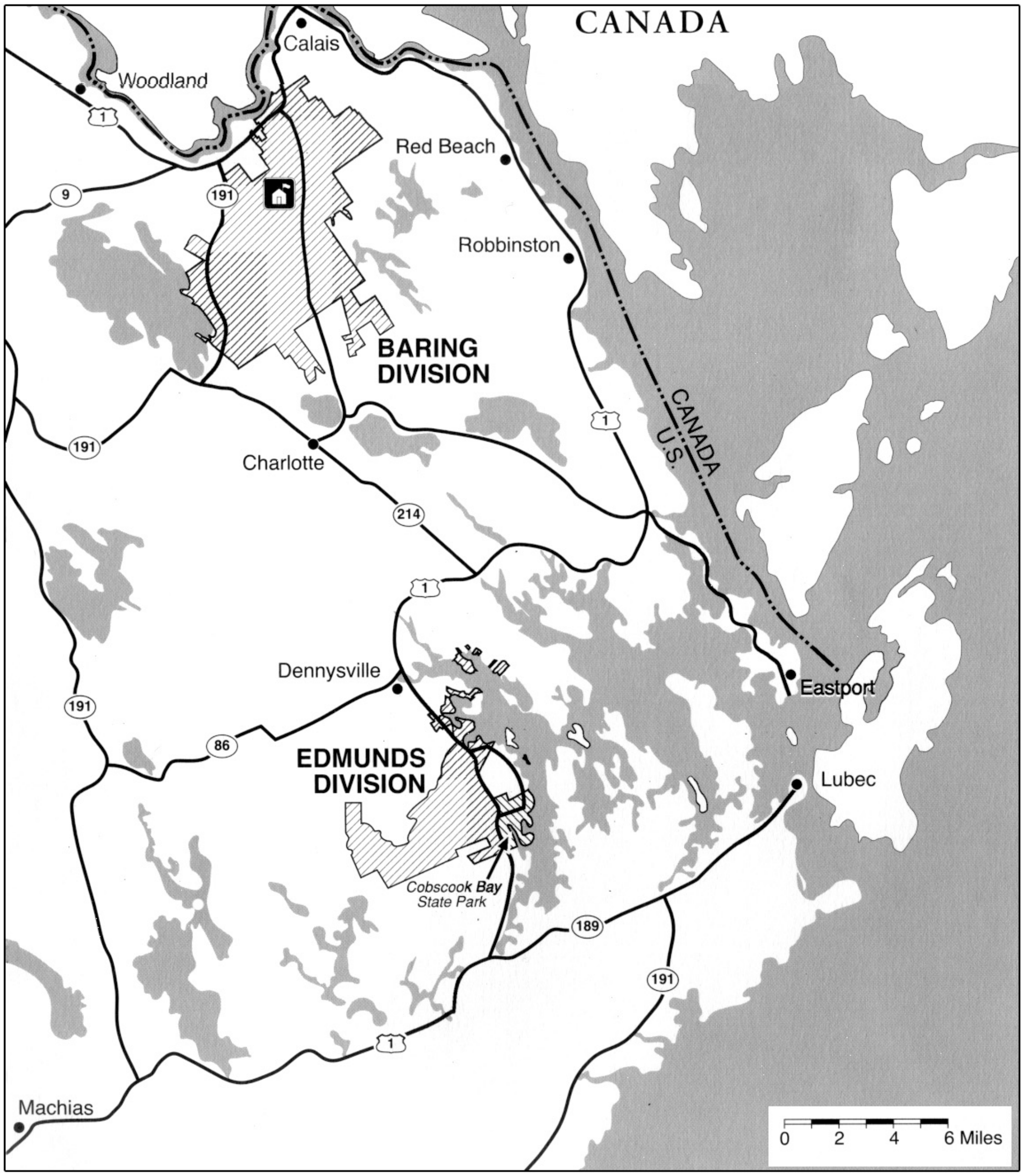
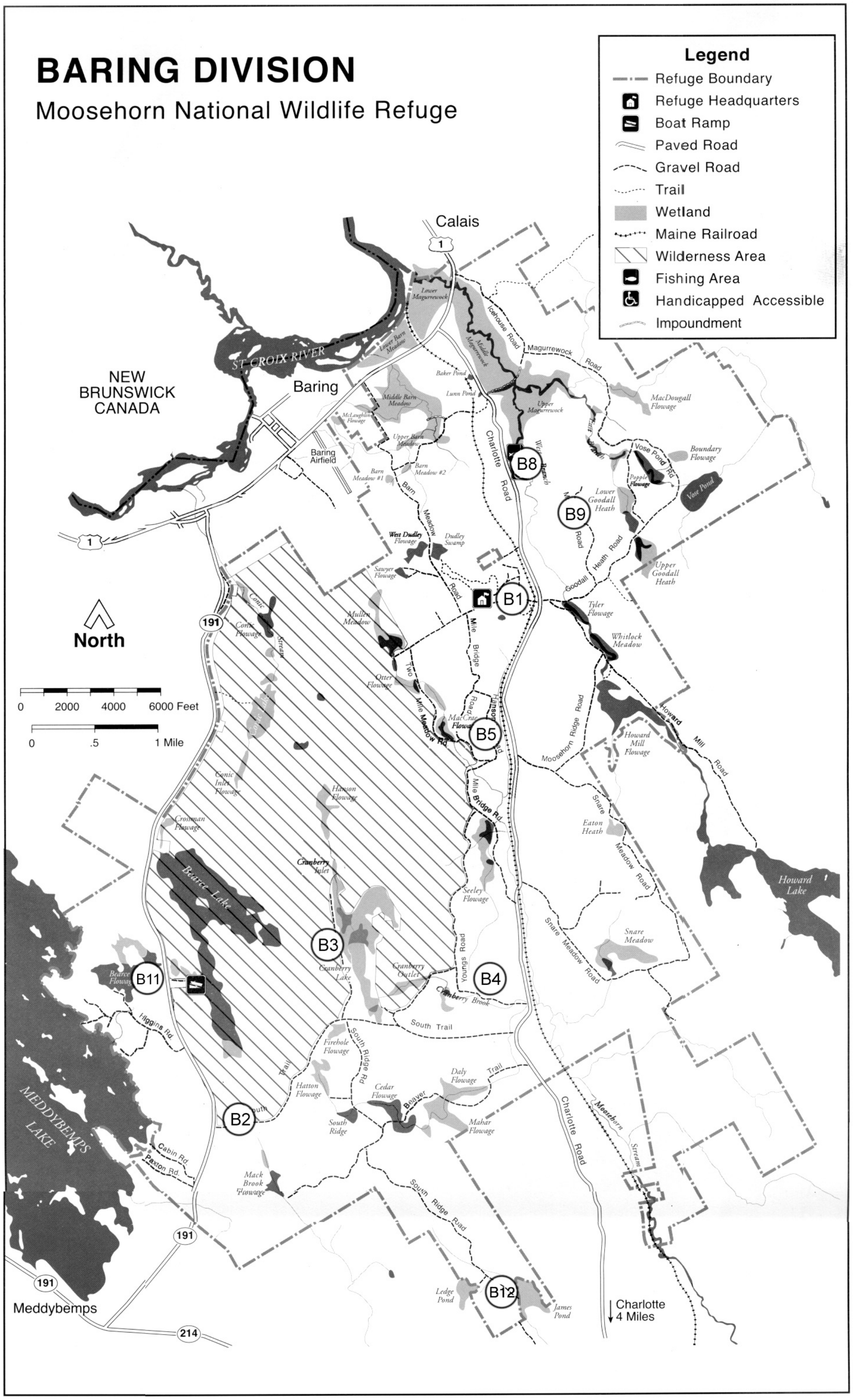
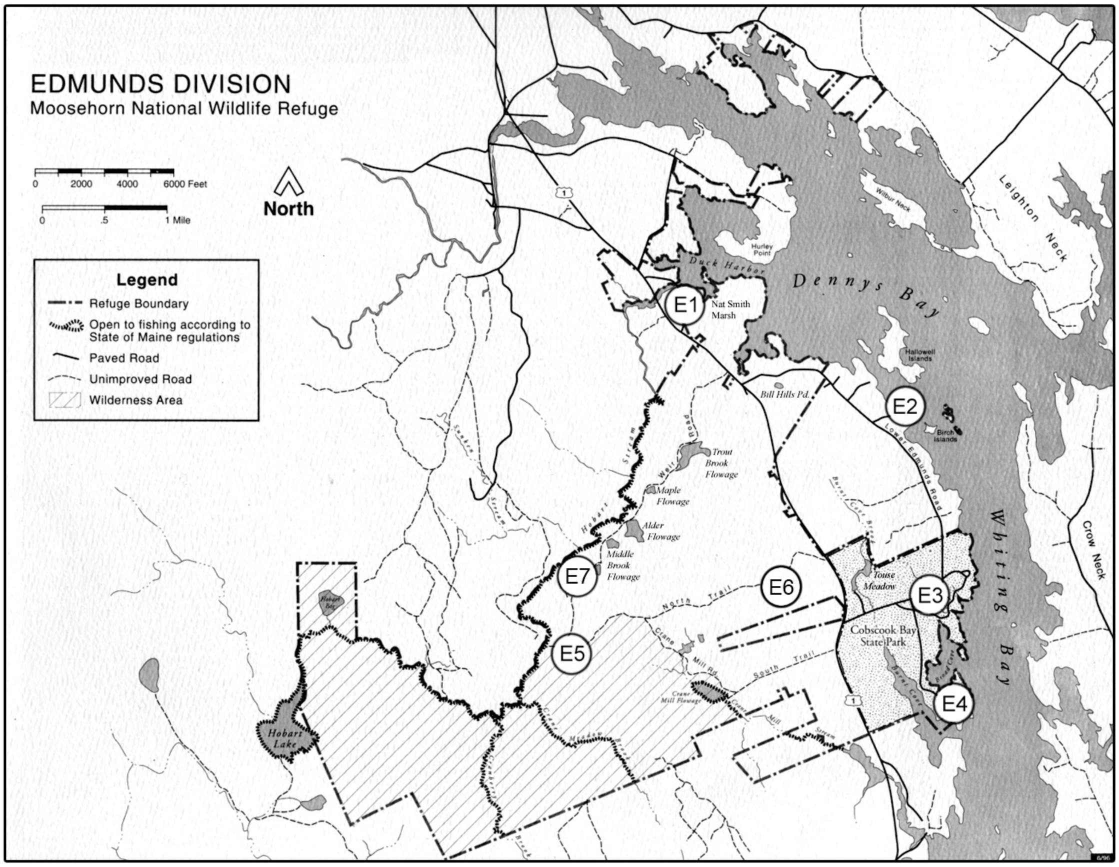


Figure 1. General map of Moosehorn National Wildlife Refuge showing location of Baring Unit and Edmunds Unit. The following two figures show location of survey sites in each unit.


BARING DIVISION
Moosehorn National Wildlife Refuge
Legend
Refuge Boundary
Refuge Headquarters
Boat Ramp
Paved Road
Gravel Road
Trail
Wetland
Maine Railroad
Wilderness Area
Fishing Area
Handicapped Accessible
Impoundment
Calais
NEW BRUNSWICK CANADA
Baring
ST CROIX RIVER
Baring Airfield
North
0 2000 4000 6000 Feet
0 .5 1 Mile
Charlotte Road
Magurrewock Road
Icehouse Road
Goodall Heath Road
Moosehorn Ridge Road
Howard Mill Road
Snare Meadow Road
Two Mile Meadow Rd
Mile Bridge Rd
South Trail
South Ridge Rd
Higgins Rd
Cabin Rd
Paxton Rd
Bearce Lake
Howard Lake
MEDDYBEMPS LAKE
Meddybemps
Charlotte 4 Miles
B1
B2
B3
B4
B5
B8
B9
B11
B12
1
191
214


EDMUNDS DIVISION
Moosehorn National Wildlife Refuge
0 2000 4000 6000 Feet
0 .5 1 Mile
North
Legend
Refuge Boundary
Open to fishing according to State of Maine regulations
Paved Road
Unimproved Road
Wilderness Area
Duck Harbor
Nat Smith Marsh
Dennys Bay
Hurley Point
Wilbur Neck
Leighton Neck
Hallowell Islands
Birch Islands
Bill Hills Pd.
Lower Edmunds Road
Trout Brook Flowage
Maple Flowage
Alder Flowage
Middle Brook Flowage
Whiting Bay
Crow Neck
Youse Meadow
Cobscook Bay State Park
North Trail
South Trail
Crane Mill Flowage
Hobart Lake
Hobart Stream
E1
E2
E3
E4
E5
E6
E7

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 2002), 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 mercury, 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 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, 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 exhibit needle tip browning. However, this latter symptom can be caused by many stresses and therefore 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 symptoms similar to that caused by ozone. Ozone injury to 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 Refuge

(Adapted from Refuge Brochures)

The Moosehorn Refuge is a highly glaciated expanse of rolling hills, large ledge outcrops, streams, lakes, bogs, and marshes. The Edmunds Unit has several miles of rocky shoreline where 24-foot tidal fluctuations are a daily occurrence. Approximately 2,780 acres of the Edmunds Unit and 4,680 acres of the Baring Unit were set aside as Wilderness Areas by Congress. As part of the National Wilderness Preservation System these areas are granted special protection in an attempt to insure the preservation of their wilderness characteristics.

Vegetation

The refuge is rich with history from the logging boom days. In the 1800s horses hauled millions of cords of wood to the shores of the St. Croix River where spring floods carried the logs to Calais mills. Logs were shipped from Calais to world markets by schooner and steamship. However, in the early 1900's, the forest industry began to mechanize and the world market for timber declined. The numerous farms that once were necessary to feed man and beast were abandoned and the forest gradually reclaimed the farmland. A diverse forest of aspen, maple, birch, spruce, and fir currently dominates the landscape and scattered stands of majestic white pine are common.

The refuge is located in terrain that consists of rolling hills with large rock outcrops and scattered boulders. The dominant vegetation in the vicinity of both Units is uneven-aged, second-growth northern conifer-hardwood forest, with some areas in pure spruce-fir. Much of the area was logged and cleared in the 1800s and early 1900s, and several fires have burned over large portions of the area, the last in 1933. Numerous stream valleys, beaver flowages, ericaceous bogs, marshes, and forest/shrub-dominated wetlands occur throughout the area. The deciduous component of the forest includes mixed stands of quaking and bigtooth aspen (*Populus tremuloides*, *P. grandidentata*), paper and gray birch (*Betula papyrifera*, *B. populifolia*), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), and black cherry (*Prunus serotina*).

Common understory species include winterberry (*Gaultheria procumbens*), bracken fern (*Pteridium aquilinum*), sedges (*Carex* spp.), and bunchberry (*Cornus canadensis*). Mixed hardwood-conifer stands occur in many areas, with the generally more shade-tolerant conifers gradually replacing the earlier successional hardwoods. The coniferous component is dominated by mixed and pure stands of spruce (*Picea* spp.) and balsam fir (*Abies balsamea*). Scattered old-growth eastern white pine (*Pinus strobus*) stands are an indication of the original climax forest that was present before the lumbering and fires of the last century. Pure stands of alder (*Alnus rugosa*) are abundant in reverting farmland and wet areas along the margins of streams and beaver flowages. Several blueberry (*Vaccinium* spp.) fields, meadows, and pastures are maintained as permanent forest openings. In 1976, a long-term management plan was implemented on the refuge to increase the diversity of forest habitat by altering age and species composition, utilizing specific timing of cutting.

Wetlands present in the area include beaver ponds and meadows, marsh, shrub, and forested wetlands of various types, as well as streams, ponds and lakes. Beaver meadows in the area are dominated by blue-joint grass (*Calamagrostis canadensis*) and sedges, with wetter sections and pond fringes supporting marsh plants such as rushes (*Juncus* spp.), cattail (*Typha latifolia*), bulrushes (*Scirpus* spp.), and other non-persistent emergents and aquatic species. Alder and willow (*Salix* spp.) are common wetland shrubs, and leatherleaf (*Chamaedaphne calyculata*), sweet gale (*Myria gale*), and sphagnum moss (*Sphagnum* spp.) are dominant bog species. Forested wetlands are dominated by stunted spruce, some white cedar (*Thuja occidentalis*), red maple, sphagnum, cinnamon fern (*Osmunda cinnamomea*), and some larch (*Larix laricina*).

The majority of the Cobscook Bay area is in second growth spruce-fir-pine forest, mixed with some maple, birch, and aspen. There is also some open land, and previously open land in regrowth stages. The waters adjoining the bay are tidal with fluctuations of up to 24 feet, creating extensive areas of intertidal mudflats in several coves. The tidal range and southern exposures create ice-free and protected wintering habitat conditions for waterfowl and bald eagles. Many large, old-growth pines are present on uplands adjacent to the shoreline, providing nesting and roosting trees for eagles and other raptors.

A listing of Moosehorn NWR vegetation, as supplied by refuge personnel, is presented in the Appendix.

Wildlife

Moosehorn Refuge is unique among the country's National Wildlife Refuges. Here the American woodcock is intensely studied and managed. This reclusive bird dwells in the alder cover by day and refuge clearings at night. Unfortunately, the Eastern Flyway woodcock population has declined steadily during recent years. Research and management programs at Moosehorn have provided valuable information that is being used to stem this decline.

The endangered bald eagle frequents both units of the refuge. In recent years as many as three pairs of eagles have nested at Moosehorn. Eagles are frequently sighted in the area around the Magurrewock Marshes near U.S. Route 1 on the Baring Unit and around the tidal waters of Dennys Bay on the Edmunds Unit.

The woodlands of Moosehorn also abound with many other species. Black bears are abundant and can often be seen along refuge roads in the spring, in the blueberry fields in August, and foraging for apples in the fall. White-tailed deer and an occasional moose feed in the many clearings scattered throughout the refuge. In mid-May a flush of migrating warbles fills the woodlands with song.

The refuge also serves as an important breeding area and migration stop for a variety of waterfowl and other waterbirds. Black ducks, wood ducks, ring-necked ducks, Canada geese, and loons can be seen on the more than 50 lakes, marshes, and flowages scattered throughout the refuge. In mid-May the Magurrewock Marsh, which borders U. S. Route 1 on the Baring Unit, abounds with goose and duck broods. Bald eagle sightings also are a common occurrence. Ospreys nest in several of the refuge marshes and the ardent observer can often find river otters frolicking amongst the cattails. Moosehorn plays an important role in protecting the fragile and diminishing wetland resources of the Atlantic Flyway.

Management

Woodcock, ruffed grouse, moose, deer, and a variety of songbirds thrive only in a young forest. In the past, wildfires periodically rejuvenated the forest. However, wildfire is a rare event today. Forest management programs on the refuge serve to take the place of fire. Small clearcuts scattered throughout the forest provide openings and young brushy growth that serve as food and cover for many wildlife species. This management has resulted in dramatic increases in many species including woodcock, grouse, bear, and moose. Timber harvesting also provides local employment, and a percentage of receipts from sales is returned to local communities.

Wetlands management on the refuge has greatly increased waterfowl numbers. Water control structures on the refuge's marshes and ponds allow managers to maintain stable water levels during the breeding season. Control of water level also improves the growth of plants that provide food and cover and allows the marshes to be emptied periodically for rejuvenation. The creation of channels, potholes, and islands, as well as shoreline improvement, also has increased waterfowl production and encouraged nesting.

METHODS

General Survey Areas

It had been predetermined that survey sites had to occur in open-areas (such as those occurring 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). Immediately prior to the initial 1998 survey, the investigator met with refuge personnel to view maps of the refuge. The ensuing discussions greatly aided selection of preliminary survey areas on the maps. Based on these initial discussions, tentative survey areas were selected throughout the refuge. These areas were visited in the field during the 1998- 2000 and 2002-2003 surveys, and their suitability for survey determined as plants were evaluated. These general areas, with slight modifications, were used in the 2004 survey.

Preliminary Selection of Bioindicator Species

An extensive list of refuge flora was provided by the U.S. Fish and Wildlife Service (Appendix). Prior to the initial (1998) survey, an initial selection of potential bioindicators that may exhibit ozone injury in the survey area had been selected from this list. Plant species or genera on the list that were selected as potential bioindicators included: ash (*Fraxinus* sp.), aster (*Aster* sp.), black cherry (*Prunus serotina*), blackberry (*Rubus* spp.), choke cherry (*Prunus virginiana*), common milkweed (*Asclepias syriaca*), elderberry (*Sambucus canadensis*), mountain ash (*Sorbus americana*), pin cherry (*Prunus pensylvanica*), poison-ivy (*Rhus radicans* = *Toxicodendron radicans*), serviceberry (*Amelanchier laevis*), sumac (*Rhus* spp.), trembling aspen (*Populus tremuloides*) and viburnum (*Viburnum* spp.).

Of course, many of the bioindicator 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 refuge biologists or local botanists. 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 wetland species, as determined by controlled exposures of ozone, is generally unknown.

Air Quality

Ozone monitoring data complement these visual injury surveys. In general, more ozone-induced stipple may occur in years with greater ozone concentrations. However, more consistent and long-term monitoring datasets are needed to further understand the relationship between foliar symptoms, ambient ozone, and environmental conditions (e.g. droughts) in our parks and refuges.

The nearest ozone monitor with the complete ozone datasets is located in the Acadia National Park at Cadillac Mountain (EPA AIRS site #23-009-0102), approximately 70 miles southwest of the Moosehorn NWR. Ambient ozone levels in this report 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 fairly well with plant damage.

In terms of relative ozone values, cumSUM60 ozone levels monitored at Cadillac Mountain during the years of survey (1998-2000, 2002-2004) in early August were greatest in 1998, and were least in 2000 and 2004 (Figures 2,3). Ozone levels were similar in 1999, 2002, and 2003, with the 2002 levels rising from mid- to late August faster than in the other 2 years.

In terms of actual ambient ozone values, the cumSUM60 levels during the years of survey were greatest in 1998, exceeding 40,000 ppb.hrs by late August. The late-August ozone levels of other years were 33,000 ppb.hrs (2002), 29,000 ppb.hrs (1999), and 26,000 ppb.hrs (2003). In 2000 and 2004 the cumSUM60 levels reached only 18,000 ppb.hrs.

Ozone injury to vegetation was observed in the Moosehorn NWR in all these years, so these ambient cumSUM60 values of ozone were obviously above the threshold for plant injury to occur. However, the ozone levels in 2000 and 2004 were probably just slightly above the threshold limits to induce plant injury.

For comparison to a refuge with high ozone concentrations, the ozone levels at the Edwin B. Forsythe NWR near Brigantine, New Jersey, reached approximately 80,000 ppb.hrs in 1991 (a very high ozone year), and are routinely greater than 40,000 ppb.hrs by the summer's end. During 1999, ozone levels in the Mingo NWR in Missouri likewise reached 80,000 ppb.hrs by early fall. For comparison to a refuge with low ozone concentrations, the cumSUM60 ozone levels monitored within the Seney NWR in the Upper Peninsula of Michigan in late August 2002 and 2003 were only about 15,000 ppb.hrs. In 2004, a record-low ozone year in much of the East, the ozone levels at Seney barely exceeded 5,000 ppb.hrs by the end of August.

Assuming that the ozone levels monitored at Cadillac Mountain (70 miles away) are similar to those occurring at the Moosehorn NWR, ozone injury is likely to occur most years on ozone-sensitive species of vegetation within the refuge. However, to my knowledge, there were no recorded surveys prior to 1998 to document whether or not ozone injury had occurred on vegetation growing within the Moosehorn NWR.

Surveys Dates and Locations

The Moosehorn National Wildlife Refuge was surveyed on July 29-August 2 and August 25-28, 1998. In 1999 the refuge was surveyed only once, during July 22-25. (In 1999 a widespread drought in the East killed the foliage of many plants; however, maximum injury occurred after the 1999 survey). During 2000, the Moosehorn NWR was surveyed in August 21-23. The refuge was not surveyed in 2001. In 2002 the refuge was surveyed during August 29-September 2. In 2003 the refuge was surveyed in August 6-8. During 2004 the survey was surveyed during August 20-22.

As described earlier, the tentative location of potential survey sites was based on discussions with refuge personnel and examination of maps at the refuge headquarters prior to the initial (1998) survey. These areas were then visited on-site during each survey, and 16 approximate locations were selected. These sites were considered generally suitable for ozone injury surveys based on openness, accessibility, and presence of bioindicators (Figure 1). An additional site (“The Woodcock Trail”) adjacent to plot B1 was added in 2002.

In 2004, Baring Division Sites 6 and 7 were eliminated, since they had not proven to be useful bioindicator sites during past years. Also, Site B10 (located just outside the refuge boundary) was heavily posted with “No Trespassing” signs and therefore eliminated in 2004. A new site, designated as Site B12, was established at the extreme southern end of the Baring Division in 2004. This “site” was the 4-mile roadside area along South Ridge Road from the Firehole Flowage to James Pond, including the side road to and from Mack Brook Flowage. Ash, aspen, and blackberry were examined along the route designated as Site B12.

In addition to the specific survey sites, the investigator observed the general foliage as he traveled from site to site.

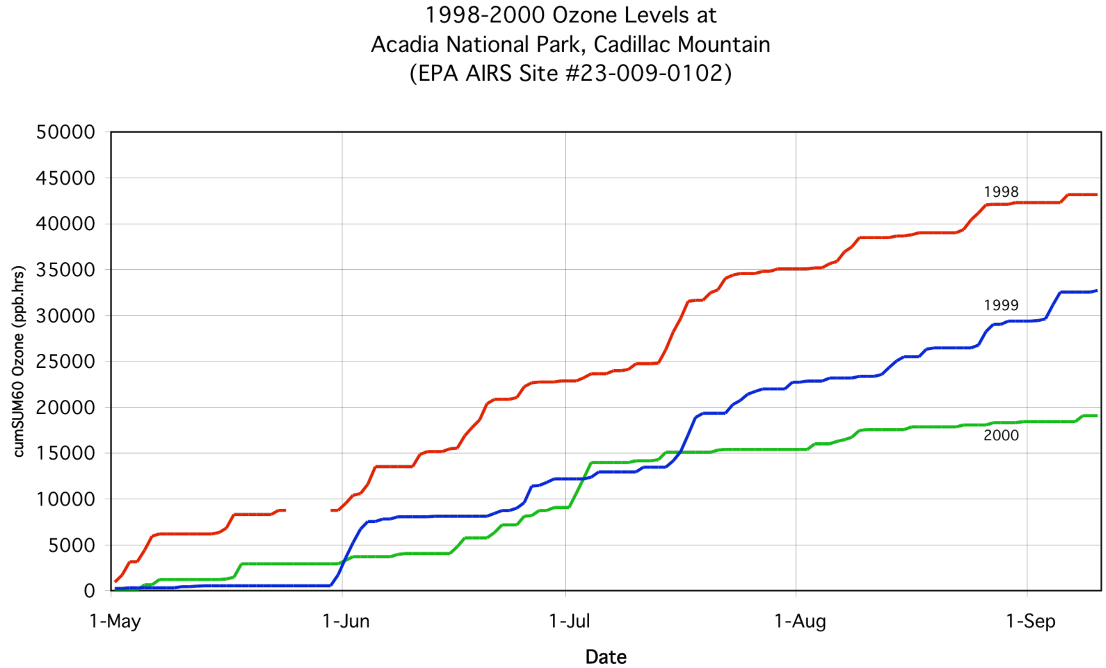


Figure 2. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumSUM60, ppb.hrs) monitored at Acadia National Park, Cadillac Mountain, Maine (EPA AIRS Site # 23-009-0102) during the first 3 years of survey (1998-2000). This monitoring site is located approximately 70 miles southwest of the Moosehorn refuge.

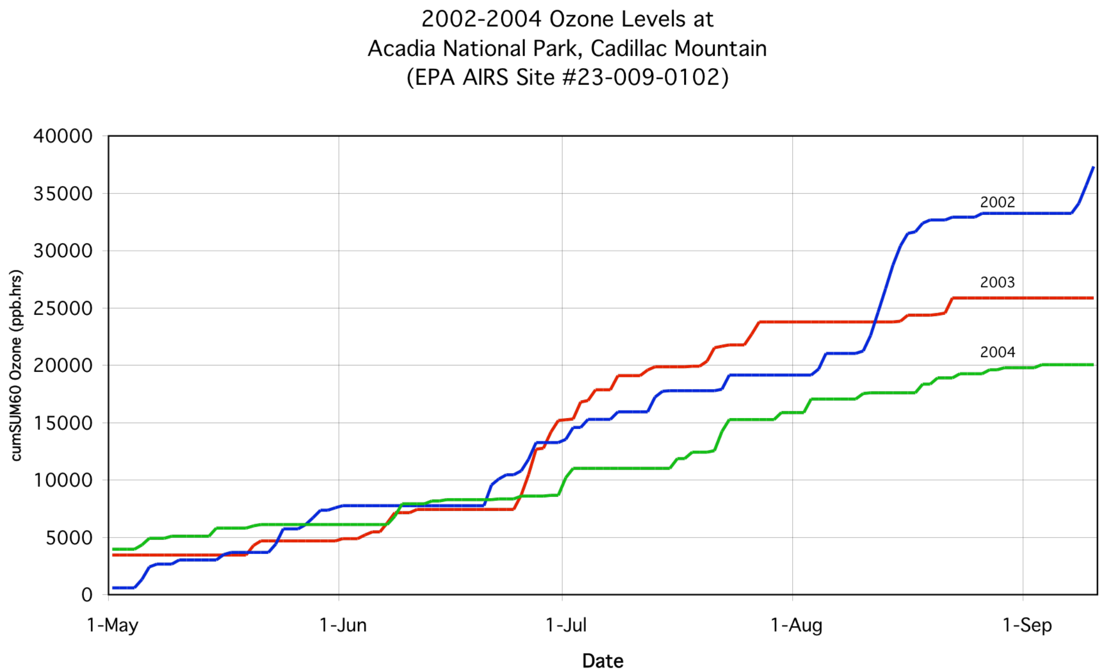


Figure 3. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumSUM60, ppb.hrs) monitored at Acadia National Park, Cadillac Mountain, Maine (EPA AIRS Site # 23-009-0102) during the second 3 years of survey (2002-2004). This monitoring site is located approximately 70 miles southwest of the Moosehorn refuge.

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 (presented as a percentage = incidence) within a species that exhibited stipple.

In addition, the 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. 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 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 plant material or scenery was present, and forwarded to the FWS Air Quality Branch in Denver.

RESULTS AND DISCUSSION

Final Selection of Bioindicator Species

Following the initial evaluation of the vegetation lists in early summer 1998, a more complete selection of bioindicator species or genera was made in the field that year. For example, during the first 1998 visit to the refuge, it was immediately obvious that spreading dogbane (*Apocynum androsaemifolium*) within the refuge was exhibiting adaxial stipple, typical of that caused by ozone. Therefore, dogbane was added to the bioindicator list, which then consisted of ash, black cherry, blackberry, choke cherry, pin cherry, serviceberry, and trembling aspen as potential bioindicator species. These were among the most common, ozone-sensitive species in the refuge, and usually occurred in open areas.

During the 1998 and 1999 field surveys, the bioindicator list was amended to also include sand cherry (*Prunus pumila*), raspberry (*Rubus idaeus*), and sarsaparilla (*Aralia nudicaulis*). The latter two species, along with blackberry, were selected as indicators for SO_2 injury. However, since there were no apparent point sources of SO_2, emphasis was placed on the ozone-sensitive bioindicators. The list, mainly compiled during the 1998-1999 surveys, was used in the 2000 and 2002-2004 surveys. (The refuge was not surveyed in 2001).

Not all species/genera listed were present at all sites. In addition, most wetland plant species of the Moosehorn refuge have not been carefully studied with regard to ozone-induced macroscopic symptoms. That is, the ozone-sensitivity of wetland plants as determined by controlled exposures of ozone is generally unknown. Of course, spring ephemerals were not evaluated at this late survey date but may represent an important, unstudied group of plants.

Foliar Symptoms

Baring Unit

Site B1 (Refuge Headquarters and "Woodcock Trail"). In 2004 vegetation was examined in the large, open fields along the entrance road leading to the refuge headquarters and along the Woodcock Trail loop (Figure 1, Location B1). There were several bioindicator "species" present in these large openings and along the trail at this excellent survey site. Data presented in Table 1 represent the combined observations taken near both the refuge headquarters building and the Woodcock Trail.

Ozone injury was not observed on any bioindicator plants at this site, including aspen, blackberry, black cherry, choke cherry, pin cherry, spreading dogbane, serviceberry, or the Viburnum species tentatively identified as *Viburnum lentago*. However, the leaves of dogbane were very chlorotic with many leafspots, so were only subjectively observed and not rated. Choke cherry and pin cherry leaves had many leafspots, as well as shotholes. Very light reddening was noted on *Rubus* species.

Near the upper edge of one field the grass and brush is routinely mowed, resulting in fast-growing, succulent aspen root sprouts (root suckers). In 2004 the lower leaves of nearly all the aspen sprouts had a fine, necrotic fleck symptom, fairly similar to that caused by ozone. However, diagnosis of ozone injury on aspen sprouts at this location is confounded by the presence of initial leafspot symptoms on the lowest aspen leaves caused by the fungus *Septoria*. In 2004 this symptom was recorded as possible (not definite) ozone injury. If the symptom was indeed ozone-induced, then nearly all of these fast-growing root suckers had ozone injury. There were no similar symptoms on the larger, adjacent aspen saplings or trees.

These succulent, fast-growing aspens suckers had been free of ozone injury in 2003. In 2002 ozone injury was present on 39.1% of the aspen sprouts at this location, but not on adjacent older, aspen saplings or trees. In 1998 this site had not been mowed, and there were no aspen sprouts present. In 1999-2000 ozone injury occurred on these fast-growing sprouts. On the sprouts, the injury was most severe on the oldest and lowest leaves at the base of the plant. The severity of the ozone injury on the lower leaves was likely due to a combination of leaf age and the high humidity of the lower, grass environment in which they were found. Again, Septoria leafspot symptoms on the lowest aspen leaves confounded the ozone injury ratings at times.

At this site in 2003, ozone injury was observed only on approximately 1.5% of the spreading dogbane plants and 13.0% of the species identified as *Viburnum lentago* (Table 1). Ozone injury was not observed on foliage of the following: aspen, blackberry, black cherry, choke cherry, pin cherry, or serviceberry. Other plants examined and noted to be free of ozone injury included arrow-wood viburnum, hawthorn, and witch-hazel. In 2002, ozone injury had been present on 32.8% of the spreading dogbane plants examined at this site, and on 16.7% of the viburnum.

The viburnum that exhibited ozone injury in 2002 and 2003 (but not in 2004) were located along the Woodcock Trail. The investigator has observed ozone stipple on various species of *Viburnum* in other surveys, and considers the genus *Viburnum* to be an under-used bioindicator with excellent potential, perhaps similar in utility to the genus *Sambucus*. This species of *Viburnum* could prove to be a valuable addition to the bioindicators already used for detecting ozone injury in the refuge. *Viburnum* species generally exhibit more of a classic stipple, as compared to ash or pin cherry, and do not defoliate as readily as spreading dogbane. In the future, consideration should be given to more thorough ozone-injury survey using this species of *Viburnum*. Refuge, or local, botanists should identify the *Viburnum* species present in the refuge.

Unlike many if the other refuges in the East, Moosehorn NWR did not suffer from the severe drought of 2002, or the exceedingly wet weather of 2003. However the weather of 2004 was wet. The climate of the refuge is moderated by its nearness to the ocean. However, there was a drought in coastal Maine in 2001, a non-survey year (Figure 4).

During the 2004 survey, leaf injury resembling that caused by SO_2 was not observed at this or any other site within the Moosehorn NWR.

			Black-	Cherry			Dogbane	Mtn-	Rasp-	Sarsap-	Service-	
Date/Site	**Ash**	**Aspen**	**berry**	**Black**	**Choke**	**Pin**	**Spreading**	**Ash**	**berry**	**arilla**	**berry**	**Viburnum**
August 98 Total	1/54	10/126	0/53	0/55	0/30	28/108	7/77					
Aug 98%	1.8%	7.9%	0.0%	0.0%	0.0%	25.9%	9.0%					
1999 Total	2/77	9/396	0/330	5/111	0/260	4/196	10/178	0/10	0/230	0/10	1/49	
1999%	2.6%	2.3%	0.0%	4.5%	0.0%	2.0%	5.6%	0.0%	0.0%	0.0%	2.0%	
2000 Total	6/150	12/154	0/200	0/86	0/60	13/176	24/120	0/10	0/180	0/30	1/40	2/10
2000%	4.0%	7.8%	0.0%	0.0%	0.0%	7.4%	20.0%	0.0%	0.0%	0.0%	2.5%	20.0%
2002 Total	4/117	30/559	0/280	0/60	0/50	6/243	45/344	0/10	0/260	0/80	0/49	2/12
2002%	3.4%	5.4%	0.0%	0.0%	0.0%	2.5%	13.1%	0.0%	0.0%	0.0%	0.0%	16.7%
2003 Total	**1/163**	**1/166**	**0/440**	**0/43**	**0/140**	**2/282**	**2/307**	**0/10**	**0/300**	**0/180**	**1/52**	**6/46**
2003%	**0.6%**	**0.6%**	**0.0%**	**0.0%**	**0.0%**	**0.7%**	**0.6%**	**0.0%**	**0.0%**	**0.0%**	**1.9%**	**13.0%**
2004												
Baring Unit												
B1			0/50	0/15	0/20	0/15					0/10	0/30
B2	0/41	0/20		0/10		0/10						
B3	0/12	0/20										
B4			0/20	0/30		0/20	0/20		0/30			
B5	0/4	0/25		0/10								
B8	0/5		0/20						0/50		0/2	
B9	6/32	0/50	0/50		0/50							
B11	0/20							0/20		0/20		
B12	0/15	0/30	0/50									
Edmunds Unit												
E1		0/20	0/20			0/20	0/10		0/20		0/20	
E2			0/40			0/30		0/10	0/30	0/20		
E3			0/50		0/50	0/40			0/100		0/10	
E4			0/50			0/60						
E5	0/4	0/50				0/30			0/50			
E6		0/50										
E7												
2004 Total	**6/153**	**0/265**	**0/350**	**0/65**	**0/120**	**0/315**	**0/30**	**0/30**	**0/280**	**0/40**	**1/42**	**0/30**
2004%	**4.5%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Table 1. Summary of observations made during the 2004 survey at the Moosehorn 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. Comparison is made with the 1998-2000, and 2002-2003 results. (The refuge was not surveyed in 2001).

Table 2. Severity of ozone-induced injury on leaves of symptomatic leaves of ash at Site B9.

Species	Plant No.	Leaf No. 1*	2	3	4	5
Ash	1	10**	20	20	10	5
	2	10	10	10	20	5
	3	20	10	10	10	0
	4	5	5	5	5	5
	5	5	5	5	5	0
	6	10	5	10	5	0

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

(Baring Unit, Cont'd.)

Sites B2-B11 (see Table 1).

At site B2 (western end of South Trail Road), none of the aspen saplings examined in 2004 had ozone injury. Nor did any of the 41 ash bioindicators examined; however, the ash had a severe, dark, leafspot. Twenty staghorn sumacs (*Rhus typhina* = *R. hirta*) growing along the road to the site were examined and found to be free of ozone injury. During 2003, none of the 61 aspen saplings examined had ozone injury. More than 75% of the aspens had a severe leafspot in 2003. In 2002 approximately 3% of the ash seedlings and saplings had exhibited classic ozone injury at this location.

At site B3 (Cranberry Lake Inlet), none of the 12 ash or 20 aspen saplings showed ozone injury in 2004. None of the 25 ash or 25 aspen saplings had ozone injury in 2003. In 2002 one ash, but none of the 20 aspens, had shown ozone injury.

At site B4 (Cranberry Brook), blackberry, black cherry, dogbane, and pin cherry plants were free of ozone injury in 2004. Dogbane at this location was growing mainly in the shade and was very green. Black cherry trees and saplings had black knot infections of branches and twigs, as well as Cercospora-type leafspots. Pin cherry leaves commonly exhibited shotholes. Fruit was ripe on blueberries. Here and elsewhere, there was little useful foliage on the (2-year old) fruiting canes of the blackberry plants, as leaves on these older canes were discolored and senescing. This area has more black cherry seedlings/sprouts than any other site in the survey. Raspberry was free of any air pollution symptoms.

In 2003 aspen, black cherry, dogbane, and pin cherry plants were free of ozone injury.

At site B5 (Hanson Soil Pit Road), there was no ozone injury on ash, aspen, or black cherry in 2004. The aspens had severe insect and disease disorders. None of the aspen sprouts in clearcuts along the road into the next site had ozone injury, nor did other plant species in the general area (data not shown). The foliage of black cherry was very green, except for injury from insect infestations.

In 2003 one ash sapling had exhibited ozone stipple. Many of the aspen sprouts were stressed by a fungal leaf and shoot blight in 2003, likely caused by the fungus *Venturia*. As in 2002, aspen plants were not evaluated in 2003 at site B5 because of this confounding factor.

Site B6 (Barn Meadows #2) and **site B7** (Powerline at the intersection of Route 1 and Charlotte Road) were eliminated from the survey in 2002 due to a lack of indicator plants.

Site B8 (West Branch Observation Deck) is marginal site in terms of usefulness, but is more useful than sites B6 and B7 and was examined in 2004. Ozone injury was not observed on any bioindicator plants at site B8. Raspberry foliage was slightly red. Hawthorn plants growing on the mound near the observation deck had severe leafspot and defoliation. Alder leaves were less skeletonized by caterpillars in 2004 than in past years.

In 2002-2003, ozone injury was not observed on any bioindicator plants at this site. Ash leaves had a severe ringspot. Raspberry leaves were often chlorotic or had light reddening. Hawthorn foliage, on plants growing on the mound near the deck, had a severe leafspot. Alder leaves were severely skeletonized by caterpillars.

Site B9 (road to air monitoring station) was expanded in 1999 to include Voss Pond and is now an excellent survey site. Ozone injury was observed on 6 of 32 (18.8%) of the ash plants at this site (Table 1), and was moderately severe on occasion (Table 2). In addition very light, classic stipple was also noted on most beaked hazel (*Corylus cornuta*) shrubs growing at this site; however, injury was so slight it was extremely difficult to photograph. This species has not been exposed to ozone under controlled conditions. Nevertheless, the symptom was so similar to that induced by ozone, that it was considered to be ozone injury. In fact, very light stipple was also noted in 2003 on beaked hazel shrubs growing at this site. Data is not presented in Table 1, since beaked hazel is not considered to be a bioindicator.

As in many past years, leafspots occurred on dogbane, hawthorn, black cherry, and red maple foliage at this site. In fact, dogbane leaves were very chlorotic with many leafspots and generally could not be rated. *Venturia* shoot blight occurred on aspen here and throughout the area, but at lower levels than in 2003. Aspens had severe, small leafspots that complicated any evaluation of stipple, but again, were less severe than in 2003. Oak seedlings had light powdery mildew infections. Fruiting canes of blackberry had few useful leaves for evaluation purposes.

Insect disorders were noted on many species of plants including alder, aspen, birch, blackberry, cherries, oaks, sarsaparilla, willow, and others. Insect infestations and resulting injuries were generally most severe on birch. Skeletonizing of alder leaves by caterpillars was less severe than in 2002-2003.

In 2003, ozone stipple had not been observed on any indicator plants. There was a trace of stipple on leaves of occasional beaked-hazelnut shrubs.

In 2002 light, marginal stipple had been observed on 8.3% of the ash plants at this site, but not on other bioindicator species.

Site B10 (Higgins Road) has been heavily posted with no trespassing signs and has been eliminated as a survey site. This site is just off the refuge.

Site B11 (Bearce Flowage) was moved about 100 m in 2003 and is now an excellent site that includes hundreds of ash seedlings and many Virginia creeper vines. Ozone injury was not observed on leaves of any ash seedlings and saplings or Virginia creeper vines in 2004. Air pollution injury was not observed on leaves of mountain-ash or sarsaparilla at this site.

Site B12 (Firehole Flowage to James Pond) was established in 2004 to extend coverage into the southern portion of the Baring Division. This "site" was actually the 4-mile roadside area along South Ridge Road from the Firehole Flowage to James Pond, including the side road to and from Mack Brook Flowage. Ash (15), aspen (30), and blackberry (50) were examined along the route and observed to be free of ozone injury.

Edmunds Unit

Site E1. Vegetation was examined in 2004 in and around the edges of the farm fields near the Nate Smith Marsh. In spite of the name "Marsh", most of this survey site was along the edge of an old hayfield that was rather sandy and droughty. Definite ozone injury was not observed on aspen, blackberry, pin cherry, dogbane, raspberry, or serviceberry (Table 1).

As in past years, most serviceberry plants had brown, curled leaves and twig swellings in 2004, most likely symptoms of *Apiosporina* witches' broom disease. Black knot disease was severe on various *Prunus* species; this perennial disease is present every year. Webworm infestations were common on foliage of the cherry saplings. Much of the shrubby vegetation had twig dieback, and associated wind pruning, that appeared to be related to wind-driven salt. Dogbane plants were very chlorotic with severe leafspots.

In 2003 one serviceberry shrub exhibited ozone injury. Occasional dogbane plants were yellow with leafspots, and sweetfern foliage was red. In 2002, ozone injury was not observed at this site.

Site E2. Ozone injury was not observed on blackberry, pin cherry, or mountain-ash plants near the boat launch in Cobscook State Park in 2004. Pin cherry leaves had leafspots and shotholes. As in past years, mountain-ash leaves at this site and throughout the study area had severe leafhopper-type injury, which confounded any ozone injury evaluation. Raspberry leaves also had insect injury. Sarsaparilla leaves exhibited a severe, very fine, dark leafspot on the adaxial surface. There was no SO_2 injury on sensitive plant species such as birch, raspberry, blackberry, or sarsaparilla at this site or elsewhere in the refuge.

In 2003, ozone injury was not observed on blackberry, pin cherry, or mountain-ash. Sarsaparilla plants also had healthy leaves at this site, but were turning yellow. Ozone injury was observed on two of the pin cherries examined. Pin cherry leaves also had a severe chlorotic mottle in 2003.

In 2002, 8% of the pin cherries had exhibited ozone stipple.

Site E3. In 2004 bioindicators were examined in and around the edge of this very large field within the Cobscook State Park, located along the edge of Whiting Bay. Ozone injury not observed on any indicator species. Pin cherry and choke cherry foliage had severe shotholes and leafspots. These species also had severe black knot disease, especially on choke cherry. Dogbane plants were to chlorotic to rate. Raspberry foliage had very small leafspots on the adaxial surface.

During 2003, ozone injury likewise was not observed. In 2002 stipple had been observed on approximately 10% of the pin cherry plants examined. Foliage of wild rose and raspberry plants was turning red in 2002.

Site E4. Vegetation was examined in a large field, containing a large clump of pin cherry saplings, near the south end of Cobscook State Park. These plants were possibly from the same seed source, or sprouts, since they were growing close together. There was no ozone injury on these pin cherry saplings (or other bioindicators) in 2004. However, the spur shoots (short side spurs arising from the 2003 woody portion of the main shoot) of 7 of 60 (11.7%) of the pin cherry saplings had red leaves with a very fine stipple. The (more distal) leaves on the main 2004 terminal shoot did not exhibit this symptom and it was not rated as ozone injury, even though it was very similar to ozone-induced stipple. Pin cherry leaves also had a moderate leafspot.

In 2003 there was no ozone injury on the pin cherry saplings.

In 2002, ozone injury had been noted on 5% of the pin cherries. However, these plants also very red in both 2002 and 2003, making it difficult to evaluate stipple. The pin cherry leaves also exhibited shotholes and leafspots. Trembling aspen seedlings had severe leafspots and tip dieback in 2002.

Site E5. In 2004 ozone injury was not observed on ash, aspen, or pin cherry examined at this site near the intersection of North Trail and Weir Road. Two elderberry plants were noted at the site and were found to be free of ozone injury. There were many succulent aspen sprouts arising along the road where the brush had been cut off. Leafspots were severe on ash, aspen, and red maple. Insect injury was very severe on birch. Chewing insect injury was common on pin cherry leaves. Sensitive ferns were turning chlorotic. Browsing was present at the site. Twenty lilac shrubs growing in a clearcut were examined on the way to this site; lilac leaves were healthy.

In 2003 bioindicators were free of ozone injury at this location. Aspens had extremely severe leafspots, and red maple leaves were red.

Site E6. This excellent site was established near the beginning of North Trail in 2002. The site consists of a large open field containing hundreds of spreading dogbane plants, thousands of small aspens, and some pin cherry. By 2004 spreading dogbane plants were being replaced in the field due to natural succession by blueberries.

Interestingly, the site also contains a large number of lilac shrubs, which were free of ozone injury. There was no ozone injury on any bioindicators in 2004.

In 2003 there was no ozone injury on the bioindicators at this site.

Site E7. This additional site was established in 2002, and is located in a large field along Weir Road near the Flatiron Flowage pond. The large field contains many spreading dogbane plants, none of which exhibited ozone injury in 2002-2004. However, in 2004 the dogbane plants were too chlorotic to rate. In addition, the dogbane plants were becoming less prevalent in the stand.

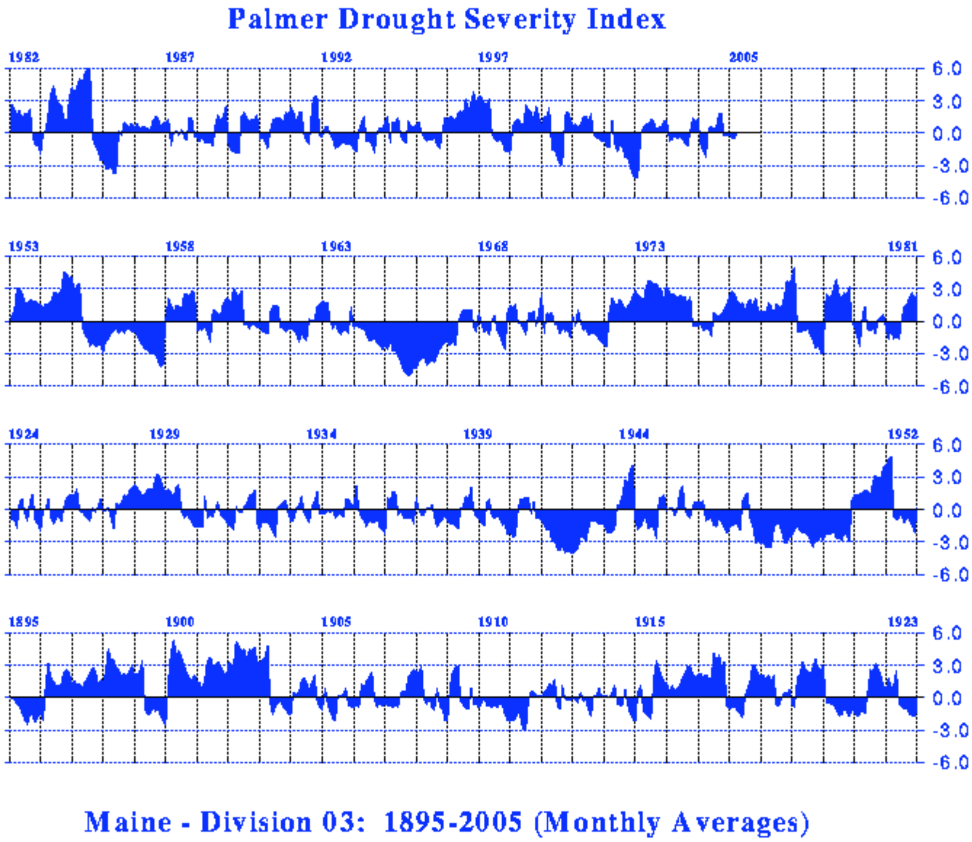


Figure 4. Palmer Drought Severity Index for coastal Maine, including Moosehorn NWR, during 1895-2004. The horizontal line at "0" is considered normal moisture levels. Areas above the line represent more than adequate moisture for normal plant functioning, whereas areas below the line represent potential water stress. A drought severity index of -3 is considered to be a severe drought, likely closing stomata and reducing ozone uptake.

SUMMARY

Within the entire Moosehorn refuge, the only known bioindicator exhibiting definite, classic, ozone-induced stipple in 2004 was ash. Ozone injury was noted on approximately 4% of more than 100 ash seedlings and saplings examined. In addition, possible ozone injury was observed on the spur shoots of approximately 3% of more than 200 pin cherries examined; however, this injury was not definite enough to be included in Table 1. Also, very light stipple was also noted on most beaked hazel (*Corylus cornuta*) shrubs growing at Site B9; this symptom had also been observed in 2003. In 2003, but not in 2004, stipple was noted on a Viburnum, likely *Viburnum lentago*. However, we have not exposed beaked hazel and this Viburnum to ozone under controlled conditions. Nevertheless, in my opinion it is very likely that these symptoms on pin cherry, beaked hazel, and Viburnum were caused by ozone.

Although choke cherry is generally evaluated during these surveys, the investigator now considers this species to be very tolerant to ambient ozone, and choke cherry should not be evaluated in the future.

During the 2004 survey, as well as all previous surveys, leaf injury resembling that caused by SO_2 was not observed at any site within the Moosehorn NWR.

Ambient ozone levels (as measured at Acadia National Park), were at their extremes in this part of Maine in 1998 (high ozone) and 2004 (low ozone). However, over the years, plant injury has not appeared to be solely related to ambient ozone levels. It is likely that the incidence of ozone injury is related to the interaction among plant species, ambient ozone levels, and soil moisture.

Nevertheless, the 2004 survey, and previous years' surveys, have illustrated that ambient ozone occurs at such levels to cause injury on sensitive bioindicators in the Moosehorn National Wildlife Refuge, and likely in the associated Class I Wilderness area. The results of these 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 at Moosehorn NWR
(As Furnished by the FWS)

Abies balsamea (balsam fir)
Acer pensylvanicum (striped maple)
Acer rubrum (red maple)
Acer saccharum (sugar maple)
Acer spicatum (mountain maple)
Achillea millefolium (common yarrow)
Actaea rubra (red baneberry)
Agropyron repens (Elytrigia repens var. repens)
Agrostis alba (Agrostis gigantea)
Alisma subcordatum (American water plantain)
Alnus crispa (Alnus viridis ssp. crispa)
Alnus rugosa (Alnus incana ssp. rugosa)
Alopecurus pratensis (meadow foxtail)
Amelanchier laevis (Allegheny serviceberry)
Anaphalis margaritacea (western pearly everlasting)
Andromeda glaucophylla (Andromeda polifolia var. glaucophylla)
Antennaria neodioica (Antennaria howellii ssp. neodioica)
Anthoxanthum odoratum (sweet vernalgrass)
Apocynum androsaemifolium (spreading dogbane)
Aquilegia vulgaris (European columbine)
Aralia hispida (bristly sarsaparilla)
Aralia nudicaulis (wild sarsaparilla)
Arctium minus (lesser burrdock)
Arisaema atrorubens (Arisaema triphyllum ssp. triphyllum)
Asclepias incarnata (swamp milkweed)
Asclepias syriaca (common milkweed)
Aster acuminatus (whorled wood aster)
Aster macrophyllus (bigleaf aster)
Aster radula (low rough aster)
Aster umbellatus (parasol aster)
Aster undulatus (waxyleaf aster)
Athyrium filix-femina (common ladyfern)
Barbarea vulgaris (garden yellowrocket)
Berberis thunbergii (Japanese barberry)
Betula papyrifera (paper birch)
Betula populifolia (gray birch)
Brassica juncea (India mustard)
Calamagrostis canadensis (bluejoint)
Capsella bursa-pastoris (shepherd's purse)
Carex crinita (fringed sedge)
Carex intumescens (greater bladder sedge)
Carex stricta (uptight sedge)
Carex trisperma (threeseeded sedge)
Carum carvi (caraway)

Cerastium vulgatum (Cerastium fontanum ssp. vulgare)
Chamaedaphne calyculata (leatherleaf)
Chelone glabra (white turtlehead)
Chimaphila umbellata (pipsissewa)
Chrysanthemum leucanthemum (Leucanthemum vulgare)
Circaea alpina (small enchanter's nightshade)
Cirsium arvense (Canadian thistle)
Cirsium discolor (field thistle)
Cirsium vulgare (bull thistle)
Clematis virginiana (devil's darning needles)
Clintonia borealis (yellow bluebeadlily)
Comptonia peregrina (sweet fern)
Coptis groenlandica (Coptis trifolia ssp. groenlandica)
Cornus alternifolia (alternateleaf dogwood)
Cornus canadensis (bunchberry dogwood)
Cornus stolonifera (Cornus sericea ssp. sericea)
Coronilla varia (purple crownvetch)
Corylus cornuta (beaked hazelnut)
Crassula aquatica (water pygmyweed)
Cycloloma atriplicifolium (winged pigweed)
Cypripedium acaule (pink lady's slipper)
Cypripedium calceolus ()
Dactylis glomerata (orchardgrass)
Dalibarda repens (robin runaway)
Danthonia spicata (poverty danthonia)
Dennstaedtia punctilobula (eastern hayscented fern)
Deschampsia flexuosa (wavy hairgrass)
Dianthus armeria (Deptford pink)
Diervilla lonicera (northern bush honeysuckle)
Distichlis spicata (inland saltgrass)
Dryopteris cristata (crested woodfern)
Dryopteris disjuncta (Gymnocarpium disjunctum)
Dryopteris marginalis (marginal woodfern)
Dryopteris noveboracensis (Thelypteris noveboracensis)
Dryopteris phegopteris (Phegopteris connectilis)
Dryopteris spinulosa (Dryopteris carthusiana)
Dryopteris thelypteris (Thelypteris palustris var. pubescens)
Dulichium arundinaceum (threeway sedge)
Epigaea repens (trailing arbutus)
Epilobium angustifolium (fireweed)
Equisetum arvense (field horsetail)
Equisetum fluviatile (water horsetail)
Equisetum hyemale (scouringrush horsetail)
Equisetum sylvaticum (woodland horsetail)
Erigeron annuus (eastern daisy fleabane)
Erigeron strigosus (prairie fleabane)
Eriocaulon septangulare (Eriocaulon aquaticum)
Eriophorum angustifolium (tall cottongrass)

Eriophorum spissum (Eriophorum vaginatum var. spissum)
Eupatoriadelphus purpureus (Eupatorium purpureum var. purpureum)
Eupatorium maculatum (spotted joepyeweed)
Euthamia graminifolia (flattop goldentop)
Fagus grandifolia (American beech)
Festuca capillata (Festuca filiformis)
Festuca elatior (Festuca pratensis)
Festuca rubra (red fescue)
Fragaria virginiana (Virginia strawberry)
Fraxinus americana (white ash)
Fraxinus pennsylvanica (green ash)
Galeopsis tetrahit (brittlestem hempnettle)
Galium mollugo (false baby's breath)
Galium palustre (common marsh bedstraw)
Galium triflorum (fragrant bedstraw)
Gaultheria hispidula (creeping snowberry)
Gaultheria procumbens (eastern teaberry)
Gaylussacia baccata (black huckleberry)
Gaylussacia dumosa (dwarf huckleberry)
Geranium bicknellii (Bicknell's cranesbill)
Glyceria canadensis (rattlesnake mannagrass)
Glyceria obtusa (Atlantic mannagrass)
Hamamelis virginiana (American witchhazel)
Hemerocallis fulva (orange daylily)
Hieracium aurantiacum (orange hawkweed)
Hieracium florentinum (Hieracium piloselloides)
Hieracium pilosella (mouseear hawkweed)
Hieracium pratense (Hieracium caespitosum)
Hordeum californicum (California barley)
Humulus lupulus (common hop)
Hypericum ellipticum (pale St. Johnswort)
Hypericum perforatum (common St. Johnswort)
Ilex verticillata (common winterberry)
Impatiens capensis (jewelweed)
Iris versicolor (harlequin blueflag)
Juniperus communis (common juniper)
Kalmia angustifolia (sheep laurel)
Kalmia polifolia (bog laurel)
Larix laricina (tamarack)
Ledum groenlandicum (bog Labradortea)
Lilium canadense (Canadian lily)
Linaria canadensis (Nuttallanthus canadensis)
Linaria vulgaris (butter and eggs)
Linnaea borealis (twinflower)
Lobelia cardinalis (cardinalflower)
Lobelia dortmanna (Dortmann's cardinalflower)
Lonicera canadensis (American fly honeysuckle)
Ludwigia palustris (marsh seedbox)

Luzula acuminata (hairy woodrush)
Luzula multiflora (common woodrush)
Lychnis alba (Silene latifolia ssp. alba)
Lycopodium annotinum (stiff clubmoss)
Lycopodium clavatum (running clubmoss)
Lycopodium complanatum (groundcedar)
Lycopodium lucidulum (Huperzia lucidula)
Lycopodium obscurum (rare clubmoss)
Lycopodium tristachyum (deeproot clubmoss)
Lycopus americanus (American waterhorehound)
Lycopus uniflorus (northern bugleweed)
Lycopus virginicus (Virginia waterhorehound)
Lysimachia terrestris (earth loosestrife)
Maianthemum canadense (Canada beadruby)
Matricaria matricarioides (Matricaria discoidea)
Medeola virginiana (Indian cucumberroot)
Medicago sativa (alfalfa)
Melampyrum lineare (narrowleaf cowwheat)
Melilotus alba (white sweetclover)
Melilotus officinalis (yellow sweetclover)
Mentha arvensis (Mentha canadensis)
Mimulus ringens (ringen monkeyflower)
Mitchella repens (partridgeberry)
Moneses uniflora (single delight)
Myrica gale (sweetgale)
Myriophyllum exalbescens (Myriophyllum sibiricum)
Nuphar variegata (Nuphar lutea ssp. variegata)
Nymphaea odorata (American white waterlily)
Nymphoides cordata (little floatingheart)
Odontites serotinus (Odontites vernus ssp. serotinus)
Oenothera biennis (common eveningprimrose)
Oenothera fruticosa (narrowleaf eveningprimrose)
Onoclea sensibilis (sensitive fern)
Oryzopsis asperifolia (roughleaf ricegrass)
Osmunda cinnamomea (cinnamon fern)
Osmunda claytoniana (interrupted fern)
Osmunda regalis (royal fern)
Oxalis europaea (Oxalis stricta)
Oxalis montana (mountain woodsorrel)
Oxalis stricta (common yellow oxalis)
Phalaris arundinacea (reed canarygrass)
Phleum pratense (timothy)
Picea abies (Norway spruce)
Picea glauca (white spruce)
Picea mariana (black spruce)
Picea rubens (red spruce)
Pinus resinosa (red pine)
Pinus strobus (eastern white pine)

Plantago major (common plantain)
Pogonia ophioglossoides (snakemouth orchid)
Polygonatum pubescens (hairy Solomon's seal)
Polygonum amphibium (water knotweed)
Polygonum careyi (Carey's smartweed)
Polygonum cilinode (fringed black bindweed)
Polygonum lapathifolium (curlytop knotweed)
Polygonum pensylvanicum (Pennsylvania smartweed)
Polygonum punctatum (dotted smartweed)
Polypodium virginianum (rock polypody)
Polystichum acrostichoides (Christmas fern)
Pontederia cordata (pickerelweed)
Populus balsamifera (balsam poplar)
Populus grandidentata (bigtooth aspen)
Populus tremuloides (quaking aspen)
Potamogeton epihydrus (ribbonleaf pondweed)
Potamogeton natans (floating pondweed)
Potamogeton pectinatus (sago pondweed)
Potamogeton zosteriformis (flatstem pondweed)
Potentilla anserina (Argentina anserina)
Potentilla argentea (silver cinquefoil)
Potentilla norvegica (Norwegian cinquefoil)
Potentilla recta (sulphur cinquefoil)
Potentilla simplex (common cinquefoil)
Prunella vulgaris (common selfheal)
Prunus pensylvanica (pin cherry)
Prunus pumila var. besseyi (western sandcherry)
Prunus serotina (black cherry)
Prunus virginiana (common chokecherry)
Pteridium aquilinum (western brackenfern)
Pyrola elliptica (waxflower shinleaf)
Pyrola rotundifolia (Pyrola americana)
Pyrus americana (Sorbus americana)
Pyrus floribunda (Aronia X prunifolia)
Pyrus malus (Malus sylvestris)
Pyrus melanocarpa (Aronia melanocarpa)
Quercus rubra (northern red oak)
Ranunculus acris (tall buttercup)
Rhinanthus crista-galli (Rhinanthus minor ssp. minor)
Rhododendron canadense (rhodora)
Rhus radicans (Toxicodendron radicans ssp. radicans)
Rhus typhina (Rhus hirta)
Ribes glandulosum (skunk currant)
Ribes hirtellum (hairystem gooseberry)
Rubus allegheniensis (Allegheny blackberry)
Rubus hispidus (bristly dewberry)
Rubus idaeus (American red raspberry)
Rubus pubescens (dwarf red blackberry)

Rudbeckia serotina (Rudbeckia hirta var. pulcherrima)
Rumex acetosella (common sheep sorrel)
Ruppia maritima (widgeongrass)
Sagittaria latifolia (broadleaf arrowhead)
Salicornia europaea (Salicornia maritima)
Salix bebbiana (Bebb willow)
Salix gracilis (Salix petiolaris)
Sambucus canadensis (American elder)
Sarracenia purpurea (purple pitcherplant)
Scirpus atrovirens (green bulrush)
Scirpus cyperinus (woolgrass)
Scirpus pedicellatus (stalked bulrush)
Scirpus rubrotinctus (Scirpus microcarpus)
Scutellaria epilobiifolia (Scutellaria galericulata)
Scutellaria lateriflora (blue skullcap)
Sedum purpureum (Sedum telephium ssp. telephium)
Senecio aureus (golden ragwort)
Senecio vulgaris (common groundsel)
Silene antirrhina (sleepy silene)
Silene cucubalus (Silene vulgaris)
Sisyrinchium montanum (mountain blueeyed grass)
Sium suave (hemlock waterparsnip)
Smilacina racemosa (Maianthemum racemosum ssp. racemosum)
Smilacina trifolia (Maianthemum trifolium)
Solanum dulcamara (climbing nightshade)
Solidago graminifolia (Euthamia graminifolia var. graminifolia)
Spiraea latifolia (Spiraea alba var. latifolia)
Spiraea tomentosa (steeplebush)
Stellaria graminea (grasslike starwort)
Taraxacum officinale (common dandelion)
Taxilejeunea (taxilejeunea)
Thalictrum polygamum (Thalictrum pubescens)
Thelypteris thelypterioides (Thelypteris noveboracensis)
Thuja occidentalis (eastern arborvitae)
Tragopogon pratensis (meadow salsify)
Trientalis borealis (American starflower)
Trifolium agrarium (Trifolium aureum)
Trifolium arvense (rabbitfoot clover)
Trifolium hybridum (alsike clover)
Trifolium pratense (red clover)
Trifolium repens (white clover)
Tsuga canadensis (eastern hemlock)
Typha angustifolia (narrowleaf cattail)
Typha latifolia (broadleaf cattail)
Utricularia cornuta (horned bladderwort)
Utricularia purpurea (eastern purple bladderwort)
Utricularia vulgaris (Utricularia macrorhiza)
Uvularia sessilifolia (sessileleaf bellwort)

Vaccinium angustifolium (lowbush blueberry)
Vaccinium corymbosum (highbush blueberry)
Vaccinium macrocarpon (cranberry)
Vaccinium myrtilloides (velvetleaf huckleberry)
Vaccinium oxycoccos (small cranberry)
Vaccinium vitis-idaea (lingonberry)
Valeriana uliginosa (mountain valerian)
Vallisneria americana (American eelgrass)
Verbascum thapsus (common mullein)
Veronica officinalis (common gypsyweed)
Veronica scutellata (skullcap speedwell)
Veronica serpyllifolia (thymeleaf speedwell)
Viburnum cassinoides (Viburnum nudum var. cassinoides)
Viburnum lentago (nannyberry)
Viburnum recognitum (Viburnum dentatum var. lucidum)
Viburnum trilobum (Viburnum opulus var. americanum)
Vicia cracca (bird vetch)
Vicia sepium (bush vetch)
Viola adunca (hookedspur violet)
Viola cucullata (marsh blue violet)
Viola pallens (Viola macloskeyi ssp. pallens)
Viola septentrionalis (northern blue violet)