AN OZONE EFFECTS MONITORING PROGRAM FOR THE CLASS I WILDERNESS AREAS IN THE WHITE MOUNTAIN NATIONAL FOREST OF NEW HAMPSHIRE

Interim Report
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- ABSTRACT -

Ozone effects on vegetation in the Class I Wildernesses of the White Mountain National Forest were assessed, over a two year period, using monitoring and survey techniques. Above background ozone concentrations were recorded from a monitoring site at the base of Mount Washington. Biomonitoring data collected from a network of tobacco field plots demonstrated that plant-damaging concentrations of ozone are widely distributed throughout the region. Out of a total of 16 bioindicator plants surveyed for foliar injury, half manifested a visible response to ambient ozone. Foliar symptoms were visible on 7 additional plant species whose sensitivity to ozone is unknown. Symptom intensity varied over the two year period with more injury occurring during the year with higher peak ozone concentrations. Tree seedlings grown in filtered and unfiltered open-top chambers verified the ozone symptom observed on the survey plants and provided preliminary evidence that ozone may influence plant growth even in the absence of significant foliar injury.

These findings provide substantial evidence that ozone is having an impact on vegetation in the wilderness areas. Recommendations for a long-term monitoring effort are as follows: (1) continue the field measurement program for 2 years, (2) intensify the evaluation of growth effects attributable to ozone, (3) conduct controlled exposure studies on symptomatic plants whose sensitivity to ozone is unknown, and (4) establish outplantings of a perennial bioindicator in order to monitor fluctuations in ozone concentration over time and possible cumulative effects.

I. INTRODUCTION

A. BACKGROUND

In 1964, the United States Congress established the National Wilderness Preservation System to protect certain land areas from man-made disturbance (11). The value of these wilderness areas depends on their continuing to be affected primarily by natural forces so that they may serve as "control" areas in a present and future world of technological expansion. In 1977, an amendment to the Clean Air Act established a program to protect wilderness areas from significant deterioration of air quality. Certain wilderness areas established prior to 1977 were designated as Class I. A Class I designation means that only very small increments of new pollution above already existing air pollution levels are allowed within the area. The amendments further established that the federal land managers of Class I areas are responsible for providing an assessment of current air quality and the potential negative effects of certain criteria pollutants (e.g. ozone) on land resource values. Such an assessment would then provide the decision framework for location or expansion permits requested by any major pollution-emission facility in a clean air area.

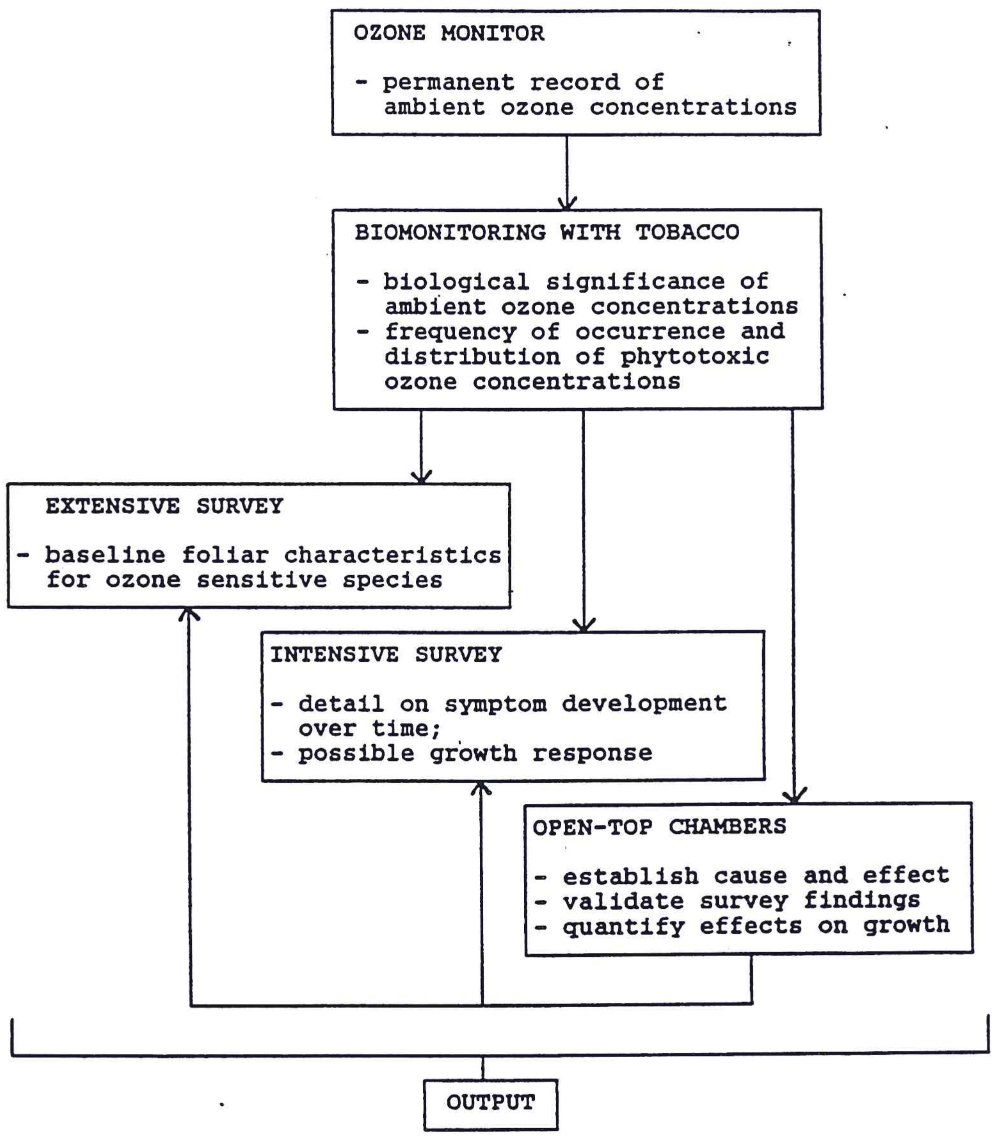
B. STATEMENT OF THE PROBLEM

Ozone is the criteria pollutant of concern in this report. It is the most widespread air pollutant in the United States, causing more plant damage than any other pollutant (19,22,27). Ozone has been shown to injure trees in remote areas. For example, in the San Bernardino Mountains of Southern California a comprehensive field effort led to the conclusion that ozone reduced growth, altered successional status and predisposed trees to insect attack (31). Similarly, a study conducted in Virginia documented widespread ozone effects on forest species in the remote Shenandoah National Park (26). Recently, ozone has also been suspect in the decline of yellow pine in the Southeastern United States and in the deterioration of red spruce populations in the montane forests of New England and New York (2,19). The White Mountain National Forest lies within the contaminated airshed of the Greater Boston and the Northeast Corridor urban-industrial complex (23). As such it is currently at risk from the degradative impact of ozone pollution.

Several researchers have demonstrated that foliar symptoms can be used effectively to survey the extent and severity of ozone injury to forest vegetation (4,8,24,30). It has also been shown that outplantings of biological indicators, specific for ozone pollution, eliminate the need for expensive air monitoring equipment and greatly facilitate symptom assessment on indigenous plants (14,30). We chose to investigate the relationship between ozone pollution and forest condition in the Class I Wilderness

Areas of the White Mountain National Forest using a survey detection approach that relies heavily on bio-monitoring procedures.

The following diagram illustrates the principal components of this investigation. The ozone monitor and biomonitoring components provided an assessment of current air quality. The survey and open-top chamber components provided an assessment of the potential negative effects of ozone pollution on sensitive vegetation. The program output is intended to be used to assist the Federal Land Manager in the screening process for new source permits.[1]



[1]Additional background information on ozone, biomonitoring, and a description of the study area is provided in the Appendix.

II. PROGRAM OBJECTIVES

The overall goal of this investigation was to gain a greater understanding of the potential impact of ozone pollution on vegetation in the Class I Wilderness Areas of the White Mountain National Forest. Specific objectives of the two-year study were as follows:

1. To evaluate the frequency of occurrence and distribution of phytotoxic ozone concentrations in the Class I Wilderness Areas.

2. To identify and describe the amount and severity of ozone induced foliar injury to sensitive species in the study area.

3. To develop a low cost monitoring system against which future conditions of ozone sensitive species can be measured.

With the addition of open-top chambers to the monitoring effort, a fourth objective became to compare foliar and growth characteristics of a representative sample of ozone sensitive plants grown in charcoal filtered, unfiltered, and ambient air plots. The controlled environment of the chambers allowed a more definitive and comprehensive evaluation of the effects of ozone on plant species common to the wilderness areas.

III. PROCEDURES

A. PRESURVEY - 1987:

The study area includes the Great Gulf and Dry River Wilderness Areas. Both are contained within the White Mountain National Forest and both are designated as Class I. Prior to the implementation of the field procedures in the study area, a number of documents were prepared (see Appendix II - IV). The approach used was as described in the USDA Forest Service, General Technical Report RM-146 (10).

A review of the literature (1,3,5,6,7,13,17,21,22,24) was conducted in order to compile plant lists and ozone sensitivity tables for the vegetation in the area. Land cover maps were prepared describing the dominant overstory and understory vegetation at different elevations. Preliminary field checks were made to obtain a rough indication of the relative abundance of plants on the ozone sensitive plant lists. The results of this presurvey were used to compile a final list of 16 bioindicators (Table 1) that would be used in the survey procedures described below.

A preliminary evaluation of air quality in the study area was conducted using tobacco bioindicators. The methods used were as described in the Handbook of Methodology for the Assessment of Air Pollution Effects on Vegetation (14). Twelve tobacco plants, six each of the ozone resistant (Bel-B) and the ozone sensitive (Bel-W3) cultivars, were transported to Pinkham Notch Camp (elevation 2,032 ft.) and the Hermit Shelter (elevation 3,871 ft.). After two weeks of ambient exposure, plant survival and ozone leaf symptoms were evaluated in order to establish the usefulness of tobacco as a biomonitor at high and low elevation sites in the study area.

Aerial photos and topographical maps were used to locate a candidate list of open areas that could be used as survey plots. The generally extreme topography and undisturbed quality of the area made it difficult to locate suitable open areas (plot size not less than 100 ft2) within the wilderness boundaries. Final plot selections were limited to 11 sites, most of them just outside the boundaries of the wilderness areas. A field data sheet was prepared for each plot describing plot location, elevation, aspect, slope, terrain position, soil depth, soil drainage, and evidence of past disturbance. Copies of all plant lists, maps, and data sheets are provided in the appendix.

B. SURVEY - 1988 and 1989:

Two types of survey plots were established to address different project objectives. Non-permanent plots, containing a mix of ozone sensitive plants, were established at 6 different locations. Data collection procedures at these 6 sites may be described as extensive. They were intended to determine whether or not ozone injury is present on vegetation native to the wilderness areas. An additional 5 plots, composed entirely of black cherry, were established and permanently marked for repeat evaluations. Data collection procedures at these 5 sites may be described as intensive. The black cherry plots were intended to monitor symptom development over time, and provide a preliminary indication of the relationship between ozone sensitivity and tree growth. Data collection procedures differed at the non-permanent and permanent plots as described below.

1. Mixed species plot (non-permanent):

Each site was visited once in 1988 between August 11th and August 16th. In 1989, each site was visited three times at two week intervals between July 24th and August 23rd. Using the plant list described in Table 1, a maximum of ten randomly selected plants of each ozone sensitive species found at each site were examined for foliar ozone injury. Each plant was assigned an injury index value from 0 to 16 by multiplying the percentage of injured area by the intensity of injury, both rated on a scale of 0 to 4 (0=no injury, 1=1-5%, 2=6-25%, 3=26-50%, and 4=>50%). Percentage of injured area was determined by estimating the proportion of live crown or leaf area injured relative to the total leaf area. Intensity of injury was determined by estimating the percentage injury to the leaf or leaves showing the most damage. A mean score was then calculated for each species at each plot location. Leaf samples representing a range of symptoms (trace, slight, moderate, and severe) were collected for each injured species and returned to the lab for additional examination and photodocumentation.

2. Black cherry plot (permanent):

Each plot was visited twice in 1988 during the first and third week in August. In 1989, each site was visited three times, once during the week of July 17th and again during the weeks of August 14th and 21st. At each site the first 5 black cherry trees with accessible crowns exposed to open air were tagged and examined. Foliar injury was scored on five branches per tree according to the formula described above except that percentage of injured area for each branch was determined by estimating the proportion of injured leaves relative to the total leaf area on each branch. The range of foliar symptoms both within and among trees was fully described and documented on color photos. In addition, height and diameter measurements were recorded for each tree in order to explore the relationship between ozone sensitivity (i.e. foliar response) and growth characteristics over the long-term.

3. Other:

In the late summer of 1987 and 1988, additional woody and herbaceous vegetation was evaluated for presence or absence of ozone-like symptoms (e.g. upper-leaf surface stipple or flecking). These one-time evaluations were made on most of the more common plant species found at the mixed species and black cherry plots even if they were not listed on the bioindicator plant list. Additional information was collected from temporary plots established in relatively small open areas along the wilderness trails. A total of 15 sites were checked in the Great Gulf Wilderness and 12 sites in the Dry River Wilderness, covering a range in elevation of from 500 to 5,018 feet.

C. MONITORING - 1988 and 1989

1. Technical:

Ozone was monitored continuously from early June to mid-September at a low elevation site (1600') bordering the Great Gulf Wilderness Area. The performance of the UV photometric ozone monitor and chart recorder were checked daily by a site operator familiar with simple electronic tests. Two models of monitors were used: Dashibi model 1003 AH and Thermo Electron model 49. During the 1989 season, the monitor was in a temperature controlled building in order to ensure operation within the certified temperature limits of the instrument. Monitor audits were conducted every 3 to 4 weeks using a Dashibi 1008 PC, certified quarterly as a transfer standard, at the Massachusetts Department of Environmental Protection, Air Quality Laboratory in Tewksbury, MA. Data which did not conform to a traceable time sequence on the chart recorder or which were recorded during a period of >10% error in monitor response, were omitted from the data base.

Mean hourly ozone concentrations were calculated and the information stored on computer disc. Tables were prepared presenting peak ozone concentrations, number of hours when ozone exceeded phytotoxic levels, cumulative exposure curves and seasonal means. The cumulative curves were smoothed when gaps of two or more days occurred due to monitor malfunction.

2. Biological:

Tobacco cultivars, Bel-B (ozone resistant) and Bel-W3 (ozone sensitive), respond to ozone in predictable and reliable ways i.e. there is a known positive correlation between degree of leaf injury and ambient ozone (14,20). For this reason, Bel-B and Bel-W3 were used to biomonitor ozone throughout the study area. Their survivability at low elevation sites had been established in 1987. Four tobacco field sites were established in open areas adjacent to the wilderness areas at strategic locations intended to reflect different air flow paths into the region. Plants were grown from seed in an air filtered greenhouse and transported to the study area as needed.

Five plants of each cultivar were placed at each monitoring site. Every two weeks in 1988 and every week in 1989 a new set of plants was placed on site. Old plants were removed regularly so that an optimal and relatively constant level of ozone sensitivity was maintained. All plants were watered and fertilized as needed and examined for foliar ozone injury on a weekly basis. Intensity of injury was evaluated on a per leaf basis and a mean score calculated for each plant. The injury scale ranged from 0 to 10 as follows: 0=no injury, 1=1-5%, 2=6-12%, 3=13-24%, 4=25-40%, 5=41-59%, 6=60-75%, 7=76-87%, 8=88-94%, 9=95-99%, 10=100%. In 1989, weekly changes in plant height and leaf area were also recorded.

In 1988, the tobacco plots were maintained from June 7th to August 27th and in 1989 from June 9th to August 24th. Weekly injury scores were compared to known ambient ozone concentrations and then plotted against time to obtain a relative measure of air quality for each site and for the region as a whole.

D. FIELD CHAMBERS - 1988 and 1989

Four open-top chambers (15), two carbon filtered and two non-filtered, plus two ambient air plots were set up at the edge of the Great Gulf Wilderness Area in the same location as the ozone monitor. The design and air flow characteristics of the chambers are illustrated in Appendix .

In 1988, the chambers were operational from June 28th to September 15th. Potted seedlings (65/species) of green ash, white ash, tulip poplar, and black cherry were randomly allocated to each chamber or ambient air plot. Ozone injury symptoms were fully described for each species in each chamber and measurements take to calculate changes in stem height and leaf number over the exposure period. At the end of the season, those individual plants showing a marked sensitivity to ozone were tagged and all plants placed in storage for use in 1989.

In 1989, the chambers were operational from June 13th to September 20th. For a variety of reasons, only a small number of the 1988 seedlings could be reused in '89. Newly purchased white ash and black cherry seedlings were potted up along with red spruce seedlings provided by the USDA Forest Service. Subsequently, the white ash seedlings had to be destroyed due to a severe TMV infection. A total of 95 red spruce and black cherry, and 30 white ash were distributed randomly between the 4 chambers and 2 ambient air plots. Stem height, stem diameter and total stem growth measurements were recorded for each plant at the beginning and end of the exposure period. In addition, all plants were evaluated weekly for ozone injury and twice, in early-September, for evidence of premature senescence. Each leaf was evaluated separately and a mean value calculated per plant using the same 0 to 4 intensity scale described in the survey section. At the end of the season, all plants were placed in cold frames for re-use in 1990.

E. PHOTODOCUMENTATION

The cumulative effects of ozone on Bel-B and Bel-W3 tobacco plants was photographed as injury symptoms progressed from slight to moderate to severe over the prescribed exposure period. A similar injury progression was documented for black cherry seedlings on the survey plots. Photographs were also taken to record the range of injury symptoms visible on the tree seedlings in the open-top chambers, ambient air plots, and on all plants included in the extensive survey procedures. This documentation is presented in an appended document with additional descriptive detail on leaf age and location, color and pattern of the injured area.

F. DATA ANALYSIS

All data entry and analyses were performed with a Statistical Analysis Package (SAS) using an IBM PC, Model 50. For all response variables, means and standard errors were calculated for each species or cultivar. Standard regression, ANOVA, and GLM procedures were used to examine the relationships between response variables.

The survey and biological monitoring procedures employed in this study were designed to collect data over a wide range of possibly relevant conditions. The number of plots established was significantly less then anticipated but was, nonetheless, the maximum number possible given the project's time and resource constraints. This survey is intended to provide baseline information on vegetation response to ozone pollution in the Class I Wilderness Areas of New Hampshire. It is not intended to prove or disprove a specific hypothesis although, the data derived from the chamber studies may be considered in that regard.

IV. RESULTS AND DISCUSSION

A. MONITORING

1. Technical:

Differences in air quality between 1988 and 1989 are best described by the summary ozone data presented in Table 2 and the yearly, cumulative ozone dosages as illustrated in Figure 1. By any measure, air quality in the study area was worse in 1988 than in 1989.

1988: The hourly ozone means exceeded 0.08 ppm for a total of 37 hours and 0.05 ppm for 279 hours. The former value used to be the National Ambient Air Quality Standard (NAAQS) for ozone and it is still considered by many scientists to be an appropriate standard to protect plant health (9,28). The latter value is considered the lower limit at which ozone concentrations are toxic to the most sensitive plants (16,22,25). Mean ozone concentrations were highest in June, decreasing steadily in July, August and September. An ozone "episode", defined as 2 or more consecutive days with 2 or more consecutive hours >0.08 ppm, occurred twice in 1988 between June 14th and June 16th and June 20th and 21st.

1989: Maximum ozone means exceeded 0.05 ppm for 159 hours. Ambient concentrations were low in June, highest in July, and relatively low again in August and September. There were no ozone "episodes" as defined above, although there was an extended period (> 2 days) of moderately high ozone (>0.05ppm) between July 16th and 19th, July 25th and 27th, August 14th and 16th, and September 6th and 10th.

At no time in either 1988 or 1989 did the ozone concentration at the monitoring site exceed the NAAQS of 0.12 ppm. Differences in the cumulative ozone dose over the two year period are illustrated in Figure 1. The disparity between the two curves demonstrates the marked difference in air quality in '88 and '89 both with respect to frequency and timing of high ozone occurrences.

Although not emphasized in this report, it is of interest to note that ozone concentrations at the summit of Mount Washington (GGWA) exceeded the NAAQS (0.12ppm) for 13 hours in 1988 and 5 hours in 1989 (19). There is little known about the gradient in ozone concentration between the summit and the base of the mountain, but the monitoring that has been done suggests that ozone levels at the summit are generally twice that of ozone concentrations at the base of the Auto Road (19). This could obviously have implications for ozone effects on alpine vegetation.

2. Biological:

1988: Ozone symptoms first appeared on the tobacco cultivar, Bel-W3, on June 12th, after 5 days of field exposure. Mean injury scores following consecutive 2 week exposure periods are illustrated in Figure 2 for the duration of the monitoring period. On June 22nd, the ozone sensitive cultivar rated 4.7 on a 0 to 10 scale compared to a zero value for the ozone resistant cultivar. Over the next two weeks, mean injury scores reached a maximum mean value of 5.3 for the ozone sensitive plants and 2.3 for the ozone resistant plants. During this same time period, ambient ozone concentrations reached seasonal highs of 0.085 to 0.095 ppm. For the remainder of the season, up to the final observation date of August 27th, the injury index for the tobacco plants generally reflected peak ozone concentrations in ambient air.

At each of the four monitoring sites the seasonal fluctuations in ozone injury scores followed the same pattern. However, there were significant differences between sites with respect to amount and intensity of foliar injury. This is reflected in the seasonal mean values presented in Figure 3. The Crawford Notch and Camp Dodge monitoring sites showed consistently higher injury scores then the Auto Road and Bartlett sites ($p=0.01$). Presumably, these differences in tobacco response are the result of differences in ambient ozone load at the four locations.

1989: Ozone symptoms were first observed on June 16th after the first set of tobacco plants had been exposed for one week. As in 1988, the highest injury scores occurred early in the monitoring season between June 16th and June 23rd. This was true at all four monitoring sites. It is not clear if this time period also corresponds to a peak ozone period as ambient ozone data is not available prior to June 16th. Fluctuations in the injury index, over the course of the monitoring season, generally corresponded to fluctuations in ambient ozone concentrations.

When averaged across sites, the 1989 mean scores tended to be lower than in 1988, with a maximum mean value of 4.5 for the ozone sensitive plants and 0.8 for the ozone resistant plants (Figure 4). Between site comparisons (Figure 5) confirmed the 1988 finding that significantly more injury occurs at the Crawford Notch site then at the other three locations ($p=0.01$).

The ozone induced leaf injury to the Bel-W3 cultivar in 1989 caused only a slight decrease in growth when compared to that of the ozone resistant cultivar. After 2 weeks of field exposure to ambient ozone concentrations, changes in stem height and leaf area were similar for both Bel-B and Bel-W3 tobacco. Nevertheless, correlation statistics demonstrated a significant inverse relationship between foliar injury and growth ($r=0.4$) for the ozone sensitive tobacco. These results underscore the concern that native plants showing a visible foliar response to ozone concentrations in the wilderness areas may also suffer some loss in growth potential.

Differences in the cumulative injury for Bel-B and Bel-W3 tobacco, over the course of the monitoring period, are illustrated in Figure 6 (1988) and Figure 7 (1989). In 1988, there was little change in Bel-B injury scores following the initial response to peak ozone values between June 22nd and July 6th. In contrast, the curve for the sensitive Bel-W3 cultivar reflects the fact that ozone concentrations remained moderately high throughout the monitoring season. In 1989, there was less difference in injury severity on Bel-B and Bel-W3 tobacco due to a reduction in the amount and intensity of injury to the sensitive Bel-W3 cultivar.

These data clearly demonstrate that phytotoxic levels of ozone are present throughout the study area during the summer months. Furthermore, given the known dose/response relationship for tobacco (12,14,20) and this study's comparison of injury severity on Bel-B and Bel-W3 tobacco, it's possible to categorize air quality for the region in 1988 as fair (i.e. moderate ozone levels) and in 1989 as good to fair (i.e. low to moderate ozone levels).

B. SURVEY - OZONE BIOINDICATORS

The survey procedures conducted at the 6 mixed species and 5 black cherry plots in 1988 and 1989 generated convincing evidence that ozone is causing visible damage to sensitive plants in the wilderness areas. The locations of all survey sites are indicated on the wilderness maps (Figures 8 and 9), and the foliar injury data in Tables 3, 4, 6, and 7. Summary data for the two year study period is presented in Table 5 to provide an easy comparative reference for the 1988 and 1989 results. Baseline damage characteristics for the sensitive species are fully described in the attached photodocument.

1. Mixed Species Plot:

1988: A total of 107 plants, including 7 different plant species identified on the ozone bioindicator list, were evaluated (Table 3a and 3b). There were from 1 to 4 different species at each site and from 2 to 10 sample trees examined per plot. More than half of all the aster (n=20) and spirea (n=10) plants examined for ozone injury showed some foliar response. In contrast, only a very few individual plants of birch (n=47), alder (n=14) and mountain ash (n=7) showed ozone injury, and no symptoms were visible on black cherry (n=5) or sugar maple (n=4). The mean injury index values for all injured species evaluated in 1988 fell into the moderate to severe categories suggesting an acute response to elevated ozone levels throughout the survey area.

1989: A total of 195 plants were examined including 9 different plant species (Table 4a and 4b). The most frequently injured species included alder (n=39), blackberry (n=30), mountain ash (n=13) and spirea (n=35). Species with only a few individual plants showing foliar symptoms included aster (n=21), birch (n=41), and poplar (n=10). As in 1988, no symptoms were visible on black cherry (n=2) or sugar maple (n=4). In contrast to the 1988 survey results, most of the mean injury index values for 1989 fell into the trace to slight categories with less then 7 percent of the total number of evaluated plants in the moderate to severe categories. Presumably this shift in severity group ratings reflects the difference in air quality in 1988 and 1989 as described above in the section on monitoring.

On the first survey observation date (August 11th in 1988 and July 26th in 1989) ozone symptoms were visible on 1 of the 7 bioindicators evaluated in 1988 and 3 of the 9 bioindicators evaluated in 1989. By mid-August an additional 4 species were responding to phytotoxic ozone concentrations in both years. This increase in injury response overtime reflects the fact that some plants, able to resist a single high ozone episode early in the growing season, may show a visual response after repeated exposures to high ozone concentrations (4,18). By the same token, prolonged exposure to relatively low ozone concentrations can cause a visual response towards the end of the growing season as ozone acts to predispose sensitive plants to premature senescence (21,28).

It is of interest to note that spirea, which fell into the highest ozone severity group rating in both 1988 and 1989, tended to show more damage in the plots to the south of the Dry River Wilderness area (e.g. at Crawford Notch where tobacco injury scores were also high) than in the more northern plots bordering the Great Gulf Wilderness Area.

Based on the summary data presented in Table 5, it is possible to infer that approximately 1/3 of the sensitive plant population is visibly affected by ambient ozone concentrations in the wilderness areas. The variable response of the bioindicator plants over the 2 year study period demonstrates the need for multi-year studies in any field evaluation of ozone stress on vegetation.

2. Black Cherry Plot:

1988: Eleven of the 26 sample trees showed evidence of ozone foliar injury (Table 6a and 6b). Symptoms were confined to the exposed branch or branches on a sample tree and were manifested as an upper-leaf surface stipple which, in some cases, preceded a general discoloration or leaf yellowing of the injured tissues. Symptoms were most visible on the older and mid-aged leaves on a single branch with different leaves of similar age showing a range of symptoms from slight to severe. The observed variability, both among and within trees, could not be readily explained except, in part, by reference to the more obvious factors of exposure and leaf age mentioned above. Many of the sample trees had other recognizable insect or disease problems including infection by *Apiosporina morbosa* and *Blumeriella jaapii*. This made it difficult to differentiate the ozone stress response for some trees and, in fact, certain problematic trees were dropped from the survey in 1989 for this reason.

1989: Only 5 of the 11 trees reexamined in 1989 showed a foliar response to ozone, and the severity of injury was reduced significantly in all cases (Table 7a and 7b). This reduction in injury intensity from one year to the next supports similar observations made on other sensitive species on the mixed species plots. In both 1988 and 1989, injury was first noted at the Davis Path Trail-Head, the closest plot to the Crawford Notch area where the biomonitoring and extensive survey procedures indicated ozone injury was most frequent and damaging.

The growth response data for black cherry has been omitted from this report because only a small number of the '88 sample trees was remeasured in '89 and because it is unlikely that a growth difference could be detected after only one year (26).

3. Other:

The list of additional plant species evaluated for presence or absence of ozone-like symptoms is presented in Table 8. Foliar symptoms, including upper-leaf surface stipple or flecking were recorded on the following 9 species: Mountain maple, wild sarsaparilla, Flowering dogwood, hop-hornbeam, meadow grass, hobblebush, blueberry, bilberry, and Mountain cranberry. Flowering dogwood has been reported as ozone sensitive in the literature (3) but the remaining 8 species have not been evaluated under controlled conditions. There were no symptoms of ozone injury on 40 other species found on the wilderness trail plots even though 3 of the 40 (red clover, sugar maple, and white oak) have been reported as ozone sensitive (3,24,29). Elevation did not appear to be a significant factor influencing the results.

C. FIELD CHAMBERS - FOLIAR INJURY AND GROWTH RESPONSE

1988: All seedling material at the open-top chamber site was evaluated for foliar ozone injury on August 12th and 13th. In the unfiltered chambers, green ash showed obvious ozone injury characterized as a purple coloration and faint to pronounced stipple on the upper leaf surface of mid-aged leaves. Most of the white ash seedlings were similarly affected. Ozone symptoms were less obvious on tulip poplar. A small number showed a glazed or water soaked appearance associated with chronic ozone injury. Shaded portions of the symptomatic leaves were free of injury.

On the black cherry, only the older leaves showed symptoms of ozone injury. It showed up as an upper-leaf surface bronzing and/or general chlorosis. Injured leaves dropped off by late August/early September.

In the filtered chambers, not all plants were free of the symptoms described above, but injury was much less severe and on a fewer number of plants. The amount and intensity of injury on seedlings in the ambient air plots were similar to that found in the unfiltered chambers. All seedlings were re-evaluated on September 5th but there was no evidence of a marked increase in either amount or severity of damage.

Despite differences in foliar response between treatments, ozone effects on stem height and leaf number were not apparent. There was, however, some indication that plants grown outside in the ambient air plots performed differently then plants grown in chambers. For example, there were nearly twice the number of leaves on white ash and black cherry seedlings grown in ambient air then on these same species grown in either filtered or unfiltered chambers.

Given the relatively high ozone concentrations in 1988, the absence of a treatment effect on stem height and leaf number may be attributable to a high variability among sample trees compounded by the relatively short treatment period i.e. chambers were operational for approximately 3 1/2 weeks. Alternatively, the results lend support to the contention that ozone induced foliar injury does not necessarily lead to growth reductions in field grown plants. In any case, the results underscore the need for uniformity in plant material in this type of field evaluation and the importance of an extended evaluation period if growth effects are to be adequately assessed. A review of the field procedures further suggests that changes in leaf number may not be a useful growth parameter unless provisions can be made to collect leaves that drop or blow off during the evaluation period.

1989: There was little evidence of foliar injury on the seedlings used in the chamber study regardless of ozone treatment. In the unfiltered chambers, only 3 black cherry and 2 white ash seedlings developed classic upper-leaf surface stipple out of a total of 56 plants. A few spruce seedlings in the unfiltered chambers developed a blanched appearance on the upper needle surface but it is not clear if this was induced by ozone or some other environmental factor. In the ambient air plots 9 of the 38 black cherry seedlings showed some faint stippling by June 28th. However, none of the symptomatic plants showed any increase in injury intensity over the course of the treatment period. On September 7th and again on September 14th, all plants were evaluated for symptoms of premature fall coloration and leaf drop. There were no significant differences between treatments with respect to leaf color. However, the white ash seedlings in the ambient air plots showed a greater percent defoliation, on September 14th, then the ash seedlings in either the filtered or unfiltered chambers.

Based on the monitoring and survey results described above, it is not surprizing that there was significantly less foliar injury noted on the tree seedlings used in the chamber study in 1989 than in 1988. These results confirm the reliability of tobacco foliar response as an indicator of ozone induced leaf injury on the indigenous woody vegetation. They also substantiate the field survey results in that the year to year variability in injury amount and severity was similar in the field and in the chambers.

Most importantly, the foliar symptoms identified as ozone stress in the field closely resemble the injury symptoms on plants in the unfiltered chambers. This, taken together with the absence of symptoms on the same species grown in filtered air provides strong evidence that ozone is the cause of the foliar injury described on the survey plants.

Table 9 summarizes the growth response data for red spruce, black cherry, and the white ash seedlings carried over from 1988. As in 1988, there was no statistically significant effect of ozone on any of the growth parameters evaluated including stem height, stem diameter, and shoot growth. Nevertheless, there is a consistent trend with growth increases highest in the filtered chambers followed by the unfiltered and ambient air plots. Variability among sample trees was high regardless of the measurement variable. The evaluation period was 10 weeks long, more then twice that in 1988. However, ambient ozone levels were relatively low, thus mitigating any treatment effect. Contrary to the results in 1988, those plants grown in ambient air plots in 1989 grew relatively more slowly than the plants grown in chambers. This is more as expected given the fact that the chambers provide partial protection from certain environmental factors common to the study area (e.g. wind stress).

V SUMMARY AND CONCLUSIONS

The ozone data obtained from the monitor at the base of Mount Washington (GGWA) clearly demonstrates that ambient ozone concentrations in the study area are above background (0.02 to 0.035 ppm) levels. The biomonitoring data collected from the 4 tobacco sites provide evidence that the ambient ozone concentrations are, in fact, phytotoxic and widely distributed throughout the region. The biological significance of the elevated ozone concentrations is further emphasized by the survey results. Clearly, a number of plant species native to the area are manifesting a visible response to ozone pollution. This conclusion is substantiated by the results of the chamber study which verify that the foliar symptoms identified in the field were ozone-induced. No significant adverse effects of ozone on plant growth were documented in this study although, the tree seedling data from the open-top chambers indicates a marked tendency for improved growth on plants grown in filtered air. This, considered together with the lack of severe injury symptoms on chamber-grown plants, suggests the potential for ozone effects on plant growth in the absence of significant foliar injury.

The number and location of the survey and biomonitoring plots were restricted by the scarcity of open areas within or close to the wilderness boundaries. Nevertheless, variability in foliar symptom development between sites suggests that there are locational differences in air quality that depend on the direction of air movement into the region or local topography. Vegetation to the south may be more at risk than vegetation to the north and east. Additional monitoring is required to corroborate this preliminary observation.

A severity classification scheme describing the relative sensitivity of the bioindicator plants evaluated in this study is presented in Table 10. According to this summary data, aster, spirea, black cherry and alder are the 4 sensitive species most likely to show a visible response to high ozone concentrations. They should therefore be included in any long-term monitoring system intended to assess future changes in air quality in the Class I Wilderness Areas of the White Mountain National Forest.

VI RECOMMENDATIONS

1. Continue with all components of the field measurement program for another two years. This should provide greater understanding and appreciation for the year to year variation in ozone levels and plant response.

2. Intensify the evaluation of growth effects in order to clarify the relationship between ozone sensitivity and growth and the potential for adverse effects on growth in the absence of foliar symptoms.

3. Conduct controlled exposure studies on those symptomatic plants native to the wilderness area that have never been evaluated for ozone sensitivity.

4. Implement special evaluation procedures for those plant species unique to the area or listed as rare or endangered.

5. Continue research on the commonness estimates and distribution of the sensitive species.

6. Replace the tobacco cultivars with a perennial indicator of ozone pollution, using resistant and sensitive individuals collected from the wilderness areas and tested under controlled conditions.

A final recommendation is made in recognition of similar field studies being conducted in other areas. Namely, to integrate the findings from the White Mountain National Forest with the results of field survey and monitoring activities on the Lye Brook Wilderness in Vermont and the Mount Greylock Reservation in Massachusetts to produce a regional document on ozone concentrations and effects in remote forested areas.

VII. ACKNOWLEDGEMENTS

This project was supported by an award from the USDA Forest Service, Northeastern Area, State and Private Forestry. Special thanks to Howard M. Wemyss, General Manager, Mount Washington Summit Road Company. Additional resource personnel, who assisted in the planning and implementation of the project, are listed below by agency association.

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Appalachian Mountain Club: Kenneth D. Kimball and Joseph E. Doucette, Research Department.

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IX. LIST OF FIGURES

Figure 1. Cumulative ozone dose at the Mt. Washington monitoring site - 1988 and 1989.

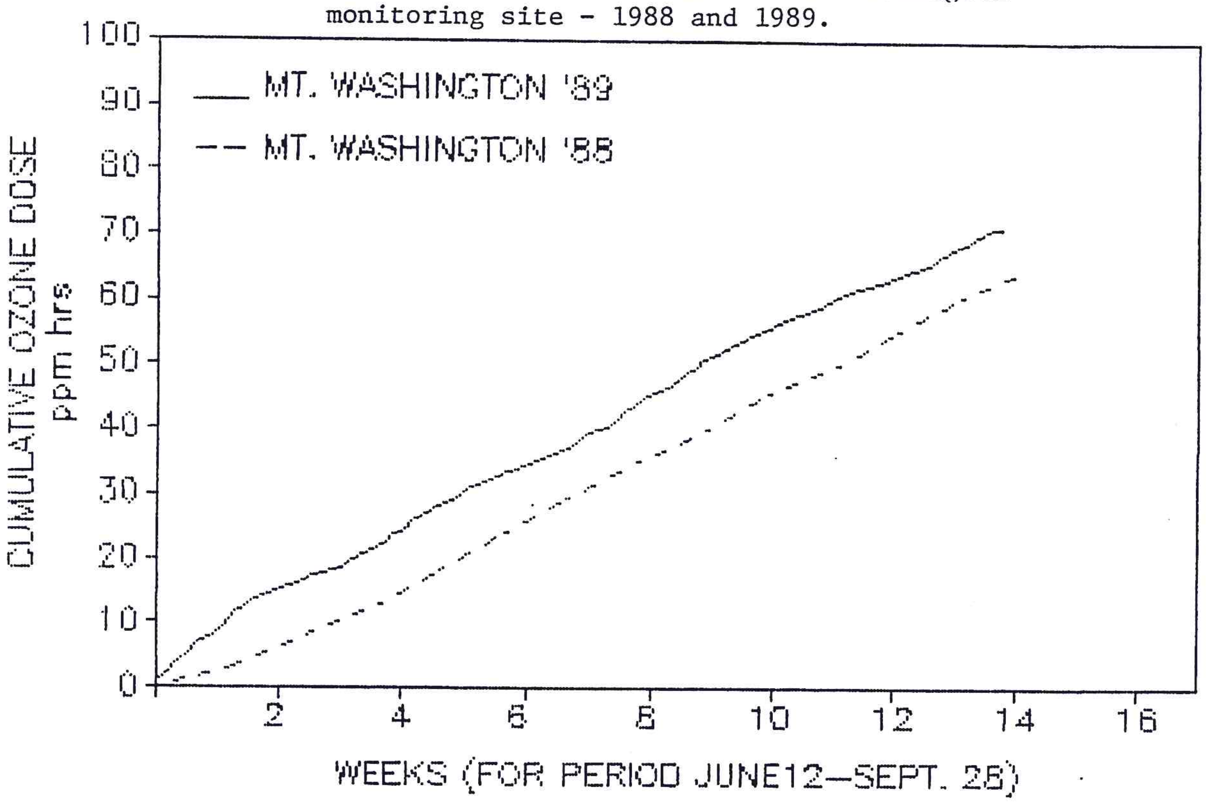
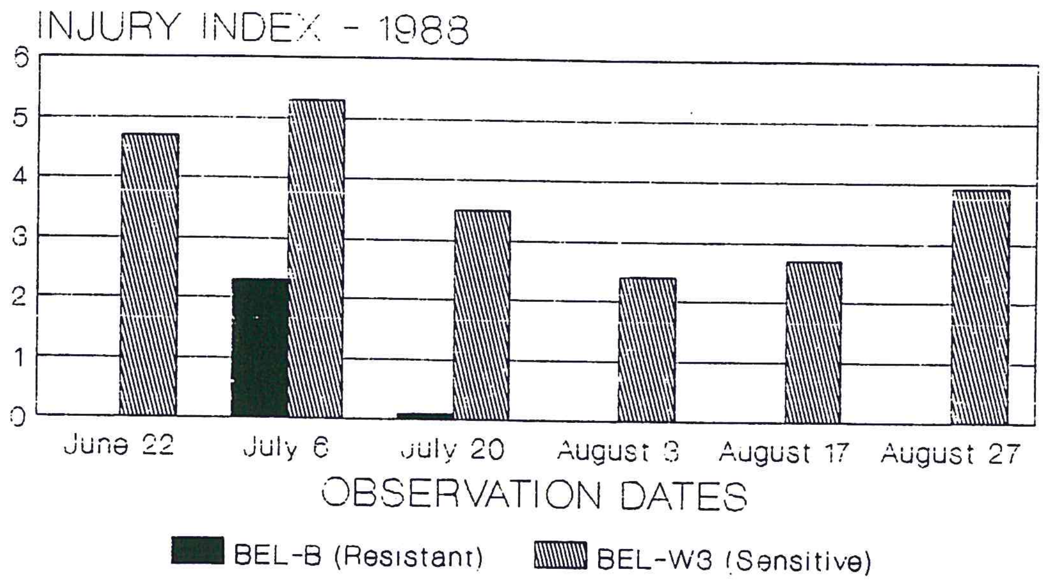
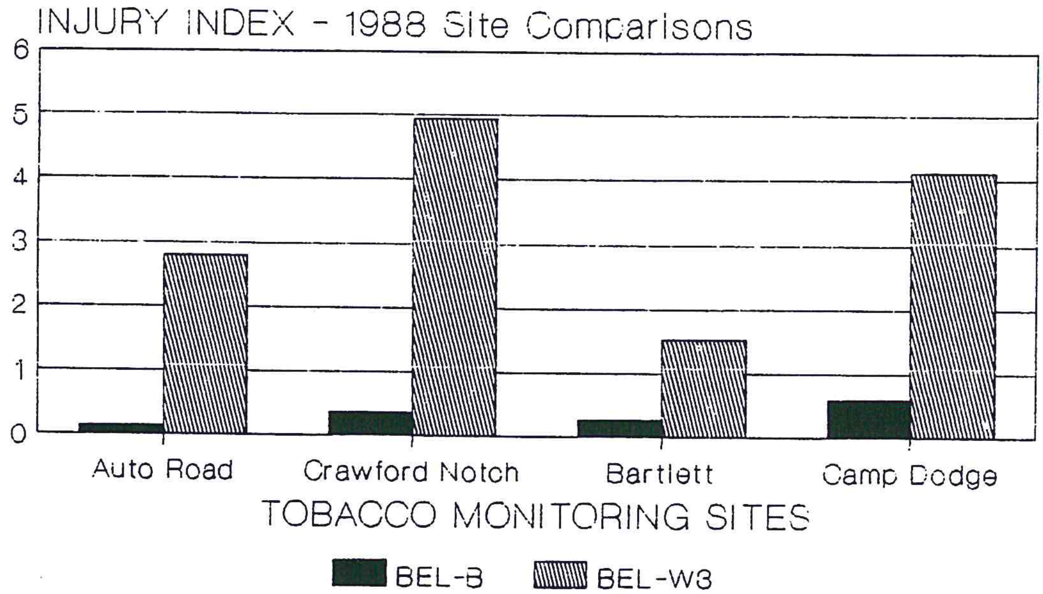


Figure 2. Mean Foliar Injury Scores for Bel-B and Bel-W3 Tobacco During the Monitoring Season - All Sites Combined.



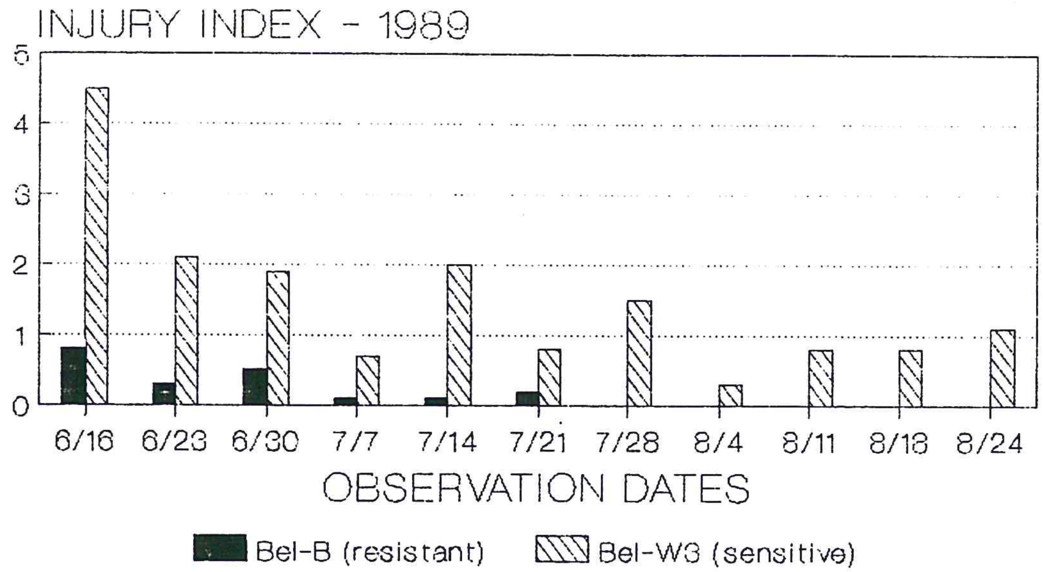
Foliar injury index explained in text.
Mean SE for Bel-B = 0.1; Bel-W3 = 0.2;

Figure 3. Seasonal Mean Foliar Injury for Bel-B and Bel-W3 Tobacco Cultivars.



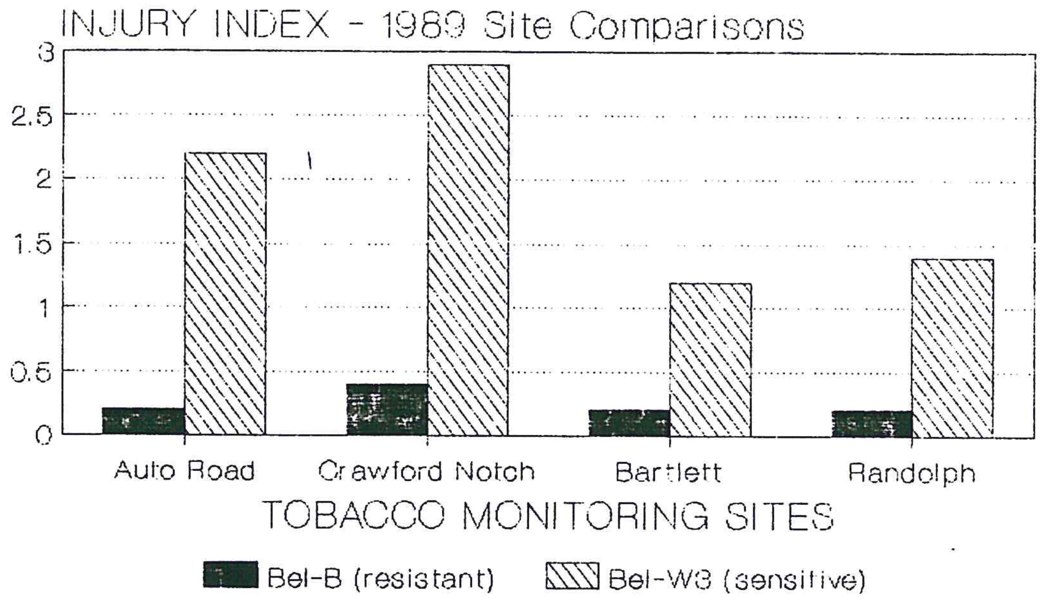
After 2 weeks exposure to ambient ozone.
Foliar injury index explained in text.
Mean SE for Bel-B = 0.1; Bel-W3 = 0.2;

Figure 4. Mean Foliar Injury Scores for Bel-B and Bel-W3 Tobacco During the 1989 Monitoring Season - All Sites Combined.



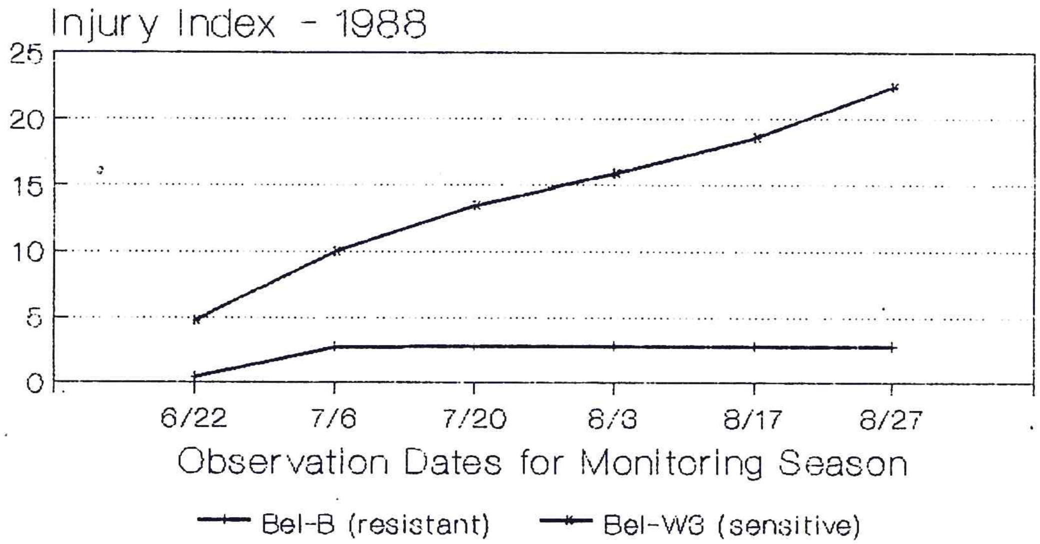
Injury Index is fully explained in text.
Mean SE for Bel-B = 0.0; Bel-W3 = 0.1;

Figure 5. Seasonal Mean Foliar Injury for Bel-B and Bel-W3 Tobacco Cultivars.



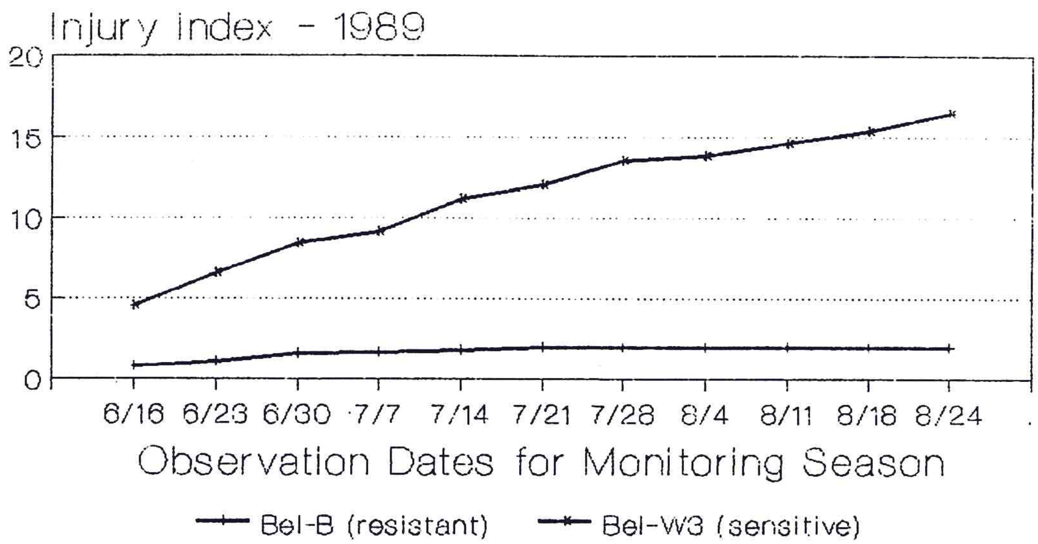
After 2 weeks exposure to ambient ozone.
Injury index fully explained in text.
Mean SE for Bel-B = 0.0; Bel-W3 = 0.1;

Figure 6. Cumulative Foliar Injury on Bel-B and Bel-W3 Tobacco for the 1988 Monitoring Season.



Note difference in injury severity for the ozone resistant and ozone sensitive cultivars. Compare to Figure 7.

Figure 7. Cumulative Foliar Injury on Bel-B and Bel-W3 Tobacco for the 1989 Monitoring Season.



Compare index values and slope to Fig 6.
Bel-B = ozone resistant;
Bel-W3 = ozone sensitive;

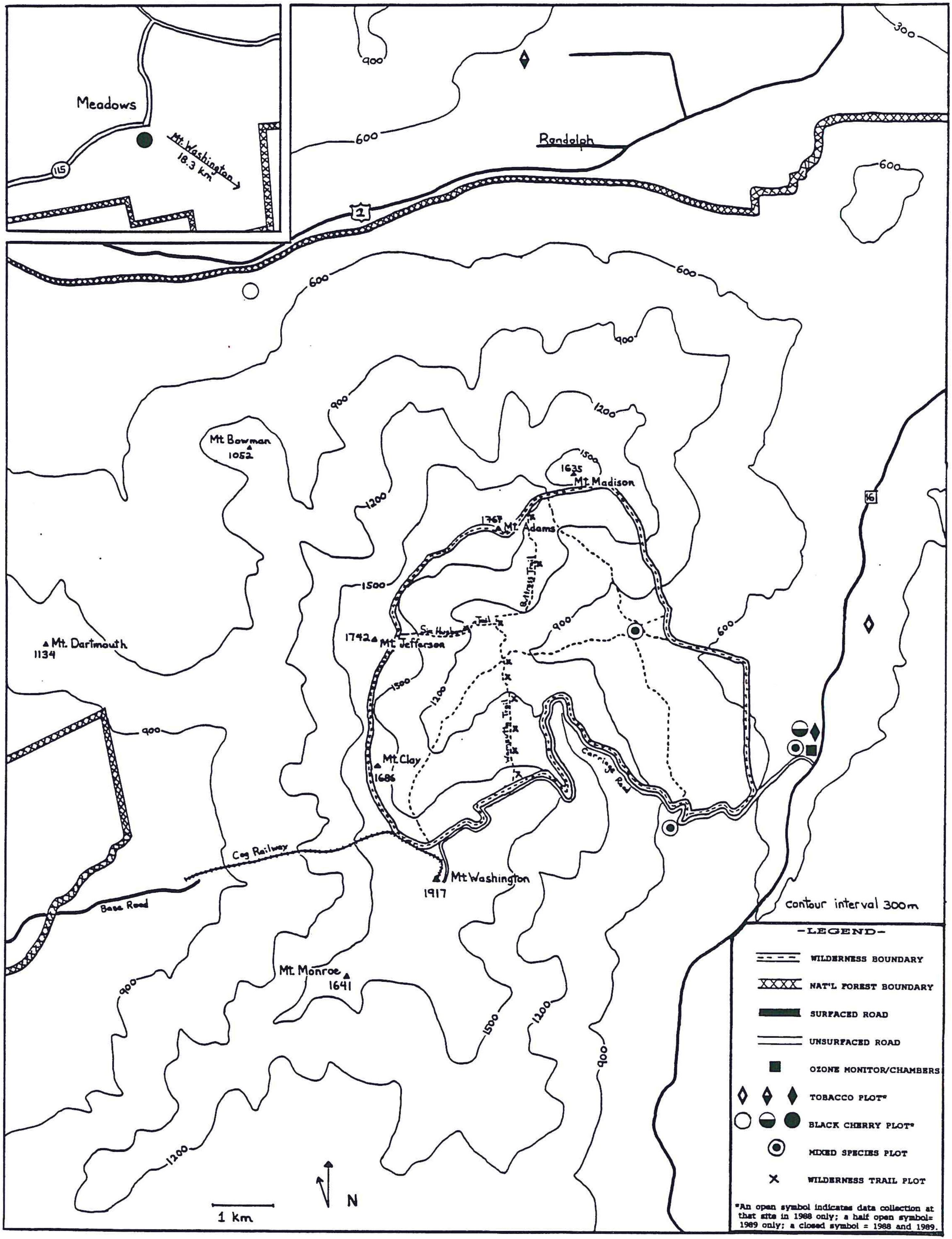


Figure 8. Map of the Great Gulf Wilderness, White Mountain National Forest.

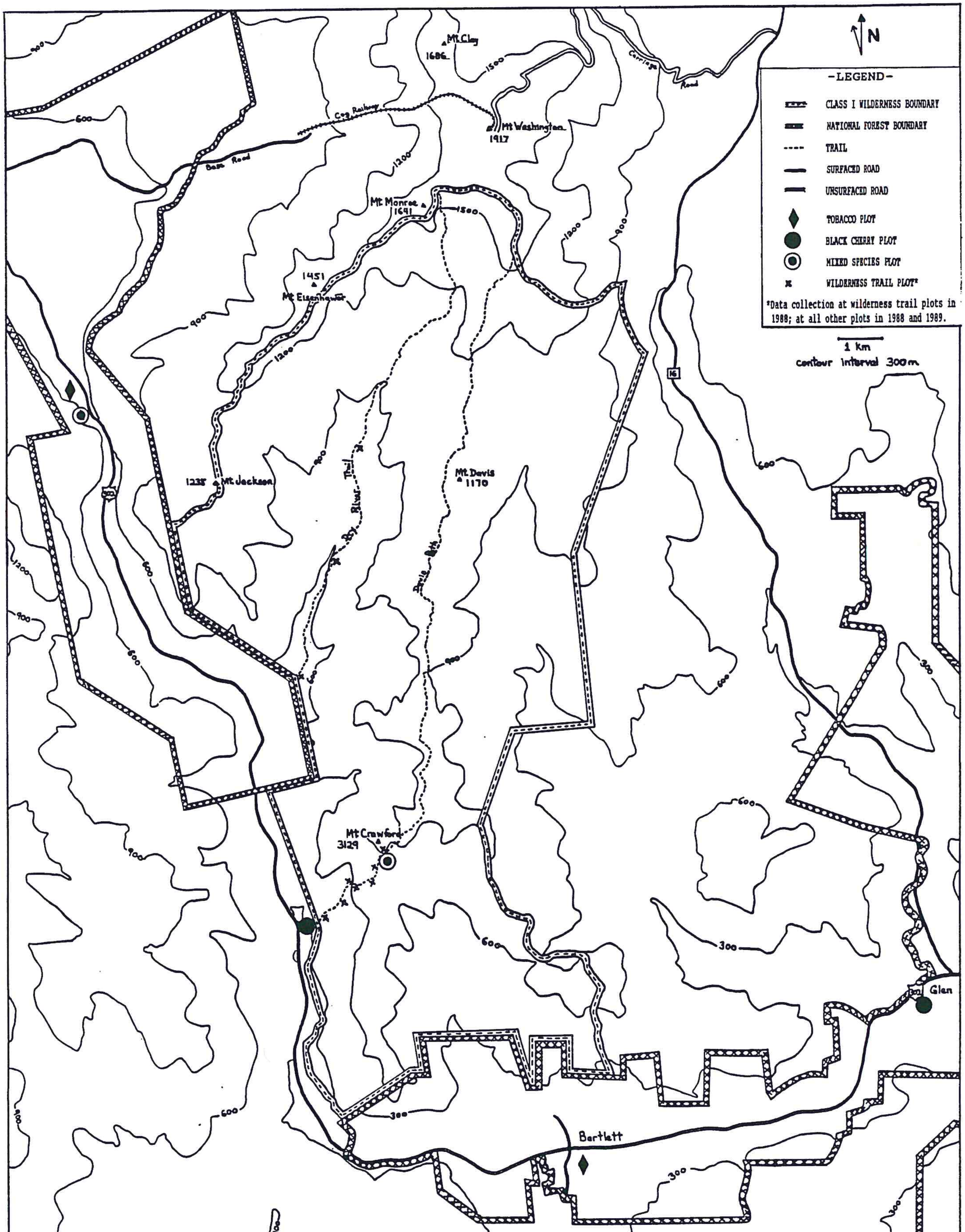


Figure 9. Map of the Dry River Wilderness, White Mountain National Forest.

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TABLE 1. Ozone Bioindicators Used in the Survey of Ozone Damage to Vegetation in the Great Gulf and Dry River Wilderness Areas - White Mountain National Forest, New Hampshire.**

+ Acer spp.	Maple (not including red maple)
* Alnus crispa	Mountain alder
Aralia nudicaulis	Wild sarsaparilla
Asclepias syriaca	Milkweed
* Aster puniceus	Aster
* Betula papyrifera	Paper birch and yellow birch
+ Cornus florida	Flowering dogwood
Fraxinus americana	White ash
Pinus strobus	White pine
Populus tremuloides	Quaking aspen
Prunus serotina	Black cherry
Rubus allegheniensis	Blackberry
* Sorbus americana	American Mountain ash
* Spiraea latifolia	Spirea
+ Tsuga canadensis	Eastern hemlock
Vitis labrusca	Wild grape

**Compiled from a variety of sources listed in the bibliography.
+ Alternately listed as ozone resistant in some sources.
* Genus, not species, listed as ozone sensitive.

Table 2. Number of hours that the ozone concentration exceeded 80 and 50 ppb, the growing season average, and the second highest 1 hour average for the monitoring season - 1988 and 1989.

	1988		1989	
Month	No. hrs. >80 ppb	No. hrs. >50 ppb	No. hrs. >80 ppb	No. hrs. >50 ppb
June*	31	117	0	8
July	4	88	0	70
August	2	65	0	40
September	0	9	0	41

Year	Growing Season Ave.**	Second Highest 1 Hour Ave.
1988	32.2 ppb	93 ppb
1989	28.8 ppb	78 ppb

*Elevation at the monitoring site = 476 m; The monitoring season in 1988 extended from June 11th to September 16th, in 1989 from June 16th to September 20th.

**Ozone concentrations recorded on the summit (elevation 1915 m): Growing season ave. = 55 ppb in 1988 and 50 ppb in 1989; Second highest 1 hour ave. = 148 ppb in 1988 and 134 ppb in 1989.

Table 3A. 1988 summary data for the bioindicator plants on the mixed species plots. Includes average injury index, severity group, and date when injury was first noted for the symtomatic plants at each site.

Site A: Gorham, N.H. - Auto Road Elevation: 1600'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Aster sp.	10	10	13.0	severe	8/11
Betula sp.	10	0	-	-	-
Prunus serotina	5	0	-	-	-

Site B: Crawford Notch, N.H. - Depot Elevation: 1900'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Acer saccharum	2	0	-	-	-
Aster sp.	10	7	9.0	severe	8/11
Betula sp.	12	0	-	-	-

Site C: Davis Path at the turnoff to Mt.Crawford Elevation: 2900'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Alnus sp.	4	1	16.0	severe	8/16
Betula sp.	10	0	-	-	-
Sorbus americana	4	0	-	-	-
Spiraea latifolia	10	7	12.5	severe	8/16

Site D: Old Jackson Road at 2 mile post on Auto Road Elevation: 2600'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Acer spicatum	2	0	-	-	-
Alnus rugosa	10	3	6.3	moderate	8/15
Betula sp.	10	1	16.0	severe	8/15
Sorbus americana	3	1	8.0	moderate	8/15

Site E: Madison Gulf Trail at junction with The Bluff Elevation: 2400'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Betula sp.	5	0	-	-	-

*The injury index includes an evaluation of both amount and severity of foliar injury due to ozone. See text for an explanation of the scale used.

**The severity group ratings are derived from the average injury index as follows: 0=none; 1-2.0=trace; 2.1-4.0=slight; 4.1-8.0=moderate; 8.1-16=severe.

Table 3B. 1988 summary data for the bioindicator plants on the mixed species plots including total number of plants evaluated and how many fell into each ozone severity group.

Total Number Of Sample Plants**	Number of Indicator Plants in Each Ozone Severity Group*				
	None	Trace	Slight	Moderate	Severe
107	77	1	2	7	20

*The severity group ratings are derived from the injury index as follows: 0=none; 1-2.0=trace; 2.1-4.0=slight; 4.1-8.0=moderate; 8.1-16.0=severe.
**All species combined from the five survey sites.

Table 4A. 1989 summary data for the bioindicator plants on the mixed species plots. Includes average injury index, ozone severity group, and date when injury was first noted on the symptomatic plants at each survey site.

Site A: Gorham, N.H. - Auto Road — Elevation: 1600'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Alnus rugosa	10	5	2.8	slight	8/3
Aster sp.	11	2	2.5	slight	8/21
Betula sp.	4	0	-	-	-
Prunus serotina	2	0	-	-	-
Rubus allegheniensis	10	2	1.0	trace	8/15
Spiraea sp.	10	0	-	-	-

Site B: Crawford Notch, N.H. - Depot — Elevation: 1900'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Acer saccharum	4	0	-	-	-
Alnus rugosa	6	2	2.5	slight	7/28
Aster sp.	10	1	2.0	trace	8/18
Betula sp.	10	4	3.2	slight	8/2
Populus tremuloides	10	1	4.0	slight	8/18
Rubus allegheniensis	10	3	3.6	slight	8/2
	10	6	3.6	slight	8/18
Spiraea sp.	10	4	13.2	severe	8/18

Site C: Davis Path at the turnoff to Mt.Crawford — Elevation: 2900'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Alnus crispa	7	4	7.7	moderate	8/2
Alnus rugosa	6	2	1.0	trace	8/22
Betula sp.	10	3	3.3	slight	8/2
Sorbus americana	10	5	8.0	moderate	8/2
Spiraea latifolia	10	5	8.6	severe	8/2

Site D: Old Jackson Road at 2 mile post on Auto Road — Elevation: 2600'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Alnus sp.	10	6	2.5	slight	7/26
Betula sp.	10	4	2.7	slight	7/26
Spiraea sp.	5	0	-	-	-
Sorbus americana	3	3	3.3	slight	7/26

Site E: Madison Gulf Trail at junction with The Bluff — Elevation: 2400'

Species	Total Number Plants Sampled	Number Plants With Symptoms	Average Injury Index*	Severity Group**	Date
Betula sp.	7	0	-	-	-

*The injury index includes an evaluation of both amount and seveity of foliar injury due to ozone. See text for an explanation of the scale used.

**The severity group ratings are derived from the average injury index as follows: 1 - 2.0 = trace; 2.1 - 4.0 = slight; 4.1-8.0 = moderate; 8.1-16 = severe.

Table 4B. 1989 summary data for the bioindicator plants on the mixed species plots including total number of plants evaluated and how many fell into each ozone severity group.

Total Number Of Sample Plants**	Number of Indicator Plants in Each Ozone Severity Group*				
	None	Trace	Slight	Moderate	Severe
195	133	22	27	7	6

*The severity group ratings are derived from the injury index as follows: 0=none; 1-2.0=trace; 2.1-4.0=slight; 4.1-8.0=moderate; 8.1-16.0=severe.
**All species combined from the five survey sites.

Table 5. Percentage of sample trees in each ozone severity group for 1988 and 1989. Summary data for the bioindicator plants on the mixed species plots.

Ozone Severity Group	Year 1988	1989
	(%)	
Trace	1.2	11.3
Slight	1.8	13.8
Moderate	6.5	3.6
Severe	18.6	3.1
Percent Uninjured	71.9	68.2

Table 6A. 1988 summary data for black cherry trees at the 5 permanent survey plots. Includes sample size, average injury index, and date when injury was first noted on branch samples of the symptomatic plants.

Site A: Base of the Auto Road in Gorham — Elevation: 1600'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
-	-	-	-	-	-

Site B: Cherry Mountain Road off Rt. 115 — Elevation: 1500'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
5	3	25	3	13.3	8/23

Site C: Davis Path - Trail Head off Rt. 302 — Elevation: 1000'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
6	4	30	6	12.0	8/8

Site D: Glen Ellis Campground off Rt. 302 — Elevation: 500'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
12	4	60	6	14.6	8/22

Site E: Bowman Base Camp off Rt. 2 — Elevation: 1500'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
3	0	15	-	-	-

*The injury index includes an evaluation of both amount and severity of foliar injury due to ozone. Mean values range from 0 to 16 as follows: 0=no injury; 1-2.0=trace; 2.1-4.0=slight; 4.1-8.0=moderate; 8.1-16.0= severe injury. See text for additional explanation.

Table 6B. 1988 summary data for the black cherry trees on the permanent plots including total number of plants evaluated and how many fell into each ozone severity group.

Total Number of Sample Trees	Number of Trees in Each Ozone Severity Group*				
	None	Trace	Slight	Moderate	Severe
26	15	0	0	0	11

*As described above and in the text.

Table 7A. 1989 summary data for black cherry trees at the 5 permanent survey plots. Includes sample size, average injury index, and date when injury was first noted on branch samples of the symptomatic plants.

Site A: Base of the Auto Road in Gorham — Elevation: 1600'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
6	3	30	4	2.0	8/15

Site B: Cherry Mountain Road off Rt. 115 — Elevation: 1500'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
5	1	25	4	11.2	8/23

Site C: Davis Path - Trail Head off Rt. 302 — Elevation: 1000'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
8	3	40	7	3.7	8/14

Site D: Glen Ellis Campground off Rt. 302 — Elevation: 500'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
10	1	48	1	2.0	8/23

Site E: Bowman Base Camp off Rt. 2 — Elevation: 1500'

No. Plants Sampled	No. Plants W/ Symptoms	No. Branches Sampled	No. Branches W/ Symptoms	Average Branch Injury Index*	Date
-	-	-	-	-	-

*The injury index includes an evaluation of both amount and severity of foliar injury due to ozone. Mean values range from 0 to 16 as follows: 0=no injury; 1-2.0=trace; 2.1-4.0=slight; 4.1-8.0=moderate; 8.1-16.0= severe injury. See text for additional explanation.

Table 7B. 1989 summary data for the black cherry trees on the permanent plots including total number of plants evaluated and how many fell into each ozone severity group.

Total Number of Sample Trees	Number of Trees in Each Ozone Severity Group*				
	None	Trace	Slight	Moderate	Severe
29	22	3	1	1	2

*As described above and in the text.

Table 9. Effect of chamber treatment on stem height, stem diameter, and shoot growth of tree seedlings in 1989.

Chamber Treatment	Change in Growth Over 10 Week Exposure Period		
	Stem Height (cm)	Stem Diameter (mm)	Shoot Growth (mm)
		White Ash	
Filtered ($-O_3$)	95.6 (45.1)[x]	0.8 (0.2)	87.7 (40.2)
Unfiltered ($+O_3$)	126.3 (19.1)	0.9 (0.1)	23.5 (12.2)
No Chamber ($+O_3$)	45.7 (18.4)	0.5 (0.1)	49.2 (31.7)
		Red Spruce	
Filtered ($-O_3$)	28.0 (5.0)	-	223.0 (30.0)
Unfiltered ($+O_3$)	13.3 (3.8)	-	212.3 (35.8)
No Chamber ($+O_3$)	18.6 (1.7)	-	169.7 (26.6)
		Black Cherry	
Filtered ($-O_3$)	171.2 (16.4)	1.3 (0.1)	154.8 (24.3)
Unfiltered ($+O_3$)	155.0 (18.6)	1.2 (0.1)	144.5 (37.6)
No Chamber ($+O_3$)	*93.4 (12.7)	*0.7 (0.1)	106.7 (21.9)

x Average of 6 replications for white ash, 26 replications for red spruce, and 20 replications for black cherry. Numbers in parentheses = standard error of the mean.

* Mean separation by DMRT at 5% level.

Table 10. Severity classification for ozone bioindicator plants indigeneous to the Class I Wilderness Areas in the White Mountain National Forest.

Ranking	Susceptibility Value*
1. *Aster* spp.	82
2. *Spiraea latifolia*	41
3. *Prunus serotina*	27
4. *Alnus* spp.	22
5. *Sorbus americana*	15
6. *Rubus allegheniensis*	13**
7. *Betula*	4
8. *Populus* spp.	<1
9. *Acer* spp.	0

*According to a procedure described by Davis and Wood (1972), the susceptibility value is obtained by multiplying the incidence of susceptible members of each species by the mean foliar index score of each species.
**Evaluated for only 1 year (1989).

APPENDIX I.

Background on Ozone and Biomonitoring:

The National ambient air Quality Standard for ozone is 0.12 ppm with an averaging time of one hour. Normal atmospheric ozone content is in the 0.020 to 0.035 ppm range while in polluted areas concentrations may exceed 0.200 ppm ozone. Concenrations of 0.05 to 0.12 ppm ozone for two to four hour exposure periods will cause injury to the most sensitive plants. Due to its phytotoxicity, ozone has long been the focus of research studies on plant-pollutant interactions. More recently, ozone has been recognized as a significant component of the complex of greenhouse gases that are contributing to the global warming trend and possible forest decline problems.

Ozone effects plants internally by diffusing into the leaf through the stomata, the pathway by which gas exchange normally occurs in plants. Because ozone is a strong oxidizing agent, once it is absorbed it will react with many chemical components of plant cells. Presumably, the primary action of ozone on plants is to increase cell permeability through oxidation of protein and lipid components of the cell membranes. This disrupts nearly all physiological functions of cells by imbalancing the osmotic relations. Visual toxicity symptoms and growth reductions result if the concentration and duration of exposure to ozone exceed a plant's genetic capability to withstand the stress. The expression of toxicity symptoms is also dependent on environmental factors (e.g. nutrition, soil moisture, insect injury and disease) that influence opening and closing of stomata.

Certain plants respond to ozone in predictable and reliable ways and can therefore be used to biologically determine that ozone is present in ambient air. These plants indicate that ozone is present at concentrations that will cause injury. For a particular geographical area and time period, we can obtain a biologically meaningful measure of air quality by observing how bioindicators respond in ambient air. For the purposes of this study, we conducted a preliminary survey to establish that the vegetation in the study area included a number of useful bioindicators of ozone pollution.

APPENDIX II.

Description of the Study Area:

The White Mountain National Forest includes a total of 752,000 acres in north-central New Hampshire. Both the Great Gulf and Presidential-Dry River Wilderness Areas are contained within the National Forest and both are designated as Class I.

The Great Gulf Wilderness Area (GGWA) constitutes 5,552 acres in the valley between Mount Washington and the Northern Peaks, beginning 0.5 miles below the summit of Mount Washington. It is bordered by the Mount Washington Carriage Road on the south, and extends to the north as far as Mount Madison. The Great Gulf itself is a bowl-shaped area drained by the Peabody River, with a depth ranging from 1,100 to 1,600 feet. The Great Gulf includes steep slopes and a number of cascades.

The Dry River Wilderness Area consists of the Dry River Valley and parts of the Montalban Ridge, for a total of 20,000 acres. It extends north as far as the Lakes of the Clouds and continues south to Hart Ledge and Cave Mountain, with Mount Webster to the western extreme and Maple Mountain to the east.

Coniferous forests (spruce and fir) dominate the higher elevation forests in both wilderness areas, whereas deciduous species (beech, birch, and maple) are more common on the lower slopes. Understory vegetation is quite varied, consisting mostly of birch and maple seedlings with lesser amounts of spruce, fir, dogwood, cherry, oak, hemlock and assorted shrubs. Both wilderness areas are almost entirely forested except for the peaks above tree line and along the steepest slopes. Open areas on the lower slopes are not common. The most common ozone sensitive plant species in the study area include alder, serviceberry, birch, dogwood, white ash, white pine, black cherry, blackberry and milkweed.

Reference should be made to the Draft Work Plan provided in June, 1988 for originals of the following:

1. Color maps that describe the predominant overstory and understory vegetation in the Great Gulf and Dry River Wildernesses.

2. Plant lists: Presidential Range - alpine and subalpine plants; Presidential Range - below tree-line herbs; Presidential range - below tree-line trees; Herbaceous plants and tree species listed as sensitive and resistant to ozone in the literature; Ozone sensitivity table for low elevation plants in the Presidential range; Ozone sensitivity table for alpine and subalpine plants in the Presidential Range.

APPENDIX III.

1. Data Sheets for the Tobacco Monitoring Procedures.

2. Data Sheets for Evaluations of Foliar Response and Growth of Tree Seedlings Growing in the Open-Top Chambers.

TOBACCO LEAF INJURY

LOCATION_____ DATE_____ SET #_____ PLANT #_____

CULTIVAR_____ EVAL.: INJ_____/GRO._____

	% LF. INJ.			PL. HT			AREA		
DATE									
LF.#									
1									
2									
3									
4									
5									
6									
7									
8									

EXPANDED SCALE FOR EVALUATING OZONE INJURY ON TOBACCO

numerical rating	% leaf injury
0	0
1	1-5
2	6-12
3	13-24
4	25-40
5	41-59
6	60-75
7	76-87
8	88-94
9	95-99
10	100

CHAMBER SURVEY

circle- ASH CHERRY SPRUCE Ring/Chamber # _____
Date initial_____/final_____

seedling #	ht.	ht.	dia.	dia.	TOTAL gr.	gr.
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

WEEKLY SURVEY OF OZONE INJURY TO SEEDLINGS

circle-ASH CHERRY ring/chamber #_____ date____

TREE # \ LF. #	1	2	3	4	5	6	7	8	9	10	TOTAL
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											

INTENSITY SCALE
0----------NONE
1---------TRACE
2---------LIGHT
3------MODERATE
4---------HEAVY

APPENDIX IV.

Field Data Sheets for the Survey Procedures.

1. Preliminary Survey - 1987
2. Preliminary Survey Code Sheet
3. Site Characterization
4. Foliar Evaluation - Broad Leaved Plants
5. Foliar Evaluation - Narrow Leaved Plants
6. Foliar Evaluation - Black Cherry

FIELD DATA SHEET PRELIMINARY SURVEY
AUGUST, 1987

Trail:
Approximate Elevation:
Slope Facing:

Samples Collected;
Photos Taken;

1. Overstory Vegetation

    Forest Type =

    Predominant Species =

    Less Frequent Species =

2. Understory Species (+ or -)

    Tree Seedlings =

    Herbacious =

3. Indicator Species

Species Present (+ or -)	Symptom (+ or -)

4. Leaf Symptoms on Species not Listed as Indicators

Species (+ or -)	Symptom (+ or -)

5. Comments

DATA CODE SHEET FOR PRELIMINARY SURVEY
AUGUST, 1987

Ozone Indicator Species

1. white ash
2. blackberry
3. black cherry
4. grape
5. milkweed
6. flowering dogwood
7. white pine
8. sassafras
9. yellow poplar
10. trembling aspen
11. sarsparilla
12. aster
13. chickweed

Forest Type

1. northern hardwoods
2. spruce-fir
3. krummholz
4. alpine tundra

Visible Leaf Symptoms

1. stipple = purple to black spotting usually on upper surface only
2. flecking = bleached spots, dead tissue usually bifacial
3. general chlorosis
4. tip or marginal chlorosis/necrosis
5. none present

(+) = use to indicate that a species is present in relatively large numbers <u>or</u> that the leaf symptoms are obvious and pronounced

(-) = use to indicate low numbers of a particular species <u>or</u> that symptoms are faint or scattered

Field Data Sheet for Site Characteristics*

Plot No:
Date:
Location:

1. Elevation (to nearest 100') ____________

2. Aspect ____________

3. Slope ____________

   1 = flat, 0 - 10%
   2 = 11 - 45%
   3 = 46 - 100%
   4 = > 100%

4. Terrain Position ____________

   1 = lowlands
   2 = hillside
   3 = ridgetop

5. Soil Depth ____________

   1 = bedrock not exposed
   2 = bedrock exposed

6. Soil Drainage ____________

   1 = well drained
   2 = wet
   3 = excessively dry

7. Disturbance ____________

   1 = no disturbance
   2 = ice, wind and snow
   3 = evidence of fire
   4 = evidence of logging
   5 = evidence of overuse
   6 = other

8. Comments:

*Adapted from Weiss et al. (1985)

EXTENSIVE SURVEY – BROAD LEAVED BIOINDICATOR PLANTS

Plot Number_______________ Date__________

Location_______________ Weather: wet__ dry__

Species_______________ Visibility: good__ bright__ poor__

FOLIAR EVALUATION	PLANT NUMBER 1	2	3	4	5	6	7	8	9	10
% Leaf Area Injured										
Severity Rating										
Injury Index										
SYMPTOMATIC LEAVES										
LOCATION										
Upper Crown										
Lower Crown										
Older Leaves										
Midaged Leaves										
Younger Leaves										
Upper Leaf Surface										
Lower Leaf Surface										
COLOR AND PATTERN										
Yellow										
Faded Green										
Brown (Tan)										
Purple – Red										
Black										
Uniform										
Intermittent										
Marginal										
PROBABLE CAUSE										
Ozone										
Other										
Photo Number(s)										

Total Number of Trees Sampled [ ] Number of Trees with Symptoms [ ]

Comments:

Percent Scale: 0 = no injury; 1 = 1–5% of the leaf area or leaf sample with symptoms; 2 = 6–25%; 3 = 26–5–%; 4 = >50%

INTENSIVE SURVEY – BLACK CHERRY

Plot Number__________ Tree Number______ Weather: wet __ dry __
Location__________ Stem Height______ Visibility:
Date__________ DBH__________ good__ bright__ poor__

FOLIAR EVALUATION	BRANCH NUMBER 1	2	3	4	5
Total No. of Leaves					
Number with Symptoms					
% Injured/Branch					
Severity Rating					
Injury Index					
SYMPTOMATIC LEAVES:					
LEAF AGE					
Older					
Midaged					
Younger					
LEAF AREA					
Upper Surface					
Lower Surface					
Margins					
Between Veins					
Across Veins					
Small Contiguous Areas					
Large Contiguous Areas					
LEAF PIGMENTATION					
Yellow					
Faded Green					
Brown (Tan)					
Purple – Red					
Black					
PROBABLE CAUSE					
Ozone					
Other					
Photo Number(s)					

Ave. Injury Index [ ]

Comments:

Percent Scale: 0 = no injury; 1 = 1–5% of the branch leaf area or leaf sample with symptoms;
2 = 6–25%; 3 = 26–50%; 4 = >50%

APPENDIX V.

Site Characterization - Summary Data For All Field Plots.

A. Mixed Species Plot - Extensive Survey.

Plot 1

Location: Northwest corner of the open field at the base of the Mt. Washington Auto Road. (GGWA)
Forest Type: northern hardwoods

Elevation: 1500'
Aspect: SE
Slope: 0 to 10%
Size: 100' x 100'

Terrain Position: lowland
Soil Depth: bedrock not exposed
Soil Drainage: wet
Disturbance: mowed field

Plot 2

Location: Clearing at the base of the Avalon-Wilhard Trailhead near the Crawford Notch Depot. (DRWA)
Forest Type: northern hardwoods

Elevation: 2100'
Aspect: SE
Slope: 0 to 10%
Size: open area

Terrain Position: lowland
Soil Depth: bedrock not exposed
Soil Drainage: wet
Disturbance: cleared at one time

Plot 3

Location: Davis Path Trailhead at base of Mt. Crawford. (DRWA)
Forest Type: spruce-fir

Elevation: 2800'
Aspect: NNW
Slope: 11-45%
Size: open area

Terrain Position: ridgetop
Soil Depth: bedrock exposed
Soil Drainage: excessively dry
Disturbance: none

Plot 4

Location: Gravel pit along Old-Jackson Road. (GGWA)
Forest Type: northern hardwoods

Elevation: 3200'
Aspect: W
Slope: 11-45%
Size: size of pit

Terrain Position: hillside
Soil Depth: bedrock exposed
Soil Drainage: wet
Disturbance: overuse

Plot 5

Location: Old shelter site at the junction of the Madison Gulf and the Bluff wilderness trails. (GGWA)
Forest Type: spruce-fir

Elevation: 2500'
Aspect: SW
Slope: 0-10%
Size: cleared area

Terrain Position: ridgetop
Soil Depth: bedrock exposed
Soil Drainage: dry
Disturbance: overuse

B. Black Cherry Plot - Intensive Survey.

Forest Type: northern hardwoods (all plots)

Plot 1

Location: Along edge of field at base of the Mt. Washington Auto Road. (GGWA)

Elevation: 1500'
Aspect: NW
Slope: 0-10%
Size: 6 trees

Terrain Position: lowlands
Soil Depth: bedrock not exposed
Soil Drainage: wet
Disturbance: mowed field

Plot 2

Location: Dry River Basin at entrance to Davis Path just off Rt. 302. (DRWA)

Elevation: 1000'
Aspect: W
Slope: 0-10%
Size: 8 trees

Terrain Position: lowlands
Soil Depth: Bedrock nor exposed
Soil Drainage: wet
Disturbance: road construction

Plot 3*

Location: Adjacent to the railroad bed across from Nancy Pond, 1 mile south of the Davis Path Trailhead. (DRWA)

Elevation: 1000'
Aspect: W
Slope: 0-10%
Size: 1 tree

Terrain Position: lowlands
Soil Depth: bedrock not exposed
Soil Drainage: wet
Disturbance: near RR bed

Plot 4

Location: Camp site at base of Mt. Bowman just off Rt.2. (GGWA)

Elevation: 1500'
Aspect: E
Slope: 0-10%
Size: 3 trees

Terrain Position: lowlands
Soil Depth: bedrock not exposed
Soil Drainage: dry
Disturbance: overuse

Plot 5*

Location: Rocky Branch shelter No. 2 near the junction of Isolation Trail and the Rocky Branch Trail. (DRWA)

Elevation: 2800'
Aspect: NNE
Slope: 0-10%
Size: 1 tree

Terrain Position: ridgetop
Soil Depth: bedrock exposed
Soil Drainage: wet
Disturbance: overuse

Plot 6

Location: Open field at Glen Ellis Campground near the junction of Rt. 302 and Rt. 16N. (DRWA)

Elevation: 500'
Aspect: NE
Slope: 0-10%
Size: 12 trees

Terrain Position: lowlands
Soil Depth: bedrock not exposed
Soil Drainage: dry
Disturbance: old field

Plot 7

Location: Cherry Mountain Road off Rt. 115 near Meadows. (GGWA)

Elevation: 1500'
Aspect: WNW
Slope: 0-10%
Size: 5 trees

Terrain Position: lowlands
Soil Depth: bedrock not exposed
Soil Drainage: dry
Disturbance: old field

*Dropped from the survey in 1989.

APPENDIX VI.

Open-Top Chamber Design.

Location: Developed at North Carolina State University with funding from the U.S. Environmental Protection Agency (EPA)

Summary: A detailed description is provided by Heagle et al. (1973) for construction and operation of one of the first open-top field chambers designed for exposures of vegetation to gaseous pollutants in the field. The chamber was adaptable for both pollutant exclusion and addition studies. Tests at multiple sites with many crops indicated the near ambient environmental conditions in the chambers and uniformity of pollutant dispersal. Tests also indicate the usefulness of the chamber for crop loss assessments on a growing season basis. This generic description is applicable to the basic chamber design as tested by a number of researchers. Table C-1 summarizes some basic characteristics of the EPA-designed chamber as it is used by a number of research groups throughout the U.S. and Canada.

1. Hardware

a. Chambers

The chambers are open-top cylinders 2.4 m high x 3.0 m in diameter with an interior plant growing area of 7.1 m^2. The frame is of three rolled-aluminum hoops 1.2 m apart with vertical and oblique aluminum crossbars. The chamber is covered with PVC plastic in separate upper and lower panels. The lower panel is two layers, an inner layer perforated with 250 0.025-m diameter holes, and an outer layer without holes. The lower panel inflates with forced air and acts as a plenum or diffuser. Air flows from the plenum across the plant canopy and out the top of the chamber. The original chamber design ended abruptly at the top of the cylinder, resulting in a turbulent flow of ambient air into the chamber which increased with increasing wind speed. Addition of a conical nozzle or frustum at the top greatly reduces the rate of ambient air incursion, and makes chamber pollutant concentrations more uniform both vertically within the chamber and at different ambient windspeeds (Davis and Rogers, 1980). The frustum is at a 45° angle rising from the top of the chamber resulting in a total chamber height of 2.9 m. This reduces the effective open-top of the chamber to 2.1 m in diameter. Slight modifications of the frustum are often made for the chamber based on local site conditions.

Air is supplied by a 0.63 hp axial-blade fan located in a sheet-metal blower box. The box is equipped with dust-filters and charcoal-filters when supplying filtered air. Air is blown into the chamber at a rate of 70.8 m^3 min^{-1}.

b. Pollutant Dispensing and Monitoring

Pollutant dispensing varies with the chamber installation. A system for dispensing and monitoring O_3 for the chamber has been described in detail by Heagle et al. (1979). Ozone is produced from oxygen with a "silent arc" generator controlled by a timer. Oxygen flow is adjusted with a pressure regulator, needle valve, solenoid, time clock, and rotameter. Safety switches in the O_3 generator stop the operation automatically if required. Ozone is dispensed from a manifold to individual chambers via rotameters. Pressure is regulated in the manifold to stabilize the rotameters.

Pollutant monitoring (O_3) is via individual air samples drawn through teflon tubing from each chamber through solenoid valves to either a sampling manifold or exhaust manifold by vacuum pumps. Both vacuum pumps exhaust O_3 to the atmosphere through charcoal filters. Sequential activation of the solenoids by a timer (scanner) causes the sample to be delivered to the sampling manifold. Samples are drawn from the sampling manifold by a chemiluminescent O_3 analyzer.

c. Environmental Control and Monitoring

The original EPA chamber has been designed to provide minimal environmental modification but without an initial capacity to control either the atmospheric or soil environment. Stretching polypropylene shade cloth (rated for different degrees of light reduction) across the top of the chamber allows for manipulation of radiation intensity x O_3 interaction studies (Heagle and Letchworth, 1982). Alteration of soil moisture through manipulation of irrigation allows for water stress x O_3 interaction studies (Temple et al., 1985). Placement of the chambers over controlled salinity soil profile plots allows for soil salinity x O_3 interaction studies (D. Olszyk, personal communication). Air flow rate through the chamber can be modified by placing baffles upstream of the fan (Unsworth et al., 1984a,b).

d. Data Aquisition

Data aquisition varies with the installation, but may include manual reduction from recorder charts, or use of a datalogger or interface-computer system for continuous storage of data.

2. Performance Evaluation

a. Pollutant uniformity

Vertical variation in O_3 concentrations is less than 6% of the mean between 0.3- and 1.2-m heights in the chamber. Horizontal variation across the chamber is less than 6, 12, and 14% of the mean at heights of 0.3, 1.2, and 1.8 m. This variation is based on wind speeds less than 4.2 m s^{-1} for a chamber without a frustum (Heagle et al., 1979). At higher wind speeds, uniformity decreases greatly unless a frustum is added. Ambient O_3 exclusion rates ranges from 75% at low wind speeds to 57% at high wind speeds.

b. Environmental Uniformity

Environmental conditions in the chambers vary slightly from outside conditions (Heagle et al., 1973; Heagle and Philbeck, 1978; Heagle et al., 1979; Heggestad et al., 1977; Olszyk et al., 1980; Weinstock et al., 1982). Air temperature generally is $\leq$ 2°C warmer than outside based on peak temperatures > 32°C. Relative humidity is generally the same as outside, but may be a few percent lower if chamber air tempertures are greater than outside, or slightly higher if air flow is reduced or the chamber contains a great deal of plant material. Irradiance is usually within 85-95% of ambient. Irradiance is decreased with dirty chamber plastic or during spring or fall months with low sun angles. Irradiance can also be temporarily increased with certain sun angles and clean plastic covering. Air movement over the plant canopy at the center of the chamber is approximately 0.6 m s^{-1}. The rainfall pattern inside the chambers varies from outside depending on wind speed.

c. Pollutant Control and Maintenance

The O_3 dispensing and monitoring system of Heagle et al. (1979) performs well over continuous growing season studies. Additional modifications to the original dispensing system, such as feedback control to the O_3 generator via a computer, provide for proportional control of O_3 concentrations as some percentage of ambient (Temple et al., 1985). Computer-control also permits programmed dynamic exposures (Hogsett et al., 1985). Fine tuning of the solenoid system and/or use of critical orifices can further reduce variability in ozone concentrations between chambers and over the growing season (E. Pell, personal communication).

d. Environmental Control and Maintenance

The environmental conditions are similar to ambient (see 2b) at least during the growing season. Maintenance of the plastic film for transparency and the blower for maximum flow rate help keep the chamber environment near outside conditions.

e. Chamber Equilibration

The chamber air exchange rate is approximately 4 chamber volumes per minute.

White Mountain National Forest - NH
Site: Great Gulf Wilderness - Gorham

SPECIES: White ash - Ambient air plot.

INJURY INTENSITY: Moderate to severe.

LOCATION: Midaged leaves, upper-leaf surface.

COLOR AND PATTERN: Purple-red coloration/stipple.

LEAF PIGMENTATION: Faded green.

PROBABLE CAUSE: Ozone.

White Mountain National Forest - NH
Site: Great Gulf Wilderness - Gorham

SPECIES: Black Cherry - Unfiltered chamber.

INJURY INTENSITY: Light to moderate.

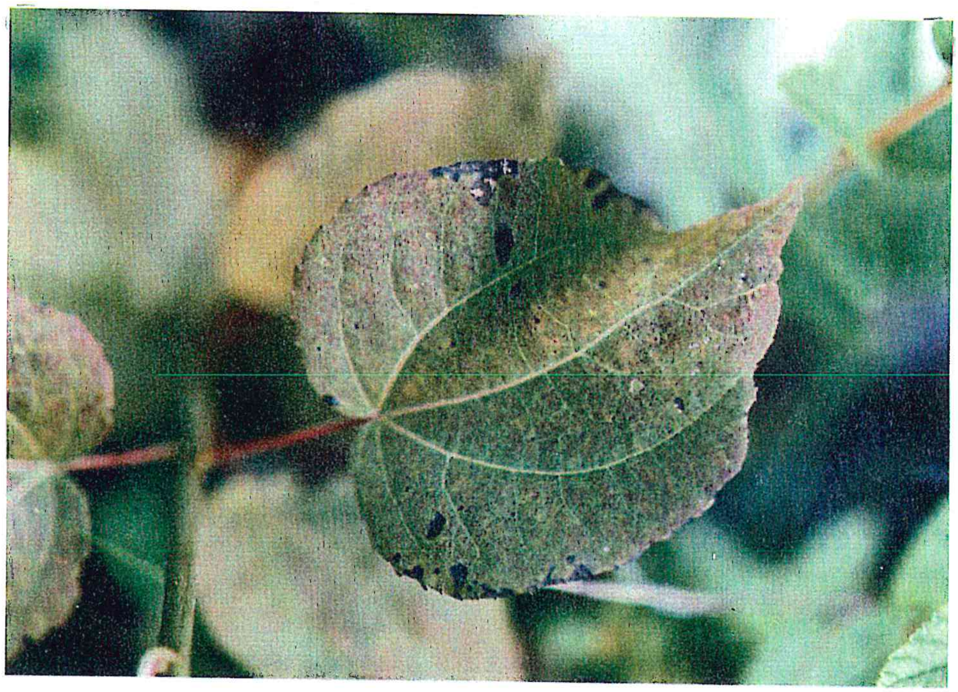
LOCATION: Midaged and older leaves, upper-leaf surface.

COLOR AND PATTERN: Purple-red stipple.

LEAF PIGMENTATION: Faded green to yellow.

PROBABLE CAUSE: Ozone.

White Mountain National Forest - NH
Site: Dry River Wilderness - Crawford Notch



SPECIES: Quaking aspen - Ambient air, survey plot.

INJURY INTENSITY: Light to moderate.

LOCATION: Midaged leaves, upper-leaf surface.

COLOR AND PATTERN: Purple-red stipple.

LEAF PIGMENTATION: Faded green to yellow.

PROBABLE CAUSE: Ozone.

White Mountain National Forest - NH
Site: Great Gulf Wilderness - Gorham

SPECIES: Birch - Ambient air, survey plot.

INJURY INTENSITY: Trace to light.

LOCATION: Midaged leaves, upper-leaf surface.

COLOR AND PATTERN: Purple-red to brown coloration.

LEAF PIGMENTATION: Faded green.

PROBABLE CAUSE: Ozone.