A Ten-Year Regional Assessment of Sugar Maple Mortality

Douglas C. Allen, Andrew W. Molloy, Robert R. Cooke, and Bruce A. Pendrel[1]

Abstract

The North American Maple Project (NAMP) monitored annual sugar maple mortality from 1988 through 1997 in Maine, Massachusetts, New Brunswick/Nova Scotia, New Hampshire, New York, Ontario, Quebec, Vermont, and Wisconsin. Annual mortality in Minnesota, Ohio and Pennsylvania was evaluated for 1992 through 1997. When data from the dominant/codominant and intermediate/suppressed crown levels were combined, average annual mortality (% trees) ranged from 1.9% (New York) to 0.3% (New Brunswick/Nova Scotia) in sugarbushes (SBs) and 1.9% (New Hampshire) to 0.4% (Wisconsin) in maple stands not managed for syrup production (NSBs). In general, mortality of dominant/codominant sugar maple was lower than in the intermediate/suppressed crown position. Average annual mortality was not significantly different among each of three elevational categories or among each of three deposition levels for wet sulfate or wet nitrate. Mortality in plot-clusters located >300 m elevation and exposed to high levels of wet nitrate (>20 kg/ha/yr) or wet sulfate (>27.5 kg/ha/yr) deposition was significantly greater in both SBs and NSBs compared to mortality in plot-clusters exposed to high levels of deposition but located <300 elevation (SB: >300 m 2.2%, <300 m 0.6%; NSB: >300 m 1.1%, <300m 0.3%). A number of small, but statistically significant ($p \leq 0.05$), differences in mortality occurred among three ecological Divisions, three Provinces and three Sections in the U.S., and three Ecozones and four Ecoregions in Canada. Within 13 geographic regions (states and provinces), two crown positions, two management categories, three levels of elevation, three deposition levels for both wet nitrate and wet sulfate, and 18 biophysical regions, annual sugar maple mortality documented by the NAMP was similar to mortality reported in the literature for typical northern hardwood stands. Mortality in SBs was similar to that in NSBs.

Introduction

The North American Maple Project (NAMP) was initiated in 1988 in response to public concern for the condition and sustainability of the sugar maple (*Acer saccharum* Marsh) resource. An earlier paper (Allen et al. 1992) reported on the crown condition of overstory sugar maple monitored during the first three years (1988-1991) of the project. More recently, Allen et al. (1995) summarized changes in crown condition for 1988 through 1995 and presented an overview of mortality. Here we examine nine years of sugar maple mortality (1989 through 1997) in the context of geographic regions (states and provinces), crown position, management category, levels of atmospheric deposition, elevation, and ecological unit. We address the hypothesis that sugar maple mortality which occurred in the NAMP plots during this period is within the range expected for the stand and site conditions included in the study.

Methods

The general methods used to select, establish and measure plot-clusters (Millers et al. 1991) changed little during the ten-year history of the NAMP (Allen et al. 1995). Stands were selected systematically to facilitate frequent visits, to cover a variety of sugar maple sites, to encompass a range of atmospheric deposition levels, and to assure long-term integrity. A cluster of five 20 x 20 m permanent plots was established in each stand. To qualify, a stand had to have an overstory that contained 50% or more sugar maple, 50-150 years old. All trees $\geq$ 10 cm diameter at breast height (1.4 m) were evaluated annually for crown condition and survival. Analyses of sugar maple mortality are presented as annual percent tree loss resulting from "natural" mortality. That is, we did not include loss of trees that were deemed healthy but died or were removed as a direct result of some forest management related activity, such as road building or thinning. Natural mortality constitutes a baseline for determining losses ostensibly due to natural stresses. The occurrence and extent of natural disturbances (e.g., insect defoliation, drought, wind damage, etc.) were incorporated into the database for each plot-cluster and used to establish the temporal occurrence and extent of stresses.

Annual mortality was determined by monitoring the number of trees surviving from one year to the next:

Annual Plot-Cluster Mortality=

$$\frac{[(\text{number of live trees in year t-1}) - (\text{number of live trees in year t})] \times 100}{\text{number of live trees in year t-1}}$$

Plot-cluster mortalities were then averaged within each year to obtain annual mortalities for the various strata. The strata were based on region (state, province, country), elevation, deposition level, and ecotype (Table 1). Estimates of wet sulfate and wet nitrate deposition for each plot-cluster were interpolated using deposition maps (5 kg/ha isopleths) provided by Environment Canada and the U.S. National Atmospheric Deposition Program/National Trends Network Coordination Office. UTM coordinates located each site relative to the nearest isopleth or monitoring station. Mortality figures are based on 7,569 dominant/codominant (D/C) and 3,885 intermediate/suppressed (I/S) sugar maples (N = 11,454) monitored annually between 1988 and 1997 (Table 2). Two-way comparisons were made with the t-test, and analysis of variance (ANOVA) in conjunction with Tukey's test for multiple comparisons. Prior to analysis all data were tested for homoscedasticity. Alpha was set at 0.05 as a nominal indicator of significance for all comparisons.

[1]Professor of Forest Entomology and Senior Research Support Specialist, State University College of Environmental Science and Forestry, Syracuse, NY.; Forest Health Protection, Northeastern Area, USDA Forest Service, Durham, New Hampshire; and Acting Director, Forest Resources, Atlantic Forestry Centre, Canadian Forest Service, Fredericton, New Brunswick, respectively.

Table 1.—Ecological variables used to stratify NAMP data on sugar maple mortality

VARIABLE	CATEGORIES	NUMBER OF PLOT-CLUSTERS
Elevation	High >450 M	39
	Medium 300-450 m	71
	Low < 300 m	53
	Divisions	
Biophysical Units	Warm Continental	25
United States	Warm Continental Regime Mts.	60
(McNab and Avers 1994)	Hot Continental	21
	Provinces	
	Eastern Broadleaf Forest (Continental)	17
	Laurentian Mixed Forest	25
	Adirondack New England Mixed Forest	60
	Sections	
	White Mountains	17
	New England Piedmont	13
	Green Taconic, Berkshire Mts.	23
Canada	**Ecozones**	
(Ecological Stratification	Atlantic Maritime	24
Working Group 1995)	Boreal Shield	16
	Mixed Wood Plain	18
	Ecoregions	
	Algonquin-Lake Nipissing	6
	Appalachian	14
	Lake Erie Lowland	6
	Manitoulin-Lake Simcoe	8
	Northern New Brunswick Uplands	5
	Southern Laurentians	8
Wet Sulfate Deposition	High >27.5 kg/ha/yr	24
	Medium 17.6-27.5	192
	Low <17.6	49
Wet Nitrate Deposition	High >20 kg/ha/yr	37
	Medium 16-20	71
	Low <16	57
Forest Management	Sugarbush	
	U.S.	53
	Canada	31
	Nonsugarbush	
	U.S.	53
	Canada	28

Table 2.—Regional distribution of plot-clusters and number of sugar maples monitored by NAMP

REGION	NO. PLOT-CLUSTERS IN 1988	INITIAL AVE.(RANGES) BASAL AREA (m^2/ha)	NUMBER OF LIVE SUGAR MAPLES BY CROWN POSITION (1988)		
			DOMINANT/ CODOMINANT	INTERMEDIATE/ SUPPRESSED	INITIAL NO. LIVE SUGAR MAPLES
Maine	18	29.1 (20.2-40.8)	726	455	1,181
Massachusetts	10	27.9 (15.4-36.2)	453	175	628
Michigan	10	24.1 (17.8-31.0)	194	78	272
Minnesota [a]	8	24.4 (24.5-31.5)	221	238	459
New Brunswick/ Nova Scotia	11	22.7 (12.9-31.0)	856	116	972
New Hampshire	6	24.6 (15.2-36.5)	257	121	378
New York	18	24.8 (15.7-35.5)	645	438	1,083
Ohio [a]	6	33.7 (28.3-39.9)	141	120	261
Ontario	24	26.8 (15.4-40.3)	928	434	1,362
Pennsylvania [a]	6	29.1 (21.6-36.4)	173	112	285
Quebec	24	27.6 (17.4-35.6)	1,285	594	1,879
Vermont	26	27.6 (12.2-43.4)	1,054	588	1,642
Wisconsin	18	24.9 (15.7-32.4)	636	416	1,052
TOTAL	185		7,569	3,885	11,454

[a]Plot-clusters were not established in these regions until 1992, the remainder were initiated in 1988.

Results

Canada vs United States

Percent sugar maple mortality in the NAMP plot-clusters by crown position from 1989 through 1997 was similar in both Canada and the United States, except in a few cases. Generally, mortality of dominant/codominant (D/C) trees was similar in both sugarbushes (SB) and non-sugarbushes (NSB). However, in four of nine years (1989, 1990, 1992, 1997), mortality of intermediate/suppressed (I/S) sugar maples in Canada's sugarbush (SB) plot-clusters exceeded that of sugar maple in the dominant/codominant crown position. During the remaining five years, average mortality in both crown positions was approximately equal (Table 3).

Mortality of understory sugar maple in U.S. SBs exceeded that in the overstory in seven of nine years; mortality in the two crown positions was approximately the same in 1992 and 1997. Sugar maple mortality in the intermediate/ suppressed crown class for NSBs always exceeded overstory mortality in both countries.

In 1989, mortality of intermediate/suppressed maples in U.S. SBs (4.0%) was more than four times that which occurred in the dominant/codominant crown class (0.8%). Comparative mortality for the two management categories was more dissimilar in the intermediate/suppressed crown position compared to the dominant/codominant trees. For Canadian SBs, annual mortality of dominant/codominant maple ranged from 0.4% (1993) to 0.9% (1995) and intermediate/ suppressed losses varied from 0.4% (1994) to 2.4% (1990). Comparative figures for maple in U.S. SBs were, D/C: 0.3% (1990) to 1.3% (1995) and, I/S: 1.0% (1993) to 4.0% (1989).

Differences in the nine-year average annual tree mortality when SB and NSB data within each country were combined

Table 3.—Average annual mortality (% trees) of sugar maple for NAMP plot-clusters in Canada and the United States (1989-1997) by management category and crown position)

COUNTRY	MANAGEMENT CATEGORY[a]	CROWN POSITION[b]	YEAR								
			1989	1990	1991	1992	1993	1994	1995	1996	1997
CANADA	SB	D/C	0.5	0.5	0.8	0.6	0.4	0.5	0.9	0.9	1.1
		I/S	1.2	1.5	0.8	2.4	0.5	0.4	1.0	0.9	2.3
	NSB	D/C	0.4	0.4	0.6	0.6	0.3	0.3	0.8	0.3	0.3
		I/S	2.1	2.2	1.3	1.4	1.8	1.6	1.6	1.2	1.1
U.S.	SB	D/C	0.8	0.3	0.8	0.9	0.6	0.7	1.3	0.7	0.7
		I/S	4.0	1.6	1.5	1.0	1.0	1.1	2.7	1.6	0.8
	NSB	D/C	0.8	0.3	0.6	0.5	0.8	0.4	0.7	0.5	0.3
		I/S	2.7	1.7	2.3	1.3	1.0	0.8	1.8	1.6	2.4

[a]SB = sugarbush, NSB = non-sugarbush
[b]D/C = dominant/codominant; I/S = intermediate/suppressed

were similar in both dominant/codominant (Can.: 0.6 ± 0.1%, U.S.: 0.7 ± 0.1%) and intermediate/suppressed (Can.: 1.4 ± 0.1%, U.S.: 1.7 ± 0.2%) crown positions and were significantly different between crown positions in each country.

Average annual mortality of dominant/codominant maples for the nine-year period was significantly lower than losses of intermediate/suppressed for both Canadian SBs (D/C: 0.7 ± 0.1%, I/S: 1.3 ± 0.2%, p=0.046) and NSBs (D/C: 0.5 ± 0.1%, I/S: 1.6 ± 0.1%, p=0.0001). Similarly, the average annual nine-year sugar maple mortality in U.S. dominant/codominant maples was significantly lower than that of intermediate/suppressed maples in both SBs (D/C: 0.8 ± 0.1%, I/S: 1.7 ± 0.3%, p=0.0258) and NSBs (D/C: 0.5 ± 0.1%, I/S: 1.7 ± 0.2%, p=0.0004).

Regional Mortality

Mortality data from the 10 states and four provinces included in the NAMP represent sugarbushes and nonsugarbushes which exist under a variety of geographic locations and site conditions. Cooperators are interested in viewing the condition of their stands relative to those in other jurisdictions. Examining regional differences is the first step in identifying unusual levels of mortality that may be linked to local disturbances.

Total average annual sugar maple mortality (i.e., all crown positions combined) for SBs within regions ranged from 0.3% in New Brunswick/Nova Scotia to 1.9% in New York (Table 4). Mortality in NSBs was lowest in Michigan (0.2%) and highest in New Hampshire (1.9%). Mortality in the understory of SBs was significantly higher than that in the overstory only in Massachusetts, New Hampshire and Vermont. In 9 of 12 regions, mortality in the understory of NSBs was significantly higher than overstory mortality (Table 4).

Overstory mortality for SBs in New York and Quebec was significantly higher than mortality in their respective NSBs (Table 5). In Massachusetts, mortality of dominant/codominant sugar maple was significantly lower in SBs compared to NSBs. For all other regions, there were no statistically significant differences in mortality of overstory sugar maples between management categories (Table 5). Similarly, in only three regions was mortality of intermediate/suppressed trees significantly different when comparing NSBs with SBs; Massachusetts, New Brunswick and New Hampshire (Table 5).

Mortality of dominant/codominant maples in SBs was higher in New York (1.8 ± 0.3) compared to mortality of overstory maple in all other regions and significantly higher than mortality in 8 of 12 regions (the eight regions: MA, NB/NS, PA, ON, WI, VT, NH, and ME). Overstory mortality in Massachusetts (0.1 ± 0.1) was significantly lower than this mortality in New York and Quebec. Average annual mortality levels for dominant/codominant trees in NSBs were statistically similar between management categories for all regions and varied from zero to 0.8% (Table 5).

There were no statistical differences in average annual mortality of understory sugar maple in SBs among the 13 regions. In NSBs, mortality in this crown position was significantly higher in New Hampshire (4.6 ± 1.1) compared to seven regions (MI, WI, ON, NY, ME, VT, QU) but not statistically different from mortality in Pennsylvania, Massachusetts, NB/NS, and Minnesota (Table 5).

Influence of Elevation

When data from SB and NSB management categories were combined, beginning with the original sample in 1988 (Table 1), average annual sugar maple mortality was significantly lower in the dominant/codominant crown level compared to the intermediate/suppressed level for plot-clusters in all three elevation categories; high (D/C: 0.5 ± 0.1%, I/S: 2.0 ± 0.2%), medium (D/C: 0.8 ± 0.1%, I/S: 1.8 ± 0.3%) and low (D/C: 0.5 ± 0.1%, I/S: 1.1 ± 0.2%). Mortality of dominant/codominant trees at medium elevations (0.8 ± 0.1%) was

Table 4.—Average (± S.E.) annual mortality (% trees) of dominant/codominant and intermediate/suppressed sugar maples by management category (1988-1997)

	SUGARBUSH			NON-SUGARBUSH		
REGION	Dom./ Codom.	Inter./ Supp.	TOTAL	Dom./ Codom.	Inter./ Supp.	TOTAL
Maine	0.8 ± 0.2	3.0 ± 1.4	1.3 ± 0.1	0.6 ± 0.2	1.8 ± 0.5	0.9 ± 0.2
Massachusetts†	0.1 ± 0.1a	1.4 ± 0.4b	0.4 ± 0.2	0.7 ± 0.2a	2.9 ± 0.5b	1.4 ± 0.2
Michigan	0.8 ± 0.3	1.2 ± 0.5	1.0 ± 0.3	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1
Minnesota‡	0.8 ± 0.3	1.0 ± 0.1	0.9 ± 0.2	0.0 ± 0.0a	1.9 ± 0.7b	1.0 ± 0.3
New Brunswick/ Nova Scotia	0.2 ± 0.1	0.6 ± 0.3	0.3 ± 0.1	0.5 ± 0.2a	2.5 ± 0.4b	0.7 ± 0.2
New Hampshire	0.6 ± 0.1a	1.8 ± 0.4b	1.0 ± 0.2	0.7 ± 0.1a	4.7 ± 1.1b	1.9 ± 0.3
New York	1.8 ± 0.3	2.0 ± 0.7	1.9 ± 0.3	0.5 ± 0.1a	1.5 ± 0.4b	0.9 ± 0.2
Ohio‡	0.9 ± 0.3	0.3 ± 0.2	0.6 ± 0.2	—	—	—
Ontario	0.4 ± 0.1	1.7 ± 0.6	0.6 ± 0.1	0.4 ± 0.1a	1.1 ± 0.2b	0.7 ± 0.1
Pennsylvania‡	0.3 ± 0.3	0.6 ± 0.2	0.5 ± 0.3	0.4 ± 0.2	3.1 ± 1.2	1.2 ± 0.4
Quebec	1.2 ± 0.2	1.3 ± 0.2	1.3 ± 0.1	0.5 ± 0.2a	1.9 ± 0.3b	0.9 ± 0.1
Vermont	0.5 ± 0.2a	1.4 ± 0.2b	0.9 ± 0.1	0.8 ± 0.3a	1.9 ± 0.3b	1.2 ± 0.2
Wisconsin	0.4 ± 0.1	0.8 ± 0.2	0.6 ± 0.1	0.2 ± 0.1a	0.9 ± 0.2b	0.4 ± 0.1

† different letters in the same row signify a statistically significant difference at α=0.05 between the dominant/ codominant and intermediate/suppressed comparisons within a region and management category.
‡ plot-clusters were not established in these regions until 1992; average mortality is for 1993-1997.

Table 5.—Average (± S.E.) annual sugar maple mortality (% trees) for management categories within sugar maple crown positions (1988-1997)

	DOMINANT/CODOMINANT		INTERMEDIATE/SUPPRESSED	
REGION	SB ± SE	NSB ± SE	SB ± SE	NSB ± SE
Maine	0.8 ± 0.2	0.6 ± 0.2	3.0 ± 1.4	1.8 ± 0.5
Massachusetts†	0.1 ± 0.1a	0.7 ± 0.2b	1.4 ± 0.4a	2.9 ± 0.5b
Michigan	0.8 ± 0.3	0.2 ± 0.1	1.2 ± 0.5	0.1 ± 0.1
Minnesota‡	0.8 ± 0.3	0.0 ± 0.0	1.0 ± 0.1	1.9 ± 0.7
New Brunswick/ Nova Scotia	0.2 ± 0.1	0.5 ± 0.2	0.6 ± 0.3a	2.5 ± 0.4b
New Hampshire	0.6 ± 0.1	0.7 ± 0.1	1.8 ± 0.4a	4.7 ± 1.1b
New York†	1.8 ± 0.3a	0.5 ± 0.1b	2.0 ± 0.7	1.5 ± 0.4
Ohio‡	0.9 ± 0.3	—	0.3 ± 0.2	—
Ontario	0.4 ± 0.1	0.4 ± 0.1	1.7 ± 0.6	1.1 ± 0.2
Pennsylvania‡	0.3 ± 0.3	0.4 ± 0.2	0.6 ± 0.2	3.1 ± 1.2
Quebec†	1.2 ± 0.2a	0.5 ± 0.2b	1.3 ± 0.2	1.9 ± 0.3
Vermont	0.5 ± 0.2	0.8 ± 0.3	1.4 ± 0.2	1.9 ± 0.3
Wisconsin	0.4 ± 0.1	0.2 ± 0.1	0.8 ± 0.2	0.9 ± 0.2

† different letters signify a statistically significant difference at α=0.05 between the sugarbush/non-sugarbush comparisons within a region and mortality type.
‡ plot-clusters were not established in these regions until 1992; annual average mortality is for 1993-1997.
SB=sugarbush, NSB=non-sugarbush.

significantly higher than dominant/codominant mortality at both high (0.5 ± 0.1%) and low (0.5 ± 0.1%) elevations. Mortality of intermediate/suppressed maples was significantly higher at high elevations (2.0 ± 0.2%) than mortality in this crown position at low elevations (1.1 ± 0.2%). When data from all crown positions were combined, mortality for both SBs and NSBs was similar at high, medium and low elevations (Fig. 1).

Nitrate Deposition

There were no significant differences in average annual percent mortality of sugar maple in SBs compared to NSBs from 1989 through 1997 when D/C and I/S crown positions were combined in areas of high (SB: 1.3 ± 0.3%, NSB: 0.8 ± 0.1%), medium (SB: 1.0 ± 0.1%, NSB: 1.0 ± 0.1%) and low (SB: 0.8 ± 0.1%, NSB: 0.8 ± 0.1%) levels of nitrate deposition. Mortality of intermediate/suppressed sugar maples was significantly higher than mortality in the dominant/codominant crown position at all deposition levels; high (SB: 1.6 ± 0.3%, NSB: 0.8 ± 0.2%), medium (SB: 1.6 ± 0.2%, NSB: 0.6 ± 0.1%) and low (SB: 1.7 ± 0.1%, NSB: 0.4 ± 0.1%). There were no statistically significant differences in total (D/C and I/S combined) average annual mortality of sugar maple when compared among the three deposition categories for wet nitrate in either SBs or NSBs.

Sulfate Deposition

There were no significant differences in average annual percent mortality of sugar maples in SBs compared to NSBs from 1989 through 1997 when D/C and I/S crown positions were combined for plot-clusters in areas of either high (SB: 1.3,± 0.3%, NSB: 0.7 ± 0.1%), medium (SB: 1.0 ± 0.1%, NSB: 1.0 ± 0.1%) or low (SB: 0.7 ± 0.1%, NSB: 0.7 ± 0.1%) wet sulfate deposition. In plot-clusters ostensibly exposed to high levels of sulfate deposition, there was no statistically significant difference in mortality of dominant/codominant maples (0.8 ± 0.2%) compared to maples in the intermediate/suppressed crown position (1.4 ± 0.4%). However, percent mortality of intermediate/suppressed maples was significantly higher than mortality of dominant/codominant trees in areas exposed to medium (SB: 1.7 ± 0.2%, NSB: 0.7 ± 0.1%) and low (SB: 1.6 ± 0.4%, NSB: 0.5 ± 0.1%) deposition levels. There were no statistically significant differences in total (D/C and I/S combined) average annual mortality of sugar maple when compared among the three wet sulfate deposition categories in either SBs or NSBs.

Interaction Between Elevation and High Levels of Deposition

To further examine the possibility that elevation may have influenced the association between atmospheric deposition and maple mortality, sugar maples in plot-clusters exposed to high levels of both wet nitrate and wet sulfate deposition were reclassified into one of two categories; those at >300m elev. (viz., high and medium elevation classes combined), and those at <300m elev. For high sulfate deposition, 12 plot-clusters occurred at elevations >300m, 11 plot-clusters were <300m. Twenty plot-clusters located at >300m and 16 at <300m were subjected to high levels of nitrate deposition.

There were no significant differences in average annual percent tree mortality between SBs and NSBs in either the high+med (SB: 2.2 ± 0.6%, NSB: 1.1 ± 0.1%) or low (SB: 0.6 ± 0.1%, NSB: 0.3 ± 0.1%) elevation categories for areas receiving high levels of wet nitrate deposition (>20 kg/ha/yr). Similarly, when SB and NSB management categories were combined, there were no significant differences in mortality between crown positions at either elevation: high+med – D/C: 1.2 ± 0.3%, I/S: 2.2 ± 0.5%; Low – D/C: 0.4 ± 0.1%, I/S: 0.7 ± 0.2%. Within SBs when crown positions were combined, average annual mortality was significantly greater at elevations >300m (2.2%) compared to that of stands occurring at <300m (0.6%) (Fig. 2). Similarly, in NSBs there was significantly greater mortality at high+med elevations (1.1%) compared to low elevations (0.3%) (Fig. 2). Mortality of intermediate/suppressed sugar maples when data from SBs and NSBs were combined was significantly greater in the high+med (2.2%) category compared to low elevations (0.7%), and there was significantly more mortality in the dominant/codominant crown position at high+med elevations (1.2%) than at low elevations (0.4%).

In like manner, mortality from plot-clusters exposed to high levels of wet sulfate deposition (>27.5 kg/ha/yr) were stratified by combining data from high and medium elevations (i.e., >300m) and comparing it to sugar maple mortality in plot-clusters at low elevations (<300m). When data from both D/C and I/S crown positions were combined, there was no statistical difference in average annual tree mortality of sugar maple when comparing SBs and NSBs at either high+med. (SB: 2.2 ± 0.7%, NSB: 1.0 ± 0.2%) or low elevations (SB: 0.5 ± 0.1%, NSB: 0.3 ± 0.1%). Mortality in the dominant/codominant and intermediate/suppressed crown positions were statistically similar for both high+med (D/C: 1.2 ± 0.3%, I/S: 2.2 ± 0.8%) and low (D/C: 0.4 ± 0.1%, I/S: 0.6 ± 0.3%) elevations. Maple mortality within SBs and NSBs when crown positions were combined was significantly higher at high+med elevations compared to mortality at <300m (Fig. 3). This can be attributed mainly to the fact that when management categories were combined mortality of dominant/codominant trees (1.2%) was significantly higher at the higher elevations compared to maples in this crown position below 300m (0.4%).

Ecological Units (U. S.)

NAMP plot-clusters in the United States are distributed over 46 Ecological Sections, five Provinces and four Divisions as mapped by Keys et al. (1995) and described by McNab and Avers (1994). The Canadian component of this project encompasses 13 Ecoregions and three Ecozones (Ecological Stratification Working Group 1995). For the purpose of examining sugar maple mortality, small sample sizes (i.e., few plot-clusters) in many ecological units limited comparative analyses in the U.S. to three Divisions and three Provinces in the Humid Temperate Domain and three Sections in the Adirondack New England Mixed Forest-Coniferous Forest-Alpine Meadow Province (Table 6). Sample size for the Canadian portion of NAMP permits mortality comparisons between three Ecozones and six Ecoregions (Table 7).

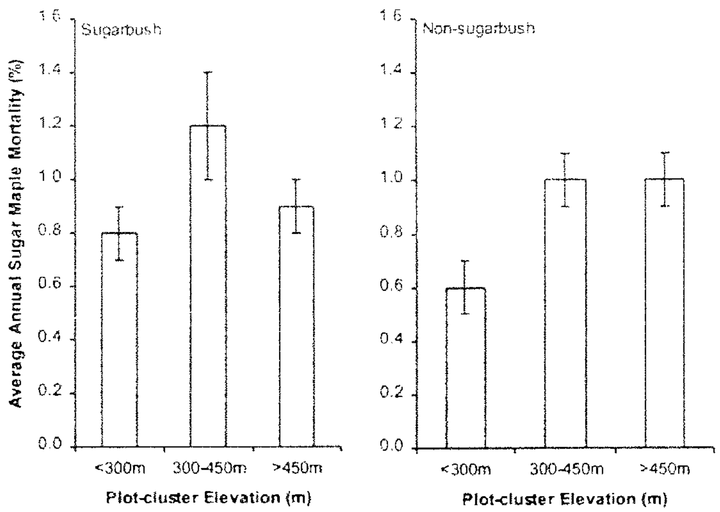

Fig. 1. Total (D/C and I/S crown positions combined) average (± SE) annual mortality (% trees) of sugar maple for SBs and NSBs in three elevational categories

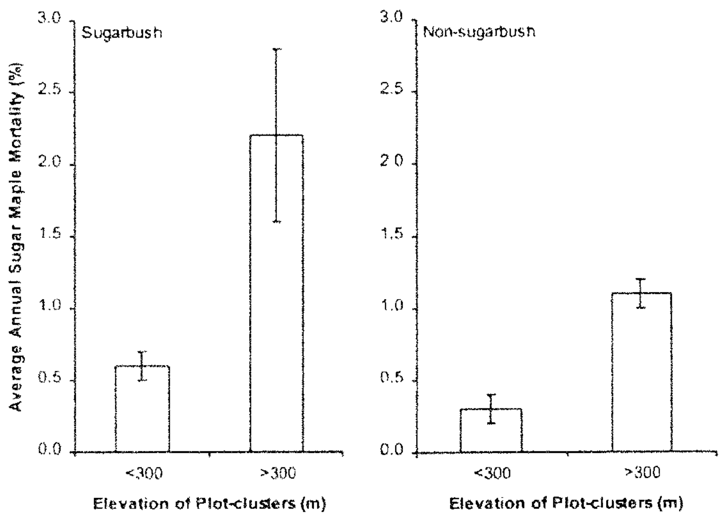

Fig. 2. Total (D/C and I/S crown positions combined) average (±SE) sugar maple mortality (% trees) for SBs and NSBs in plot-clusters occurring at high-medium (>300m) and Low (<300m) elevations in regions exposed to high (>20 kg/ha/yr) levels of wet nitrate deposition.

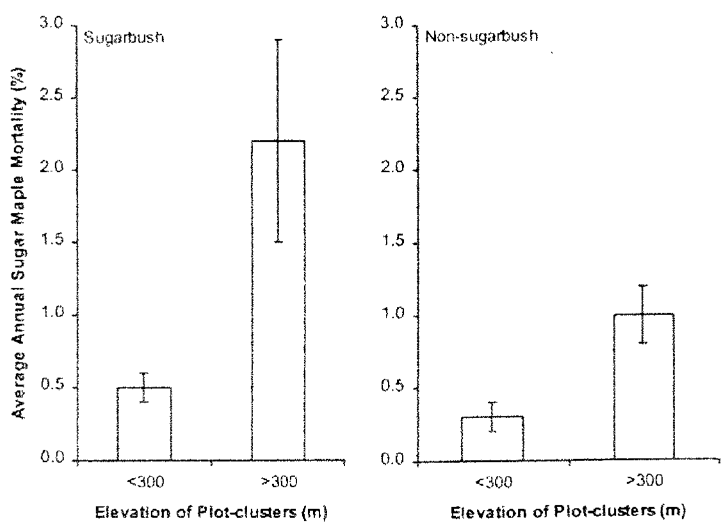

Fig. 3. Total (D/C and I/S crown positions combined) average (±SE) annual sugar maple mortality (% trees) for SBs and NSBs in plot-clusters occurring at high+medium (>300m) and low (<300m) elevations exposed to high (>27.5 kg/ha/yr) levels of wet sulfate deposition.

Table. 6.—Original (1988) number of live sugar maples monitored by NAMP in each of eight ecological regions, two management categories and two crown positions in the United States

Ecological Classification[a]	Management Category (No. Plot-Clusters)[b]	No. of Sugar Maples by Crown Position Dom./Codom.	Interm./Supp.
Warm Continental Division (210)	SB (13)	818	550
	NSB (12)	885	591
Warm Continental Regime Mts (M210) Division	SB (29)	841	333
	NSB (31)	843	467
Hot Continental Division (220)	SB (12)	332	159
	NSB (9)	246	171
Laurentian Mixed Forest Province (212)	SB (13)	818	550
	NSB (12)	885	591
Adirondack New England Mixed Forest Province (212)	SB (29)	841	333
	NSB (31)	843	467
White Mts. Section (M212A)	SB (8)	337	251
	NSB(9)	322	182
East. Broadleaf Forest (Continental) Province (222)	SB (9)	210	114
	NSB (8)	213	155
New England Piedmont Section (M212B)	SB (7)	344	137
	NSB (6)	225	160
Green Taconic, Berkshire Mts. Section (M212C)	SB (11)	404	167
	NSB (12)	572	316

[a]Source: McNab and Avers 1994. Numbers are codes for ecological units.
[b]SB = sugarbush, NSB = nonsugarbush.

U.S. Ecological Divisions

Average annual percent tree mortality was similar for comparisons of SBs and NSBs when D/C and I/S crown positions were combined for plot-clusters located in the Warm Continental (WC) and Warm Continental Regime Mountain (WCRM) Divisions (Fig. 4). In the Hot Continental (HC) Division, annual mortality was significantly higher in SBs compared to NSBs (Fig. 4). Mortality of intermediate/suppressed sugar maples was significantly higher than that of dominant/codominant trees in both the WC (I/S: 0.9 ± 0.1%, D/C: 0.4 ± 0.1%) and WCRM (I/S: 2.3 ± 0.4%, D/C: 0.8 ± 0.1%), but did not differ statistically in HC (I/S: 1.1 ± 0.3%, D/C: 0.7 ± 0.1%). Combined mortality for SBs in WC (0.6%) was significantly lower than SB mortality in WCRM (1.3%). In NSBs, combined mortality was significantly higher in WCRM (1.1%) than in WC (0.7% and HC (0.6%) (Fig. 4).

U.S. Ecological Provinces

There were no significant differences in the overall (D/C and I/S crown categories combined) average annual percent tree mortality between SBs and NSBs in either the Laurentian Mixed Forest (LM, SB: 0.6 ± 0.1%, NSB: 0.7 ± 0.1%) or the Adirondack New England Mixed Forest (ANE, SB: 1.3 ± 0.2%, NSB: 1.1 ± 0.1%) Provinces. Mortality in the Eastern Broadleaf Forest (Continental) Province (EBFC), however, was significantly higher in SBs (1.2 ± 0.3%) compared to NSBs (0.4 ± 0.1%). Annual mortality of intermediate/suppressed maples was significantly higher than mortality of dominant/codominant trees in ANE and LM (data not shown). Mortality of sugar maple in the dominant/codominant crown position was statistically similar in all three regions (data not shown). Mortality of intermediate/suppressed sugar maples in ANE (2.3%) was significantly

Table. 7.—Original (1988) number of live sugar maples monitored by NAMP in each of nine ecological regions, two management categories and two crown positions in Canada

		No. of Sugar Maples by Crown Position	
Ecological Classification[a]	Management Category (No. Plot-Clusters)[b]	Dom./Codom.	Interm./Supp.
Atlantic Maritime Ecozone (AM)	SB (14)	943	262
	NSB (10)	670	188
Boreal Shield Ecozone (BS)	SB (8)	398	201
	NSB (8)	397	218
Mixed Wood Plain Ecozone (MW)	SB (9)	286	136
	NSB (9)	361	137
Algonquin-Lake Nipissing Ecoregion (ALN)	SB (3)	142	68
	NSB (3)	136	80
Appalachian Ecoregion (APP)	SB (7)	401	191
	NSB (7)	370	145
Lake Erie Lowland Ecoregion (LEL)	SB (3)	68	51
	NSB (3)	110	29
Manitoulin-Lake Simcoe Ecoregion (MLS)	SB (4)	137	70
	NSB (4)	141	70
Northern New Brunswick Uplands Ecoregion (NNBU)	SB (4)	305	38
	NSB (1)	51	7
Southern Laurentians Ecoregion (SL)	SB (4)	187	118
	NSB (4)	213	112

[a]Ecological Stratification Working Group 1995.
[b]SB = sugarbush, NSB = nonsugarbush.

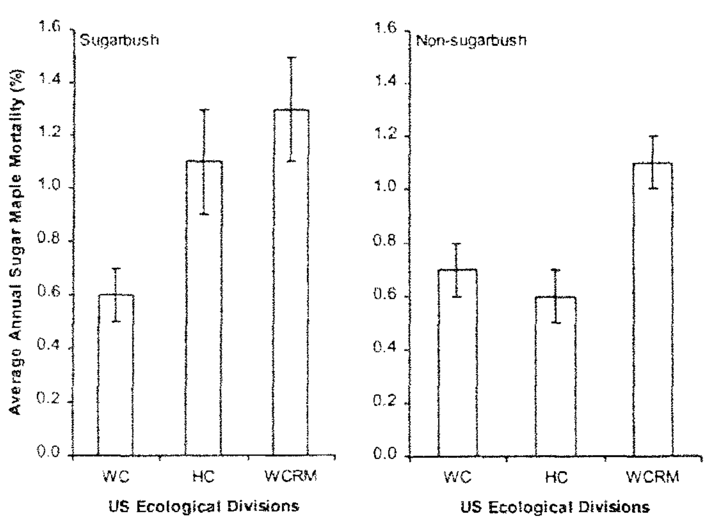

Fig. 4.—Total (D/C and I/S crown positions combined) average (± SE) annual sugar maple mortality (% trees) for SBs and NSBs in three ecological Divisions in the United States; WC = Warm Continental, HC = Hot Continental, WCRM = Warm Continental Regime Mountains.

higher than mortality at this crown position in either LM (0.9%) or EBFC (0.9%). Total average annual mortality (crown positions combined) among these Provinces was not significantly different for SBs (range 0.6 - 1.3%), but in NSBs overall mortality was significantly higher in ANE compared to LM and EBFC (Fig. 5).

U.S. Ecological Sections

The distribution of NAMP plot-clusters permits a comparison of three Sections within the Adirondack New England Mixed Forest-Conifer Forest-Alpine Meadow Province: White Mountains (WM); New England Piedmont (NEP); and Green, Taconic, Berkshire Mountains (GTBM). Sections are the smallest ecological units in the U.S National Hierarchical Framework for which NAMP sample sizes permit reasonable comparisons, and it is at this level that comparisons are most meaningful (McNab and Avers 1994).

There was no statistically significant difference between the 9-year average annual mortality of sugar maple in SBs compared to NSBs when both D/C and I/S crown positions were combined for WM, NEP or GTBM (Fig. 6). For SBs, combined mortality in both WM and NEP was significantly higher than combined mortality in GTBM. There were no significant differences in NSB mortality between Sections when crown levels were combined (Fig. 6). In all three Sections, mortality in the intermediate/suppressed crown position was significantly higher than that of overstory trees (Fig. 7). Mortality of trees within dominant/codominant and intermediate/suppressed crown positions was similar among the three Sections (Fig. 7).

Ecological Units (Canada)

Canadian Ecozones

Average annual mortality of sugar maple in Atlantic Maritime Ecozone (AM) SBs (0.6%) was significantly lower than maple mortality in NSBs (0.8%). There were no significant differences between management categories for either the Boreal Shield or the Mixed Wood Plains Ecozones (data not shown). When SB D/C and I/S crown positions were combined, mortality in BS (1.2%) was significantly higher than comparable mortality in either AM (0.6%) or MW (0.8%) (Fig. 8). Similarly, total mortality in NSBs was significantly higher for the BS Ecozone (1.1%) compared to AM (0.8%) or MW (0.5%) (Fig. 8). Mortality of intermediate/suppressed sugar maple was significantly higher than that of dominant/codominant maple in AM (I/S: 1.4 $\pm$ 0.2%, D/C: 0.4 $\pm$ 0.1%) and BS (I/S: 2.3 $\pm$ 0.5%, D/C: 0.7 $\pm$ 0.4%) but not in MW (I/S: 0.7 $\pm$ 0.1%, D/C: 0.6 $\pm$ 0.1%). There were no statistically significant differences among Ecozones in mortality of dominant/codominant sugar maples (data not shown). However, mortality of intermediate/suppressed trees was significantly higher in BS (2.3%) compared to mortality at this crown level in either AM (1.4%) or MW (0.7%).

Canadian Ecoregions

Total (D/C and I/S crown positions combined) sugar maple mortality in SBs and NSBs was similar within all six Ecoregions (data not shown). When SB D/C and I/S crown positions were combined, average annual mortality of sugar maple in the Southern Laurentians (SL) Ecoregion was significantly higher than mortality in the Northern New Brunswick Uplands (NNBU) region (Fig. 9). Likewise, in NSBs the only statistically significant difference in total mortality among Ecoregions occurred between SL and NNBU (Fig. 9). In three regions (ALN, APP, MLS), mortality of overstory D/C maple was significantly lower than understory I/S mortality (Fig. 10). Mortality of dominant/codominant trees in SL was significantly higher than mortality at this crown level in MLS or NNBU (Fig. 10). Intermediate/suppressed mortality in SL was significantly higher than understory I/S mortality in either the LEL or NNBU Ecoregions (Fig. 10).

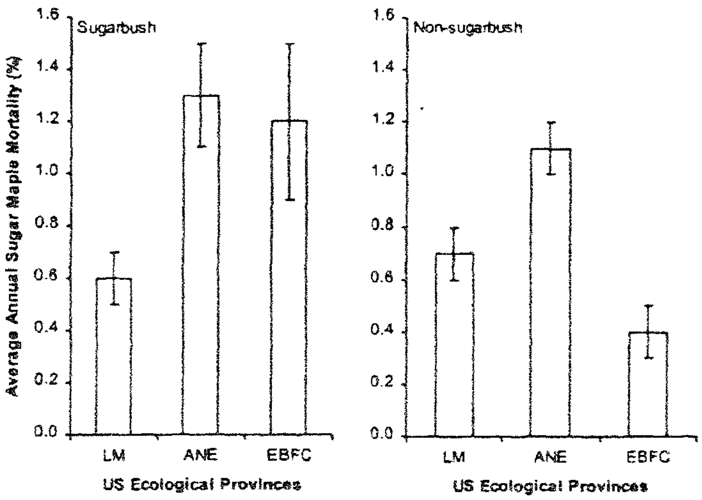

Fig. 5.—Total (D/C and I/S crown positions combined) average ($\pm$ SE) annual sugar maple mortality (% trees) for SBs and NSBs in three ecological Provinces in the United States; LM = Laurentian Mixed Forest, ANE = Adirondack New England and Mixed Forest, EBFC = Eastern Broadleaf Forest (Continental).

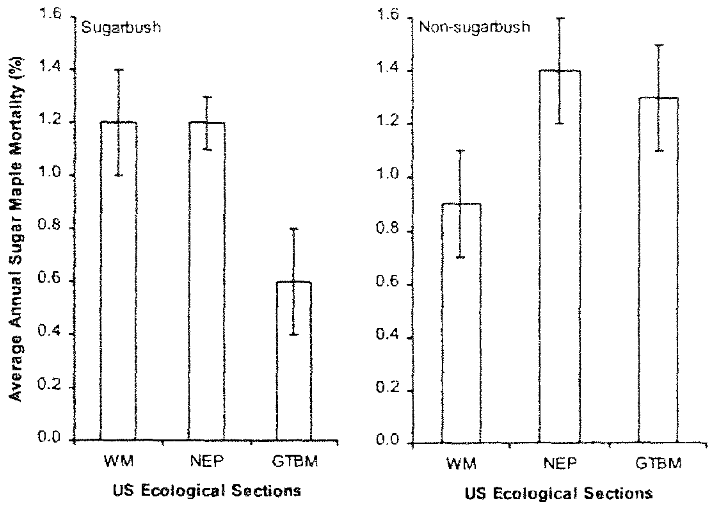

Fig. 6.—Total (D/C and I/S crown positions combined) average (± S.E.) annual sugar maple mortality (% trees) for SBs and NSBs in three ecological Sections in the United States; WM = White Mountains, NEP = New England Piedmont, GTBM = Green, Taconic, Berkshire Mountains.

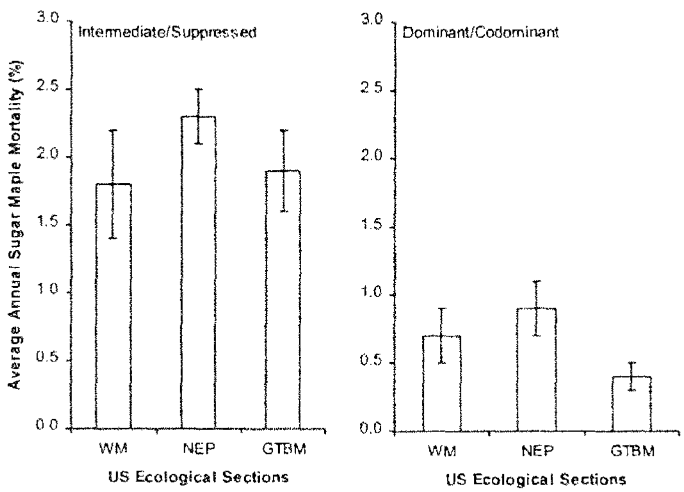

Fig. 7.—Average (± SE) sugar maple mortality (% trees) for intermediate/suppressed and dominant/codominant trees in three ecological Sections in the United States; WM = White Mountains, NEP = New England Piedmont, GTBM = Green, Taconic, Berkshire Mountains.

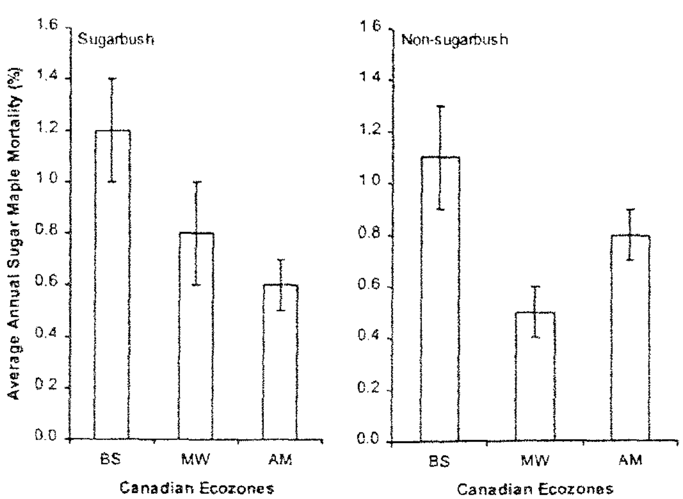

Fig. 8.—Total (D/C and I/S crown positions combined) average (± SE) annual sugar maple mortality (% trees) in three Canadian Ecozones: Boreal Shield (BS), Mixed Wood Plains (MW) and Atlantic Maritime (AM).

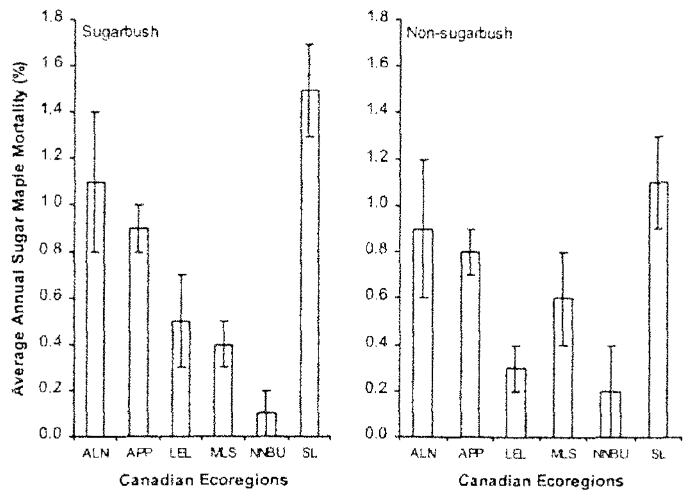

Fig. 9.—Total (D/C and I/S crown positions combined) average (± S.E.) annual percent sugar maple mortality (% trees) for SBs and NSBs in six Canadian Ecoregions; Algonquin-Lake Nipissing (ALN), Appalachians (APP), Lake Erie Lowland (LEL), Manitoulin-Lake Simcoe (MLS), Northern New Brunswick Uplands (NNBU) and Southern Laurentians (SL).

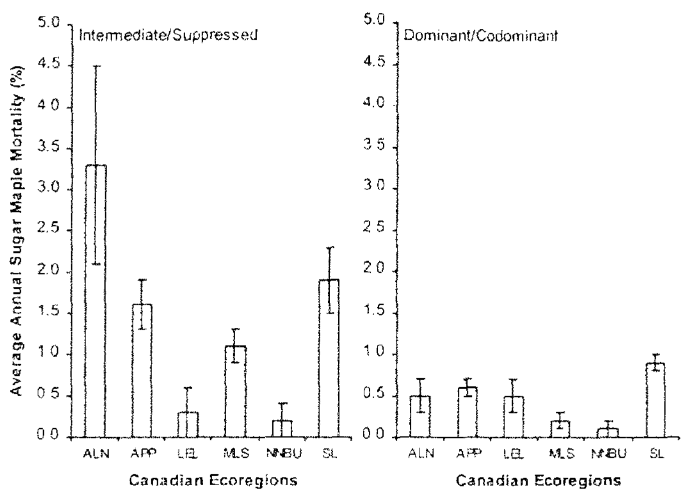

Fig. 10.—Average (± SE) annual sugar maple mortality (% trees) for intermediate/suppressed and dominant/codominant trees in six Canadian Ecoregions; Algonquin-Lake Nipissing (ALN), Appalachians (APP), Lake Erie Lowland (LEL), Manitoulin-Lake Simcoe (MLS), Northern New Brunswick Uplands (NNBU), and Southern Laurentian (SL).

Discussion

Results of monitoring and evaluating sugar maple mortality in the NAMP plot-clusters should be viewed with the understanding that stands were selected on the basis of regional location, accessibility, condition (age, species mix), and security (assurance of long-term use). In other words, sites were not picked at random and, in a statistical sense, results may be biased and not generally applicable to the maple resource. In our view, this does not detract from the ability to identify a normal or expected threshold of mortality in the absence of disturbance. Neither does it hinder evaluation of the immediate and long-term consequences of natural disturbances in terms of annual mortality or changes in crown condition of sugar maple, nor does it disallow comparison of ecological conditions included within the study. Long-term, quality controlled monitoring and subsequent evaluation is requisite to developing a baseline with which to compare changes following stress. Similarly, this type of monitoring is necessary to identify causes of unusual mortality and to facilitate early detection of potentially harmful effects (Spellerberg 1991).

The results, analyses and discussion are specific to sugar maple even though other species occur in all plot-clusters. Therefore, total tree mortality (i.e., all species combined) for each stand may be slightly higher than the values given for each crown level and when crown levels are combined. For example, at nine of the ten sites where monitoring was initiated in 1988 (Table 2), sugar maple comprises 75% to 92% of the dominant/codominant trees in SBs and 63% to 80% in NSBs. In Wisconsin, sugar maple constitutes only 56% of the overstory in SBs and 38% in NSBs.

When sugar maple mortality from NAMP plot-clusters in the United States and Canada are combined (Fig. 11), a clear pattern emerges in both SBs and NSBs. Average annual percent mortality of intermediate/suppressed trees consistently exceeds or approximates that of dominant/

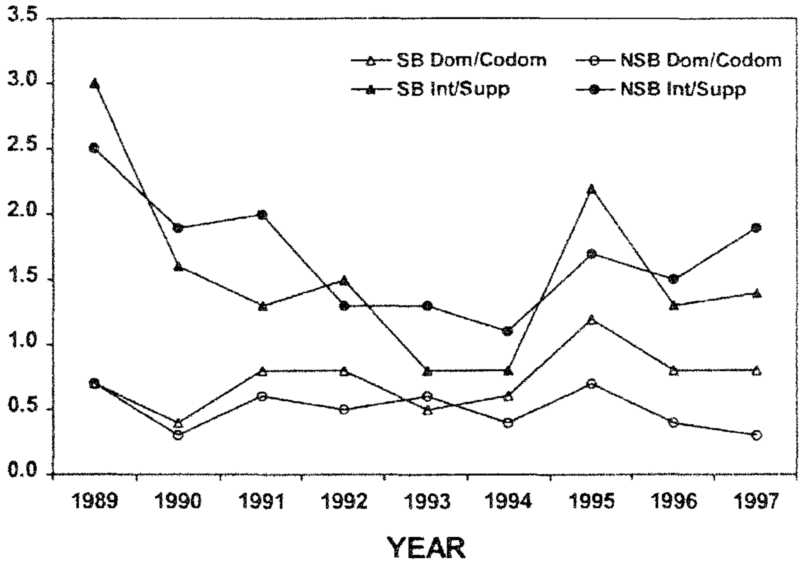

Fig. 11.—Annual natural mortality (% trees) of sugar maple (1988-1997) in Canadian and U.S. plot-clusters combined according to management category (SB = sugarbush, NSB = non-sugarbush) and crown position.

codominant trees; in SBs the difference in annual average mortality between crown positions was as much as 1% to 3%. The pattern of mortality within each crown position is very similar for both countries. With two exceptions (Ohio - SBs, Michigan - NSBs), this pattern of higher mortality in the intermediate/suppressed crown position is a consistent, though not always statistically significant, pattern when viewed at the regional level (Table 4).

Differential mortality between crown levels is expected given the more intense competition for light, moisture and soil nutrients typically experienced by trees in the understory (Peet and Christensen 1987). In all likelihood, this discrepancy is enhanced because the dominant/codominant trees are at a competitive advantage for resources disproportionate to their size (Weiner and Thomas 1986). The variation in crown level mortality within each country and within each state and province results from many factors, the most important of which are variation in stocking (Leak 1961, 1970; Solomon 1977), uneven moisture conditions (Stephens and Waggoner 1980, Hopkin and Dumond 1994), species characteristics (Westoby 1984), stage of stand development (Franklin et al. 1987), and nutrition and stress conditions (Long et al. 1997; Horsley et al. this volume). In a five-year study of mortality in a *Fagus-Magnolia* forest, Harcombe and Marks (1983) were able to demonstrate only a weak relation between death rate and stand density, suggesting that between-tree competition was not merely related to density. Indeed, in only three NAMP regions was the nine-year average annual percent sugar maple mortality positively and significantly correlated with stand basal area: New Brunswick/Nova Scotia ($r = .750$, $p = 0.012$), New York ($r = 0.604$, $p = 0.008$) and Quebec ($r = 0.520$, $p = 0.009$). The correlation coefficients indicate that even in these three examples, site and species characteristics are important, because only 27% to 56% of the variation in the dependent variable is explained by stand density alone.

One of the major questions of concern to NAMP is how total sugar maple mortality (i.e., the average annual mortality when crown positions are combined) compares with mortality of northern hardwoods reported in the literature in the absence of disturbance. A look at comparative differences or similarities is especially meaningful because the NAMP sites cover a broad geographic range for sugar maple. Total mortality in SBs (col. 4, Table 4) ranged from a high of 1.9%/yr in New York to 0.3%/yr in NB/NS. NSB mortality was highest in New Hampshire (1.9%/yr) and lowest (0.2%/yr) in Michigan (col. 7, Table 4). There are several reports of annual mortality for different broadleaved species and combinations of species in the eastern U.S. and Canada (Table 8). Two, dealing specifically with sugar maple, indicate that mortalities of <1% (Hall 1995) to 1.2% (McLaughlin et al. 1996) are typical. Kelley and Eav (1987) reported 0.5% mortality for dominant/codominant sugar maple in Vermont. Mortality in this crown position varied from 0.1% (Massachusetts) to 1.8% (New York) in NAMP SBs and 0% (Minnesota) to 0.8% (Vermont) in NSBs (Table 4). Levels of total mortality reported for eastern hardwoods range from <1% to 3.2% (Table 8). The annual mortality reported in this paper refers solely to sugar maple; therefore, mortality for the NAMP sites might be slightly higher if all species were included. Also of interest is the comparative mortality of sugar maple in SBs compared to NSBs. The hypothesis of interest here is that stands subjected to management and tapping activities associated with the maple syrup industry are subjected to repeated physical stresses which may increase annual mortality compared to less intensively managed forests. Mortality of dominant/codominant sugar maple in only two regions was significantly higher in SBs compared to NSBs; New York (1.8% vs 0.5%) and Quebec (1.2% vs 0.5%). In Massachusetts, mortality in NSBs (0.7%) was significantly higher than in SBs (0.1%). Mortality in the lower crown position was significantly higher for NSBs in Massachusetts (I/S: 2.9%, D/C: 1.4%), New Brunswick/Nova Scotia (I/S:

Table 8.—Examples of normal or expected annual mortality (% trees) for eastern hardwoods

Source	Mortality
Frelich and Lorimer (1991)	So. Appalachian, old growth mixed mesophytic, 0.6-1.0%; Lake States, old growth sugar maple/hemlock, 0.6-0.7%
Hall (1995)	Canada, sugar maple, <1%
Hall (1996)	Canada, mixed woodland plains, 0-3.2%
Hall et al. (1996)	Canada, temperate broadleaved forests and woodlands, 1-3%
McLaughlin et al. (1996)	Ontario, sugar maple, 1.2%
Buchman (1983)	Lake States, major tree species, 2.6%/yr for saplings and 0.3%/yr for poles and small sawtimber
Kelley et al. (1992)	VT, northern hardwoods, upper canopy <1%
Stephens and Waggoner (1980)	CT, mixed hardwood forests; moist site, 1.2-1.4%; medium site 1.2-2.0%; dry site 0.8-2.0%
Waring and Schlesinger (1985 ref. therein)	Generally 1-2%
Leak (1970)	NH, second growth northern hardwoods, high stocking-1.4%; med. Stocking-0.3%; low stocking-0%
Kelley and Eav (1987)	VT, dominant/codominant maple mortality, 0.5
Abrell and Jackson (1977)	IN, old growth beech-maple, 1.2%

2.5%, D/C: 0.6%) and New Hampshire (I/S: 4.7%, D/C: 1.8%) (Table 4). The relatively high average annual mortality of sugar maples in New York's SBs, and overall mortality in this region compared to other regions when data from management categories and crown levels were combined, can be attributed to an unusually severe windstorm (Pendrick 1996) that eliminated a majority of the trees in one plot-cluster in 1995. At this site, approximately 65% of the understory and 35% of the overstory maples were lost due to this one disturbance (Fig. 12). Eliminating this plot-cluster from the analysis reduces New York's annual average mortality to approximately 1.1%. Total mortality in New Hampshire (1.4%) was the second highest of the 13 regions and can be attributed mainly to relatively high losses in the intermediate/suppressed crown position in NSBs (4.6%, Table 5).

Currently, there is growing interest in the effects of atmospheric pollution on sugar maple growth and mortality. The evidence presented to date is equivocal because underlying mechanisms are poorly understood (Foster 1989). Contradictory results also confuse the issue. Bernier and Brazeau (1988), for example, speculated that a combination of P and K deficiency play a major role in maple decline. However, reports from Quebec (Payette et al. (1996), Pennsylvania (Brooks 1994) and Ontario (Hart 1991) suggest the impact of atmospheric deposition is minor, and the key factors are a combination of insect defoliation and drought (Kolb and McCormick 1993). Other evidence suggests winter weather conditions that promote deep soil frost reduce sugar maple growth (Bauce and Allen 1991), may initiate maple decline (see Auclair this volume) or alter soil solution chemistry in ways that are detrimental to maple condition (Boutin and Robitaille 1995).

We do not have on-site measures of wet sulfate or wet nitrate deposition for the NAMP plot-clusters and had to classify stands according to deposition levels determined at the nearest monitoring site (Allen et al. 1995). It seems reasonable, however, that if atmospheric conditions relative to these two elements had a major influence on maple crown condition or mortality, detectable changes in both would appear in regions receiving relatively high levels of sulfate or nitrate deposition compared to regions receiving relatively low exposure.

To examine this hypothesis, plot-clusters were first stratified by elevation, under the assumption that due to orographic uplift atmospheric deposition in eastern North America tends to increase with elevation (Lovett and Kinsman 1990, Garner et al. 1989). Differences in annual percent sugar maple mortality between the three elevation categories were significantly greater for dominant/codominant maples in plot-clusters located at mid-elevations compared to mortality in this crown position at either high or low elevations, and for intermediate/suppressed maples mortality was significantly greater at high compared to low elevations. When total (D/C and I/S crown levels combined) plot-cluster mortality was examined by deposition level regardless of elevation, there were no significant differences between deposition categories for either nitrate or sulfate. Only in SBs was

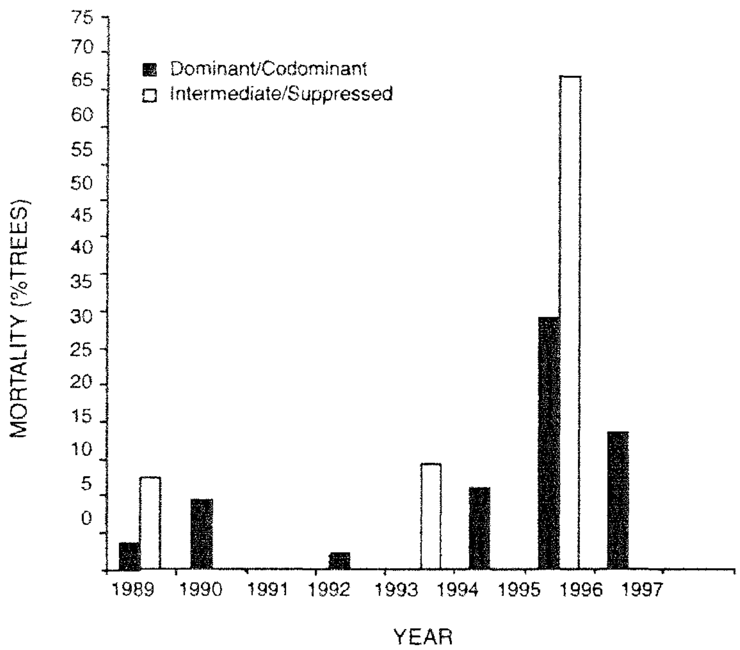

Fig. 12.—Annual mortality (% trees) of sugar maple for the Altmire Bros. Sugarbush in New York (1989-1997).

mortality above 300m (1.1%) significantly higher than mortality below 300m (0.3%). Whether differences described above are biologically significant can not be determined. These subtle differences may become more obvious when plot-clusters experience severe disturbances (Horsley et al. this volume). However, since the beginning of the NAMP several plot-clusters have experienced severe drought and heavy defoliation, yet unusual levels of mortality have not materialized. Studies in states that do not have significant sources of pollution (e.g., Vermont, Tennessee and North Carolina) may not show strong trends in precipitation chemistry with elevation (Scherbatskoy and Bliss 1984). Neither Mielke et al. (1991) working along a pH gradient in Wisconsin nor Linzon's (1987) studies of maple decline on acidic compared to calcareous soils in Ontario demonstrated significant differences in the condition of sugar maple under these ranges of conditions.

Assessment of sugar maple mortality across the range of ecological units examined by NAMP revealed no differences that appear biologically significant. These regions are described on the basis of predominant biotic and abiotic features that control or modify inputs of solar energy, precipitation and nutrients; for example, climate, geology, soils, water and vegetation. Different units are identified or described through spatial differences in a combination of these characters (Smith and Carpenter 1996, Ecological Stratification Working Group 1995). The generally similar condition of sugar maple throughout such a broad range of soils, parent geology and climate suggests that if atmospheric deposition is affecting maple or the sites on which it exists, the effect or effects are subtle and not reflected in crown condition (Allen et al. 1995) or differential mortality. Only long-term monitoring that documents the occurrence and extent of stresses and provides well-structured, chronologically collected data (Stout 1993) will determine whether what appear to be negligible affects are exacerbated by stress complexes.

Results from the 233 stands that have been monitored by NAMP for the past six to nine years indicate that in these northern hardwood stands maple crowns are in good condition (Allen et al. 1995) and mortality occurs at levels generally associated with normal stand development. Similarly, independent studies in Canada (Hall 1996, Hopkin and Dumond 1994), Vermont (Kelley and Eav 1987), and Wisconsin (Mielke et al. 1991) have been unable to document unusual levels of sugar maple mortality. However, studies in northwestern and north central Pennsylvania outside the area monitored by the NAMP plot clusters show unusual levels of sugar maple mortality (Kolb and McCormick 1993; Laudermilch 1995; McWilliams et al. 1996; Horsley et al. this volume).

Nevertheless, we recognize that in some regions extensive sugar maple mortality has occurred during the past four decades (Table 9). It is important to examine these events in order to identify the factor or factors that precipitated unusual levels of mortality and, more importantly, to distinguish causes related to human activities from those which are not directly related to human intervention. Since the classic study of maple blight in Wisconsin during the early 1960s (Giese et al. 1964), very few maple declines have been investigated with scientific rigor involving a structured look at cause and effect. However, anecdotal information is available for many episodes, provided by

Table 9.—Examples of physical and biological stresses associated with sugar maple decline

Source	Example
NH Dept. Res. And Econ. Develop. 1998 [a]	Central NH, Cardigan Mt.; 1,013 ha; cutting history; maple now on sites not previously occupied; 640-670 m elev.; *Heterocampa guttivitta*; frequent ice damage; shallow soils
Payette et al. 1996	So. Quebec; drought in combination with *Malacosoma disstria*
Rhodes 1997	Northeastern PA; 15-30% mort. On 44,145 ha >30% mort. On 27,540 ha; *M. disstria, Alsophila pometaria, Ennomos subsignarius*, anthracnose
Penn. Dept. Environ. Res. 1985	Northwestern PA; 1,215 ha; >640 m elev., *A. pometaria*; history of heavy logging
NYS Dept. Environ. Cons. 1982[a]	SE NY; 81,000 ha; *M. disstria*; drought; mort. 95% in many stands
Gross 1981a	So. Ontario; 16% mort.; *M. disstria*, site conditions, weather
Can. For. Serv. 1980	So. Ontario; >50% mort.; 8,500 ha; *M. disstria*
Giese et al. 1964. U.S. Dept. Of Agric. 1964.	NE Wisc.; 4,050 ha; 2-33% mort. Overstory. 1-56% mort. Understory; cutting hist. favored intolerants; drought killed hemlock; hem./hdwd. stand converted to maple; defoliator complex
Wink 1998[a]	North. NY, Tug Hill Plateau; 48,600 ha; 17-20% mort.; *M. disstria*; highgrading

[a]Data on file, unpublished.

professionals with knowledge of local forest types, past land use practices and disturbance histories for the areas involved. We should pay attention to these observations, because several common threads connect past episodes of sugar maple mortality.

Several recent reviews of sugar maple decline and mortality cataloged these events (e.g., Barnard et al. 1990, McIlveen et al. 1986, Millers et al. 1989). The examples chosen here (Table 9) are some of the best documented incidents of true maple declines and not merely examples of temporary crown dieback resulting from a single, short-term stress. The two predisposing factors mentioned most frequently relate to stand composition and site condition. In most instances, affected stands are predominantly sugar maple as a consequence of selective cutting, which often allows maple and other shade tolerant species to dominate sites (Nyland 1986) where historically it may have constituted a relatively small percentage of the stand. Of course, under favorable site and stand conditions sugar maple naturally attains dominance, largely due to its long life, prolific seed production, extreme shade tolerance, and persistence in the understory. These characteristics account for its ability to quickly exploit gaps in the overstory and sustain this position (Abrell and Jackson 1977). Site seems to become particularly critical when, as a consequence of either selective cutting or natural events, northern hardwood stands that are predominantly sugar maple occur at elevations where soils are thin and trees are exposed repeatedly to adverse weather events.

The most common inciting event is insect defoliation, occasionally exacerbated by drought (Kolb and McCormick 1993). Forest tent caterpillar, *Malacosoma disstria* Hubner, has been most frequently associated with maple decline and mortality, but the literature also indicates that saddled prominent, *Heterocampa guttivitta* (Walker); fall cankerworm, *Alscphila pometaria* (Harris); and elm spanworm, *Ennomos subsignarius* (Hubner) have played inciting roles as well.

Acknowledging and addressing factors that have been consistently associated with maple decline and mortality is important, because they are manageable and predictable. That is, in most situations applying appropriate silvicultural methods to alter stand conditions (encourage sugar maple on appropriate sites, maintain species diversity, optimize stand density) and maintaining conscientious pest management strategies (annual monitoring and evaluation, appropriate controls) will lower the susceptibility of northern hardwood forests to sugar maple decline.

Conclusions

During the mid- to late 1980s, the general public was inundated by sensational press describing maple decline as "a catastrophe in the making" (Jones 1986), a "mysterious plague destroying a way of life" (Pawlick 1985) and that, in general, we were "losing our forests to acid rain" (Kappel-Smith 1985). These claims were made without the benefit of long-term observations and adequate scientific investigation. After monitoring the condition of sugar maple from a variety of site conditions and geographic locations, we conclude that levels of mortality observed in plots maintained by the North American Maple Project are within normal bounds reported for a variety of broadleaved forests, including those dominated by sugar maple.

Mortality of dominant/codominant sugar maple in stands actively managed for sap production (sugarbushes) is similar to that of stands that have not been as intensively managed.

Unusual levels of mortality associated with forest declines in the past have been associated generally with a combination of nonanthropogenic biotic and abiotic stresses, and forest management activities that decrease tree diversity, or damage residual trees during stand intervention. Most forest declines can be explained by documenting the extent, timing and nature of on-site disturbances combined with a knowledge of land use history. Continued quality controlled monitoring is necessary to reveal what, if any, long-term effects may result from changes in soil chemistry and to determine whether these changes magnify the impact of other stresses.

Acknowledgements

We thank the following team leaders and their respective technical staffs for undertaking annual remeasurements of NAMP plot-clusters in their respective regions or agencies; Richard Bradbury (Maine), Gretchen Smith and Ken Gooch (Massachusetts), John Witter and Robert Heyd (Michigan), Edward Hayes (Minnesota), Ed Hurley (New Brunswick/ Nova Scotia), Robert Long (Ohio), Anthony Hopkin (Ontario), E. Alan Cameron (Pennsylvania), D. Lachance and Pierre DesRochers (Quebec), H. Brent Teillon and Sandra Wilmot (Vermont), Allen Prey and Ed Jepsen (Wisconsin), Alfred Avery and Jennifer Bofinger (New Hampshire), Manfred Mielke and Imants Millers (USDA Forest Service). Assistance with SAS programming by Lawrence Layne, BioComp Systems, and statistical guidance from Stephen Stehman, SUNY College of Environmental Science and Forestry, Syracuse, are very much appreciated. We are beholden to the USDA Forest Service, Canadian Forest Service and all states and provinces involved for funding this project. A special thank you to Catherine Westfall for her patience while typing many drafts of this manuscript and to three reviewers for their helpful comments and suggestions.

Literature Cited

Abrell, D.B.; Jackson, M.T. 1977. **A decade of change in an old growth beech-maple forest in Indiana.** Am. Midl. Nat. 98:22-32.

Allen, D. C.; Barnett, C. J.; Millers, I.; Lachance, D. 1992. **Temporal change (1988-1990) in sugar maple health, and factors associated with crown condition.** Can. J. For. Res. 22:1776-1784.

Allen, D.C.; Molloy, A.W., Cooke, R.R.; Lachance, D.; Barnett, C. 1995. **North American Maple Project, seven year report.** Radnor, PA: U.S. Department of Agriculture, Northeastern Area, Forest Service. 57 p.

Barnard, J.W.; Lucier, A.M.; Johnson, A.H.; Brooks, R.T.; Karnosky, D.F.; Dunn, P.H. 1990. **Changes in forest health and productivity in the United States and Canada.** Acidic deposition; State of science and technology report 16. National Acid Precip. Assess. Prog., Washington, D.C. 186 p.

Bauce, E.; Allen, D.C. 1991. **Etiology of a sugar maple decline.** Can. J. For. Res. 21:686-693.

Bernier, B.; Brazeau, M. 1988. **Foliar nutrient status in relation to sugar maple dieback and decline in the Quebec Appalachians.** Can. J. For. Res. 18:754-761.

Boutin, R.; Robitaille, G. 1995. **Increased soil nitrate losses under mature sugar maple trees affected by experimentally induced deep frost.** Can. J. For. Res. 25:588-602.

Brooks, R.T. 1994. **A regional-scale survey and analysis of forest growth and mortality as affected by site and stand factors and acidic deposition.** Forest Science 40:543-557.

Buchman, R.G. 1983. **Survival predictions for major Lake States tree species.** Res. Pap. NC-233. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northcentral Forest Experiment Station. 7 p.

Canadian Forest Service. 1980. **Forest insect and disease conditions.** Survey Bull. Sault Ste. Marie, Ontario: Great lakes Forest Research Centre. 9 p.

Ecological Stratification Working Group. 1995. **A national framework for Canada.** Ottawa, Canada: Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch Report and national map at 1:7,500,000 scale. 125 p.

Foster, N.W. 1989. **Acidic deposition: What is fact, what is speculation, what is needed.** Water Air Soil Pollut. 48:299-306.

Franklin, J.F.; Shugart, H.H.; Harmon, M.H. 1987. **Tree death as an ecological process.** BioScience 37:550-556.

Frelich, L.E.; Lorimer, C.G. 1991. **Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region.** Ecol. Mono. 61:145-164.

Garner, J.H.B.; Pagario, T.; Cowling, E.G. 1989. **An evaluation of the role of ozone, acid deposition, and other airborne pollutants in the forests of eastern North America.** Gen. Tech. Rep. SE-59. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 172 p.

Giese, R.L.; Houston, D.R.; Benjamin, D.M.; Kuntz, J.E. 1964. pp. 1-19. In: **Studies of Maple Blight.** Univ. Wisconsin Res. Bull. 250.

Gross, H.L. 1981a. **Maple decline.** Newsletter (summer issue). Sault Ste. Marie, Ontario, Canadian Forest Service, Great Lakes Forest Research Centre.

Hall, J.P. et al. (compilers) 1996. **Health of North American forests.** Ottawa, Ontario: Canadian Forest Service. Science and Sustainable Development Directorate. 66 p.

Hall, J.P. 1995. **ARNEWS assesses the health of Canada's forests.** For. Chron. 71:607-613.

Hall, J. P. 1996. **ARNEWS annual report for 1994.** Inf. Rep. ST-X-1. Ottawa, Ontario: Canadian Forest Service. 26 p.

Harcombe, P.A.; Marks, P.L. 1983. **Five years of tree death in a *Fagus-Magnolia* forest, Southeast Texas.** Oecologia 57:49-54.

Hart, G. (Ed.). 1991. **Air pollution and forests - the Turkey Lakes Watershed Study.** Ontario Region Forestry Newsletter. Winter/Spring, Sault Ste. Marie, Ontario: Can. For. Serv. 9 p.

Hopkin, A.A.; Dumond, T. 1994. **Sugar maple health shows general improvement in Ontario.** Frontline Forestry Research Applications. Can. For. Serv., Ontario Region. Tech. Note No. 17. 4 p.

Horsley, S.B.; Long, R.P.; Bailey, S.W.; Hallett, R.W.; Hall, T.J. 1999. **Factors contributing to sugar maple decline along topographic gradients on the glaciated and unglaciated Allegheny Plateau.** In: Proceedings Sugar Maple Ecology and Health: An International Symposium. This volume.

Jones, A.R.C. 1986. **Maple decline, a catastrophe in the making.** Macdonald Jour. 47:10-12.

Kappel-Smith, D. 1985. **We are losing our forests to acid rain.** New England Farmer. January 1985.

Kelley, R.S.; Smith, L.; Cox, S.M. 1992. **Vermont hardwood tree health in 1991 compared to 1986.** Waterbury, VT: Vermont Department of Forests, Parks and Recreation. 25 p.

Kelley, R.S.; Eav, B. 1987. **Vermont hardwood tree health survey 1986.** Waterbury, VT: Vermont Department of Forests, parks and Recreation. 30 p.

Keys, Jr., J.; Carpenter, C.; Hooks, S.; Koenig, F.; McNab. W.H.; Russell, W.; Smith, M.L. 1995. **Ecological units of the eastern United States - first approximation (map and booklet of map unit tables).** Atlanta, GA: U.S. Department of Agriculture, Forest Service. Presentation scale 1:3,500,000; colored. Also available on CD-ROM consisting of GIS coverage in ARCINFO format and map unit descriptions of subsections and sections. 83 p.

Kolb, T.E; McCormick, L.H. 1993. **Etiology of sugar maple decline in four Pennsylvania stands.** Can. J. For. Res. 23:2395-2402.

Laudermilch, G. 1995. **Northern area report.** In: Forest Pest Management News. Commonwealth of Pennsylvania, Dept. of Environ. Res., Bur. of For., Div. of Pest Mgmt., Middletown, PA 13(2):6-7.

Leak, W.B. 1961. **Development of second-growth northern hardwoods on Bartlett Experimental Forest.** Station Pap. No. 155, Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Leak, W.B. 1970. **Successional change in northern hardwoods predicted by birth and death simulators.** Ecology 51:794-801.

Linzon, S.N. 1987. **Effects of airborne sulfur pollutants on plants.** pp. 109-162 In: J.O. Nriagu (ed.). Sulfur in the environment, Part II. New York, NY: John Wiley and Sons.

Long, R.P.; Horsley, S.B.;Lilja, P.R. 1997. **Impact of forest liming on growth and crown vigor of sugar maple and associated hardwoods.** Can. J. For. Res. 27:1560-1573.

Long, R.P.; Horsley, S.B.; Lilja, P.R. 1999. **Impact of forest liming on growth, vigor, and reproduction of sugar maple and associated hardwoods.** This volume.

Lovett, G.M.; Kinsman, J.D. 1990. **Atmospheric pollutant deposition to high-elevation ecosystems.** Atmos. Environ. 24A:2767-2786.

McIlveen, W.D.; Rutherford, S.T.; Linzon, S.N. 1986. **A historical perspective of sugar maple decline within Ontario and outside of Ontario.** ARB-141-86-Phyto. Ottawa, Ontario: Ministry of the Environment. 40 p.

McLaughlin, D.; Kinch, C.; Liljalehto, H.; Boysen, E. 1996. **Hardwood forest health surveys in Ontario - the first 10 years: 1986 to 1995.** Brampton, Ont.: Min. of Environ. and Energy. 17 p.

McNab; H.W.; Avers, P.E. 1994. **Ecological subregions of the United States: Section descriptions.** Administrative Bulletin WO-WSA-5. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 267 p.

Mielke, M.E.; Rezabek, C.L.; Carlson, J.C.; Gillespie, A.J.R. 1991. **Survey to assess the health of sugar maple and other northern hardwoods across a pH gradient in Wisconsin, 1987-1988.** Wisc. Dept. Natl. Resources, Bureau of Air Management, Madison. Publ. No. AM-052. 39 p.

Millers, I.; Shriner, D.S.; Rizzo, D. 1989. **History of hardwood decline in the eastern United States.** Gen. Tech. Rep. NE-126. Broomall, PA: U.S. Department of Agriculture, Forest Service. Northeastern Forest Experiment Station. 75 p.

Millers, I.; Lachance, D.; Burkman, W.D.; Allen, D.C. 1991. **North American Sugar Maple Decline Project: Organization and field methods.** Gen. Tech. Rep. NE-154. Broomall, PA: U.S. Department of Agriculture, Forest Service. Northeastern Forest Experiment Station. 26 p.

Nyland, R.D. 1986. **Important trends and regional differences in silvicultural practice for northern hardwoods.** pp. 156-182. In: G.D. Mroz and D.D. Reed (eds.). The Northern Hardwood Resource: Management and Potential. Proc. Conf., Aug. 18-20, 1986. Mich. Technol. Univ., Houghton, MI.

Pawlick, T. 1985. **What's killing Canada's sugar maples?** Intl. Wildlife 15:35-40.

Payette, S.; Fortin, M.J.; Morneau, C. 1996. **The recent sugar maple decline in southern Quebec: probable causes deduced from tree rings.** Can. J. For. Res. 26:1069-1078.

Peet, R.; Christensen, N. 1987. **Competition and tree death.** BioScience 37:586-595.

Pendrick, D. 1996. **Blown away.** Earthbeat 96(2):24.

Pennsylvania Department of Natural Resources. 1985. **Forest pest management news, 1985.** March-April. Middletown, PA: Bureau of Forestry, Division of Forest Pest Management:3-6.

Rhodes, L.D. 1997. **Forest Pest Management News.** Middletown, PA: Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, Middletown. 13 p.

Scherbatskoy, T.; Bliss, M. 1984. **Occurrence of acidic rain and cloud water in high elevation ecosystems in the Green Mountains, Vermont.** pp. 449-463. In: P.J. Sampson (ed.) The meteorology of Acid Deposition. Air Pollut. Control Assoc., Pittsburgh, PA.

Smith, M.L.; Carpenter, C. 1996. **Application of the USDA Forest Service national hierarchical framework of ecological units at the sub-regional level: the New England-New York example.** pp. 187-198. In: R.A. Sime (ed.). Global to local: ecological land classification. Dordrecht, The Netherlands: Kluwer Academic Publishers. 610 p.

Solomon, D.S. 1977. **The influence of stand density and structure on growth of northern hardwoods in New England.** Station Res. Pap. NE-362. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

Spellerberg, I.F. 1991. **Monitoring ecological change.** New York, NY; Cambridge Univ. Press. 334 p.

Stephens, G.R.; Waggoner, P.E. 1980. **A half century of natural transitions in mixed hardwood forests.** Conn. Agric. Exp. Stn. Bull. 783. New Haven, CT. 43 p.

Stout, B.B. 1993. **The good, the bad and the ugly of monitoring programs: defining questions and establishing objectives.** Environ. Monitoring 26:91-98.

U.S. Department of Agriculture. 1964. **The causes of maple blight in the lake States.** Res. Pap. LS-10. St. Paul, MN: Forest Service, Lake States Forest Experiment Station. 15 p.

Waring, R.H.; Schlesinger, W.H. 1985. **Forest ecosystems, concepts and management.** Orlando, FL: Academic Press. 340 p.

Weiner, J.; Thomas, S.C. 1986. **Size variability and competition in plant monocultures.** Oikos 47:211-222.

Westoby, M. 1984. **The self-thinning rule.** Adv. Ecol. Res. 14:167-225.