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North American Maple Project

Seven Year Report

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Cooperators

The following cooperators are responsible for all field operations in their respective regions, and they participated in the original design of field protocols. Additionally, each is an integral part of annual project reviews and data quality assurance activities.

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Maine	**Richard Bradbury**, *Maine Forest Service*
Massachusetts	**Gretchen Smith**, *University of Massachusetts*
Michigan	**John Witter**, *University of Michigan* **Robert Heyd**, *Michigan Dept. of Natural Resources*
Minnesota	**Edward Hayes**, *Minnesota Dept. of Natural Resources*
New Brunswick, Nova Scotia	**Bruce Pendrel**, *Canadian Forest Service*
New York	**Douglas Allen**, *SUNY, College of Env. Sciences & Forestry*
Ohio	**Robert Long**, *USDA, Forest Service*
Ontario	**Anthony Hopkin**, *Canadian Forest Service*
Pennsylvania	**E. Alan Cameron**, *Pennsylvania State University*
Quebec	**Denis Lachance**, *Canadian Forest Service* (retired)
Vermont	**H. Brenton Teillon** and **Sandra Wilmot**, *Dept. of Forests, Parks and Recreation*
Wisconsin	**Allen Prey**, *Dept. of Natural Resources*
New Hampshire	**Alfred Avery** and **Jennifer Bofinger**, *Division of Forests and Lands*
Other USDA Forest Service Cooperators	**Manfred Mielke**, *St. Paul* and **Imants Millers**, *Durham* (retired)

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Introduction

During the late 1970s and throughout the 1980s, maple syrup producers, foresters who managed northern hardwood stands and the general public became concerned about sugar maple decline and its relation to acidic deposition. A working group of scientists recommended that a special project be designed to monitor and evaluate sugar maple condition, particularly in relation to air pollution and stand management intensity. The North American Sugar Maple Decline Project was formed in 1987 between Canada and the United States and authorized by a Memorandum of Understanding and Special Project Agreement. In the U.S., initial funding and project administration was provided through the Eastern Hardwood Research Cooperative, Northeastern Forest Experiment Station, USDA Forest Service, sponsored by the National Acid Precipitation Assessment Program. Administration and financial support was transferred to Forest Health Protection, Northeastern Area, State and Private Forestry, Forest Service in 1991, at which time the activity was renamed North American Maple Project (NAMP). In Canada, funding and administration are provided by the Canadian Forest Service. Field work began in 1988 and will continue at least through 1996.

This report highlights accomplishments and results from the first seven years of the North American Maple Project. Material presented was selected to illustrate examples of ways in which analysis and interpretation of data addresses original project objectives. Also, procedural changes that occurred as NAMP evolved are noted. It is not intended to be an exhaustive treatment of any one aspect of program results.

The Resource

Sugar maple, *Acer saccharum* Marsh., is one of the most important broadleaved trees in the northeastern United States and southeastern Canada. Its continued dominance in many ecological regions is likely due to its high seed production, high shade tolerance and long life. The income attached to sugar maple is especially important to the economic health of many rural communities. The value accrues either individually or collectively from stumpage sales, primary processing, secondary manufacturing, the maple syrup industry, and tourism. Employment opportunities and cash flow are limited in most of these communities, and the diverse array of maple products and tourist benefits help to ease both problems.

In 1988, for example, New England and New York manufactured approximately 890,000 gal. (US) (3,368,650 liters) of maple syrup worth $25,000,000 (New York Agricultural Statistics 1989). Canada produced for the same period approximately 3.75 million gal. (US) (14,193,750 liters) valued at $ (US) 72,358,000 (Bureau of Statistics of Quebec 1988). The average value of sugar maple sawlogs (including veneer) for New York's 14 price-reporting regions in January 1991 was $113/MBF (range $65 to $165) (Bureau of Land Resources 1991). In 1995, this figure had increased 153% to $287/MBF (range $175 to $410) (Bureau of Land Resources 1995). Tens of millions of dollars are attached to the annual fall tourist trade in the northeastern United States and eastern Canada. Sugar maple is a key element of this attraction.

Sugar maple is a major component of seven cover types and a common associate in 17 others in the northeastern U.S. and southeastern Canada (Eyre 1980). It occurs on a wide range of site conditions throughout this region (Godman *et al.* 1990).

The above suggest that for both social and ecological reasons sugar maple is a key species for detecting the occurrence and evaluating the effects of both natural and human related disturbances.

NAMP Objectives

The purposes of the North American Maple Project are:

- To determine the rate of change in sugar maple condition,
- To determine if observed changes in sugar maple condition differ between two types of stand management, sugarbushes and stands not managed for syrup production (the latter are referred to as non-sugarbushes); among various levels of initial stand conditions; and (or) among various levels of atmospheric pollution measured as wet deposition of sulfate and nitrate,
- To identify possible causes of sugar maple decline and the geographical relation between cause(s) and extent of damage.

Methods

Project Management

NAMP is guided by a Joint Management Team co-chaired by Gerard D. Hertel, USDA Forest Service and J. Peter Hall, Canadian Forest Service. Ten states and four provinces cooperate in the project. National Coordinators provide day-to-day guidance: Robert R. Cooke, USDA Forest Service, and Denis Lachance, Canadian Forest Service. Planning and organization began in 1987 (McFadden 1991).

Data Quality and Assurance

Methods to assure quality of data collection and analysis have been a high priority. The need for careful monitoring of project methods and their application was deemed especially important because of the diverse people involved in data collection, the large data base that evolved, the fact that data collection encompassed a wide geographical area and multiple jurisdictions, and because the project used relatively untested visual estimates of crown condition. Annual remeasurements are done between crews, states and provinces and then evaluated by a QA/QC specialist at the Northeastern Forest Experiment Station, Radnor, PA (Burkman et al. 1991). Data management and analyses are provided by the State University College of Environmental Science and Forestry, Syracuse, NY.

A recent evaluation serves as an example of the QA/QC approach used by NAMP. In 1994 a total of 2,499 trees were remeasured on 140 plots, of which 1,643 were sugar maples.

There were two types of remeasurements in 1994. Same-crew remeasurements are defined as those remeasurements done on plots where original field data were taken by that same crew. Between-crew remeasurements are those remeasurements done on plots where the field data were taken by a different crew. Of the 2,499 remeasurements made, 104 trees (spread over seven plots) were remeasured with both methods. The two variables that are of primary interest are crown dieback and transparency. The data quality standard for these two variables requires that 90% of remeasurements should be within 10% (i.e., 1 rating class, *Table 1*) of the original measurement.

The difference between the original and remeasurement values was calculated for each variable for each observation. These differences were combined into Difference Groups defined as follows:

<20% – Original values were lower than remeasurement values by more than 20% (2 classes).

-20% – Original values were lower than remeasurement values by 15 or 20%.

-10% – Original values were lower than remeasurement values by 5 or 10%.

0% – No differences between original and remeasurement values.

10% – Original values were higher than remeasurement values by 5 or 10%.

20% – Original values were higher than remeasurement values by 15 or 20%.

>20% – Original values were higher than remeasurement values by more than 20%.

Table 1. *Rating classes used by NAMP and acceptable range of observer variability for estimates of crown dieback and crown transparency.*

Rating Class (%)	Class Range (%)	Acceptable Observer Variability (%)
0	0	0-5
5	1-5	0-15
10	6-15	1-25
20	16-25	6-35
30	26-35	16-45
40	36-45	26-55
50	46-55	36-65
60	56-65	46-75
70	66-75	56-85
80	76-85	66-95
90	86-95	76-100
100	96-100	86-100

A methods manual was developed at the start of the program and published in French and English. It outlined field methods and requirements for data recording and transmittal (Millers *et al.* 1991). This document has been revised as needed for the purposes of clarification or to redefine methods. The latter involved minor alterations that occurred only after cooperators agreed that a modification was needed to more clearly reflect how a measurement was made in the field. Measurement of a variable was dropped only when collective thinking and experience indicated that the cost (field time, analysis) of continued measurement was substantially greater than the value of information derived.

Protocol Modifications

Methods used to select and measure plot-clusters and overall plot design have changed little since the beginning of this project. The latest revision of the field manual (Cooke *et al.* 1995) reflects the following alterations that have been made since the inception of NAMP:

a. Estimates of the amount of dwarfed foliage and epicormic branching were eliminated in 1989 because they were ambiguous and not repeatable,

b. Foliage discoloration was reduced to a noncritical variable in 1989 (i.e., no longer included in the training sessions) for the same reasons,

c. An early summer visit to each plot-cluster to assess early season defoliation was incorporated into the field procedures in 1989,

d. Annual estimates of seed production for all dominant/codominant sugar maples have been required since 1993,

e. Several clarifications have been made in the definition of "tree vigor", but the manner in which it is determined and its purpose have not changed,

f. Initially, the terms "sugarbush" and "undisturbed" were used to identify plot-clusters at the time of establishment. Similarly, this distinction was the basis of stratifying plot-clusters according to forest management intensity when crown data were analyzed (Allen *et al.* 1992). Cooperators at the winter meeting in 1993 agreed that "undisturbed" was not an appropriate category and at this time "non-sugarbush" was adopted as the correct designation for stands not actively managed for sap production,

g. Beginning in 1991, records have been collected and maintained on the disturbance history of each stand that contains a plot-cluster, and a "Disturbance History" form was developed for this purpose,

h. NAMP has utilized three different data analysts since the project began. This change occurred because people who held this temporary position had an opportunity to move on to permanent jobs, and

i. Administratively, a major change occurred when the National Acid Precipitation Assessment Program ended and NAMP became part of Northeastern Area State and Private Forestry, USDA Forest Service.

Increased Data Base

In 1988, NAMP established 165 plot-clusters in seven states and four provinces. This number has increased to 233 plot-clusters during the past seven years, because five of the original cooperators elected to expand geographic coverage and three additional states joined the study (*Table 2*). This expansion increased the total number of sugar maples under observation from 10,738 in 1988 to 15,798 (including 9,466 live trees in the dominant/codominant crown positions) by 1994 (*Table 3*).

Table 2. *Regional distribution of NAMP plot-clusters and year established.*

Number of Clusters and Year Established									
State/Province	1988	1989	1990	1991	1992	1993	Total No. Sugarbushes	Total No. Non-Sugarbushes	Total
Maine	18	-	-	-	-	-	9	9	18
Massachusetts	10	-	-	-	-	-	5	5	10
Michigan	10	-	-	8	-	6	9	15	24
Minnesota	-	-	-	-	8	-	4	4	8
New Brunswick/ Nova Scotia	11	3	-	-	-	-	7	7	14
New Hampshire	6	-	-	-	-	4	5	5	10
New York	18	-	-	9	-	-	11	16	27
Ohio	-	-	-	-	6	-	6	0	6
Ontario	24	-	-	-	-	-	12	12	24
Pennsylvania	-	-	-	-	6	4	5	5	10
Quebec	24	-	-	-	-	-	12	12	24
Vermont	26	2	1	1	10	-	21	19	40
Wisconsin	18	-	-	-	-	-	9	9	18
Total	**165**						**115**	**118**	**233**

Table 3. *Number of sugar maples under observation in each NAMP region - 1994.*

State/Province	Live Dominant/Codominant Sugar Maples 1994	Total Sugar Maples[1] 1994
Maine	778	1,261
Massachusetts	470	668
Michigan	825	1,531
Minnesota	251	471
New Brunswick/Nova Scotia	1,044	1,347
New Hampshire	426	630
New York	941	1,830
Ohio	104	267
Ontario	917	1,394
Pennsylvania	389	672
Quebec	1,134	1,956
Vermont	1,566	2,634
Wisconsin	621	1,137
Total	**9,466**	**15,798**

[1] *Includes live, dead and cut sugar maples in all crown positions.*

External Project Review

An external project review that included a two-day meeting with NAMP management and a one-day field session was commissioned by NAMP's Joint Management Team (Dr. Les Carlson, Canadian Forest Service and Dr. Gerard Hertel, USDA Forest Service) in 1992. The review team (*Table 4*) consisted of seven experts in the areas of survey/monitoring, evaluation and (or) sugar maple health, that met in Burlington, VT during August 1993. Their objectives were to review field protocols and analytical methods, to determine the effectiveness of international involvement, to judge whether or not a five-year program was adequate to meet project objectives, to assess the validity of the original objectives (1988) in view of current (1993) knowledge about forest health, and to identify additional field procedures that NAMP should be encouraged to incorporate into the field methods to take full advantage of knowledge gained.

Internal Project Reviews

Once each year NAMP cooperators, the Joint Management Team and the National Project Coordinators meet for two and one-half days to review and discuss data analyses resulting from the most recent field season and compare these results to previous years, to examine results of field audits by the QA/QC coordinator, to review plans for disseminating results and other information relative to NAMP, to identify training needs for the forthcoming field season, and to discuss concerns regarding the definition of variables or data collection.

Data Management and Analyses

The general methods involved in managing the data and discussion of the statistical tools employed in data analyses were summarized in Allen and Barnett (1990) and Allen *et al.* (1992).

Each plot-cluster consists of five, 20m x 20m plots, and individual tree crown ratings for dieback and transparency within each plot-cluster are averaged to obtain a plot-cluster average; n = 165 in 1988, n = 233 in 1994. Plot-cluster averages are also used to determine regional average crown dieback and crown transparency ratings that provide the basis for comparisons between years and management types. The null-hypothesis states that there are no differences between means.

Initially, Scheffe's method was used for all multiple comparisons except for regional comparisons of dieback and transparency, which were tested using Tukey-Kramer's studentized procedure (Allen *et al.* 1992). A reassessment of this analytical approach in 1992, suggested that the Bonferroni method (Sokal and Rohlf 1995) was more appropriate for controlling the experimentwise error rate. This method has a higher probability of rejecting the null hypothesis when it is false (i.e., increased power) and is useful when sample sizes are unequal and a small number of comparisons are specified. All multiple comparisons are now done using this technique and a 0.05 level of significance.

For the purposes of this report, the short- and long-term impact of stresses such as defoliation and drought are limited to sugar maple in plot-clusters (or affected plots within a plot-cluster) established in 1988. Paired t-tests were employed to compare year-to-year changes in crown condition. Only one or two comparisons are made per region and the study design is that of repeated measures. The null hypotheses tested were that differences between yearly means for crown dieback or crown transparency equaled zero. For a single comparison (e.g., crown dieback means in New Hampshire for 1993 *vs.* 1994) the significance level is 0.05. However, when two comparisons are made (e.g., crown condition of ice damaged trees in NY for 1991 *vs.* 1992 and 1991 *vs.* 1994), the significance level is divided by the number of comparisons, in this case two (alpha = 0.025), to maintain the overall significance level at 0.05 (Sokal and Rohlf 1995).

Table 4. *Members of the Review Team convened in Burlington, VT August 1993 to evaluate NAMP.*

Name	Affilation
Dr. John Skelly	Dept. of Plant Pathology Pennsylvania State University University Park, PA, USA
Dr. A.R.C. Jones	Professor Emeritus Ste. Anne-De-Bellevue Quebec, CANADA
Dr. David Reed	School of Forestry Michigan Technological University Houghton, MI, USA
Dr. Tim Perkins	Botany Department University of Vermont Burlington, VT, USA
Dr. John Innes	Swiss Federal Institute for Forest and Landscape Research SWITZERLAND
Dr. Jan Volney	Canadian Forest Service Forest Pest Management Systems Northern Forestry Centre Edmonton, Alberta CANADA
Mr. Robert Loomis	USDA Forest Service Forestry Sciences Lab Research Triangle Park, NC, USA

One of NAMP's original objectives was to determine the relationship between sugar maple crown condition and levels (kg/ha/yr) of wet deposition for sulfate (SO_4^{2-}) and nitrate (NO_3^-). Initially, deposition levels were estimated using data provided by the Canadian National Atmospheric Chemistry (NATChem) Data Base to the Canadian Forest Service. These data were obtained as maps of mean wet deposition by 5 kg/ha isopleths (1982-86). Data points (deposition levels) for each plot-cluster were extrapolated from the nearest isopleths and estimated to the nearest 5 kg/ha/yr. In 1990, estimated sulfate values ranged from 10 kg/ha/yr for two Wisconsin plot-clusters to a high of 35 kg/ha/yr for several plot-clusters in Michigan. Deposition levels for nitrate ranged from 10 to 20 kg/ha/yr.

Plot-clusters were reclassified in 1994 because new clusters had been incorporated into the data set, updated information on deposition was available and additional stations had been added to the monitoring network. Deposition figures were provided by Environment Canada, Downsview, Ontario and the National Atmospheric Deposition Program/National Trends Network Coordination Office (NADP/NTN, 1995) in Fort Collins, Colorado. UTM coordinates for each plot-cluster identified the nearest monitoring station as a source of mean deposition estimates for each monitoring period: Canada 1980-91, U.S. 1984-93. Some U.S. annual deposition data did not meet a standard set of validity criteria established by NADP/NTN; these data were not included in the calculation of mean deposition estimates. For example, the number of years used to determine a mean for some monitoring sites was as few as seven. Using this approach, mean annual sulfate values ranged from 12 to 35 kg/ha/yr for Canadian plot-clusters and 6 to 39 kg/ha/yr in the U.S. Nitrate values were 8 to 24 kg/ha/yr for Canadian and 6 to 30 kg/ha/yr for U.S. plot-clusters.

The first assessment of sugar maple crown condition (Allen *et al.* 1992) indicated that there were no statistically significant differences in crown dieback for trees in NAMP plot-clusters exposed to three levels of wet sulfate deposition (High = 30-35 kg/ha/yr, Medium = 20-25 kg/ha/yr; Low = 10-15 kg/ha/yr). However, at that time plot-clusters exposed to **low** levels of sulfate deposition had significantly higher crown transparency. The relationship between nitrate deposition and crown condition was not examined because there appeared to be little between-plot variation in this variable. All plot-clusters were classified in the range of 10-20 kg/ha/yr.

In the current (1994) analysis of deposition and crown condition, the original sulfate deposition classes were widened to accommodate plot-clusters that did not fall within the bounds of the original classification: Low = 7.6-17.5; Medium = 17.6-27.5; High = > 27.5 kg/ha/yr. This scheme placed 33 of 226 plot-clusters in the High class (42 of 165 plot-clusters occurred here in 1992 analysis); 126 in the Medium class (91 in 1992) and 67 were classified as Low (38 in 1992).

Updated information on nitrate deposition levels indicated that plot-clusters could now be placed in one of three categories for analytical purposes: Low = 0-15 (n = 90); Medium = 16-20 (n = 96); High = >20 (n = 40) kg/ha/yr.

All available plot-clusters (n=226; deposition data were unavailable for seven plot-clusters) were used to examine the relation between crown condition and atmospheric wet deposition of sulfate and nitrate for 1994. If the overall ANOVA model (SAS PROC GLM) was significant, the Bonferroni method was then used to determine if average cluster dieback and transparency differed significantly between plot-clusters ostensibly exposed to High, Medium and Low levels of deposition.

Annual mortality of the sugar maples (% of trees and % basal area) that were alive when the original plot-clusters were established (1988) was determined by tracking the number of sugar maples that died from one year to the next. Mortality expressed as a percentage of basal area lost was calculated based on total basal area of sugar maples alive the previous year. Cumulative mortality for the period 1988 through 1994 is the sum of annual mortalities. In an effort to calculate a more accurate picture of "natural" mortality, trees that were otherwise healthy but cut for management-related reasons or killed due to management activities were excluded from the mortality data. Losses from all other causes were considered "natural". To accomplish this, the record of each dead or cut tree was reviewed back to 1988. If a tree was healthy when cut, then it was deleted from the data set used to determine annual natural mortality. Also, if there was evidence that an otherwise healthy tree was killed as a result of a forest management-related activity (such as skidder damage), then this tree was also excluded for the purpose of determining annual natural mortality. "Healthy" was defined as a tree whose record prior to death revealed no consistent evidence of declining vigor, increasing dieback or increasing transparency, and whose field notes did not indicate a serious pathological condition or physical damage. When the history of a tree prior to its death was unclear, the loss was classified as natural mortality. Two types of mortality are presented for each region: "natural" and management-related. Each mortality category is further stratified by management type (sugarbush, non-sugarbush) and crown position (dominant/codominant, intermediate/suppressed). Ingrowth associated with the 1988 plot-clusters in later years was not included when computing mortality figures.

Results and Discussion

Data Quality and Assurance

Of 2,170 live hardwood trees available for remeasurement of crown dieback in 1994, there was agreement between measurements and remeasurements for 2,103 trees (97%). The average difference in dieback measurements was 0.3% with a standard deviation of 6.2% (*Table 5*). Of the 67 trees with differences that fell outside of the standards, 48 (72%) were within 20% (two classes) of the original measurements (*Fig. 1, Table 6*).

There were 2,181 live hardwood trees for which a field measurement and a remeasurement were available to evaluate the repeatability of crown transparency estimates. There was agreement between measurements and remeasurements for 2,057 trees (94%). The average difference in the transparency measurements was 0.3% with a standard deviation of 7.9%. Of the 124 trees with differences that fell outside of the standards, 110 (89%) were within 20% (2 classes) of the original measurements (*Fig. 2, Table 6*).

These results are consistent with results from previous years. Typically, over 95% of the dieback remeasurements and over 90% of the transparency remeasurements meet the data quality standard of ± 10% (one class). Most often, the 1994 measurements that did not meet the standard were from trees with high dieback and/or transparency (*Table 6*). This, too, is consistent with previous years' results.

External Project Review

Overall, this review was very complimentary. The opportunity for project personnel to exchange ideas, defend methods used and discuss future plans with an outside group was very beneficial. The results also were reassuring in that the review team generally determined that NAMP was well planned, managed and executed (USDA Forest Service - Canadian Forest Service 1992), and it warranted continuation long enough to complete at least a ten-year period of data collection. The review team made 14 recommendations, most of which were either under consideration by NAMP at the time of the review or were subsequently addressed by the cooperators or by project management. Three recommendations have not been fully addressed due to lack of time and/or inadequate funding: i) collection of additional site data (*e.g.*, site quality, soils), ii) a comprehensive analysis of the relation between crown transparency in year **t** and future crown dieback and iii) use of total (wet + dry) sulfate and nitrate deposition in the analyses. The second and third items will be incorporated by late 1996. Anticipated funding levels will not allow NAMP to address the site/soil aspects.

Crown Dieback

The average cluster dieback rating for all plot-clusters combined ranged from 5.2% to 8.7% annually for 1988 through 1994, whether using the original set of plot-clusters established in 1988 or including plot-clusters established in later years (*Figs. 3* and *4*). In both sugarbushes (SB) and non-sugarbushes (NSB), the seven-year trend reveals little change in dieback (*Tables 7* and *8*); the 1988 vs. 1994 decrease in average cluster dieback in NSBs (-1.2%) is not statistically significant. The 1988 vs. 1994 comparisons for sugarbushes, on the other hand, reveal a statistically significant decrease in average cluster ratings for both the original data set (-1.8%) and when using plot-clusters added after 1988 (1.9%). Ten of 12 annual comparisons have differences of less than 1-percent (Columns 2 & 3 in *Tables 7* and *8*), and none are statistically significant. A comparison of average cluster dieback between management categories reveals two out of seven statistically significant differences of higher average dieback (of 1.6%) in SBs for 1988 and 1989.

Table 5. *Sample size, percent of measurements meeting the data quality standard, average difference and standard deviation for between-crew, same-crew and all measurements.*

	n	Percent Agreement	Differences	
			Mean	Standard Deviation
Dieback				
Same-Crew	1,134	98	0.8	5.9
Between-Crew	1,036	96	-0.3	6.5
All	2,170	97	0.3	6.2
Transparency				
Same-Crew	1,145	95	-0.5	7.9
Between-Crew	1,036	94	1.2	7.7
All	2,181	94	0.3	7.9

Table 6. *Distribution of differences by severity of dieback and transparency ratings. See text for explanation of Difference Groups.*

	n	Percent Agreement	-20%+	-20%	-10%	0%	10%	20%	20%+
Dieback									
Low (0-5%)	1,769	99	6	18	287	1,188	270	0	0
Moderate (10%)	289	97	3	7	17	68	194	0	0
High (>20%)	112	71	3	5	13	35	31	18	7
Total	**2,170**	**97**	**12**	**30**	**317**	**1,291**	**495**	**18**	**7**
Transparency									
Low (0-20%)	1,933	97	2	42	472	1,072	328	17	0
Moderate (30-50%)	229	79	0	1	16	70	95	43	4
High (>50%)	19	21	0	0	1	2	1	7	8
Total	**2,181**	**94**	**2**	**43**	**489**	**1,144**	**424**	**67**	**12**

For all years combined, SBs had a statistically significant 1.2% higher average cluster dieback rating than NSBs. Although certain dieback comparisons are statistically significant, they have little biological significance based on the rating class system used and given that all differences were less than the width of a rating class.

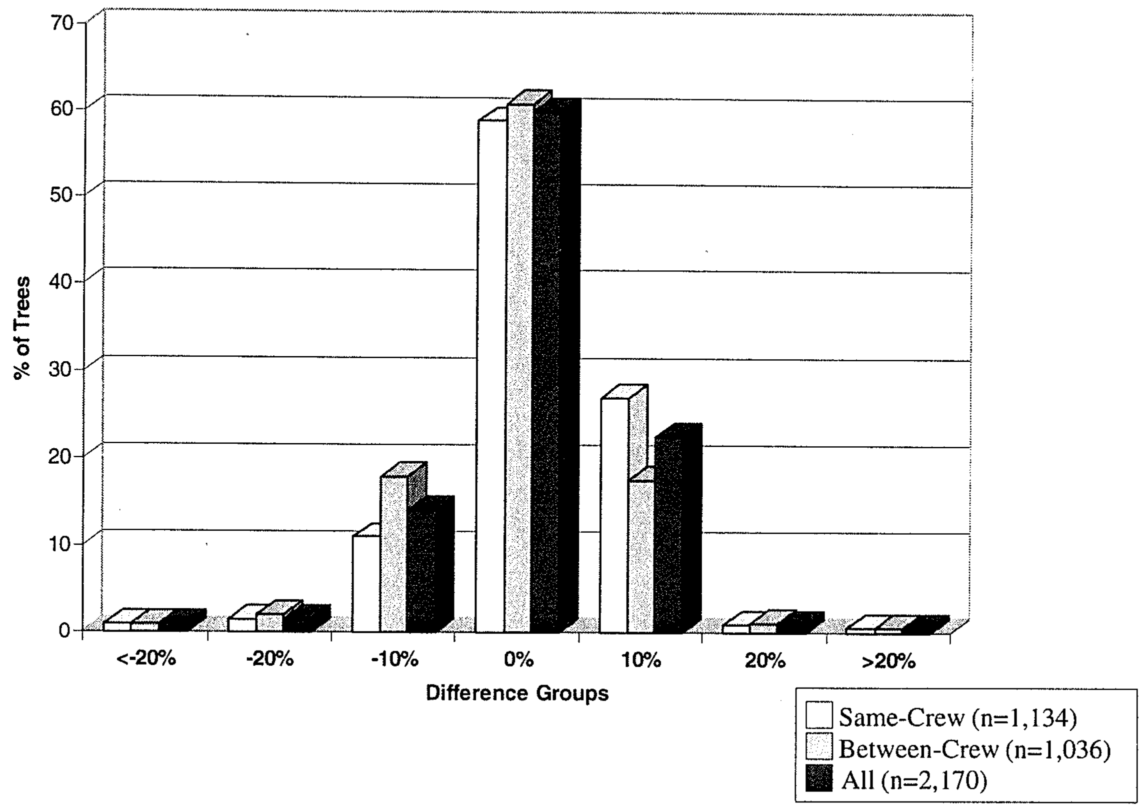


Figure 1. *Distribution of differences in field and remeasurement dieback ratings.*

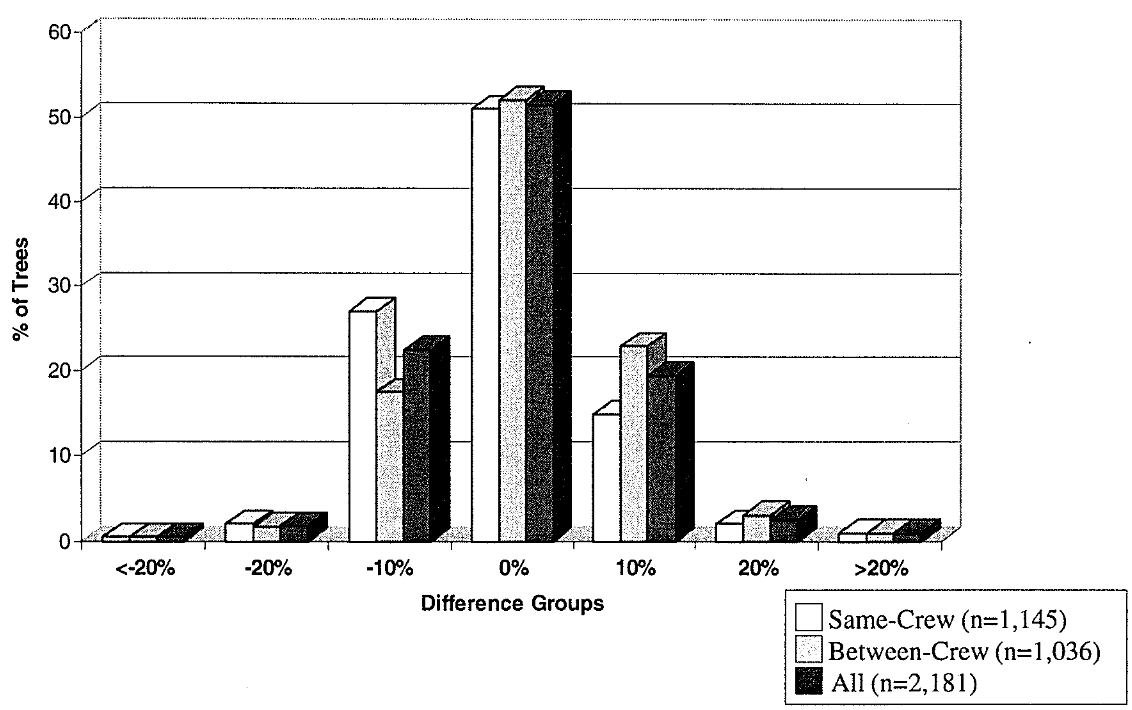


Figure 2. *Distribution of differences in field and remeasurement transparency ratings.*

The frequency distributions indicate that most trees (60-80%) were in the 5% dieback class for all years, whether looking at original plot-clusters only or the combined data set (*Figs. 5* and *6*). SBs have slightly higher dieback ratings, as evidenced by shorter bars for SBs in the 0% class and taller bars for SBs in the 10% and greater classes. These figures show a shift from the 0% to the 5% rating class from 1992-1994; that is, bars are shorter for both management categories in the 0% class and bars are higher in the 5% class.

The cumulative density functions for dieback vary little from year to year for both SB and NSB samples, as evidenced by the similar positions of the lines on the two graphs. That is true for both the original plot-clusters (*Fig. 7*) only and the total data set (*Fig. 8*). With the exception of the 1988 curve, which is noticeably separated on the graph, all years appear to be similar (i.e., the lines on the graph overlap). Approximately 90% of the live, dominant/codominant sugar maples were rated as having 10% dieback or less during all seven years.

Average cluster dieback within the ten states/provinces established in 1988 (original plot-clusters only) ranged from 2.9% to 10.6% in SBs and 2.1% to 7.9% in NSBs during 1994 (*Table 9*). Michigan had the lowest and Quebec had the highest average cluster dieback in each management category. When all 233 plot-clusters in 13 regions were compared, average dieback in SBs in 1994 ranged from 3.9% to 10.6% (lowest in Minnesota, highest in Quebec) and in NSBs the range was 4.2% to 7.9% (lowest in Michigan, Minnesota and New York, highest in Quebec) (*Table 10*). None of the regional comparisons between average dieback for SBs and NSBs were statistically significant in 1994.

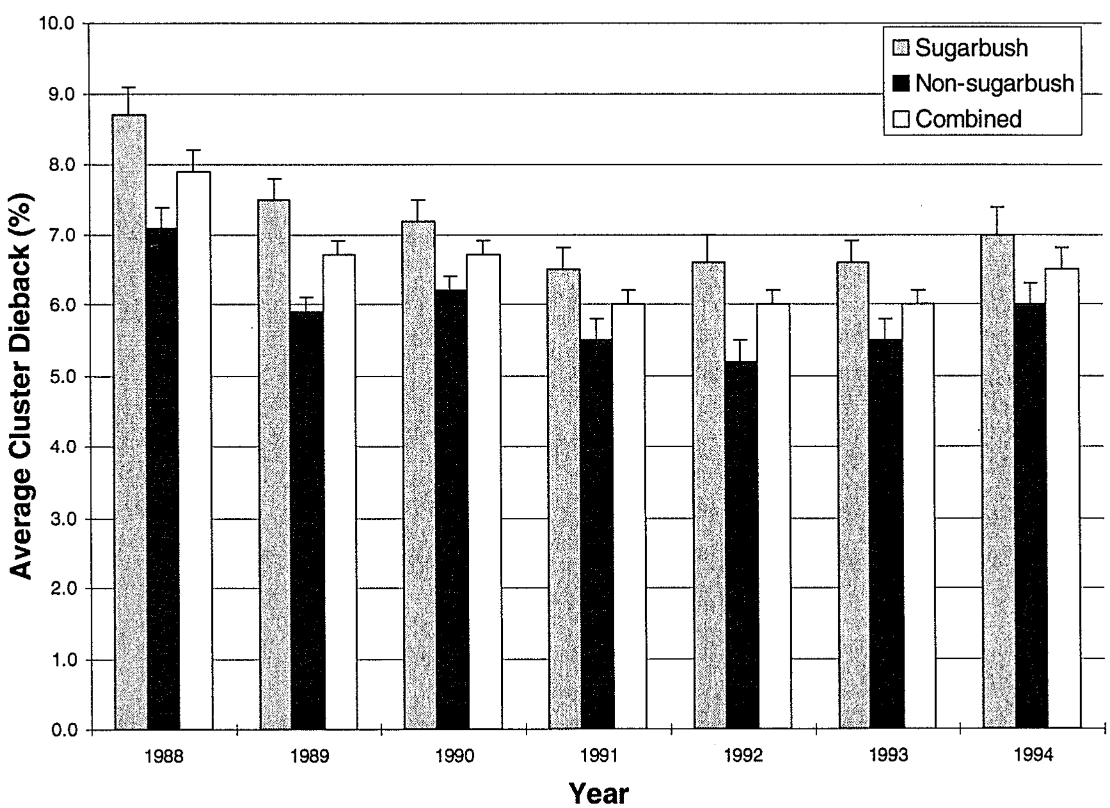


Figure 3. *Average cluster dieback ratings (% ± SE) for live, dominant/codominant sugar maples by year (1988-1994) and management category (sugarbush, non-sugarbush, both combined). Includes only plot-clusters established in 1988. For sugarbushes* n=*84 plot-clusters (1988-1991) and* n=*85 (1992-1994); for non-sugarbushes* n=*81 (1988-1991) and* n=*80 (1992-1994); for combined* n=*165 (all years).*

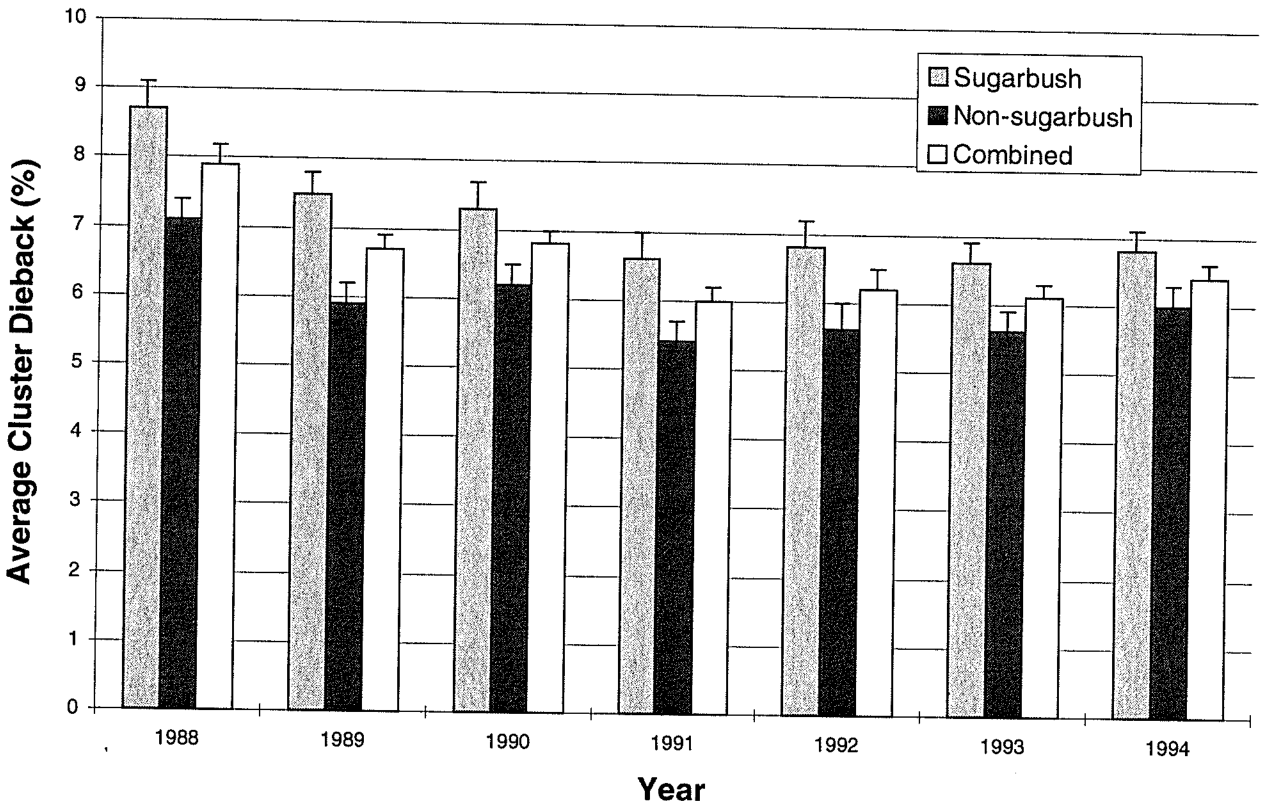


Figure 4. *Average cluster dieback ratings (% ± SE) for live, dominant/codominant sugar maples by year (1988-1994) and management category (sugarbush, non-sugarbush, both combined). Includes plot-clusters established after 1988. For sugarbushes* n *varies from 84 to 115 as plot-clusters were added; for non-sugarbushes* n *varies from 81 to 118; for combined* n *varies from 165 to 233.*

Table 7. *Differences between average cluster dieback ratings for live, dominant/codominant sugar maples by year (1988-1994) and management category (includes only plot-clusters established in 1988).*

Change in Average Cluster Dieback (%)

Between-year comparisons ($Yr_t - Yr_{t+1}$)	Sugarbushes %	Sugarbushes p-value	Non-sugarbushes %	Non-sugarbushes p-value	Within-year comparisons	Sugarbush *vs.* Non-sugarbush %	Sugarbush *vs.* Non-sugarbush p-value
1988-1989	-1.2	0.02	-1.2	0.02	1988	1.6	<0.01*
1989-1990	-0.3	0.51	+0.3	0.51	1989	1.6	<0.01*
1990-1991	-0.6	0.20	-0.7	0.18	1990	0.9	0.06
1991-1992	+0.1	0.80	-0.3	0.57	1991	1.0	0.5
1992-1993	-0.1	0.89	+0.3	0.60	1992	1.4	0.01
1993-1994	+0.4	0.45	+0.5	0.36	1993	1.1	0.04
					1994	1.0	0.05
1988 *vs* 1994	-1.8	<0.01*	-1.2	0.02	All Years	1.2	<0.01*

**Statistically significant difference (Bonferroni method), alpha = 0.05.*

Table 8. *Differences between average cluster dieback ratings for live, dominant/codominant sugar maples by year (1988-1994) and management category (includes plot-clusters established after 1988).*

Change in Average Cluster Dieback (%)							
Between-year comparisons (Yr_t - Yr_{t+1})	Sugarbushes %	Sugarbushes p-value	Non-sugarbushes %	Non-sugarbushes p-value	Within-year comparisons	Sugarbush *vs.* Non-sugarbush %	Sugarbush *vs.* Non-sugarbush p-value
1988-1989	-1.2	0.02	-1.2	0.02	1988	1.6	<0.01*
1989-1990	-0.2	0.72	+0.3	0.57	1989	1.6	<0.01*
1990-1991	-0.7	0.16	-0.8	0.10	1990	1.1	0.04
1991-1992	+0.1	0.78	+0.2	0.70	1991	1.2	0.02
1992-1993	-0.1	0.81	0.0	0.97	1992	1.2	0.01
1993-1994	+0.2	0.68	+0.3	0.44	1993	1.0	0.02
					1994	0.9	0.05
1988 vs 1994	-1.9	<0.01*	-1.2	0.01	All Years	1.2	<0.01*

**Statistically significant difference (Bonferroni method), alpha = 0.05.*

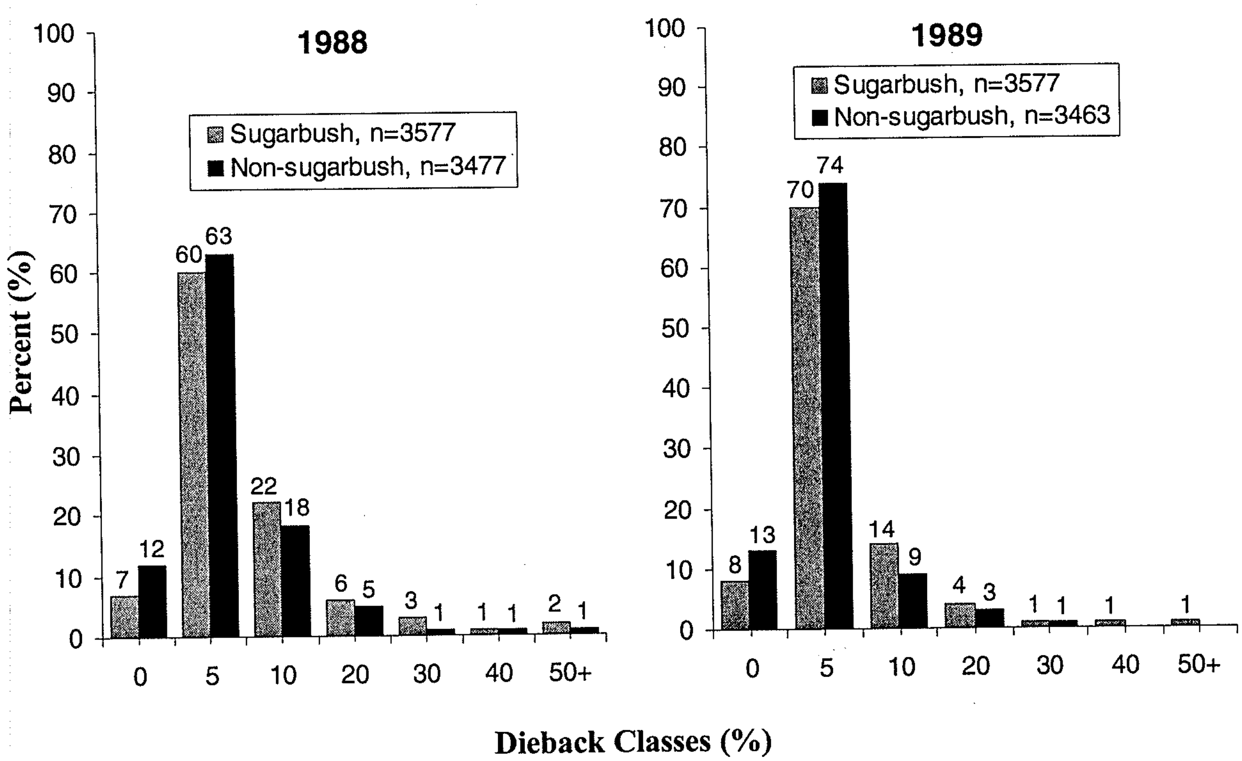
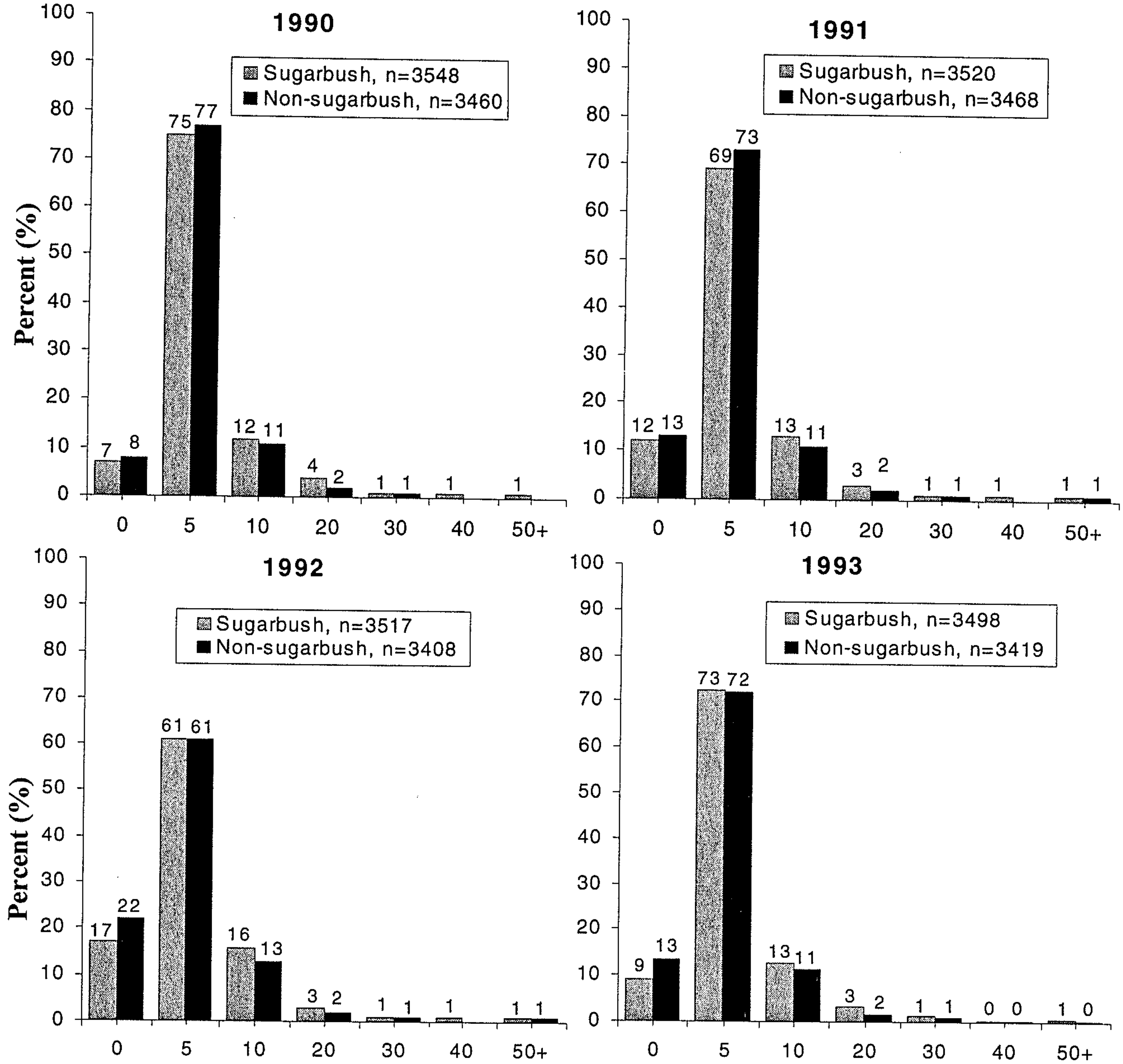
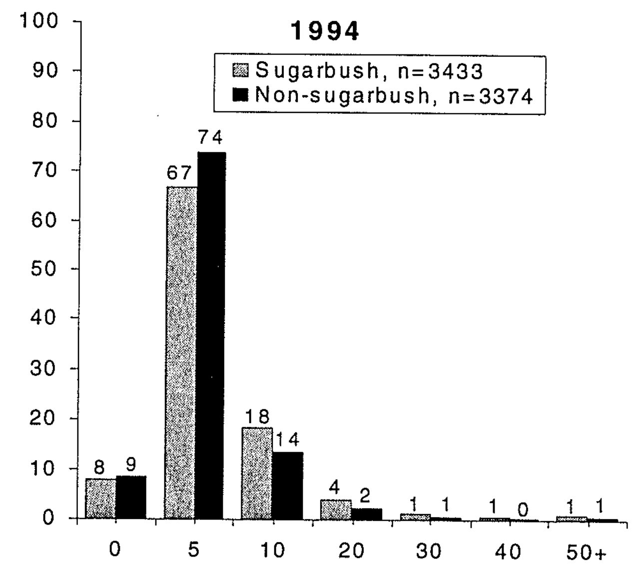


Figure 5. *Seven-year frequency distributions of crown dieback by management category for live, dominant/ codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes only plot-clusters established in 1988.*





Dieback Classes (%)

Figure 5 (cont.). *Seven-year frequency distributions of crown dieback by management category for live, dominant/codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes only plot-clusters established in 1988.*

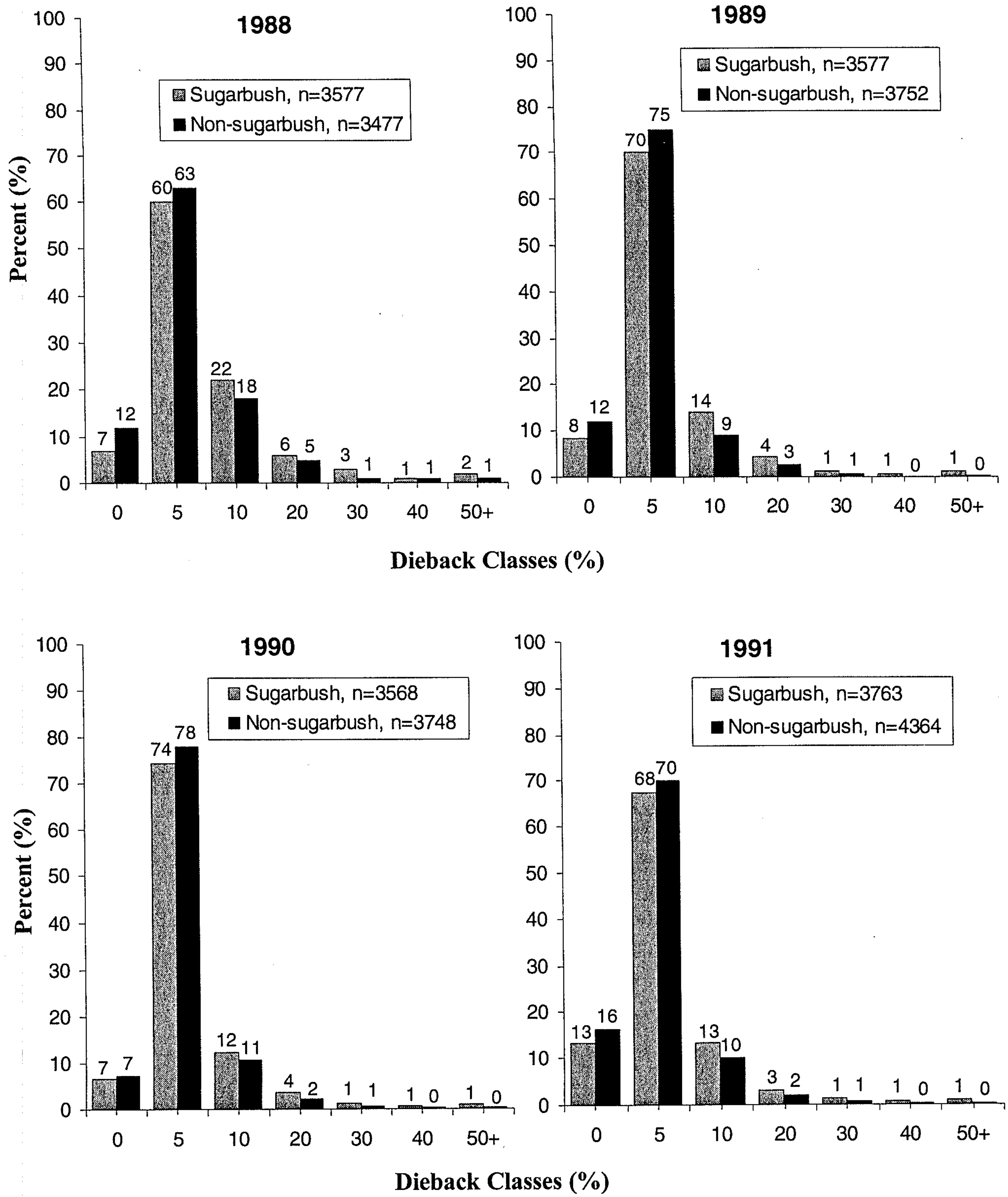


Figure 6. *Seven-year frequency distributions of crown dieback by management category for live, dominant/ codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes plot-clusters established after 1988.*

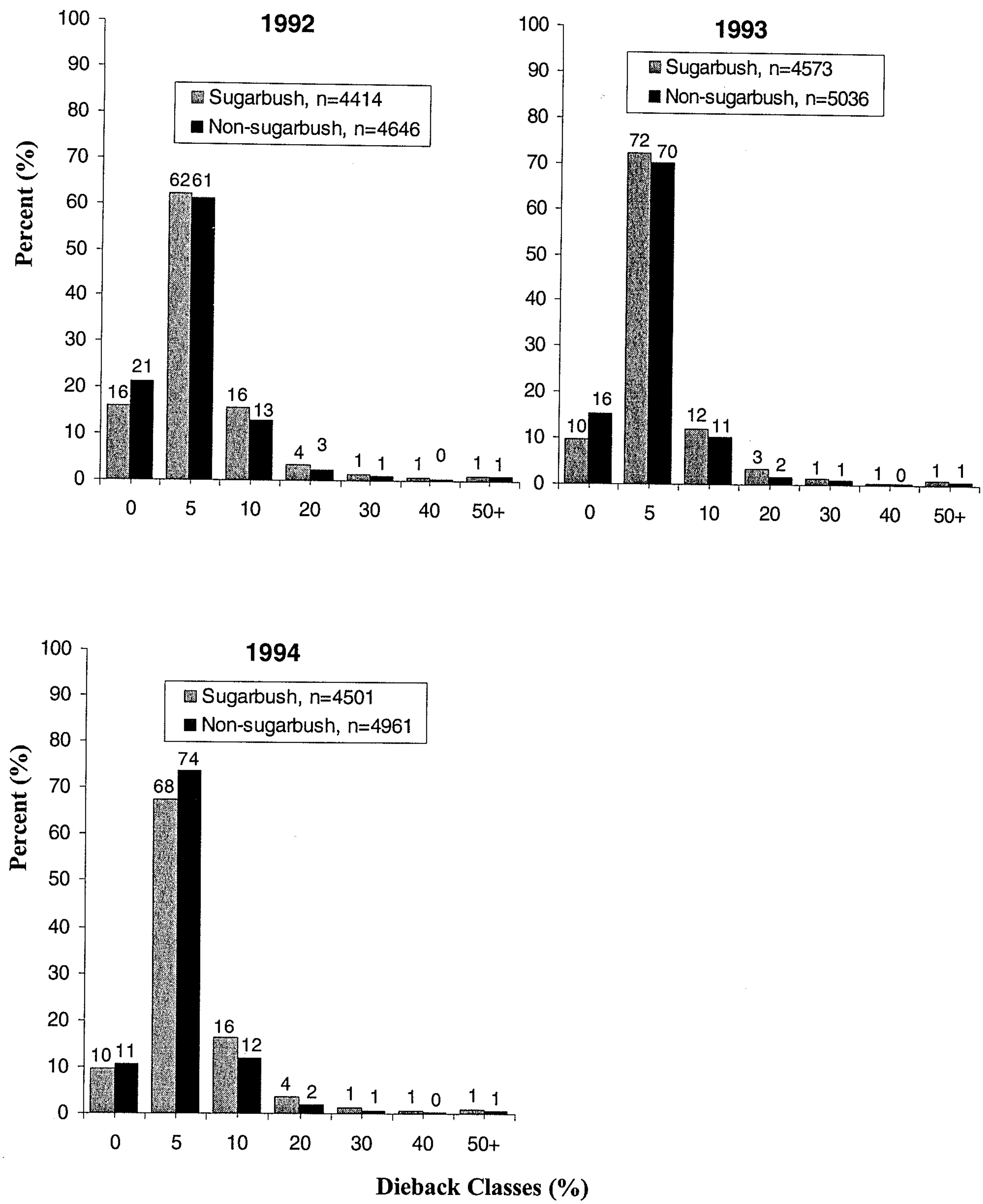
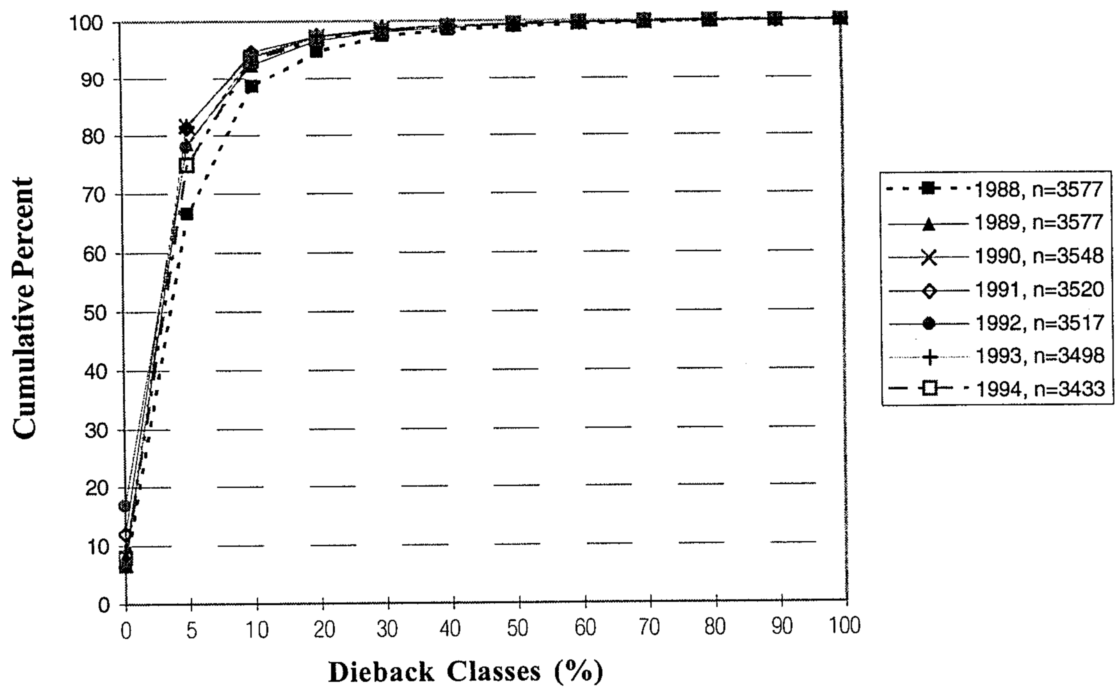


Figure 6 (cont.). *Seven-year frequency distributions of crown dieback by management category for live, dominant/codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes plot-clusters established after 1988.*

Sugarbush



Non-sugarbush

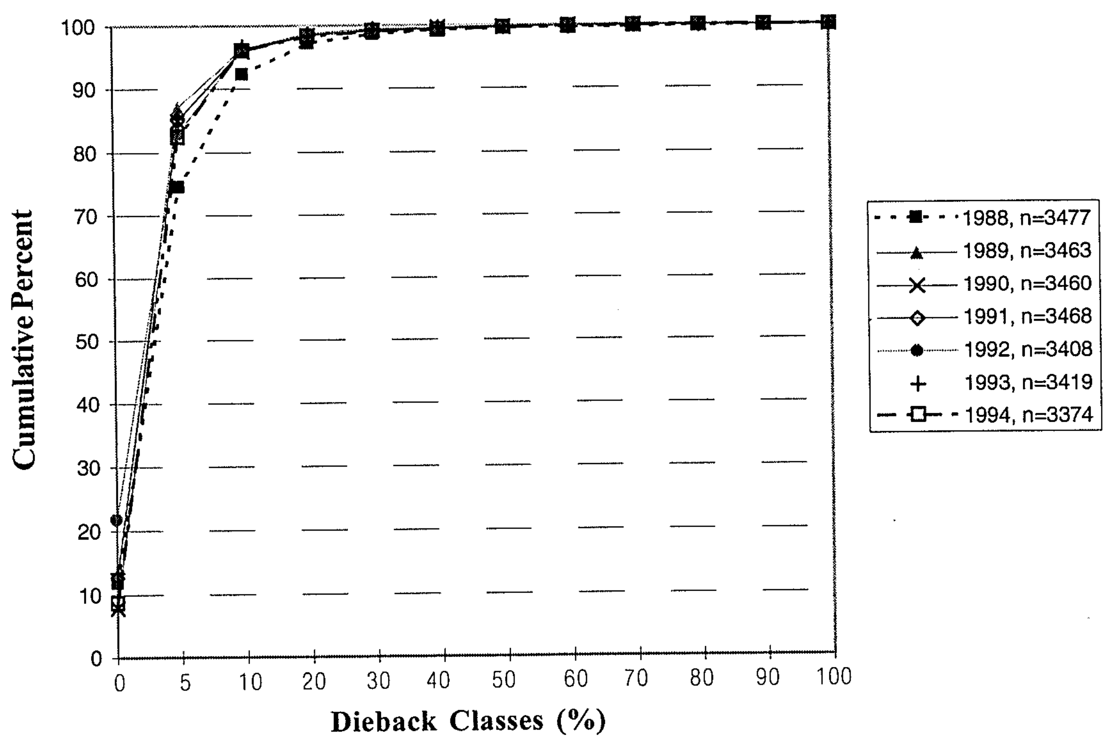


Figure 7. *Cumulative density functions for dieback for live, dominant/codominant sugar maples for 1988-1994 in all plot-clusters. Includes only plot-clusters established in 1988.*

Sugarbush

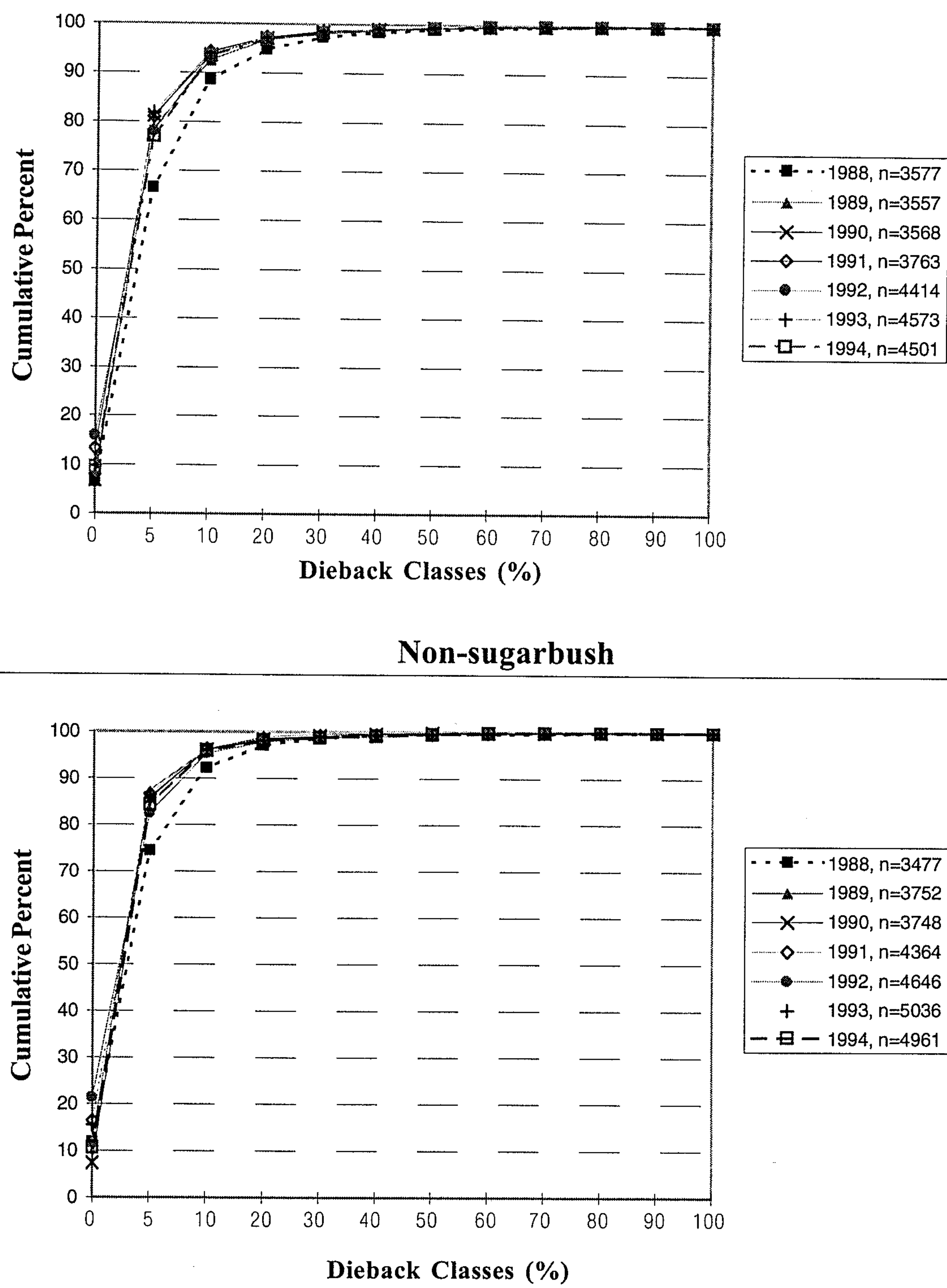


Figure 8. *Cumulative density functions for dieback for live, dominant/codominant sugar maples for 1988-1994 in all plot-clusters. Includes plot-clusters established after 1988.*

Table 9. *Average plot-cluster dieback (%) in 1994 for original 165 plot-clusters only by state/province and management category.*

State/Province	Average Cluster Dieback (± SE) 1994			
	n	Sugarbush	n	Non-sugarbush
Maine	9	6.4 (±0.7)	9	5.8 (±0.5)
Massachusetts	5	7.6 (±0.9)	5	7.2 (±0.9)
Michigan	5	2.9 (±0.7)	5	2.1 (±0.2)
New Brunswick/Nova Scotia	7	7.6 (±1.0)	4	7.1 (±0.8)
New Hampshire	3	7.9 (±0.6)	3	7.3 (±0.3)
New York	9	5.6 (±1.4)	9	4.5 (±0.9)
Ontario	12	6.3 (±0.7)	12	6.1 (±1.0)
Quebec	12	10.6 (±1.5)	12	7.9 (±1.0)
Vermont	13	7.2 (±1.0)	13	5.8 (±0.4)
Wisconsin	9	5.9 (±0.4)	9	5.8 (±0.4)

Table 10. *Average plot-cluster dieback (%) in 1994 for all plot-clusters (n=233) by state/province and management category.*

State/Province	Average Cluster Dieback (± SE) 1994			
	n	Sugarbush	n	Non-sugarbush
Maine	9	6.4 (±0.7)	9	5.8 (±0.5)
Massachusetts	5	7.6 (±0.9)	5	7.2 (±0.9)
Michigan	9	4.7 (±1.0)	15	4.2 (±0.4)
Minnesota	4	3.9 (±0.7)	4	4.2 (±0.6)
New Brunswick/Nova Scotia	7	7.6 (±1.0)	7	7.1 (±0.6)
New Hampshire	5	6.9 (±0.7)	5	6.3 (±0.8)
New York	11	5.4 (±1.3)	16	4.2 (±0.5)
Ohio	6	7.3 (±0.7)	-	NA
Ontario	12	6.3 (±0.7)	12	6.1 (±1.0)
Pennsylvania	5	4.5 (±1.1)	5	4.4 (±0.4)
Quebec	12	10.6 (±1.5)	12	7.9 (±1.0)
Vermont	21	7.8 (±0.9)	19	7.6 (±1.3)
Wisconsin	9	5.9 (±0.4)	9	5.8 (±0.4)

Crown Transparency

Annual average transparency ratings for all NAMP plot-clusters varied from 11% to 20% during 1988 to 1994 for both the original set of plot-clusters and after data from new plot-clusters were included (*Figs. 9* and *10*). Project wide, transparency increased in 1989, decreased the following two years, and has remained relatively stable since 1991. Three of six annual changes for SBs and one annual change for NSBs (original plot-clusters) are statistically significant, as are the differences between average transparencies for 1988 vs. 1994 (*Table 11*). The 1988 vs. 1994 comparisons indicate a statistically significant decrease in average cluster transparency of 3.4% and 3.5% in SBs and NSBs, respectively.

The results are similar with additional plot-clusters established after 1988 incorporated into the analysis (*Table 12*). As with average cluster dieback ratings, the statistically significant changes in transparency have little biological significance given that the differences are less than the width of a rating class.

The annual distribution of crown transparency estimates approximates a bell-shaped curve. The shape and position of the distribution varies slightly from year to year (*Figs. 11* and *12*). This reflects sugar maple's response to stresses like drought or pear thrips, and probably natural variation in annual transparency as well. Each year approximately two-thirds (*Fig. 11 - 1988*) to almost 90% (*Fig. 11 - 1994*) of the data are centered on a single rating class or two adjacent classes. Annual changes in number of trees in the 20-50+ % transparency classes indicate that after 1989, crown condition improved overall (transparency decreased); that is, the centroids of the distributions shifted from the 20% to the 10% class. Over time, crown transparency appears to be centering on the 10% rating class. The results are similar for both the original plot-clusters alone or in combination with plot-clusters established in later years.

The cumulative density functions for SB and NSB crown transparencies clearly illustrate the increased levels of transparency that occurred in 1988 and 1989 (indicated on each graph by two lines set apart to the right) (*Figs. 13* and *14*). The remaining years are all similar and the lines for these years overlap. At least 80% of live, dominant/codominant sugar maples were rated as having 20% transparency or less throughout seven years. Again, the results are similar with or without the plot-clusters that were added after 1988 (*Fig. 13* vs. *Fig. 14*).

Average cluster transparency in 1994 within the original (1988) plot-clusters ranged from 11.0 to 20.8% in SBs and 10.2 to 16.8% in NSBs (*Table 13*). The lowest transparency occurred in New Brunswick/Nova Scotia for each management category; the highest in New York for SBs and highest in Ontario for NSBs. When all 233 plot-clusters in 13 regions were compared (*Table 14*), average transparency in SBs in 1993 varied from 7.4 to 19.9% (lowest in Minnesota; highest in New York) and in NSBs ranged from 8.4 to 16.8% (lowest in Minnesota; highest in Ontario). In general, results indicate that crown condition (dieback, transparency) of dominant/codominant sugar maples monitored by NAMP has improved since 1988 and, overall, trees appear in good condition. These results are consistent with those from similar, but independent, surveys conducted in Wisconsin (Drillias *et al.* 1990), Ontario (Hopkin and Dumond 1994), and Vermont (Kelley *et al.* 1992) during the same period. In only one instance was there a significant difference in average crown transparency between regional SBs and NSBs during 1994. Crown transparency of dominant/codominant sugar maples was significantly higher in New York's SBs ($\bar{x}$=20.8%) compared to NSBs ($\bar{x}$=11.4%) for both the original plot-clusters (*Table 13*) and all plot-clusters combined (*Table 14*, $\bar{x}$=19.9% vs. 10.7%, respectively). We attribute this to moderate levels (31-60%) of forest tent caterpillar and pear thrips activity in several sugarbush plot-clusters.

Relation Between Transparency and Dieback

To see if crown transparency might presage crown dieback, we correlated mean transparency for year **t** (t=1988, 1989, ..., 1992) with mean crown dieback for years **t+1** and **t+2**. The 1993 transparency data were correlated only with dieback in 1994. Sample size varied from 165 (1988) to 233 (1994), because as new plot-clusters were established (*Table 2*) they were included in the analyses. Of 11 comparisons, 10 provided statistically significant (alpha=0.05), positive correlations. However, correlation coefficients were low (**r** ranged from 0.09 to 0.44) and indicate a weak relation between crown dieback and transparency.

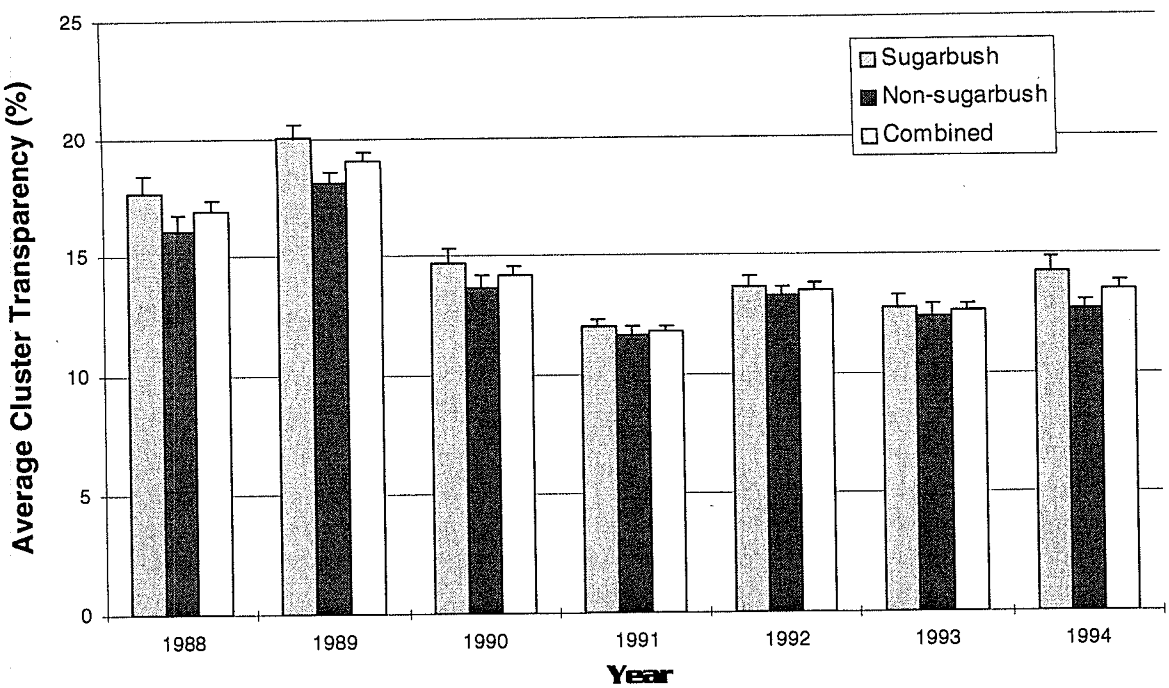


Figure 9. *Average cluster transparency ratings (% ± SE) for live, dominant/codominant sugar maples by year (1988-1994) and management category (sugarbush, non-sugarbush, both combined). Includes only plot-clusters established in 1988. For sugarbushes* n = *84 plot-clusters (1988-1991) and* n = *85 (1992-1994); for non-sugarbushes* n = *81 (1988-1991) and* n = *80 (1992-1994); for combined* n = *165 (all years).*

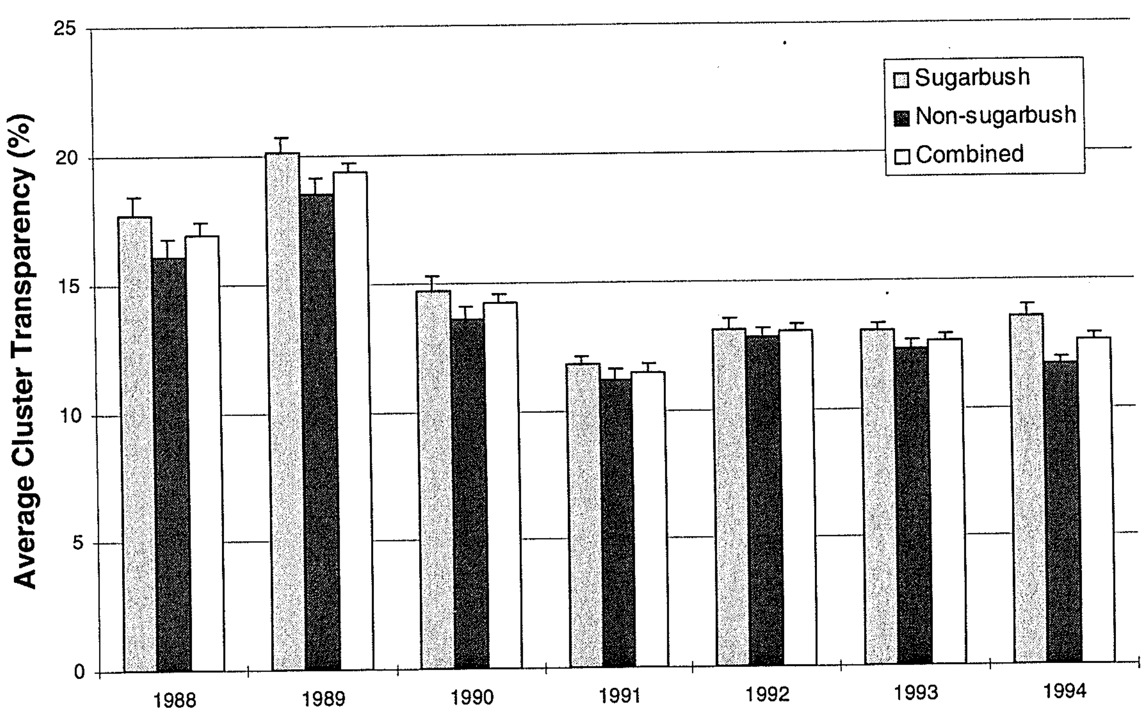


Figure 10. *Average cluster transparency ratings (% ± SE) for live, dominant/codominant sugar maples by year (1988-1994) and management category (sugarbush, non-sugarbush, both combined). Includes plot-clusters established after 1988. For sugarbushes* n *varies from 84 to 115 as plot-clusters were added; for non-sugarbushes* n *varies from 81 to 118; for combined* n *varies from 165 to 233.*

Table 11. *Differences between average cluster transparency ratings for live, dominant/codominant sugar maples by year (1988-1994) and management type (includes only plot-clusters established in 1988).*

Change in Average Cluster Transparency (%)							
Between-year comparisons	**Sugarbushes**		**Non-sugarbushes**		**Within-year comparisons**	**Sugarbush *vs.* Non-sugarbush**	
(Yr_t - Yr_{t+1})	**%**	**p-value**	**%**	**p-value**		**%**	**p-value**
1988-1989	+2.4	<0.01*	+1.9	0.01	1988	1.6	0.04
1989-1990	-5.4	<0.01*	-4.4	<0.01*	1989	2.0	0.01
1990-1991	-2.6	<0.01*	-2.1	0.01	1990	1.0	0.20
1991-1992	+1.7	0.03	+1.8	0.02	1991	0.4	0.58
1992-1993	-0.9	0.22	-1.0	0.20	1992	0.4	0.65
1993-1994	+1.5	0.04	+0.3	0.67	1993	0.4	0.59
					1994	1.6	0.04
1988 *vs.* 1994	-3.4	<0.01*	-3.5	<0.01*	All Years	1.1	<0.01*

**Statistically significant difference (Bonferroni method), alpha = 0.05.*

Table 12. *Differences between average cluster transparency ratings for live, dominant/codominant sugar maples by year (1988-1994) and management type (includes plot-clusters established after 1988).*

Change in Average Cluster Transparency (%)							
Between-year comparisons	**Sugarbushes**		**Non-sugarbushes**		**Within-year comparisons**	**Sugarbush *vs.* Non-sugarbush**	
(Yr_t - Yr_{t+1})	**%**	**p-value**	**%**	**p-value**		**%**	**p-value**
1988-1989	+2.4	<0.01*	+2.3	<0.01*	1988	1.6	0.04
1989-1990	-5.4	<0.01*	-4.9	<0.01*	1989	1.6	0.03
1990-1991	-3.0	<0.01*	-2.4	<0.01*	1990	1.1	0.15
1991-1992	+1.4	0.06	+1.6	0.02	1991	0.5	0.47
1992-1993	-0.1	0.82	-0.5	0.41	1992	0.3	0.66
1993-1994	+0.5	0.42	-0.6	0.35	1993	0.7	0.29
					1994	1.8	0.01
1988 *vs.* 1994	-4.3	<0.01*	-4.5	<0.01*	All Years	1.1	<0.01*

**Statistically significant difference (Bonferroni method), alpha = 0.05.*

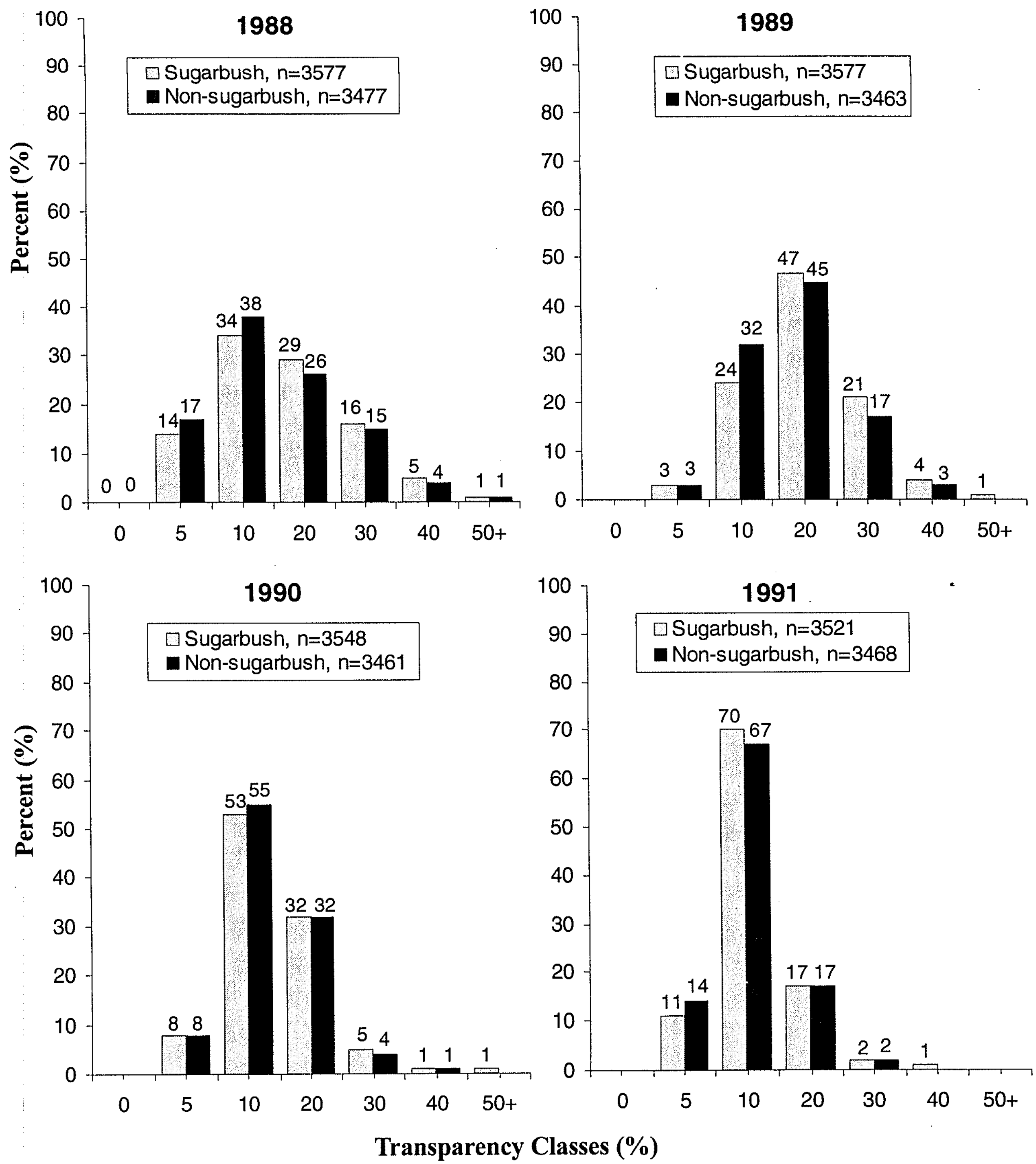


Figure 11. *Seven-year frequency distributions of crown transparency by management category for live, dominant/ codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes only plot-clusters established in 1988.*

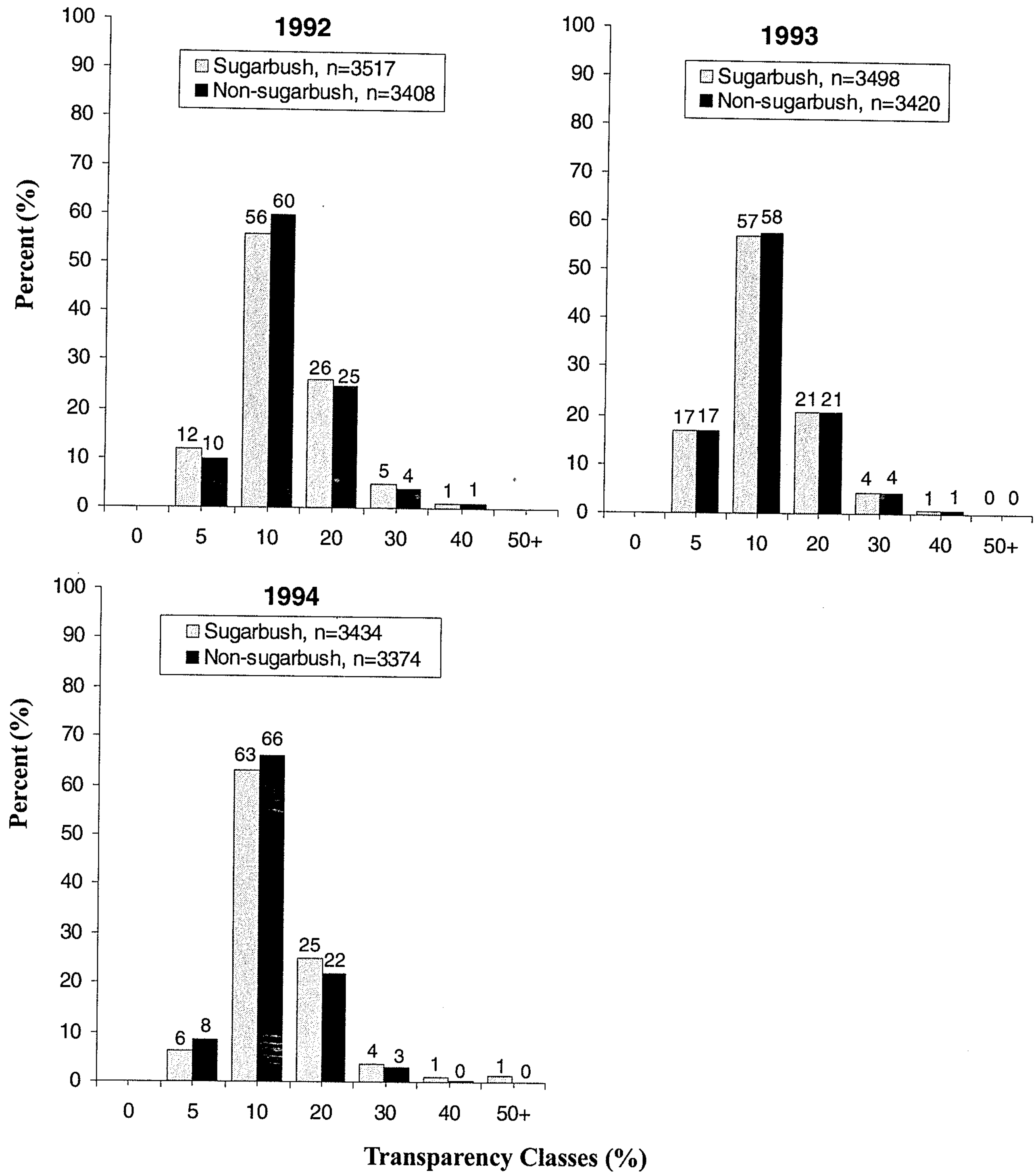


Figure 11 (cont.). *Seven-year frequency distributions of crown transparency by management category for live, dominant/codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes only plot-clusters established in 1988.*

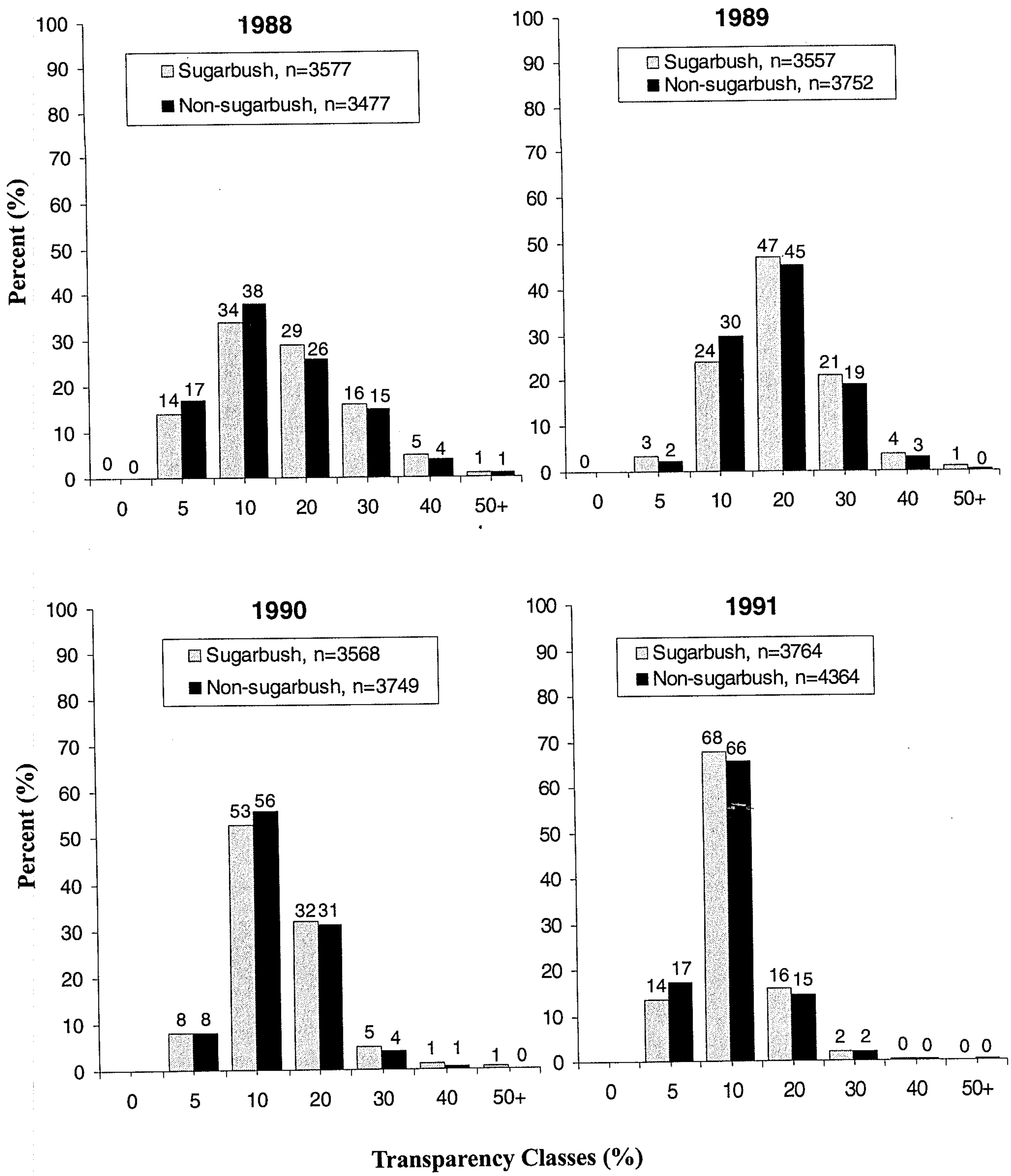


Figure 12. *Seven-year frequency distributions of crown transparency by management category for live, dominant/ codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes plot-clusters established after 1988.*

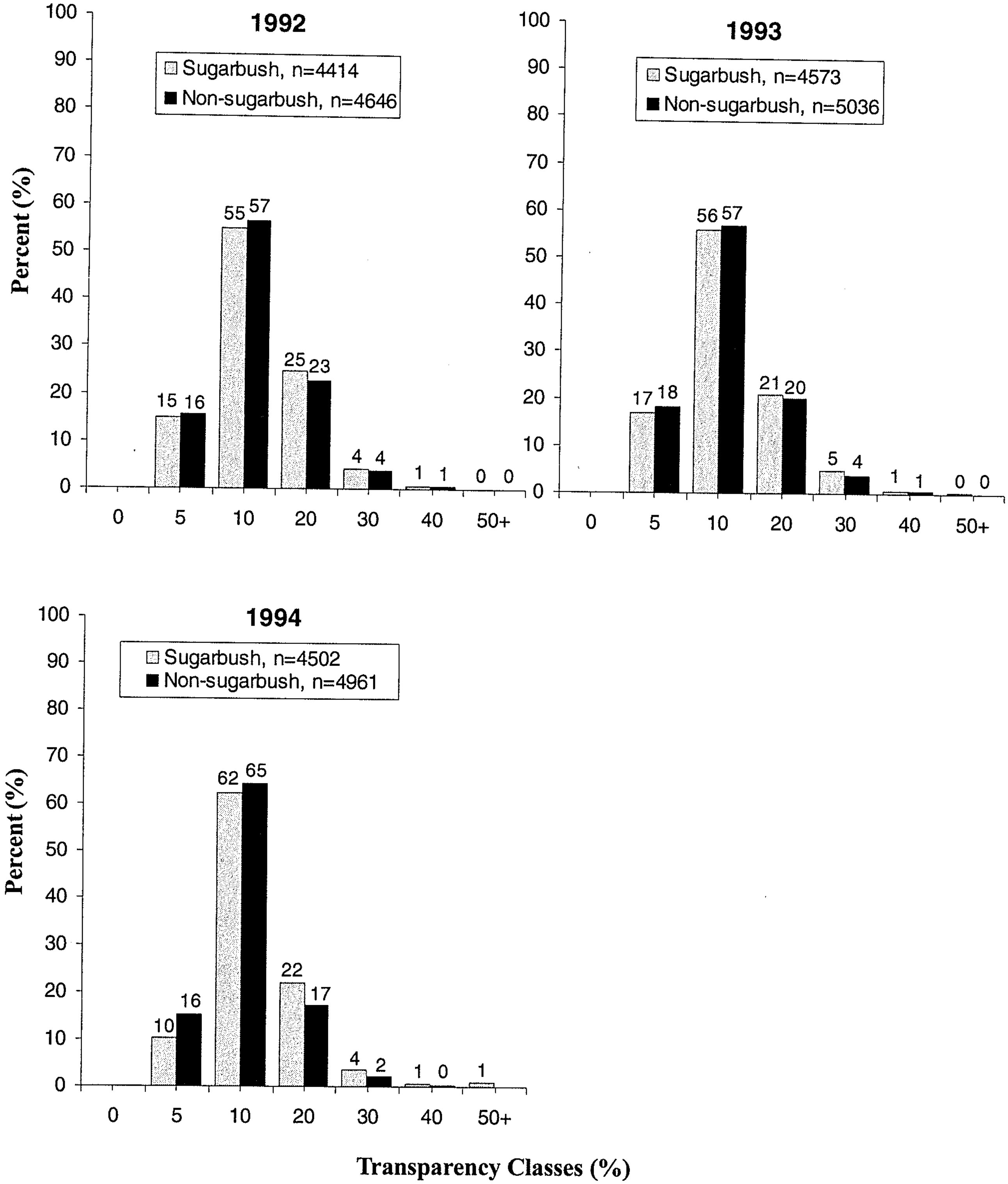
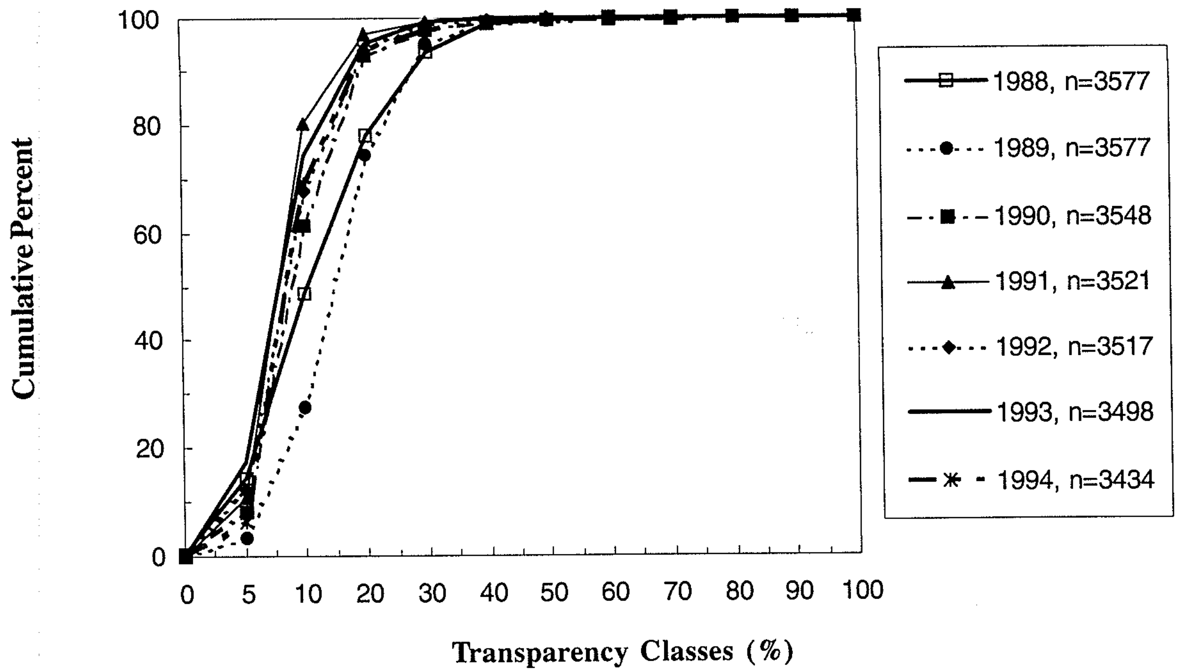


Figure 12 (cont.). *Seven-year frequency distributions of crown transparency by management category for live, dominant/codominant sugar maple, 1988-1994, in sugarbushes and non-sugarbushes in all plot-clusters. Includes plot-clusters established after 1988.*

Sugarbush



Non-sugarbush

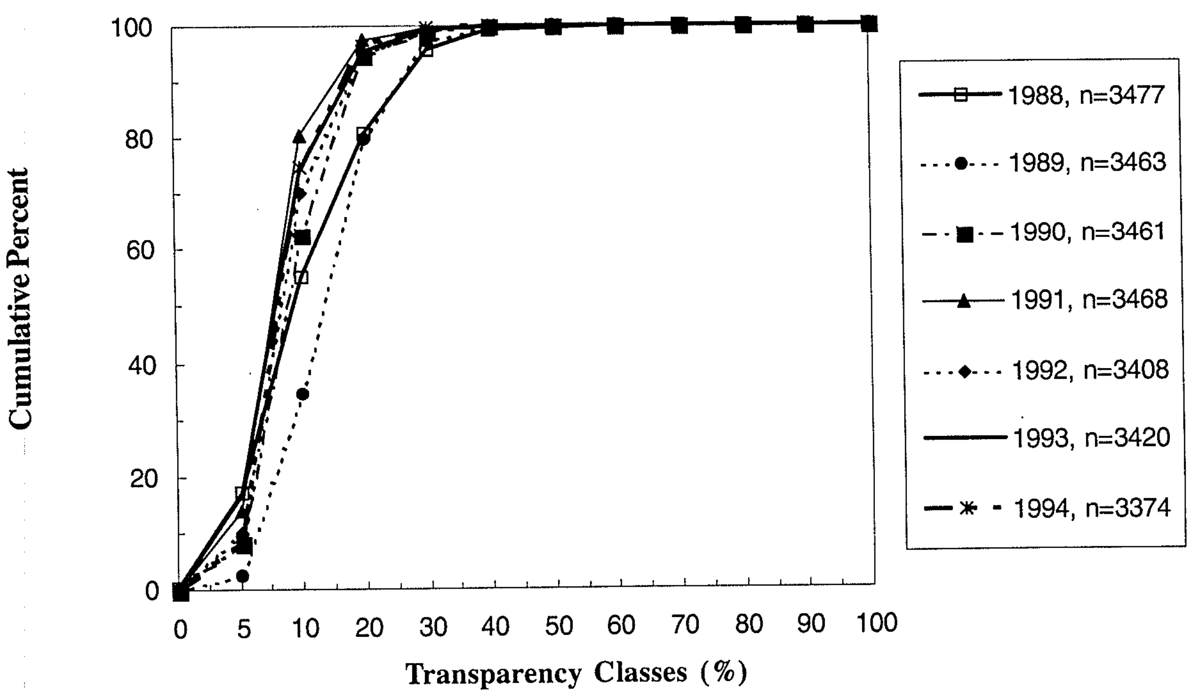
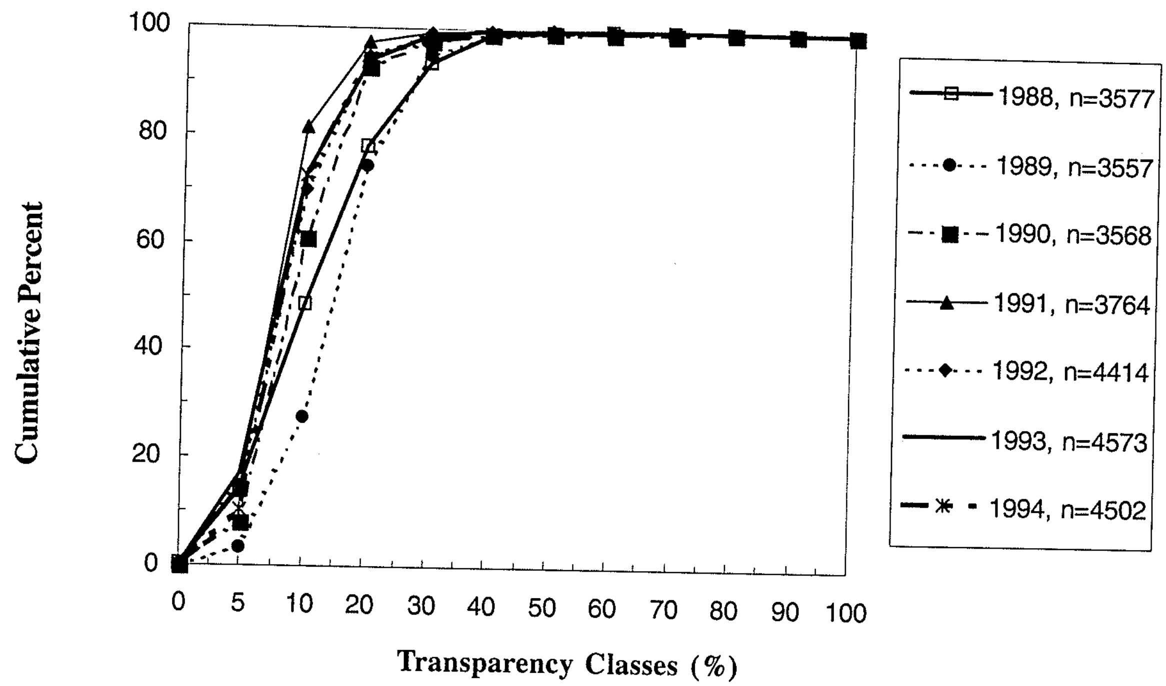


Figure 13. *Cumulative density functions for transparency for live, dominant/codominant sugar maples, 1988-1994, in all plot-clusters. Includes only plot-clusters established in 1988.*

Sugarbush



Non-sugarbush

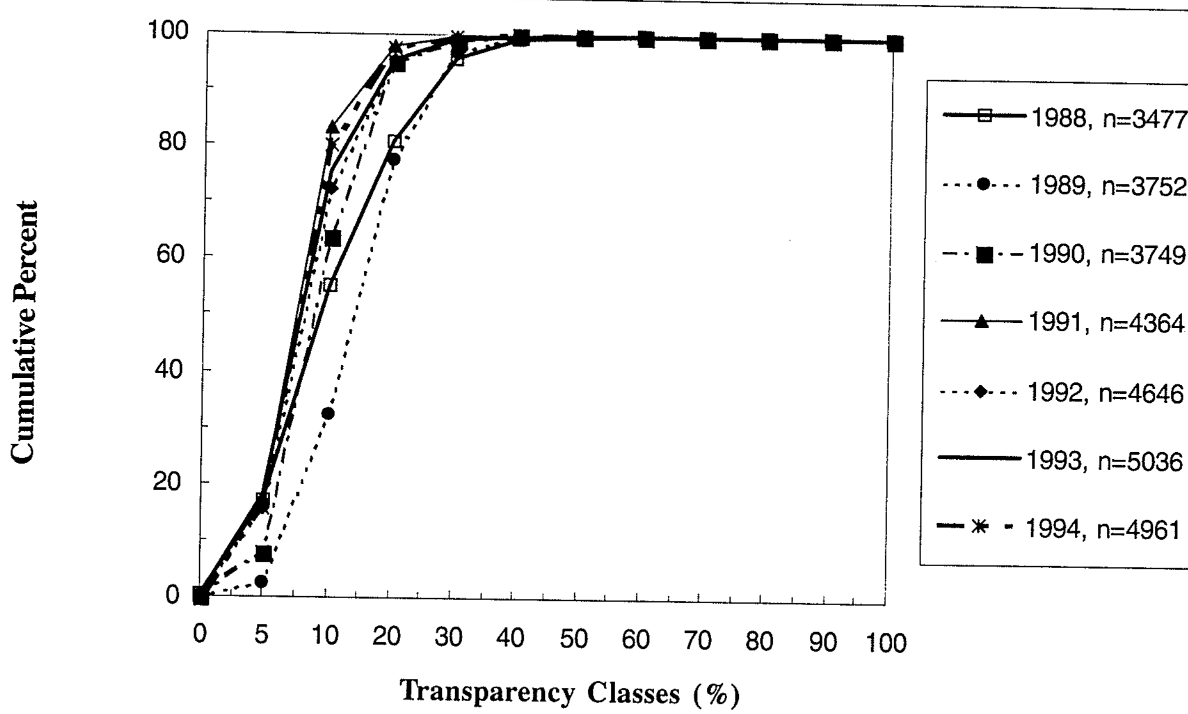


Figure 14. *Cumulative density functions for transparency for live, dominant/codominant sugar maples, 1988-1994, in all plot-clusters. Includes plot-clusters established after 1988.*

Table 13. *Average plot-cluster transparency (%) in 1994 for original 165 plot-clusters only by state/province and management category.*

Average Cluster Transparency (± SE) 1994				
State/Province	n	Sugarbush	n	Non-sugarbush
Maine	9	11.8 (±0.7)	9	10.8 (±0.5)
Massachusetts	5	14.8 (±0.9)	5	13.1 (±0.8)
Michigan	5	13.7 (±1.0)	5	13.4 (±1.0)
New Brunswick/Nova Scotia	7	11.0 (±0.9)	4	10.2 (±0.5)
New Hampshire	3	14.1 (±1.8)	3	13.8 (±0.9)
New York	9	20.8 (±4.2)*	9	11.4 (±0.5)
Ontario	12	17.3 (±0.8)	12	16.8 (±1.1)
Quebec	12	12.7 (±0.5)	12	10.8 (±0.8)
Vermont	13	13.5 (±1.3)	13	12.9 (±1.3)
Wisconsin	9	11.8 (±0.5)	9	12.9 (±0.6)

* *Sugarbush vs. Non-sugarbush comparison statistically significant at alpha =0.05.*

Table 14. *Average plot-cluster transparency (%) in 1994 for all plot-clusters (n=233) by state/province and management category.*

Average Cluster Transparency (± SE) 1994				
State/Province	n	Sugarbush	n	Non-sugarbush
Maine	9	11.8 (±0.7)	9	10.8 (±0.5)
Massachusetts	5	14.8 (±0.9)	5	13.1 (±0.8)
Michigan	9	11.0 (±1.2)	15	8.7 (±1.0)
Minnesota	4	7.4 (±0.3)	4	8.4 (±1.5)
New Brunswick/Nova Scotia	7	11.0 (±0.9)	7	10.8 (±0.9)
New Hampshire	5	13.4 (±1.3)	5	12.5 (±1.0)
New York	11	19.9 (±3.9) *	16	10.7 (±0.3)
Ohio	6	10.4 (±0.3)	-	NA
Ontario	12	17.3 (±0.8)	12	16.8 (±1.1)
Pennsylvania	5	12.8 (±4.9)	5	8.9 (±1.0)
Quebec	12	12.7 (±0.5)	12	10.8 (±0.8)
Vermont	21	13.7 (±0.9)	19	13.3 (±1.0)
Wisconsin	9	11.8 (±0.5)	9	12.9 (±0.6)

* *Sugarbush vs. Non-sugarbush comparison statistically significant at alpha =0.05.*

Fate of Affected Trees

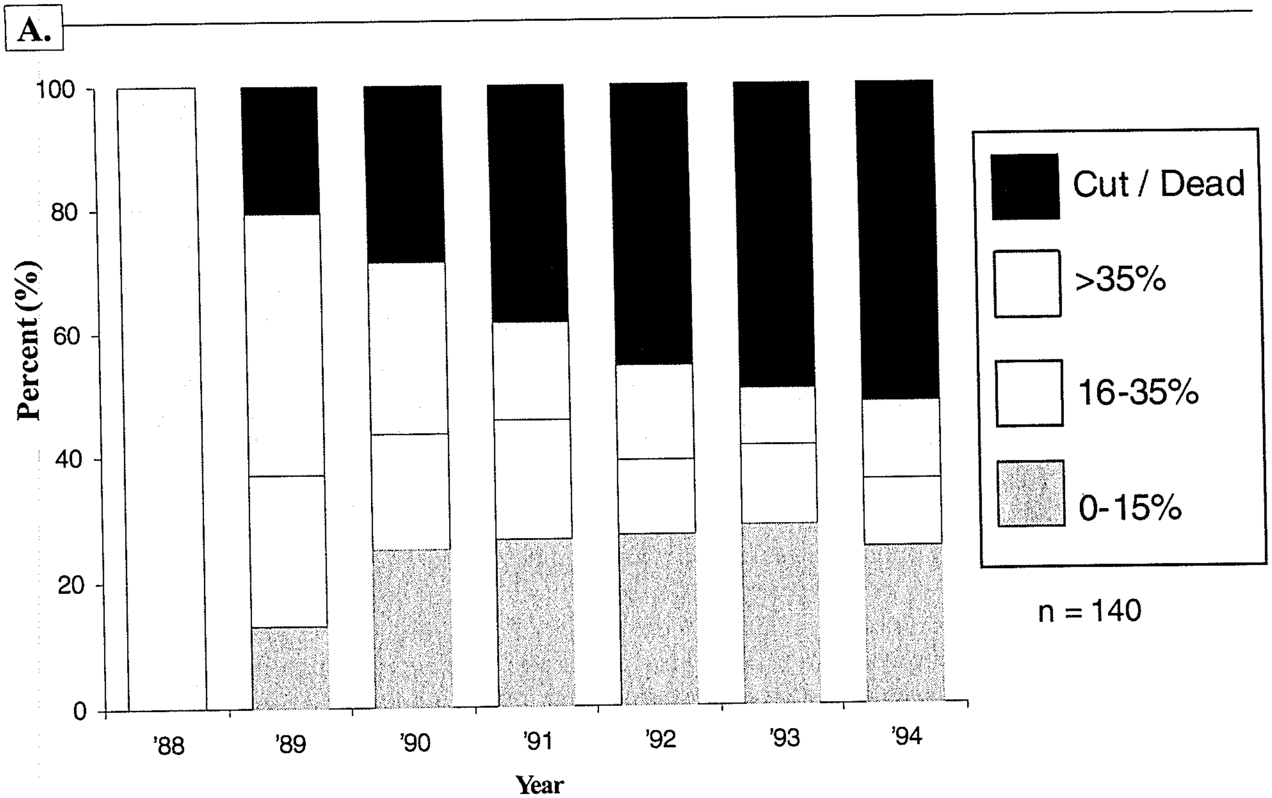
The vulnerability or risk (i.e., likelihood of mortality or continued deterioration) for sugar maples with varying levels of crown dieback and transparency is of interest to people who must make forest management decisions. Selection of trees to remove during silvicultural operations or when determining whether or not to spend funds to protect trees from stresses such as defoliation depends, in part, on their present condition and probability of surviving to the end of a rotation. Similarly, knowing the probability that a tree will survive following a disturbance is of ecological interest. Evaluation of crown condition may help identify the segment or segments of a population most susceptible to different stressors. This, in turn, may permit predictions of future stand conditions such as species composition, age structure and density, for example. Understanding the relation between a disturbance, or a combination of disturbances, and community structure has implications in terms of elucidating the role that specific disturbances play in determining the character of a forest, rate of change in forest conditions and other characteristics. NAMP provides a limited data base for assessing probability of survival based on current crown condition.

Approximately 65% of the dominant/codominant sugar maples that were rated with crown dieback >35% (i.e., in the 40% class or higher) in 1988 (n=140) were either dead in 1994 or remained in poor condition. The crown condition of 35% of these trees improved (*Fig. 15, A*). Trees in dieback classes 20% and 30% (16-35% dieback) had a much lower probability of dying (approximately 1 in 10) and for 80% of them crown condition apparently returned to a healthy condition. That is, crown dieback was 15% or less in 1994 (*Fig. 15, B*).

Sixty percent of the overstory sugar maples with a crown transparency >55% in 1988 were dead by 1994 and crowns of the remaining 39% improved to what NAMP considers "healthy" levels (≤25% transparency) (*Fig. 16, A*). Only 10% of maples with 26-55% transparency in 1988 died by 1994 (*Fig. 16, B*).

Tree and stand vulnerability are influenced by historical events, aggressiveness of secondary insects and disease-causing organisms, stand conditions, and site. When the data set is viewed by region, it is obvious that the likelihood of mortality varied. For example, none of the three trees in Massachusetts that were rated with >35% dieback (i.e., placed in dieback classes ≥ 40%) in 1988 were dead by 1994, but 7% of those with 16-35% dieback died. However, all ten of the trees with >35% dieback in New York died during this period (*Table 15*). Predicting survival based on transparency is even more problematic (*Table 16*). Not only does transparency appear to be a poor predictor of future condition, but the small sample available indicates that reliability of high (>50%) transparency estimates is low (*Table 6*). The expected variation associated with very small sample sizes may account as much for regional differences in the fate of trees with >35% crown dieback as the biological events enumerated above.

A monitoring effort in Vermont from 1986 through 1991 (Kelley *et al.* 1992) indicated that trees with "severe" dieback (>50%) had a 50:50 chance of surviving five years. This study and results from NAMP also demonstrated that 30-40% of the trees that had >40% dieback at the beginning of the study eventually recovered; that is, their crowns had little evidence of dieback seven (NAMP) or five (VT) years following initial observations.



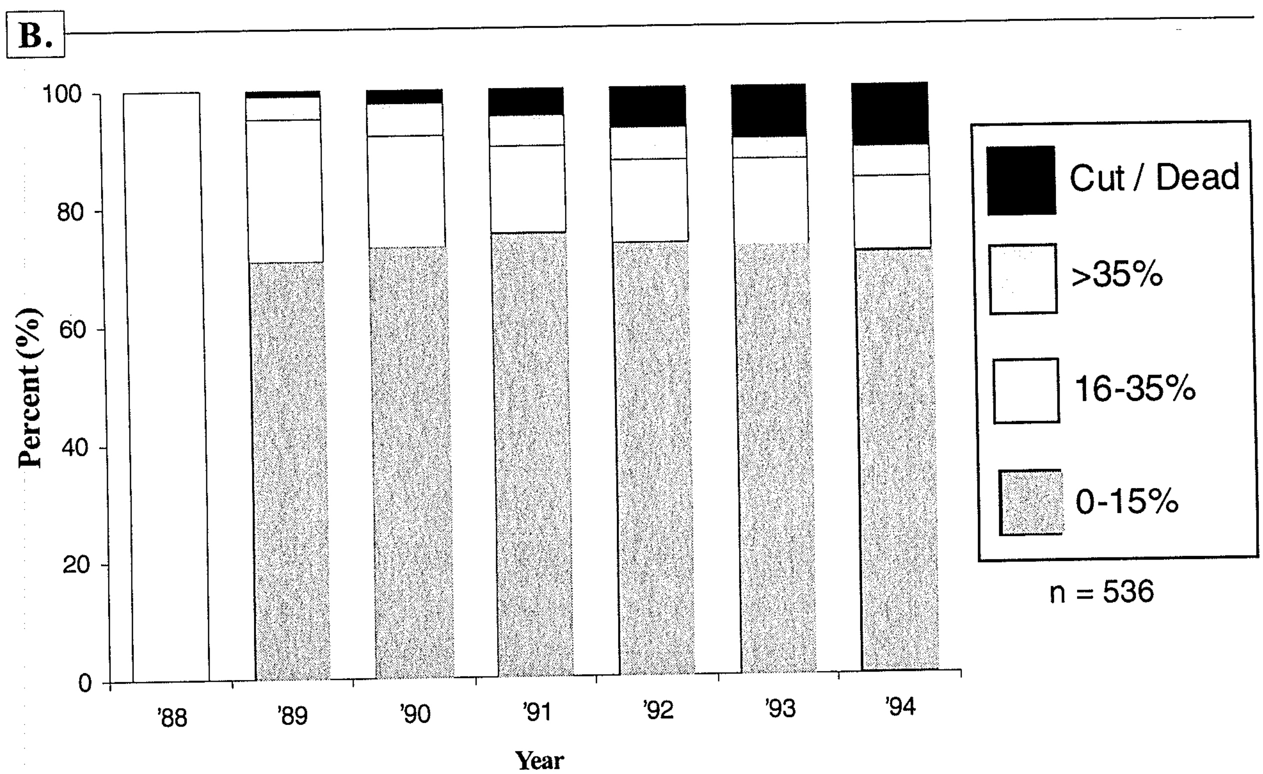


Figure 15. *Condition of upper canopy sugar maples in 1994 that had (A) >35% crown dieback (n=140) and (B) 16-35% crown dieback (n=536) in 1988.*

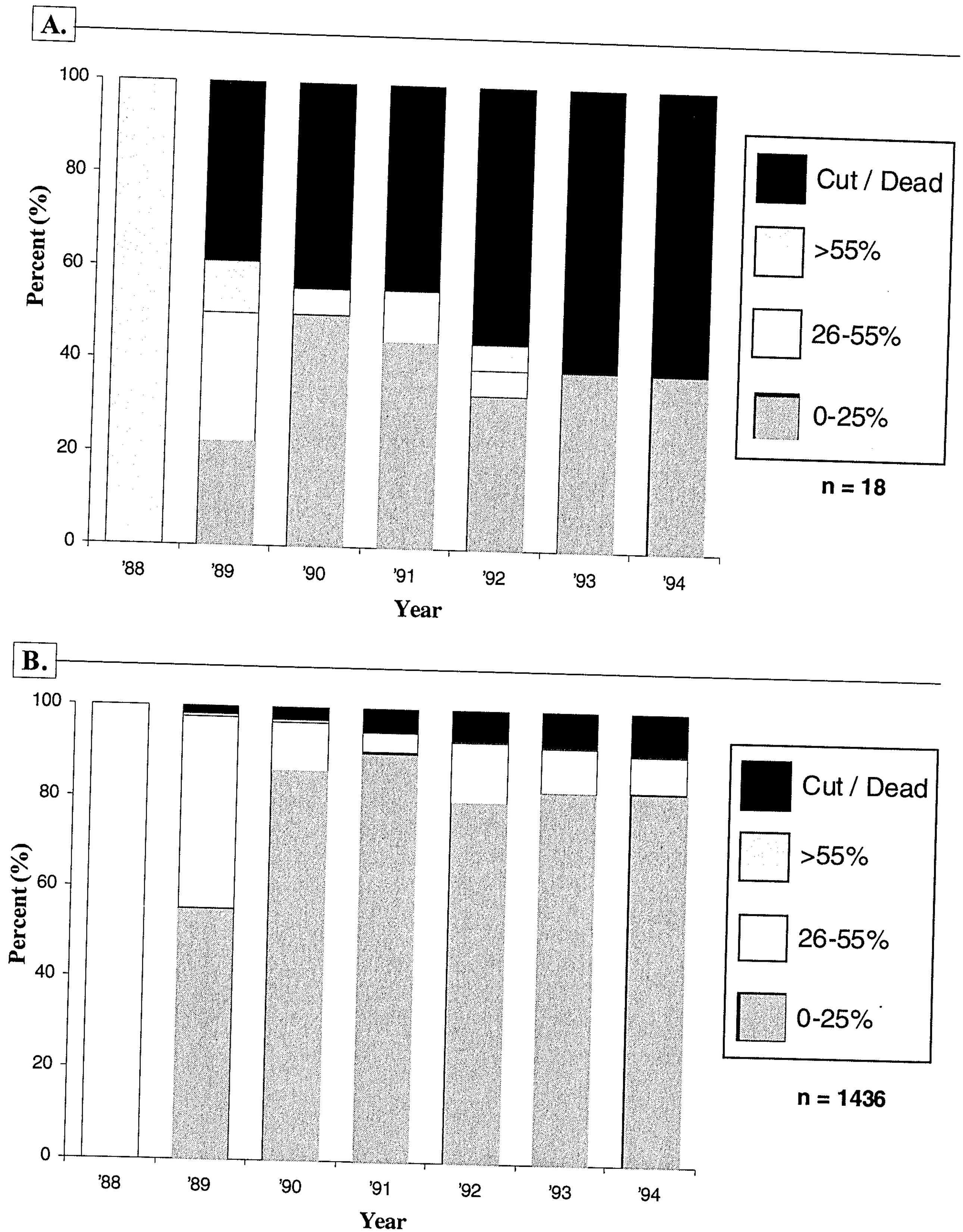


Figure 16. *Condition of upper canopy sugar maples in 1994 that had (A) >55% crown transparency (n=18) and (B) 26-55% crown transparency (n=1436) in 1988.*

Table 15. *Crown condition in 1994 of upper canopy (dominant/codominant) sugar maples that had 16-35% and >35% crown dieback in 1988.*

	Condition of maples in 1994 that had 16-35% crown dieback in 1988			Condition of maples in 1994 that had >35% crown dieback in 1988		
State/Province	n	Healthy %	Dead %	n	Healthy %	Dead %
Maine	26	69	27	7	14	71
Massachusetts	41	80	7	3	67	0
Michigan	17	88	6	2	50	50
New Brunswick/Nova Scotia	34	71	12	5	40	20
New Hampshire	12	83	17	8	13	50
New York	17	35	29	10	0	100
Ontario	60	62	8	5	40	60
Quebec	97	58	10	59	29	42
Vermont	158	77	9	38	21	58
Wisconsin	74	88	8	3	33	33
Total/Average	**536**	**71**	**13**	**140**	**31**	**48**

Table 16. *Crown condition in 1994 of upper canopy (dominant/codominant) sugar maples that had 26-55% and >55% crown transparency in 1988.*

	Condition of maples in 1994 that had 26-55% crown transparency in 1988			Condition of maples in 1994 that had >55% crown transparency in 1988		
State/Province	n	Healthy %	Dead %	n	Healthy %	Dead %
Maine	41	76	20	1	100	0
Massachusetts	126	93	5	2	100	0
Michigan	19	84	16	1	100	0
New Brunswick/Nova Scotia	17	59	12	2	0	100
New Hampshire	86	84	3	3	33	67
New York	216	75	10	1	0	100
Ontario	49	78	12	1	0	100
Quebec	536	85	8	2	50	50
Vermont	335	81	12	5	20	80
Wisconsin	11	82	9	0	0	0
Total/Average	**1436**	**82**	**9**	**18**	**39**	**61**

Influence of Stress on Crown Condition

During the past seven years, sugar maples in 66 of the original 165 plot-clusters were affected by one or more of the following potential stress agents: drought, forest tent caterpillar defoliation, pear thrips damage, Bruce spanworm defoliation, late spring frost, severe winter temperatures, or ice damage. What follows is a summary of the appearance of sugar maple crown condition subsequent to these disturbances.

Forest Tent Caterpillar, *Malacosoma disstria*

Moderate to severe damage by this early season defoliator occurred to six plot-clusters representing two regions (New York, Ontario) during 1988 through 1994. Defoliation was noted in at least one of these stands five of these seven years. To date, only one plot-cluster (New York 005) has received more than a single moderate (31-60%) or severe (>60%) defoliation (*Table 17*).

The impact of this stress on the average transparency of dominant/codominant sugar maple crowns varied between years and locations. In some instances (e.g., Ontario cluster 020 - 1989 defoliation; New York cluster 005 - 1989) average transparency differed little (1-6%) from that of the years previous to or immediately following defoliation. Other times (e.g., New York cluster 006 - 1993 defoliation; New York cluster 005 - 1990; cluster 006 - 1993; Ontario clusters 017 and 022 - 1990) differences in average transparency during years of defoliation were 18 to 32% higher compared to that of the year following damage. For one NY plot-cluster that was moderately to severely defoliated three times (1989, 1990, 1994), average crown transparency in 1994 (49%) was approximately double that of 1993 and double that of the regional average (21%; n = 27 plot-clusters) in 1994.

Crown dieback changed less than 4% when comparing crown condition the year of defoliation to that of the previous or succeeding years for both the individual plot-clusters and when comparing that plot-cluster to the region as a whole.

Pear Thrips, *Taeniothrips inconsequens*

An unprecedented outbreak of pear thrips in 1988 (Parker 1991) significantly changed the appearance of sugar maple crowns throughout the northeast. From 1988 through 1993, 53 NAMP plot-clusters, all in the United States, experienced moderate (31-60%) or heavy (>60%) defoliation by thrips.

All plot-clusters in Massachusetts were heavily damaged by this sucking insect in 1988, the year of the most widespread thrips activity. No significant stress has occurred to these plot-clusters since then. Therefore, NAMP data from this state affords an opportunity to evaluate the consequences of a single year of thrips damage.

Average crown dieback (± SE) for the original 451 overstory sugar maples under observation in Massachusetts was approximately 8 ± 0.7% in 1988, dropped to a low of 3 ± 1.1% in 1991 and by 1994 returned to 8%. This variable changed little during the past seven years. Average crown transparency, on the other hand, was high in 1988 (22 ± 2.1%) and 1989 (17 ± 0.9%) relative to 1990-1993 (9-13%). In 1988, transparency of understory sugar maples was approximately 10-15% higher (average 30%) than that of the overstory sample from both SBs and NSBs. A discrepancy of approximately 8-10% occurred between these crown strata in 1989, but thereafter

Table 17. *Date and location of NAMP plot-clusters moderately to severely defoliated by forest tent caterpillar, 1988-1994.*

Year	State/Province	Identification Nos. of Plot-Clusters Affected
1988	Ontario	019
1989	Ontario New York	020 005
1990	Ontario New York	017, 022 005
1993	New York	005, 006
1994	New York	005

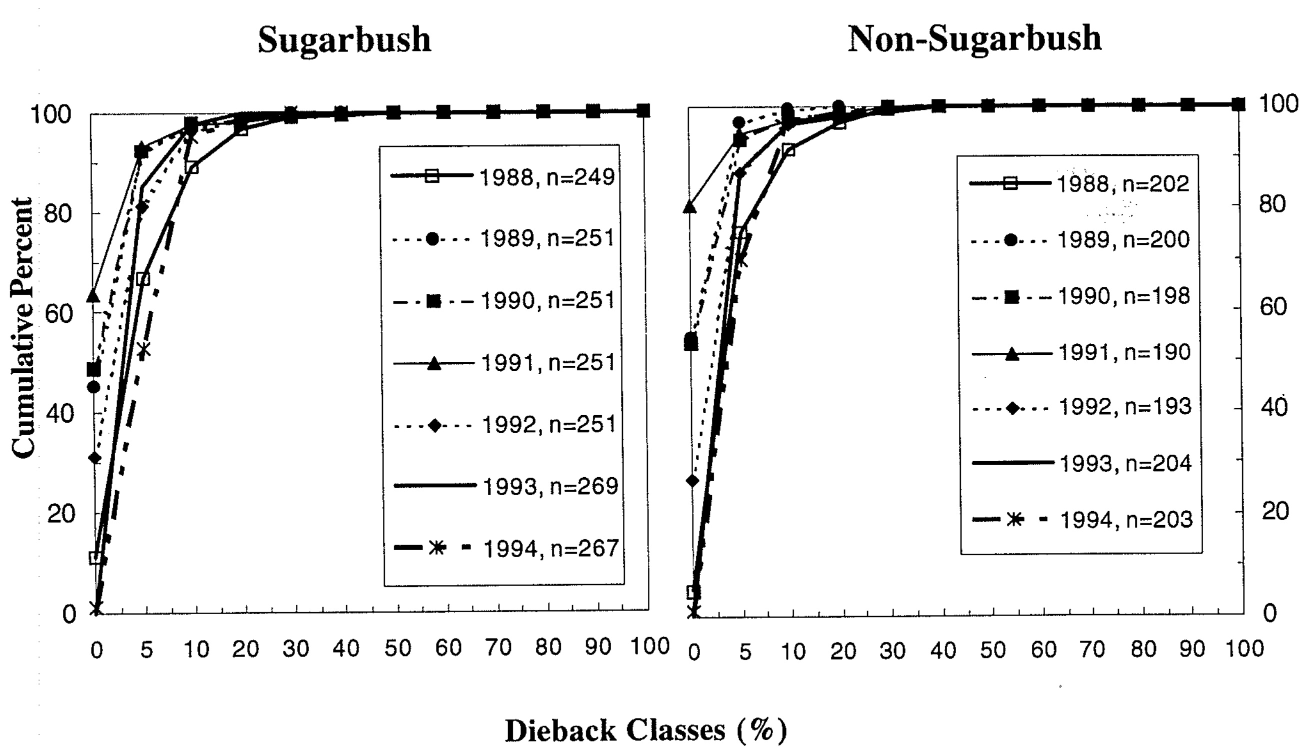


Figure 17. *Cumulative density functions for dieback for live, dominant-codominant sugar maples, 1988-1994, in Massachusetts plot-clusters.*

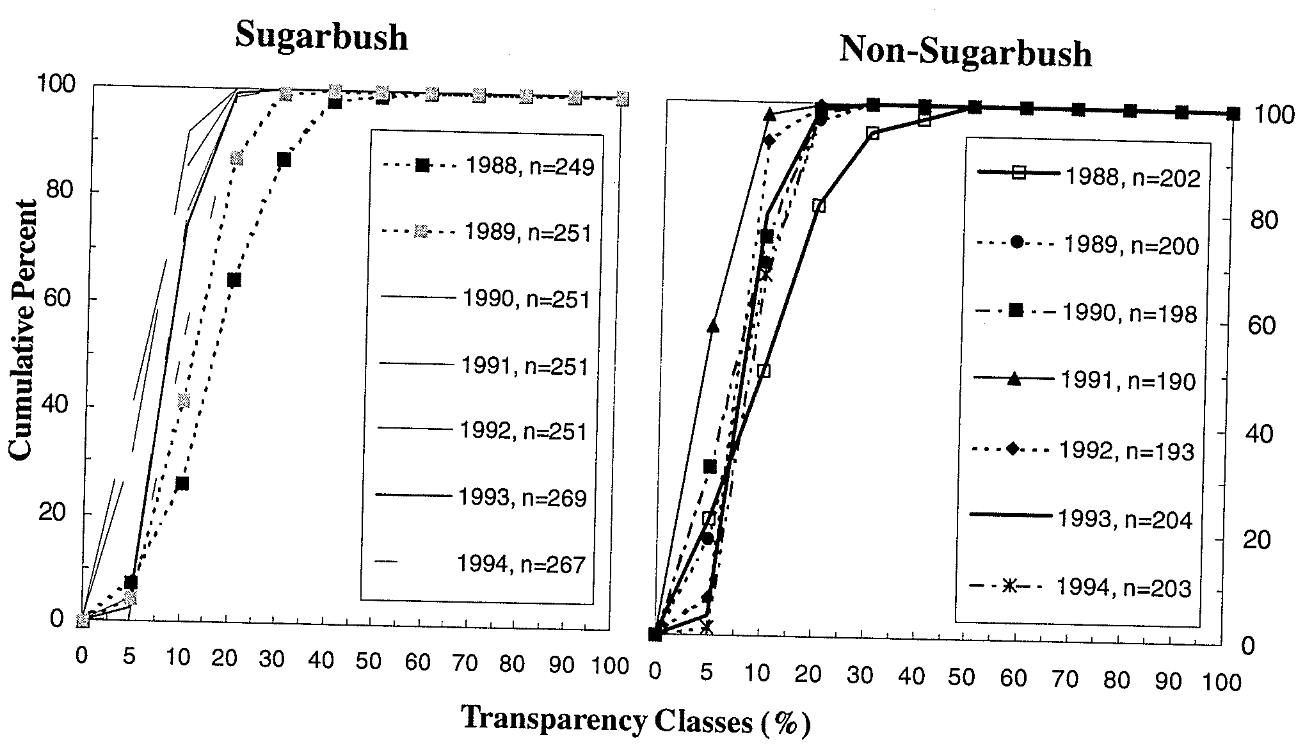


Figure 18. *Cumulative density functions for transparency for live, dominant/codominant sugar maples, 1988-1994, in Massachusetts plot-clusters.*

yearly average transparency of overstory and understory sugar maple crowns was similar. Cumulative density functions for overstory sugar maples in Massachusetts (*Figs. 17, 18*) illustrate that i) SBs and NSBs responded similarly to thrips damage, ii) crown dieback changed little in response to thrips damage and iii) crown transparency decreased to what appears to be normal levels one year following the thrips outbreak.

Fourteen of Vermont's plot-clusters experienced thrips damage comparable to Massachusetts in 1988, and the general response to this stress was similar following a single episode of defoliation.

Full recovery of crown transparency occurred two years following defoliation. For example, average transparency dropped from 22 $\pm$ 1.1% in 1988 (n = 1053 trees) to 13 $\pm$ 0.9% in 1990. Improvement in crown transparency is also reflected in changes in number of trees each year that were given a high (>20% class) transparency rating. During the year of thrips damage, 66% of the crown ratings for overstory sugar maples in Vermont's affected plot-clusters exceeded the 20% class. This proportion dropped to 46% the following year and by 1990 only 10% of these trees were rated in high transparency classes.

Only one site (Vermont - Hooper sugarbush) was stressed by pear thrips for three years (1988, 1990 and 1993). The principal effect was a temporary increase in crown transparency, and to some extent dieback as well, compared to NAMP as a whole. This is indicated by the relatively high proportion of overstory trees ranked in high transparency and high dieback classes (*Table 18*).

Three Pennsylvania SBs received moderate to severe thrips damage in 1993. The effect of moderate damage on two of them (Shiloh, Peckham) mirrors what occurred in other examples; a substantial increase in crown transparency the year of damage and recovery the following year. The third plot (Russell), however, was severely defoliated and more than half of the overstory maples in this plot-cluster were ranked in high transparency classes (>20%) for two consecutive years (*Table 19*). Average crown dieback was 5% or less both years for the two moderately damaged plot-clusters, but was approximately 9% both years for the Russell Site.

A recent study of pear thrips impact in another Pennsylvania sugarbush (Kolb *et al.* 1992) demonstrated that trees sustaining heavy (60%-90%) damage did not refoliate the year of attack. This resulted in reduced quantity and quality of sap and thinner crowns the following two years.

Bruce Spanworm, *Operophtera bruceata*

This geometrid occurred only in Vermont where one SB and one NSB plot-cluster received moderate defoliation (30-61%) in 1994. Average crown transparency of overstory sugar maples in both plot-clusters decreased by only 2-3% the year of defoliation (SB = 11%; NSB = 12%) compared to 1993 (both approximately 14%). Transparency for trees in lower crown strata changed by a similar amount.

Ice Storm Damage

West central regions of New York were hit by a severe ice storm during late winter 1991. Five NAMP plot-clusters were involved to varying degrees, one of which sustained severe damage. That is, 60% or more of the overstory sugar maple crowns sustained branch damage. When crown data for these sites are viewed collectively, average dieback changed by 2% or less between 1990 and 1991. Transparency changes were similar in magnitude. Crown dieback ratings for the severely damaged plot-cluster and the plot-clusters closest to it geographically (both NSBs) in 1991 also did not reflect a major impact of this stress. Dieback was actually lower in 1991 (no trees above the 5% class) than in 1990, but 13-14% of the overstory trees occurred in the 10% class in 1992. Since then (1993, 1994) no tree crowns were rated above the 5% class.

Table 18. *Effects of three years of moderate to severe pear thrips damage to one Vermont sugarbush (Hooper; n = 36 overstory sugar maples).*

Year	% of Sample Rated Crown Transparency Classes >20%	% For all Sugarbushes		% Of in Sample Rated in Crown Dieback Classes >10%	% For all Sugarbushes	
		Vermont[1]	NAMP		Vermont[1]	NAMP
1988[2]	94	31	22	48	18	12
1989	78	24	26	28	7	7
1990[2]	14	7	7	18	10	7
1991	3	4	3	15	8	6
1992	9	5	6	12	10	6
1993[2]	50	12	5	21	12	5
1994	0	5	6	21	8	7

[1]*Excludes Hooper SB*
[2]*Years of reported damage by pear thrips*

Table 19. *Response of overstory sugar maples in three Pennsylvania plot-clusters (sugarbushes) to one year (1993) of moderate to heavy pear thrips damage.*

Plot-cluster	n	Year	% of Sugar Maples Ranged in Crown Transparency Classes > 20%	Extent of Thrips Damage
Shiloh	27	1992	0	—
		1993	26	31-60%
		1994	0	—
Peckham[1]	63	1993	28	31-60%
		1994	0	—
Russell[1]	47	1993	55	>60%
		1994	58	—

[1]*Plot-cluster established in 1993.*

A substantial change in transparency occurred in 1992, however, one year after the storm. At this time, 34% of the trees in the severely damaged stand were rated in the 20% or 30% transparency classes. This is approximately double the percentage of trees that occurred in these classes (18%) the summer (1991) following the storm. In 1990 only 2% of the overstory maples were rated in these classes, and none were ranked higher than 10% transparency in 1993.

Stem Damage

As indicated in an earlier publication (Allen *et al.* 1992), only 83 of the 7,316 dominant/codominant sugar maples in the original 165 plot-clusters had a crown dieback rating equal to or greater than the 50% class in 1988. Eighty-six percent of these trees had bole and/or root damage. The 68 plot-clusters added between 1989 and 1993 provide a second opportunity to examine this relationship. These additional data represent 2,936 overstory maples, 36 of which had crown dieback ratings $\geq$ the 50% class when plot-clusters were established. Of these, 21 (58%) had bole and/or root damage. Based on these two, admittedly small, samples, we hypothesize that major bole and/or root damage is a likely precursor of mortality.

Frost Damage

Moderate to severe late spring frost damage appeared during 1992 in one of New Brunswick's SB and one NSB plot-clusters. Average crown dieback of overstory and understory maples changed little for both management classes in 1992 compared to the previous year. Average crown transparency of overstory trees actually decreased in both the SB (18% *vs* 11%) and NSB (16% *vs* 11%) between 1991 and 1992.

Moderate frost damage reportedly occurred in one Vermont NSB plot-cluster during spring 1994. No crown effects were apparent in the 1994 crown ratings of overstory sugar maples.

Drought

All of Wisconsin's plot-clusters (n=18) were exposed to severe drought in 1988 and moderate drought in 1989. Anecdotal evidence indicates that the original ten plot-clusters in Michigan's Lower Peninsula also experienced drought during the same period. Additionally, at some point during 1989 through 1992 drought occurred in three of Ontario's plot-clusters. Two New Hampshire sites were subjected to drought in 1993. Because Wisconsin offers a relatively large sample and represents the only NAMP region where drought has been documented (USDA Forest Service 1993), it will be used as an example.

Average crown dieback in Wisconsin's SBs (8.6 ± 0.9%) and NSBs (9.0 ± 0.8%) during the year of severest drought (1988) and the two following years: 1989 (SB: 7.8 ± 0.7%, NSB: 6.6 ± 0.6%) and 1990 (SB: 9.8 ± 1.1%, NSB: 9.6 ± 0.6%) were within the same crown rating classes as that of sugar maple in other NAMP regions.

The principal effect of drought in Wisconsin occurred as changes in crown transparency, probably reflecting production of fewer and/or smaller leaves for a year or two following the stress. This is illustrated nicely by the cumulative density functions for both SBs and NSBs (*Fig. 19*). The further a curve is to the right, the more trees (arrows in *Fig. 19* identify 1989 and 1990) there are in high transparency classes. By 1991, the curve moved to the left and since then years have been relatively indistinguishable.

Another way to view changes in crown transparency during and immediately following the drought is to compare annual means. The year of drought (1988) and the third year following drought (1991) average crown transparency was 9.5 ± 0.7% and 11.8 ± 0.7%, respectively. Means both years were significantly (alpha = .05) lower than average transparency in 1989 (SB:

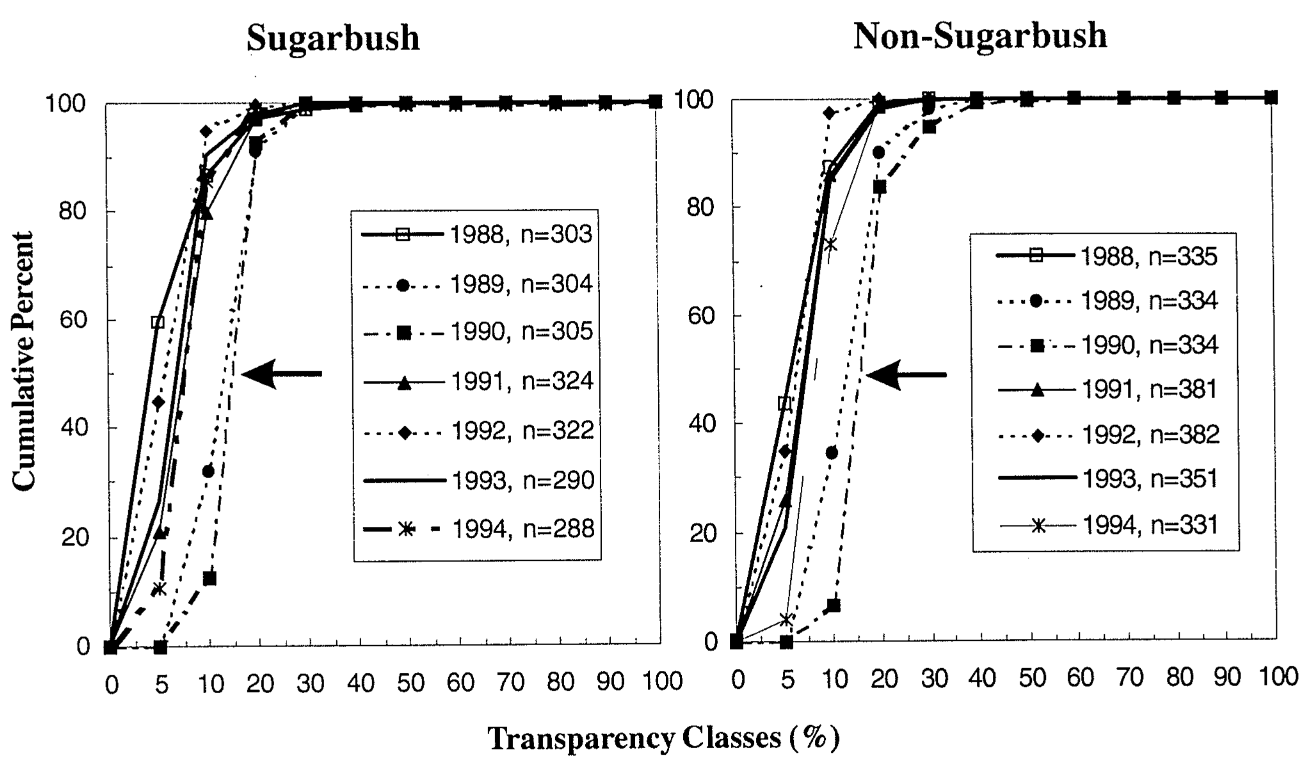


Figure 19. *Cumulative density functions for transparency for live, dominant/codominant sugar maples, 1988-1994, in Wisconsin plot-clusters.*

17.1 $\pm$ 0.5%, NSB: 17.5 $\pm$ 0.6%) and 1990 (SB: 20.5 $\pm$ 0.5%, NSB: 22.2 $\pm$ 0.8%). In the absence of additional contemporaneous or sequential stresses, under these site conditions dominant/codominant sugar maples recovered from a severe drought within two years of the event.

Atmospheric Deposition of Sulfate and Nitrate

Crown condition data for 1994 are used to examine the relation between crown condition and deposition level for all plot-clusters (*Table 20*) and for plot-clusters in Canada and the United States separately (*Table 21*). Column (A) in both tables gives average cluster dieback and transparency values ($\pm$ SE) for overstory sugar maples in all plot-clusters thought to have received High (H), Medium (M) or Low (L) levels of sulfate and nitrate. Column (B) indicates the statistical comparisons that were made; average cluster dieback and transparency of trees in the High deposition category compared to those from Medium and Low categories, and average cluster dieback and transparency for Medium compared to Low categories.

There are seven statistically significant comparisons when data from NAMP plot-clusters for Canada and the United States are combined (*Table 20*). Average cluster dieback of plot-clusters assumed to have been exposed to High levels of wet sulfate deposition ($\bar{x}$=5.2%) was significantly **lower** than dieback in plot-clusters exposed to Medium deposition levels ($\bar{x}$=7.0%). Average cluster transparency of plot-clusters presumably exposed to High levels of sulfate deposition ($\bar{x}$=16.0%) was significantly higher than that of plot-clusters placed in Medium ($\bar{x}$=13.1%) and Low ($\bar{x}$=10.7%) deposition classes. Also, average cluster transparency of stands exposed to High levels of nitrate deposition was significantly higher ($\bar{x}$=16.6%) compared to average cluster transparency in the Medium ($\bar{x}$=12.9%) and Low ($\bar{x}$=11.0%) classes. For both sulfate and nitrate, average cluster transparency of plot-clusters exposed to Medium deposition levels was higher than that of plot-clusters receiving Low levels of deposition.

Similarly, when the 1994 data are stratified by country (*Table 21*), average cluster transparency generally increases with increasing deposition levels. Sugar maples exposed to High sulfate deposition in the United States' plot-clusters had significantly higher average cluster transparency (14.7%) than that of trees exposed to Low levels of deposition (10.6%), though both means are within the same rating class. Sugar maples exposed to High levels of both nitrate and sulfate in Canada not only had higher average cluster transparencies, but the means were in different rating classes compared to trees exposed to Medium or Low deposition levels. Long-term monitoring is necessary to determine if these differences are real or merely reflect natural variation in crown condition. In Canada, average cluster dieback for High exposure plot-clusters was significantly **lower** (4.7%) than that of plot-clusters receiving Medium ($\bar{x}$=8.9%) levels of wet sulfate deposition. The two means are within the same crown rating class.

If, indeed, deposition affects crown transparency, we speculated that this might be explained, in part, by plot-cluster elevation. The assumption is that plot-clusters at higher elevations are exposed to heavier loads of airborne pollutants (Garner *et al.* 1989). There were no statistically significant differences (alpha=0.05) in average cluster transparency between plot-clusters at high (>450m, n=61), medium (300-450m, n=90) and low (<300m, n=73) elevations.

A recent Wisconsin study (Mielke *et al.* 1991) reported no significant differences in sugar maple health (% decline, number of dead trees or extent of crown dieback) across four zones based on average weighted mean pH of rainfall. Innes (1993) concluded that there is no evidence suggesting atmospheric pollution has been involved in sugar maple declines or is associated with temporary changes in sugar maple crown condition.

As indicated in Methods, deposition was not monitored at individual NAMP study sites. We assumed that average annual deposition received at the closest monitoring station reflected on-site deposition. At the least, it seems legitimate to assume that an adjacent off-site measure would allow us to identify plot-clusters that received High, Medium or Low levels of pollutants **relative** to other plot-clusters. Even though periodic deposition at a given site can be quite variable (i.e., on a daily, weekly or monthly basis, for example, a plot-cluster may move from one deposition category to another), mean annual deposition accounts for this variation and is a legitimate estimate of relative deposition. After seven years of monitoring the crown condition of sugar maple, we have identified no evidence of sugar maple decline in the NAMP plot-clusters. What appear at this point to be temporary, short-term changes in crown condition (specifically transparency) are associated with a variety of biotic and abiotic stresses. The confounding effects of natural variation in crown transparency, the influence of biotic stresses on transparency and lack of on-site deposition measurements make it difficult to reach a conclusion about the relation between transparency and deposition. Given these limitations, however, the combined data indicate that increasing crown transparency may be associated with increasing levels of wet sulfate and nitrate deposition (*Tables 20 and 21*).

Table 20. *Results of ANOVA of crown transparency and crown dieback for overstory sugar maple at three levels of wet sulfate and wet nitrate deposition in 1994. All plot-clusters.*

Deposition Variable	(A) Crown Variable ($\bar{x} \pm$ SE)	n[2]	(B) Comparison	F-value	p-value
Sulfate	**Dieback**				
High	5.2 ± 0.5	33	High vs. Medium	6.96	0.009*
Medium	7.0 ± 0.4	126	High vs. Low	1.44	0.231
Low	6.0 ± 0.3	67	Medium vs. Low	2.97	0.086
	Transparency				
High	16.0 ± 1.6	33	High vs. Medium	10.19	0.002*
Medium	13.1 ± 0.3	126	High vs. Low	29.17	0.0001*
Low	10.7 ± 0.3	67	Medium vs. Low	12.03	0.001*
Nitrate	**Dieback**				
High	6.3 ± 0.6	40	NA[2]	NA[2]	NA[2]
Medium	6.6 ± 0.4	96	NA[2]	NA[2]	NA[2]
Low	6.2 ± 0.2	90	NA[2]	NA[2]	NA[2]
	Transparency				
High	16.6 ± 1.3	40	High vs. Medium	19.71	0.0001*
Medium	12.9 ± 0.4	96	High vs. Low	43.12	0.0001*
Low	11.0 ± 0.3	90	Medium vs. Low	7.90	0.005*

* *Significant at alpha=0.05*

[1] *n=plot-clusters. Data for six Michigan plot-clusters and one plot-cluster in New Brunswick not available.*

[2] *Comparisons test not applicable because overall ANOVA not statistically significant (p-value=0.72).*

Table 21. *Results of ANOVA of crown dieback and crown transparency for overstory sugar maple at three levels of wet sulfate and wet nitrate deposition in 1994. All plot-clusters separated by country.*

Country	Deposition Variable	(A) Crown Variable ($\bar{x}$ ± SE)	n[1]	(B) Comparison	F-value	p-value
United States	***Sulfate***	**Dieback**				
	High	5.4 ± 0.8	21	NA[2]	NA[2]	NA[2]
	Medium	6.3 ± 0.4	92	NA[2]	NA[2]	NA[2]
	Low	5.7 ± 0.2	52	NA[2]	NA[2]	NA[2]
		Transparency				
	High	14.7 ± 2.4	21	High vs. Medium	2.01	0.159
	Medium	13.0 ± 0.4	92	High vs. Low	10.18	0.002*
	Low	10.6 ± 0.4	52	Medium vs. Low	7.73	0.006*
	Nitrate	**Dieback**				
	High	5.8 ± 1.1	15	NA[2]	NA[2]	NA[2]
	Medium	6.0 ± 0.5	77	NA[2]	NA[2]	NA[2]
	Low	6.0 ± 0.2	73	NA[2]	NA[2]	NA[2]
		Transparency				
	High	16.6 ± 3.2	15	High vs. Medium	6.21	0.014*
	Medium	13.1 ± 0.5	77	High vs. Low	16.03	0.0001*
	Low	10.9 ± 0.3	73	Medium vs. Low	6.99	0.009*
Canada	***Sulfate***	**Dieback**				
	High	4.7 ± 0.5	12	High vs. Medium	12.69	0.001*
	Medium	8.9 ± 0.7	34	High vs. Low	3.69	0.06
	Low	7.3 ± 0.5	15	Medium vs. Low	2.13	0.15
		Transparency				
	High	18.1 ± 0.7	12	High vs. Medium	22.55	0.0001*
	Medium	13.3 ± 0.6	34	High vs. Low	37.09	0.0001*
	Low	11.0 ± 0.6	15	Medium vs. Low	6.08	0.017
	Nitrate	**Dieback**				
	High	7.1 ± 0.8	25	NA[2]	NA[2]	NA[2]
	Medium	9.0 ± 1.0	19	NA[2]	NA[2]	NA[2]
	Low	7.6 ± 0.5	17	NA[2]	NA[2]	NA[2]
		Transparency				
	High	16.8 ± 0.7	25	High vs. Medium	27.84	0.0001*
	Medium	12.0 ± 0.6	19	High vs. Low	34.06	0.0001*
	Low	11.2 ± 0.5	17	Medium vs. Low	0.47	0.496

** = Significant at alpha = 0.05*

[1]*n=plot-clusters. Data for six Michigan plot-clusters and one plot-cluster in New Brunswick not available.*

[2]*Comparisons test not applicable, because overall ANOVA not statistically significant (p-value= 0.45, 0.97 and 0.07 for U.S. Sulfate, U.S. Nitrate and Canada Nitrate, respectively).*

Tree Mortality

With the addition of new regions and new plot-clusters within currently participating regions, the number of sample trees of all species increased from approximately 15,400 in 1988 to 22,400 by the end of 1994. Presently, 15,798 sugar maples occur in the sample plots, 9,466 of which are alive and occupy dominant or codominant crown positions (*Table 3*). Of these, 6,701 have been observed since 1988. For mortality calculations, the base number of live sugar maples of all crown positions in 1988 in the original ten states/provinces was 10,493 trees.

Average annual mortality of sugar maple (% of trees) for the period 1989 through 1994 was 0.9% for natural, 0.3% for management-related and 1.2% for both categories combined (*Table 22*). Average annual natural mortality for all crown positions combined was equal for SBs and NSBs (0.9%); however, average annual natural mortality for dominant/codominant SB trees was slightly higher than for NSB trees (0.6% vs. 0.5%). Average annual natural mortality of trees in intermediate and suppressed crown classes was more than twice that of individuals in dominant and codominant classes for both SBs (1.5% *vs* 0.6%) and NSBs (1.8% *vs* 0.5%) (*Table 22*). Annual mortality of sugar maple was higher in understory crown positions compared to mortality in the overstory for both Canada (*Fig. 20*) and the U.S. (*Fig. 21*), except for 1994 when mortality in the intermediate/suppressed crown classes for Canadian SBs equaled that of overstory trees. This pattern and level of mortality is to be expected because of competition associated with normal stand development.

Cumulative annual natural mortality for the six year period (all sugar maples) was 5.4% and cumulative annual total mortality equaled 7.2% (*Table 23*). Cumulative annual natural mortality of dominant/codominant trees in SBs was higher than in NSBs (3.7% vs. 3.0%). When stratified by crown position, cumulative annual natural mortality was 3.3% for dominant/codominant trees and 9.7% for intermediate/suppressed trees (both management categories combined).

Average annual natural mortality of dominant/codominant sugar maples from 1989 through 1994 ranged from 0.3-1.0% (highest in New York; both management categories combined). Average annual natural mortality for both crown positions combined ranged from 0.4-1.3% (highest in New Hampshire). Cumulative annual natural mortality as of 1994 for dominant/codominant trees ranged from 1.6-5.6% (highest in New York; both management categories combined), and for both crown positions combined mortality ranged from 2.6-7.4% (highest in New Hampshire).

The number of trees that die in a forest each year depends on many variables: site conditions, stand density, age of stand, stand structure, and disturbance history. In every situation, natural thinning (mortality) occurs as the stand ages, and the number of trees present decreases exponentially as the size of individuals increases (Mohler et al. 1978). Rate of death under normal conditions is typically 1 to 2% each year (Waring and Schlesinger 1985, Hall 1993). In a study of transition in a mixed hardwood stand in Connecticut, Stephens and Waggoner (1980) reported an annual mortality (% of trees) for sugar maple ranging from 0.8% to 1.4%/yr. for three site conditions and three periods of growth from 1927 through 1977. A recent study in Vermont (Kelley et al. 1992) reported an annual sugar maple mortality of 0.4%/yr. Overall, the average annual natural mortality of dominant/codominant sugar maple observed in NAMP SBs (0.6%) and NSBs (0.5%) (*Table 22*) appear to be consistent with mortality reported for other stands in the absence of unusual disturbances.

A preliminary look at stand stocking (*Table 24*, Col. A) indicates that, on average, stands in both management categories in 8 of 11 regions were fully stocked in 1988. Stocking was determined by applying mean tree d.b.h. (Col. B) and mean basal area (Col. C) for all plot-clusters in each of the two management categories (SB, NSB) in each region to a stocking guide (Leak *et al.* 1987). Exceptions to full stocking are SBs and NSBs in New Hampshire and NSBs in New York, which were moderately stocked and overstocking that occurred in Vermont's NSBs.

Average annual natural basal area mortality (% of sugar maple basal area in all crown classes and for both management categories combined) for 1989 through 1994 ranged from a high of 1.1% in Quebec to 0.4% in Wisconsin (*Table 24*, last col.). Generally, basal area mortality of sugar maple in intermediate and suppressed crown classes was higher than that of trees in the upper canopy in each region (*Table 24*) and when regions were combined for both the United States (*Fig. 22*) and Canada (*Fig. 23*). Basal area mortality in the lower canopy (intermediate and suppressed crown classes) decreased by approximately 1.0 to 2.0% after 1991, approximately half of the mortality that occurred in these crown strata from 1988 through 1991. After 1991, mortality of upper canopy sugar maple more closely approximated that of trees in the lower canopy. Annual natural basal area mortality of upper canopy trees in both countries varied little during the seven years of observation and never exceeded 1.2% (Canadian sugarbushes in 1994). The highest basal area losses in any year (shaded boxes, *Table 24*) occurred in the Intermediate/Suppressed crown class for both SBs and NSBs. This mortality is accounted for by as few as one and as many as five trees. We speculate that this mortality is a result of between-tree competition for growing space, nutrients and/or moisture.

This annual loss in sugar maple basal area is within the range of that reported for maples (red and sugar combined) by Solomon (1977) in a ten-year evaluation of northern hardwood plots representing a spectrum of both initial stand densities and densities of sawtimber. In Solomon's study, annual maple mortality ranged from 0.14% to 1.19% of the initial basal area. Similarly, in a study of second growth northern hardwoods in northeastern Wisconsin that were exposed to a variety of cutting regimes, annual mortality of sugar maple averaged 0.3% to 0.4% of the initial basal area for all treatments. Seven percent of the maple stems $\geq$ 4.6" d.b.h. or larger died during this period; approximately 0.5%/yr (Erdmann and Oberg 1973).

Table 22. *Annual mortality (1988-1994) for sugar maples in the NAMP project as a whole by management type (sugarbush, non-sugarbush), crown position (dominant/codominant, intermediate/suppressed), and mortality type ("natural", management-related). Includes only trees in original (1988) plot-clusters.*

Management Type	Crown Position	Annual Mortality (% of trees)											
		1988[1]			1989			1990			1991		
		N[2]	M	T	N	M	T	N	M	T	N	M	T
Sugarbushes	Dom/Cod	-	-	-	0.7	0.1	0.8	0.4	0.1	0.5	0.7	0.5	1.3
	Inter/Supp	-	-	-	2.3	0.1	2.3	1.8	0.1	1.9	1.6	0.4	2.0
	Combined	-	-	-	1.2	0.1	1.3	0.8	0.1	0.9	1.0	0.5	1.5
Non-sugarbushes	Dom/Cod	-	-	-	0.6	0.3	0.9	0.3	0.0	0.3	0.7	0.5	1.1
	Inter/Supp	-	-	-	2.1	0.3	2.4	2.1	0.0	2.1	2.1	0.4	2.5
	Combined	-	-	-	1.1	0.3	1.4	0.9	0.0	0.9	1.1	0.5	1.6
Combined	Dom/Cod	-	-	-	0.7	0.2	0.9	0.4	0.1	0.4	0.7	0.5	1.2
	Inter/Supp	-	-	-	2.2	0.2	2.4	1.9	0.0	2.0	1.8	0.4	2.3
	Combined	-	-	-	1.2	0.2	1.4	0.9	0.0	0.9	1.1	0.5	1.5
		1992			1993			1994			Average[3]		
		N[2]	M	T	N	M	T	N	M	T	N	M	T
Sugarbushes	Dom/Cod	0.8	0.1	0.9	0.4	0.3	0.7	0.7	0.7	1.4	**0.6**	**0.3**	**0.9**
	Inter/Supp	1.5	0.2	1.7	1.0	0.4	1.4	1.0	0.1	1.1	**1.5**	**0.2**	**1.7**
	Combined	1.0	0.1	1.1	0.6	0.3	0.9	0.8	0.5	1.3	**0.9**	**0.3**	**1.2**
Non-sugarbushes	Dom/Cod	0.5	0.3	0.8	0.5	0.1	0.5	0.4	0.8	1.2	**0.5**	**0.3**	**0.8**
	Inter/Supp	1.5	0.2	1.6	1.3	0.1	1.4	1.4	1.2	2.6	**1.8**	**0.4**	**2.1**
	Combined	0.8	0.3	1.1	0.7	0.1	0.8	0.7	0.9	1.6	**0.9**	**0.4**	**1.2**
Combined	Dom/Cod	0.6	0.2	0.8	0.4	0.2	0.6	0.5	0.7	1.3	**0.6**	**0.3**	**0.9**
	Inter/Supp	1.5	0.2	1.7	1.1	0.2	1.4	1.2	0.7	1.9	**1.6**	**0.3**	**2.0**
	Combined	0.9	0.2	1.1	0.6	0.2	0.8	0.7	0.7	1.5	**0.9**	**0.3**	**1.2**

[1]*Annual mortality data for 1988 is not available. Dead trees identified in 1988 at the time of plot-cluster establishment represent detectable cumulative mortality (see 1988 col.,* Table 23*).*

[2]*N = natural, M = management-related, T = combined.*

[3]*Represents average annual mortality (1989-1994).*

Table 23. *Cumulative annual mortality (% of trees) (1988-1994) for sugar maples in the NAMP project as a whole by management type (sugarbush, non-sugarbush), crown position (dominant/codominant, intermediate/suppressed), and mortality type ("natural", management-related). Includes only trees in original (1988) plot-clusters.*

Management Type	Crown Position	Cumulative Annual Mortality (% of trees)											
		1988[1]			1989			1990			1991		
		N[2]	M	T	N	M	T	N	M	T	N	M	T
Sugarbushes	Dom/Cod	-	-	1.3	0.7	0.1	0.8	1.1	0.2	1.3	1.8	0.7	2.6
	Inter/Supp	-	-	5.9	2.3	0.1	2.3	4.1	0.2	4.2	5.7	0.6	6.2
	Combined	-	-	2.8	1.2	0.1	1.3	2.0	0.2	2.2	3.0	0.7	3.7
Non-sugarbushes	Dom/Cod	-	-	1.4	0.6	0.3	0.9	0.9	0.3	1.2	1.6	0.8	2.3
	Inter/Supp	-	-	6.4	2.1	0.3	2.4	4.2	0.3	4.5	6.3	0.7	7.0
	Combined	-	-	3.4	1.1	0.3	1.4	2.0	0.3	2.3	3.1	0.8	3.9
Combined	Dom/Cod	-	-	1.3	0.7	0.2	0.9	1.1	0.3	1.3	1.8	0.8	2.5
	Inter/Supp	-	-	6.1	2.2	0.2	2.4	4.1	0.2	4.4	5.9	0.6	6.7
	Combined	-	-	3.1	1.2	0.2	14	2.1	0.2	2.3	3.2	0.7	3.8

Management Type	Crown Position	1992			1993			1994		
		N	M	T	N	M	T	N	M	T
Sugarbushes	Dom/Cod	2.6	0.8	3.5	3.0	1.1	4.2	3.7	1.8	5.6
	Inter/Supp	7.2	0.8	7.9	8.2	1.2	9.3	9.2	1.3	10.0
	Combined	4.0	0.8	4.8	4.6	1.1	5.7	5.4	1.6	7.0
Non-sugarbushes	Dom/Cod	2.1	1.1	3.1	2.6	1.2	3.6	3.0	2.0	4.8
	Inter/Supp	7.8	0.9	8.6	9.1	1.0	10.0	11.0	2.2	13.0
	Combined	3.9	1.1	5.0	4.6	1.2	5.8	5.3	2.1	7.4
Combined	Dom/Cod	2.4	1.0	3.3	2.8	1.2	3.9	3.3	1.9	5.2
	Inter/Supp	7.4	0.8	8.4	8.5	1.0	9.8	9.7	1.7	12.0
	Combined	4.1	0.9	4.9	4.7	1.1	5.7	5.4	1.8	7.2

[1] *Mortality data for 1988 represent detectable cumulative mortality at the time of plot-cluster establishment. This mortality is not carried into the following year for purposes of calculating cumulative mortality.*

[2] *N = natural, M = management-related, T = combined.*

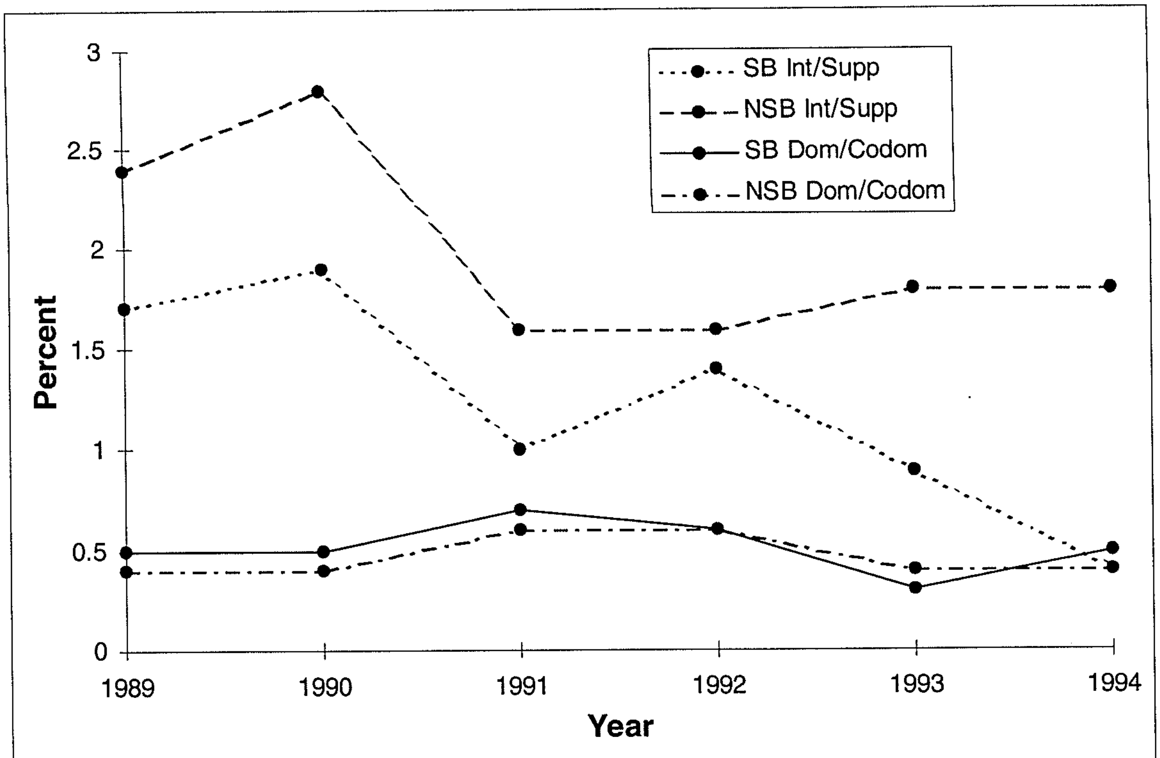


Figure 20. *Annual natural mortality (% of trees) of upper (dominant/codominant) and lower (intermediate/suppressed) canopy sugar maples by stand management class (sugarbush, non-sugarbush), 1989-1994. Includes only trees established in Canadian regions in 1988.*

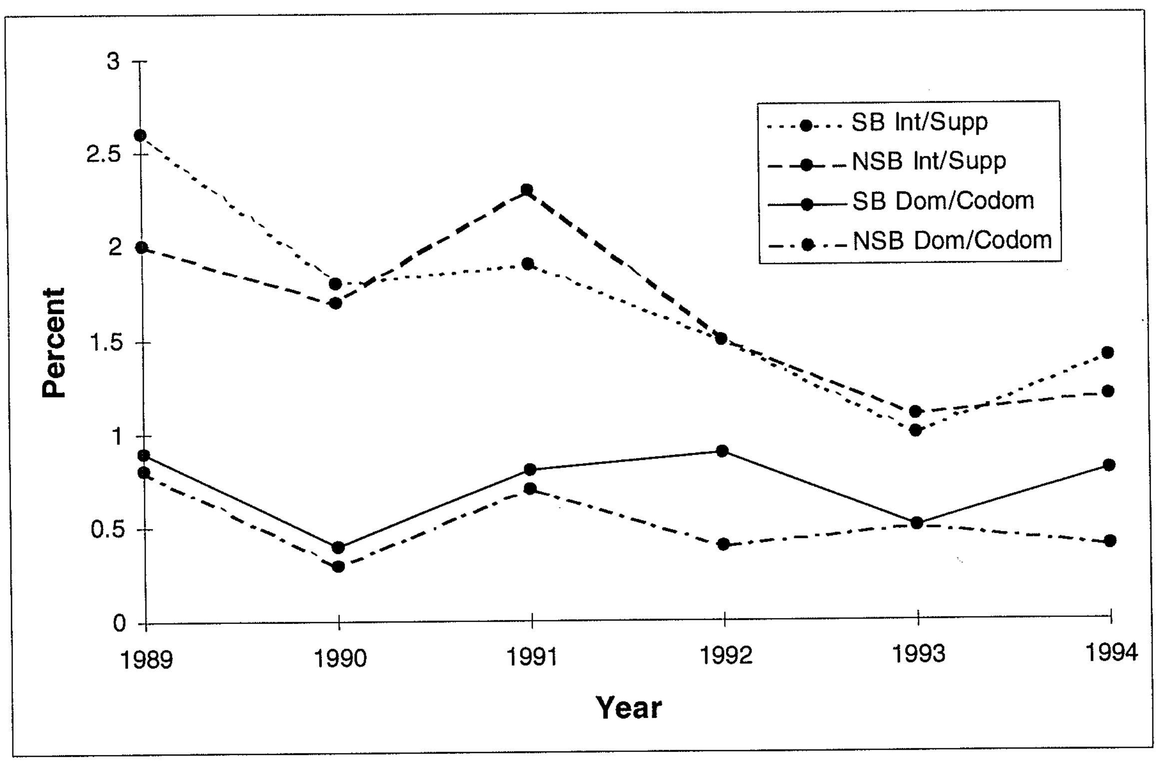


Figure 21. *Annual natural mortality (% of trees) of upper (dominant/codominant) and lower (intermediate/suppressed) canopy sugar maples by stand management class (sugarbush, non-sugarbush), 1989-1994. Includes only trees established in U.S. regions in 1988.*

Table 24. *Annual natural mortality (1988-1994) of sugar maple (% of sugar maple basal area) for each NAMP region by management type, crown position, and mortality type. Includes only trees in original (1988) plot-clusters.*

State/ Province	Management Category	Crown Position	(A) Stocking Level	(B) dbh (cm) All trees $\bar{x}$	(C) Basal Area in 1988 (m²/ha)		(D) Annual natural mortality (% of sugar maple basal area)						
					All Trees	Sugar Maple	1989	1990	1991	1992	1993	1994	$\bar{x}$
ME	SB	Dom/Codom	Full	31.7	24.5	20.2	2.1	0.0	0.5	2.0	0.9	1.1	1.1
	SB	Inter/Supp		15.7	4.8	3.1	2.6	1.2	0.2	1.2	0.8	1.8	1.3
	SB	Crown Positions Combined		24.4	29.3	23.2	2.2	0.2	0.5	1.9	0.8	1.2	1.1
	NSB	Dom/Codom	Full	27.8	23.0	14.9	0.9	0.0	0.8	0.3	0.3	1.0	0.6
	NSB	Inter/Supp		15.4	5.8	2.1	2.9	1.4	1.4	0.5	0.7	2.1	1.5
	NSB	Crown Positions Combined		22.0	28.8	17.0	1.1	0.2	0.9	0.3	0.3	1.2	0.7
	Combined	Dom/Codom	Full	29.5	23.8	17.5	1.6	0.0	0.6	1.3	0.6	1.1	0.9
	Combined	Inter/Supp		15.5	5.3	2.6	2.7	1.3	0.7	0.9	0.7	1.9	1.4
	SB, NSB and Crown Positions Combined			**23.1**	**29.1**	**20.1**	**1.7**	**0.2**	**0.6**	**1.2**	**0.6**	**1.2**	**0.9**
MA	SB	Dom/Codom	Full	29.4	22.8	21.2	0.0	0.0	0.0	0.0	0.0	0.5	0.1
	SB	Inter/Supp		16.9	3.0	2.0	1.7	7.4	1.5	0.0	1.0	1.5	2.2
	SB	Crown Positions Combined		25.7	25.8	23.2	0.1	0.6	0.1	0.0	0.1	0.6	0.3
	NSB	Dom/Codom	Full	32.2	26.0	18.0	0.6	0.9	0.1	0.0	0.3	0.9	0.5
	NSB	Inter/Supp		16.5	3.9	2.6	1.1	1.7	6.3	2.7	2.1	0.0	2.3
	NSB	Crown Positions Combined		26.5	30.1	20.6	0.6	1.0	0.9	0.3	0.6	0.8	0.7
	Combined	Dom/Codom	Full	30.9	24.4	19.6	0.3	0.4	0.1	0.0	0.1	0.7	0.3
	Combined	Inter/Supp		16.7	3.5	2.3	1.4	4.2	4.3	1.6	1.6	0.6	2.3
	SB, NSB and Crown Positions Combined			**26.2**	**27.9**	**21.9**	**0.4**	**0.8**	**0.5**	**0.2**	**0.3**	**0.7**	**0.5**

State/ Province	Management Category	Crown Position	(A) Stocking Level	(B) dbh (cm) All trees ($\bar{x}$)	(C) Basal Area in 1988 (m^2/ha) All Trees	Sugar Maple	(D) Annual natural mortality (% of sugar maple basal area) 1989	1990	1991	1992	1993	1994	$\bar{x}$
MI	SB	Dom/Codom	Full	47.0	21.2	18.8	1.4	0.0	1.6	1.5	0.0	0.0	0.8
	SB	Inter/Supp		17.6	2.7	1.3	3.9	4.0	8.7	0.0	0.0	0.0	2.8
	SB	Crown Positions Combined		33.4	23.9	20.0	1.5	0.2	2.0	1.4	0.0	0.0	0.9
	NSB	Dom/Codom	Full	40.9	21.6	14.4	0.0	0.7	0.0	0.6	0.0	0.0	0.2
	NSB	Inter/Supp		17.5	2.8	1.5	0.8	0.0	0.0	0.0	0.0	0.0	0.1
	NSB	Crown Positions Combined		31.7	24.4	15.9	0.1	0.6	0.0	0.5	0.0	0.0	0.2
	Combined	Dom/Codom	Full	43.4	21.4	16.6	0.8	0.3	0.9	1.1	0.0	0.0	0.5
	Combined	Inter/Supp		17.6	2.7	1.4	2.2	1.8	3.8	0.0	0.0	0.0	1.3
	SB, NSB and Crown Positions Combined			**32.5**	**24.1**	**18.0**	**0.9**	**0.4**	**1.1**	**1.0**	**0.0**	**0.0**	**0.6**
NB/NS	SB	Dom/Codom	Full	21.1	20.2	16.3	0.2	0.6	0.3	0.4	0.0	1.4	0.5
	SB	Inter/Supp		12.0	1.2	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.2
	SB	Crown Positions Combined		19.6	21.5	16.9	0.2	0.6	0.3	0.4	0.0	1.3	0.5
	NSB	Dom/Codom	Full	21.0	23.6	15.8	0.0	0.0	2.3	0.5	0.0	0.3	0.5
	NSB	Inter/Supp		11.9	1.2	0.7	3.5	2.6	1.6	1.6	0.0	2.8	2.0
	NSB	Crown Positions Combined		19.7	24.8	16.5	0.1	0.1	2.3	0.6	0.0	0.4	0.6
	Combined	Dom/Codom	Full	21.1	21.5	16.1	0.1	0.4	1.0	0.4	0.0	1.0	0.5
	Combined	Inter/Supp		11.9	1.2	0.6	2.0	1.1	0.6	0.6	0.0	1.1	0.9
	SB, NSB and Crown Positions Combined			**19.6**	**22.7**	**16.7**	**0.2**	**0.4**	**0.9**	**0.4**	**0.0**	**1.0**	**0.5**
NH	SB	Dom/Codom	Moderate	25.4	18.3	15.3	1.1	0.0	0.0	0.4	0.0	0.0	0.3
	SB	Inter/Supp		13.7	2.6	1.5	1.1	2.2	1.6	2.9	0.0	1.2	1.5
	SB	Crown Positions Combined		21.4	20.9	16.8	1.1	0.2	0.1	0.6	0.0	0.1	0.4
	NSB	Dom/Codom	Moderate	28.9	23.8	16.3	0.0	0.9	0.0	0.1	0.1	0.0	0.2
	NSB	Inter/Supp		15.0	4.5	1.9	2.8	6.6	7.6	1.0	2.3	0.9	3.5
	NSB	Crown Positions Combined		23.0	28.3	18.2	0.3	1.5	0.7	0.2	0.3	0.1	0.5
	Combined	Dom/Codom	Moderate	27.1	21.0	15.8	0.5	0.5	0.0	0.3	0.1	0.0	0.2
	Combined	Inter/Supp		14.4	3.5	1.7	2.1	4.7	4.9	1.9	1.2	1.0	2.6
	SB, NSB and Crown Positions Combined			**22.2**	**24.6**	**17.5**	**0.7**	**0.9**	**0.4**	**0.4**	**0.2**	**0.1**	**0.5**

State/ Province	Management Category	Crown Position	(A) Stocking Level	(B) dbh (cm) All trees ($\bar{x}$)	(C) Basal Area in 1988 (m²/ha)		(D) Annual natural mortality (% of sugar maple basal area)						
					All Trees	Sugar Maple	1989	1990	1991	1992	1993	1994	$\bar{x}$
NY	SB	Dom/Codom	Full	36.0	28.9	25.2	1.0	0.9	0.6	1.5	0.9	2.5	1.2
	SB	Inter/Supp		14.9	3.2	2.5	2.5	3.4	1.9	0.5	1.3	0.4	1.7
	SB	Crown Positions Combined		27.6	32.1	27.8	1.2	1.2	0.7	1.4	1.0	2.3	1.3
	NSB	Dom/Codom	Moderate	32.5	16.3	13.0	0.3	0.0	0.0	0.0	0.5	0.4	0.2
	NSB	Inter/Supp		14.3	2.7	2.0	0.6	1.1	1.9	0.0	0.7	1.2	0.9
	NSB	Crown Positions Combined		24.2	19.0	15.1	0.3	0.1	0.3	0.0	0.5	0.5	0.3
	Combined	Dom/Codom	Full	34.4	21.9	18.5	0.7	0.6	0.3	0.9	0.7	1.6	0.8
	Combined	Inter/Supp		14.5	2.9	2.3	1.6	2.2	1.9	0.2	1.0	0.8	1.3
	SB, NSB and Crown Positions Combined			**25.9**	**24.8**	**20.7**	**0.8**	**0.8**	**0.5**	**0.8**	**0.8**	**1.6**	**0.9**
ON	SB	Dom/Codom	Full	36.7	27.0	24.8	0.4	0.0	1.1	0.0	0.4	1.4	0.6
	SB	Inter/Supp		16.3	2.7	1.9	3.1	1.9	1.1	0.6	0.0	1.2	1.3
	SB	Crown Positions Combined		29.7	29.7	26.7	0.6	0.1	1.1	0.0	0.4	1.4	0.6
	NSB	Dom/Codom	Full	30.1	21.3	15.6	0.4	0.7	0.5	0.8	0.4	0.5	0.6
	NSB	Inter/Supp		15.4	2.5	2.0	1.0	2.7	3.9	0.4	0.9	0.8	1.6
	NSB	Crown Positions Combined		25.6	23.8	17.6	0.5	0.9	0.9	0.8	0.5	0.5	0.7
	Combined	Dom/Codom	Full	33.0	24.2	20.2	0.4	0.3	0.9	0.3	0.4	1.1	0.6
	Combined	Inter/Supp		15.8	2.6	1.9	2.0	2.3	2.5	0.5	0.5	1.0	1.5
	SB, NSB and Crown Positions Combined			**27.5**	**26.8**	**22.2**	**0.6**	**0.4**	**1.0**	**0.3**	**0.4**	**1.1**	**0.6**
QU	SB	Dom/Codom	Full	30.2	24.9	22.1	1.4	0.8	1.5	1.5	1.0	0.9	1.2
	SB	Inter/Supp		14.9	3.0	2.7	2.8	2.6	2.7	1.7	0.9	0.1	1.8
	SB	Crown Positions Combined		25.0	28.0	24.8	1.6	1.0	1.6	1.5	1.0	0.8	1.3
	NSB	Dom/Codom	Full	28.4	24.7	19.7	1.1	1.4	0.7	1.4	0.1	0.1	0.8
	NSB	Inter/Supp		14.1	2.6	1.9	2.6	2.9	1.1	1.3	2.3	1.4	1.9
	NSB	Crown Positions Combined		24.1	27.3	21.6	1.2	1.6	0.7	1.4	0.3	0.2	0.9
	Combined	Dom/Codom	Full	29.2	24.8	20.9	1.2	1.1	1.1	1.5	0.6	0.5	1.0
	Combined	Inter/Supp		14.5	2.8	2.3	2.7	2.7	2.0	1.5	1.5	0.6	1.8
	SB, NSB and Crown Positions Combined			**24.5**	**27.6**	**23.2**	**1.4**	**1.3**	**1.2**	**1.5**	**0.6**	**0.6**	**1.1**

State/ Province	Management Category	Crown Position	(A) Stocking Level	(B) dbh (cm) All trees ($\bar{x}$)	(C) Basal Area in 1988 (m²/ha)		(D) Annual natural mortality (% of sugar maple basal area)						
					All Trees	Sugar Maple	1989	1990	1991	1992	1993	1994	$\bar{x}$
VT	SB	Dom/Codom	Full	35.9	24.8	23.1	0.5	0.1	0.9	0.5	0.8	1.0	0.6
	SB	Inter/Supp		16.7	3.1	2.4	1.1	0.8	2.8	3.5	1.1	2.0	1.9
	SB	Crown Positions Combined		28.7	27.9	25.5	0.5	0.2	1.0	0.8	0.8	1.1	0.7
	NSB	Dom/Codom	Over	30.3	23.8	17.9	0.9	0.2	0.8	0.5	1.5	0.4	0.7
	NSB	Inter/Supp		15.6	3.6	3.0	3.3	1.6	2.2	3.0	0.3	0.5	1.8
	NSB	Crown Positions Combined		24.9	27.4	20.8	1.3	0.4	1.0	0.9	1.3	0.4	0.9
	Combined	Dom/Codom	Full	32.6	24.3	20.5	0.7	0.1	0.8	0.5	1.1	0.7	0.7
	Combined	Inter/Supp		16.1	3.3	2.7	2.3	1.2	2.5	3.3	0.7	1.2	1.9
	SB, NSB and Crown Positions Combined			**26.5**	**27.6**	**23.2**	**0.9**	**0.3**	**1.0**	**0.8**	**1.0**	**0.8**	**0.8**
WI	SB	Dom/Codom	Full	28.3	21.6	12.8	0.4	0.0	0.6	0.3	0.4	0.0	0.3
	SB	Inter/Supp		14.5	2.7	1.8	1.5	1.7	0.2	0.8	0.6	1.0	1.0
	SB	Crown Positions Combined		23.5	24.3	14.6	0.6	0.2	0.6	0.3	0.4	0.1	0.4
	NSB	Dom/Codom	Full	22.5	21.8	7.7	1.2	0.0	0.8	0.0	0.0	0.0	0.3
	NSB	Inter/Supp		14.0	3.7	2.0	0.0	1.1	0.9	0.0	0.5	1.0	0.6
	NSB	Crown Positions Combined		19.8	25.4	9.7	1.0	0.2	0.8	0.0	0.1	0.2	0.4
	Combined	Dom/Codom	Full	24.7	21.7	10.3	0.7	0.0	0.7	0.2	0.2	0.0	0.3
	Combined	Inter/Supp		14.2	3.2	1.9	0.7	1.4	0.6	0.4	0.6	1.0	0.8
	SB, NSB and Crown Positions Combined			**21.3**	**24.9**	**12.2**	**0.7**	**0.2**	**0.7**	**0.2**	**0.3**	**0.2**	**0.4**

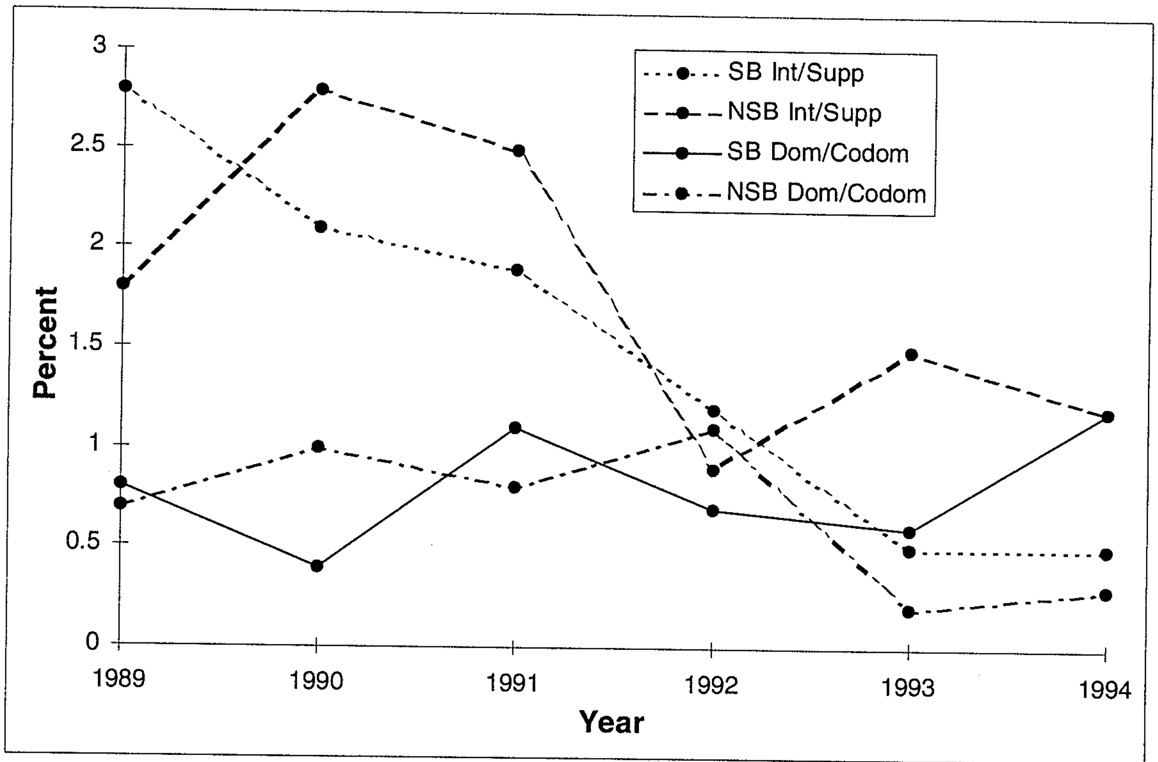


Figure 22. *Annual natural mortality (% basal area) of upper (dominant/codominant) and lower (intermediate/suppressed) canopy sugar maples by stand management class (sugarbush, non-sugarbush), 1989-1994. Includes only trees established in Canadian regions in 1988.*

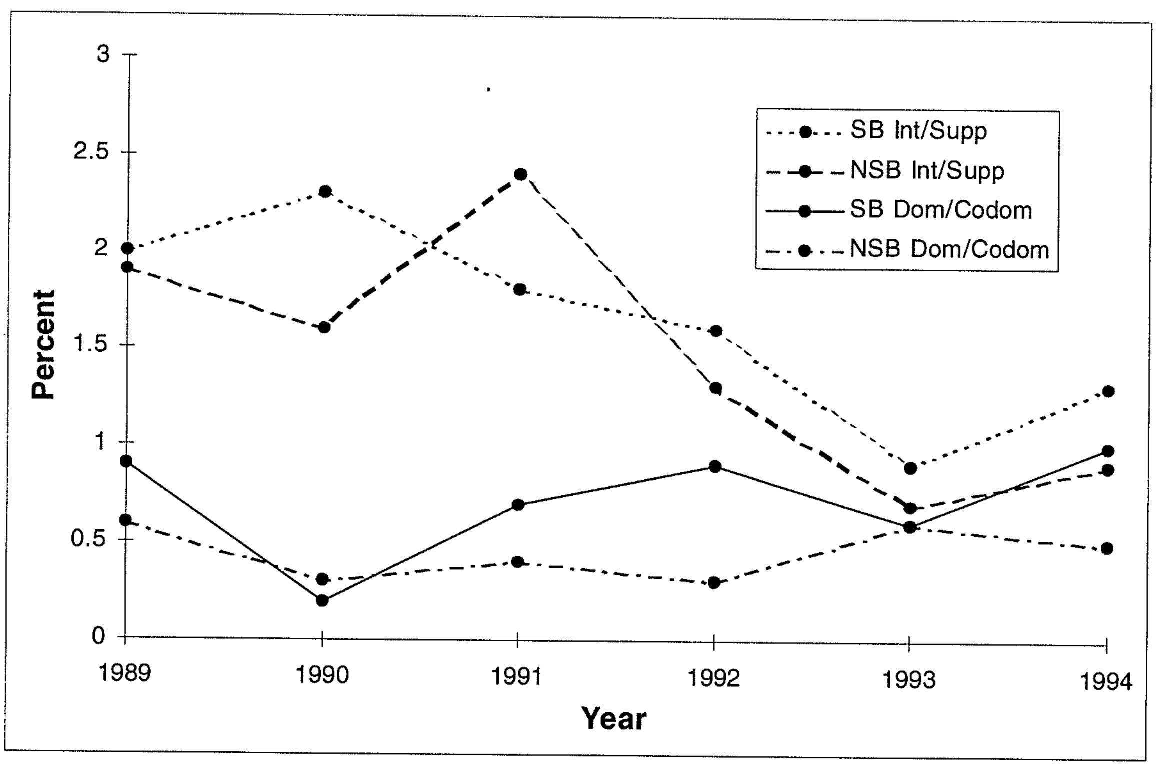


Figure 23. *Annual natural mortality (% basal area) of upper (dominant/codominant) and lower (intermediate/suppressed) canopy sugar maples by stand management class (sugarbush, non-sugarbush), 1989-1994. Includes only trees established in U.S. regions in 1988.*

Conclusions

- ❑ More than 95% of sugar maple crown dieback remeasurements and more than 90% of crown transparency remeasurements meet data quality standards every year.
- ❑ An external project review of NAMP was very complimentary overall and identified a number of items that could improve management, data collection or data analyses.
- ❑ Average crown dieback and transparency of sugar maple improved after 1988 and has remained consistent (within same rating class) since then.
- ❑ Drought in 1988 significantly increased crown transparency for two years, after which transparency stabilized at acceptable levels.
- ❑ Significant but temporary (1-2 yrs.) increases in crown transparency are attributed to pear thrips damage and forest tent caterpillar defoliation.
- ❑ In general, the condition of sugar maple in sugarbushes and non-sugarbush stands is similar.
- ❑ Sugar maple under both management regimes responded similarly to stress.
- ❑ Overall, sugar maples with more than 40% crown dieback in 1988 had a 1 in 3 chance of surviving seven years.
- ❑ High crown dieback (>50%) is associated with bole and/or root damage.
- ❑ Sugar maples in NAMP plot-clusters exposed to High levels of both wet sulfate (>27.6 kg/ha/yr) and wet nitrate (>20 kg/ha/yr) deposition had significantly higher mean crown transparencies than trees exposed to Medium or Low levels of deposition.
- ❑ Annual mortality of sugar maple occurred at levels and followed a pattern similar to that reported for normal tree mortality in other studies.

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