The Health of Vermont's Hardwood Resource: 1985 to 2001

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ABSTRACT

A statewide hardwood tree health survey was conducted in 2000-2001, using both aerial photos and ground evaluations. This was the fourth cycle of a 5-year periodic survey initiated in 1985-86. This survey shows that overall, Vermont's hardwood forests remain in good condition. The health of the state's hardwood resource has remained relatively stable since the last survey in 1995-96, after a dramatic improvement between 1985 and 1991 and continued improvement between 1991 and 1996. Three million acres of hardwoods were estimated to occur statewide by interpretation of photography taken in 2000 and 2001. One thousand acres were estimated to have moderate mortality (10-30% of upper canopy trees dead). This equals the 1995 estimate and is an improvement over the 4000 acres of moderate mortality interpreted from 1990 photography. In 1985, there were 13,000 acres of moderate mortality and 500 acres of heavy mortality (>30% of upper canopy trees dead). Nearly 91 percent of the dominant/codominant trees remain healthy, with little change since 1996. However, within the healthy class, there were fewer trees with 0-5% dieback and more trees with 10% dieback than in 1996. Crown transparency was generally higher than normal, as well. This probably reflects recent drought conditions and could mean greater dieback in future years. Annual tree mortality increased from 0.8 percent in 1996 to 1.4 percent in 2001, probably as a result of the 1998 ice storm.

The presence of exotic invasive plants was recorded for the first time during this survey. Nearly 19 percent of the sites contained invasive plants, with buckthorn and honeysuckle being the most common. There appears to be a stronger relationship between decreasing stand density and increasing exotic plant density for honeysuckle than for buckthorn.

INTRODUCTION

In 2000 and 2001, the Vermont Department of Forests, Parks and Recreation conducted a survey to determine the current health of Vermont's hardwood forests. This was the fourth such survey in the past sixteen years. All four surveys used were based on interpretation of aerial photographs, followed by ground evaluations, and were a cooperative effort with the U.S.D.A. Forest Service Forest Health Technology Enterprise Team (formerly Forest Pest Management Methods Application Group) in Fort Collins, Colorado, and Forest Health Protection Staff in Durham, New Hampshire.

The specific objectives of each survey were:

Using aerial Photography

- Determine average number of dead and declining hardwood trees per acre.
- Determine the area of hardwood decline and mortality by mortality class.

From ground plots

- Provide data on tree mortality, crown condition, site and stand factors to be used to determine trends in tree condition over time.

The initial survey in 1985-86 established the database for future monitoring of tree condition and the effects of various stresses on all species of trees in Vermont hardwood stands (Kelley and Eav 1987).

This initial survey followed a period between 1977 and 1982 when over one-fourth of Vermont's northern hardwoods (about 498,000 acres) were defoliated at least once by the forest tent caterpillar (*Malacosoma disstria*). This resulted in 33,000 acres of tree crown dieback and tree mortality. Thousands of additional acres had been defoliated by outbreaks of gypsy moth (*Lymantria dispar*), maple leaf cutter (*Paraclemensa acerifoliella*), and saddled prominent (*Heterocampa quttivata*), as well as by late-spring frosts in 1980 (Table 1, Figure 1).

Additional stress factors during this period included below average precipitation and a cold winter with little snow cover in 1980-81. This abundance of natural stress factors occurred when there was much public concern about the impacts of pollutants on tree health.

The first two repetitions of this survey showed improvements in tree condition (Kelley, Smith and Cox 1992; Kelley, Smith, Cox and Frament 1997). Some of the ground evaluation procedures were refined in 1991 to correspond with national monitoring standards that had been developed since 1986.

Since the last survey in 1996, abiotic events have had the greatest impact on forest condition. An unusually severe ice storm struck northern New England, northern New York and southeastern Canada during the second week of January, 1998. Damage in Vermont occurred in every county and was mapped on 951,589 acres or about one-fifth of the forest land in the state. A regional damage survey found that about 17 % of trees over 5" dbh in the affected area of Vermont had crown losses of more than 50% (Miller-Weeks and Eager 1999). Drought conditions in 1999, 2001 and 2002 further stressed trees.

METHODS

SURVEY DESIGN

A two-stage sampling design was used for the initial 1985-86 survey and the subsequent resurveys in 1990-91, 1995-96 and 2001-02. First, aerial photos representing approximately 1% of Vermont's forested area were used to get a broad view of tree dieback and mortality and to serve as a basis for selection of ground plots. Then the ground survey was used to take a closer look at the extent of dieback and mortality. Ground plots were selected based on photo interpretation results for 1985. Those photo cells with the heaviest mortality were most likely to receive ground plots. These same ground plots were remeasured every 5 years. The average numbers and volumes of trees in each of the crown condition classes computed from ground data were expanded into estimates of totals and per-acre means for the entire state.

Table 1. Five major insects and three abiotic agents responsible for defoliation or other damage to hardwood forests in Vermont from 1976 to 2001.[1]

Agent[2]	Year(s)	Primary Hosts	Acres Mapped[3]	Remarks
Gypsy Moth (GM)	1976-82 1989-91	Oaks Oaks	179,800 86,000	Mortality observed acres not mapped No mortality observed
Forest Tent Caterpillar (FTC)	1976-82	Sugar Maple White ash	650,000	33,500 acres of mod-heavy mortality mapped
Saddled Prominent (SP)	1979-81	Sugar Maple	102,700	2,300 acres of mod-heavy mortality mapped
Maple Leaf Cutter (MLC)	1972-83	Sugar Maple	286,700	Dieback but not mortality observed
Pear Thrips (PT)	1987-93	Sugar Maple	607,000	Dieback but no mortality observed
Frost (FR)	1980	Sugar Maple Other hardwoods	124,500	Heavy localized mortality, particularly in areas infested by forest tent caterpillars
Ice Storm	1998	All species	951,600	The most devastating such storm on record. 17% of trees in damaged areas with more than 50% crown loss.
Drought	1999 2001	All Hardwoods All Hardwoods	84,700 170,400	No defoliation observed. Caused defoliation in August on dry sites. Acres actually defoliated unknown. A small amount of mortality to date. Total impact not yet known.

[1]From NOAA records from the Northeast Regional Climate Center, Cornell University, Cornell, NY.

[2]From Forest insect and disease conditions in Vermont, annual reports from 1970 to 2001. Vermont Department of Forests, Parks and Recreation, Waterbury, VT.

[3]Total cumulative acres of defoliation mapped during annual aerial surveys. Mod-heavy mortality = more than 10% of upper canopy trees dead.

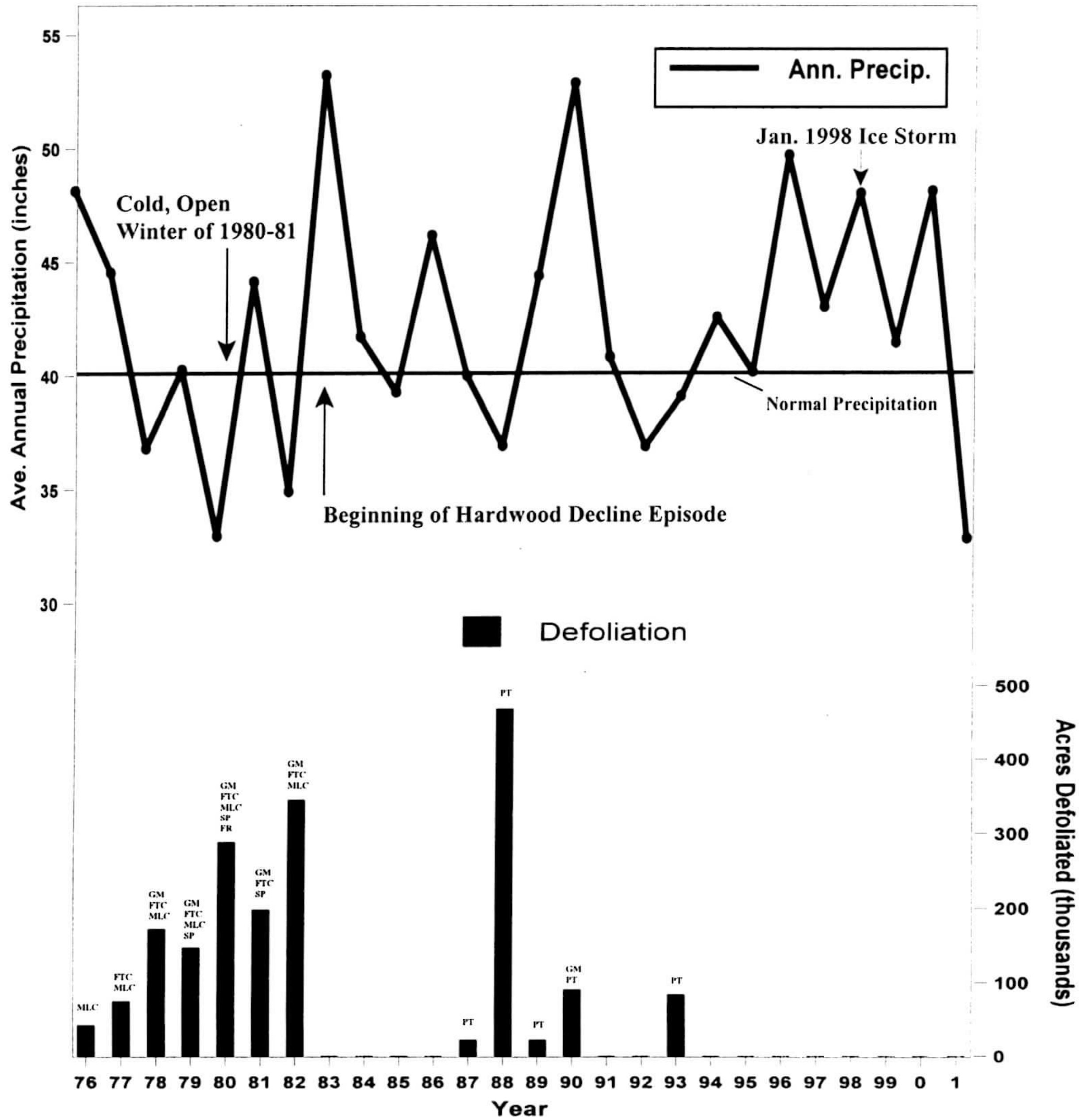


Figure 1. Defoliation of Vermont hardwood forests from 1970 to 2001 in relation to precipitation and other abiotic stressors. Defoliator abbreviations (MLC, FTC, etc.) refer to insects in Table 1.

METHODS

AERIAL PHOTOGRAPHY

Color infrared aerial photographs of 360-acre blocks at a nominal scale of 1:8000 were obtained in late August to mid September 1985, August of 1990, and late July to early August 1995. In 2000, cloud cover was so pervasive during the acquisition flights in late July and August that 62 of the photo points had to be taken in late July, 2001. One hundred seventy photo points were systematically established over the entire state in 1985 on flight lines 7.4 miles apart at 7.4 mile intervals (Figure 2). Five consecutive 9" x 9" transparencies with 70% forward overlap were taken at each point by a Zeiss RMK 21/23, large format aerial camera. Kodak Aerochrome color infrared film (type 2443) was used in combination with a Wratten 12 (minus blue) filter. The first flight line and first photo on each flight line in 1985 was based on a random start.

In 1990, a Loran C navigational system and color aerial prints of the 1985 blocks were used in the airplane to help locate the same points for new photography.

In 1995 and 2000 - 01, a Global Positioning System (GPS) navigational unit and color aerial prints of the 1985 blocks were used in photo acquisition. In addition, a video navigation camera and recorder were used to assist with navigation. The video footage was compared to color aerial prints after each flight to determine if the correct area was photographed. This allowed almost 100% of the original area from the 1985 survey to be re-photographed.

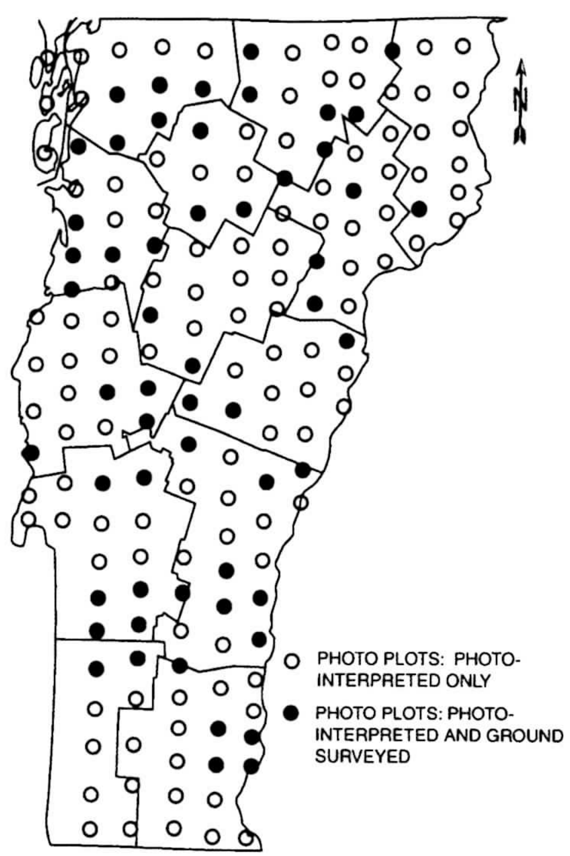


Figure 2. Sample point distribution.

PHOTO INTERPRETATION

For the original survey, completed in 1985, a 360-acre sample block, consisting of 144 2.5-acre cells on a 12 x 12 grid, was centered over the principle point of the center photograph of each flight strip. In subsequent surveys, whenever possible, the same area of land was used as in the 1985 survey. To accomplish this, the original 1985 sample block corners were transferred to the most recent photograph either visually or by using a stereoscope (Old Delft scanning stereoscope or Bausch & Lomb Zoom stereoscope). Two options were used for placing the grid onto the photograph. If all four corners were within one-quarter of a grid cell of fitting the sample block corners, a standard grid was used (1:7000 through 1:9000); if none of the standard grids fit, then one was made to fit all four corners. To make a grid, a clear photo sleeve was secured to the photograph using drafting tape. A pilot marking pen was used to draw outer grid lines con- necting all four corners. The distance was measured be- tween the corners and divided by 12 to determine spacing of the grid lines. These resulted in a grid that consisted of 144 2.5-acre cells. Cells that showed obvious damage due to the 1998 ice storm and all adjacent cells were rated for crown closure to the nearest 10 percent by comparing damaged cells with the same cells on 1995 photography.

Each 2.5-acre grid cell was examined in stereo and classified into one of the following vegetation types and hardwood mortality classes.

1. Vegetation Type

A. Hardwood - all cells where one-half or more of the cell area consists of forest cover and where 75 percent or more of the canopy is hardwoods.

B. Other Forest[1] - all forested cells where one-half or more of the cell does not meet the criteria. Include mixed wood and conifer forest in this class. Cells classified as "other" require no further classification.

C. Non-Forest - all cells where one-half of the cell is not forested. Include agricultural areas, lakes, ponds, urban areas, etc. Cells classified as "non-forest" require no further classification.

D. Cloud Cover - all cells where one-half or more of the cell is obscured by clouds and, therefore, cannot be accurately interpreted.

E. Inundated - all forested cells that would otherwise be classified as Hardwood, but one-half or more of the cell is obviously affected by standing water or poor drainage. No further classification is required.

2. Size Class

In 1985, stands were identified as either poletimber or sawtimber. This interpretation proved to be less repeatable than mortality class information. Stands were not separated by size class in future years and combining them simplified analysis and reporting.

3. Mortality Class[2]

Photo cells were examined under stereo and the number of recently dead hardwood trees counted (excluding snags[3]) to determine the following mortality classes:

Class 1 - no dead trees within the grid cell.

Class 2 - a single dead tree within the grid cell.

Class 3 - two to four dead trees within the grid cell.

Class 4 - five or more dead trees, but less than 10% dead trees within the grid cell.

Class 5 - from ten to thirty percent dead trees within the grid cell.

[1]In 1985, "Other Forest" and "Non-Forest" were combined into one category called "Other".
[2]In 1985, only one light class was used for cells where less than 10 % of the hardwood canopy trees were dead (classes 1 to 4). Class 5 was called moderate mortality.
[3]Snags - Dead trees with only a main stem or 1 - 2 lateral branches remaining.

GROUND SURVEY

A ground survey was conducted in the year following each aerial survey to take a closer look at the extent of dieback and mortality. Ground plot locations were selected to represent heavy, moderate and light mortality areas identified by 1985 photo interpretation. Based on the 1985 photos, all of the heavy mortality cells, 50 percent of the moderate mortality cells, and 5 percent of the light mortality cells were randomly selected for ground survey. This resulted in 2, 22, and 51 cells, respectively, for a total of 75 cells. Thirteen additional cells for ground plots were added in 1991. By 2001, 7 cells had been lost due to harvesting or restrictions due to ownership changes so that in 2001, 68 cells were common to all four survey periods and 81 cells were common to 1991, 1996 and 2001. All tables and graphs comparing the 4 survey periods are based on data from 68 cells, while those comparing 2001 to 1991 and 1996 are based on data from 81 cells. Five 10-factor prism points were established in each 2.5 acre cell, and site and tree data were collected in 1986 and again from the same points in 1991, 1996 and 2001.

Site Data

At each prism point, the following site data were taken: elevation, percent slope, aspect, stand geography (hillside, rolling, swamp, mountain top, plateau, cove, flat, bench), drainage (poor, well, excessive), crown closure (<25%, 25-74%, >75%), and evidence of logging activity (none, recent-slash present, recent-stumps only, old-stumps). Rock outcrops and roads were recorded as present or absent within each plot. Site information was collected from an area with a radius equal to the distance from the point to the bole of the furthest plot tree. (Plot survey data form, Appendix A-1)

Defoliation history since 1975, by insect or agent responsible, was determined for each cell from department aerial survey records. In each cell, two healthy hardwood plot trees in dominant or codominant canopy positions were cored and height measured with a clinometer to determine site index information. Regeneration data for trees less than one inch dbh were taken from five milacre plots at each prism point. In addition, plant species that are indicators of good, wet, or dry sites were recorded as present if within 20 feet of plot center for each prism point.

In 1986, soil depth was measured and soil samples were collected and analyzed for pH, nutrients and heavy metals. This was not repeated in 1991 or 1996. In 1998, 17 plots that fell within areas mapped as having been impacted by the ice storm were visited in early spring to collect damage information. Plots were rated the same as for the regional survey (Miller-Weeks and Eagar 1999). Since many of these plots had only very light damage, it was decided that only those plots that had two or more dominant/codominant trees with more than 25% crown loss would be visited for follow-up evaluations during the summer. Nine plots exceeded this threshhold, and ice storm impact data is based on these 9 plots. In 2001, the presence of any exotic invasive plants was recorded for each plot from a list of common species, by 5 broad density classes. (Appendix B)

Tree Data

In 1986 all trees greater than one inch diameter at breast height (dbh) that fell into each prism point were numbered with paint and tallied for tree data (point survey data form, Appendix A-2). Ingrowth trees were added in all subsequent surveys. All trees were scribed at dbh in 1996 to reduce the need for paint and improve the accuracy of dbh measurements. General tree data collected included information on: species, dbh to the nearest 0.1", crown class (dominant, codominant, intermediate, overtopped), sawlog height to the nearest eight feet, cordwood height to the nearest four feet, and crown condition. Tree heights were measured in 1986 and 1996 only, because change in volume of hardwoods due to increased height growth in 5 years was not expected to be very significant and any gain might be offset by variation in re-measurement estimates. Dead trees were recorded as recently dead (fine branches present), older dead (no fine branches, but two or more lateral branches present), snags (only the main stem and 1-2 lateral branches remaining) or dead and on the ground. Snags and trees on the ground were excluded from volume estimates.

Crown Condition Data

Crown condition evaluations included ratings for crown dieback, crown transparency, and crown symptoms and injuries. Dieback was based on visual estimates of the portion of tree crowns represented by twigs and branches that had recently died from the tips back. Beginning In 1991, 5 percent crown dieback categories were used to coincide with national standards developed by the National Forest Health Monitoring Program. These were combined into broader categories during analysis to compare with the following 1986 categories: All crown condition estimates were made by two observers on opposite sides of each tree.

Quality control assurance was obtained by remeasuring 6.6% of the ground points by different observers to assess crown dieback and transparency measurement repeatability.

Crown transparency ratings were taken for the first time in 1991 to correspond with national standards. Transparency reflects foliage size and abundance for the current year. It is a measure of the amount of skylight visible through the foliated portion of the crown and was estimated in the same 5% classes as used for dieback ratings.

Crown vigor ratings were added in 1996, following the procedures used for North American Maple Project plots (Cooke, Barnett and Allen 2001). These ratings include an estimate of the amount of crown area missing.

Crown Dieback Ratings	Crown Dieback (Percent)	
	1986	1991 - 2001
Healthy	0	0
	1-10	1-5, 6-10
Moderate Dieback	11-25	11-15, 16-20, 21-25
	26-50	26-30, 31-35, 36-40,41-45, 46-50
Heavy Dieback	51-75	51-55, 56-60, 61-65, 66-70, 71-75
	76-99	76-80, 81-85, 86-90, 91-95, 96-99

DATA ANALYSIS

Simple random sampling formulas were used to estimate the area in each vegetation/mortality class and the standard error of each estimate (Cochran 1977). It was assumed that there is no definite pattern in the unit values of acreages of each class in the population.

To compute estimates of the number and volume of trees in each crown condition class, the mean values and variances of the means were computed from ground cell means for each vegetation/mortality class in the hardwood type. The estimates of total values for each class is the product of the estimates of the mean values with the estimates of acreage for the class. The formula for computing standard errors of the estimates is given by Freese (1962).

The combined statewide estimates were computed by the stratified random sampling (with relative stratum size) approximation formulae (Freese 1962). Per-acre averages are weighted averages based on acres in the three mortality classes.

Crown condition classes for individual tree species were combined into generic groups for oaks, spruce, and pines, although the predominant species within each group were northern red oak, red spruce, and white pine, respectively.

Snags were excluded from data analysis. All 2001 volume calculations were based on 1996 tree heights.

When diameters of dead trees were not collected, the most recent previous diameter was used for calculations of dead trees per acre and dead tree volume per acre.

Board-foot unit and cordwood volumes were computed from International one-quarter inch rule formulas by Gevorkiantz (Beers and Miller 1966). Cubic-foot volume was computed from the cordwood formula modified to include tops to a two-inch branch diameter. Moderate and heavy photo interpretation mortality classes were combined during data analysis because of little heavy mortality in 1986 and none since 1991. Data for 1991, 1996 and 2000-01 were recalculated to reflect this combining of the two size classes and to adjust for the loss of several ground cells.

PHOTO INTERPRETATION RESULTS AND DISCUSSION

HARDWOOD AREA

The total hardwood forest area estimated from the 200-01 photographs was 3.04 million acres. This compares to 3.20 million acres in 1995, 2.69 million acres in 1990 and 2.51 million acres in 1985.

The 1995 value was considered an overestimate of actual area due to some problems with photo interpretation. The current estimate is considered to be the more accurate one.

AREA OF MORTALITY

The statewide area of moderate or heavy tree mortality based on interpretation of aerial photographs decreased from nearly 14,000 acres in 1985 to 4,000 acres in 1990 and 1,000 acres in 1995 and 2000-2001 (Table 2).

ICE STORM DAMAGE

Only 4 of 170 or 2.3 percent of the aerial photographs showed noticeable damage attributed to the 1998 ice storm. The cells classified as damaged represent 26,400 acres on a statewide basis. This is less than 1 percent of the statewide hardwood area but it must be remembered that photography was three growing seasons after the storm event so damage was difficult to detect. Average crown loss for the damaged areas averaged about 14 percent and was greatest for forests that had the highest amount of crown closure before the storm.

Table 2. Area of hardwood mortality in Vermont in 1985, 1990, 1995 and 2000-2001 estimated by photo interpretation.

(Thousands of Acres)

Mortality Class*	1985		1990		1995		2000-2001	
	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Light 1			1493	90	2431	115	2185	104
Light 2			665	40	547	33	597	43
Light 3			464	37	215	23	242	28
Light 4			67	14	16	4	14	5
Total Light	2,519	138	2,689	143	3,209	147	3,038	143
Moderate	13	4	4	2	1	1	1	1
Heavy	0.5	0.5	0	0	0	0	0	0

Mortality Classes

* Light 1 = 0 dead canopy trees/2.5 acres
Light 2 = 1 dead canopy tree/2.5 acres
Light 3 = 2-4 dead canopy trees/2.5 acres
Light 4 = 5 or more but <10% dead canopy trees/2.5 acres

Light category used in 1985 = 0-10% dead canopy trees/2.5 acres.
Moderate = 10 - 30% of hardwood canopy trees dead.
Heavy = >30% of canopy trees dead.

The number of dead upper canopy trees visible in aerial photographs within the light mortality classes changed little between 1996 and 2001.

The number of acres with 1 to 4 dead trees visible per acre increased slightly while the number of acres with 5 or more dead trees visible did not significantly change. (Table 2, Figure 3).

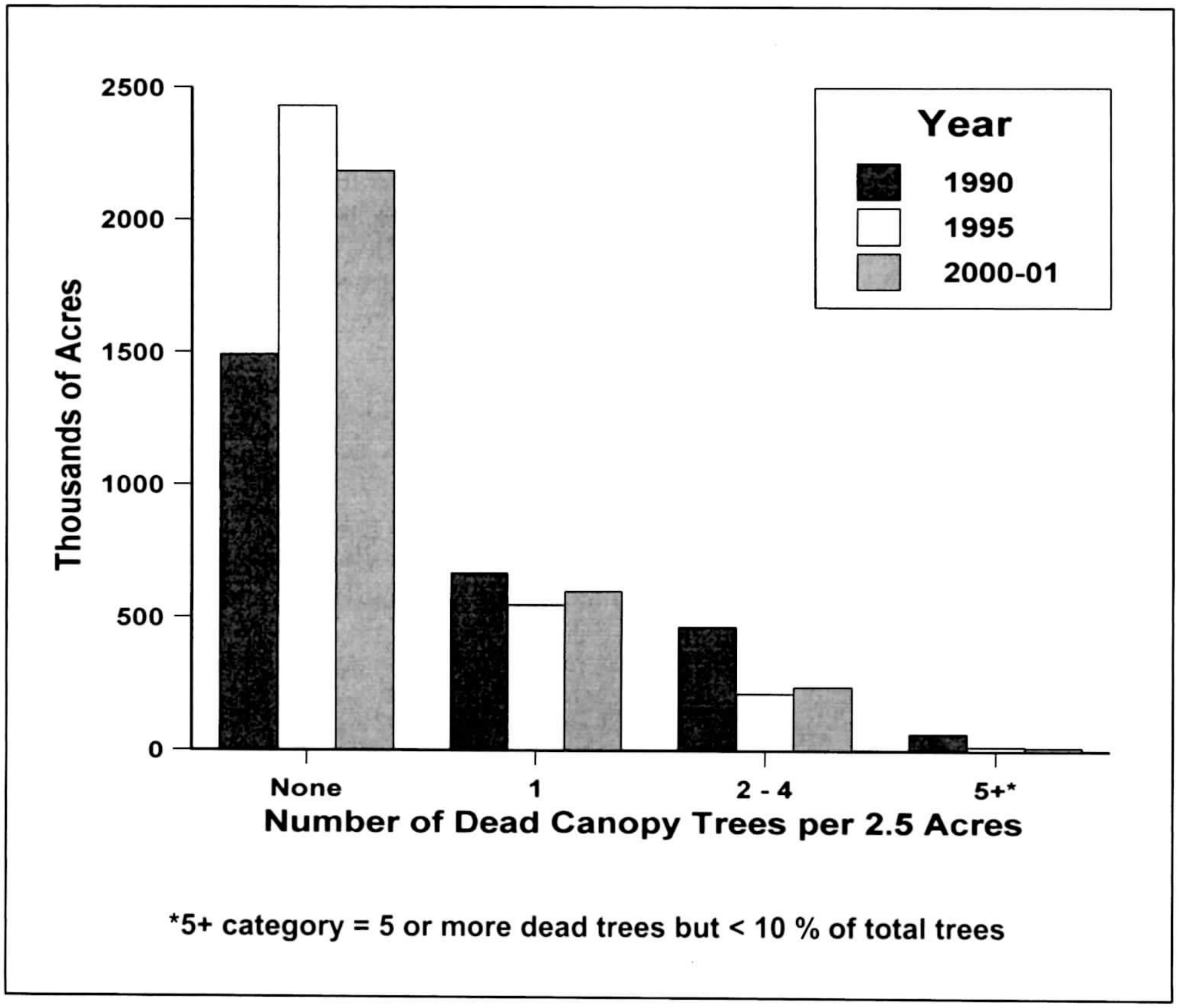


Figure 3. Statewide area of hardwoods estimated for the light mortality classes in 1990, 1995 and 2001-2002 based on counts of dead canopy trees visible on aerial photographs.

SPECIES COMPOSITION

Approximately 2,500 trees in dominant/codominant (upper canopy) crown positions were evaluated in 2001 (Appendix E). Sugar maple, red maple and yellow birch continue to be the most abundant species in upper canopy positions in the ground plots (Figure 4).

GENERAL TREE CONDITION

The percentage of trees in dominant or codominant crown positions rated as healthy, increased from 79.9 percent in 1986 to 90.5 percent in 1991 and has remained at 90-91 percent since then (Figure 5). Both hardwood and conifer trees within these predominately hardwood stands showed similar trends in crown condition improvements over the ten years (Table 3). The percentage of trees with moderate dieback dropped dramatically after 1986 and severe dieback has remained at less than one percent since 1996. Data based on number of trees per acre also shows fewer trees with moderate to severe dieback over time for both upper canopy trees and trees in all canopy positions (Appendix C, Figure C-1). Within the healthy class, there were fewer dominant/codominant trees with 0 to 5 percent dieback and more with 10 percent dieback than in 1996 (Appendix C, Figure C-2). This trend was not evident for all species but was very noticeable for red and sugar maple, the two most abundant species. This may be due to stress associated with the drought of 1999.

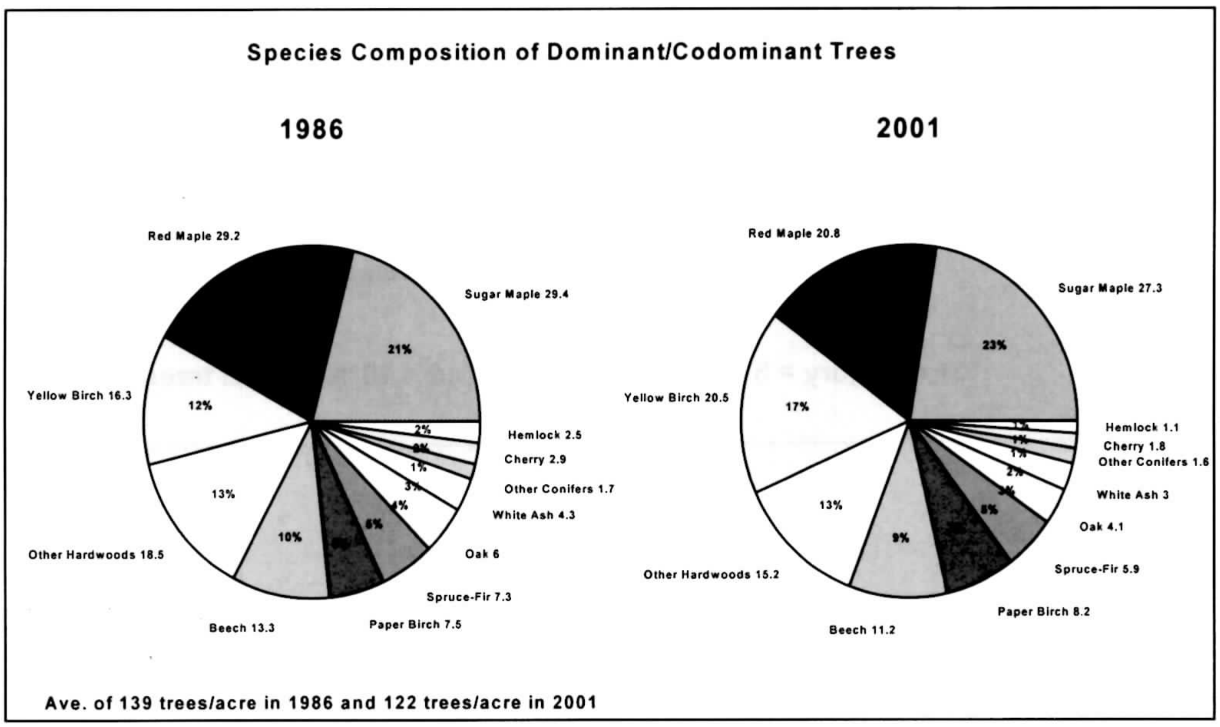


Figure 4. Average number of live upper canopy position (dominant/codominant) trees per acre and percent of total, by species. Data from ground plots evaluated in 1986 and 2001 (68 plots).

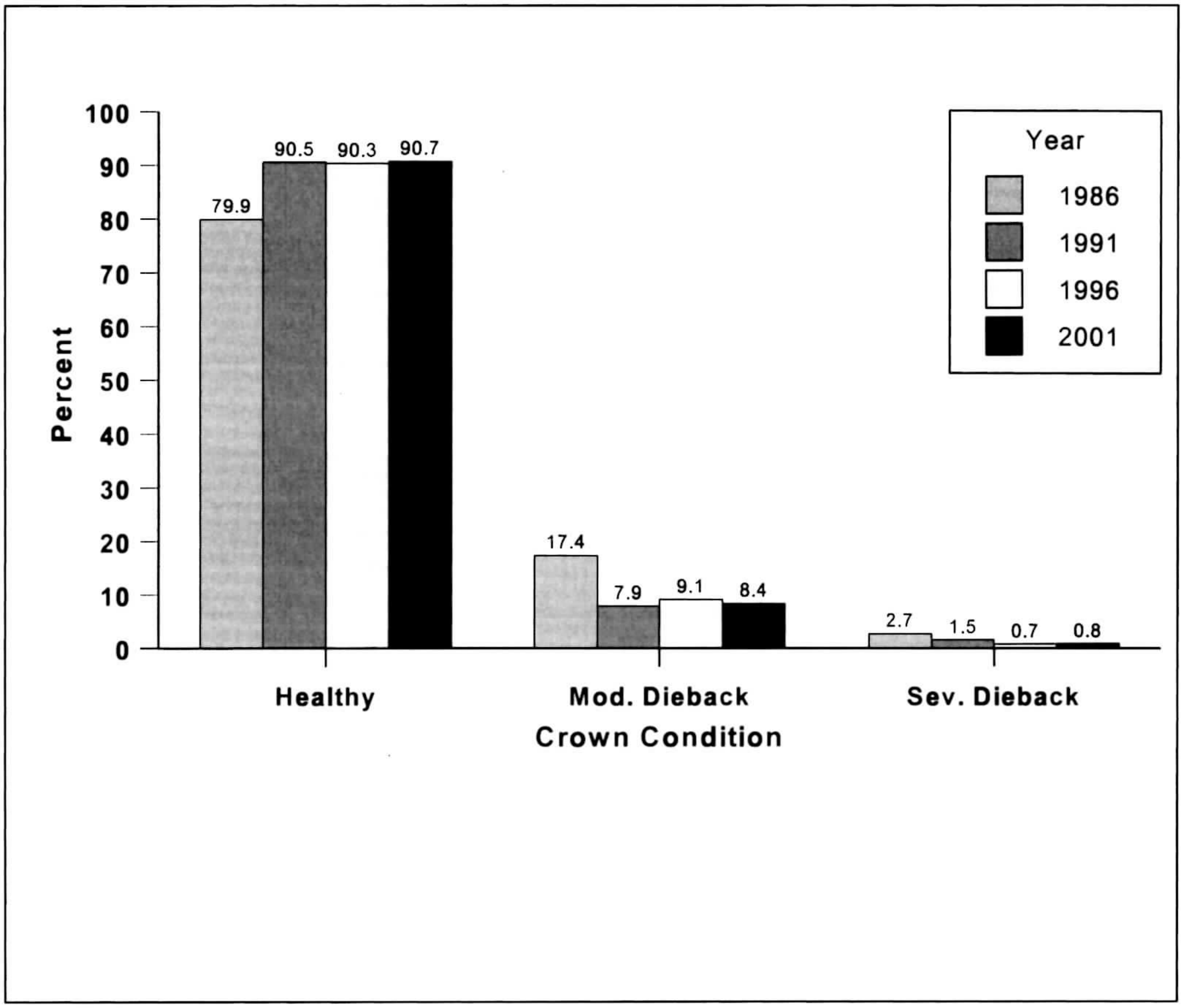


Figure 5. Crown dieback ratings of all live dominant/codominant trees in Vermont hardwood stands in 2001 compared to 1986, 1991 and 1996 (68 plots).

Table 3. Percentage of live dominant/codominant trees healthy, with moderate dieback, or with severe dieback, by tree species in Vermont hardwood stands, 1986, 1991, 1996 and 2001 (68 plots).

	Crown Condition Class [1]															
Species	Trees per Acre				Healthy				Moderate Dieback				Severe Dieback			
	.......Number......				- - - - - - - - Percent - - - - - - - -											
Hardwoods	**1986**	**1991**	**1996**	**2001**	**1986**	**1991**	**1996**	**2001**	**1986**	**1991**	**1996**	**2001**	**1986**	**1991**	**1996**	**2001**
Sugar Maple	29.4	27.3	27.0	27.3	81	93	88	92	15	6	11	8	4	1	1	0
Red Maple	29.2	26.5	21.1	20.8	79	91	87	90	19	7	12	10	2	2	1	0
Yellow Birch	16.3	11.6	10.8	20.5	73	87	92	96	13	13	7	4	14	0	1	0
American Beech	13.3	10.6	18.5	11.2	53	82	87	83	41	16	13	2	6	2	0	15
Paper Birch	7.5	9.3	9.3	8.2	94	96	95	88	5	4	4	8	2	0	1	4
Oak	6.0	5.4	5.3	4.1	81	88	90	82	18	12	10	18	1	0	0	0
White Ash	4.3	3.9	3.1	3.0	85	91	90	96	15	5	8	3	0	4	2	1
Black Cherry	2.9	2.9	2.5	1.8	84	79	78	63	11	21	16	37	5	0	6	0
Basswood	1.5	1.5	0.5	1.0	95	98	75	98	5	2	25	2	0	0	0	0
American Elm	0.6	0.2	0.2	0.2	76	100	100	100	23	0	0	0	1	0	0	0
Aspen	2.7	1.4	1.1	2.2	91	75	82	79	9	0	18	21	0	25	0	0
Hickory	1.0	1.3	0.6	1.7	100	100	100	100	0	0	0	0	0	0	0	0
Other Hardwoods	12.7	9.8	7.6	10.1	87	91	92	86	11	7	8	10	2	2	0	4
All Hardwoods	**127**	**113**	**108**	**112**	**79**	**91**	**90**	**90**	**18**	**7**	**9**	**9**	**3**	**2**	**1**	**1**
Conifers																
Spruce	3.6	3.3	2.8	2.2	79	84	90	90	20	15	10	10	1	1	0	0
Balsam Fir	3.7	4.2	2.4	3.7	99	100	97	100	1	0	3	0	0	0	0	0
Pine	1.4	1.1	1.3	1.2	98	95	100	100	2	5	0	0	0	0	0	0
Hemlock	2.5	2	2.7	1.1	96	99	93	98	4	1	7	2	0	0	0	0
Other Conifers	0.3	0.3	0.3	0.3	97	100	100	100	3	0	0	0	0	0	0	0
All Conifers	**11.4**	**10.9**	**9.5**	**8.4**	**92**	**94**	**94**	**97**	**3**	**6**	**6**	**3**	**5**	**0**	**0**	**0**
All Species	**139**	**129**	**117**	**122**	**80**	**90**	**90**	**91**	**15**	**8**	**9**	**8**	**5**	**2**	**1**	**1**

[1]Healthy = 0-10% crow n dieback; moderate dieback = 11-50% crown dieback; severe dieback = more than 50% crown dieback.

FATE OF TREES WITH DIEBACK IN 1986

The risk of death for trees with varying levels of crown dieback is of interest to those who must make forest management decisions on what trees to remove during thinning operations. Generally, trees with severe crown dieback (>50%) have been considered high risks. Just over half (53%) of the overstory trees with severe dieback in 1986 died within the first five years, but this increased to 69 percent after ten years and 74 percent after 15 years (Figure 6). Another 10 percent of them remained in the moderate to severe dieback categories, while 14 percent were rated as healthy by 2001.

In contrast, more than half (55%) of the overstory trees with moderate dieback (11-50%) in 1986 had healthy crowns fifteen years later (Figure 6). Another 13% still had moderate dieback, and only 1 percent had severe dieback.

Although most overstory trees with more than 50% crown dieback were more likely to die than to recover within the fifteen-year period, there were some species differences, especially for trees in the 26-50 percent category (Figure 7, Table 4). Sugar maple and beech with 26-50 percent crown dieback fared better than red maple and birch. Paper birch had the lowest ability to recover. Nearly all paper birch with over 25% dieback in 1986 were dead by 2001.

A somewhat lower crown dieback threshold for likeliness of death was reported for sugar maples in Vermont North American Maple Project plots (Allen et al. 1995). They reported that 58% of dominant/codominant sugar maples with more than 35% crown dieback in 1988, were dead in 1994.

ANNUAL LOSSES

The average annual mortality rate for this fifteen-year period was 1.4% for all dominant/ codominant trees and 1.0% for sugar maple (Table 4). This is an increase from 0.8% reported in 1996 but is within the range of 0.5% to 2.8% reported for USDA Forest Service inventory plots for all trees 5.0 inches dbh or larger in northeastern forests (Teck and Hilt 1990). Sugar maple mortality is not much higher than the 0.7% for dominant\codominant sugar maples in sugarbushes and forested stands reported by the North American Maple Project for the period of 1988 to 1994 (Allen et al. 1995). The 1998 ice storm contributed to this small increase in mortality. Only the yellow birch losses of 2.1% per year seem above average for this time period.. We speculate that much of this yellow birch decline was a result of the cold, snow-less winter of 1980-81 and its affect on the shallow birch roots, as reported in Quebec and elsewhere (Clark and Barter 1958, Pomerleau 1991). The surviving overstory yellow birch trees in our plots were healthier (96% healthy) than the average for all hardwood species (90% healthy) in 2001, reflecting that recent conditions have allowed yellow birch to recover (Table 3).

DEAD TREES BY 1985 PHOTO INTERPRETATION MORTALITY CLASSES

Within ground survey plots classified into light and moderate mortality classes by initial 1985 photo interpretation, number and volume of standing dead trees of all tree sizes (excluding snags) increased between 1986 and 1991 and then decreased (Table 5). Number and volume of dead dominant/codominant trees increased from 3.7 per acre (58 cu.ft.) in 1986 to 9.5 pe acre (109 cu. ft.) in 1991, then dropped to 7.4 per acre (98 cu. ft.) in 1996 and 5.0 trees per acre (66 cu. ft.) in 2001. Ground cells classified into moderate to heavy mortality classes by 1985 photo interpretation continue to have a greater than average number of dead upper canopy trees and dead tree volume. This peaked at 18.9 dead trees per acre in 1991, but then decreased to 12.4 trees in 2001.

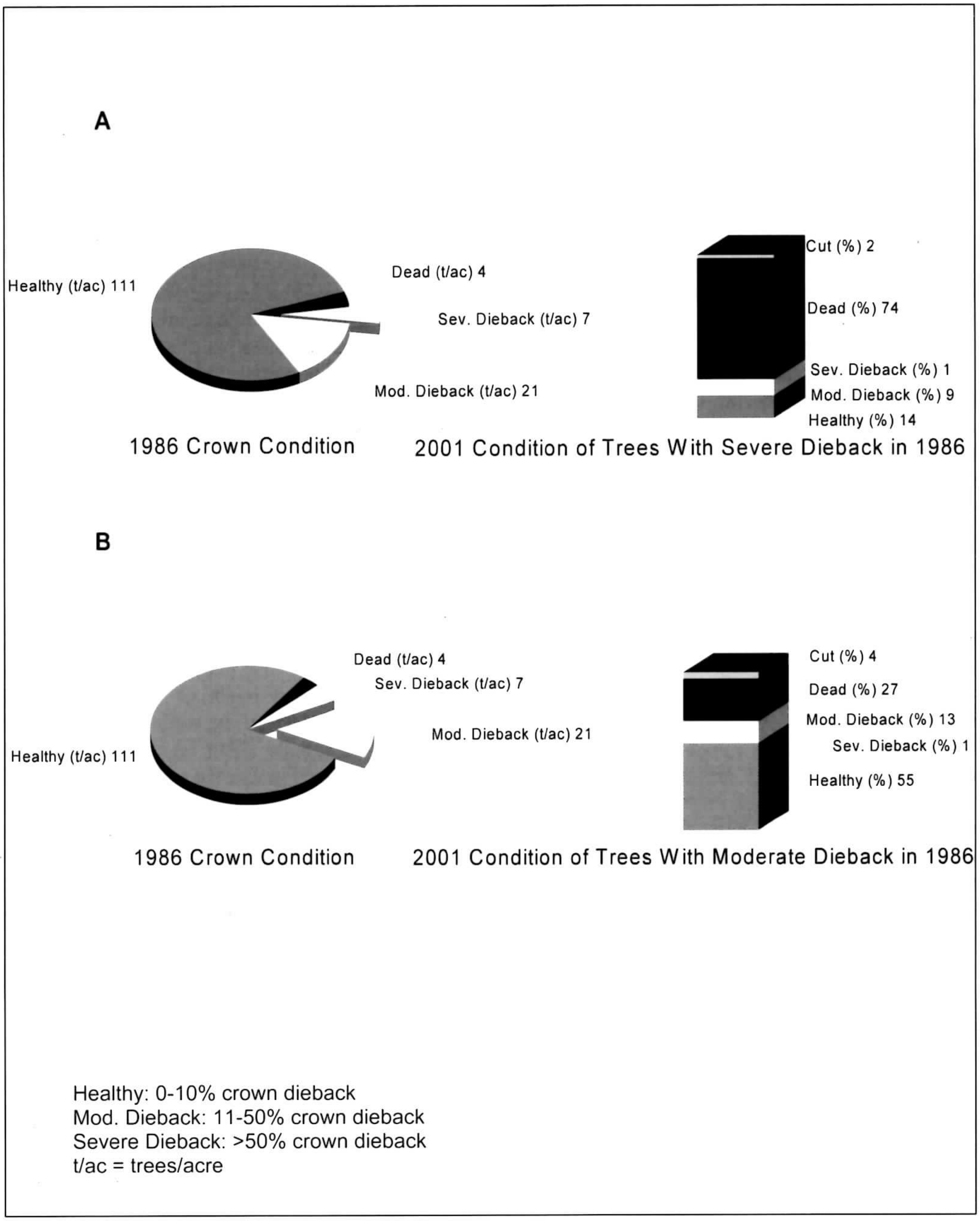


Figure 6. 2001 condition of all dominant/codominant trees with severe (A) or moderate (B) dieback in 1986 (68 plots).

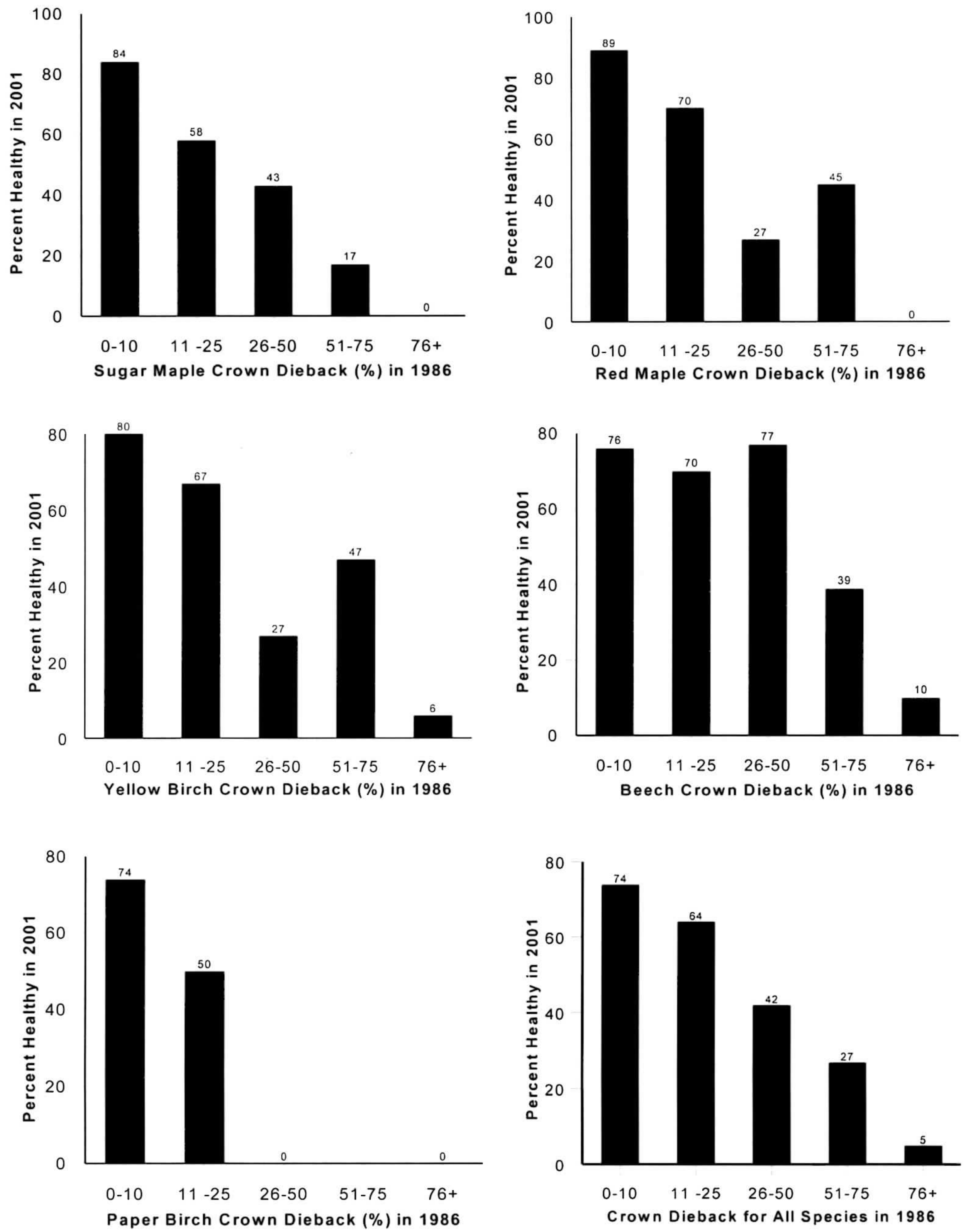


Figure 7. Recovery of several hardwood species and all species in hardwood stands, expressed as percent of dominant/codominant trees in various dieback classes in 1986 that were healthy (0-10% dieback) in 2001 (68 plots).

Table 4. Percent of dominant/codominant trees living in 1986 (by 1986 crown dieback classes) that were dead[1] in 2001, by species, in Vermont hardwood stands (68 plots).

Percent Crown Dieback in 1986 for Live Trees	Sugar Maple	Red Maple	Yellow Birch	Paper Birch	American Beech	All Species
	Percent of trees dead - 2001					
0-10	10	4	14	12	5	16
11-25	21	18	33	41	14	22
26-50	31	54	73	98	14	46
51-75	77	50	39	--[2]	56	56
76 +	95	100	94	100	77	91
All Dieback Classes	15	8	31	15	15	21
Annual Mortality	1.0	0.5	2.1	1.0	1.0	1.4

[1]Dead = all dead trees (including those on the ground) that were living in 1986, except harvested trees.
[2]No trees in this dieback class in 1986.

Table 5. Average number of trees per acre and volume per acre in 1986, 1991, 1996 and 2001 for standing dead trees (excluding snags) in ground plots based on the 1985 photo interpretation mortality classes in which the plots were located (68 plots).

Photo Interpretation Mortality Class	1986 # of Dead Trees/ Acre	1986 Cubic Feet[1] Dead/Acre	1991 # of Dead Trees/ Acre	1991 Cubic Feet[1] Dead/Acre	1996 # of Dead Trees/ Acre	1996 Cubic Feet[1] Dead/Acre	2001 # of Dead Trees/ Acre	2001 Cubic Feet[1] Dead/Acre
-- All Trees[2] --								
Light	22.89	161.65	58.25	342.17	50.09	294.91	33.73	210.96
Mod-Heavy	34.16	330.30	42.62	361.62	54.51	346.98	54.79	319.66
All	22.95	162.46	58.18	342.26	50.11	295.16	33.83	211.48
-- Dominant/Codominant Trees --								
Light	3.67	57.52	9.44	107.87	7.30	97.40	4.96	65.23
Mod-Heavy	12.61	211.46	18.91	239.57	17.45	178.17	12.44	128.83
All	3.71	58.26	9.48	108.50	7.35	97.79	5.00	65.53

1. Net volume of trees 4.0 inches dbh and greater.

2. 1.0 inches dbh and greater.

IMPACT OF THE 1998 ICE STORM

Nine of the plots (11%) were heavily damaged by the ice storm. In these plots, 5.5 dominant/codominant trees per acre and 52.4 trees per acre in all canopy positions had been killed when the plots were visited in the summer of 1998. Many of the dead trees were lower canopy beech trees in one severely damaged stand.

Trees with more than 50 percent crown loss due to ice storm breakage were considered high risk for recovery from the damage. About 15 percent of all the upper canopy position trees in the 9 plots fell into this category. The majority of these trees(70%) were rated as healthy in 2001, another 15 percent had moderate dieback and 15 percent were dead (Figure 8). There were some species differences. Of the three predominant species in upper canopy classes, paper birch had the poorest crown condition. Sixteen percent of these had died and the rest had moderate crown dieback. Black cherry was intermediate, with 46 percent of the trees healthy, 27 percent with moderate dieback and another 27 percent dead. Sugar maples in these damaged stands fared the best. Sixteen percent of these were dead, but all of the remaining live trees were rated as healthy.

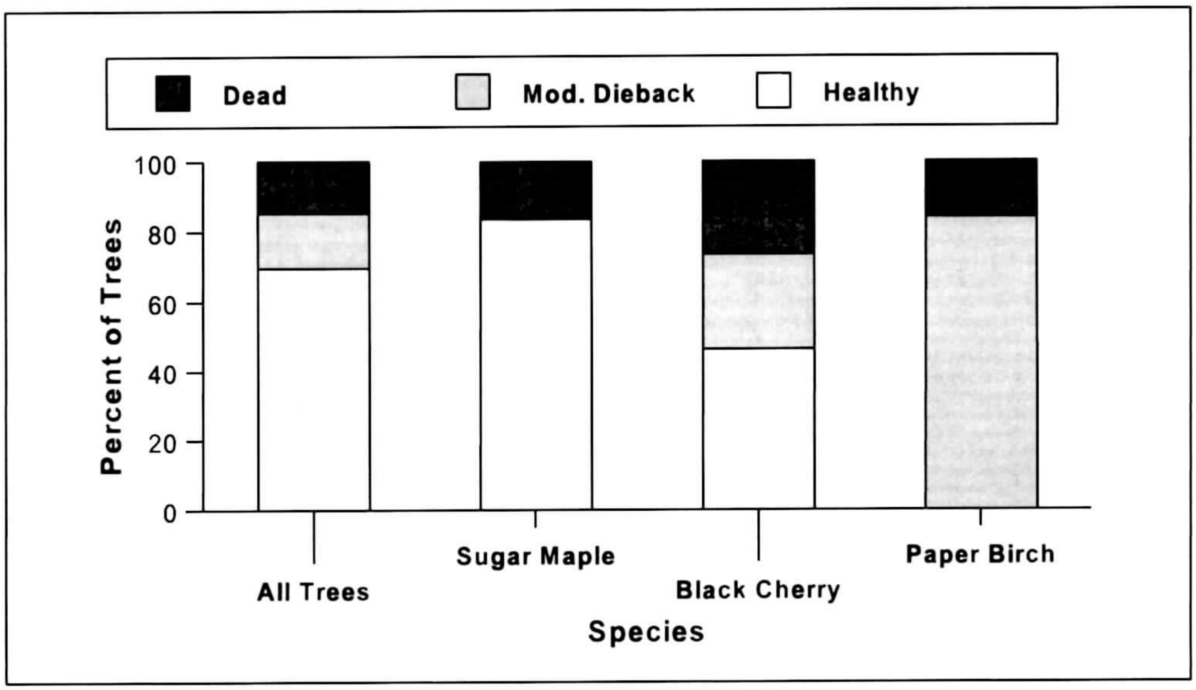
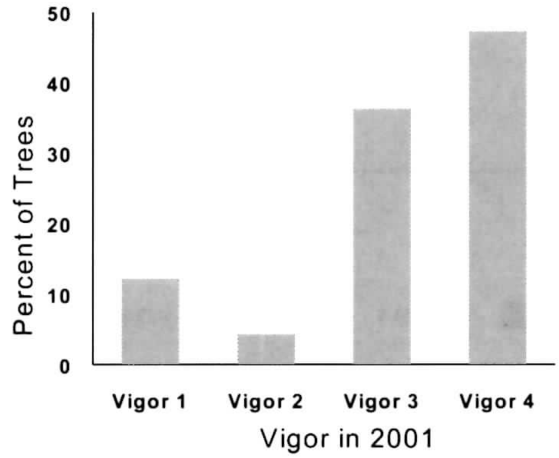


Figure 8. 2001 condition of dominant/codominant trees that were alive in 1998 but had more than 50 percent crown loss due to the January ice storm.

Trees rated as healthy may still have a lot of crown loss due to ice storm breakage, as it takes time to replace lost crown area. Since crown loss is evaluated in the vigor ratings, one way to follow this is to look at change in vigor. More than half of the dominant/codominant trees rated as vigor 4 (severe decline, more than 50% crown loss) in 1998 had improved by one or more vigor classes in 2001, while 47% remained vigor 4 (Figure 9).



Vigor 1: healthy, <10%of crown area missing, Vigor 2: light decline, 11-25% of crown area mising, Vigor 3: moderate decline, 26-50% of crown area missing, Vigor 4: severe decline, > 50% of crown area missing.

Figure 9. 2001 Vigor of dominant/codominant trees in ice storm damaged stands that were rated as vigor 4 (more than 50% of crown missing) in 1998.

TREE VOLUME

Sawtimber and cordwood volume has dropped slightly over the past 15 years (Appendix D). All stands had an estimated 3561 board feet per acre in 1986 and 3293 board feet per acre in 2001. Reductions are probably the result of harvesting in a number of plots as well as the impact of the 1998 ice storm.

Sawtimber volume in areas with moderate to heavy mortality in 1986 has remained at about half that of the volume in all stands. This probably reflects the initial tree mortality and site-related poor quality of trees. Even cordwood volume remains far below normal. However, cubic foot volume in these areas has increased to a level equal to that of all stands in 2001. This is probably due to an increase in regeneration on these sites.

TREE CONDITION BY SPECIES

Crown condition for most species of trees in Vermont hardwood stands stayed about the same or continued to improve between 1991 and 2001. While the percentage of living trees with healthy crowns varied widely by species in 1986, most species were close to the survey average of 90 percent healthy in 2001 (Figure 10). Yellow birch and beech showed the most improvement between 1991 and 2001. The small decrease in healthy beech, paper birch and possibly oak, between 1996 and 2001, probably reflect the impact of the 1998 ice storm. Beech has also been affected by a recent increase in the amount of beech bark disease, as detected by aerial survey in 2001.

Within the healthy crown dieback class, the maples had fewer trees with 0-5 percent dieback and more with 10 percent dieback. (Appendix C, Figure C-2). This may be due to recent drought conditions. Our 92 percent of overstory sugar maples healthy in 2001 is similar to the 93 percent for overstory sugar maples in Vermont North American Maple Project plots in 2001 (Teillon et al. 2001).

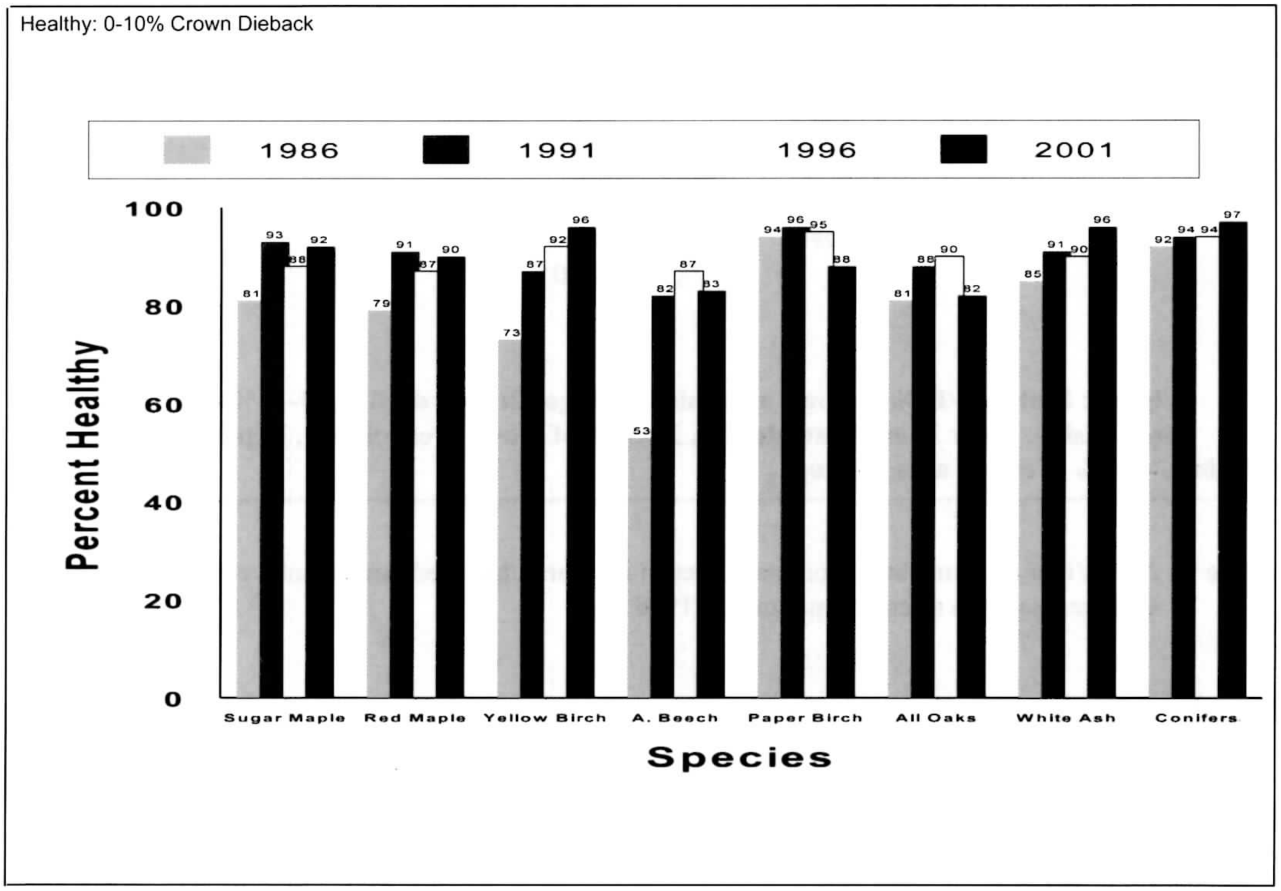


Figure 10. Percent of living dominant/codominant trees rated as healthy for predominant species in Vermont hardwood stands in 1986, 1991, 1996 and 2001 (68 plots).

CROWN TRANSPARENCY

Average crown transparencies were much higher (thinner crowns) than normal for most hardwood species in 2001 (Figure 11). 7.5 percent of all overstory trees had high transparency (>30%) in 2001 compared to a low of 1.6 percent in 1996 and 3.7 percent in 1991. This probably reflects stress due to the drought of 2001 when the crowns were evaluated. The threshold of up to 30 percent for normal transparency was chosen to agree with the National Forest Health Monitoring program. According to their summary for Vermont, four percent of the trees had high transparency in their plots in 1999 (Barnett 2002). Crown transparency does not have a direct affect on the level of dieback but appears to be an independent indicator of stress related to current growth conditions. It tends to fluctuate annually in response to recent environmental conditions or the presence of stressors such as defoliating insects. Trees with high transparency may exhibit higher dieback in future years depending on the level of stress associated with recent drought, as well as future conditions.

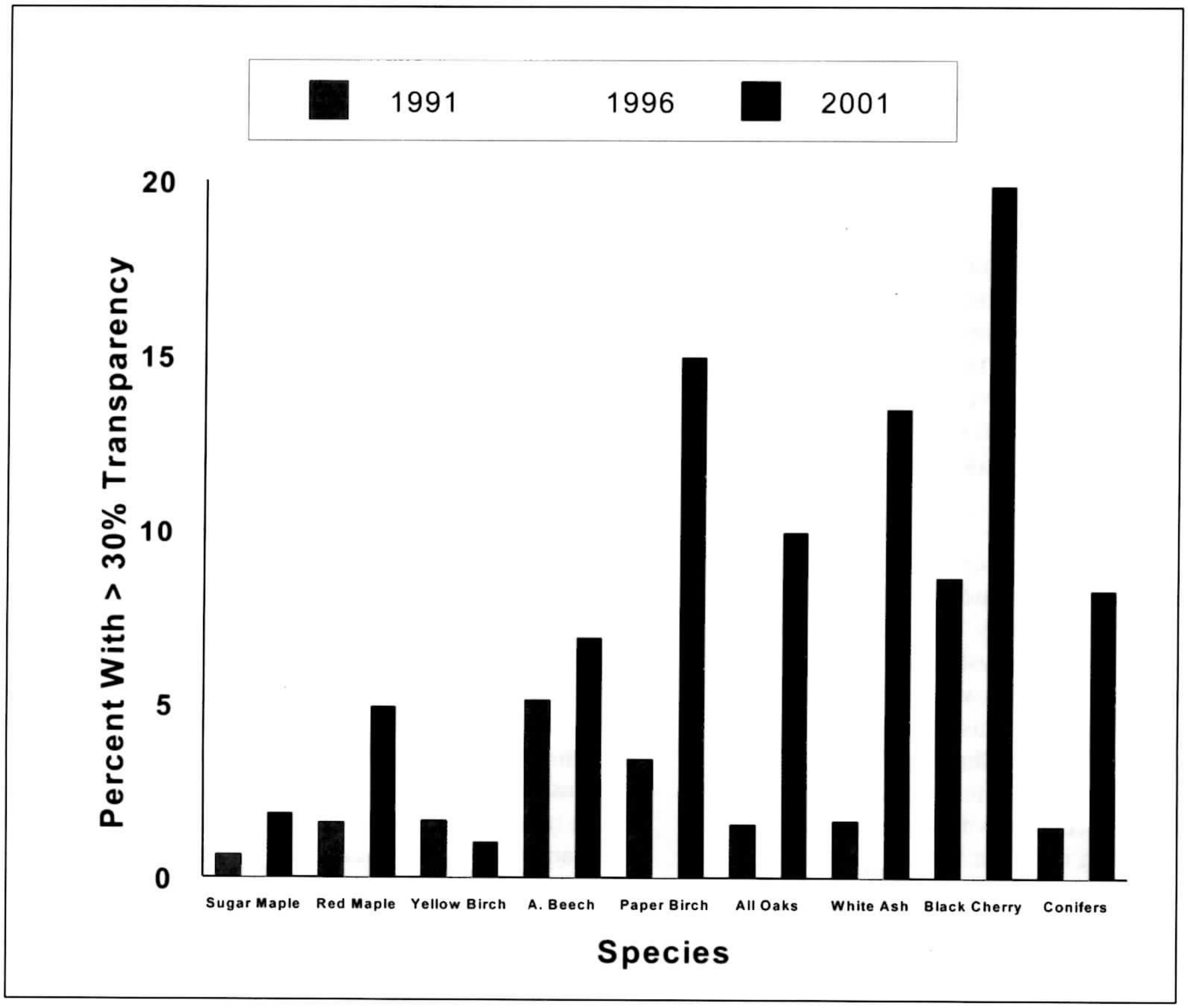


Figure 11. Percent of dominant/codominant trees with high (over 30%) transparency ratings in Vermont hardwood stands in 2001 compared to 1996 and 1991 (81 plots).

The "normal" transparency range can vary between species. Sugar maple tends to have a normal transparency rating that is lower (less light visible through the crown) than for most other hardwoods. The North American Maple Project considers high transparency for sugar maple to be any rating over 20% (Allen et al. 1995). They found that in 1994, 5% of overstory sugar maples in Vermont sugarbushes and 6% in all project area sugarbushes had over 20% transparency. Sugar maples in this survey had much higher transparency in 2001, with 12.8% of the overstory trees exceeding the 20% threshold. Allen, et al. (1995) found some positive correlations between transparency in year one and dieback in year two, but the correlation between crown dieback and transparency was a weak one.

EXOTIC INVASIVE PLANTS

Exotic plants, mostly shrubs, were reported present in 15 of 81 cells, or 18.5 percent of the sites. Buckthorn and honeysuckle were the exotic plants most often reported as frequent or dense within plots (Figure 12). Other plants encountered were barberry, Japanese knotweed, garlic mustard and giant reed. Exotic plants were most commonly reported from Chittenden County, followed by Franklin, Windham, Addison and Windsor counties.

As might be expected, density of buckthorn and honeysuckle increased with decreasing stand density but the relationship was strongest for honeysuckle (Table 6). In plots where honeysuckle was dense throughout, the average basal area was 36 square feet. This was significantly lower than the 83 square feet of basal area for plots where this invasive plant was listed as frequent, with dense areas of the plants occurring in only a few locations.

QUALITY ASSURANCE AND CONTROL

Remeasurement of randomly selected points (6.6% of original points) by different crews to determine repeatability in crown dieback and transparency ratings indicated that data quality was acceptable. These results are similar to those in 1991 and 1996, as well as those from other forest health monitoring programs (North American Sugar Maple Decline Project and National Forest Health Monitoring Program). Ninety-six percent of the crown dieback remeasurements and 92% of the crown transparency remeasurements fell within two classes (+ 10%) of the original measurements. Vigor rating remeasurements were within one class on more than 97% of the trees.

POSSIBLE REASONS FOR IMPROVED TREE CONDITION

Improvements in crown condition may be related to more favorable weather conditions between 1986 and 2001 and less insect damage compared to the 10 years preceding 1986.

Most dieback recorded in 1986 was probably initiated between 1978 and 1982, when growing season temperatures were generally above average and annual precipitation was below average in Vermont (Ludlum 1985). This included a cold, snow-less winter in 1980-81 which may have affected shallow-rooted trees such as yellow birch (Clark and Barter 1958, Pomerleau 1991). In contrast, precipitation was near or above normal for most of the years from 1986 to 2001 (except for moderate drought in 1988, 1995 and 1999), and there were no cold, open winters. Severe drought in late summer, 2001, was too late to be reflected in the crown dieback ratings of this survey. The especially wet years of 1989, 1990, 1996, 1998 and 2000 probably contributed to the improvement in tree condition since 1986. According to data from the National Oceanic and Atmospheric Administration, annual precipitation for all stations in Vermont averaged about 4 inches above normal in 1989, 13 inches above normal in 1990 and nearly 10 inches above normal in 1996. 1990 was the third wettest year on record for Vermont, and 1996 was the fifth wettest on record. Despite more drought in the past 5 years, including the severe drought in 2001 when precipitation averaged 9.9 inches below normal, every other year has been wetter than normal. For the 5-year period of 1997 through 2001, precipitation has averaged about normal (+ 0.3").

Late spring frosts have occurred since 1986, but none have been as damaging to forest trees as the June 1980 frost (Figure 1). The death of many trees that were unhealthy in 1986 also contributed to improved tree health results since then.

Defoliation of sugar maple and other hardwoods by forest tent caterpillar and saddled prominent was widespread between 1976 and 1982. Populations of these two defoliators have remained low since then. (Figure 1). A gypsy moth outbreak occurred from 1989 to 1991, but it was shorter in duration, less extensive and less sever than the previous outbreak.

The wetter years during the most recent outbreak led to a disease epidemic among the insects and presumably contributed to tree recovery following defoliation. The fungus responsible for most of the gypsy moth mortality has continued to keep populations at low levels. Pear thrips, another insect, defoliated over 600,000 acres of sugar maple between 1987 and 1993, but this is an early-season defoliator and trees recovered well.

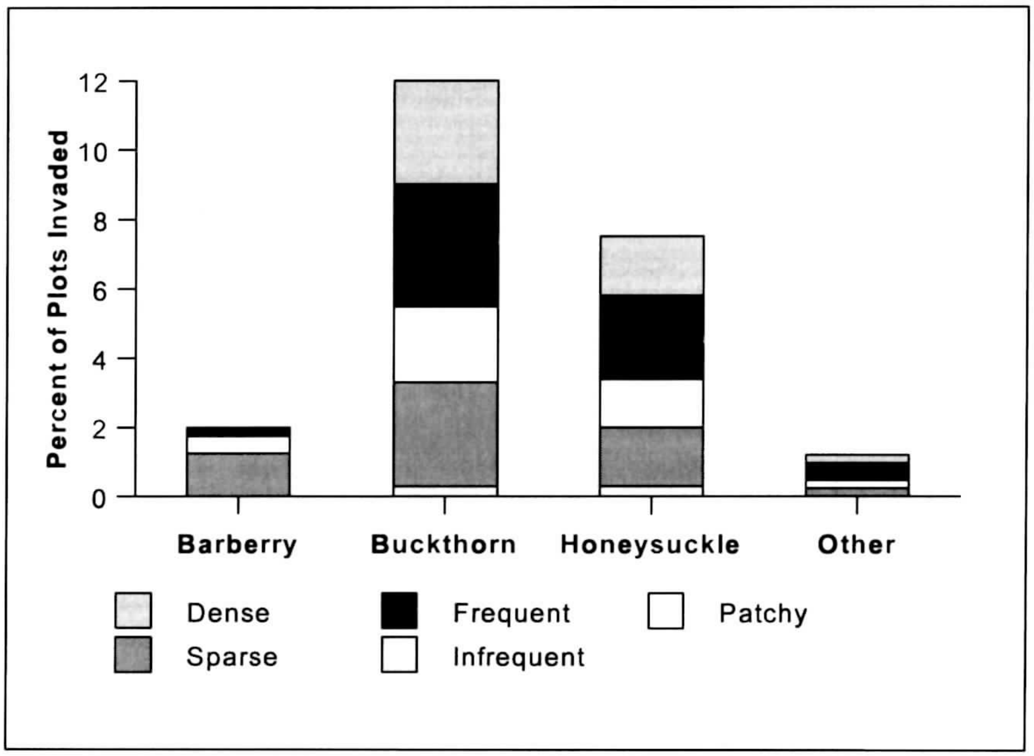


Figure 12. Frequency and density of exotic invasive plants, by species, within plots (5 per site) in Vermont hardwood stands in 2001. Densities are defined in Table 6 and Appendix B.

Table 6. Relationship of stand basal area[1] to the density of buckthorn and honeysuckle in Vermont hardwood stands in 2001.

	Density of Exotic Plants			
	Sparse [2]	**Patchy** [3]	**Frequent** [4]	**Dense** [5]
		Buckthorn		
Ave. Basal Area (sq.ft.)	107	103	86	82
Range of Basal Area	50-140	40-210	20-150	20-140
		Honeysuckle		
Ave. Basal Area (sq.ft.)	119	105	83	36*
Range of Basal Area	90-160	40-210	50-110	10-80

* Significant difference (0.05 level) in basal area between dense and frequent.
[1] Basal area of all trees greater than 1 inch dbh.
[2] Sparse throughout: 1-2 plants together, occurring in a few locations.
[3] Localized patches: several plants together, occurring in a few locations.
[4] Frequent: dense areas of plants occurring in a few locations.
[5] Dense throughout: high populations making up the understory and/or regeneration.

Allen and Barnett (1991) evaluated data from North American Maple Project study sites in Vermont and Massachusetts and found that sugar maple crown condition improved significantly one year after heavy thrips defoliation.

The 1998 ice storm had some impact on tree health but few trees died and most surviving trees continue to improve in crown condition.

CONCLUSIONS

This survey shows that overall, our hardwood forests are in good condition, with continued improvement since 1985. The large decrease in dead trees visible in aerial photography and the continued good health of overstory trees in ground plots indicates that the tree decline episode that began in the early 1980's has run its course. Over 90% of all trees in upper canopy positions have remained healthy (less than 10% crown dieback) since 1991.

Variability in tree health between species has also decreased. Except for paper birch, with its poor ability to recover from stress events and beech, with its susceptibility to beech bark disease, over 90 percent of dominant/codominant trees were healthy in 2001 for each of the eight most frequently encountered species in the ground plots. Improvements in crown condition since 1986 may be related to decreased insect damage and more years with above average precipitation.

RECOMMENDATIONS

Tree health, as reflected by crown dieback, is always fluctuating in response to changes in environmental conditions and interactions with other organisms. This varies tremendously from one site to another based on the history of that site, specific species of trees and the other organisms involved. There are always sites where tree crown condition is better or worse than average for the region. Continued periodic broad-based monitoring is important to detect changes. Timely investigation of any specific areas of concern will strengthen our ability to link tree health with specific stressors.

Invasion of our forests by exotic plants is an increasing concern. This is the first survey where we've collected information on these plants, and this information should be continued and strengthened in future surveys.

Evaluation of these monitoring plots on a five-year basis seems satisfactory for determining trends over time. This remains a reasonable goal for future monitoring of this type as long as we maintain other plots that are annually monitored for stressors affecting individual trees.

As more national Forest Health Monitoring plots are evaluated for forest health, we may want to reduce the number of plots in this survey or discontinue it at some point. We will continue to adopt any national forest health monitoring standards that are widely accepted and improve on our ability to describe tree conditions.

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APPENDIX A-1. Plot Survey Data Form

Plot Data

Stand Geography
1. hillside
2. roling
3. swamp
4. mtn. top
5. plateau
6. cove
7. flat
8. bench

Drainage
1. poor
2. well
3. excessive

Crown Closure
1. <25%
2. 25-74%
3. >75%

Logging History
1. no evidence
2. recent- slash
3. recent- stumps
4. old- stumps

Defoliation
1. none
2. GM
3. FTC
4. SP
5. MLC
6. frost
7. other
8. thrips

Outcroppings/Roads
1. present
2. absent

Update information for shaded item numbers during resurveys.

09	Plot No.	
10	Elevation (100s of feet)	
11	Slope (%)	
12	Aspect (degrees azimuth)	
13	Distance from Tree 1 to Center (_ _._ ft.)	
14	Bearing from Tree 1 to Center (degrees azimuth)	
15	Stand Geography	
16	Outcroppings	
	Actual (1) or greater than (2) ↘	
17	Depth to Bedrock (inches)	18
19	Depth to Hardpan (inches)	20
21	Depth to Mottles (inches)	22
23	Drainage	
24	Crown Closure	
25	Roads	
26	Logging History	
27	Defoliation History	
Site Index — 28	Tree No.	
Site Index — 29	Species	
Site Index — 30	Height (feet)	
For plots 3 & 5 — 31	Age	
For plots 3 & 5 — 32	Site Quality	

Indicator Plants	Species 33		Milacre Plots Ground Cover/ Regeneration	Regeneration 34		No.of 1s 35
	1			1		
	2			2		
	3			3		
	4			4		
	5			5		

Vermont Hardwood Tree Health Survey

1. Photo Point No. ______ 2. Photo Frame No. ______ 3. Cell No. ______ 4. Crew ______

5. Landowner ______ 6. Forest Type Code ______ 7. Date ______

8. Town ______ USGS Sheet ______ Lat. ______ Long. ______

Yr. Plot Established ______ Remarks ______

Sketch Map Of Cell Location- show landmarks, roads, bearings, distances and north arrow.

Ground Cover

1. Adv. com. Hdw>3'
2. Any com. Hdw.
3. conifer
4. rasberry
5. other woody
6. ferns
7. grass
8. other

Indicator Plants

1. blue cohosh
2. wild ginger
3. wild leek
4. maidenhair fern
5. wild sarsasparilla
6. wild lily-of-the-valley
7. staghorn clubmoss
8. bracken fern
9. wintergreen
10. starflower
11. meadow-rue
12. false hellebore
13. ostrich fern
14. interrupted fern
15. cinnamon fern
16. royal fern
17. jewel weed

rev.2/96

APPENDIX A-2. Plot Survey Data Form

SPECIES
1)s.maple
2)r.maple
3)striped maple
4)y.birch
5)paper birch
6)gray birch
7)aspen
8)w.ash
9)beech
10)cherry
11)basswood
12)elm
13)hickory
14)r.oak
15)w.oak
16)butternut
17)ironwood
18)hemlock
19)w.pine
20)r.pine
21)fir
22)r.spruce
23)w.spruce
24)other hdwd
25)other conifer

CROWN CLASS
1)dominant
2)codominant
3)intermediate
4)overtopped

TREE VIGOR
1)healthy
2)Light decline
3)Mod. decline
4)Severe decline

TREE HISTORY
0)surviving
1)ingrowth
2)stump
3)recent dead
4)old dead
5)snag
6)down dead
7)living-missed last survey

DIEBACK/TRANS
00 0
05 1-5
10 6-10
15 11-15
: :
99 96-100

SYMPTOMS
1)scorch
2)chlorosis
3)small leaves
4)tattering
5)defoliation
6)offcolor leaves
7)dead areas in leaves
8)dead leaves
9)fine twigs dead
10)branches dead
11)flagging
12)broken branches

LOCATION OF SYMPTOMS
1)upper 1/2
2)lower 1/2
3)side
4)whole tree

% OF CROWN AFFECTED
1)1-10%
2)11-25%
3)26-50%
4)51-75%
5)>75%

Data checked before leaving plot on day of survey by______________

CAUSAL AGENTS
1)logging
2)bird/anim.
3)other wounds or mech.
4)stemrot
5)canker
6)s.m. borer
7)beech bk dis.
8)d.elm disease
9)W.P.B.R.
10)leaf dis.
11)other dis.
12)ice/snow
13)wind
14)wet feet
15)lightning
16)tapping
17)oystershell scale
18)B.L.M.
19)MLC
20)thrips
21)frost
22)other insects
23)unknown
24)weather
25)bnut canker

Photo	Point	Cell #	Plot #	Tree #	Hist	Vigor	SPP	DBH Inches	Distance	Azimuth	Cr Class	Saw Logs 8'	Pulp 4'	Crn Comp	Agent 1	Agent 2	Agent 3	Crown Dieback	Crown Trans	Symp 1	Loc	% Crown	Causal Agent	Symp 2	Loc	% Crown	Causal Agent	Symp 3	Loc	% Crown	Causal Agent	REMARKS
			9	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	

APPENDIX B

Appendix B: Protocol for recording the presence of exotic invasive plants.

Look for invasive plants (listed below) within 20' radius of the plot center.

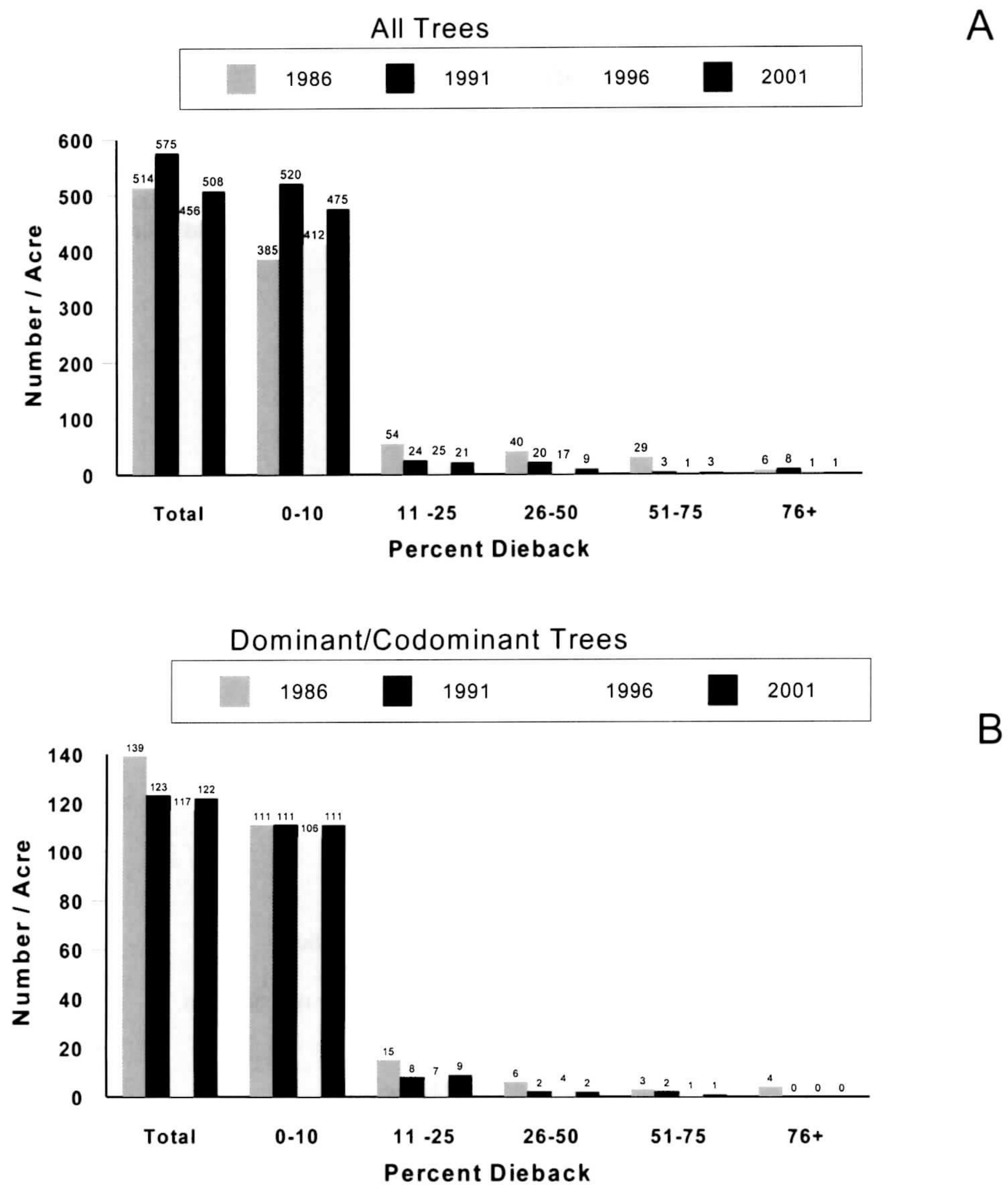
If invasive plants are found record each species and rate the density. Record up to five species in the spaces which were designated for indicator plants. The first column consists of numbers 1-5. In the second column write in a species code. In the third column evaluate the density of that species.

Species

1	Barberry
2	Buckthorn
3	Bittersweet
4	Honeysuckle
5	Multiflora Rose
6	Norway Maple
7	Autumn Olive
8	Japanese knotweed
9	Garlic Mustard
10	Privet
11	Tree of heaven
12	Wild Chervil
13	Burning bush - Euonymus alatus
14	Goutweed
15	Oriental bittersweet
99	Other - please specify other species found

Density

1	Infrequent occurrence - 1 to a few present
2	Sparsely throughout - 1-2 plants together, in a few locations
3	Localized patches - several plants together, occurring in a few locations
4	Frequent stands - dense areas of plants occurring in a few locations
5	Densely throughout - high population making up understory and/or regeneration



All Trees:Trees in all canopy positions greater than 1 inch dbh
Dead: All standing dead except snags

Figure C-1. Number of live trees per acre by crown dieback classes for all trees (A) and dominant/codominant trees (B) in Vermont hardwood stands in 1986, 1991,1996 and 2001 (68 plots).

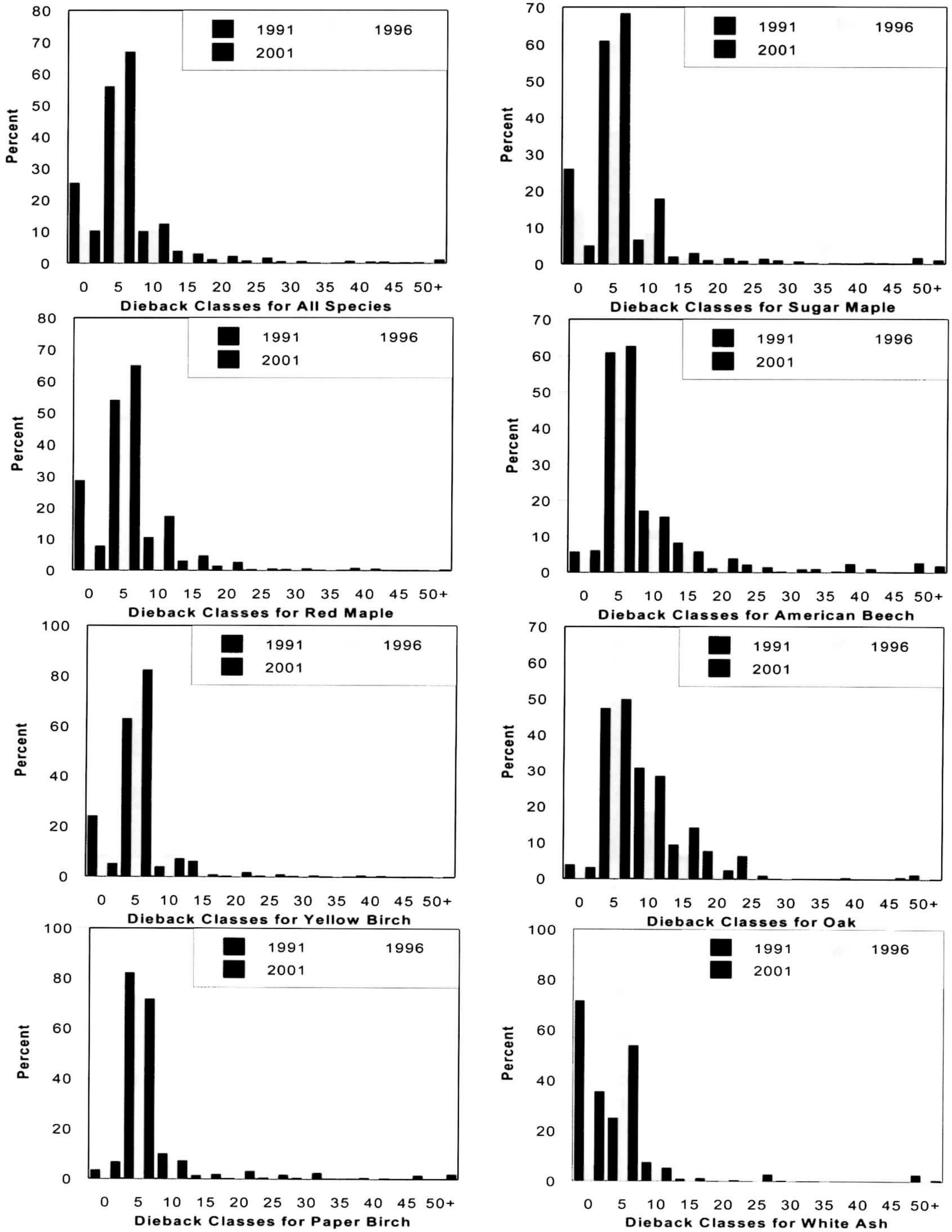


Figure C-2. Crown dieback frequency distributions in 1991, 1996 and 2001 of live dominant/codominant trees for all species and some individual species (81 plots).

APPENDIX D - Trees per acre and volume for all trees in 1986 and 2001 (68 plots)

Table D-1. Trees per acre and sawtimber volume/acre in 1986 and 2001 for all live trees ground surveyed within hardwood stands, based on the 1985 photo interpretation mortality classes in which the plots were located.

	1986 Sawtimber Volume[1]				**2001 Sawtimber Volume[1]**			
	Board Feet/Acre				**Board Feet/Acre**			
P.I. Mortality Class	**TPA**	**SE[2]**	**BF/A**	**SE[2]**	**TPA**	**SE[2]**	**BF/A**	**SE[2]**
Light	**515**	**15**	**3570**	**97**	**508**	**15**	**3301**	**90**
Mod-Heavy	**435**	**21**	**1764**	**93**	**594**	**26**	**1687**	**69**
All	**515**	**7**	**3561**	**44**	**508**	**7**	**3293**	**41**

[1]For sawtimber quality logs at least 8 feet long and a minimum diameter outside bark of 10.0 inches for conifers, white ash, and white birch, and 12.0 inches for other hardwoods.

[2]SE = standard error of the mean.

Table D-2. Cordwood volume/acre in 1986 and 2001 for all live trees ground surveyed within hardwood stands, based on the 1985 photo interpretation mortality classes in which the plots were located.

	1986 Cordwood Volume[1]		**2001 Cordwood Volume[1]**	
	Cords/Acre		**Cords/Acre**	
P.I. Mortality Class	**Cords**	**SE[2]**	**Cords**	**SE[2]**
Light	**20.7**	**.32**	**17.5**	**.28**
Mod-Heavy	**13.0**	**.38**	**11.9**	**.31**
All	**20.7**	**.14**	**17.5**	**.12**

[1]The sound volume of trees 4.0 inches dbh and greater for logs at least 4 feet long, to a top diameter of 4 inches inside bark, based on 1986 tree heights.

[2]SE = standard error of the mean.

[2]SE = standard error of the mean.

[3]Dead= all standing dead trees.

Table D-3. Cubic foot volume/acre in 1986 and 2001 for all live trees ground surveyed within hardwood stands, based on the 1985 photo interpretation mortality classes in which the plots were located.

	1986 Cubic Foot Volume[1]		**2001 Cubic Foot Volume**[1]	
	Cubic Feet/Acre		**Cubic Feet/Acre**	
P.I. Mortality Class	**CF/A**	**SE**[2]	**CF/A**	**SE**[2]
Light	3799	67	3744	62
Mod-Heavy	2977	96	3786	117
All	3795	30	3744	28

[1]Estimated net volume of trees 4.0 inches dbh and greater.

[2]SE = standard error of the mean.

APPENDIX E

APPENDIX E. Sampling frequency of live trees by species and crown position in ground plots in 1986, 1991,1996 and 2001.

	68 Plots*								81 Plots					
	Crown Position								Crown Position					
	Overstory (n)				All (n)				Overstory (n)			All (n)		
Species	**1986**	**1991**	**1996**	**2001**	**1986**	**1991**	**1996**	**2001**	**1991**	**1996**	**2001**	**1991**	**1996**	**2001**
Sugar maple	704	701	686	707	912	898	858	848	777	771	803	998	965	965
Red maple	388	388	370	392	453	450	453	471	425	404	431	497	493	517
Yellow birch	273	271	277	274	316	326	342	347	330	343	343	278	278	277
Beech	226	224	260	247	382	393	417	456	259	294	287	445	474	521
Paper birch	133	137	122	129	150	154	146	143	184	169	168	222	207	189
Oak	112	118	123	118	119	125	132	133	141	145	142	151	156	158
White ash	94	96	88	103	107	112	109	121	120	122	138	137	145	159
Black cherry	38	41	42	41	51	57	52	54	42	43	42	58	53	56
Basswood	17	19	13	23	22	24	23	30	21	15	25	28	27	34
American elm	19	4	6	11	22	8	6	15	10	12	15	14	13	20
Aspen	29	24	31	33	31	27	32	35	32	37	37	35	38	39
Hickory	15	19	18	28	17	22	22	31	19	18	28	22	22	31
Other hardwoods	87	84	92	99	218	208	216	214	120	126	127	399	423	430
Spruce	64	64	58	54	117	122	120	123	70	64	59	129	128	131
Balsam fir	40	38	34	38	80	87	91	90	47	43	49	114	120	119
Pine	67	77	97	113	95	110	133	151	92	114	145	128	159	190
Hemlock	65	55	69	81	188	180	191	206	60	74	86	195	209	224
Other conifers	19	21	23	21	25	28	28	35	22	26	23	31	32	38
TOTAL	2390	2381	2409	2512	3305	3331	3371	3503	2771	2820	2948	3881	3942	4098

[1]Plots common to all 4 survey years. [2]Plots common to 1991 and 1996 and 2001 only.