Retrospective evaluation of the onset period of the visual symptoms of dieback in five Appalachian sugar maple stand types

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In the early 1980s, a sharp increase in dieback of sugar maple (*Acer saccharum* Marsh.) was reported across large areas of the north-eastern American continent. Despite numerous studies, there are conflicting interpretations as to the causes of dieback that can be linked to uncertainties as to when the occurrence of the visual symptoms appeared. Three different approaches were used to determine the onset period of the visual symptoms of dieback in Appalachian sugar maple stands: (1) dendrochronological analysis; (2) retrieval of information in official documents that reported dieback symptoms; and (3) development of a questionnaire sent to private forest land owners. Dieback severity was evaluated annually in 104 Appalachian sugar maple stands in southwestern Quebec. Results indicated that the pattern of dieback progression did not vary significantly among the five different types of sugar maple stand that were examined. The three investigative approaches led to the conclusion that the onset of the visual symptoms occurred between 1974 and 1978.

Key words: *Acer saccharum* Marsh., dieback, sugar maple, symptoms, progression

Au début des années 1980, une augmentation subite du dépérissement de l'érable à sucre (*Acer saccharum* Marsh.) a été reportée dans de nombreuses régions du nord est de l'Amérique du nord. En dépit de nombreuses études, il y a des interprétations conflictuelles sur les causes du dépérissement qui peuvent être associées aux incertitudes de l'apparition des symptômes visuels. Trois approches différentes ont été utilisées pour déterminer la période d'apparition des symptômes visuels du dépérissement des érablières des Appalaches: (1) l'analyse dendrochronologique, (2) la recherche de documents officiels traitant des symptômes de dépérissement, et (3) l'envoi d'un questionnaire à des propriétaires d'érablières. Le dépérissement a été évalué sur une base annuelle dans 104 érablières appalachiennes du sud-ouest du Québec. Les résultats du suivi annuel ont indiqué que le taux de progression du dépérissement n'a pas différé significativement entre les cinq différents types d'érablières étudiées. Les trois approches ont permis de conclure que les symptômes visuels de dépérissement sont apparus entre 1974 et 1978.

Mots clés : *Acer saccharum* Marsh., dépérissement, érable à sucre, symptômes, progression

Introduction

During the summer of 1981, a significant increase was observed in the number of trees with symptoms of dieback in sugar maple (*Acer saccharum* Marsh.) stands located in the Laurentian and Appalachian regions of southern Quebec (Robitaille *et al.* 1982). The death rate of sugar maple was also unusually high during this period (Robitaille *et al.* 1982). Private forest owners, forest contractors and maple syrup producers became extremely concerned by this situation. Dieback occurred over large areas in Quebec (Benoit *et al.* 1982, 1983; McGauley 1983; Lachance 1985; Bordeleau *et al.* 1988; Gagnon and Roy 1994; Bell *et al.* 1998.), Ontario (Griffin 1965, Gross 1981, McLaughlin *et al.* 1985, McLaughlin 1987, Bell *et al.* 1998), New Brunswick (Pendrel *et al.* 1987) and northeastern Unit-

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ed States (Allen *et al.* 1992, Millers *et al.* 1994, Lachance *et al.* 1995, Horsley *et al.* 2000).

Considerable attention has been devoted to explain the causes of dieback and suggest remedies. Defoliation and severe drought were the factors that were most often suspected of causing dieback (Dessureault 1985; Bause and Allen 1991; Roy 1993, 1998; Auclair *et al.* 1996). Robitaille *et al.* (1982) suggested several factors that may have triggered sugar maple dieback in the Appalachian region: absence of snow or small snowpacks in the winters of 1979–1980 and 1980–1981, eight to ten consecutive days of thawing in February 1981, severe drought during leaf formation in May 1982, foliage damage caused by the forest tent caterpillar (*Malacosoma distria* [Hbn.]) in the summers of 1980 and 1982, and removal of more

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than 20% of the stand in successive heavy cuts. Bernier *et al.* (1989) attributed sugar maple dieback to severe defoliation from 1979 to 1985, absence of snow in January and February 1980, frost in June 1980, snowmelt in February 1981, poor precipitation during the summers of 1982 and 1983, and severe droughts in June and August 1983 and in August 1987. Other factors associated with dieback included the last infestation of the forest tent caterpillar (e.g., Bause *et al.* 1990, Gross 1991, Payette *et al.* 1996, Bell *et al.* 1998, Horsley *et al.* 2000), deep soil frost and poor growing season (e.g., Bernier *et al.* 1989, Roy *et al.* 1990, Pomerleau 1991, Pagé *et al.* 1992, Boutin and Robitaille 1995, Payette *et al.* 1996, Horsley *et al.* 2000) and nutrient deficiency mainly in Mg, Ca and P (Bernier and Brazeau 1988a, 1988b; Côté *et al.* 1995). These observations on the causes of dieback in Appalachian sugar maple stands were based on the concept of forest dieback defined by Manion (1981).

The concept defined by Manion (1981) specifies that forest dieback results from the interaction of several stress factors that act independently, additively, synergistically or antagonistically. The effect of these stress factors reduces tree vigour and can cause their death (Houston 1981, Manion 1981, Manion and Lachance 1992). This definition also relies on the interactions of three groups of stress factors: predisposing, inciting and contributing (Manion 1981). The effectiveness of these stress factors depends upon their intensity and period of occurrence (Manion 1981, Dessureault 1985). This concept implies that the onset of the visual symptoms of dieback results from the action of one or several aggravating factors (Houston 1981, Dessureault 1985). These factors, also qualified as triggering or accidental, act over relatively short, identifiable periods of time.

Even though the various studies increased our understanding of dieback, many questions were left unanswered on the causes of dieback. For instance, Bernier *et al.* (1989) recognized that the stress factors they identified cannot explain by themselves all the symptoms of dieback. Therefore, it is imperative to determine as exactly as possible the onset period of the first visual symptoms of dieback. This precise determination is important in order to substantiate the conclusions of some of the studies mentioned above that identified triggering factors taking place in the early 1980s. Thus, if it is concluded that the effectiveness of the factors previously mentioned occurred after the onset of the first symptoms of dieback, these factors merely accentuated the intensity of dieback and, therefore, did not initiate their development. The objectives of the present study were (1) to examine if there were differences in the onset and progression in the degree of severity of dieback among five types of Appalachian sugar maple stands and (2) to determine the onset period of the visual symptoms of dieback using three different investigative approaches.

Material and Methods

Study sites

The study was conducted in five Appalachian sugar maple forest types containing more than 65% of sugar maple trees greater than 9.1 cm in diameter at breast height (dbh) (Table 1). The stands were located in southwestern Quebec, between latitude 45°00'N and 46°27'N and longitude 72°00'W and 70°12'W, respectively, which covered an area measuring approximately 9700 km² (Fig. 1). A total of 104 0.1-hectare (ha) circular sample plots were used for this study. All the trees

greater than 9.1 cm in dbh (dead or alive) within the sample plots were numbered and measured.

Dieback survey

The severity of dieback was evaluated annually from 1983 to 1992 between mid-June and mid-August in all the stands for each species, except for American elm (*Ulmus americana* L.). American elms showing visual symptoms of dieback could in fact have been affected by the Dutch elm disease well before the occurrence of maple dieback. This evaluation was conducted by two trained staff members who looked for the presence of the following visual symptoms: (1) the presence of small, paler leaves in the top of the crown (Fig. 2a); (2) dense foliage clusters on small sections of branches (Fig. 2b); high occurrence of twig mortality at the top of the crown (Fig. 2a); (3) bud opening on the trunk resulting in high foliage density (Fig. 2c); and (4) sloughing of bark on twigs, branches and stems (Fig. 2d). The severity of dieback for an individual tree was rated on the basis of the amount of foliage missing on the crown and the ratio of the number of dead branches to the total number of branches. The severity of dieback for an entire plot is the average for all the trees. An analysis of variance based on a repeated measures design was performed to compare the pattern of annual progression in dieback severity among forest types. The Wilks Lambda test was used to compare the annual trends.

Investigation approaches

The determination of the onset period of dieback symptoms was performed using three different approaches: (1) detailed dendrochronological analysis using cores sampled in trees located throughout southwestern Quebec (Fig. 1); (2) retrieval of information in official documents that reported dieback symptoms in sugar maple stands; and (3) development of a questionnaire sent to private forest landowners.

Five dominant and co-dominant trees greater than 20 cm dbh were randomly selected within each sample plot for the extraction of increment cores at breast height to measure the age and growth rate. Ring width analysis was conducted using a Henson optical table and a binocular microscope. Cross dating of dendrochronological data was performed in the Becker laboratory in Nancy, France, using the methodologies described in Becker (1987, 1989). For each core, a curve was fitted to detect missing rings, false rings or measurement errors (Roy *et al.* 1993). A general mean curve of annual radial growth as a function of cambial age was then derived for each forest type to standardize ring width values. This approach allowed the adjustment of ring width values into radial growth indices (expressed in %) that removed the effect of cambial age (Becker 1987).

Maple dieback was documented in several reports published by the Direction de la recherche and the Direction de la conservation (insect infestation and pathology) in the former Ministère des terres et forêts du Québec. Among the 29 studies that were related to sugar maple dieback, only three contained sufficiently detailed information to identify dieback symptoms, and thus were used in the preparation of this publication.

The third source of information on maple dieback was obtained from a postal survey conducted by the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, Service de recherche acéricole, in the winter of 1983. This survey contained several questions addressed to the owners of sugar maple

Table 1. Ecological and allometric characteristics of the five sugar maple forest types studied in southwestern Quebec^a. (Abbreviations are indicated within brackets)

Forest type	Drainage and topography	Number of Sample plots	Stand density (# stems ha ⁻¹)	Merchantable	Volume (m ³ ha ⁻¹)
				Basil area (m ² ha ⁻¹)	
Sugar maple, yellow birch nd beech (YEBBEG)	Dry Crest or Upper Slope	24	410	25.8	212.5
Sugar maple and yellow birch (YEBTYP)	Fresh Mid or Lower Slope	44	520	26.4	212.1
Sugar maple, yellow birch and black ash (YEBBLA)	Very Moist Depression	8	427	21.5	171.3
Sugar maple, yellow birch and basswood (YEBBAW)	Fresh Level Slope or Table Land	11	572	26.6	215.9
Sugar maple and basswood (BAWTYP)	Fresh Level Slope or Table Land	17	524	27.5	233.5

^a Adapted from Roy and Gagnon (1991).

stands on the management of their forests. Some questions referred to the observation of dieback symptoms, such as those displayed on Fig. 2. In particular, the landowners were asked if they observed an increase in the number of trees affected by dieback or in mortality rate in both current and previous years. The description of the symptoms that were observed and the year they occurred were requested. A short description of dieback symptoms were included with the questionnaire to help the landowners to provide the information as exactly as possible. About 2000 private landowners who managed their sugar bush for maple syrup production provided information on sugar maple dieback. Of this number, 567 lived within the study area (Fig. 1).

Results

Annual progression of dieback

The severity of dieback increased gradually from 1984 to 1987, followed by small fluctuations (Fig. 3). ANOVA results indicated a significant time effect for the period between 1984 and 1992 (Table 2). Vegetation type was not significant, nor was its interaction with time, which indicated that the pattern of progression in the severity of dieback did not differ significantly among vegetation types (Fig. 3). The second step of ANOVA analysis, which focused on comparing the annual dieback progression rates, indicated that the amplitude of dieback severity stabilized in 1987–1988, following a steady increase from 1984 when year was significant (Fig. 3, Table 3). There was a significant decrease in 1988–1989 for each forest type, and then an increase in 1989–1990. The fact that forest type was significant only in 1989–90 can be explained by the greater decrease in the YEBBAW forest type relative to the other forest types (Table 3). Despite this temporary trend, all the forest types were characterized by the same pattern of evolution in the severity of dieback from 1984 to 1992.

Dendrochronology

The dendrochronological results indicated relatively large fluctuations in the annual radial growth index from 1900 to 1990 in each forest type (Fig. 4). However, a sharp relative long-term decrease in radial growth took place from around 1974 in all the forest types. The decrease was relatively steady from 1974 to 1978 and increased in amplitude thereafter until 1981. The year 1978 coincided with the first substantial increase in the number of observations of dieback symptoms reported by forest land owners, while the year 1981 coincided with the greatest number of observations (Fig. 5). The annual radial growth indexes from 1980 to 1990 were among the lowest values measured between 1940 and 1990. The 1981 radial growth index was the lowest between 1900 and 1990 for the YEBBLA, YEBBEG and BAWTYP forest types.

The lowest increment rate was obtained in 1980 for YEBTYP. For YEBBAW, the lowest radial growth index was obtained in 1902. However, the radial growth indexes obtained in 1980 and 1981 for this forest type were nearly as low as those obtained for the other forest types.

Documented reports on sugar maple dieback

The reports examined originated from the studies of Veilleux (1973), Davidson *et al.* (1977) and Bernier and Laflamme (1979) for sugar maple stands located in the Beauce (Tring-Jonction) and Mégantic (Saint-Antoine-de-Pontbriand) regions. Both regions were within the present investigation area (Fig. 1) and were severely affected by the last occurrence of dieback (Direction de la conservation 1987). Bernier and Laflamme (1979) observed the disappearance of bark on the main branches and a progression of dieback symptoms from the outside to the inside of the crowns. These two symptoms were also observed in 1983 (Dessureault 1985, Roy and Gagnon 1991). Other symptoms, such as those illustrated by Fig. 2, were observed and their onset was estimated to have occurred as early as 1973. Veilleux (1973) observed that the foliage nitrogen concentration in sugar maple stands affected by dieback decreased substantially relative to that of healthy stands (1.41% vs. 2.01%, respectively). Veilleux (1973), Davidson *et al.* (1977) and Bernier and Laflamme (1979) attributed sugar maple dieback to different factors: asbestos dust from nearby mines, extensive pasture, damage caused by excessive wind in some stands, presence of wood decay resulting from ice storms and lack of appropriate management. However, the three reports suggested that the effect of asbestos dust from nearby mines probably had more effect than the other factors on sugar maple dieback. In particular, they emphasized that the accumulation of mine residues increased the soil magnesium concentration and the pH, resulting in antagonistic reactions with calcium (Bernier and Laflamme 1979) or nitrogen and potassium (Veilleux 1973).

Postal survey

The information obtained from the questionnaires indicated that approximately 10% of landowners observed dieback symptoms in their sugar maple stands before 1979 (Fig. 5). Relatively few landowners noticed visual symptoms from 1970 to 1977. From 1978 to 1981, the number of observations increased sharply every year and then decreased in 1982. Many landowners reported the presence of black ash (*Fraxinus nigra* Marsh.), beech (*Fagus grandifolia* Ehrh.) and hop-hornbeam (*Ostrya virginiana* (Mill.) K. Koch) in the sugar maple stands where they observed dieback. According to Roy and Gagnon (1991), sugar maple stands that contain these species are particularly vulnerable to dieback, as are stands

Fig. 1. Study area in southwestern Quebec. (H: location of sample plots throughout the study area).

growing under extreme (xeric and hydric) drainage conditions that contain sugar maple, yellow birch and beech.

Discussion

The fact that the patterns of dieback progression for different sugar maple stand types were similar suggests that they were affected by the same types of stress (Fig. 3). The differences in severity of dieback can probably be explained by the difference in vigour of the different sugar maple stand types (Roy and Gagnon 1991, Roy *et al.* 1985). It is likely that the visual symptoms of dieback first appeared in sugar maple stands growing on sites that were considerably different from the optimal conditions for sugar maple (YEBBLA and YEBBEG). The symptoms appeared later in sugar maple stands growing on sites considered as optimal.

The sugar maple forest types growing on very dry (YEBBEG) or very wet (YEBBLA) sites were more affected (Fig. 3). Other studies on sugar maple dieback came to a similar conclusion (Gagnon *et al.* 1990, Roy and Gagnon 1991). In particular, the YEBBLA forest type, which had the greatest severity of dieback, had the lowest growth rate for several years between 1900 and 1990 (Fig. 4). As suggested by Houston (1981), Manion (1981), Dessureault (1985) and Manion and Lachance (1992),

unfavourable site conditions may result in predisposing conditions for dieback. Sugar maple stands growing on sites with sub-optimal growing conditions (Godman *et al.* 1990, Anonymous 1995) become more sensitive to abiotic or biotic stresses that may result in dieback (Manion and Lachance 1992). Inciting factors, such as large climatic deviations (drought or deep soil frost), may have an additive effect. For instance, the root systems of sugar maple stands growing close to the F and Ah horizons (Canada Soil Survey Committee 1978) on humid sites located downhill or in depressions are more sensitive to climatic deviations (Badibanga *et al.* 1992; Pagé *et al.* 1992; Sauvesty *et al.* 1993a, 1993b). On the other hand, the effects of drought are more intense on very dry sites than on more humid or well-drained sites. The consequences of drought conditions are more important in the Appalachian region because of the frequent presence of brittlepan in the soils, which are not very deep in these sugar maple stands (Roy and Gagnon 1991). The combination of loss of vigour and the intense effect of severe climatic fluctuations explain why sugar maple stands on very dry or very wet sites were the first ones to display the visual symptoms of dieback.

The results of the present study suggest that the initial stage of dieback occurred between 1974 and 1978. The first

Fig. 2. Illustration of the visual symptoms of dieback. (Detailed description is provided in the text).

Fig. 3. Annual progression of the mean values in the severity of dieback in five sugar maple forest types in southwestern Quebec.

official documents that reported sugar maple dieback were also published in this period (Veilleux 1973, Davidson *et al.* 1977 and Bernier and Laflamme 1979). Even though Veilleux (1973), Davidson *et al.* (1977) and Bernier and Laflamme (1979) emphasized the effect of Asbestos mine residues, the effect of

the other factors mentioned in their reports were probably as important because not all the sugar maple stands examined were located close to mine residues. Both the postal survey and the dendrochronological study pointed out at least two significant changes between 1974 and 1978. There was a significant

Table 2. ANOVA results to compare the pattern of annual progression in dieback severity among five sugar maple forest types in southwestern Quebec from 1984 to 1992

Source of variation	F	Degrees of freedom		Significance level (P value)
Year	39.04	8	90	<0.0001**
Year and forest type	0.93	32	333	0.5812 ^{NS}

** Significant at the level of probability of 0.01.

^{NS}Not significant.

Fig. 4. Average annual increment in five Appalachian sugar maple forest types in southwestern Quebec. (The arrow indicates the beginning of a sharp relative long-term decrease in annual growth rate).

increase in the number of forest landowners who noticed the presence of visual symptoms of dieback in their sugar maple stands in 1978 and 1979 relative to previous years (Fig. 5). These two years were within the period of the accentuation of the decline in growth in Appalachian sugar maple stands (Fig. 4). In 1981 the proportion of forest landowners who confirmed the presence of dieback reached a maximum. This year coincided also with the smallest annual radial growth values measured between 1900 and 1990 for three forest types (Fig. 4). For the other two forest types, the growth rates in 1981 were among the smallest values for the same period. A decrease in ring width in the early 1980s was also observed by Payette *et al.* (1996) in their dendrochronological study on sugar maple dieback in the same region.

A literature review indicated that the determination of the onset period of the visual symptoms of dieback is controversial. For instance, Bell *et al.* (1998) indicated that the onset of dieback symptoms took place between 1972 and 1976. However, Payette *et al.* (1996) indicated that the onset of dieback symptoms took place in the early 1980s and was probably caused by the combined effect of drought, insect infestation and

extreme climatic differences. Kolb and McCormick (1993) attributed the decline of sugar maple trees in Pennsylvania to defoliation and drought that took place in the mid-1960s and early 1970s. It is possible that the onset of the visual symptoms of dieback was related to sugar maple forest types (Hendershot and Jones 1989, Roy and Gagnon 1991). For instance, sugar maple stands with poor drainage conditions, which are not good growing conditions for the species (Godman *et al.* 1990, Roy *et al.* 1995, Roy 1998), were most affected by dieback (Roy and Gagnon 1991), probably because the visual symptoms first appeared in these stands.

The onset of visual symptoms of dieback in the mid-seventies probably resulted from the interactive action of several environmental stresses that began several years earlier. Their occurrence took place well before the factors mentioned by Robitaille *et al.* (1982), Bernier *et al.* (1989) and Payette *et al.* (1996). Consequently, attributing sugar maple dieback to a forest tent caterpillar infestation, deep soil frost in 1982, and severe drought in the summer of 1983 (Dessureault 1985, Roy *et al.* 1985, Bernier *et al.* 1989, Pomerleau 1991, Roy 1993) cannot be retained as triggering factors. However, these environmental

Fig. 5. Number of observations of dieback symptoms by forest land owners from 1970 to 1982.

Table 3. ANOVA results for annual increment rate in dieback severity from 1984 to 1992 in five sugar maple forest types in southwestern Quebec

Period	Source of variation	Degree of freedom	F	Significance level (P value)
1984–1985	Year	1	41.78	<0.0001**
	Forest type	4	0.80	0.5292 ^{NS}
1985–1986	Year	1	181.94	<0.0001**
	Forest type	4	1.60	0.1801 ^{NS}
1986–1987	Year	1	110.01	<0.0001**
	Forest type	4	0.03	0.9979 ^{NS}
1987–1988	Year	1	0.01	0.9205 ^N
	Forest type	4	0.73	0.5741 ^{NS}
1988–1989	Year	1	56.07	<0.0001**
	Forest type	4	2.19	0.0763 ^{NS}
1989–1990	Year	1	55.19	<0.0001**
	Forest type	4	3.30	0.0139*
1990–1991	Year	1	0.97	0.3268 ^{NS}
	Forest type	4	0.69	0.5995 ^{NS}
1991–1992	Year	1	0.07	0.7988 ^{NS}
	Forest type	4	0.36	0.8337 ^{NS}

*Significant at the level of probability of 0.05.

**Significant at the level of probability of 0.01.

^{NS}Not significant.

stresses certainly contributed to magnifying the decline of sugar maple stands and as such can be considered as aggravating factors (Manion and Lachance 1992). The loss of vigour of sugar maple stands, as recorded in the dendrochronological profile, make them more susceptible to insect attacks, such as the forest tent caterpillar (Bauce *et al.* 1990).

Conclusion

Three different approaches were used to determine the onset period of the dieback symptoms in sugar maple stands: (1) extraction of increment core within sample plots for detailed growth analyses; (2) retrieval of information in official documents that reported dieback symptoms in sugar maple stands; and (3) analysis of a questionnaire sent to private forest landowners. All three methods indicated that the onset of dieback symptoms took place between 1974 and 1978. Thus, our results suggest that the stands that were the most severely affected by dieback were the first ones to have dieback symptoms appear. In addition, the factors in the early 1980s that were

previously identified as responsible for the appearance of the visual symptoms of dieback in other studies did not, in fact, initiate dieback. However, they certainly contributed to increasing its severity. Sugar maple dieback is a complex phenomenon that must be studied further to better understand its effect on the dynamics of sugar maple stands. This will help forest managers develop management prescriptions that will take into account the factors that predispose sugar maple to dieback in order to minimize its effect on stand productivity.

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