Norwegian Journal of Agricultural Sciences

Supplement No. 20 1995

PEDER BRAATHE

Birch dieback – caused by prolonged early spring thaws and subsequent frost

Norwegian Forest Research Institute, Ås, Norway

Forskningsparken i Ås AS, Infosenteret, Ås, Norway
The Science Park at Aas, Infosenteret

NORWEGIAN JOURNAL OF AGRICULTURAL SCIENCES

Norwegian Journal of Agricultural Sciences fills a need created by the folding of Scientific Reports of the Agricultural University of Norway and Research in Norwegian Agriculture for a forum for publishing Norwegian research with international interest within the following areas: Aquaculture, Animal Science, Soil Science, Agricultural Engineering and Technology, Natural Resources and Environment, Food Technology, Crop Science, Forestry, Economics and Society Planning.

PUBLISHER

The journal is published by the The Science Park at Ås, Infosenteret, N-1430 Ås, Norway, Norwegian Journal of Agricultural Sciences (ISSN 0801-5341) is published four times a year, each issue containing approximately 100 pages. Four issues comprise one volume. Annual subscription NOK 500,–. Subscribers receive supplement issues free of charge, but these can also be ordered separately through the publisher.

REFEREE

All papers submitted for publication will be sent to one or more competent referees.

CORRESPONDENCE

All Correspondence, editorial or otherwise, should be adressed to the The Science Park at Ås, Infosenteret, N-1430 Ås, Norway.

The drawing on the cover: Kjell Aukrust

ISSN 0802-1600

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Preface

As a National Research Council postdoctorate fellow at the University of New Brunswick 1955-56, I was faced with the mysterious birch dieback malady. Close to 20 years of investigations had not jet led to any explanation. According to my temperature studies and ideas in 1957, I started in 1989 experiments in Norway and continued further studies of climatic events in east Canada and north-east USA. The results seem to clarify the main cause of birch dieback and they are presented here now, although there still are some questions that could need further research. Some additional plans are under preparation.

The manuscript was sent for reviewing to the Canadian Journal of Forest Research. It was found too long for printing, but the four referees made several valuable comments, partly used in the final reversion.

I want to thank all who have supported me in different ways. Sincere thanks go to John Blenis, Forestry Ranger School, Fredericton and Ronald Hallet Forestry Canada - Maritime Region for supplying seed of yellow and white birch.

Meterological observations were copied and sent me by Harald Pine, John McColm and Roger Cox, Fredericton, and by John Zazada, Rhinelander.

State maps of US and meterological data were supplied by Gunnar Wilhelmsen, Norwegian Embassy, Washington D.C., and provincial maps of Canada by the Canadian Embassy, Oslo.

Valuable literature has been supplied by John McColm, Gordon F. Weetman, Vancouver, Harold Tremblay, Quebec, and Jon Dietrichson, Aas.

Special thanks go to Roger Cox who gave the thaw-frost idea great attention. His views during the talks in Fredericton/Montreal 1990 and later contacts have been of great help. The manuscript has been reviewed by Harald Opdahl, who gave highly appreciated advice regarding content and the use of language.

Ås, March 1995 Peder Braathe

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Birch dieback - caused by prolonged early spring thaws and subsequent frost

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Braathe, P. 1995. Birch dieback - caused by early spring thaws and subsequent frost. Norwegian Journal of Agricultural Sciences. Supplement No. 20. 1-59 ISSN 0802-1600

The dieback of yellow birch (*Betula alleghaniensis* Britton) and white birch (*B. papyrifera* Marsh) has from the middle thirties been a mystery in Eastern Canada and Northeast U.S. The extent was enormous, covering an area of at least 490.000 km2. An idea of early spring climatic damage was set forth in 1957, and thaw- and freezing experiments in Norway since 1989 have reproduced the birch dieback symptoms; small, more or less chlorotic and curled leaves, failure of bud growth and progressive dying back of twigs from the ends. Such symptoms on yellow birch appeared by frost of at least -5°C at bud burst stage 3, where green tips of leaves were visible. In March and early April this stage seems to need at least 100 day degrees (base temp. 4°C), whereas about 50 day degrees are adequate in late April and May. Between 1936 and 1954 four thaw-frost events in Canada and US exceeded these values of day degrees before the frost, and the areas correspond very well with those hit by birch dieback.

Rootlet dying, which was considered the first symptom, turns out to be a secondary one after the frost injuries. The frost damage to the vulnerable crown brings the tree out of physiological balance, the water content increases and movement becomes irregular.

Key words: Birch dieback, day degrees, budburst, spring frost

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1. INTRODUCTION

During a study trip in Eastern Canada and the North-Eastern United States in 1956, the author was faced with the mysterious birch dieback which had affected most of the area visited.No explanation of the phenomenon had so far been found in spite of numerous investigations carried out from 1938 to the middle fifties.

The summarized results were presented at the Symposium on Birch Dieback, held in Ottawa, Canada, on March 21 and 22, 1952. The report from the meeting included 26 papers and probably covered all the features known. Insects, virus disease, drought and rise of temperature in air and soil during the growing season were mentioned as possible causes of the dieback, or at least playing an important role. No definite conclusion, however, could be drawn.

A striking feature of the birch dieback, as it appeared during the travels in 1956 was the uniformity over large areas. It was therefore hard to believe that any of the causes mentioned could be accepted as a main explanation. Insects and diseases do not usually cover an area so completely that no pockets remain undisturbed. If a change in summer climate had taken place and caused the damage, large variations would have been expected, because during the growing season there is a tremendous variation in the microclimate. It is therefore unlikely that a general change in temperature or a deficit of moisture could have nearly the same uniform effect irrespective of site, soil moisture, soil fertility, slope exposure, elevation, etc. Variations seemed far too small to indicate any effect from abnormal climate condition during the growing season.

However, damage caused by abnormal winter climate, directly or indirectly, will strike an area with much greater uniformity, because the microclimate does not play the same role during the winter and early spring.

Looking for abnormal winter-climate conditions in the middle thirties, when the extensive birch dieback appeared in New Brunswick, Nova Scotia, Quebec and Maine, one event stood out as very extreme: the heavy, prolonged thaw in March 1936. Temperature studies resulted in an article published in Forestry Chronicle: "Is there a connection between the birch dieback and the March thaw of 1936?" (Braathe 1957). The conclusion was that in spite of the fact that in Quebec the correlation was not quite as exact, the area affected by the thaw and the dieback area corresponded so well that the connection could not be fortuitous.

The article ended (p. 362). "Irrespective of whether there is a virus involved or not, the question of what happened to the trees during and after the thaw is important. It can probably not be explained without research, but it should not be too difficult to give trees artificial "March thaw" treatments to confirm or deny its role in the birch dieback."

Since the article was published in 1957, it has been difficult to get the birch dieback - March thaw idea out of the mind. In recent years therefore, some trials have been carried out in Norway. The results of these trials are dealt with here, and comparisons are made to the affected areas in Canada and The United States.

Part of the extensive literature is referred to in some detail to recall the picture of the malady that had its boom 1937-1949, more than 50 years ago.

2. LITERATURE OF BIRCH DIEBACK

2.1 Description

A definition of the malady was given by Balch (1953, p. 1) "Birch dieback is a condition which produces the following symptoms in yellow or white birch regardless of age, vigour or stand condition: small, more or less chlorotic and curled leaves, failure of bud growth, and progressive dying back of twigs from the ends. These symptoms appear over the whole periphery of the crown, and tend to progress basipetally until they affect all the foliage. The dying back of twigs may continue until the branches are involved and the whole tree may be gradually killed, but in the absence of attack by the bronze birch borer and other secondary organisms, the tree may recover partially or completely. Reduced wood growth in the stem accompanies or follows the initial symptoms, but does not precede it. The initial symptoms affect all trees in all types of stands of a locality or region, but the later stages do not occur equally on all trees and appear to be governed by tree vigour or prevalence of borer attack".

To distinguish the "birch dieback" from the dying back of twigs and branches that occurs after severe disturbances such as heavy cutting or is associated with old age, the latter situation is termed "decadence".

Balch (1953 p. 3) in his brief history as it was observed by the personel of the Fredericton Laboratory said: "Between 1932 and 1935 it was noted that a number of birch stands in central-southern New Brunswick had an unhealthy appearance but no careful examination or description of the injury was made. The picture was confused somewhat by the widespread injury to foliage by the case-bearer and leaf-nursing sawflies. It is not possible to say how much of this injury, which was very casually recorded, was due to post-logging decadence or borer attack. By 1935, however, there is no doubt that what we now call dieback was present in this general region. By 1937 dying of birch from the top was widespread in this part of the province and recorded in the Annual Report of the Department of Lands and Mines of New Brunswick".

2.2 The first investigations

The first preliminary investigations on birch dieback were started in New Brunswick in 1938 by Balch and Prebble (1940, p. 188).

They described the further development: "In 1938 there was a particularly striking increase in the occurrence of the injury and most stands of mature birch in this general region (some 15.000 square miles) took on a brownish to greyish appearance caused by the dying of foliage and branches. Reports of damage were also received from northerly parts of the province. The condition was still more noticeable and widespread in 1939, when dead branches were more evident, but browning foliage was rather less conspicuous.

The above symptoms are exactly those which are usually associated with attack by the bronze birch borer (*Agrilus anxius* Gory), but the widespread occurrence of the injury, and the fact that it was found in areas which had not been cut over, suggested that some other factors might be either primarily responsible or, at least, predisposing the trees to borer attack". Later, other authors again and again have reached the same conclusion, that the bronze birch borer is not the primary cause of birch dieback. This will be dealt with in a later chapter.

During the course of the investigations in 1939, tallies were made in ten localities distributed throughout the province, and some 400 cut trees were studied. The summarized results showed that severe damage was largely confined to mature stands. It occurred in mixed wood and pure hardwood types, affected yellow, white and grey birches, and was found in fully stocked as well as cut-over stands. In general, however, the most severe injury was found in hardwood types, on yellow birch and on cut-over lands.

In practically all of the central and southern part of New Brunswick, the mature birch had already suffered serious injury and there were few stands showing less than 25 per cent of the birch trees dead or with over half the crown dead (Balch and Prebble 1940, p. 181-2). The Green River area which showed the least damage lies in the northern part of the province.

Studies were made of the condition of yellow birch on areas being cut over for veneer logs or lumber still considered merchantable by the operator. From four areas in Southern New Brunswick the average age of the merchantable trees was around two hundred years. In these stands, which had a healthy appearance until a few years ago, sound trees over three hundred years old were not uncommon. Such conditions were typical of the tolerant hardwood stands of the province where young second growth were comparatively scarce.

Balch and Prebble examined the deviations from normal of the monthly means of temperature and the monthly precipitation during the past fifteen growing seasons for five stations in New Brunswick and a similar number in Nova Scotia. "No period was found in which the combination of these figures suggested a very serious condition of drought likely to cause wide spread injury to a native tree. Nor was there any striking difference between the deviations in the region of severe injury and those in districts where injury is virtually absent. It is possible that a better knowledge of the most critical periods and more detailed information on the water conduct in the soil would give a different result, but the evidence available suggests that climatic factors have not been of major importance except perhaps through their indirect effect on other factors".

2.3 Symposium on birch dieback

Twelve years after the publication by Balch and Prebble the birch dieback malady was still as mysterious. Therefore the Forest Biology Division - Science Service, Department of Agriculture, Ottawa held a symposium on birch dieback in Ottawa, Canada, on March 21 and 22, 1952. The list of participants contained 59 names, and 26 papers were presented. These were published in December 1953.

This symposium, supported by all the experts in the matter from Canada and New England, intended to summarize all the knowledge and conclusions up to that time. The report therefore has become one of the main literature sources.

Among the items the question of spread was discussed. Birch dieback first appeared in southern - central New Brunswick in the middle thirties. During the next 6-8 years it was gradually discovered in northern New Brunswick, eastern and northern Main, and parts of Nova Scotia and Quebec. A continuous spreading of the dieback seemed obvious, though some investigators doubted this, especially Daviault (1953, p. 49) and Pomerleau (1953, p. 51) suggesting that the trees all over the area were affected in their vitality at the same time more or less severely in the different regions, but that the external manifestation of the trouble took place at different periods.

In the middle forties, foresters became concerned about the health of birch stands in greater parts of Quebec and in Ontario as well. The first steps toward an assessment of the condition of yellow birch in Ontario were taken in 1947 (Sinclair and Hill, p. 167). "In that year Mr. G. W. Barter, an expert in determining the amount of dieback in the Maritimes, made a preliminary survey of the condition of yellow birch in Ontario. He returned in 1948 to review the areas visited the previous year. In his report (1949) it is stated "that the birch in the areas visited in Ontario as far west as North Bay are in a state of deterioration which may be the early stages of the condition which preceded the dying of birch in New Brunswick. Whether such a condition will develop in Ontario or reach such proportions as it did in the Maritimes can only be determined by an annual check on the condition of individual trees in the main birch-growing regions of the province"".

In the report of the symposium Barter (1953b, p. 20) presented a map showing the area affected and damage caused to yellow birch by dieback in eastern Canada as of 1948. This map clearly shows that huge areas in Quebec, especially north of St. Lawrence River had been affected by birch dieback, and large areas in eastern Ontario as well had indications.

2.4 Crown classification system

Balch and Prebble (1940, p. 181) adapted a classification of trees according to condition in order to standardize the methods of reporting by rangers and others. The following five classes were used: 1. Healthy, 2. With weak foliage in top, 3. With less than half the branches dead, 4. With over half the branches dead, 5. Tree dead.

During the years the classification system got additions. It became evident that a wider range was needed to record the various stages represented and to describe minor annual changes.

In the assessments in the late forties slightly different systems were used. Fraser (1959, p. 8) used one of the most detailed systems in his observations at Chalk River, and that is reprinted here.

1 A Normal tree. Foliage full size and normal in colour. No dead twigs or branches.

1 BA As in 1 A, except dead twigs or branches that may be attributed to suppression, whipping, breaking, wind or logging injury.

2 A Foliage abnormally small, thin, curled, yellowish or otherwise weak in appearance but not conspicuously so. No dead twigs or branches.

2 B As in 2 A, but conspicuously so.

3 AD Tree with small twigs dead for no apparent reason, such twigs occurring at the ends of branches, usually at the top of the crown, and for a distance not to exceed three inches from the periphery.

3 A Tree with small branches dead for no apparent reason usually at the top of the crown, dying back not more than three feet from the periphery.

3(A) Tree with twigs and not more than three branches dead for no apparent reason, such twigs and branches usually being located in the apical half of the crown.

3 B Tree with more than three branches dead for no apparent reason, constituting up to one-quarter of the crown.

3 B̲ Tree with branches dead for no apparent reason, constituting one-quarter to one-half of the crown.

4 A Tree with one-half to three-quarters of the crown dead.

4 A Tree with more than three-quarters of the crown dead.

4 B Tree with no living branches except vigorous adventitious ones usually found at the base of the crown.

4 B̲ As 4 B, except with adventitious branches which are not vigorous.

5 A Tree with crown dead, but having cambium green at breast height.

5 B Tree with crown dead but cambium brown at breast height. Tree has recently died and has most of the fine twigs still adhering.

6 A Tree dead for several years. Some smaller branches remain.

6 B Tree dead for several years but only stem and primary branches remain.

In addition to their very similar system Sinclair and Hill (1953, p. 169) added three series of symbols, indicating location in the crown, appearance of the foliage, and causes of damage to class 1 B.

This gradual development and widening of the classification system clearly show the complexity of the condition and the difficulty of classifying the different stages of injury precisely enough.

Adventitious branches (watersprouts) grow out from the stem from the time when about half the crown is dead (4A). "These sprouts often stay alive for one or two years after all main branches are dead. In fact there are cases where these alone have remained alive long enough to indicate they will continue to grow indefinitely and form a new crown" (Nash and Duda 1951, p. 7). Also Greenidge (1953b, p. 552) described adventitious branches on 4A and 4B trees.

2.5 Extensive assessments and their results up to autumn 1951

The changed situation after the extended birch dieback observations in Ontario, and intensified effect on most of the earlier hit areas, resulted in a series of extensive assessments. Based on the reommendation of Barter (1949), permanent plots with annual check of individual trees were established throughout the birch growing regions. Results from all these assessments were presented at the symposium in March 1952, covering observations up to the autumn of 1951.

2.5.1 Ontario

In Ontario a joint project, supported by the Dominion Laboratory of Forest Pathology, Toronto, the Research Division of the Ontario Department of Lands and Forests and the Forest Insect Laboratory, Sault Ste. Marie, was begun in 1949 and continued through 1950 and 1951 (Sinclair and Hill 1953, p. 168). Twenty-seven permanent sample plots were established in accessible areas throughout the range of yellow birch in the area between Sault Ste. Marie district in the west and the Petawawa Forest Experiment station in the east.

During the years 1949-51 the deterioration of yellow birch was progressive, but the rate 1950-51 was slower, and the number of trees showing a cessation of decline was increasing and the condition of some trees was improving.

The percentage of healthy trees (1A, 2A, 2B) was reduced from 28 to 7 in the period, and dominant trees were harder hit than intermediate trees.

2.5.2 Quebec

In the Province of Quebec the information accumulated on birch dieback from its first appearance in 1939 up to 1947, was very fragmentary. In the spring of 1947 the Forest Insect Ranger corps was organized and sample plots were established all over the province south of the 51° of latitude. The plots were grouped in 4 zones, and in 1951 202 permanent sample plots were surveyed (Daviault 1953, p. 42).

During the years 1948-51 there was a gradual increase in crown injury and in the percentage of trees injured for both species of birch in the four zones. The most serious damage to that time was in Zone I, which could be expected since this zone comprised many of the regions where the phenomenon was first reported. The percentage of dead trees in Zone I by 1950 was 58, and in the other three zones 11-13.

Another series of permanent sample plots was established in Quebec in 1948, confined to white birch in the Lake St. John district (Martineau 1953, p. 163). The result from 1948-51 was a continuous progression in deterioration of white birch in the area.

2.5.3 New England and New York State

In the United States a survey was carried out from 1949 cooperatively between the states of Maine, New Hampshire, Vermont, New York and the Division of Forest Pathology and Forest Insect Investigations of the U.S. Department of Agriculture. The series included 123 plots, and a comparison between 1949 and 1951 was presented by Crosby (1953, p. 159). The data indicated that the general trend in birch condition in the northeast was still downward.

Prior to this interstate survey, the Maine Forest Service gathered information for several years. Prepared interviews were held with nearly all of the birch operators in order to obtain the benefit of their practical experience and ideas.

Permanent study plots were first established in birch areas in 1941 and were gradually increased in number as the years went on. From 1946 to 1951 the Maine Hardwood Association sponsored the work (Nash and Duda 1951, p. 6).

Damage over the state had been severe in all sections except for two areas, one being the southwestern part of the State, and the other was in the northwestern Maine at the head waters of the St. John, Penobscot, and Kennebec Rivers.

Thirty nine percent of the trees were dead by 1950.

2.5.4 Nova Scotia

In Nova Scotia, studies of birch dieback in the years prior to 1948 were extensive rather than intensive in nature, a natural consequence of the status of the problem at that time (Greenidge 1953a, p. 70). From 1948 53 plots were studied, especially the moisture regime within the trees. The results of these studies will be dealt with in a separate chapter.

Hawboldt however, had in 1944 started laboratory tests and field investigations. In old growth yellow birch stands in northern Nova Scotia a rapid deterioration by crown classes was demonstrated for the years 1945-8. A graph (Greenidge 1953a, p. 75) showed that overtopped classes were initially healthier than the co-dominant and dominant classes. This relationship remained unchanged throughout the examination period. Hawboldt (1947, p. 414) also made intensive root studies which will be covered in a separate chapter.

2.5.5 New Brunswick

The first plots established in New Brunswick were laid out in the Fredericton and Green River areas in 1939 by Barter (1953a, p. 13). At Fredericton yellow birch were measured annually from 1939, but at Green River no annual figures were available for the 6-year period from 1940 to 1945.

Trees commenced dying on plots at Fredericton around 1937. During the first three years, this was relatively light (2-3 % per year), but during the next six years severe (5-14 % yearly).

At Green River no mortality was recorded on the plots at establishment in 1939, but the records showed that about 54 per cent of the trees had died by 1946. The number of dead trees had reached 58 per cent in 1951.

In 1952, Barter classed all New Brunswick as an "Old Dead Area", with most of the yellow birch of merchantable size either dead or dying. "In mature or overmature stands undisturbed by cutting, total mortality of trees over 12 inches D.B.H. amounts to between 70 and 85 per cent, of trees 24 inches D.B.H. and up, 85 to 100 per cent" (Barter 1953 a, p. 19).

2.5.6 Petawawa Forest Experiment Station

After Barter's visits and extensive surveys of birch dieback in Ontario in 1947 and 1948, Fraser (1959, p. 6) established in May 1949 an 8-acre experimental plot at Petawawa Forest Experiment Station. There intensive studies could be carried out throughout the entire year in a hardwood stand containing yellow birch. These studies were concerned with the physical ecology of the stand and growth responses of selected trees in various stages of decadence.

On the plot there were 241 yellow birch trees. These were listed in 1949, and their crowns classified each year during August. Over the three-year period 1949-51, these yellow birch trees showed a marked improvement in crown condition (1953, p. 98).

The plot was closely monitored further, and a detailed view of the progress up to 1957 was given by Fraser (1959, p. 20).

During the nine years of observation there was a gradual improvement in crown condition from 1949 to 1951, followed by a slow decline until conditions in 1957 were essentially the same as those in 1949 except for the trees which had been wind-thrown.

The general level of injury at Petawawa seems moderate in relation to the survey in the province in general (compare Sinclair and Hill 1953, p. 171).

2.6 Detailed studies in Nova Scotia 1945-1951

2.6.1 Root studies

Hawboldt carried out his first root studies near Willowdale in the autumn of 1945, primarily to develop techniques (Hawboldt 1947, p. 416). These studies have turned out to be the most elucidating so far and have to be dealt with in some length here. From Hawboldt's description (p. 417-8) the following summary is taken.

The area had been lightly cut over in 1939-40 and supported in 1945 a residual yellow birch-maple type with heavy fir undergrowth. The birch was in advanced stages of dieback. Five co-dominant trees were selected for excavation about 25 m above a brook on a west slope of 20 to 25 degrees. The five trees analyzed were chosen as illustrative of various degrees of decadence.

After felling the trees, soil was sluiced from the roots with a fire pump and samples of the rootlets were taken for examinations, an average of over 1200 being examined from the system of each tree.

Tree No. 1, 28 cm d.b.h., was situated within a small area in which there had been no cutting and was, therefore, not subjected to any increased exposure.

While standing, its crown appeared perfectly normal. The foliage was full-size and healthy, and no dead twigs were apparent. It was placed in the apparently normal Class 1. After felling, the tree was found to have 10 percent of terminal twigs dead. This mortality was apparently very recent, since the twigs still bore their complement of full, green foliage. The bark was stripped completely from the entire tree down to about 2 cm branches, without finding any evidence of past or present *Agrilus anxius* attacks.

The tree had about 30 percent of its rootlets dead with a small amount of mortality among the branchings, to zero mortality in the tertiary group. No mycelial fans of *Armillaria mellea* Wehl were present.

Tree No. 2, about 36 cm d.b.h., was placed in injury class 2B, having decidedly small, thin and curled foliage, particularly in the top quarter of the crown. While the tree was standing no dead twigs were evident, but when felled, the mortality was found to be about 33 per cent. These dead twigs still bore small, curled foliage. Some of the nodes were devoid of leaves, these presumably having been dropped during the season. Some buds had burst in the spring, but the leaves failed to flush before conduction was entirely cut off, and they had remained small, shrivelled, and curled. Other buds did not burst. All of this, along with the size of the foliage, contributed to the thin appearance of the crown.

Other observations and the analyses during the past three years lead one to believe that the first stage of visible die-back was observed in tree No. 1, and that tree No. 2, in the fall of 1944 was like tree No. 1 in the fall of 1945. Apparently there was insufficient conduction in the twigs of tree No. 2 for the foliage to develop. These twigs of tree No. 2 may have been moribund in the fall of 1944. The dead twigs of this tree also produced *Gelgtinosporium magnum* Ellis.

Rootlet mortality was higher than in tree No. 1, it being 44 per cent of the total sampled. None of the tertiary group was dead.

Again mycelial fans of *Armillaria mellea* were absent, although subterranean rhizomorphs were present. There was no evidence of attacks by *Agrilus anxius* in the crown or stem.

Tree No. 3, 33 cm d.b.h., was categorized as a class 3A, with very thin, small, curled foliage over the entire crown and with some dead twigs. After it was felled, considerably more mortality appeared. There was 68 per cent dead twigs over the crown, and mortality included several of the smaller branches. Some of these branches had apparently died during the 1945 season.

Exposure of the roots revealed 63 per cent of the rootlets dead. Mortality among the root branchings decreased to zero in the secondaries. Again no mycelial fans of *Armillaria mellea* were found.

Only current year's attacks of *Agrilus anxius* were present, galleries ranging in length from 2 to 13 cm, the average length being 5 cm. Most of these attacks were unsuccessful at the time of examination, about 65 per cent of the 51 larvae in the tree being dead. All the attacks were located in those branches of the crown between 2.5 and 8 cm in diameter. The tree was 16.8 m high and the galleries occurred in the branchings of those 1.5 m sections from 10.5 to the 15 m levels.

Tree No. 4 was 33 cm d.b.h. The entire crown of this tree was dead, except for three living, adventitious branches at the base of the crown, a class 4B tree.

There was mortality among the entire root system except for the primary branchings, mortality in the rootlets being about 89 per cent. Rhizomorphs of *Armillaira mellea* were adhering to the roots but no mycelial fans were found when the roots were peeled.

There was an abundance of attacks by *Agrilus anxius*, but no attempt was made to analyses this tree as carefully for extent or degree of attack. It was obviously sufficient to be detrimental to the tree.

Tree No. 5, 40 cm d.b.h., was entirely dead except for green streaks of cambium at breast height (class 5B).

The root system was entirely dead to the primary branchings. Of the six primary laterals, four were dead, while two had living streaks continuous with the green cambium of the stem.

Mycelial fans of *Armillaria mellea* were present in the stump, root collar, and primary lateral roots.

Successful attacks of *Agrilus anxius* were plentiful, as well as attacks by other secondary insects.

Howboldt (1947, p. 418) ended his description of the root studies: "In deciding what records to take on decadence, it was felt that condition of the twigs and rootlets presented the major part of the story in the early stages of dieback. Later analysis of the data seemed to substantiate this."

2.6.2 Relation between damage in the crown and root death

The studies by Hawboldt revealed very close relationships between crown damage and rootlet dying, dead rootlets occurring at 30, 44 and 63 per cent in classes 1A, 2B, 3A.

Continued root studies in 1947 gave very similar results (Hawboldt and Skolko 1948 p. 667). After exclusion of four abnormal trees, the rootlet mortality was about 30 percent in class 1, 32 - 33 percent in class 2, 33 - 44 percent in class 3A and 44 - 69 percent in class 3B.

Later, Redmond (1955 pp. 617, 620) found a normal rootlet mortality of about 6 per cent in a 55-year-old yellow birch stand near Acadia Forest Station.

The root studies in Nova Scotia, which continued in 1948 and on a much expanded scale in 1950, confirmed the close relationship of percentage rootlet mortality to crown injury class. "It is now quite evident that abnormally high rootlet mortalities in apparently healthy trees may be considered the initial indication of a diseased condition in yellow birch." (Greenidge 1953, p. 86).

The findings of a close relation between crown damage and rootlet dying in Nova Scotia were important, and led to increased interest of root studies, especially in relation to soil temperature.

2.6.3 The moisture regime of healthy and diseased birch

In Nova Scotia another very important study was carried out in 1950-51 on the moisture regime of healthy and diseased yellow birch, reported by Greenidge (1953a and 1953b).

The patterns of moisture movement were traced within approximately 90 healthy and diseased trees by means of the injection of water soluble dyes into the lower boles. The trees were felled and analyzed for the purpose of following the paths of moisture movement.

The staining patterns observed in trees of injury classes 1A to 2B inclusive were identical, illustrated by pictures of sections taken at 1.22 m intervals. The dye solution moved vertically upwards in the outer growth layers, giving in longitudinal surface section, a continuous staining pattern. In addition to its vertical component, the injection fluid also moved radially inwards a variable distance, frequently to the outer limits of the heartwood. The entire cross section of the sapwood thus appeared to be capable of functioning in water-conduction.

In apparently healthy material the injection fluid reached the apex readily. The time required for the movement of the solution from breast height to the terminals of the crown varied widely with weather conditions, crown class and size of tree, which ranged from 5 to 18 m in height with diameters of 10 to 30 cm.

In the 3A trees the dye solution commonly rose only a short distance in the outer rings. Further upwards the dye moved in the inner sapwood, leaving the outer 13-20 mm of sapwood unstained. The dye solution reached the apex in the majority of trees in class 3A. However, the staining patterns observed in the crowns of these trees were, in contrast to those of healthier classes, very irregular and discontinues. In class 3B material, the dye solution failed in every case to reach the terminals of the upper crowns.

The upward movement of dye solution in class 4A and 4B trees were very restricted, and infrequently went above the adventitious branches.

Six trees of injury classes 3A and 3B were analyzed also for borer galleries. Marked radial transfer of the dye solution was as evident in these infested trees as it was in non-infested material. Thus it may be stated that bronze birch borer activity appears to have no apparent influence on the movement of moisture in the secondary xylem of yellow birch.

In connection with the moisture movement studies, an additional 167 trees were felled for studying the distribution of moisture in healthy and diseased stems of yellow birch. (Greenidge 1953a pp. 77, 88). The studies indicated that moisture is an important factor in dieback. The potential of the individual tree for the absorption of water is of greater importance to the vigour of that tree than the mere presence of adequate moisture.

From a study in Ontario of the moisture content of yellow birch, two general impressions were revealed. The moisture content of healthy trees decreased from the beginning of the season until the third week in July, and thereafter, increased until the end of the season. In unhealthy trees the moisture content increased from the beginning of the season until the second week in July, and thereafter decreased until the end of the season. The increase early in the season was more pronounced in the case of trees in the intermediate stages than in the trees in the initial stages of deterioration (Sinclair and Hill 1950 p. 178).

From studies in cut-over areas in 1929 Hall (1933, p 15) demonstrated that the moisture content in the sapwood at breast height of paper birch increased with increasing decadence.

Thrifty trees with normal leaf development had a moisture content of about 50 per cent, whereas those with leaves 25 per cent of normal size averaged about 100 per cent, and those with still smaller leaves averaged much higher. "This high moisture condition in decadent trees may be due to decrease in transpiration surface."

The moisture content of the leaves was essentially the same regardless of size, averaging about 212 per cent, and remained relatively constant throughout the summer (p 16).

2.7 Experiments with soil temperatures

The conclusion that high rootlet mortalities may be considered the first stages of birch dieback (Hawboldt and Skolko 1948, p. 668) was considerably enforced by Greenidge (1953a, p. 90 and 1953b, p 548) and led to a greater interest in soil conditions.

After five years of studying fungus on leaves, twigs and roots of yellow birch at the Dominion Laboratory of Forest Pathology at Fredericton N.B., Redmond (1953a, 1953b, 1953c) could conclude that the cause of birch dieback was not to be found among fungi.

2.7.1 High temperature

A closer study of a few selected fungi on root systems of yellow birch was carried out in a chamber with observations of differences in root development, mortality, and occurrence of mycorrhiza at different temperatures (Redmond 1955, p. 610). The results showed that soil temperature can influence the balance of microbiological populations and the vigour of rootlets. To investigate this further, the soil in a 6 by 9 m area was artificially heated and the effects on yellow birch rootlets were measured in a 55 year old stand near Acadia Forest Station, N.B.

The results after the heating between June 3 to September 6 1952, was that 2°C rise of soil temperature increased the rootlet mortality from a normal of 6% to about 60%, and a 5°C rise gave 96% mortality. The heating caused no decline of vigour in foliage.

A few rootlets within the experimental plot from one sugar maple indicated differences between the two species. Maple had a normal rootlet mortality of about 2% at 5°C rise.

It had been reported that the average summer temperature in Nova Scotia and New Brunswick increased 1.0 - 1.4°C during the 30 year period prior to 1950. Consequently, increased soil temperatures might have caused abnormal rootlet mortality. "However, it is difficult to reconcile the reported spread of dieback from a focal point in New Brunswick with the warmer climate unless higher temperatures originated and spread from approximately the same point. There is no satisfactory evidence that this is so" (Redmond 1955, p. 625).

2.7.2 Low temperature

In his summary of birch dieback history Pomerleau (1953a, p. 11) stated that neither the borer nor any fungus were the primary cause of the injury. But there was evidence to say that the responsibility of the damage could more likely be attributed to physical conditions.

He also questioned the reality of a gradual spread which was commonly accepted during the first decade of the malady (Pomerleau 1953b, p. 50). Dieback symptoms occurred in central Quebec as early as 1935 or 1937 at about the same time as in New Brunswick. It was his opinion that spread should be interpreted as a gradual intensification of the damage. Also Daviault (1953, p. 49) followed the idea of intensification rather than spread or extension.

Pomerleau (1953c, p. 114) stressed the observation that trees on damp sites, along swamps, rivers and lakes often were badly damaged. In a conclusion Pomerleau (1953d, p. 149) stated again that only physical factors and more specifically unbalanced water conditions could produce the extensive dying of birch and other species.

In accordance with Pomerleau's conclusion that physical factors, and more particularly anomalous climatic conditions, had been responsible for the birch dieback, he conducted a study 1955-1957. The goal was to obtain more precise information on the effects of soil temperature and soil moisture on dieback of white birch seedlings (Pomerleau 1991). The results of white birch root experiments refuted Redmond's (1955) results of yellow birch with considerable rootlet dying as a result of increased soil temperature.

However, some appendixes were added, based on older material.

Appendix 3 describes a deep soil freezing experiment by removal of insulating snow during the winters 1953/54 and 1954/55.

Based on numerous detailed observations, Pomerleau (1991, p 41) had formed the hypothesis that only climatic factors could explain the disaster of birch dieback. He carried out the deep soil frost experiment to verify his idea that forest dieback could be caused by absence of snow cover sufficiently deep to prevent deep soil frost penetration.

To reproduce the effects of snowless winters, the snow on 65 m^2 p lots in maple-birch stands were removed after each snowfall. Depth of freezing reached 1.27 m and the ground surface was heaved

46 cm by formation of ice lenses. Soil thaw came abnormally late.

In places where the ground had thawed and the surface was depressed, ice was visible, particularly around the tree roots. Superficial roots and rootlets were frequently broken, and some young birch and maple were falling down. By July or August, tree crowns within the experimental plots showed signs of dieback and mortality.

Appendix 4 describes a laboratory experiment performed in the late fifties. Yellow birch potted seedlings, 9-12 dm high with frozen soil, got room temperature and light on the crowns only, whereas root temperature was kept below 0°C. The root was kept for 5, 10, 15, 20 and 30 days before removal of the cover, allowing the soil to thaw gradually in the room temperature. The results were normal development for the 5 day treatment. For 10, 15 and 20 days, foliage dieback appeared through the course of experiment and became increasingly intense. For 30 days of soil frost, the seedlings had died by the end of the experiment.

The results indicated that trees with roots imbedded in frozen soil are killed by desiccation when the crown is subject to summer- level temperature and light conditions for sufficiently long periods (Pomerleau 1991, p. 46).

2.8 The role of the bronze birch borer

In nearly all the reports on birch dieback the bronze birch borer (*Agrilus anxius* Gory) is mentioned.

In their studies of birch decadence on cut-over forest land Spaulding and MacAloney (1931, p 1149) concluded that the bronze birch borer can not be considered a primary insect pest, and Hall (1933, p 18) could fully confirm that conclusion.

Regarding uncut forests, Balch and Prebble (1940 p. 180) after their investigations in 1938 and 1939 concluded that the bronze birch borer did not produce the first symptoms of birch dieback. Other authors have repeatedly confirmed that the borer can not be the primary cause.

Barter (1953d, p. 122) summarized the knowledge and concluded that: "While moribund material is required for rapid multiplication of the borer, such conditions are not invariably required for its survival. Some individuals are capable of either completing their life cycle, or a major part of it, in trees putting on sufficient wood growth to heal over the galleries and survive if not repeatedly attacked. Therefore, the borer is capable of causing severe injury or death to healthy trees or those capable of recovering from a temporary weakened state, by repeated attacks, when sufficient moribund material is available to produce or maintain a high population level. Thus it is considered a major factor in the final death of trees affected by dieback."

Of special interest are the borer studies in Nova Scotia where Hawboldt (1947 p. 418) found no attacks in crown class 2 trees. Hawboldt and Skolko (1948 p. 665) could from their studies in 1947 confirm that result and concluded: "Although borer infestations do not follow a given pattern as a basis for broad generalizations, it would appear that, at least in areas of more recent dieback and decadence, trees usually reach class 3A and frequently class 3B before any significant degree of borer infestation can be expected. There is a good probability that, as the amount of dying material increases and the borer population becomes sufficiently great, attacks in individual trees become more numerous in the earlier stages of dieback and decadence."

2.9 Experiments with virus

Besides fungi and insects, viruses have been mentioned as a possible cause of birch dieback. Redmond (1955, p. 625) said: "There is a possibility that a virus yet to be discovered is responsible."

Berbee (1957) studied the virus on yellow and white birch from New Brunswick and Nova Scotia. Since many of the birch dieback symptoms seemed to be typical of virus diseases, a vide variety of transmission trials were set out in growth chambers, in greenhouses, in nurseries, and in the field. Some of the healthy seedlings were approach-grafted, either by roots or by stems of typically diseased trees in the field. Many of the seedlings that received scions from diseased trees showed striking symptoms during the second growing season following the grafting.

In the nursery an attempt was made to secure transmission of the disease with leaf hoppers. This experiment and a wide variety of trials designed to test mechanical transmissibility were inconclusive.

In field experiments healthy 40 to 60-years-old yellow birch trees were grafted in various ways, and bark patch grafts were applied. Conclusive results were not obtained by top grafts, but ten out of twelve of the trees that received bark patches from deceased trees exhibited definite symptoms the second season. These were suggestive of the early symptoms of birch dieback.

The conclusion from Berbee was that although many of the transmission trails had failed or still not yielded conclusive information, the results to that date had shown promise. Still it was not known whether the disease that had been transmitted would prove sufficiently severe to account for the birch dieback malady.

The virus theory was taken into account by Clark and Barter (1958, p. 351) in their review of literature of growth and climate in relation to birch dieback. Also the June to August net water balance was calculated as an important climatic parameter. Their conclusions were that the variations in the water balance and the fact that growth reduction was greatest in vigorous trees cannot be reconciled with the hypothesis that dieback is a purely physiological disturbance brought about by climatic stress. Nor was there a coherent theory of the mechanism by which the suggested physiological disturbance is related to climatic factors. "Instead, these facts, together with our evidence of spread and Berbee's description of typical virus symptoms, suggest that the birch dieback is an infectious disease" (p. 362).

2.10 Damage to other species in connection with birch dieback

In the assessments in the late forties other species also were tallied on the plots. From Ontario, Sinclair and Hill (1953 p. 177) presented tables showing the situation for yellow birch and hard maple in 1950 and 1951. A comparison indicated that the condition of hard maple showed a slight decline in the period, but that this decline was less marked than that exhibited by yellow birch. Pomerleau (1953, p. 11) mentioned that the disease had continuously increased in intensity on birch since about 1937, but especially from 1940 until about 1950. He thought it important that during this period, but more especially in 1946, 1947, 1948 and 1949, beech, maple, elm, cherry, and poplar were similarly damaged to a more or less intense degree. Even conifers such as balsam fir, spruces, pines and hemlock were affected, although less so.

From the birch dieback event at Upper Michigan Peninsula, Jacobs (1960) noted that foresters and loggers throughout the peninsula reported top-dying in 1959 not only of yellow birch, but also of other associated hardwoods. On the observation plots at Dukes the injury to other hardwoods was minor compared to that to yellow birch, 12 per cent of all trees against 47% of yellow birch in 1958, and 17 per cent against 68 per cent in 1959.

The question of injuries to other species will not be followed further here, but the increasing research in forest decline includes several species.

2 .11 New research activities in Canada on forest decline

In recent years new interest and increasing activities have taken place on forest decline. Reasons are that the primary causes still are unexplained, damage is possibly increasing, and the changes in climate and in environment by pollution may be influential.

In this connection a Forest Decline Workshop was held in Wakefield, Quebec, October 20-22, 1986. The workshop was arranged by LRTAP (Long Range Transported Air Pollution), and 25 researchers participated. Decline was reported in at least 16 hardwood and conifer tree species. However, birch dieback was scarcely mentioned, except for an intergraded map (version 31/01/87) on yellow birch in eastern Canada (LRTAP Workshop No. 6, 1986, p. 215). With reference to Rose et. al. (1969) a small dieback area is indicated on this map at Montreal River, 1950-1968.

Following the workshop a concept paper and research proposal were worked out. In the summary, the value of timber volume loss to birch dieback (1935-1955) alone was estimated to be $60 billion in current dollars. (Auclair 1987a.) In this paper a new map was presented (Figure 5C) identifying the maximum occurrence of dieback on yellow birch reported in the symposium on birch dieback (Canada Department of Agriculture 1953) and in the forest decline workshop (Canada Department of the Environment 1987). This map is reprinted as Fig. 6 in Chapter 4 in a slightly magnified version.

In July 1987 a IUFRO conference on woody plant growth in a changing physical and chemical environment was held in Vancouver, Canada. A paper on forest decline was given by Auclair (1987b). The objectives were three-fold: 1. to present new evidence on the role of climate in the hardwood decline, 2. re-interpret the concept of climate-forest decline interactions, and 3. define the kind of research needed.

Based on preliminary results, the concept of climatic influence was formed in the theory: "Long-term climate change toward increased temperatures and associated variability in weather is a primary factor inciting forest decline in northern hardwoods of eastern Canada and northeastern United States" (p. 8).

With references to Spaulding and MacAloney (1931), Hall (1933), Hawboldt and Skolko (1948) and Greenidge (1953b), Auclair stressed that the key to understanding the cause of dieback on Northern Hardwoods is a pivotal observation made early in the study of birch dieback, namely that damage and mortality of the root systems occurred prior to the onset of the symptoms in the crown. This was apparent as early as 1931.

In a continued, extensive literature review and discussion Auclair et.al. (1992, p54, Fig5) presented a conceptual model linking global climatic change to forest dieback in the north temperate and boreal zones. Among the six points listed, winter thaw-freeze was included.

Auclair also made a historical reconstruction of the incidence and severity of the dieback in eastern Canada. Year to year changes in progress of disease were tabulated and judged on a relative scale of low to high.

The result for yellow and white birch expressed graphically by Auclair (1987b, p 26) is reprinted in Fig. 7B. The graph clearly shows the huge birch dieback from 1937 to 1949 and a fairly low latent phase in later years.

3. THAWING AND FREEZING EXPERIMENTS IN NORWAY

3.1 Seed Supply

Preparations for the birch dieback trials in Norway started in 1984, and University of New Brunswick was asked for seed of yellow and white birches. The seed was received through the Forestry Ranger School at Fredericton in the spring of 1985.Unfortunately the germination failed, probably due to improper watering in the greenhouse.

New seed was obtained through Forestry Canada - Maritimes Region and sown in the spring of 1987. The seed of yellow birch (*Betula alleghaniensis* Britton) was collected at Cent. Res. For. Ottawa, Ontario 1970, latitude 45°24', longitude 75°33'. The seed of white birch (*B. papyrifera* Marsh) was collected at Acadia For. Exp. Station, New Brunswick 1984, latitude 46°00', longitude 68°19'.

The two tree formed birch species native to Norway, silver birch (*B. pendula* Roth.) and common white birch (*B. pubescens* Ehrh.),were taken into the experiments for comparison. The seed of both species was collected in south-eastern Norway.

After one growing season in multipots, the seedlings were single tree potted in five litre pots in the spring 1988. After the growing season 1988, the two year old seedlings in the autumn had an average height 0.6-0.8 m for yellow birch and a little higher for the other species (0.8-1 m).

3.2 Temperature pattern - diagrams

Besides studying the injury symptoms on buds and twigs, the intention of the thawing experiments and calculations of temperature levels and sums was to find values against which the effects of natural thawing events on birch dieback could be judged.

The temperature observations available from Canada and US are the daily maximum and minimum. Consequently, the only values for the daily means are the average of these two, and this temperature expression is used even in the experiments where more frequent observations were made.

The pattern and level of temperatures are shown in several diagrams. Fig. 1, D-E, show temperatures during the experiments in Norway 1989-90. The upper curve (broken line) shows the daily maximum temperature in centigrade, and the lower curve (solid line) the minimum temperature. A solid line is drawn through the freezing point. Broken lines are drawn at +6°C where biological activity may be expected, and at -5°C where frost damage is expected to occur on trees in vulnerable stages.

The diagrams are split into periods by vertical lines. The length and pattern of periods vary. A main feature is that last or second last line is drawn a day or two before the latest frost temperature of -5°C or lower, because a calculation of sum of day-degrees up to the freezing seems important. Another feature is that periods of 21 days of mild weather are chosen where possible. The origin were the length of the 1936 March thaw and the same standard length in the thaw experiments in 1989 and 1990.

For each of the periods the average max and min temperatures are calculated and put into the diagrams as second upper and lower line of figures. For the thaw period also the average mean temperature (average of max and min) is calculated and put in parenthesis.

3.3 Climatic warming - sum of day degrees

Measures of climatic warming have been used in studies of flowering of trees, date of budburst of different species and for genetic variation within species (Sarvas 1967, 1972 and Murray et. al. 1989).

The base temperature mostly used seems to be 4°C, and the degrees of one day is then the mean temperature minus 4. Days with mean lower than 4°C (negative values) are neglected.

The sum of day degrees (DDG) for a given period of n days is calculated by the formula

$$DDG = \sum_{i=1}^{n} ([max + min]/2 - 4)$$

This sum of day degrees is calculated for each period in the diagrams and put in the top line. Accumulated DDG before the last frost (-5°C or lower) is placed after the equation sign in the period where the last frost occurred. This total sum of day degrees is also displayed on the maps in Fig. 5.

In a phytotron experiment with constant temperatures Heide (1993, p 534) found a base temperature of 0°C for silver birch. For other hardwood species effective base temperatures were estimated to be between 1 and -5°C.

The base temperature for yellow birch under natural conditions based on the max and min average may therefore be different from 4°C. Nevertheless, 4°C is used for the calculations of day degrees both in the experiments in Norway and the comparisons in Canada and USA. So far it seem somewhat uncertain how much a deviation from a true base temperature influence such comparisons.

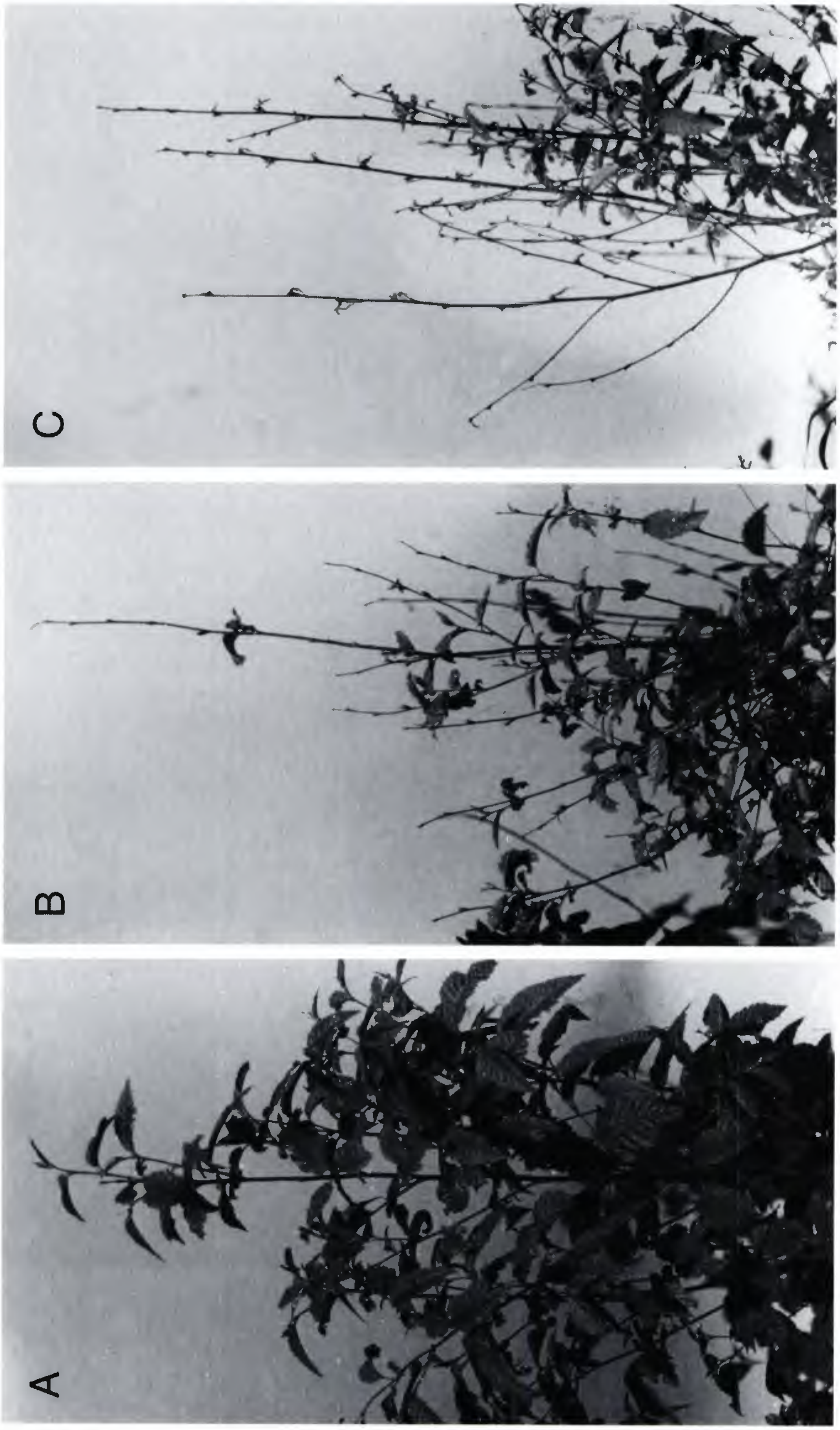
3.4 The first thaw experiment 1989

The purpose was to give the seedlings an artificial thaw of the same nature as had occurred in central New Brunswick and Maine in 1936. Nine seedlings of each species were put into a greenhouse for mild weather treatment. The March thaw in 1936 lasted for 21 days, and thawing periods of 14 days, 21 days and 26 days were chosen with three seedlings in each.

The potted seedlings were on February 19th brought from the Soensterud nursery to Aas. The weather at the nursery had been rather cold the first third of January, and from January 12 to March 9 the maximum temperatures lay in the range of 5°C and the minimum between 2° and -5°C. The last 11 days before moving the seedlings into the greenhouse had an average max and min temperature of 3.5° and -2.8°C as shown the temperature diagram, Fig. 1 D. This means that the seedlings had no mild spell before the artificial thaw experiment, and the soil in the pots was completely frozen.

The treatment started February 22. Lumps of ice were put between the pots to keep the root temperature low, and the pots were covered with polystyrene. The temperature between the pots varied from 5°C the first few days when the soil in the pots still was frozen, up to 9°C later in the period. On this point the research conditions differed from those in the field where the root temperature must have been about zero at start or may be a few degrees plus in the later part of the period.

A self-recording thermograph gave the temperature curve, and the max and min were read for each day. The period of maximum was rather short, usually not more than two to four hours, because it took considerable time to heat the greenhouse up to that temperature, and the heat was cut off again in the afternoon. For this reason the biological effect of the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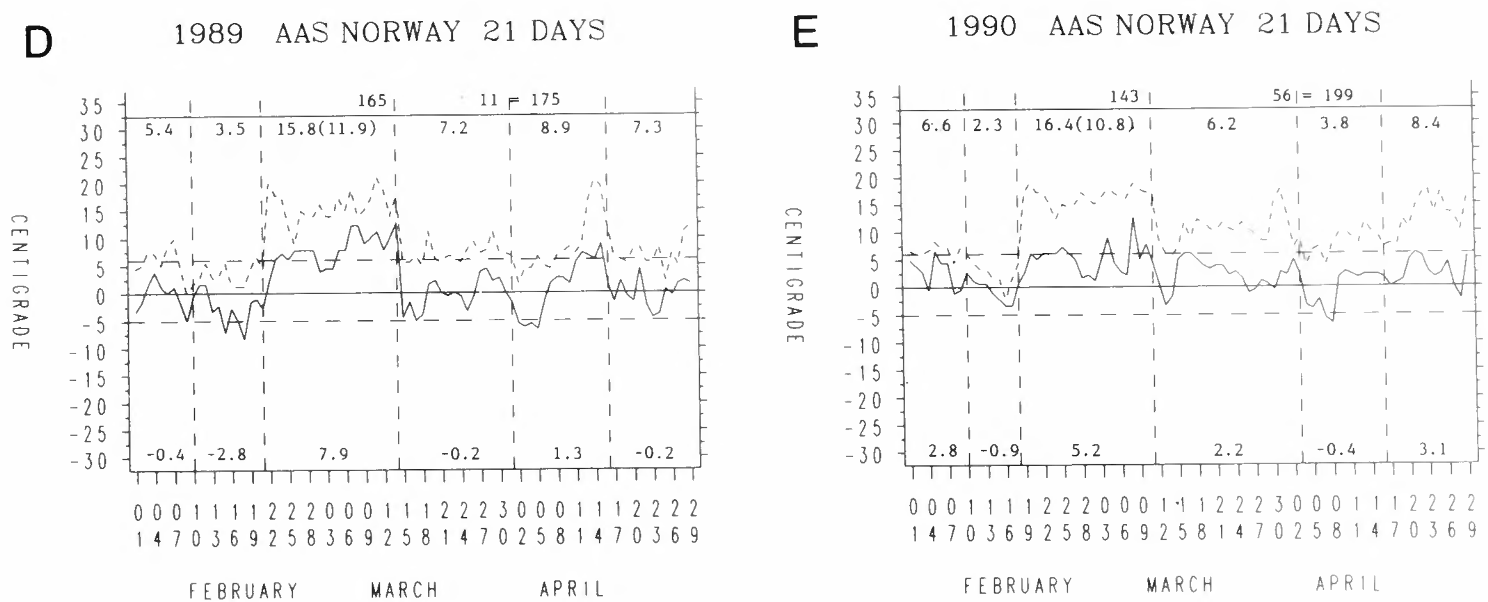


Fig. 1. Artificial thaw experiments at Aas, Norway, 1989 and 1990. Yellow birch, pictures taken June 12, 1989. A. Thaw period 14 days, DDG=98/113 (98 during treatment period, total 113 at frost). B. Thaw period 21 days, DDG =165/175. C. Thaw period 26 days, *DDG=211/219.D. Temperature diagram, 21 days 1989. E. Temperature diagram, 21 days 1990. Legend to diagrams: Upper curve (broken line) shows daily max temperature C° and lower curve (solid line) daily min temperature. Calculated periodic average max and min temperature are given in second and bottom line of figures. For the thaw period the average mean is put into paranthesis. Periodic sums of day degress (DDG, base temp. 4°C) is given in first line and summed up before the last frost of -5°C or lower*

heating may be less than normal for the calculated day degrees.

The experimental temperature turned out to be considerably higher than desired, it was especially difficult to reduce the min temperature at night downwards to about zero, but also the max temperature became higher than expected. The development of the seedlings were followed with notes, but no budburst scale was used.

After the end of the thaw periods the seedlings were placed outside the greenhouse until May 2 and then replanted in the field without pots.

The results of the artificial thaws are mainly given in pictures. Both the control seedlings and the 14 days thaw treatment developed normal leaves. The seedlings given 21 days thaw had got nearly 100 per cent injured twigs at the top with only yellow or brown fringes of leaves. (Fig. 1 B). For the 26 days treatment the picture was similar with 100 per cent bare tops, but the bare or dead parts of the twigs were about twice as long as for 21 days. The leaves which developed close below the dying part of the twigs were smaller, somewhat deformed and thicker.

These results are very similar to the symptoms for yellow birch dieback described by Balch (1953) with bud failure and dying twigs from the top, and to the descriptions in the crown classification system used.

Later in the summer and autumn the twigs with failing buds died and deteriorated. Some of them fell off in the autumn, but some were still on in the spring of 1990. A few of the dead twigs seemed to some extent to die off somewhat further down in 1990, but this was not observed as closely as it might have been, and no definite conclusion can be drawn on this point.

For the white birch the effect was not so clear, although noticeable for the 26 days thaw period. The symptoms however, were not the dying off from the top, but more a scattered thinning out of the leaves, and some smaller but thicker leaves occurred. For the silver birch seedlings no or very small effects of the thaw treatments were observed.

The results of this 1989 thaw experiment were very interesting. Consequently, they stimulated to further experiments and studies.

3.5 The second thaw experiment 1990

The birch seedlings not used in the first experiment were in May 1989 repotted into 10 litre pots and placed in the nursery at Aas. These trees were suitable for a second experiment which was started at February 19, 1990.

As the 1989 experiment showed no effect of the 14 days thaw treatment, this treatment was left out and a longer treatment of 32 days was added. From January 7 and onwards the winter was unusually mild at Aas. Only two times before the experiment started the maximum temperature fell below zero.

Through the 42 days period (January 7 to February 18) average min was 0.7°C and the average max temperature 4.6°C. This long mild weather period caused no visible signs of bursting buds or other biological activities, but the soil in the pots was soft and completely unfrozen.

The temperature diagram (for 21 days) - in 1990 shows a similar pattern as in 1989 (Fig. 1, E). However, the average max temperature in the thaw period was slightly higher (16.4° against 15.8), but the average min temperature was somewhat lower. As a result the mean temperature was 10.8°C against 11.1°C, but this is still higher than intended.

For the yellow birch any response as

top dying was hardly observable. No clear symptoms such as dead twigs occurred, except maybe two or three small tops in treatment 32 days. However, the crowns had fewer leaves and appeared somewhat more open, especially after 28 days of treatment.

Also for the white birch the symptoms were slight, but the crowns were somewhat more open after the thaw treatment. In conclusion, white birch was in 1990 a little more affected than yellow birch in contrast to the 1989 results when the situation was clearly opposite.

3.6 Frost damage - differences between 1989 and 1990

An important difference between the two years seems to be the frost pattern the seedlings, placed outside the greenhouse, were exposed to after the thawing period. Temperatures were measured at the weather station at the Agricultural University of Norway, which is situated 1.3 km south-east from the greenhouse. Height above see level is 93 m against 130 m for the greenhouse.

A test of temperature differences was made the last 4 nights of March 1993, which had min temperatures at the station between -4.3 and -6.8°C. The wind direction was SW with a force between 0.5 and 2.4 m/s, during the 2-6 hours with temperature lower than -5°C.

The result was that a wind force between 1.4 and 2.4 m/s gave no difference in min temperature, whereas only 0.5 - 0.7 m/s gave a min temperature 0.6°C lower at the weather station.

Using these values for adjustment, the min temperature is estimated in the following table for the nights with observed min temperature of -5°C or lower.

The low temperatures are in the same interval for the two years, but two differences may have influenced the frost effect. In 1989 three of four nights were below -5°, and the wind directions during the cold hours were north to northeast and east. As the seedlings were placed 20-60 cm outside the northern wall of the greenhouse, they were fully exposed to the cold air draft. In 1990 only two nights were that cold, and with wind directions from south and southeast the seedlings were sheltered from the draft.

From the experiments in 1989 and 1990 it is not possible to draw an exact temperature limit where frost damage occur on flushing yellow and white birch. It seems however, not doubtful that the damage observed in the experiments is

Estimated minimum temperatures at the greenhouse wall during the frosty nights

	Aas 1989				Aas 1990	
	April 2	3	4	5	April 7	8
Recorded °C	-5.3	-6.2	-5.4	-6.9	-5.5	-6.7
Wind m/s	0.5	1.1	1.1	0.6	0.9	0.7
Wind direction	NE	N	NE	E	S	SE
Estimated °C	-4.7	-6.2	-5.3	-6.3	-5.3	-6.1

caused by frost in a vulnerable stage of early flushing.

3.7 A freezing experiment 1993

During the work with the thaw temperatures and subsequent frost patterns, it stood out clear that a late spring frost was very disastrous.

To look more closely at the symptoms of such a late frost would be of interest, and a freezing experiment was carried out on yellow birch May 12, 1993.

The spring in South-Norway 1993 was rather early and warm (Fig. 2 E). Flushing on the yellow birch occurred quickly, and on May 11 the length of new leaves ranged between 12 and 20 mm (DDG= 156).

A yellow birch tree, 1.8 m in height, was surrounded by 4 layers of eye bubbled plastic sheet on a 1 x 1 m wooden frame (scaffold). In the height of 1.6 m four wire baskets were placed in the corners holding lumps of the so-called dryice (CO_2 at -79°C). Thermographs were placed at 1.7 m height and on the ground together with minimum thermometers (Fig. 2 A). At midnight May 11 about 5 kg dryice was apportioned into the baskets. At 0210 another 5 kg dryice was refilled in the baskets, as little was left of the first filling.

The effect of the first filling was moderate. Lowest temperature at ground were about -4°C after less than 30 minutes, but the cold was gradually decreasing. After the second filling the temperature fell directly to below -10°C. The thermograph was not constructed to record temperatures below -10°, but the minimum thermometer showed -10.8°C, occurring sometime between 0200 and 0600 in the morning.

The upper thermograph with the sensor 25 - 30 cm above the bottom of the baskets reached the lowest temperature at about 0400, but still not lower then 1.5°C.

It was known that the cold CO_2 gas is heavier than air, and a small electric fan was placed on the ground to stir and mix the air. It is not known weather the fan had any effect.

At the demounting of the set up about 10 ò clock the response was already recognizable below the bottom of the dryice baskets (Zone 3). The sprouting leaves had turned greyish green and with a trace of softness.

As the freezing experiment took place during the night, it is assumed that the concentrated CO_2 gas did not hurt the leaves. The stomata are then closed and no photosynthesis takes place. The effect observed therefore, is expected to be a result of the freezing of vulnerable tissue. The upper 20 - 25 cm of the top that had been above the freezing zone looked green and unaffected (Zone 1). Between zone 1and 3 a transition zone about 10 cm wide appeared untouched, but developed anomalously later. (Fig. 2 B).

After the night of freezing the weather continued warm, and undamaged leaves

The temperatures recorded (°C) were as follows:

	May 11	May 12			
Time	2330	0015	0200	0400	0600
Upper thermograph	10°	6°	4°	1.5°	2°
Ground thermograph	9°	-4°	-0.5	-10°(-10.8°)	

at the top developed quickly and vigorously whereas the damaged leaves shrank and turned brown.

In June vigorous growth of the top zone continued with rapidly prolonged top shoots, and in the middle of the month the first watersprouts appeared scattered on the lower 80 cm of the stem in zone 3 (C). At that stage some twig tops which had ended in the transition zone during the freezing had wilted and turned brown after 5 - 6 weeks of fairly normal leaf development.

During the summer the top twig increment had been larger than on the neighbouring trees, with some extraordinarily big leaves. This made the top twigs too heavy to stand upright in rainy weather, and they were tied up with strings. The watersprouts developed vigorously on the lower 90 cm of the stem, partly with extra large, wrinkled and slightly curled leaves.

This experiment, even in its simple and spontaneous form, yielded interesting results.The unfrozen top gave possibilities to observe the development within the three zones. Especially the transition zone with somewhat variable and less freezing, exhibited leaf forms resembling those described as part of the birch dieback throughout the history of the malady (Fig. 2 D). Also the watersprouts are an interesting development. As a whole, the experiment supported the idea of late freezing as an initial factor of birch dieback.

3.8 Budburst observations and freezing experiments 1994

The notes on bud development during the experimental thaws, were merely descriptions. The need for more systematic observations on bud burst of yellow birch under natural conditions was obvious, and such observations were carried out in April and May 1994 at Aas, Norway. Twenty-four yellow birch trees in natural positions in the nursery were used. The trees, left over from the 1989 and 1990 thawing experiments, were 7 years old. Heights varied between 1.1 and 2.1 m, with an average of 1.62 m.

3.8.1 Budburst - day degrees

Three twigs were selected on each tree, two upright twigs and one side twig at about half the tree height. Selected twigs were permanently marked with a numbered paper collar 3-5 buds from the end of the twig. These buds were observed from April 12 to May 13, and the twigs were each time classified on the most advanced bud above the collar, according to the following scale (Murray et.al. 1989, p 695): 1=slightly swollen, 2=swollen, 3=green foliage showing (<3 mm) and 4=elongation (> 3 mm).

The development of bud bursting of the 72 twigs is summarized in Table 1, and accumulated DDG at each date is given.

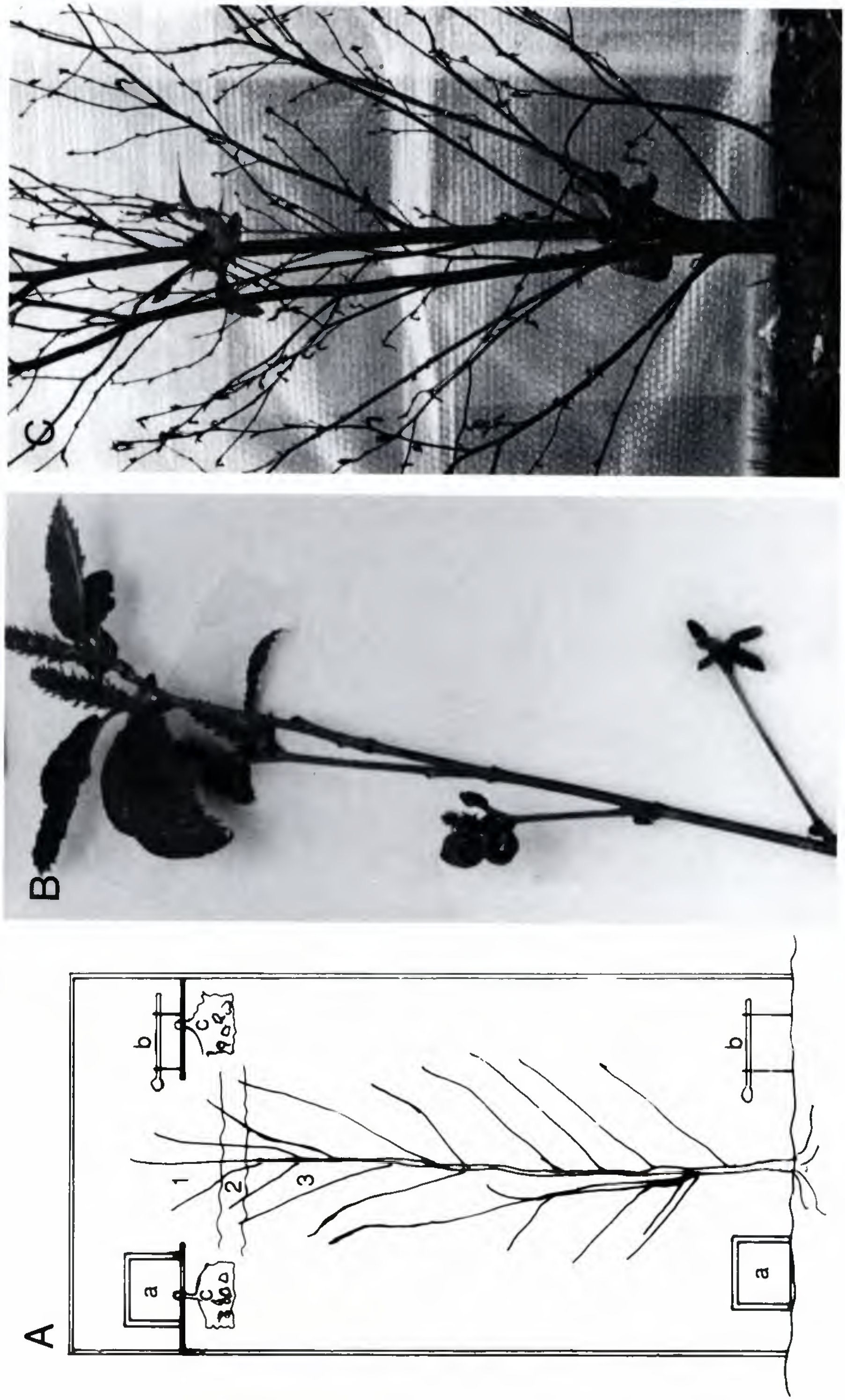
Although all the trees are of the same provenance (Petawawa, Ont. Canada), bud bursting into stage 3 varied from about April 20 to 28.

Crown side twigs of six trees had budburst different, earlier or later, than top twigs which mainly had simultaneous budburst. Only on five trees the two top twigs entered stage 3 at different dates. Variation of budburst within the trees is then very limited.

3.8.2 Freezing trials

The difference between the results of the trials in 1989 and 1990 most probably was caused by the level and length of following frost . A better knowledge of the vulnerability of the budburst stages to various frost temperatures was then of greatest interest.

Parallel to the budburst observations, freezing trials were carried out five times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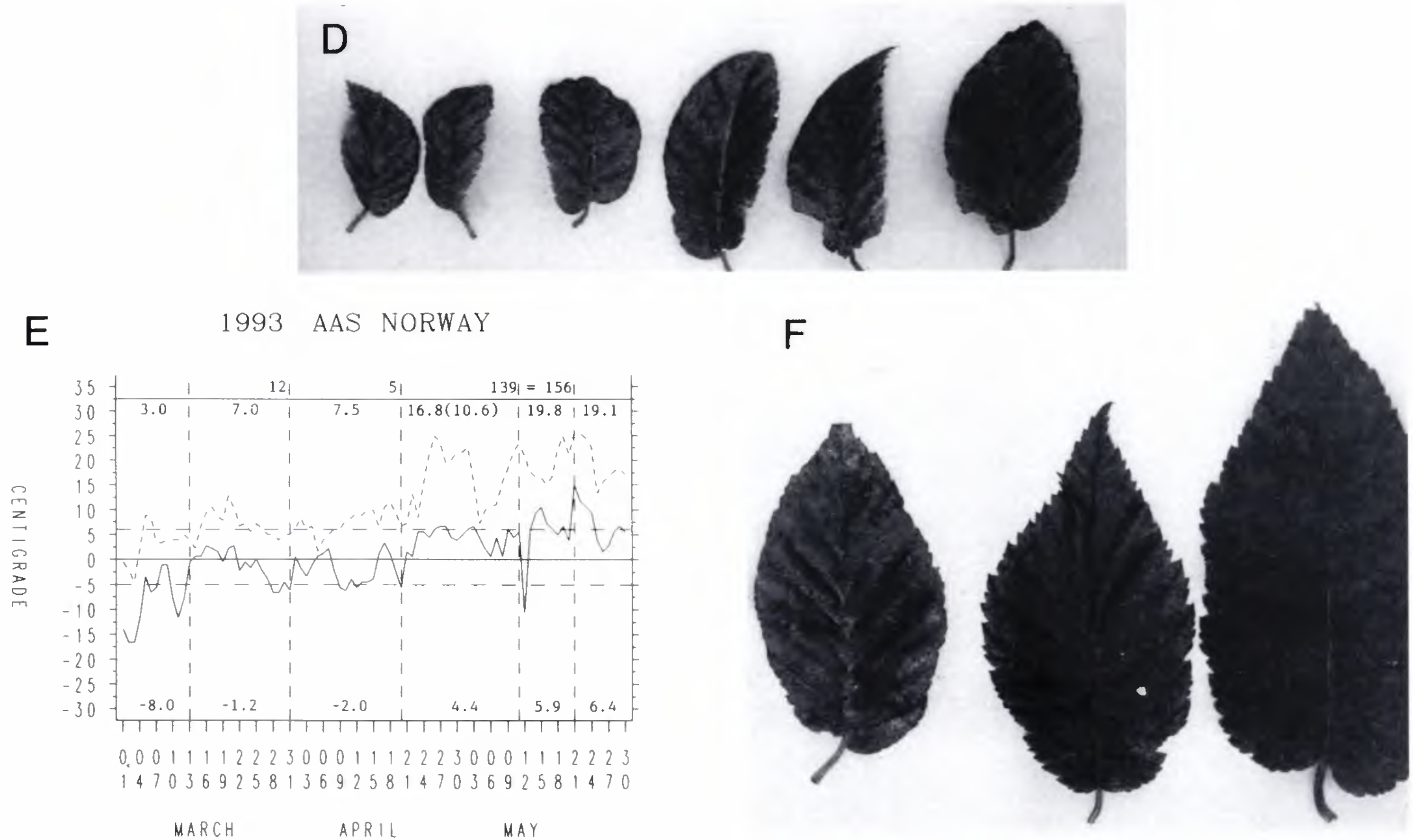


Fig. 2. Freezing experiment at Aas. Norway, May 12, 1993. A. Sketch of freezing set up; (a) thermograph, (b) minimum thermometer, (c) dryice basket, (1) Zone 1, no freezing, (2) zone 2, touch of freezing, (3) zone 3, freezing. B. May 18. Twig in zone 3, with the top in zone 2. C. Middle June. Watersprouts appearing in zone 3. D. September 19. Display of leaves from zone 2. E. Temperature diagram, artificial freezing May 12. F. Display of leaves from zone 1

Table 1. Sum of day degrees (DDG) and number of twigs in different budburst stages 1994. Yellow birch

	Apr. 12	15	18	21	24	27	30	May 4	8	13
DDG	12	20	23	29	45	64	80	94	116	164
Stage 1	38	34	21	16						
Stage 2	34	38	51	51	43	7				
Stage 3				5	29	33	7	1		
Stage 4						32-5*	65-7	71-8	72-18	72-35
" Average	1.47	1.53	1.71	1.85	2.40	3.35	3.90	3.99	4.00	4.00

* *For budburst stage 4 the leaf length in mm is added*

Table 2. Leaf injuries at freezing experiments 1994. Yellow birch

	April 11	18	25	29	May 5
DDG	10	22	52	75	99
Budburst stage	1	2	3	4-7*	4-14*
Zero treatment	0	0	0	0	0
Min temp -3°	0	0	0	0	0
" -5°	0	0	X	X	X
" -7°	0	0	X	X	X
" -9°	0	0	X	X	X

X indicates leaf injuries and subsequent death
**For budburst stage 4 the leaf length in mm is added*

between April 11 and May 5, 1994. Twigs 10 cm long with 3-6 buds were cut off in the afternoon, placed in wet sphagnum moss in small multipots, and then exposed to temperatures of -3°, -5°, -7° and -9°C. The zero treatment (0) refers to twigs not placed inside the freezers (10-15°C).

Advanced automatic freezing cabinets were at my disposal. From an acclimatizing base temperature of 5°C, the cooling took place at a rate of 3 degrees/hour down to the programmed freezing level, which was kept for four hours. Then temperature rose with 4 degrees/hour to the base temperature of 5°C which was kept for some hours to the morning. Then the twigs were kept with surplus of water in room temperature (about 20°C) for observations.

To minimize the variation between the twigs regarding budburst stage and vulnerability to frost, they were cut for each freezing from one tree only. Ten twigs were cut and placed 2 in each of the five treatments. Also white birch and silver birch were included in the freezing trials. The results however, are not generally different from those of yellow birch and will not be commented further here.

The temperature diagram at Aas 1994 (Fig. 3 F) shows day degrees for periods to the freezing dates, and Table 2 the temperatures that gave leaf injuries and death.

No frost injuries were observed at bud stages of 1 or 2 after freezing April 11 and 18. It seems then safe to conclude that buds are invulnerable to frost until stage 3, when the buds open and ends of the leaves become visible. Stage 3 had appeared in about 40% of the twigs at 45 day degrees April 24 (Table 1). At April 25 all the twigs collected from that day's experimental tree had reached stage 3 as seen on Fig. 3 B. Sum of day degrees added up to 52.

At freezing temperature of -7° and -9°C the leaves turned greyish in a day or two in room temperature. At -5°C only vague colour changes occurred during the first 2-3 days, but the growth of leaves was hampered and came soon to a standstill. In less than a week the leaves started turning brownish in the same way as with -7 and -9°C treatments. The end results became then very much the same for -5, -7 and -9°C.

The last freezing was carried out May 5 on twigs in stage 4 with average leaf length of 12-15 mm. On May 13, the results were just as after the freezings on April 25 and 29. Twigs after 0 and -3° treatment appeared thrifty, whereas twigs after -5, -7 and -9°C frost were all dead (Fig. 3, C, D and E).

Six to ten days after freezing some twigs and buds were split to look for where and in what way the frost had struck. Generally the cellular tissue at the base fastening the buds to the twig had turned yellow or brownish, while the middle part of the buds still was green. The fringes of leaves at the end of the buds had gradually changed colour and started wilting. It was difficult to decide whether the cambium of the twigs was hurt as well.

All these four experiments in Norway have greatly contributed to clarify the budburst pattern and the vulnerability to frost at various stages.

However, the results are not complete in every detail. Especially, it is not yet clarified which budburst stage - freezing temperature coincidences that create the small, curled leaves. Such abnormal leaves were not produced in the 1994 freezing experiment, because the cut-off twigs could not be kept growing long enough to get adequate leaf differentiation.

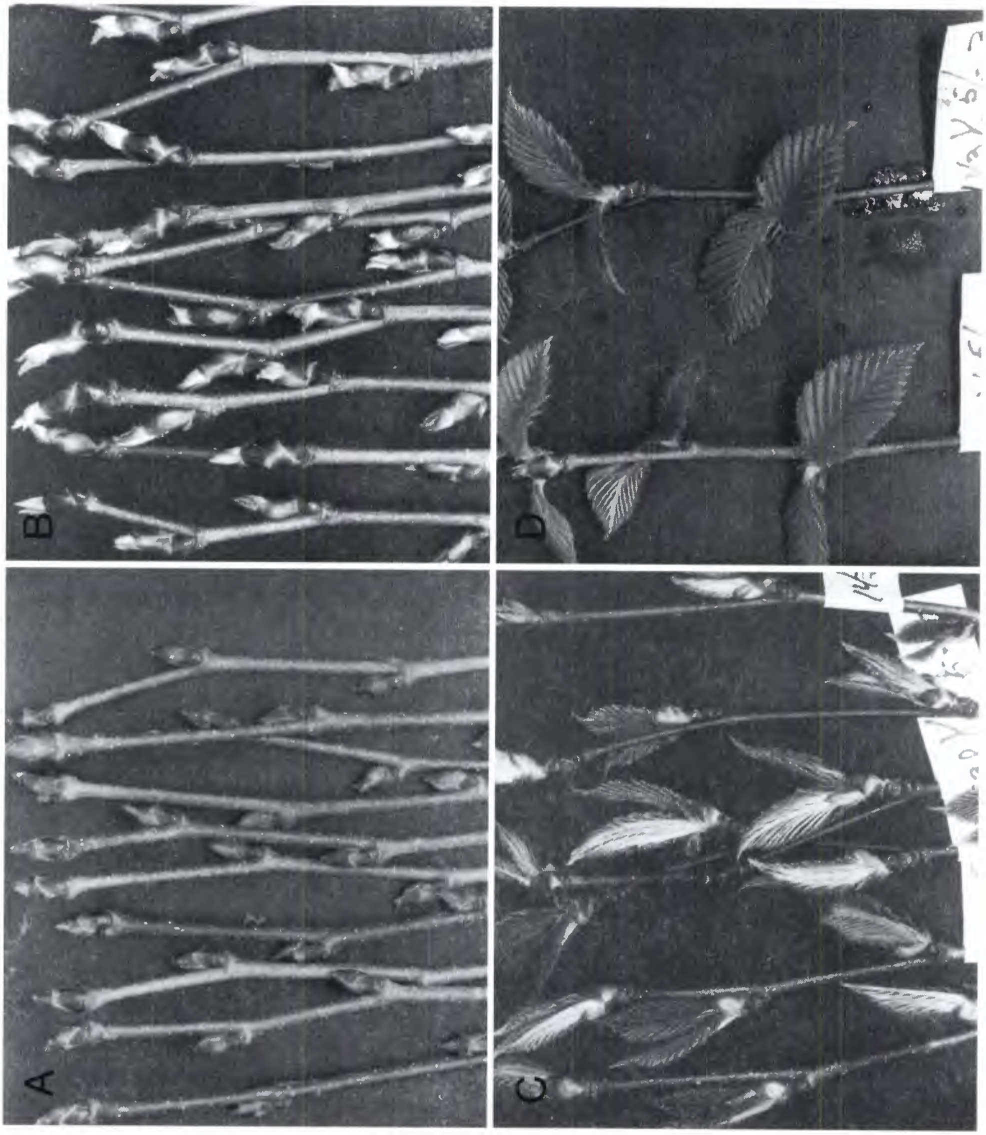
Abnormal leaves might perhaps be a result of heavy frost at an early, less vulnerable stage of budburst, or a very gentle touch of frost, with higher minimum temperature or shorter duration.

Necessary studies of this question should be done on living trees where the root system is intact during and after the experimental treatments of the twigs.

4. SPRING THAWS AND SUBSEQUENT FROSTS IN CANADA AND USA

4.1 Variations in the heat sum requirements for budburst

The huge areas hit by birch dieback in Canada and USA are occupied by many provenances of yellow birch, and no exact heat sum required for bud burst can be expected for all the area. Sharik (1970) observed the stage of leaf flushing on 23 seedling populations of yellow birch in a uniform garden near Howell, Michigan. He found (p. 21) stages of flushing ranging from 1.65 to 3.18 (in a 5-point scale of leaf length; 1 1/4 of bud scale and 5 >60 mm) with increasing latitude from 35.2 to 44.4°N (r=0.86). The observations were made May 2, 1969 at the beginning of the second year of the seedlings. The nearest weather station was Milford, nearly 30 km westwards, showing DDG= 179.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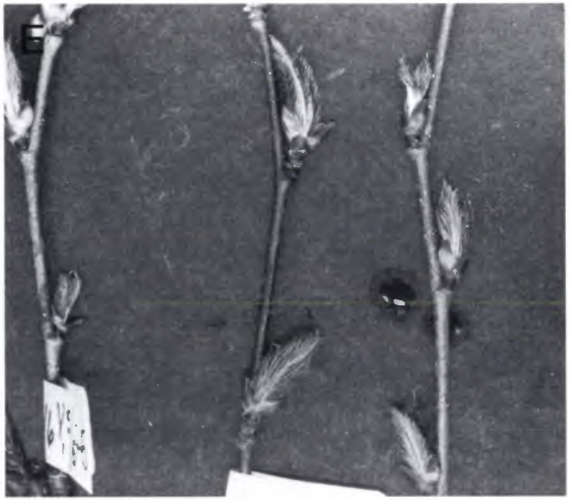


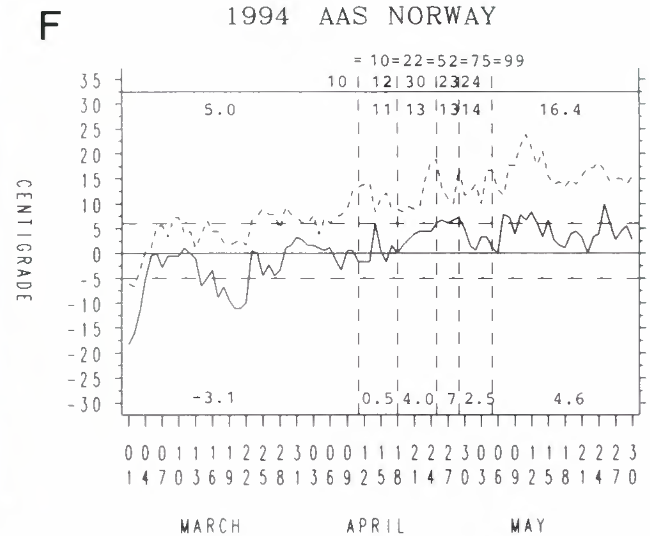


Fig. 3. Budburst observations on yellow birch and freezing experiments at Aas, Norway 1994. A. Budburst stage 2 at freezing April 18, DDG=22, no frost injuries observed within 2 weeks. B. budburst stage 3 at freezing April 25, DDG=52, injured by frost at -5°, -7° and -9°C. C. Budburst stage 4 at freezing May 5, DDG=99. D. Twigs of 0 and -3°C treatment unhurt 8 days after freezing. E. Twigs of -5°, -7° and -9°C treatment dead 8 days after freezing. F. Temperature diagram

The result that northern provenances need lower heat sum to flush than southern ones is commonly recognized. However, the variation within seedling populations was great enough to result in overlap in stage of leaf flushing between individuals of the most northern and southern latitudes of sampling. In natural populations at the source of origin, northern provenances flushed 3 to 4 weeks later than southern ones.

Likewise Clausen (1973 p. 14) followed the flushing of 10 provenances in the Rhinelander nursery (Wisconsin) for 2 years. The greatest differences among the provenances was observed on April 28, 1970 (DDG = 60) and on May 7 in 1971 (DDG = 89).

As the weather observations were taken in Rhinelander, little temperature deviation is expected at the nursery. In this way the DDG values for the time of greatest differences in leaf flushing at Rhinelander seem to be the most reliable ones. As expected, time of budburst was closely related to latitude of seed origin (r=0.93 and 0.96).

In the Rhinelander study the provenances differed in mean flushing time, but there was considerable overlap among the progenies. Individual seedlings showed even greater overlap, some seedlings of the latest flushing provenance were as far advanced as some late seedlings of the earliest flushing provenances in both years (p. 17). Time of flushing and need of heat sum probably are also influenced by previous chilling and the photoperiod.

In his studies of daylength and thermal time at budburst Heide (1993, p. 535) found falling number of day degrees with the date of intake. For silver birch DDG requirement (effective base temp. 0°C) for intake December 15 was reduced to less than one third for the intake March 15. If this trend continues into the next month, an intake in April would need a still lower DDG. This means that an early March thaw needs more DDG to budburst than a similar thaw starting in April.

From these observations in The United States and from the experiments in Norway, it seems possible to conclude that about 50 day degrees cause budburst to a vulnerable state for yellow birch (Petawawa provenance) when the heating takes place as late as the second half of April. Earlier periods like in March and early April need more day degrees to give the same stage of budburst and 100 day degrees may be set as a main limit. This limit is expected to give birch dieback symptoms in most cases. In addition comes the uncertainty from frosty spells during the period of mild weather, and of course the provenance variation.

4.2 The March thaw of 1936 - late frost in May

In his first article Braathe (1957) mainly laid the emphasis on the relative temperature during the March thaw of 1936. Now the thermal time is calculated as day degrees (DDG, base temperature 4°C) on actual daily temperatures, measured as maximum and minimum at the available meterological stations in the birch dieback areas in Canada and United States.

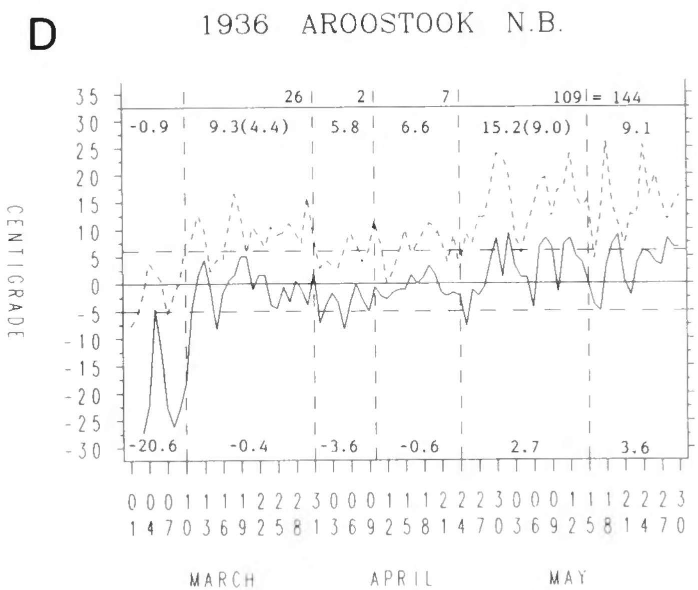
In this expression of temperature the March thaw of 1936, although a very extraordinary climatic event, did not produce high day degree values. In New Brunswick only three weather stations had values above 50; Fredericton (farm) = 51, Moncton = 59 and Sackville = 54, all exposed to calculated frost of -5°C or lower in April. No stations in New Brunswick had DDG over 100. In Nova Scotia 10 stations ranged between 50 and 80. In the province of Quebec, and the New England States one station, had day degrees above 100, Durham N. H. = 104.

Consequently, it is doubtful that the March thaw itself could cause enough flushing among yellow birch trees to create an extensive vulnerability at a freezing temperature already in April.

However, information in the literature indicated for some years frost also in May. So Nash and Duda (1951 p. 27) in discussing the role of climatic factors on injuries on birch in Maine said: "Other climatic factors adverse to tree growth have been low winter temperatures and late spring freezes. The winters 1933, 1934 and 1935 had exceptionally low temperatures. Low records were set in the winter of 1942-1943 and were apparently responsible for light to severe killing back of trees, particularly visible on beech and white oak (Nash, 1943). The effect of late spring freezes has been most apparent from the killing back of the new growth of conifers in several of the last twenty years. In May 1936 a severe freeze over the state generally killed new foliage and shoot growth which was well advanced on the hardwoods. Similar damage occurred in 1944 and 1945".

Fig.4A. Birch dieback area in nothern New Brunswick. The picture is taken from the summit Tower at Green River August 1956 (photo P. Braathe)


C
B



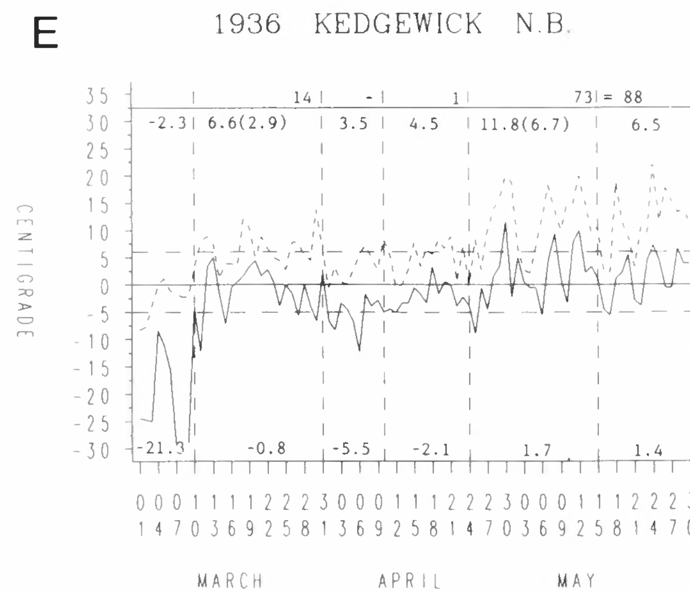
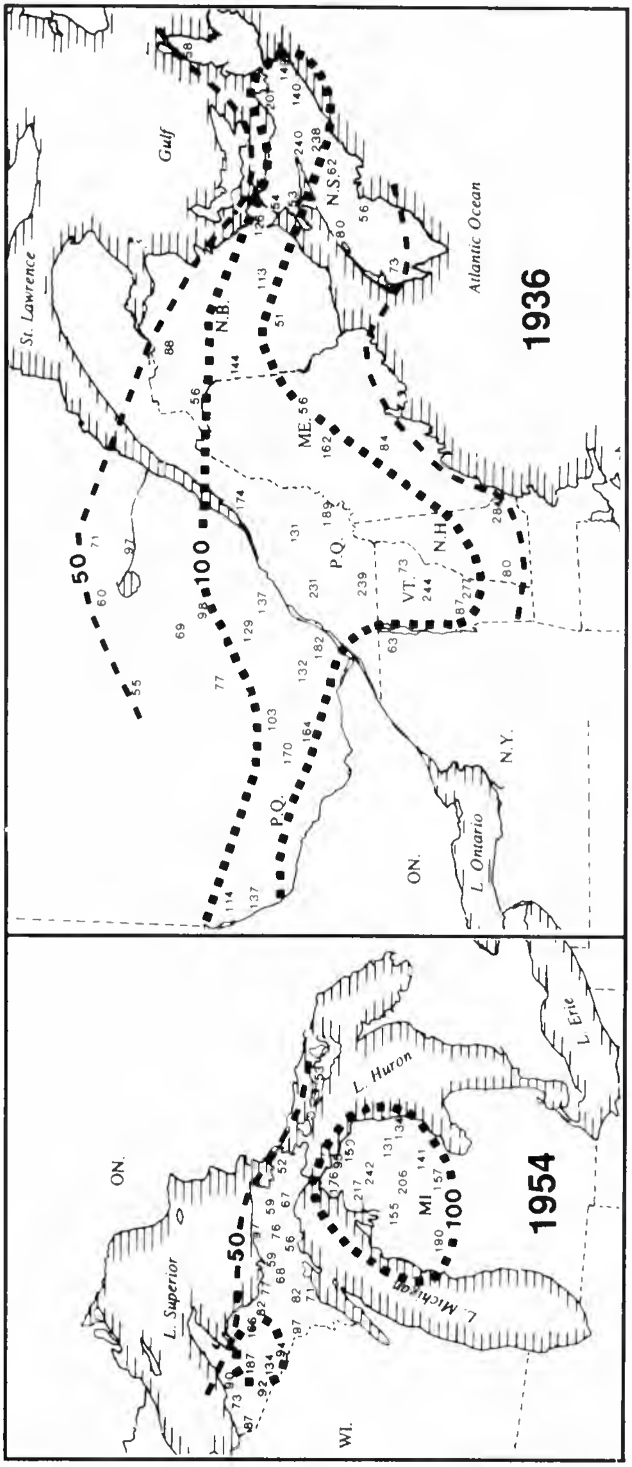


Fig. 4 (continued) B. Birch dieback area in central N.B. C. Yellow birch trees at Green River where mainly adventitious branches constitute the crowns (class 4 B and 4 B). August 1956 (photo P. Braathe). D. Temperature diagram Aroostock. DDG=144. E. Temperature diagram Kedgewick, DDG=88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St. Lawrence
Gulf
Atlantic Ocean
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ME.
P.Q.
VT.
N.H.
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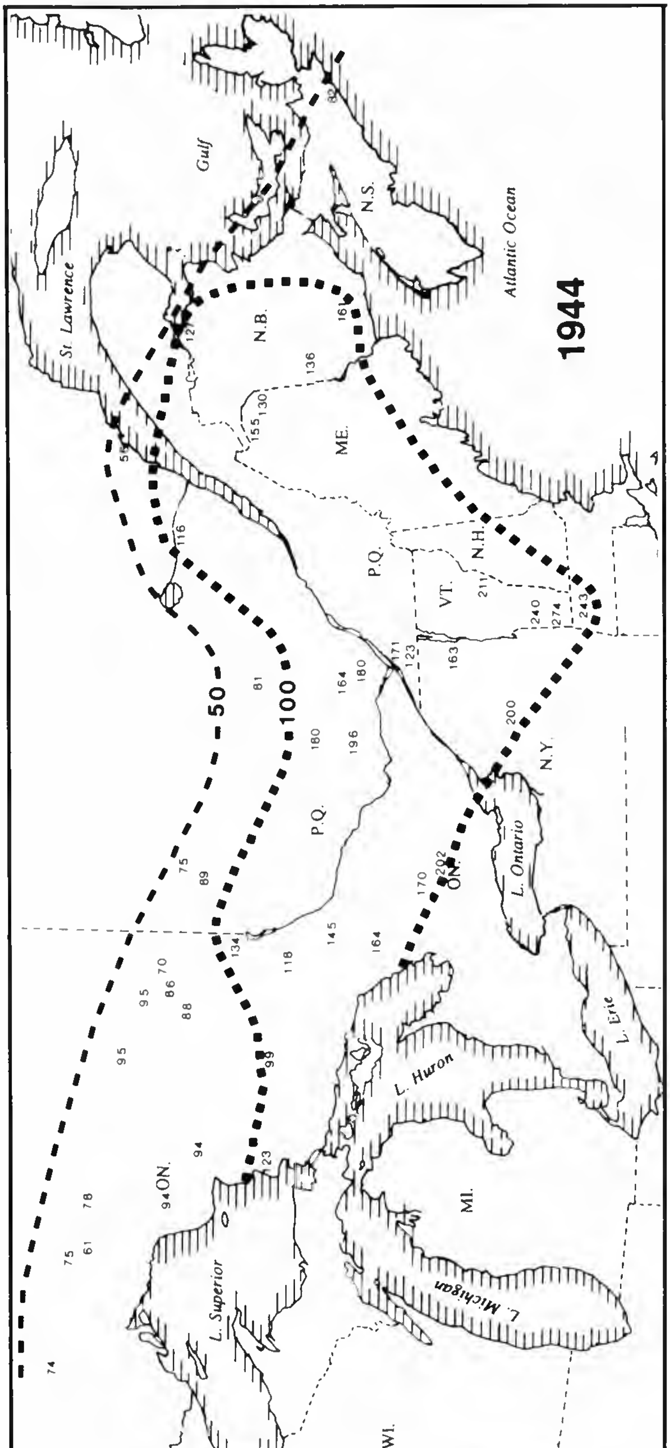


Fig. 5. Maps showing DDG before frost of -5°C or lower with isotherms at 50 and 100 day degrees for the years 1954, 1936 and 1944

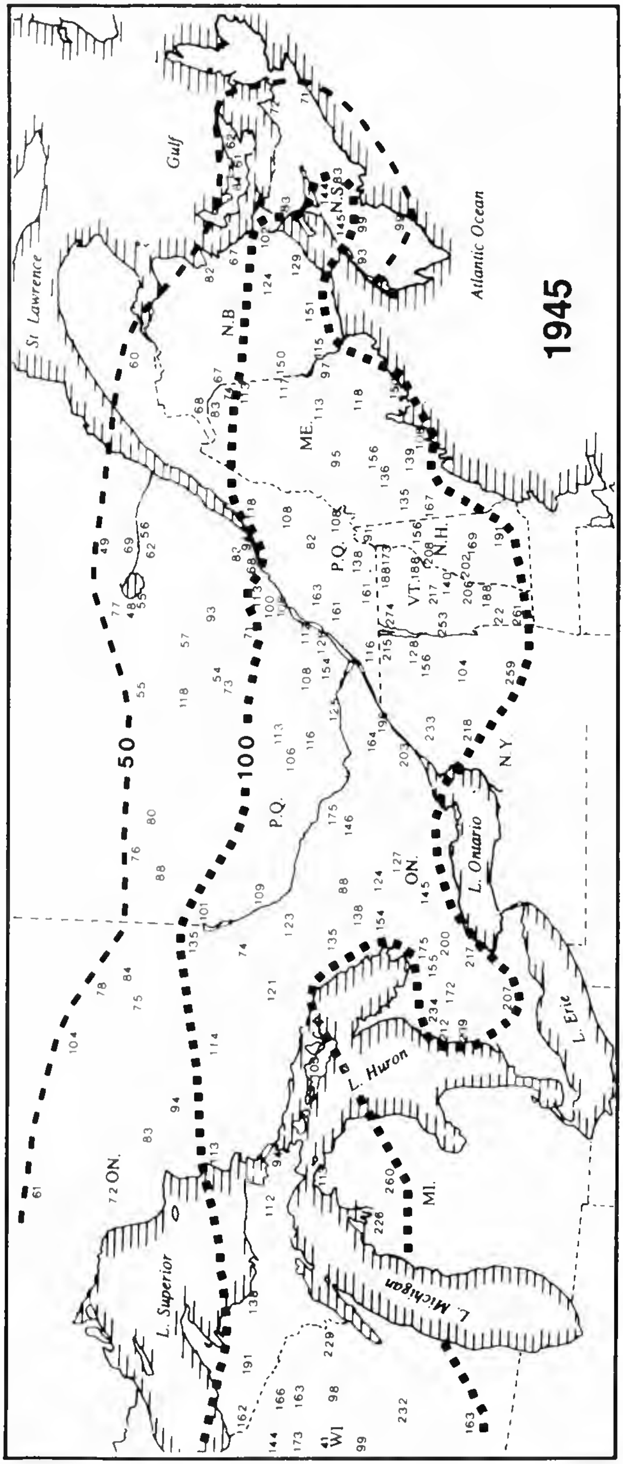


Fig. 5 (continued). Map showing DDG before frost of -5°C or lower with isotherms at 50 and 100 day degrees for the year 1945

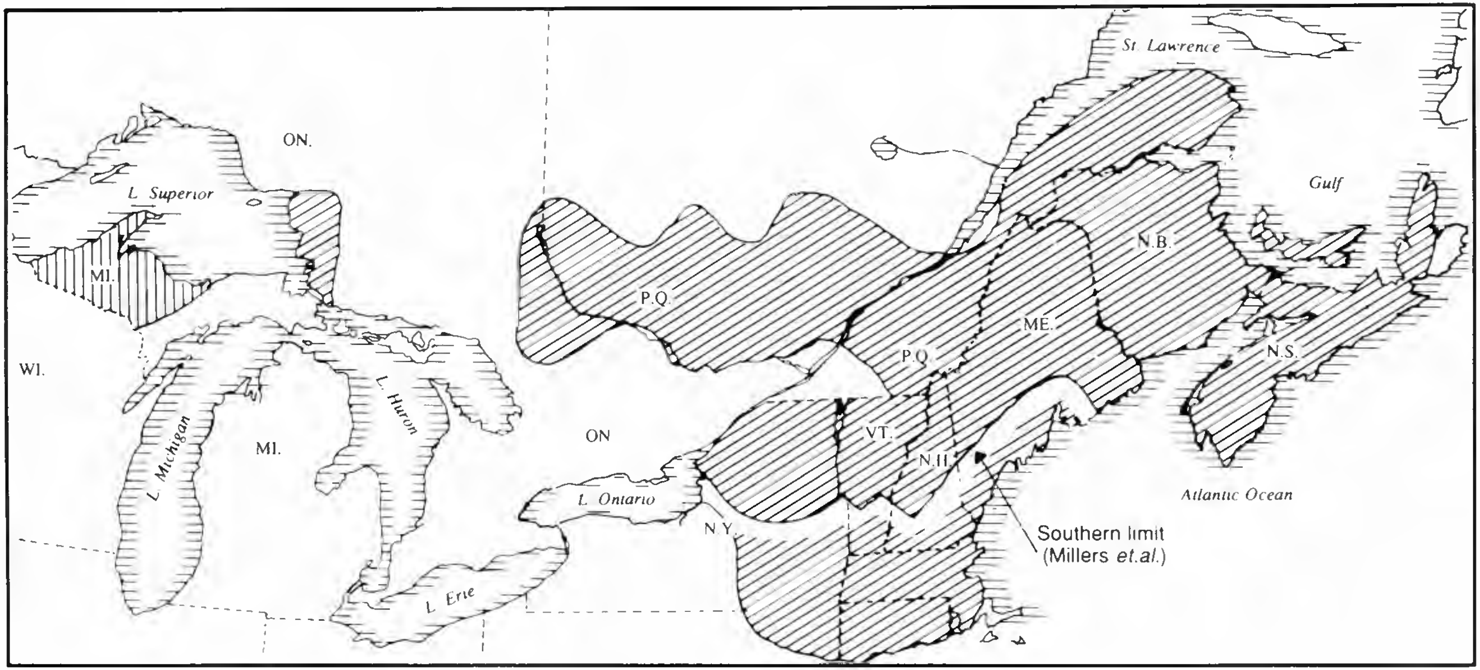


Fig. 6. Map of aaccumulated birch dieback, reprinted by courtesy of Dr. Allan D.N. Auclair (Auclair 1987a, Figure 5c). For comparison the map is enlarged to the scale of the DDG maps in Fig.5. Shaded area identifies the maximum occurrance of dieback of yellow birch reported in the symposium on birch dieback 1952 (Canada Department of Agriculture 1953) and in the forest decline workshop (LRTAP, Workshop No. 6 1986). A southern limit of birch mortality, and the birch dieback area in Upper Michigan (1954 to early 1960's, vertically shaded), both from Millers et al. (1989, Fig. 7) are added on the map

This very important information made it necessary to study the May temperatures as well. Minimum temperature of -5°C or below occurred on May 16 or 17, 1936 and was recorded at a number of weather stations.

On the maps in Fig. 5 are placed the stations with DDG >50 before a frost of -5°C. Isotherms of DDG 50 and 100 are drawn. Most of the other stations also had min temperatures below zero but higher than -5°C. (Some stations are not placed on the map because the names were not found on the maps available).

Values of DDG above 100 with subsequent frost occurred in northern Nova Scotia, central New Brunswick, northern Maine, New Hampshire and Vermont, and large areas of Quebec, both south and north of the St. Lawrence River. Additional areas of about the same size had DDG between 50 and 99. The areas on the map, even part of those with DDG below 100, correspond quite well with the early descriptions of the Birch dieback.

In addition to the day degrees accumulated during early thaw periods a normal spring rise of temperature adds considerably to DDG sum when the damaging frost comes as late as in middle May. This is clearly illustrated in Fig. 4 D-E showing two temperature diagrams from central and northern New Brunswick.

The visible situation in New Brunswick during the study trip in August 1956 is shown in Fig. 4. Picture A, taken from the summit Tower at Green River, northern New Brunswick, shows large birch dieback areas quite to the local horizon. Picture B from central New Brunswick shows what Barter (1953) called an "Old dead area" with very few living birch trees. Still some stems were standing with few branches left, but most of the trees had fallen down. Picture C from Green River shows typical yellow birch trees still alive, with crowns mainly of adventitious branches (class 4B and 4B).

4.3 The second thaw - frost event in 1944

The second year Nash and Duda referred to as having frost injuries in May was 1944. That year no early thaw period occurred. The weather was rather chilly until late April, but frost occurred May 18th. At three stations in New Brunswick (Blissville, Woodstock and Campbellton) DDG exceeded 100 and the same was the case at 9 stations in Quebec. Also eastern Ontario had 9 stations between 100 and 200 DDG, the most western one being Montreal River. Day degrees between 50 and 99 occurred at one station in Nova Scotia and 4 in Quebec. The map in Figure 5 shows the situation for 1944 with high temperatures before frost in the Montreal area, in Quebec and in New Brunswick. This late frost surely caused injuries locally, but these are difficult to distinguish from the 1945 injuries in the same areas.

4.4 The third and greatest thaw - frost event in 1945

The year 1945 had a very extraordinary spring, and March had the highest mean temperature recorded after 1890 in The New England States and New York State. Also further west, March was very warm. In Michigan the mean was higher than ever, and in Wisconsin and Minnesota the March mean was the second highest since 1890 (second to 1910).

Also the first two or three weeks of April had the same mild weather. This resulted in very high sums of day degrees over huge areas.

The map shows that number of day degrees exceed 100 in western part of Nova Scotia, central New Brunswick, southern Quebec and southern and central Ontario to Montreal river and Sault Ste. Marie.

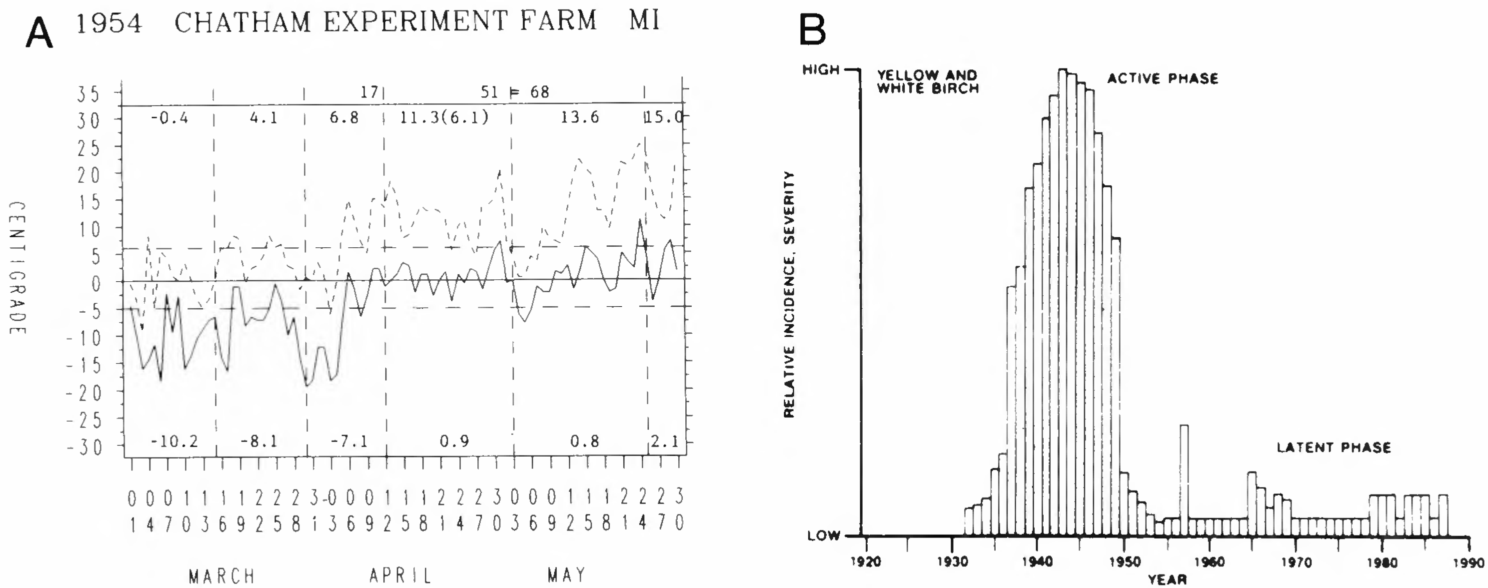


Fig. 7. A. Temperature diagram. Chatham, Upper Michigan 1954. B. The relative incidence/severety of crown dieback of yellow and white birch in northern hardwoods of eastern Canada. Reprint concerning birch by courtesy of Dr. Allan D.N. Auclair (Auclair 1987b, p 26, and Auclair et.al. 1992, Fig. 1B)

In the USA, most of Maine, New Hampshire, Vermont and northern part of New York State got the same values. Westwards in the Great Lakes area, northern parts of Michigan and Wisconsin, and south-east Minnesota had quite a few stations with DDG above 100.

Along the southern isotherm very high values of DDG, frequently above 200, had accumulated before the frost. To the south therefore, the occurrence of frost seems to be the dominating factor delimiting the birch dieback as was also the case in 1944.

Also within this huge area the occurrence and intensity of frost caused various levels of birch dieback. One well documented case is Petawawa Forest Experiment Station. Fraser (1959, p 20) found in 1951 about 65 per cent of the trees rather healthy in classes 1A-3A. This level of injury is low in relation to the survey in the province which showed only 30 percent in the same healthy classes in 1951. (Sinclair and Hill 1953, p 171).

Pembrooke is the nearest weather station to Petawawa, only about 14 km down the Ottawa River. A temperature diagram shows DDG = 175 in 1945 which is a heavy thaw. However, the frost of -5°C occurred only one night, April 15, and this gentle touch of frost only once has probably caused the moderate degree of injury at Petawawa.

Along the northern isotherm with DDG = 100 there was a belt in Canada from eastern Nova Scotia westwards to Lake Superior in USA, approximately 200 km wide and 1750 km long, with DDG between 50 and 99.

The 1945 thaw-frost event covered again nearly all the area struck by the first March thaw and the May frost nine years earlier in Nova Scotia, New Brunswick, Quebec and New England. In addition, the 1945 event covered large previously untouched areas.

Peculiar enough also 1946 had a mild spell in March, but lasting for only 17 days. In the Great Lakes area of Ontario, Michigan, Wisconsin and Minnesota several stations had day degrees above 100. In Ontario just north of Lake Erie three new stations had DDG > 100. Elsewhere the 1946 spring probably added little to the great thaw-frost event of 1945.

4.5 The local thaw-frost event in Upper Michigan 1954

Hansbrough (1953, p. 7) mentioned that since 1947 more or less casual observations in northern hardwood stands in Michigan and Wisconsin had not disclosed any evidence of the appearance of birch dieback in the Lake States region. Some birch mortality had occurred there, but it was limited to old, overmature yellow birch or to cut-over lands. None of the symptoms of dieback had been observed in young thrifty stands of either paper or yellow birch.

However, from May 1954 a top-dying of yellow birch was recorded in Upper Michigan, although not called birch dieback (Godman 1956, 1958, Jacobs 1960, Kessler 1967). This rather local top-dying description clearly falls into the pattern known from 1936, 1944 and 1945. If the idea of thaw-frost events as the initial cause of dieback should be valid, injuring frost would have to be expected in late April or in May 1954. The meterological data provided by the U.S. National Climatic Data Centre, Asheville (December 1993) revealed just that.

Of the 30 meterological stations on the Upper Peninsula, 28 had frost of -5°C or lower in May. Only 5 other Mays since 1887 have had minimum temperatures lower than this one in 1954. The coldest spell occurred between May 4 and 6, but also later in the month frost occurred. So 9 stations had -5°C or lower as late as May 26.

Day degrees in Michigan for 1954 are shown on a map in Figure 5. A temperature diagram for Chatham Experiment Farm about 20 km east of observation plots at Dukes, given in Fig. 7 A, shows 68 day degrees before the heavy frosts May 4-6.

This thaw-frost event has the common pattern of birch dieback. The most interesting features seem to be the rather local limitation and the special weather situations in May. So a foot or more of snow fell in Upper Michigan. On May 4 rural schools were closed in Gobebic County because of heavy snow clogging the roads. Dust devils or whirlwinds were reported several times, and on May 15 between 9 p.m. and 10.30 p.m., an unusual mirage gave South Haven residents a glimpse of the Chicago skyline 130 km away across Lake Michigan.

Jacobs (1960) stressed that the cause of top-dying in Upper Michigan still was undetermined, but mentioned that the determining factor could be a prolonged high water table during or just prior to the beginning of the growing season in 1954. Whether this high ground water table has played any role is difficult to judge from the available information.

4.6 The main period of birch dieback 1937-1949

The repeated thaw-frost events explain why new birch dieback turned up in new places in the outskirts, and was intensified in central areas which had been injured before. The impression of a spreading malady has then got a satisfactory explanation.

A reconstruction of the relative incidence and severity of the dieback in eastern Canada was made by Auclair (1987 b, p 26). Year to year changes in progress of disease were tabulated and judged on a relative scale from low to high. Limited interpolation between years of little information was used. Years of high confidence were identified by tabulating the number of authors independently reporting particular events. In the case of birch dieback for example, dramatic changes such as the sudden widespread appearance of dieback in 1937, and marked, general recovery in 1950 were widely reported. The massive nature of the disease of birch and maple resulted in abundant observations.

The result for yellow and white birch expressed graphically is reprinted in Fig. 7 B. The graph clearly shows the large birch dieback from 1936 to 1950, and a fairly latent phase in later years.

This reconstruction of birch dieback falls very well into the pattern and period of the thaw-frost events.

4.7 The accummulated birch dieback area in Canada and USA

The sum of day degrees and isotherms of 50 and 100 are given on the maps in Fig. 5. Patterns for 1936, 1944 and 1945 are of a similar nature, but the coverage varies somewhat, with overlaps and new areas in the outskirts.

The accumulated area of birch dieback is given in Fig. 6, which is a reprint from Auclair (1987 a, Figure 5 C). The shaded area identifies the maximum occurrence of dieback on yellow birch reported in the symposium on birch dieback in 1952 and in the forest decline workshop in 1986.

From the workshop the integrated map was based on data provided by participants and from follow-up correspondence. The map shows complete coverage in the New England States (except the south-eastern part of Massachusetts, and Rhode Island) and a great part of New York State. Possibly these far south area contains dieback from recent years not known to the author from available literature.

For comparison to the maps of thaw-frost events in Fig. 5, the southern limit of birch dieback published by Millers et. al. (1989, p 22, Fig. 7) is more appropriate. This limit through New York, Vermont, New Hampshire and Maine is added on the map in Fig. 6. It is related to the birch dieback in these states from 1939 to the middle fifties, recorded with the cause: not determined (p 24, Table 4).

Millers et. al. also recorded the severe crown dieback in Upper Michigan from 1954 to the early sixties, with causes: high water tables, stand disturbance and possibly secondary organisms. This area is also added on the map in Fig. 6, vertically shaded.

Moreover, also the northern limits of the birch dieback area need a comment. They seem to indicate the situation as of 1948 (Barter 1953 c, p 21), partly based on the travels by Barter that year, before any results from the main assessments were available. So, adjustments of the northern limit through Quebec and especially Ontario were to be expected.

The extensive assessment in Ontario 1949-51 between Sault Ste. Marie district in the west and the Petawawa Experimental Station in the east, showed great injuries with only 7 percent healthy trees in 1951 (Sinclair and Hill 1953, p 171). No indication of birch dieback on the map (Fig. 6) in the greater part of this area then seems strange and may be questionable.

The small dieback area at Montreal River had been put on the map with reference to Rose et. al. (1969) for the period 1950-1968. (LRTAP, Workshop No. 6, 1986, p 215).

The limits for day degrees and frost in the single years, as well as the limits for the accumulated birch dieback, may seem coarse and little detailed. Nevertheless, a comparison between the maps in Fig. 5 and the accumulated area in Fig. 6 exhibits its great similarities. A strong connection seems to exist. However, there are local uncertainties as mentioned for the borders both in south and north.

Uncertainty of how good the weather stations represent some areas is another question. For instance, the Gaspe peninsula had rather few weather stations in 1936, and nearly all were situated on the coastline of the lower St. Lawrence and the Gulf. Minimum temperatures below zero occurred at most stations several times in May, especially 16, 17, 21 and 22.

However, nowhere was temperatures of -5°C recorded. Nevertheless, all of the Gaspe was struck by birch dieback (Fig. 6). A possible explanation may be that the temperature fall is slower at the coast. Inland minimum temperatures at some distance from the open sea may very well have fallen to -5°C or lower in one or more nights during the second half of May.

In Fredericton N.B. two stations were operated in 1936, at the University and at the Experimental Farm. During May the minimum temperatures recorded were equal in 8 nights, lower at the farm 14 nights and higher 9 nights. The differences ranged from -1.7° to 2.8°C, which are rather great in relation to a fixed frost damage limit. Such deviations in both directions demonstrate that the minimum temperatures are variable and sensitive to the weather situation such as slow wind or drafts, as well as the terrain.

5. DISCUSSIONS AND CONLUSIONS

My study travels in June-August 1956 through New Brunswick, Nova Scotia, Quebec, Ontario, Maine, New Hampshire, Vermont and New York State initiated speculations of the birch dieback causes. The dimension of the malady was enormous. Total area hit was at least 490 000 km^2 measured on the map Fig. 6, and the value of timber volume loss has been estimated to \$ 60 billion in current dollars. Limited to Quebec and the Atlantic Provinces, Pomerleau (1991, p 43) estimated the loss of yellow and white birch to about 1400 million m^3.

A lot of extensive assessments and investigations had been carried out, but no explanation was found. Of course, such a malady must have a cause, and still a great task was to find it.

A striking feature was the uniformity of the occurrence of injury nearly irrespective of variation in growing conditions. Greenidge (1953, p. 70) confirmed that the incidence of disease was not correlated with site quality, slope, exposure, soil depth, age or stand composition, and Pomerleau (1953, p. 51) stressed that a parasitic disease could not attack most of the trees in a stand to such a uniform degree. "Over a period, most of the trees may succumb to the attack of a parasite, but this will never be so uniform as in the case of birch dieback". Uniformity here means that the nature of the malady was the same, but the level of intensity could differ from area to area.

This uniformity gave nourishment to the idea that some climatic factors could have affected the areas outside the growing season. In searching for such factors the March thaw of 1936 first caused attention, as published by Braathe (1957, p. 358).

On this basis thaw and frost experiments were started and carried out in Norway 1989, 1990, 1993 and 1994. The results achieved and presented here show symptoms strikingly similar to those described for birch dieback. After budburst to the vulnerable stage 3, with visible green tips at the end of the buds, a frost probably of at least -5°C causes the birch dieback symptoms.

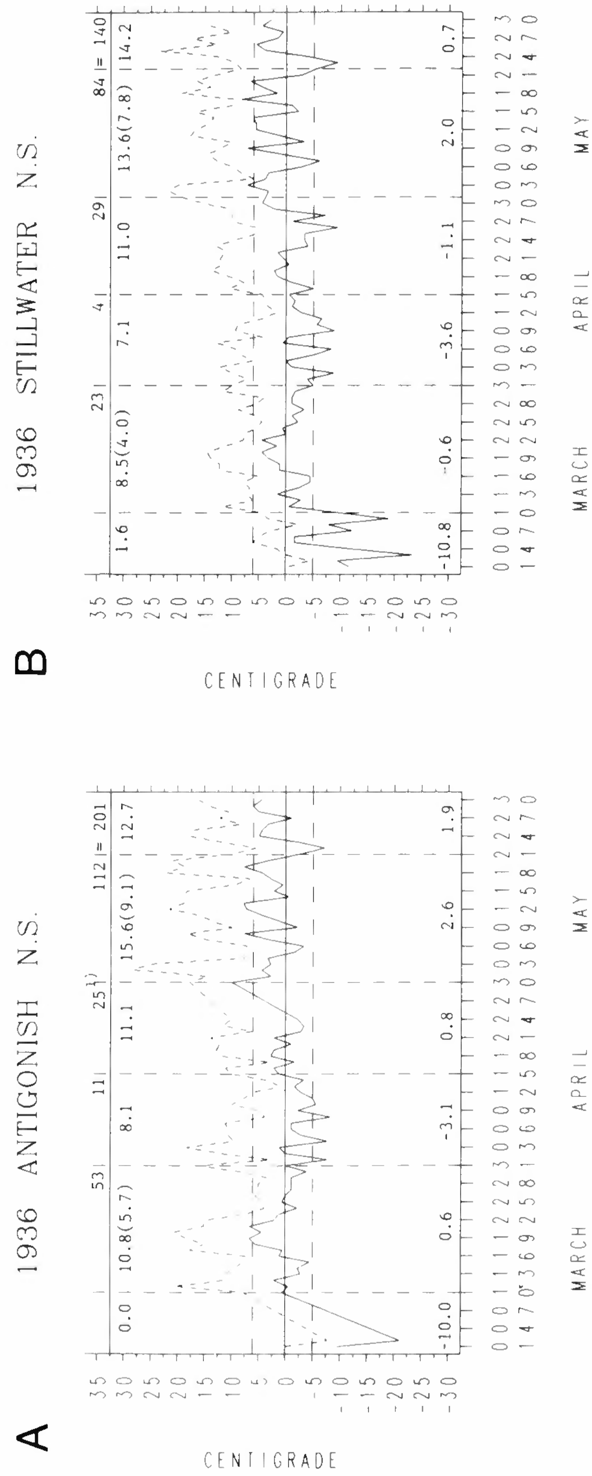
This means that the frost is the real injuring factor, when occurring on shooting buds and twigs in the periphery of the crown.

This coincidence of budburst and frost may occur as very early thaws and normal spring frost like 1945 and partly in 1936, or as a normal spring development like 1944 and 1954 in Upper Michigan with late frosts in May.

There seem to be two main reasons why thaws and frost were not earlier related to the causes of birch dieback. The first descriptions (Balch 1953, p. 3) stated that without doubt birch dieback was present in New Brunswick by 1935, one year prior to the thaw-frost event in 1936. Also earlier years were mentioned having unhealthy birch. This time-setting seems to have effectively blocked the possibility of a 1936 start (Clark and Barter 1958, p 359). The descriptions cited (Balch 1953, Balch and Prebble 1940 and Auclair 1987b) strongly point to 1937 as the year the malady really took hold. It may be rather likely however, that thaw-frost events have occurred sometimes before 1936, but coincidences of DDG and frost may have given only weak symptoms or only in smaller local areas. It might be of interest to look for thaw-frost episodes in New Brunswick at least a decade or two before 1936.

5.1 Relation between frost damage in the crown and the rootlet dying

The other and the strongest feature has been the conclusion that rootlet dying occurred prior to the crown damage. Such a conclusion was vaguely indicated by Hawboldt (1947, p. 418) and strongly reinforced by Greenidge (1953a, p. 86 and 1953b, p 548) who wrote: "The cumulative results of injection studies, root


A
1936 ANTIGONISH N.S.
CENTIGRADE
MARCH
APRIL
MAY
B
1936 STILLWATER N.S.
CENTIGRADE
MARCH
APRIL
MAY

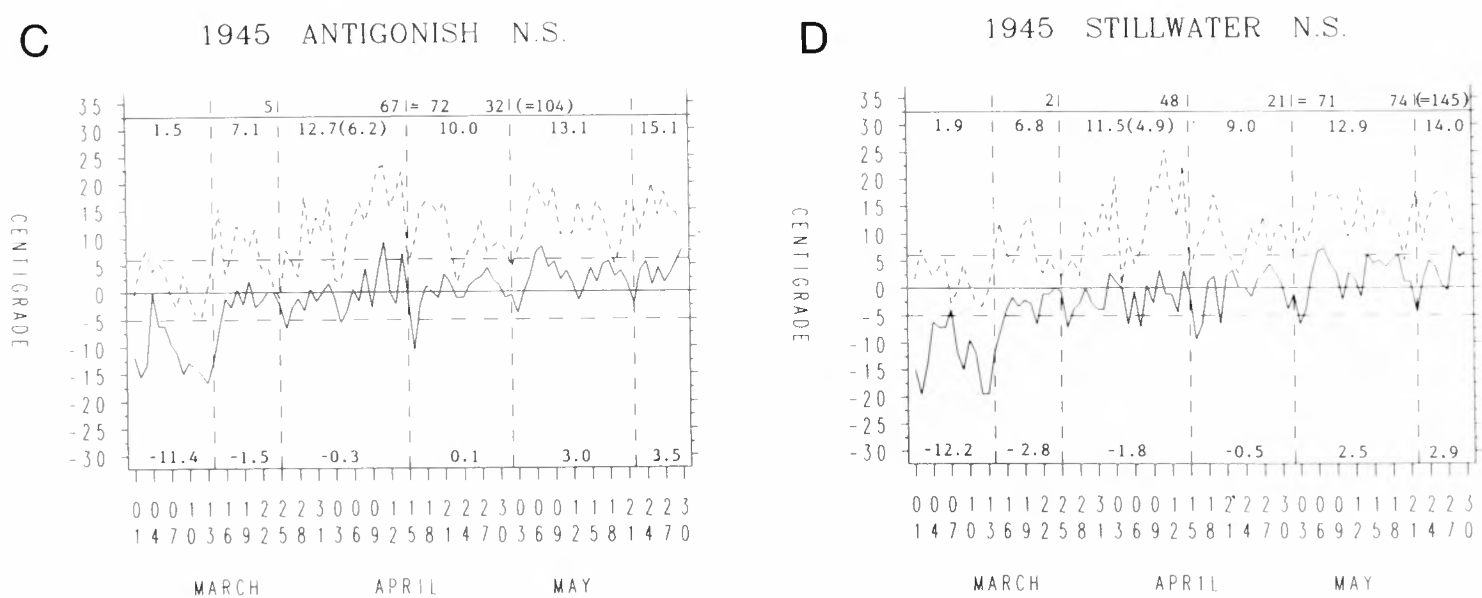


Fig. 8. A-B. Temperature diagrams. Antigonish and Stillwater 1936. C-D. Temperature diagrams. Antigonish and Stillwataer 1945
1) In diagram A, temperature obs. April 25 - 29 are missing

excavations, and an extended survey of the trends in moisture distribution in the species over a prolonged period, suggest that the locus of action of the disease is, in the first instance, in the roots, and that excessive rootlet mortalities in apparently healthy trees constitute the initial indication of a diseased condition in the species".

This conclusion of rootlet death as the first sympton of birch dieback inspired to experiments on rootlet death at high soil temperature (Redmond 1955). In 1953-57 Pomerleau (1991) studied rootlets at high and low soil temperature, without full breakthrough on the question.

Still, the refereed conclusion of initial root dying seems gradually to have been accepted as the truth. Ideas and reserch activities concerning the possibility of direct, climatic injuries in the crowns seem to have been practically absent. As such a conclusion now seems false, it is of interest to look into the investigations and arguments.

As early as the late twenties observations were done on dying rootlets on decadent trees on heavily cut-over areas. Dead rootlets were counted by Spaulding and MacAlony (1931, p 1146) on two yellow birch and two white birch trees, classified as remnant trees of the original stand in a cut-over area in northern New Hampshire. Such cuttings usually removed 75 per cent or more of the canopy, and the remaining trees on a cut-over area were subjected to a tremendous shock caused by the logging operation and drastic opening of the canopy.

The first yellow birch studied had 5 m of crown dead, leaving one third alive, 8,4 per cent of the root tips were dead. The other one had a healthy crown and 3.8 per cent of dead root tips. The first paper birch with tips of topmost branches dead for 30 to 60 cm, had 15.9 per cent of dead root tips. The other one, showing the earliest stage of trouble, detectable from the ground, had 16.3 per cent of dead root tips.

These percentages of dead root tips were very low, especially for yellow birch. "The relative number of dead root tips showed no marked correlation to the decadence of the tree crown" the authors concluded.

Hall (1933) studied the post-logging decadence on 77 sample plots in hardwoods in New Hampshire, Wisconsin and Minnesota. After examining feeding roots on twelve decadent and two thrifty trees (sum 9154 roots, not specified as to species) Hall (p 11-12) said: "It was found that decadence in the roots usually, if not always, precedes decadence in the crown; and it therefore seems likely that the death of the feeding roots may explain the death or decadence of the leaves in the top of the crown."

"Death of the feeding roots is undoubtedly an important cause, as well as an evidence, of decadence. On cut-over areas it is directly attributable to the changes in the physical factors of the environment which follow cutting."

In connection to birch dieback in undisturbed or lightly cut stands, Hawboldt (1947, p 416) studied in detail the crowns, roots and bark of five selected yellow birch trees near Willowdale, Nova Scotia. A more complete description of the trees is given in chap. 2.6.1. As these studies were carried out in the autumn of 1945, the year of the greatest thaw-frost event, the results are particularly valuable and elucidating.

The two nearest meterological stations to Willowdale are Antigonish, 30 km to the north-east, and Stillwater 35 km to the south-east. Temperature diagrams are given in Fig. 8 for 1936 and 1945. In 1936 heavy frost occurred in the area on May

22 (at Stillwater also May 23) at day degrees 201 and 140.

Tree No 4 with only three living, adventitious branches at the base and tree No 5 with only green streaks of cambium at breast height were obviously hit by the 1936 thaw-frost event. In the tenth growing season after the frost they were placed in class 4B and 5B as almost dead or dead. Rootlet mortality in tree No. 4 was 89 per cent and No. 5 100 per cent.

After so many years it is impossible to judge to what degree these two trees were damaged in 1936, and when the bronze birch borer could successfully attack. Tree No. 4 however, shows that adventitious branches can help a damaged tree to stay alive.

Tree No. 1 seemed perfectly normal while standing (class 1 A). After felling 10 per cent dead terminal twigs were found, and about 30 per cent dead rootlets.

Tree No. 2 was placed in class 2B having decidedly small, thin and curled foliage. While the tree was standing no dead twigs were evident, but felled, the twig mortality was found to be about 33 per cent. Rootlet mortality was 44 per cent.

Tree No. 3 was categorized as class 3 A, with very thin, curled foliage over the entire crown and with some dead twigs. After felling, considerably more mortality was found with 68 per cent dead twigs including several smaller branches. Dead rootlets were counted to 63 per cent.

The dead twigs on these three trees still bore small, curled foliage. Some nodes were devoid of leaves, these presumably having been dropped during the season. Some buds had burst in the spring, but the leaves failed to flush before circulation was entirely cut off, and they had remained small, shrivelled and curled. Other buds had not burst.

Hawboldt's description pointed in detail to the probability that the main symptoms appeared in 1945, although he indicated a possible belief that tree No. 2 may have had symptoms in the fall of 1944. Hawboldt (1947, p 418) ended his description of the root studies: "In deciding what records to take in decadence, it was felt that the condition of the twigs and rootlets presented the major part of the story in the early stages of dieback. Later analysis of the data seemed to substantiate this".

The temperature diagrams in Fig. 8 C-D on the 1945 thaw-frost event show DDG values of 72 and 71 before the last frost of -10.6°C at Antigonish (April 16), and -6.7°C at Stillwater (May 3). Cold nights occurred also later: Antigonish -3.9°C (May 3) and Stillwater -4.4°C (May 22) at DDG of 104 and 145. Because the weather stations are situated 30-35 km away, the DDG values and the frost temperatures at Willowdale are somewhat uncertain, but it seems quite clear that frost occurred on April 16 and very probably also May 3 (-3.9°C and -6.7°C). The alternative DDG values are put in parenthesis on the diagrams.

This strong frost in the Willowdale area April 16, 1945 and probably again May 3 must have caused the early visible damage by which Hawboldt classified his trees in the autumn. Results obtained in the cited experiments in Norway, support this conclusion.

In the judgement of cause and impact this knowledge of frost damage to the crowns turns the earlier conclusion around. Rootlet dying can not be the first stage of dieback, but a secondary one as a result of frost damage and dying buds and twigs.

Rootlet dying obviously occurred quickly in the course of the first growing season after the April/May frost. This succession of the symptoms is logical and in accordance with the experiments 1989-

1994, where the frost caused birch-dieback-like symptoms on thrifty but vulnerable trees. Unfortunately no root studies were made in these experiments, but such ought to be part of future research.

5.2 Variation in crown injury classes

Hawboldt's observations show very important features of the birch dieback in relation to a thaw-frost event. Three trees close to each other in the same stand were hit by the same thaw followed by the same frost nights. Nevertheless, they were affected to highly different degrees showing up the first autumn.

The first feature to be stressed is the fact that tree No. 1 appeared perfectly normal with full-size foliage. Still ten per cent of the terminal twigs were dead. Surely, more trees in the stand are affected in the same way. Some of these may have less or even scarcely visual injury on buds or twigs. An important question is then if these trees are developing into visible injury classes in coming years, and then showing a kind of increasing or spreading of the dieback. For standing trees recorded in the lower injury classes, the general impression from the assessments is an increasing state of injury from year to year until some recovery occurs. A good example of this development are the results from the observation plots at Dukes 1954-57 after the May frost in Upper Michigan 1954. (Godman 1956 and 1958.)

Many trees had no visible injuries the first season, and may be even the second one after the frost. The injured trees were hurt to highly different degrees. These circumstances made it very difficult to determine the start of the crown injuries. As long as frost was not observed as an injuring cause to the crown, the confusion regarding the succession of damage symptoms is very understandable. The gradual manifestation of frost injuries contributed to the belief of spread.

The other important feature is the great variation of injury among the trees. The main reason for that seems to be the variation of budburst time within a population of trees (provenance) as cited in previous chapters. So Table 1 shows that the twigs in the 1994 experiment entered the vulnerable bud burst class 3 from April 21 to about April 28. A frost within this 7-9 days period would hurt only a few trees early in the period and nearly all trees at the end.

The position of the trees in the stand certainly contributes to the variation. The assessments cited indicate more injuries to dominant trees and less to intermediate and suppressed trees (e.g., Greenidge 1953a, p 73, Nash and Duda 1951, p 17). This probably indicates that bud burst on intermediate and suppressed trees occurred somewhat later (less vulnerable to frost at a certain date) than on dominant trees. In addition, the crowns of dominant trees possibly are more exposed to the frost than the somewhat sheltered crowns of intermediate and suppressed trees.

5.3 The moisture regime of diseased birch

An early indication of increased water content in wood of decadent trees was given by Hall (1933, p 15). The moisture content of the sapwood at breast height of paper birch increased with the degree of decadence. Thrifty trees had a moisture content of about 50 per cent, whereas those with leaves 25 per cent of normal size averaged about 100 per cent, and those with still smaller leaves averaged much higher. "This condition in decadent trees may be due to a decrease in transpiration surface."

Studies by Sinclair and Hill (1953, p. 178) revealed that in unhealthy trees the moisture content increased from the beginning of the season until the second week in July, and thereafter decreased until the end of the season. These moisture fluctuations within injured trees are opposite to those of healthy trees with lowest water content in July.

In the large studies of moisture regimes in Nova Scotia 1950-51 the moisture pattern within the stems of damaged yellow birch were very much out of order as described by Greenidge (1953). In 3 A trees the upward water movement took place only a short distance in the outer rings. Further upwards the water moved in the inner sapwood, leaving the outer sapwood unstained. In the crown the staining pattern was irregular and discontinuous.

Certainly, such a 3A tree i out of physiological balance. Outer symptoms are dead twigs and small dead branches at the top of the crown, as well as about 60 per cent dead rootlets.

Further studies are needed to clarify the water content variation and the rootlet dying. One hypothesis may be that trees damaged by frost get water through the root pressure in quantities exceeding the transpiratory capacity of the reduced crown. Consequently, a sort of self-drowning may take place within each tree, independent of the water regime of the outer environment. In such a situation rootlets exist in abundance and may start dying. Watersprouts on the stem appearing already the same season, is another sign of unbalance in the tree, as in the 1993 experiment.

In injury class 3 A the bronze birch borer seems to turn up already the first season as described by Hawboldt (1947). More than half of the attacks were then unsuccessful, but the borer certainly is expected to continue attacking next season. Although the borer has no role in initiating the birch dieback, it is a major factor for the development of the dieback from crown class 3 A and onwards.

5.4 Conclusion

Clear birch dieback symptoms on yellow birch trees appear after a frost of at least -5°C after budburst where green tips of leaves are visible at the end of the buds. (Stage 3).

Budburst stage 3 in March and early April seems to need at least 100 day degrees (base temp. 4°C), whereas between 50 and 100 day degrees are adequate for bud burst in late April and May. The thaw and frost experiments in Norway 1989, 1990, 1993 and 1994 yielded these results. The requirements of day degrees however, are also somewhat varying with the provenances.

The birch dieback had its main period 1937-1949, and studies of the early spring climate (March - May) for the years 1936, 1944, 1945 and partly 1946 revealed day degree values above 100 with subsequent frost over huge areas in Eastern Canada and North-Eastern USA. The areas hit in one or more of these years corresponds very well with the accumulated birch dieback areas. (Compare Figs. 5 and 6).

As damaging weather events occurred at least three times, covering partly different areas, the early feeling of spreading of the malady is explained. Also a local top dying event in Upper Michigan in 1954, showed a clear birch dieback pattern, and is explained by the frost in May 1954.

These circumstances give basis for the conclusion that dieback of yellow and white birch was caused by spring frost in the vulnerable stage of budburst.

Rootlet dying, which has been considered as the first symptom of birch dieback, turns out to be a secondary one, resulting from the frost damage in the crown. In the references of literature, no evidence is found contradicting this conclusion.

Frost injuries to the periphery of the crown with a decrease in transpiration surface, seems to bring the tree out of physiological balance. The moisture content increases in the wood, and the pattern of the upwards water movement in the stem gets much out of order. A kind of self-drowning seems to take place, and shooting of watersprouts on lower stem and branches are common.

Although the main cause of birch dieback seems clarified, there are still some questions that need further research. One is the physiological state and development of yellow birch after a spring frost damage in the crown, and the relation of rootlet dying and water movement in stem and branches.

Another question is why birch obviously was harder damaged than other broadleaves, although damage was also observed on several other species, among them the maples.

LITERATURE

Report = Canada Department of Agriculture 1953. Report of the symposium on birch dieback. Summary of the meetings held in Ottawa, March 21 and 22, 1952. Forest biology division, Science Service, Department of Agriculture, 182 pp.

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Auclair, A. N. D., 1987a. The climatic change theory of forest decline. Concept paper and research proposal. Version B, Atmospheric Environment Service, Downsview, Ontario, pp. 25 + Figures.

Auclair, A. N. D., 1987b. The climate change theory of forest decline. IUFRO Conference on woody plant growth in a changing physical and chemical environment, Vancouver, Environment- Canada, pp. 29.

Auclair, A. N. D., R. C. Worrest, D. Lachance, and H. C. Martin, 1992. Climatic perturbation as a general mechanism of forest dieback. In: Forest decline concepts, edited by P. D. Manion and D. Lachance: 38-58. The American Phytopathological Sosiety, St. Paul, Minnesota.

Balch, R. E., 1953. The birch dieback problem. In: Report 1-4.

Balch, R. E. and J. S. Prebble, 1940. The bronze birch borer and its relation to the dying of birch in New Brunswick forests. Forestry Chronicle XVI: 1179-201.

Barter, G. W., 1947. Inspection of hardwood stands in New Brunswick, Quebec and Ontario regarding spread of birch dieback. Mimeographed report of the Dominion Entomological Laboratory, Fredericton, N. B.

Barter, G. W., 1949. Condition of birch in northern Ontario and summary of present status of birch "dieback" in Quebec and the Maritime Provinces 1948. Canada Dept. of Agriculture, Science Service Res. Note Series, No. E-3.

Barter, G. W., 1953a: Work on the birch dieback problem in the Maritime region. In: Report 12-21.

Barter, G. W., 1953b. Some characteristics of birch dieback. In: Report 22-33.

Barter, G. W., 1953c. Evidence of spread of dieback as indicated by location and time of injury. In: Report 34-40.

Barter, G. W., 1953d. Role of the bronze birch borer to dieback in the Maritimes. In: Report 118-22.

Barter, G.W., 1953e. The variation within injury classes from year to year in sample trees. In: Report 150-5.

Berbee, J. G., 1957. Virus symptoms associated with birch dieback. Can. Dep. of Agriculture, Science Service - Forest Biology Division. Bi-monthly Progress Report 13:1.

Braathe, P., 1957. Is there a connection between the birch dieback and the March thaw of 1936? Forestry Chronicle XXXIII: 358-63.

Clark, J. and G. W. Barter, 1958. Growth and climate in relation to dieback of yellow birch. Forest Science 4:343-64.

Clausen, K. E., 1973. Genetics of yellow birch, USDA For. Serv. Res. Pap. WO-18, 28 pp.

Crosby, D., 1953. The variation within injury classes from year to year in the Northeastern States. In: Report 159-62.

Daviault, L., 1953. Evidence of spread or intensification as indicated by location and time of injury. In: Report 42-9.

Dominion of Canada, Dep. of Marine (or Transport) Meteorological Division. Monthly record of meteorological observations in Canada and New Foundland, 1936, 1944, 1945 and 1946.

Fraser, D. A., 1959. Ecological studies of forest trees at Chalk River, Ontario, Canada. V. Nine years of observations on the condition of 241 yellow birch. For. Res. Division Tech. Note No. 69: 1-23.

Godman, R. M., 1956. Progress of top-dying in yellow birch - Upper Mishigan, 1954-1955. Lake States For. Exp. St., Tech Notes 444:1-2.

Godman, R. M., 1958. Changes in yellow birch top-dying. Upper Michigan 1954-1957. Lake States For. Exp. St., Tech. Notes: 527:1-2.

Greenidge, K. N. H., 1953a. The moisture regime of healthy and diseased birch. In: Report 70-91.

Greenidge, K. N. H., 1953b. Further studies of birch dieback in Nova Scotia. Canadian Jour. of Botany 31:548-59.

Hall, R. C., 1933. Post-logging decadence in northern hardwoods. Univ. Mich. School For. and Conserv. Bul. 3:66 pp.

Hansbrough, J. R., 1953. History of birch dieback in New England. In: Report 6-7.

Hawboldt, L. S., 1947. Aspects of yellow birch dieback in Nova Scotia. Jour. of Forestry 45:414-22.

Hawboldt, L. S. and A. J. Skolko, 1948. Investigations of yellow birch dieback in Nova Scotia in 1947. Jour. of Forestry 46:659-71.

Heide, O. M., 1993. Daylength and thermal time responses to budburst during dormancy release in some northern deciduous trees. Physiologia Plantarum 88: 531-40.

Jacob, R. D., 1960. Top-dying of yellow birch, Upper Michigan, 1955-59. Lake States For. Exp. St., Tech. Notes 585:1-2.

Kessler, K. J., 1967. Dieback not a cause of mortality or reduction of growth or quality inLake States northern hardwoods. Jour. of Forestry 65: 892-3.

LRTAP, Workshop No. 6., 1986. Forest decline workshop Wakefield, Quebec, October 20-22, 1986. Atmospheric Environment Service, Downsview, Ontario, pp. 223.

Martineau, R., 1953. The variation within injury classes from year to year in white birch in Quebec. In: Report 163-6.

Millers, I., D. S. Shriner and D. Rizzo, 1989. History of hardwood decline in the Eastern United States. Northeastern Forest Experiment Station. US Forest Service General technical report NE-126: 1-74.

Murray, M. B., M. G. R. Channel & R. I. Smith, 1989. Date of budburst of fifteen tree species in Britain following climatic warming, Jour. of Applied Ecology 26:693-700.

Nash, R. W. and E. J. Duda, 1951. Studies on extensive dying, regeneration and management of birch. Maine Forest Service, Bulletin No. 15:1-82.

Pomerleau, R., 1953a. History of hardwood species dying in Quebec. In: Report 10-1.

Pomerleau, R., 1953b. Spread versus intensification of dying in hardwood species in Quebec. In: Report 50-1.

Pomerleau, R., 1953c. The relation between environmental conditions and the dying of birches and other hardwood trees. In: Report 114-7.

Pomerleau, R., 1953d. Development of dieback in trees and stands. In: Report 147-9.

Pomerleau, R., 1991. Experiments on the causal mechanisms of dieback on deciduous forests in Quebec. Information report LAU-X-96, Forestry Canada, Quebec Region. pp. 48.

Redmond, D. R., 1953a. Twig-inhabiting fungi on yellow birch. In: Report 136-7.

Redmond, D. R., 1953b. Inoculations of twigs of living birch with fungi. In: Report 138-9.

Redmond, D. R., 1953c. Root-inhabiting fungi of yellow birch. In: Report 140-3.

Redmond, D. R., 1955. Studies in forest pathology XV. Rootlets, mycorrhiza, and soil temperatures in relation to birch dieback. Can. J. of Botany 33: 595-627.

Rose, A. H., F. A. Bricault and A. A. Harnden, 1969. A review and assessment of the Dimorphopteryx sawfly problem on yellow birch in central Ontario (Hymenoptera: Tenthridinidae). Int. Rpt. 0-15. Canada Department of Fisheries and Forestry, Sault Ste. Marie, Ontario, Canada.

Sarvas, R. 1967. The annual period of development of forest trees. Proceedings of the Finnish Academy of Science and Letters 1965: 211-31.

Sarvas, R. 1972. Investigations on the annual cycle of development of forest trees. Active period. Comm. Inst. forest. fenn. 76.3. pp. 110.

Sharik, T. L., 1970. Leaf flushing and terminal growth cessation in populations of yellow birch (Betula alleghaniensis Britton) and Sweet birch (Betula lenta L.) in the Appalachian Mountains. Ph. D. thesis, Univ. of Mich. 66 pp.

Sinclair, G.A. and A. W. Hill, 1953. Study of the condition of birch in Ontario. In: Report 167-78.

Spaulding, P. and H. J. MacAloney, 1931. A study of organic factors concerned in the decadence of birch on cut-over lands in northern New England. Jour. of Forestry 29:1134-49.

US Dep of Agriculture (or Commerce), Weather Bureau. Climatological Data. 1936, 1945, 1946, 1954, 1969, 1970 and 1971.

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The pages shall be numbered consecutively beginning with the title page.

Articles will usually be organized as follows: (1) introduction, (2) materials and methods, (3) results, (4) discussion and (5) summary. Up to three grades of headings can be used to divide up the text. Articles must not exceed 20 manuscript pages, and two copies should be submitted to the managing editor.

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Avoid horizontal and vertical rules (lines) in tables. Tables shall be self explanatory as far as possible without the reader having to refer to the text.

FIGURES

All illustrations, line drawings as well as photographs, shall be considered as figures. Figures shall be numbered consecutively with Arabic numerals. Letters, numerals and symbols must stand out clearly and be in relation to each other. Make sure they are large enough to take reduction. Before preparing line drawings the author should decide wether they are to be of 1 column, 1½ columns, or 2 colums width so that lettering, etc., after reduction, will be the same size on all drawings. Photographs should be submitted as near to their printed size as possible. If enlargement or reduction is significant in an photograph, the scale should be given on the back and not in the legend. The legend should make the general meaning comprehensible without reference to the text. Figure legends shall be typewritten together on one or more sheets of paper.

REFERENCES

Reference indicators in the text will follow the Harvard style, with the author's name and the year of publication: Høeg (1971), or (Høeg 1971). The text reference indicator to a work by two authors is given by naming both authors: Oen & Vestrheim (1985) or (Oen & Vestrheim 1985). If three or more authors, the text reference indicator is given by adding et al. to the first named author: Aase et al. (1977) or (Aase et al. 1977).

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Høeg, O.A. 1971. Vitenskapelig forfatterskap. 2. utg. Universitetsforlaget, Oslo. 131 s.

Oen, H. & S. Vestrheim 1985. Detection of non-volatile acids in sweet cherry fruits. Acta agriculturae scandinavia 35: 145-152.

Strømnes, R. 1983. Maskinell markberedning og manuell planting. Landbrukets årbok 1984: 265-278.

Uhlen G. 1968. Nitrogengjødsling til ettårig raigras. Jord og avling 10(3): 5-8.

Aase, K.F., F. Sundstøl & K. Myhr 1977. Forsøk med strandrøyr og nokre andre grasartar. Forskning og forsøk i landbruket 27: 575-604.

Notice that:

- Only the first named author's initials and surname are inverted.
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