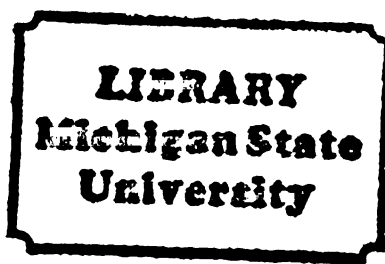


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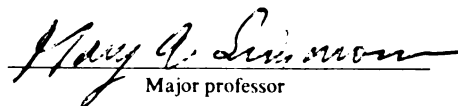
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behavior and development

By

John Jeffrey Ball

A THESIS

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ABSTRACT

Changes in physiological conditions of European white birch (Betula pendula Roth) and its relationship to birch dieback and bronze borer (Agrilus anxius Gory) behavior and development

John Jeffrey Ball

The onset of dieback of European white birch cannot be predicted by root starch or mycorrhiza infection. However, levels of root starch and mycorrhizae do decrease once a tree is afflicted with dieback. Dieback is preceded by changes in the sugar ratio. In addition, measurements of stem electrical resistance (ER) can be used to indicate a tree's attractiveness to adult bronze birch borers. Trees with high ER have some adult borer activity about them, regardless of their external appearance. The bronze birch borer can survive from the second instar to adult stage in healthy trees. Their galleries are not greatly affected by the vigor of the host. Parasitoids are an important regulating factor of bronze birch borer populations. Cannibalism may also exist during the larval stage.

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John Jeffrey Ball

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INTRODUCTION

Objective

Man, in a desire to create a more natural environment, has softened his surroundings by planting ornamental trees and shrubs. Unfortunately, a limited knowledge of factors influencing tree survival and growth has caused many ornamentals to be placed in marginal growth situations. Trees growing under these circumstances are stressed, which increases the frequency of pest problems. One of the more dramatic problems occurring in urban areas is tree dieback and decline. Several genera afflicted with this problem are maple (Acer spp.), (maple blight), ash (Fraxinus spp.), (ash dieback), and birch (Betula spp.) (birch dieback). In each case attempts have been made to associate an organism with the disease. In the case of birch, the organism connected with the symptomatology is the bronze birch borer (Agrilus anxius Gory). It is unfortunate that the birch borer was so quickly associated with the symptoms since most of the efforts to control the syndrome has centered around the insect. Relatively little effort has been expended to determine physiological conditions of the primary host, European white birch (B. pendula Roth), that can be correlated with borer attack. Kozlowski (1969) stated that a tree must undergo some physiological changes before it can be successfully attacked by an insect. This change to a more susceptible state may be related to several stress factors (Houston, 1981) Therefore, dieback and decline should be more accurately described as a

stress-host change-organism attack relationship rather than an organism attack-host change relationship. If changes in physiological conditions were better understood, perhaps management of birch dieback could consist of environment modifications to relieve stress rather than the present day strategies of chemicals directed against the bronze birch borer. Not only is this reliance on a chemical protective barrier costly and environmentally unsound; it does nothing to alter the initial host changes.

Information on the interaction among the bronze birch borer, its parasitoids and predators and the European white birch in urban areas is rather sparse. While the bronze birch borer was first discovered as a pest of European white birch in urban areas of northeastern United States, most attention was soon turned to the major problem of birch dieback in forests. Hence we have information on the interaction of the borer with paper birch (B. papyrifera Marshall) and yellow birch (B. alleghenensis Britton) in forest situations (Barter, 1957) but we do not have this same information with the European white birch.

Performing research on phloem-feeding insects in urban areas is a difficult task. Land ownership is very fragmented, making it difficult to accumulate a large enough sample of trees to study. The research must be tailored not only to provide useful information, but also to gain the cooperation of the homeowners who own the trees. This cooperation between researcher and the general public can also generate many useful by-products. By observing the research process

first hand, homeowners may gain a better understanding of the natural world about them.

Borer research, in itself, presents some difficulties. To examine the larval stage often requires removing the inner bark. Many past studies on Agrilus larvae such as those performed by Anderson (1944), Barter (1957) and Staley (1965) have required the removal of the bark, a process that is destructive to both the tree and the borer. It would be extremely useful to have a method that permits examining the larvae while minimizing the disturbance to the borer and its host.

The objectives of this research project were:

1. To determine physiological conditions of European white birch that can be correlated with the various aspects of bronze birch borer attack.
2. To develop methods urban forest managers can use to predict which trees may begin to exhibit symptoms of dieback.
3. To examine the population regulating factors of the bronze birch borer in urban situations.
4. To develop a method which researchers can use to observe borer larvae that is not destructive to either the host or the insect.
5. To develop a process that will aid in soliciting the cooperation of the owners of the urban forest for urban forestry research projects.

Background Information on Birch Dieback

The bronze birch borer is a native North American species. The larvae feeds within the phloem-cambium region of the tree. This causes extensive girdling which may be a contributing factor in the death of the tree (Barter, 1957).

Bronze birch borer was first recognized as a pest in the late 1890's. At that time the insect was associated with the crown dieback and death of European white birch in Buffalo, New York (Chittenden 1898, Chamberlain 1900). Several other urban accounts of this relationship soon followed (Larsen, 1902; Slingerland, 1906). For the next 40 years attention was shifted to the forested areas of Northeastern North America where bronze birch borer was observed attacking over-mature paper and yellow birch (Spaulding and MacAloney, 1931; Balch and Prebble, 1940; Hawboldt and Skolko, 1948). Originally, bronze birch borer was thought to be the cause for the massive dieback of birch. However, the borer ceased being considered a primary forest pest in the 1950's as the dieback of birch became an infrequent occurrence. It was generally concluded that the abnormally high temperatures and low rainfall during the previous two decades provided the initial decline, with extensive dieback beginning after borer colonization (Hawboldt, 1947; Barter, 1957). Trees in the early stages of dieback were often found free of borer and were capable of improving if environmental conditions became more favorable (Hawboldt, 1947; Barter, 1953).

With the widespread expansion of the suburbs after WWII, home landscaping increased dramatically. As planting of European white birch increased so did the problem of bronze birch borer. Despite the long association of the bronze birch borer and European white birch, surprisingly little is known about the relationship. Cultural controls have not changed in the past 80 years. A continual major recommendation is to avoid planting European white birch (Peirson, 1929; Kozel and Toth, 1975) a recommendation which has been ignored by nurserymen and homeowners. A recent survey of a midwestern town revealed that one out of every three home lawns contained a European white birch (Dirr, 1975).

Bronze Birch Borer

Bronze birch borer, so named because of the color of the adult, is a phloem-cambium feeder during the larval stage. The borer generally develops through four instars during the summer and fall and then forms the fifth instar at the onset of winter. However, all instars may be found beneath the bark during the winter (Barter, 1957). The fifth instar is the only over-wintering instar capable of developing into an adult the following summer (Barter, 1957). The pupal stage forms in May and is approximately a month in duration. Adults begin emerging from the bark in early June with emergence usually lasting for about 6 weeks (Wellso et al., 1976).

Adults are dark bronze in color and subcylindrical in shape. They are usually between 7 and 11 mm in length, with the female slightly larger than the male (Barter, 1957). The adult borers feed

sparingly on leaves of several genera of trees (Nash et al., 1951). They do not cause any aesthetic damage. Eggs are laid singularly in bark crevices or under loose bark flakes. The eggs hatch in 14 days with the first instar immediately burrowing into the bark and proceeding to the phloem-cambium region. The bronze birch borer generally has a one year life cycle, but in parts of northern United States and Canada a two year life cycle is common (Balch and Prebble, 1940). A two year life cycle may also occur in vigorous hosts (Nash et al., 1951).

The physiology of the host may influence the behavior and development of the borer in many other ways. While in the larval stage, the borer has often been observed making occasional departures into the xylem and constructing sinuate galleries. These galleries zigzag along the phloem--occasionally the galleries will wind completely around the stem or branch. Several researchers believe this behavior is a response to the physiological condition of the host (Barter, 1957). Galleries may also be longer in more vigorous hosts (Barter, 1957). Adult bronze poplar borer (A. liragus Barter & Brown) that emerge from relatively vigorous hosts may be smaller than their counterparts that lived in weaker hosts (Barter, 1965). Adult bronze birch borers are generally more commonly observed in the vicinity of weaker hosts (Anderson, 1944; Barter, 1957).

European White Birch

Birches are represented by about 40 species of trees and shrubs.

They are widely distributed throughout the arctic and Northern Temperate Zone. Most birches are readily identified by smooth, papery, light colored bark, but there are species such as B. lenta Linnaeus that are missing some of these characteristics. Agrilus anxius is host specific to birch and appears to attack species in the northern United States and Canada. Both native and exotic birches may serve as a host. River birch (B. nigra Linnaeus) is not a host (Carlson and Knight, 1969).

The most common host in urban areas of the northeastern United States is the European white birch and its varieties. While paper and grey birch (B. populifolia Marshall) are also very common in urban areas, European white birch appears to be suffering most from birch dieback and attack from the bronze birch borer (Ball and Simmons, 1980). Despite these problems, European white birch continues to have great popularity with homeowners. It is a graceful tree with slightly pendulous branches and white, exfoliating bark.

In addition to the bronze birch borer, European white birch planted in the United States may serve as host to a number of other pests. The birch leafminer, (Fenusa pusilla Lepeletier), is a serious defoliator. Disease organisms of European white birch are relatively uncommon. A dieback disease has been reported in the central United States (Carter, 1936). Symptoms of trees afflicted with this disease are a slow decline with eventual death (Graves, 1923). Trees infested with bronze birch borer are susceptible to this disease (Carter, 1967).

In its natural range, which is throughout Europe and many parts of northern Asia, European white birch suffers from several problems. A borer has been reported associated with birch in Europe, A. viridis Linnaeus (Slingerland, 1906). There are also several diseases of minor importance. European white birch also suffers from dieback after about 40 years, the cause of which is unknown (Rushforth, 1975). Trees may begin to decline from old age at 50 years (Gardiner, 1981).

European white birch has several varieties. The most popular is the cutleaf Swedish birch (B. pendula dalecarlica Schneider). This variety has very long, pendulous branches covered with deeply cut leaves. It is also extremely susceptible to bronze birch borer attack. European white birch is generally propagated by seed (Santamour, 1977).

Brief History of Bronze Birch Borer Research

The first cited evidence of widespread mortality of birch related to the bronze birch borer is in a letter to the editors of Garden and Forest, July 1, 1896. A Mr. J. Jack of the Arnold Arboretum noticed some foreign birches being attacked by a boring Agrilus beetle. He believed the borer had been introduced from Europe. Chittenden (1898) was informed of the dieback of many birches around the Buffalo, New York, area. He captured adult beetles flying around the trees and identified them as A. anxius. Since a common name was not yet provided, Chittenden named the beetle

the bronze birch borer in reference to the color of the adults and the host that they fed on.

Larsen (1902) was the first to publish information on the bronze birch borer in Michigan. He noted that European white birch in the Detroit and Ann Arbor areas were dying from the top down and were infested with bronze birch borer larvae. Slingerland (1906) also discussed bronze birch borer in relation to the dieback of European white birch. He also stated that, "as yet," there was no record of injury in forests or woodlands.

The first report of the bronze birch borer as a forest pest was by Swaine (1918). He noted dying birch in the Ottawa River watershed. Peirson (1927) also mentioned bronze birch borer being a problem in forest areas. He stated that the top of the tree was the first attacked, with infection proceeding downward in later years. Trees usually died in three or four years after attack.

Birch dieback in forested regions of northeastern North America began reaching epidemic proportions in the early 1930's. Though some investigators implicated the borer as the primary cause (Peirson, 1927), trees free of borer infestation were found in the early stages of dieback (Spaulding and Mac Aloney, 1931). Several other investigators also expressed the view that the borer was not an initiating factor in birch dieback (Pomerleau, 1944; Hawboldt and Skolko, 1948).

Other organisms were considered as possible primary causes of birch dieback. Hahn and Eno (1956) explored the idea of a fungi association, but results were negative. All fungi tested were

saprophytic or very weak pathogens. Other researchers noted the symptoms exhibited by the early stages of dieback were characteristic of viruses (Hansbrough and Stout, 1947). Clark and Barter (1958) felt the spread of dieback across northeastern North America was typical of a virus. This hypothesis was given further weight by Berbee (1957) who was able to transmit virus-like symptoms from trees with dieback to healthy seedlings and older yellow birch trees. No further research on this interesting relationship has been published in the last 25 years.

It was also suggested that the dieback was caused by physiological disturbance brought about by climatic stress. Braathe (1957) traced a connection of dieback to the weather in 1937. He believed that the dieback occurred simultaneously throughout the affected region and this could only be explained by a weather phenomenon. However, Balch and Prebble (1940) traced the beginning of the dieback to 1932, four years earlier. Pomerleau also gave environmental stress as an explanation for birch dieback (Hepting, 1971). He believed that the 5 winters without snow between 1923 and 1943 resulted in the freezing and death of the shallow roots of birch. Others explored the possibility that the abnormally high temperatures and low precipitation during the 1930's and 1940's were responsible for the dieback. Redmond (1955, 1957) found that slight increases in soil temperature resulted in increased mortality of roots and decreased frequency of mycorrhizae on roots. Hawboldt and Greenridge (1952) reported that rootlet mortality was the first symptom of

dieback.

Regardless of the initial stress agent, it is now generally conceded that bronze birch borer is a secondary insect, usually capable of successfully attacking only weakened trees (Mac Aloney, 1968). The primary reason for the upsurge in borer populations during the two decades preceeding 1950 was due to a stress which persisted during that time period. The stress reduced the vigor of birch throughout a large geographical area. This situation increased the food supply of the borer. Once conditions became more favorable the birch were less stressed and recovery was possible. Many trees afflicted with dieback showed improvement rather than decline (Barter, 1953). The borer population decreased to the point where it, and birch dieback, were no longer considered of economic importance.

This is not the case in urban areas. Bronze birch borer and birch dieback are major limiting factors to the ornamental usefulness of European white birch and its varieties. While this problem has been known since the beginning of this century, management strategies have changed very little. Fertilizing and watering the tree to increase vigor has been a major recommendation for the last 5 decades (Felt and Bromley, 1930, 1931). Pruning out infested crowns was a recommendation at the beginning of this century (Slingerland, 1906) and still is today (Nielsen, 1979).

The most effective management strategy has been known for over half a century. Birch dieback in urban areas can not be managed effectively when the management unit is a single tree (Kotinski, 1921;

Britton, 1923). Managing birch dieback should be a community effort. A first step should be identifying internal changes in the tree in response to stress and then base management actions on these predicted changes in tree vigor.

METHODS

Location and Characteristics of Research Sites

This research project was conducted in three separate locations. The locations were different from one another in several regards. The Lansing location site was located in the suburban neighborhoods of East Lansing and Okemos, Michigan. The 60 trees selected for the study were European white birch that ranged in diameter from 9 to 35 cm DBH. These trees were being managed by the individual homeowners. Some trees were being managed properly but the vast majority were not being cared for or management consisted of ill-timed or inadequate treatments. The trees ranged in vigor, based on crown classification, from high vigor (class 1) to very low vigor (class 5) (fig. 1).

The second site was located within the village of Richland, a small community approximately 23 km northeast of Kalamazoo, Michigan. The site was a tree nursery owned by Light's Landscape until 1978. Since that time the property has been owned by the Richland Covenant church. Management has changed very little with the new ownership. The site is periodically mowed but the trees are not watered, fertilized or managed for pests. Hence, in terms of management the site does not differ greatly from the one in Lansing. The trees selected for the study were 20 European white birch ranging in diameter from 3.5 to 9.5 cm DBH. Five trees were selected from each of the 4 highest crown vigor classes (classes 1 through 4). We could not locate 5 trees representing vigor class 5. The site contained over

45 European white birch with the majority representing class 1 and 2 though there were many class 3 and 4 along with trees that had recently died. Since the site was located in a populated area there were many birch trees in the area surrounding the study site.

The third study site was located at the Tree Research Center on the campus of Michigan State University, East Lansing, Michigan. Fifty European white birch 2 - 2-1/2 in. (5.0 - 6.4 cm) caliper were transplanted to the site in early April, 1981. The trees were purchased from White Birch Farms, located near Charlotte, Michigan. The trees were moved before the buds began opening and were balled and burlap stock. The trees were planted on a 3 m spacing between and within rows. The holes were filled with a 1:1:1 ratio of peat, vermiculite and original soil. Overhead irrigation was put in place to insure an adequate supply of moisture. The trees established quickly, with only 4 failing to leaf out.

The reason for the three separate study sites was due to the nature of the research project. The research efforts centered around measuring vigor and predicting dieback in mature European white birch populations, correlating borer activity to the physiological condition of the host and altering host condition to test the affect on borer development.

Research Conducted at the Lansing Site

The vigor and prediction studies were conducted on a typical birch population in a suburban community since this is where the

Fig. 1. Crown vigor classification.

				
Class 1	Class 2	Class 3	Class 4	Class 5
A healthy, vigorous tree. The crown full and consisting of normal size, green foliage	Scattered patches of flagging	Twig and small branch dieback	Dieback of no more than 50 percent of the crown	More than one-half of the crown devoid of foliage, but crown must still contain at least several branches with foliage

information may prove most valuable. This is not an easy task. Urban tree pest studies suffer from a problem not usually associated with forest tree pest studies. While a forest pest researcher may be able to locate 100 study trees under the ownership of one individual or organization, urban landownership is more fragmented. Tree selection had to be done on a door-to-door basis, a process that requires a considerable amount of time.

In order to enlist their tree in a study, homeowners were approached on an individual basis. An initial effort in the search for study trees was to conduct a street survey of the European white birch trees in the two adjacent communities of East Lansing and Okemos. Each European white birch was noted as to its location and relative vigor according to the crown vigor classification system. Once the list was compiled, trees were placed into 5 sublists based on their vigor classification. Next was the task of obtaining the homeowner's cooperation for the study.

The first step in this process was to identify reasons why a homeowner would want to participate. Once their motivation was understood, reward could be built into the program as incentives for their cooperation. People volunteer for a variety of needs; self growth, enjoyment of the work and to improve the quality of their community, among others. I felt people might 'volunteer' their tree for many of the same needs. Rewards were built into the program to meet these needs. Homeowners would be kept informed of the objectives and progress of the program. The problem of birch dieback

would be explained along with how the results would benefit them and their community.

Homeowners were contacted in the evening hours to obtain their cooperation in the study. The program was explained in detail, what would be done and when, and most importantly, why. They were assured that the tests represented no risk to their trees and the information collected by this study would be of personal interest to them. All were informed that they would be notified of the results of the study and would be provided with recommendations on how to improve the vigor of their trees. In addition, for their cooperation, advice and recommendations would be made for any other plant problem that might occur during the duration of the study. A note of thanks was sent to the homeowners shortly after the visit (appendix I). The note reiterated the information discussed the night before and gave a telephone number where I could be reached for further information.

This process was very time consuming. Generally, a home visit required 60 to 90 minutes since many homeowners requested the identification of various pest problems during the visit. However, this personal approach paid off; of the 61 homes contacted about involvement in the study, 60 agreed to cooperate. The main reasons expressed for their cooperation were that the study would be of benefit to them and that someone took the time to personally invite their participation. Several homeowners remarked that they have been contacted in the past for other studies and now routinely ignore any request that is not personally made.

A second note was mailed in the fall of 1981 informing the homeowners that the program was completed and thanking them for their cooperation (appendix II). The following spring a third note was mailed to the participants (appendix III). This note provides a diagnosis of their tree and included an extension bulletin (Kennedy and Ball, 1981) that provided recommendations for their trees.

Two methods of evaluating the physiological condition of the tree were used at the Lansing site. They were (1) measurement of the ratio of stem inner bark sugars and (2) stem electrical resistance. Both measurements were correlated to present crown class (late summer 1980) and were used to predict changes in crown vigor one year later (late summer 1981). In addition, the onset and uniformity of the fall color change was noted.

Research Conducted at the Richland Site

While the vast majority of homeowners were willing to cooperate with the research there were some studies that could not be conducted at the Lansing site due to the destructive nature of the study or the distance between trees. To solve this problem a second study site was selected in Richland, Michigan. At this site, in addition to measuring stem electrical resistance, mycorrhizae abundance was noted along with tree root starch levels. These two analyses would have required digging in homeowner's lawns. Adult activities were also monitored on the Richland trees. Since the borer has a limited time of daily peak activity, the study trees had to be close to one

another to reduce the time between observations. In addition, larvae were implanted into the trees and all trees were cut down in 1982 to observe gallery construction of implant larvae as well as development of borers resulting from natural attacks. Mortality factors were also considered for both implant and borers from natural attacks. Obviously all this activity required trees that could be destroyed; hence the use of the abandoned nursery site rather than trees in the community.

Research conducted at the Tree Research Center

Another aspect of the study was concerned with the development of borers in trees grown under controlled conditions. The trees in the community and the abandoned nursery were influenced by previous stresses that were outside of our control. By using young nursery trees I could control the stresses and observe differences in borer development among treatments. Another important factor in the consideration of the use of young uninfested trees was to have some control over the number of borers attacking the tree. In previous research I found that often in infested trees the attack was so heavy that individual galleries were almost impossible to follow, a problem noted by several other researchers (Larsen, 1902; Slingerland, 1906).

The nursery trees planted at the the Tree Research Center were grouped into four treatments; a control, defoliated, girdled and a group that was both defoliated and girdled. There were 11 trees in each treatment. One possible criticism of this approach might be

that since the trees are only recently transplanted they are all stressed; hence tree response may not have been what it would be with established trees. This is a valid point especially since birch is moved with great difficulty (Pirone, 1978). However, I could measure changes in the response of these trees to the various controlled stresses and levels of bronze birch borer infestation.

Trees at the Tree Research Center were randomly assigned to 4 different treatments; a control, defoliation, girdled and a group both defoliated and girdled. Stresses were not applied until after July 5, 1981 so trees would be in similar states of vigor during the time borers were caged on them. This was necessary since caged oviposition can be influenced by the vigor of the host (Barter, 1957). Defoliation was accomplished by the removal of every other leaf blade on the assigned trees. Petioles were left attached. This operation resulted in a reduction of approximately 50 percent of the leaf surface area of the trees. The trees assigned to be girdled were cut to the outer xylem. The cut was in a complete circle around the stem and was made about 10 cm above ground level. The cut was 1 to 2 cm wide.

Changes in physiological conditions of the trees at the Tree Research Center were measured by changes in inner bark reducing sugar content, differences in stem electrical resistance readings and in root starch levels. Sugar samples were made in the early summer of 1981 and 1982. Stem electrical resistance readings were taken monthly from June 1981 until October 1981 and also May and June 1982.

Root starch samples were collected only once. This was during March, 1982.

Electrical Resistance Measurements

Tree stress at these various sites was qualified by a number of different methods since no one method has been shown to be an excellent indicator of stress. In addition, each of the methods measures different changes in the physiology of the tree. One method of measuring stress, electrical resistance, was employed at all three sites. Stem electrical resistance was measured with the Shigometer model 7950. The Shigometer produces a pulsed current of 0.5 uA for 0.5 ms. The intervals between pulses is 10 ms (Skutt et al., 1972). The meter was equipped with two scales, 25 and 50 kohms. At the suggestion of Dr. Shigo (personal communication), I used the 50 kohm scale. The meter was attached to a plastic handle containing two 1 cm uninsulated stainless-steel needle electrodes. The two needles were inserted vertically into the bark. They were inserted until deeper manual insertion became difficult. Deeper insertions did not result in a lowering of resistance, a fact pointed out by Wargo and Skutt (1975). All measurements were made between 10 am and 1 pm EDT with air temperature recorded, since electrical resistance measurements are influenced by air temperature (Davis et al., 1979). Hence, measurements may need to be adjusted using air temperature as a covariant. However, there was only a 2°C difference among measurement so this variable was not found to be significant and was

ignored. Each tree had the electrodes inserted at a height of 1.37 m with measurements made on both the north and south side of the tree. The two readings were not significantly different and were averaged for the analysis. Several past studies have noted that ER was correlated with tree diameter (Wargo and Skutt, 1975; Newbanks and Tattar, 1977). There was no strong or significant correlation between ER and tree diameter with trees located at the Tree Research Center ($R = -0.05$). This may be due to the small size difference among the trees. The correlation between ER and tree diameter for the mature trees at the other two sites will be discussed later. All ER measurements for the mature trees were analyzed with diameter as the covariant.

Wound Closure

In addition to experiments using the Shigometer to detect and predict decline, I also elected to measure the degree of wound closure among trees of the different crown vigor classes. The relationship of tree vigor on a tree's response to wounding has been well documented (Neely, 1970; Wargo, 1977). Trees suffering from low vigor require a longer time to close a wound than their higher vigor counterparts. This may be due to more bark tissue dying and slower rate of radial growth (Wargo, 1977). During August of 1980 I wounded the same trees in East Lansing and Okemos from which was recorded stem electrical resistance. The wounds were created during the same week that the resistance readings were taken. The trees were wounded

with a 2.54 cm diameter arc punch. The wounds were made in the general vicinity of 1.5 m above ground but were made slightly higher or lower if the wound would be more hidden from view. This was done to reduce altering the appearance of the homeowner's tree. The slight differences in height of the wound was not a concern. Neely (1970) observed that variation in wound height had no significant effect on the rate of closure. The following August (1982) the trees were checked to observe current crown condition and wound closure. Wound closure was divided into 5 categories based on the degree of closure. These categories were related to the percent of wound closure; 0, 25, 50, 75 and 100 percent closure.

Inner Bark Sugar Measurements

Change in carbohydrate, particularly the monosaccharides and disaccharides, have been used as indicators of a tree's response to girdling (Baldwin 1934, Siminovitch et al., 1953) and moisture deficiency (Hodges and Lorio, 1969). Samples taken for carbohydrate analysis were taken with a 2.54 cm diameter arc punch. Samples were taken to the depth of the outer xylem and the bark peeled off the sample. The samples were taken between 7 and 8 am EDT on the same day for each site. After being removed from the tree, each sample was immediately placed in a flask filled with liquid nitrogen. After all the samples were taken for a particular day they were brought into the laboratory and stored at -15°C until analyzed. Samples from the Kalamazoo and Lansing sites were taken from a height of 0.75 to

1.5m. Since the Lansing trees were specimen trees the holes were made at a place on the stem where it would be the least noticeable, thus accounting for the range of sample heights. Samples at the Tree Research Center were taken at a height between 25 and 30 cm since the trees were greater than 3 cm at this point.

Samples were analyzed for reducing sugars by the Nelson's colormetric method as reported in Hodge and Hofreiter (1962). Total sugars were analyzed by the sucrose volumetric method reported by Ward and Johnston (1960) with minor modification. The dilute hydrochloric acid bath time limit was increased from 9 to 30 minutes. This change was based on preliminary studies which showed that 9 minutes was not long enough to completely reduce 0.8 mgs of sucrose into reducing sugar. No additional reduction was noted between 30 and 90 minutes; hence 30 minutes was the time period selected for the dilute hydrochloric acid bath. Sucrose and glucose solutions were prepared for each sample run. Aliquots of these solutions from 0.1 mg to 0.6 mg were made and a standard curve drawn from their absorbance. Absorbances for each sample were compared to these curves and converted to mg glucose equivalents.

Samples can not be reduced to dry weight before sugar analysis as heating will result in changes in the carbohydrate composition of the sample (Parker, 1979). Two methods are commonly employed to determine dry weight without altering the composition of the sample's carbohydrate; freeze-drying and section division. Section division was used for dry weight sugar analysis. Each 2.54 cm diameter sample

was divided into two approximately equal halves and use one side for analysis and the other for determination of dry weight. Sections used for dry weight determination were first weighted to determine the fresh weight then placed in an oven at 105^o C for 24 hours. When the weight no longer decreased that weight was considered the dry weight (Gibbs, 1939).

The section used for sugar analysis was quickly crushed into fragments roughly no larger than 3 mm. A 0.50 gram portion was placed in a Waring blender with 100 ml of 80 percent ethanol and blended for 5 minutes. The extract was then rinsed through Whatman #1 filter paper under vacuum with an additional 50 ml of 80 percent ethanol. The filtrate was then placed in an air stream and evaporated to 15 mL (Parker, 1970). Since the Nelson colormetric test is capable of determining reducing sugars only within the range of 0.1 mg to 0.6 mg, further dilutions were necessary. For determination of reducing sugar, 1 ml of the extraction was diluted with 5 ml of distilled water and 1 ml of this solution was used for analysis. For determination of total sugars 1.5 ml were used. The extractions were golden brown in color. This coloration would interfere with the absorbance. Such coloration can be removed by deproteinization (Somogyi, 1945), but this also removes a small amount of carbohydrates (Tainter and Lewis, 1982). I did not find deproteinization necessary due to the large dilution of the sample used for analysis.

Fall Color Change

It was decided to see if low vigor trees began their autumn color change at a different time than their high vigor counterparts. Trees at the Lansing site were checked once a week from mid-September, 1980 until the end of November. The week the autumn coloration began was noted for each tree along with how uniform the color change was.

Root Starch Measurements

Starch is a major source of reserve carbohydrates in many deciduous trees. Starch is stored in tissues throughout the tree, but the highest content resides in the roots (Wargo, 1971). Changes in root starch are of a greater magnitude than those in the stem (Wargo, 1978) hence are often used to detect changes in the tree that reflect reaction to stress such as defoliation (Parker and Houston, 1971), drought (Parker, 1970) and girdling (Siminovitch et al., 1953).

Since the starch content of a tree's roots is highest and most stable during the dormant season (Wargo, 1978), root samples were collected in early March of 1982. Root samples were collected from trees at Richland and the Tree Research Center. Trees located at the Lansing site were not sampled for root starch.

Root samples were analyzed by two separate methods. One involved extracting the starch from the roots and the other analyzed starch by staining. The extraction method is more precise but requires a laboratory and equipment hence may not be useful to an urban forest manager. Therefore, staining was also examined to see

if the values obtained would be useful to the manager.

Starch extraction was a modification of the method used to analyze sugars in stem inner bark. One gram of root samples was blended with 80 percent ethanol to separate out the sugars. The residue was then washed with ether to remove the fats. It was necessary to extract the fats before starch analysis because European white birch is known to store high concentrations of fats during the winter (Gibbs, 1940). The remaining residue contained the starch which was broken down into reducing sugar by a method outlined by Smith et al. (1964). Once reduced to glucose these sugars were analyzed by the Nelson colormetric method. Since there are differences between starches of different plants (Siminovitch et al., 1953) a standard starch was not used. Instead the reducing value of the starch was compared to glucose standards.

The histochemical technique was the other method used to analyze root starch (Wargo, 1978). Two sections were cut from each of three roots from each tree. These were stained with potassium iodide. They were then compared to each other and other trees on a relative scale based on the density of the staining; low, medium and high. The same root sections were used in the extraction method.

Mycorrhizae Study

The degree of mycorrhizae infestation with birch roots may vary depending upon the condition of the host (Hahn and Eno, 1956). Hence, one aspect of the research was to examine the mycorrhizae associated with trees and determine if any evidence exists to suggest

whether mycorrhiza changes occur before or after decline has begun. Birch, as with many other Amentifera and members of the family Pinaceae, form ectomycorrhizae. Ectomycorrhiza form a fungus mantle and are visible without staining. Trees at the Richland site were checked for mycorrhizae during spring, 1982. Three 20 cm diameter holes were dug at equal distances around each tree. Holes were made approximately 60 cm from trunk. Another three holes were made 90 cm from the trunk. The sampling procedure was modified from that suggested by Anderson and Cordell (1979) when total examining time is greater than 15 minutes. The species of ectomycorrhizae was not identified.

Borer Oviposition

For trees at the Tree Research Center it was necessary to force oviposition on the trees to insure enough borers to complete the experiment. The idea was not a new one, Nash et al. (1951) and Barter (1957) caged adults on birch trees to see if oviposition would result. Nash et al. (1951) reported that their attempts to force oviposition on trees in various stress conditions was a failure. Barter spent a great deal of time on trying to improve the success of forced oviposition by caged adults. He found the best results were with 4 foot cages and only one pair of beetles. Fifty five percent of his cages (n=115) produced borer attack. Success was influenced by many variables; condition of host, size of cage, number of adults in the cage and how close fitting the sleeve cage was to the tree.

I designed a 60 cm long sleeve cage with two 30 cm separating zippers so that cages could be easily placed around the trees. The zippers also permitted the easy transfer of adults. The cages were held to the trees with nylon rope tied at each end. A heavy gauge wire hoop was sewn around the middle of the cage to prevent the nylon mesh from collapsing. A small sponge-stopped vial similar to those used to maintain fresh cut flowers was used to hold fresh foliage in each of the cages. All foliage was cut daily from a class 1 European white birch. All the foliage for this experiment came from the crown of the same tree.

Adults used in this study were obtained from caged logs of European white birch. During the last week of May, 1981, 10 European white birch were felled, cut into 1 m sections and placed in cages in a lath house. The cages were checked three times daily and any new emergence collected and identified as to sex by using the presence or absences of a groove in the ventral first and second abdominal segment (Barter, 1957). The day's catch was segregated by sex and placed in cages marked for that day.

Fresh foliage from the same tree used in the field cages was placed in the cages daily. After six days a male and female were placed in a field cage. All 44 cages were filled within 5 days. At this time pairs of beetles were rotated among the trees. Every morning when foliage was replaced the pair was transferred to the next highest numbered cage. Beetles in cage number 44 were transferred to cage number 1. Dead adults were replaced from recent

emergence from the logs. Caging began on June 2 and continued until June 24. The cages were emptied on July 5.

The majority of the caged logs were from class 5 trees (1980) that failed to leaf out in the spring of 1981. The trees were donated by homeowners in the East Lansing-Okemos-Williamston area. Homeowners were personally contacted to request the donation of their trees. The reason for needing their tree was explained along with benefits of having us remove their tree. Benefits included all brush hauled away and logs returned for firewood at the completion of the project. The benefit of removing infested trees before the beetles emerged was also explained. All homeowners contacted agree to the request, several even offered to pay. Again, if homeowners are personally approached and treated as cooperators they generally are pleased to aid in urban research projects.

Larval Implant Operation

Larvae were implanted into the trees at the Tree Research Center and the Richland site. This practice has been successfully done with several larvae of Agrilus species (Barter, 1957; Carlson and Knight, 1969). Barter transferred second instar bronze birch borer larvae by cutting a v-shaped groove along and across the cambium-xylem surface. After depositing the larvae the bark was replaced and covered with beeswax. Survival of the larvae ranged from 36 to 100 percent depending upon the vigor of the host. Carlson and Knight successfully transferred first instar A.horni Kerremans. Transfer techni-

ques were similar to those of Barter but the bark was held in place by tape rather than beeswax.

On August 1, 1982 a mature class 3 tree in Okemos was selected as the donator for the larvae. Branches were cut and carried to the Tree Research Center. There they were peeled to expose the cambium-xylem region and any feeding bronze birch borer larvae. Once a larva was located the urogomphi were measured to determine the instar. As with Cote (1980) I found measuring the head capsule difficult since it can be retracted. The urogomphi were measured from their tip to the point of juncture with the abdomen. Second instar were considered to be those larvae with an urogomphi length of approximately 0.25 mm. Once discovered and identified these larvae were placed into a 3 cm v-shape groove cut into the cambium-xylem region. The bark was then replaced and covered with tape. The larvae were checked two days later so dead ones could be replaced. Over the course of the experiment 29 larvae had to be replaced.

Trees at the abandoned nursery were not stressed since they already represented 4 classes of vigor. Caged adults were not used with these trees due to the distance of the site from the Michigan State University campus and the complication of the caging process. In addition, these trees were being used for a host attraction experiment during oviposition time. However, I was able to implant second instar A. anxius into these trees in early August. The technique was identical to the one used at the Tree Research Center. The second-instars were obtained from branches of the same tree used for

the Tree Research center. Half of the study trees at the Richland site were in class 1 or 2. These classes normally are not infested with larvae (Ball and Simmon, 1981). I was interested in determining if larvae could survive in such hosts. Previous studies held that a successful attack was impossible unless the tree was attacked in great numbers (Barter, 1957). Since I did not want to greatly alter the tree from this operation, only 1 second instar larvae was implanted into each tree. Larvae were implanted at approximately 50 cm from the base of the tree. During the course of this transfer operation 8 larvae had to be replaced. Larvae for both the Richland and Tree Research Center site were replaced until mid-August when it became increasingly difficult to locate second instars. At this time the implanting operation stopped.

The following summer (1982) the trees at the Tree Research Center were caged to collect any emerging adults. The cages were the same style as used for caging adults on the trees the previous summer. I did not have enough cages to cover the entire bole of the tree but this did not present any difficulties. Oftentimes a rusty brown spot appears on the bark covering the cell of a hibernating larve (Slingerland, 1906). I found this stain to be an excellent indicator of the location of a borer. Many times the faint outline of a D-shaped hole could even be spotted in the stain. Cages were positioned over the stains. These cages were checked daily and newly emerged adults collected. These were placed into labelled 2 dram vials filled with 95 percent alcohol. They were then taken to the

laboratory, the sex determined and the adult measured. This same procedure was used with the trees at the abandoned nursery site in Richland. Again, cages were placed over likely emergent sites for the implant larvae. Several other portions of the bole and branch exhibiting reddish stain were also caged. These trees were checked once a week and the adults collected.

At the end of June, 1982, trees from both the Tree Research Center and Richland sites were felled and the bole and branches peeled back to expose the cambium-xylem region. Galleries of individual borers collected at the Tree Research Center were measured with a plan measure (Dietzgen model 1719B). The number of xylem departures and turns greater than 90 degrees were also recorded. Also recorded was the current life stage of the borer; adult (emerged), adult (emerging), pupa or larva. Number of borers that died before they could emerge were noted, along with probable cause of death. Any life stages found, along with any parastoids, were placed in 2 dram vials filled with 95 percent alcohol. The present instar of the larva was determined in the laboratory from urogomphi measurements.

The examination of trees at the Richland site was identical except only the galleries of the implant larva were followed. In mature class 3,4 and 5 trees borer densities can be so high that a complex network of galleries results. This makes it extremely difficult to follow the meandering gallery of an individual borer. Hence no attempt was made to follow galleries constructed by larvae from natural attack. This difficulty of following galleries has been

reported by other researchers (Larsen, 1902; Slingerland, 1906).

Attractiveness of Hosts Studies

In addition to studies on the larval habits of the bronze birch borer, a study was performed on the attraction of borers to trees in various stages of decline. During June, 1978, records were made on the number of adults observed on the lower bole of trees representing the 5 crown vigor classes. The trees chosen for the study were located within two adjacent neighborhoods in Okemos, Michigan. The trees selected for this study were not managed for pests. All observations were made daily between 11:00 am and 3:00 pm EDT, the time period when adults are most active (Barter, 1957). Each tree was observed for 30 seconds. During that time the number of adults walking on the bark was recorded. Obviously information that can be gleaned from a study of this nature is of limited value. But it did provide me with some trends which were examined during June and July, 1980.

In 1980, 25 trees, 5 from each crown vigor class were selected for another study of the attraction of borer adults to trees in various stages of decline. All trees were located in two adjacent neighborhoods of Okemos, Michigan. As with the earlier study, the trees did not receive pesticide applications. Two sticky board traps were placed on each tree. The basic design of the traps was taken from one devised by Mahar (1978). The boards were constructed of 1/4" (0.63 cm) plywood panels. They were soaked in linseed oil to

prevent warping and then covered with Bird Tanglefoot (Tanglefoot Co., Grand Rapids, Michigan). The surface area of each board was 0.3m. The traps were suspended from rope. One trap was placed near the top of the living crown, the other placed at the base of the crown. There was no attempt to hang them at uniform heights. Adults were collected on a weekly basis.

During June and July, 1981, a third study of adult attraction to trees in various stages of dieback was initiated. The study was performed on the trees located at the abandoned nursery site in Richland. To estimate the populations on these trees a chemical knock-down agent, pyrethrum (Dill's Pyrethrin EMS) was used (Collyer, 1951). This site was selected for a number of reasons. A survey of homeowners found that many of the homeowners did not spray to control the bronze birch borer and did not want any chemical sprayed on their trees, regardless of its safety. Also those homeowners that did spray did not want the trees sprayed with a pesticide with such a short life. They preferred to continue their use of lindane. There still existed a large group of homeowners that did not spray for borers and were receptive to pyrethrum sprays. But several other shortcomings remained: 1) the presence of small children and pets in the area and 2) the travel time between trees. During previous studies in urban areas we found that the presences of ladders and equipment acted as a magnet to neighborhood children. Hence, additional personnel would have been necessary to prevent children from interfering with the spray operation. Also, since all trees needed

to be sprayed at approximately the same time, travel time had to be reduced as much as possible. An additional reason for selecting the trees at the Richland site was that they were short enough to examine in detail.

The spray dosage used was 3.0 ml of pyrethrum in 1.0 L of water. A white tarp was wrapped around the base of the tree to be sprayed. The tree was then sprayed and the adults collected from the tarp. I did not want to interfere with adult borer activity during the 48 hours between sprays. To check on this, at the conclusion of the daily spray operation adults were caged on branches of some of the sprayed trees. These were then checked two days later. Mortality was never noted within the cages. Spray operations were carried out between 11:00 am and 4:00 pm EDT every other day during June and the first two weeks in July. Weather conditions were noted for each day. At the conclusion of each spray day each tree was examined for new emergence holes. The number of new holes were counted and then each of the new holes filled with caulking compound to prevent recounting.

X-ray Study

X-rays have been used in the detection of cryptic insect pests of trees for several decades. Unfortunately, much of the research has concentrated on the detection of bark beetles within wood and bark slabs. Relatively little work has been published on the detection of borers within standing trees. Knight and Albertin (1965)

successfully used a Picker 50 kv x-ray unit to study Oberea schaumii LeConte, as spend twig borer. They also used the unit to detect various weevils and borers in jack pine (Pinus banksiana Lambert) and aspen (Populus tremuloides Michaux). John Beaton et al. (1972) used a Picker Ranger 100 for the detection of phloem borers.

The objectives of this study were to provide a quick, accurate and nondestructive method of detecting bronze birch borer larvae within European white birch. Previous studies of the larvae involved removal of the bark phloem to observe the larvae (Ball and Simmons, 1981). This method was destructive to both the tree and the larvae and prevented tracing the development of the borer within its host. To overcome this difficulty a study on the possibility of using x-rays for borer detection was initiated.

The x-ray unit selected was a Phillips Practic with a mobile demountable stand. The unit was small and light enough to be transported by truck to the study trees. The stand permitted the unit to be raised by any distance up to 2 m and the head could be detached to reach higher within the canopy of the tree. The accompanying control desk was model number xb 7009/00-/02. Kilovolts could be varied from 45 to 100 at 5 kv intervals. Time was adjustable from .08 seconds to 5.0 seconds. The exposure current was fixed at 20 mA's. At the suggestion of Dr. Wortman of the Michigan State University Veterinary Radiology Clinic the film used was Kodak RP/M X-OMAT.

To facilitate handling the greatest number of samples, the x-ray unit was housed at the Veterinary Radiology Clinic and cut branches

were brought in. This saved considerable time from moving the unit from tree to tree while determining the correct technique. The standard procedure was to cut branches in the field, immediately bring them into the lab to be radiographed, develop the negative and then strip the bark from the branches to determine if all the larvae were detected. Every attempt was made to maintain realistic field conditions. Since living branches contain a high moisture content which tends to fog the film we needed to develop a technique which would be able to compensate for this condition in the field. Branches were cut into 25 cm sections, the diameter was measured and then the branch was radiographed at various kvp's and exposure times.

RESULTS AND DISCUSSION

Lansing Site--An Overview

The year between the beginning and end of this portion of the research witnessed many changes in the composition of the urban forest. Forty-three percent of the study trees changed vigor classes (table 1). Most of this change was a decline in class, though 2 trees improved from a class 2 to a class 1. No other improvements were observed.

Lansing Site--Stem Electrical Resistance

The Shigometer has been used for a variety of purposes; detecting the initiation and cessation of annual cambial activity (Santamour, 1982), detecting discoloration and decay in trees (Shigo and Shigo, 1974) and hazard rating (Davis et al., 1980), among others. Perhaps the most experimentation has been devoted to examining the relationship between electrical resistance and tree stress. What the Shigometer is actually measuring has often been debated. Resistance of a tree's tissue has been described as analogous to resistors in parallel (Carter and Blanchard, 1978). The three resistors being the phellem, cork cambium-phloem-vascular cambium and xylem. The phellem is composed of dead cells, while the xylem contains both dead and living cells (Kramer and Kozlowski, 1979). Fensom (1966) noted that conductance of plant tissue increases as the concentration of free ions increases in the aqueous

Table 1. Class changes of the Lansing site Betula pendula from 1980 to 1981.

Vigor Class (1980)	(n)	Vigor Class (1981)					
		1	2	3	4	5	Dead
1	28	26	1	1			
2	9	2	3	4			
3	9			3	4	2	
4	6				2	2	2
5	8						8

Table 2. Average stem electrical resistance readings ($\pm$ SE) for Betula pendula among four crown vigor classes.

Class	average ER (kohms)	n
1	10.60 $\pm$ 0.56	28
2	12.54 $\pm$ 1.07	9
3	14.56 $\pm$ 1.11	9
4	17.10 $\pm$ 1.14	6

solution. Therefore, resistance is manifested in the cell-wall fluids of living cells. Since the cork-cambium-phloem-vascular cambium regions contain more living cells than the adjacent regions, it should determine the lower limits of electrical resistance (Carter and Blanchard, 1978). This is in agreement with Wargo and Skutt (1975). They found no change in electrodes which were inserted deeper than the outer xylem.

While it is now generally assumed that electrical resistance is measured in the phloem region, what influences the resistance is not well understood. Resistance has been described as an indicator of the internal chemistry of the tree (Santamour, 1982). Studies have linked increased potassium concentrations to decreased electrical resistance (Tattar et al., 1972). However, Carter and Blanchard (1978) did not find a relationship between electrical resistance and potassium concentration in the phloem of red maple (Acer rubrum Linnaeus). Instead they found electrical resistance was related to phloem width. Presently, it is believed that the Shigometer measures levels of cambium activity (Shigo, personal communication, 1982).

While the actual mechanism may not be well understood, many studies have documented the relationship between stem electrical resistance and tree vigor. Wargo and Skutt (1975) found that defoliated oaks (Quercus spp.) had higher electrical resistance than non-defoliated oak trees. They did not discuss why the difference in resistance occurred, but Carter and Blanchard (1978) speculated that some of the tissue in the phloem region may have died in response to

the defoliation. Since dead tissue has a higher resistance, electrical resistance would increase for the defoliated trees. Wargo and Skutt (1975) also noted a relationship between stem electrical resistance and crown condition of oaks. Trees with poorer crowns had higher electrical resistance than those trees with healthy crowns. Zhuravleva (1972) reported a similar relationship for spruce (Picea spp.). Newbanks and Tattar (1977) received mixed results in their study on the relationship between electrical resistance and crown condition on sugar maple (Acer saccharum Marshall).

In the study on mature European white birch I was interested in determining if there was a significant relationship between stem electrical resistance and crown condition. Trees were placed into 5 classes based on the condition of their crown (fig. 1). Class 5 trees were not included in the analysis because of the wide range of readings received among trees within this class and even on the same tree. Readings do not normally vary throughout a healthy tree (Skutt et al., 1971). However, class 5 trees are not healthy. They often contain numerous pockets of decay which have no visible indication (Ball, 1979). These same necrotic pockets have also been observed on dying oaks colonized by the two-lined chestnut borer (A. bilineatus Weber) (Cote, 1981). On several occasions class 5 trees had electrical resistance readings ranging from 2 to 20 kohms. Several others had readings between 2 and 6 kohms. While low electrical resistance is generally highly correlated to high vigor, low electrical resistance readings also occur with discolored and decayed wood

(Skutt et al., 1971). Hence, measuring electrical resistance of birch trees near death may be of little value due to the wide range. There is little need to measure vigor of such trees since from their external appearance it is quite evident that the trees are in a state of low vigor.

As mentioned earlier, stem electrical resistance is negatively correlated with tree diameter (Wargo and Skutt, 1975; Newbanks and Tattar, 1977). Newbanks and Tattar (1977) observed a relationship between electrical resistance and stem diameter in sugar maple ($r = -0.67$). I was puzzled by the correlation coefficient obtained by using the Lansing data ($r = 0.06$) meaning there was no strong relationship between electrical resistance and tree diameter. However, this was soon easily explained. Older trees, hence greater diameter, tend to suffer more from birch dieback. I separated the trees into two categories, one for class 1 and 2 and another for class 3 and 4 and performed a t-test (Alder and Roessler, 1968) on tree diameter between the two groups. While not highly significant statistically $P < 0.10$, class 1 and 2 trees had an average diameter (SE) of 20.6 ± 1.86 cm. when I examined only class 1 and 2 data, I obtained a correlation coefficient that showed a negative correlation ($r = -0.36$). It was apparent that the high stem electrical resistance reading received from the low vigor, large diameter trees was overshadowing the decrease that should have been obtained due to their large diameter.

I also attempted to examine stem electrical resistance and present crown vigor classification. Using diameter as a covariate, I

performed an analysis of covariance. There was a significant difference in stem electrical resistance. A Scheffe's interval (Gill, 1978) showed a significant difference ($P < 0.01$) between class 1 and 2 versus 3 and 4.

While several studies have attempted to link stem electrical resistance to present crown class, few have tried to correlate these readings to rates of decline, perhaps a far more useful measurement. Trees do not decline at a constant rate. In the work on urban birch dieback I have observed many trees that decline to a class 3 or 4 and then remain at that class for many years before further declining. While a relationship between stem electrical resistance and current crown condition can be found, this may not be extremely important to the urban forest manager. Present crown condition is an indication of the tree's past vigor, but provides little information on the present vigor (Wargo, 1978). We already know the tree's past vigor by it's crown appearance. What would be more valuable to the urban forest manager would be if the Shigometer could be used to predict short-term decline in trees. Trees that gave indication that they would decline further in the next year could be singled out and treated to prevent further decline. To test the usefulness of stem electrical resistance as a predictor of further decline the trees were divided into 2 groups, each with 2 subgroups. Group 1 contained high vigor trees (class 1 and 2) that remained in high vigor one year later and high vigor trees that declined to medium vigor (class 3). Group 2 contained medium/low vigor trees (class 3 and 4) that re-

maintained unchanged and medium/low vigor trees that suffered further decline. I did not find a significant difference within each of the subgroups (tables 3 and 4). Hence, the Shigometer may be able to separate mature European white birch into general crown vigor class but does not fulfill a more useful role as a predictor of future short-term decline. However, several of the subgroups were rather small and represented 2 separate classes. The values obtained may not reflect a true picture of the relationship.

Lansing Site-Wound Closure

In addition to recording stem electrical resistance readings, I also collected data on rate of wound closure. Since rates of wound closure have also been correlated to tree vigor we were curious whether the average relative rate of wound closure and stem electrical resistance would be similar or the same for each class. An analysis of variance (Gill, 1978) showed there was a significant relationship between wound closure and present class (1980) (Appendix V). Application of a Scheffe's test confirmed that class 1 and 2 trees had a significantly ($P < 0.01$) faster closure rate than class 3, 4 and 5 trees. Wound closure for trees in classes 1 and 2 generally were completed in one year (Table 5). The only exception to this was high vigor trees that declined in class. Generally trees in low vigor classes (3 through 5) exhibited partial wound closure or the wounds failed to close at all. Trees in these classes that further declined or died did not show any wound closure. Oftentimes the wound

Table 3. Comparison of average stem electrical resistance readings ($\pm$ SE) between class 1 and 2 trees that remaining stable versus those that declined in crown vigor.

crown vigor	average ER (kohms)	n	t-statistic
stable	10.67 $\pm$ 0.57	31	-1.86 ^{ns}
declined	13.17 $\pm$ 0.98	6	

^{ns}t not significant at 0.05 level.

Table 4. Comparison of average stem electrical resistance readings ($\pm$ SE) between class 3 and 4 trees that remained stable versus those that declined in crown vigor.

crown vigor	average ER (kohms)	n	t-statistic
stable	14.2 $\pm$ 1.32	5	-1.11 ^{ns}
declined	16.2 $\pm$ 1.08	10	

^{ns}t not significant at 0.05 level.

Table 5. Average area of wound opening, in percent, ($\pm$ SE) one year after wounding for five crown vigor classes of Betula pendula.

class	average area of wound opening	n
1	23.21 $\pm$ 5.4	28
2	52.8 $\pm$ 12.8	9
3	88.7 $\pm$ 8.4	9
4	87.5 $\pm$ 8.5	6
5	100.0 $\pm$ 0.0	8

Table 6. Reducing sugars, as a percent of total sugars, ($\pm$ SE) for Betula pendula in each of the five crown vigor classes.

class	average percentage of reducing sugars	n
1	0.57 $\pm$ 0.02	28
2	0.65 $\pm$ 0.02	9
3	0.76 $\pm$ 0.02	9
4	0.73 $\pm$ 0.02	6
5	0.75 $\pm$ 0.03	8

failed to even form any callus tissue around the edge of the wound surface. An analysis of covariance was performed to determine the relationship between stem electrical resistance readings and rates of wound closure. Wound closure was broken into 3 groups; fully closed, partially closed and fully open. There was a highly significant relationship between electrical resistance and wound closure (Appendix VI). A Scheffe's test showed that trees that had the wound fully closed had significantly ($P < 0.01$) lower ER than trees in the other two groups.

Lansing Site--Sugar Ratio

Another measure of stress can be obtained by examining differences between the nonstructural carbohydrate content of healthy and declining trees. Several studies have shown that chemical changes occur in stressed trees and these changes enable subcortical organisms to develop. Wargo (1972) observed that defoliated sugar maple had a decrease in root starch along with an increase in reducing sugars. This increase in reducing sugars favors the development of root fungus (Wargo, 1981). In their study on chemical changes in moisture-stressed loblolly pine (Pinus taeda Linnaeus), Hodges and Lorio (1969) suggested that the increase in reducing sugars may favor the development of the southern pine beetle (Dendroctonus frontalis Zimmerman). This conclusion was partially based on an associated study by Barras and Hodges (1969). These studies are in agreement with the theory that stress and colonization by secondary organisms

are parts of the disease cycle (Kozlowski, 1969; Houston, 1973; Wargo, 1981). The tree is first stressed by moisture deficiency, defoliation or other means. This initiates chemical changes in the tree which makes it more attractive to secondary organism colonization. Both parts of disease cycle, the initial stress and the subsequent colonization by secondary organisms, are of equal importance in bringing about the death of the tree.

Investigation of chemical change in trees has centered around carbohydrates, though nitrogen changes have also been well documented. Carbohydrates are a direct product of photosynthesis and account for approximately 75 percent of the dry weight of woody plants (Kramer and Kozlowski, 1979). Carbohydrates are generally classified into three groups, the monosaccharides, oligosaccharides and polysaccharides. Monosaccharides, otherwise known as simple or reducing sugars, include two important six carbon sugars, glucose and fructose. Both can be found in living cells. An important member of the oligosaccharides is sucrose, a disaccharide. Cellulose and starch are members of the polysaccharide group. Both are abundant in trees. In studies of temperate trees generally sucrose, glucose and fructose are generally the most abundant reducing and nonreducing sugars (Gibbs, 1940; Siminovitch et al., 1953; Hodges and Lorio, 1969).

In studies on carbohydrate changes researchers have found that sugars, particularly reducing sugars, increase in stressed trees (Ilyin, 1957; Tainter and Lewis, 1982). The reason for this increase is not primarily due to starch hydrolysis, but rather the reduced

need for sugars due to the decrease in growth. Instead of being used for growth, the sugars accumulate (Hodges and Lorio, 1969).

The gallery construction by Agrilus larvae is often cited as the mechanism responsible for damaging trees. Their galleries disrupt movement in the phloem and is generally referred to as girdling (Dunbar and Stephens, 1975). Mechanical girdling of deciduous trees also results in chemical changes within the tree. Baldwin (1934) in a study on girdling of three northern hardwoods observed that reducing sugars increased above the girdle. However, this change in the internal chemistry of a tree is heavily influenced by the season of girdling (Noel, 1970). Girdles made just after the spring flush will not result in an accumulation of carbohydrates. Samples for the study were collected from inner bark tissue in mid-August, a time of active feeding by the borer. Hence, the sample would reflect the carbohydrate content of the tree at the time girdling occurred.

In many tree species, sucrose, a nonreducing sugar, is the dominant sugar in the phloem (Kramer and Kozlowski, 1979). In Black locust (Robinia pseudoacacia Linnaeus) at certain times of the year sucrose may make up approximately 90 percent of the sugars in the phloem (Siminovitch et al., 1953). This does not hold true in some birch species. Gibbs (1940) found approximately equal concentrations of reducing and nonreducing sugar.

This high concentration of reducing sugar was also observed in birch xylem sap. Birch, like maple, is often tapped for its sugar (Sendak, 1978). However, their sugar compositions differ. Maple

xylem sap is composed mainly of sucrose while birches contain mainly reducing sugars (Johnson, 1944). While direct comparisons of xylem and phloem sap are difficult to make due to their different origins (Haq and Adams, 1962) it is apparent that the dominant sugars in birch, regardless of origin, are the reducing sugars. Sap from the European white birch cambial zone is extremely high in reducing sugars relative to sucrose (Lohir, 1953). The reducing sugar is composed of glucose and fructose in approximately a 1:1 ratio (Stewart, 1957).

In the study of the mature European white birch I did not separate glucose and fructose, but instead analyzed them together as reducing sugars. I was primarily interested in examining differences in the percentage of reducing sugars in total sugars. Total sugars in this study include only glucose, fructose and sucrose. Based on the literature review I expected reducing to be the dominant sugars and their percentage of the total sugars to be highest in class 4 and 5 trees. My expectations were correct, I found a highly significant difference among the vigor classes (Appendix VII). There was a significant difference ($P < 0.01$) between class 1 and 2 versus 3, 4, and 5. The average class 1 total sugars were 57 percent reducing sugars, this percentage increased to 65 percent for class 2 and approximately 75 percent for class 3, 4, and 5 (Table 6). Again, these results agreed with the expectations. Stresses such as drought tend to decrease carbohydrate utilization more than photosynthesis (Stewart, 1957). Reducing sugar production does not decrease but

instead of being used for growth, it accumulates (Hodges and Lorio, 1969).

Since a time-sequence measurement of change in sugar content was not performed it is not possible to determine if this change occurred before or after colonization by bronze birch borer larvae. Class 3 trees, the intermediate vigor class, generally have larvae throughout the bole and branches while class 1 and 2 trees do not (Ball and Simmons, 1981). The increase in reducing sugar could be due to environmental stress (Ilyin, 1957) or from girdling (Noel, 1970) as a result of borer gallery construction. However, an examination of the class 1 and 2 trees that declined within a year showed that on the average 69 percent of their total sugars were reducing sugars. Since they were examined a year prior to their decline, and class 1 and 2 trees do not generally contain larvae, the trend appears to show an increase in reducing sugar prior to successful colonization though these results cannot conclusively prove this.

Lansing Site-Autumn Coloration

During the autumn of 1980 I also examined the autumn coloration of the Lansing birch trees. Trees, such as maples, have an autumn display that can be related to carbohydrate accumulation (Kramer and Kozlowski, 1979). This is due to the production of anthocyanins which are responsible for the reds and purples. Birch produces a yellow autumn color due to the disintegration of chlorophyll which unmasks the carotene pigments. Hence, autumn coloration of birch can not be

related to carbohydrate accumulation. However, premature fall coloration has been shown in girdled birch (Baldwin, 1934). I observed premature fall coloration in approximately one-third of the class 3, 4, and 5 trees. On several class 1 and 2 trees an occasional branch would exhibit yellow leaves weeks ahead of the rest of the crown. These branches generally were infested with borer. The early color change may have been in response to gallery construction by the larvae.

Lansing Site-Homeowner Cooperation

Before completing the discussion on the results obtained from the trees at the Lansing site it would be appropriate to add some additional comments on the homeowners who cooperated on the project. At the beginning of the project the homeowners were surveyed as to their knowledge of birch dieback. The majority were aware that an insect was associated with the dieback but a few homeowners were unaware of this and several thought the dieback was due to a disease organism. Twenty-eight percent of the homeowners were managing the borer by pesticide applications. The most common pesticide used was lindane though disulfoton and DDT were also employed by a few individuals. Only about a fourth of these homeowners were applying the pesticide during early June. The majority made one application in mid-May while a few executed control measures in July and August.

The response of the homeowners was extremely gratifying. While several approved the use of their tree, but had no other interest in

the research project, most were interested in what was being done to their tree. The management recommendations I made near the conclusion of the project were generally carried out by the homeowners. In fact, several, after hearing our recommendations and reading the literature, made recommendations for their neighbors that were not involved in the research project. Citizen involvement in the project worked extremely well and I offer the following suggestions for any future homeowner cooperation with urban pest research. These suggestions are based on my experience and homeowner evaluation.

1. Homeowners should be personally invited to participate in the project in person. Again, several homeowners remarked that they would have ignored the request if it had come through the mail.
2. Follow up the visit with a letter thanking them for their cooperation and explaining the project. This confirms to the homeowner that their tree will be used in the research and provides them with additional information on the project.
3. Keep lines of communication open. Homeowners were provided with office phone numbers that they could call any time they had a question.
4. Provide tangible rewards. At the first meeting several homeowners asked "what's in it for me?" In return for the use of their tree I offered advice on managing birch dieback and any other plant problem they had.

Most felt this was the key to their cooperation. If their tree was used in a research project they wanted information they could use.

As the problem of urban tree pests gains more attention, more researchers may have to seek out mature study trees from the urban forest. While some may view this as a limitation it also provides a wealth of benefits. The most important benefit is the interaction between the researcher and the homeowner. The researcher learns how the research may be applied to the situations the homeowner faces and the homeowner gains an appreciation of the research methodology.

Tree Research Center--An Overview

The research project at the Tree Research Center began at the beginning of April, 1981 and terminated at the end of June 1982. Of the 49 trees planted in April, 1981, four failed to leaf out, the rest leafed out by mid-April and appeared healthy. The trees were cared for according to their treatment. By the spring of 1982 it was apparent which trees were treated by girdling. The majority of girdled trees suffered a loss of approximately 60 percent of the primary branches along with their associated secondary and tertiary branches. All other trees appeared healthy, regardless of the number of borers they contained or the treatment group they were in. There appeared to be no visual difference between the control and defoliated groups. None of these trees suffered any dieback. The same was true when comparing the girdled and the girdled/defoliated group.

They each suffered extensive dieback. Differences as detected by vigor measurements will be discussed later.

Tree Research Center--Natural and Forced Attacks

The borers survived longer in the field oviposition cages than reported by Barter (1957). He noted an average life span of 12 days (includes the 6 days in the insectary) and a maximum of 16 days. This study had an average borer life span of 21 days (including 6 days in the insectary) and a maximum of 35 days. Balch and Prebble (1940) recorded an average life span of 23 days.

Eight-three borers resulted from natural or forced attack. Forced attacks are defined as those larvae that resulted from adults placed within the cages, while natural attacks are larvae from adults that were outside the cages. Twenty-four implants were successful. The success with forcing attack with caged adults was similar to that obtained by Barter (1957). He reported that 30 percent of the cages on ungirdled trees produced attack. Thirty-four percent of our cages produce attacks. Barter (1957) also reported that cages on girdled trees resulted in an attack percentage of 82 percent. Hence, there appears to be a relationship between oviposition and host condition even with caged studies.

In addition to cages, I also allowed natural attacks to occur. Since the trees were new to the site and isolated from other birches I believed the overall numbers from natural attacks would be low. Natural attack resulted in 49 borers, 59 percent of the total number,

not including implants. Natural attacks were concentrated on the same trees as the forced attacks. Of the 15 trees in which borers were found, 11 received attacks from within and outside the cage. I performed a chi-square evaluation of the four possibilities of borer attack (Alder and Roessler, 1968); both inside and outside the cage received attack, that neither did, that attack occurred only inside the cage and that attack occurred only outside the cage. I found the relationship significant ($P < 0.02$) (Appendix VIII). It appears that the same tree was selected for natural and forced attack more often than would be expected by chance. Obviously, the same trees were more suited for attack though this difference cannot attribute to treatment effect since they were not introduced until after the majority of eggs would have hatched. While I can not be certain of the number of trees which may have received eggs I am positive of the number that contained larvae. Even if the larvae only survived the first instar, evidence of its passing is left. While the galleries of the first instar are not long or wide they are highly visible. Hence, I am certain that I located all the larvae that penetrated the bark. I am unable to say why only these trees were selected for attack. They did not significantly differ from the other trees in stem electrical resistance or in sugars. However, since all the trees had been transplanted in April, hence they could all be considered stressed and the difference between the trees may not be noticeable with the measurement used. For this particular set of trees it was not possible to determine which tree would be successfully attacked

based on vigor measurements. I know that certain trees are singled out for attack but I was not able to predict them at this site. Perhaps the stress imposed by transplanting masked such differences.

Tree Research Center-Implant Operation

Only 24, or a little over half, of the implants were successful. The problem I had in the transfer operation was keeping ants out of the groove with the borer larvae. I would often remove the tape only to find a swarm of ants. There was no significant difference among the various treatments in terms of implanting success. Approximately half the trees in each treatment were successfully implanted with larvae. All larvae that were successfully implanted survived until June 1982 with the exception of one.

Tree Research Center--Gallery Construction

Differences in the number of attacks among treatments was not significant. This was also true with gallery construction. There was not a significant difference in gallery length among the 4 treatments though those in the control were shortest (table 7, appendix IX). Implant larvae produced galleries of approximately equal length for all treatments except for those trees girdled and defoliated, though again the differences were not significant (Table 8, appendix X). The observations on forced and natural attacks in this study differs from reports published earlier. It has been generally assumed that bronze birch borer larvae construct longer

Table 7. Average gallery length ($\pm$ SE) of naturally occurring Agrilus anxius larvae among the four host treatment groups.

treatment	average gallery length (cm)	n
Control	39.03 $\pm$ 5.99	9
Defoliated	54.86 $\pm$ 7.95	7
Girdled	51.15 $\pm$ 2.59	10
Girdled/defoliated	53.31 $\pm$ 1.96	7

Table 8. Average gallery length ($\pm$ SE) of implanted Agrilus anxius larvae among the four host treatments.

treatment	average gallery length (cm)	n
Control	36.00 $\pm$ 3.98	5
Defoliated	36.08 $\pm$ 3.51	5
Girdled	37.68 $\pm$ 2.67	6
Girdled/defoliated	48.16 $\pm$ 5.64	5

galleries in vigorous hosts than in weaker hosts (Carlson and Knight, 1969). Barter (1957) noted that larvae in dying birch made galleries of 15 to 20 inches (38.1 to 50.8 cm) in one year. Larvae in more vigorous hosts required two years to complete their development and constructed galleries 20 to 52 inches (50.8 to 13.21 cm) in length. Anderson (1944) observed a similar trend in aspen for the bronze poplar borer. Carlson and Knight (1969) speculated that the longer gallery lengths in more vigorous host may be due to: 1) larvae must expend more energy to assimilate the nutrients necessary for development, or 2) certain conditions are required for molting of the later instars.

The results only include those borers that completed their life cycle by the end of June, 1982. This was 76 percent of all natural and forced attacks. However, this percentage did vary in response to different treatments. In the control group only 57 percent of the borers complete their life cycle, while percentage rose to 72, 81 and 87 for the defoliated, girdled and girdled defoliated groups, respectively. This trend may be in agreement with the findings of previous researchers. It is not possible to tell if any of the larvae would require another year to mature. Some would have undoubtedly still pupated during the same season since some emergence still occurs during mid-summer (Wellso et al., 1976). But it does appear that development proceeds faster in less vigorous hosts.

Tree Research Center-Sinuate Gallery Construction

In addition to measuring gallery length I counted the number of transverses made by the larvae as it constructed its gallery. The function of the turns made by bronze birch borer larvae as they construct galleries has been a topic of discussion for many years. Heering (1956) in his work on the European A. viridis believed that the sinuate galleries were part of a fixed behavior pattern. Barter (1957) wrote that A. anxius larvae may construct sinuate galleries as a way to survive the phloem sap flow in vigorous hosts since he found the sinuate gallery pattern more evident in more vigorous hosts. He believes the girdling effect of the gallery above the larvae would stop the downward flow of phloem sap. Larvae can be observed moving in an upward or downward direction in the same tree, however. Hence, Barter's conclusion may be incorrect, as pointed out by Carlson and Knight (1969). In their assessment of Barter's remarks on gallery construction Carlson and Knight (1969) contend that sap flow during the growing season normally would be from the crown to the roots. This is not always true. There are several sites in a tree that act as a sink for food. The strength of these sites and their distance from the source influences the partitioning of food and sap flow (Kramer and Kozlowski, 1979). While roots are a very strong sink, they are very distant from the source. Hence, more local sinks such as fruits, and young stem tips and leaves may receive the majority of the food during the growing season. Roots may function as a strong sink only in late summer and early spring (Kramer and Kozlowski, 1979). This corresponds with the feeding time of A. anxius larvae.

Hence, the assessment of Carlson and Knight (1969) may be correct, but not for the reasons they provide.

Barter (1965) in his work with A. liragus observed the same twisted gallery construction. He stated that the compactness of the turns was related to the condition of the host. The turns are further apart in less vigorous hosts. He also observed galleries where it appeared the larvae backed up and changed direction. Carlson and Knight (1969) also discussed the function of sinuate gallery construction. They believe this form of gallery construction may serve only to minimize the effects of sap flow from newly-severed sieve elements. By zigzagging back and forth the larvae forms peninsulas with reduced sap flow. The larvae opens its spiracles on the side of the body adjacent to the peninsula thus minimizing the possibility of suffocating. This behavior has not been actually observed but is only speculated. In the trees at the Tree Research Center there was an extreme variation in the number of turns made by the larvae. Some completed as few as 2 turns while others completed as many as 24. In forced and natural attacks a significant difference was found in the number of turns with regards to treatment (appendix XI). The larvae made significantly ($P < 0.05$) fewer turns in the control and defoliated groups than the other two treatments (table 9). There was no significant difference for the implants (table 10, appendix XII). Many of the larvae constructed almost straight galleries for a while and then made several turns before proceeding straight again. These

observations agree with Carlson and Knight (1969). If sinuate galleries are made in response to local turgidity, one might expect different gallery patterns in a stem in response to localized condition. Few turns were observed in the control group. More turns may be unnecessary since the tree provides more uniform conditions. In dying birch it was observed that the inner bark dies in patches. Perhaps the larvae galleries are in response to patches of tissue of different turgidity or nutritional value.

One additional possible function of the sinuate galleries needs to be examined. While not significant, it was observed that fewer turns occurred when the implant larva was alone in a tree as opposed to when it was accompanied by several natural attack companions (table 11). There are two possible reasons for this behavior, 1) the girdling effect created by the feeding of many larvae created localized conditions in the tree and the larvae are responding to this or 2) the sinuate gallery construction permits larvae to avoid one another. While not reported for A. anxius, cannibalism has been identified with some Agrilus. Cote and Allen (1980) in a study of A. bilineatus found cannibalism occurred in late third and fourth instars in heavily infested material. No direct evidence of cannibalism was found within the trees at the Tree Research Center. However, I found 5 dead larvae that had galleries passing through them. Whether this was the cause of death or occurred later is unknown. Nevertheless, it would appear useful for larvae to avoid contact with other larvae. One method of avoidance might be to concentrate feeding in a small

Table 9. Average number of turns ($\pm$ SE) made by naturally occurring Agrilus anxius larvae among four host treatment groups.

treatment	average number of turns	n
Control	6.3 ± 2.1	9
Defoliated	8.4 ± 1.4	7
Girdled	12.3 ± 1.7	10
Girdled/defoliated	12.3 ± 2.1	7

Table 10. Average number of turns ($\pm$ SE) made by implanted Agrilus anxius larvae among four host treatment groups.

treatment	average number of turns	n
Control	3.0 ± 0.3	5
Defoliated	1.8 ± 0.5	5
Girdled	2.2 ± 1.1	6
Girdled/defoliated	5.8 ± 1.6	5

area. Precisely what is accomplished by sinuate gallery construction is still unconfirmed.

Tree Research Center--Adult Size

The size of the adults has also been considered to be influenced by host condition. Barter (1965) stated that A. Liragus adults that emerge from the least vigorous hosts are smaller than normal. He attributed this as possibly due to the nutritional quality of the larval diet. I measured the length of the A. anxius adults that emerged from the trees at the Tree Research Center. The males were between 8.0 and 8.8 mm in length while the females were between 8.6 mm and 10.0 mm. They are within the range of the values obtained by Barter (1957). Length of adults were approximately the same for all treatments. Barter (1965) does not mention size of adults emerging from vigorous hosts. He indicated only that adults attempting to emerge from vigorous trees are often trapped in pupal cells by callus growth.

Tree Research Center--Population Regulating Factors

Host condition has often been mentioned as a population regulating factor (Carlson and Knight, 1969). While the larvae require living cambium in order to develop (Anderson, 1944), many authorities believe the tissue surrounding the borer must die before the adult can emerge (Balch and Prebble, 1940; Balch, 1946). Why this condition must occur is unclear. Balch and Prebble (1940) stated that

pupation can only occur in dead tissue, while Barter (1965) found Agrilus can pupate in living tissue but have difficulty emerging because of callus growth covering the emergence hole. Hence, the borer must be in the unique position of being in tissue that lives long enough for the borer to complete it's larval development, but dies before the borer pupates. In addition, Barter (1957) states that the larvae feed toward fresh tissue. Therefore, we have a situation where the larvae does not actively seek out dying tissue to pupate but instead the larvae must appear in such situations only by chance. I did not find any evidence in the study to support the hypothesis that the borer can not complete its life cycle in a living host. Adults successfully emerged from trees in all treatment groups. There was not any evidence of an adult trapped by callus growth. Other population regulating factors were found to be important. Nineteen of the borers died during the year, six died during the larval stage while 13 died as pupae. The 6 larvae were in their third instar when they died. They appeared to have died sometime before the winter based on their appearance. The cause is unknown but cannibalism is suspected. Of the 13 dead pupae, 7 were found already transformed but had failed to emerge. Since the gallery to the bark surface was not yet grown over it does not appear that the condition of the host prevented emergence. They were all covered with fine mycelium of a fungus but it was impossible to determine if the fungus caused the death or occurred afterwards. The identity of the fungus was not determined. The remaining 6 borer contained

Table 11. Comparison of the number of turns ($\pm$ SE) made by a solitary implanted Agrilus anxius versus one with companions.

number of companions	average number of turns	n	t-statistic
0	3.0 ± 0.8	11	0.95^{ns}
1+	4.2 ± 1.0	10	

ns t not significant at 0.05 level.

Table 12. Cell means and replications for changes (% odw) in reducing sugar of Betula pendula inner bark among four treatment groups and three levels of borer infestation.

treatment	number of larvae			$\bar{y}_{\dots}$
	0	1	2+	
Control	-0.26	+0.15	+1.38	+0.42
n	5	2	4	
Defoliated	-0.25	+2.70	-0.67	+0.59
n	4	4	3	
Girdled	+1.70	+1.05	+2.62	+1.79
n	2	4	5	
Girdled/defoliated	+2.05	+2.60	+2.25	+2.30
n	4	3	4	
$\bar{y}_{\dots}$	+0.81	+1.63	+1.40	

parasiboids. The parasiboids began appearing about two weeks after the borer emergence began. All were identified as Phasgonophora sulcata Westwood. This parastoid is associated with several Agrilus species (Barter, 1957, 1965; Cote and allen, 1980) and has been associated with the bronze birch borer and the bronze poplar borer.

Tree Research Center--Host Condition

In addition to monitoring borer development in each of the treatment groups various conditions in the trees within each treatment were also monitored. Since transplanting must also be considered a stress I expected to observe changes in all the trees. Initially, all trees would be in a stressed state but after one year the trees in the control group should improve in vigor while the trees in the other treatments should stay the same or continue to decline. The choice of measurements was designed to reflect this change. In addition the borers must be considered a stress, hence control trees in which larvae failed to establish may improve in vigor more than control trees that are infested. To examine these possibilities data was subject to analysis of variance by the Federer-Zelen method (Gill, 1978) with Scheffe's interval technique used for multiple comparisons of means.

Over the year there was a change in the quantity of reducing sugar in the stems of the trees at the Tree Research Center. Many trees showed an increase in concentration of reducing sugars from one year to the next, while others showed a slight decrease. The average

tree showed an increase but this increase was significantly ($P < 0.01$) smaller for trees in the control and defoliated treatment groups than it was for the two groups that were girdled (table 12, appendix XIII). Based on this measurement it would appear that the girdled trees were under more stress and sugars normally used for growth were being stored. There were only slight differences with defoliation. Defoliated trees have a slightly higher percentage of reducing sugars than control trees while girdled and defoliated trees had a slightly higher percentage of reducing sugars than trees that were only girdled. It does not appear that presences of borers significantly altered this condition, though the interaction did produce significant results.

Stem electrical resistance readings failed to identify any significant differences among the trees at either the beginning (table 13, appendix XIV) or end of the experiment (table 14, appendix XV). Nor did the borer activity produce any significant difference in the readings. However, with the readings of stem electrical resistance one interesting phenomenon occurred. Readings were taken during early August before the implanting operation began. While no significant difference occurred among the four treatment groups, trees with one or more larvae had significantly lower readings than trees that were not infested (table 15, appendix XVI). This difference in electrical resistance between trees that were infested with bronze birch borer larvae and those that were not disappeared by the following spring. By mid-May, 1982, there was no significant dif-

Table 13. Average stem electrical resistance reading ($\pm$ SE) of Betula pendula among four treatments before treatments implemented.

treatment	average ER (kohms)	n
Control	34.23 $\pm$ 1.12	11
Defoliated	30.86 $\pm$ 1.17	11
Girdled	30.95 $\pm$ 1.14	11
Girdled/defoliated	33.45 $\pm$ 0.98	11

Table 14. Cell means and replications for stem electrical resistance readings (kohms) for Betula pendula among four treatment groups and three levels of borer infestation.

treatment	number of larvae			$\bar{y}_{i..}$
	0	1	2+	
Control	30.60	29.00	28.38	29.33
n	5	2	4	
Defoliated	26.75	30.00	30.17	28.97
n	4	4	3	
Girdled	30.75	28.00	27.70	28.82
n	2	4	5	
Girdled/defoliated	27.63	32.33	31.25	30.40
n	4	3	4	
$\bar{y}_{...}$	28.93	29.83	29.38	

ference among treatments or between trees infested versus those that were not. A study that involved inoculating elm trees (Ulmus americana Linnaeus) with Dutch elm disease found inoculated trees had a gradual increase in stem electrical resistance while control trees had a gradual decline (Blanchard and Carter, 1980). Hence, the mid-experiment dip in readings appears difficult to explain. One possible explanation was that perhaps the infested trees became decayed. But decay was not observed in these trees when they were examined during June 1982. A more probable explanation is that the gallery construction by the larvae caused an increase in callus formation in response to the internal wounding. Since stem electrical resistance is related to cambial activity, this increase in cambial activity resulted in a decrease in electrical resistance (Shigo, personal communication, 1982).

The vigor of the trees at the Tree Research Center was also assessed by measuring the starch content of the roots. While many methods of assessing vigor may indicate response to past conditions, root starch measurements provide an indication of current vigor (Wargo, 1978). Root starch was determined colorimetrically and histochemically. The colorimetric method is quantitative but the histochemical technique will be more useful to the urban forest manager.

The trend in root starch levels was a mirror image of the results obtained from the test of reducing sugars (table 16, appendix XVII). The control trees exhibited the highest average level of root starch with the defoliated group being the lowest. The two treatment

Table 15. Cell means and replications for stem electrical resistance readings (kohms) of Betula pendula among four treatment groups and two levels of borer infestation.

treatment	number of larvae		$\bar{y}_{i..}$
	0	1+	
Control	34.29	25.50	29.90
n	7	4	
Defoliated	30.69	29.83	30.34
n	8	3	
Girdled	28.50	24.10	26.30
n	6	5	
Girdled/defoliated	30.57	27.50	29.04
n	7	4	
$\bar{y}_{j.}$	31.01	26.73	

Table 16. Cell means and replications for root starch (% odw) for Betula pendula among four treatment groups and three levels of borer infestation.

treatment	number of larvae			$\bar{y}_{i..}$
	0	1	2+	
Control	7.00	6.45	6.23	6.56
n	5	2	4	
Defoliated	6.90	5.90	6.00	6.27
n	4	4	3	
Girdled	5.70	5.35	4.30	5.12
n	2	4	5	
Girdled/defoliated	5.70	4.13	4.18	4.67
n	4	3	4	
$\bar{y}_{j.}$	6.33	5.46	5.18	

groups that had been girdled had significantly ($P < 0.01$) lower root starch levels than the other two treatments. As with the results on reducing sugar, it appears that defoliation did not result in enough stress to significantly change the results. This may be related to the severity of the defoliation. Wargo et al. (1972) found that root starch levels were reduced only when defoliation was severe enough to cause immediate refoliation.

The gallery construction by the larvae has a girdling effect which may also stress a tree. Girdling will also cause a reduction in starch in the roots (Noel, 1970). This occurred in the trees that were infested with larvae. Trees that were infested had significantly ($P < 0.01$) lower root starch levels than those that were not. The difference between these groups is due to the girdling effect of gallery construction before the trees were mechanically girdled.

Previous studies have found the visual method of estimating root starch content compares favorably to chemical methods (Wargo, 1975). I reached the same conclusion. Trees that had low root starch as determined by chemical analysis were also placed in the lowest category of visual starch content. An urban forest manager may find the visual technique an easy and valuable method of assessing the current vigor of birch.

Tree Research Center--Emergence Study

The main purpose of collecting adults from caged logs was to have an assured supply of adults for the oviposition cages at the

Tree Research Center. However, I felt valuable data could also be obtained from these cages so records were kept. Emergence began on May 30, 1981 and ended June 28. Over 50 percent of the adults emerge during the first 9 days (fig. 2).

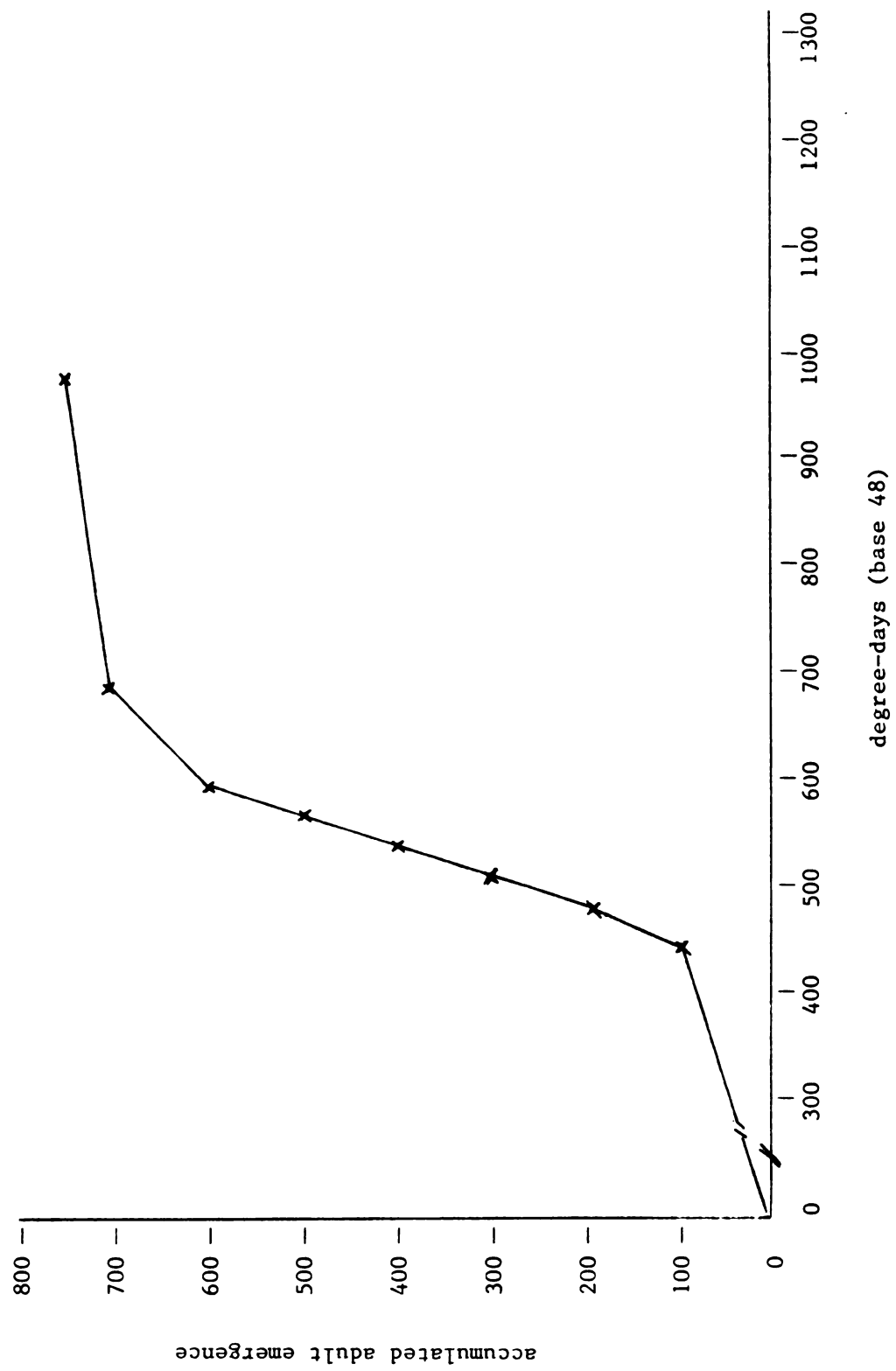
During the flight time period a total of 749 adults emerged with 63 percent of them being female. This is a slightly higher percentage than observed by Barter (1957) who found 54 percent being female. While females dominated for the total emergence, males dominated during the first 6 days.

Emergence was not evenly spread through the day. Sixty-nine percent of the adults emerged during the hours of 8:00 am and 2:00 pm ESDT, 17 percent between 2:00 pm and 8:00 pm and the remaining 14 percent between 8:00 pm and 8:00 am. The sex ratio did not greatly vary among these different time periods. The temperature peak for each day did not generally occur until after 2:00 pm and the late afternoon was generally warmer than any time in the morning. Hence, borers emerged during the light, but cooler morning and early afternoon hours. Many of the adults required over 30 minutes to complete their emergence. Several required more than 24 hours. I also observed 10 borers that only partially emerged and died in that position.

Richland Site--An Overview

There were some changes in the vigor composition of the birch stand from 1981 to 1982 (table 17). Class 1 trees remained stable,

Fig. 2. Accumulated Agrilus anxius emergence from Betula pendula logs.



but several class 2 trees improved in crown vigor and became class 1. Several of the class 3 and 4 trees declined in crown vigor.

Richland Site--Attractiveness of Hosts

The trees at the abandoned nursery in Richland were subject to a variety of experiments that could not be conducted at the other sites. One of the most important of these experiments was a study of the attractiveness of the various crown vigor classes to adult bronze birch borers. The foundation of this experiment was laid over the previous summers. During the time period of adult flight in 1978, 20 trees in Lansing, Michigan representing the 5 crown vigor classes were observed for adult borers along their lower bole surface. While numbers were small ($n=100$), I found that the high vigor trees generally did not have any visits while the trees in the lowest crown vigor class had, as a group, the highest number of visits (table 18). This is consistent with the findings of Anderson (1944) who concluded that borers are attracted to decadent trees. I also noticed that two class 2 trees had some adult borer activity about them on several of the days. These trees declined to class 3 the following year. Hence, adults were also attracted to trees that appear healthy. In 1980 this experiment was repeated, but using sticky traps rather than visual observations. Anderson (1944) performed a similar study on aspen with the bronze poplar borer¹ as did Cote and Allen (1980) with two-lined chestnut borer. In both studies, suppressed or girdled trees had significantly higher traps catches than the healthy control

¹Anderson considered the bronze birch borer and bronze poplar borer as one species, but kept separate records for the two hosts, birch and aspen.

Table 17. Class change for the Richland site Betula pendula from 1981 to 1982.

vigor class (1981)	n	vigor class (1982)					dead
		1	2	3	4	5	
1	5	3					
2	5	3	2				
3	5			3	1		1
4	5				3	1	1

Table 18. Average number of ($\pm$ SE) for Agrilus anxius observed among five classes of Betula pendula crown vigor.

class	average number of adults per tree	n
1	0.0 $\pm$ 0.0	4
2	1.3 $\pm$ 0.8	4
3	9.8 $\pm$ 7.5	4
4	5.5 $\pm$ 1.9	4
5	8.5 $\pm$ 2.8	4

trees. I observed the same trend in this study (table 19). The majority of the adults were collected from traps placed in the upper crown of the tree though the difference was not significant (table 20). Again, several trees that appeared healthy at the beginning of the study attracted a large number of adult borers. These same trees declined in crown vigor by the following year.

These events lead me to believe that these "healthy" trees must differ in some manner from the rest of the population and borers are able to detect this difference. To examine this possibility another study of host attractiveness was conducted at the abandoned nursery site in Richland. To increase the catch the method was changed to a pyrethrum spray. The spray operation was conducted on alternate days. Emergence from the 20 monitored trees began on June 1 and continued until June 19. Adults were collected from June 1 until July 12. A total of 202 adult bronze birch borers were collected. Sixty-three percent were female. Again, this percentage is higher than that reported by Barter (1957) who observed an almost 1:1 ratio. However, the sex ratio is the same obtained from the logs at the Tree Research Center. Females dominated each day except on the two days that scattered showers occurred, Barter (1957) also observed that males dominated on cooler days. In addition to the bronze birch borer one other *Agrilus* species was captured. On June 9, *A. obsole-toguttatus* Gory² was recovered. No specific host is known for them, but they are known to infest hardwoods (Wellso et al., 1976). No other adult or larval specimens of this species were found during the

²Identification by Dr. Stanley G. Wellso, Michigan State University, East Lansing.

Table 19. Average number ($\pm$ SE) of Agrilus anxius collected among five classes of Betula pendula crown vigor.

class	average number of adults per tree per sticky board trap	number of sticky board traps
1	0.0 $\pm$ 0.0	8
2	7.0 $\pm$ 4.5	8
3	6.9 $\pm$ 3.6	8
4	3.4 $\pm$ 1.5	8
5	4.9 $\pm$ 2.2	8

Table 20. Comparison of average number ($\pm$ SE) of Agrilus anxius collected from upper crown and lower crown sticky board traps.

trap position	average trap catch	n	t-statistic
upper crown	5.6 $\pm$ 2.1	20	1.84 ^{ns}
lower crown	3.0 $\pm$ 1.5	20	

^{ns}t not significant at 0.05 level

experiments at the Richland site.

There was a significant difference among classes in attractiveness (table 21, appendix XVIII). Class 1 and 2 trees had significantly ($P < 0.01$) lower collection rates than class 3 and 4 trees. While no adults were collected for 3 of the class 1 trees, the other 2 captured many adults. Only 1 class 2 tree had any adults collected from it.

This phenomenon was similar to that observed during the previous adult studies. Generally trees that occupy the lower crown vigor classes were the ones with the most visits. But several trees in the high crown vigor classes also have some adult borer activity surrounding them. The next question, was there a way to identify these trees? During the time of peak adult activity a Shigometer was used to measure stem electrical resistance of the twenty trees at the Richland site. There was not found a significant difference among the different classes (appendix XIX). This was quite surprising since there were clear differences in stem electrical resistance among the classes at the Lansing site. Each class contained electrical resistance readings within the range recorded for that particular class in Lansing. The difference was due to several class 1 and 2 trees that had adult borer activity and subsequent attack. These trees all had high electrical resistance readings and this raised the average reading for that class. A later check of these trees produced no evidence of previous attacks before the 1981 season. Apparently these healthy appearing trees were stressed, as

Table 21. Average number ($\pm$ SE) of Agrilus anxius collected from the crowns of Betula pendula representing four different crown vigor classes.

class	average number of adults collected per m ³ of crown	n
1	1.0 $\pm$ 0.8	5
2	0.1 $\pm$ 0.1	5
3	2.1 $\pm$ 0.5	5
4	4.5 $\pm$ 0.8	5

Table 22. Average stem electrical resistance readings ($\pm$ SE) for Betula pendula that were attacked by Agrilus anxius versus those that were not.

attack	average ER (kohms)	n	t-statistic
no attacks	8.3 $\pm$ 0.9	6	3.62**
attacks	16.4 $\pm$ 1.4	14	

** t significant at 0.01 level

shown by electrical resistance readings, and the adult borers are able to identify these trees as evident by their activity.

A t-test of electrical resistance between trees attacked in 1981 and those that were not produced a significant difference ($P < 0.01$). Trees that were attacked during 1981 had higher electrical resistance readings during the period of adult flight activity than trees that were not attacked (table 22). Hence, a Shigometer may be used to identify those established trees which will be most likely candidates for attack.

Richland Site--Mycorrhizal Infection

The extent of mycorrhizal infection is often influenced by the condition of its host. Bjorkman (1944) observed that girdling Scots pine (Pinus sylvestris Linnaeus) seedlings resulted in the loss of their mycorrhizae. He believed this decrease in mycorrhizal infection was due to a shortage of root carbohydrates. The same experiment was performed on yellow birch with similar results (Redmond, 1955). Twelve weeks after the girdling operation the rootlets and associated mycorrhizae were dead.

Few reports on mycorrhizae infection of mature birch suffering from birch dieback has been published, but many studies have examined the extent of rootlet mortality. Obviously this condition would have an influence on mycorrhizae. Hawboldt and Skolko (1947) examined the rootlets of mature yellow birch in various stages of crown dieback. They found a correlation between crown condition and rootlet mortal-

ity. A similar trend was reported by Hall (1933) and Greenridge (1953). They observed that trees in advanced stages of dieback had over 50 percent mortality while healthy trees suffered rootlet mortality of only 20 percent. However, there were wide variation within these groups, with some healthy trees having over 40 percent of their rootlets dead. Hawboldt and Skolko (1948) suggested these trees may represent the first stages of decline. Hahn and Eno (1956) in their investigation of fungi associated with birch dieback observed symptoms of dieback. They were uncertain if this decrease preceded, accompanied or followed the decline.

The examination of the root zone of the Richland trees was not concerned with rootlet mortality directly but with the extent of the mycorrhizae infestation. There was a wide variation among the trees (table 23, appendix XX). Class 1 and 2 trees had significantly ($P < 0.01$) higher percentage of the feeder roots infested with ectomycorrhizae than the other two classes. Class 3 and 4 trees showed a wide variation in percent infestation, ranging from 95 to 0 percent of the feeder roots examined being infected. On the trees with very few mycorrhizae (5%) it was difficult to find living roots. Two of the 4 trees in this condition died in the early spring of 1982. The remaining class 3 and 4 trees had between 40 and 95 percent of the feeder roots infested with ectomycorrhizae. This experiment provides only a "snap-shot" of the trees condition, a time-sequence measurement of changes in mycorrhizae infection was not possible on these trees. From this experiment it is not possible to determine if the

decline in mycorrhizae infection precedes or follows the decline of the crown. One tree, a class 3 that had been only lightly attacked by the bronze birch borer over the past several years, still had a high percentage of it's feeder root infected. The class 1 and 2 trees that were attacked this year also had a high percentage of their feeder root infected. Based on this and the two previous studies of the effect of girdling on mycorrhizae I believe that the decline in mycorrhizal infection is probably related to the girdling effect of larvae gallery construction and follows the decline rather than precedes it. Future study is needed.

Richland Site--Root Starch

Roots of the trees at the Richland site were also examined for the starch content of the roots. As expected there was a highly significant difference in root starch content among the 4 classes (table 24, appendix XXI). Class 1 and 2 trees had significantly ($P < 0.01$) higher starch levels than class 3 and 4 trees. Classes 1 and 2 had the same average percent root starch while class 3 trees had a smaller percent root starch and class 4 trees had the lowest. As with the root starch examined from the trees at the Tree Research Center both the colorimetric and histochemical portrayed the same trend. All high vigor trees showed high levels of root starch, including the trees that experience attacks in 1981. The class 1 and 2 trees that were only lightly attacked also had high root starch levels. The remaining class 3 and 4 trees that had numerous borer

Table 23. Average percentage of feeder roots ($\pm$ SE) infested with ectomycorrhizae for Betula pendula in four crown vigor classes.

class	% of infection	n
1	93.0 $\pm$ 1.2	5
2	92.0 $\pm$ 1.2	5
3	57.0 $\pm$ 16.3	5
4	23.0 $\pm$ 11.5	5

Table 24. Average root starch content (% odw) ($\pm$ SE) for Betula pendula in four crown vigor classes.

class	average % root starch	n
1	6.2 $\pm$ 0.3	5
2	6.2 $\pm$ 0.3	5
3	4.0 $\pm$ 0.5	5
4	3.5 $\pm$ 0.1	5

attacks over the past several years all showed low root starch levels.

As shown from the results of the trees at the Tree Research Center, gallery construction by larvae of the bronze birch borer can result in a decrease in root starch levels. It appears from the data obtained from the mature trees at the Richland site that the decline in root starch occurs after attack from the borer and the decline in root starch is due to the girdling effect of gallery construction rather than an initial stress. Hence, as with changes in mycorrhizal infection, reduction in root starch appear to be a response to borer attack rather than precede it.

Richland Site--Implant Operation

At the end of June 1982 the trees at the Richland site were felled and peeled to expose the cambium-xylem region. Of the 20 larvae implanted in these trees, 13 (65 percent), were successful. All of these larvae completed their development and emerged. The vigor of the tree did not appear to influence the life cycle of the borer. There was no significant difference in gallery lengths of larvae in class 1 and 2 trees versus those in class 3 and 4 (table 25). The galleries were generally shorter than those that occurred in the trees at the Tree Research Center. Larvae in class 3 and 4 trees produce slightly more turns than their counterparts in the higher vigor trees.

The ability of the second instar to survive in healthy trees was

unexpected. Much of the previous literature expressed doubts as to the ability of the borer to survive in healthy trees. Balch and Prebble (1940) did not believe that the larvae could complete development in living tissue. Barter (1957) stated that larvae may not be able to survive in living cambium and under such conditions its best chance of survival is to make sharp turns to prevent being suffocated by phloem sap. Barter (1965) also believed that Agrilus beetles may be unable to emerge from living bark as the bark would heal over the exit tunnel, created by the larva, before the borer was able to emerge. We did not find this to be the case with the borers at the Richland site. The implants all survived, did not make a large number of turns and were not prevented from emerging by the tree healing over the exit tunnel.

The implanted borers that emerged from class 1 and 2 trees made very few turns though their average gallery length was the same distance as their counterparts in class 3 and 4 trees. In many places their galleries were in a straight vertical direction. The implanted larvae in class 3 and 4 trees made more turns (table 26). The highest number of turns (9) were made in a class 4 tree by an implanted larvae that passes through large areas of necrotic inner bark. While the implant larvae in class 1 and 2 trees did not make more turns turns they did make longer xylem departures.

There was no apparent difficulty for the borer to emerge from healthy trees. The adult bronze birch borers have powerful mandibles. Several were capable of chewing their way through several

Table 25. Average gallery length ($\pm$ SE) of Agrilus anxius in different crown vigor classes of Betula pendula.

classes	average gallery length (cm)	n	t-statistic
1 and 2	26.33 $\pm$ 1.62	6	-0.71 ^{ns}
3 and 4	27.81 $\pm$ 1.36	7	

^{ns}t not significant at 0.05 level

Table 26. Average number of turns ($\pm$ SE) made by Agrilus anxius larvae in different crown vigor classes of Betula pendula.

classes	average number of turns	n	t-statistic
1 and 2	0.7 $\pm$ 0.2	6	-1.53 ^{ns}
3 and 4	2.6 $\pm$ 1.1	7	

^{ns}t not significant at 0.05 level

layers of duct tape that was wrapped around the tree. I do not believe bark growth would prevent adults from emerging.

Richland Site--Population Regulating Factors

In addition to collecting data on the implant larvae I also made some observations on the natural population that occurred. The data on the number of borers which naturally attacked each tree may not be very accurate since these same trees were sprayed with pyrethrum the previous summer. Natural attacks were only found in class 3 and 4 trees along with several class 1 and 2 trees. If implant larvae were capable of surviving in high vigor trees why were not adults observed visiting these trees and why were not any natural attacks found?

Healthy trees may prevent successful attack by causing excessive mortality before the larvae reach the second instar. Resistance could occur either before or after the first instar penetrates the bark surface. Heering (1956) observed that newly-hatched A. viridis larvae could be repelled by sap flow as they attempted to penetrate the bark. The other possibility is that the larvae may be able to penetrate the bark but dies soon after. Balch and Prebble (1940) reported many unsuccessful attacks on healthy trees. The larvae died after producing galleries one or two feet long (30.5 to 61.0 cm). They did not state what instar the larvae were in when they died. But Barter (1957) observed that while first instar feed for a distance of 3 inches (2.6 cm) before molting, they may die after feeding only a short distance in a healthy host. Hence, it is probably

unlikely that the dead larvae Balch and Prebble (1940) observed were only first instars. Barter (1957) also noted that early instars were more capable of surviving in vigorous hosts than the later instars. It appears that the data does not conform with the observations of previous researchers. Borers from the second instar were capable of completing their development in healthy trees. The only reason for borers not successfully attacking healthy trees may be due to host resistance that affects the first instar before it can penetrate the bark.

I also examined other population regulating factors. At the end of June I found a number of late instars feeding in the trees along with prepupae, pupae and a large number of recent emergence holes. A check found that 96 percent of the pupae still in the tree had been parasitized. Many times the pupa was only a fragment with a small circular hole cut through to the bark's surface. Cages surrounding these sections of the stems would contain the adult Phasgonophora sulcata. These parasitoids began emerging several weeks after the adult borers. Occasionally the parasitoid was discovered still in the pupal chamber or emerging. Several other pupal chambers were discovered containing an ichneumon (Ichneumonidae). This parasitoid also began emerging several weeks after emergence began for the bronze birch borer. It appeared that 39 percent of the borers were killed by these parasitoids but this percentage may not represent what normally occurs since these trees were sprayed during the flight period of the borer and the parasitoids. Both parasitoids have been reported

in the past. Phasgonophora sulcata and several ichneumon species has been reported by Nash et al. (1951) and Barter (1957). In addition, 7 dead larvae were found. While the reason for their death is unknown, several had galleries of another larvae passing through them. As with the findings at the Tree Research Center, it was not possible to tell if death occurred at the time of the crossing or preceded it, but cannibalism remains a distinct possibility.

X-ray Study

X-rays can be used to detect cryptic insects because wood is relatively transparent to this form of radiation (Maloy and Wilsey, 1930). Generally there is a difference in density between a borer and the wood. When two different objects are radiographed the denser one will absorb more radiation. Fewer x-rays will pass through the dense object to be absorbed by radiosensitive emulsion of the film. The denser object will appear darker than the other object when the negative is held before an x-ray illuminator. The density, hence x-ray absorption, changes throughout the life stages of an insect. X-rays are partially absorbed by water and since larvae contain more water than do pupae and adults, they are easier to detect (Havel, 1974). Dead insects have a low absorption to x-rays (Fisher and Tasker, 1940). Insect galleries are easily detected. Since they have extremely little absorption, they contrast with both the borer and the wood (Berryman and Stark, 1962). Frass-packed galleries do absorb some x-rays but generally there is still adequate contrast

among the borer, galleries, and surrounding wood. Occasionally, borers will be hidden by density changes in the wood from cracks and wound tissue (Berryman and Stark, 1962). Living trees also contain a large amount of moisture and the variations in moisture content of the wood can also prevent detection of borers (Amman and Rasmussen, 1969).

The penetration power of x-rays is controlled by several factors. The kilovoltage (kv) primarily influences the quality of the x-ray beam. Lower kilovoltage produces a higher proportion of short high-energy rays. High-energy rays have more penetration power and cause less secondary radiation which reduces image contrast (Stacey and Motherhead, 1965). The kilovoltage selected will also have some influence on the quantity of the x-ray beam. The higher the kilovoltage the more x-rays transmitted. The quantity of x-rays transmitted is also influenced by the milliamperes (mA's), exposure time and target-to-film distance (TFD) selected. The TFD was held constant at 75 cm to permit maximum use of the x-ray film.

The primary control of the x-ray beam quality and quantity was through the manipulation of kilovolts. The one major drawback of the Phillips Practic x-ray unit was that the kv's could not be reduced below 45 and mA's could not be adjusted at all. Previous research on radiographs of the mountain pine beetles found 25 kv was optimum for small and medium-sized larvae while 25 or 45 kv was best for large larvae, pupae and adults. The machine was operating at 10 mA's (Amman and Tasmussen, 1969). The exposure time was approximately 20 seconds at 65 to 85 kvs, but image contrast was extremely poor. At

45 kvs the exposure time was over 1 minute. Unfortunately, enough low energy rays are produced at that kilovoltage to cause more secondary radiation. To combat this problem a 3.6 mm lead filter was placed behind the film to absorb the secondary radiation. Stacey and Motherhead (1965) found secondary radiation could be much reduced by placing thin lead filters in front and behind the film, but one filter was more than adequate for this experimnt. The final technique for radiographing bronze birch borer larvae in European white birch branches was as follows; for branches between 18 to 38 mm in diameter the exposure time was 40 seconds. Fifty-five kvs were used in both cases with a TFD of 75 cm. Radiographing larger diameter branches has not yet been attempted.

In later summer 1981 a Picker 50 kv x-ray unit was obtained on loan from the University of Michigan. The original choice of units was the Phillips Practic, the unit which the technique was developed on. However, a unit of this type was not available at the time the study began. The Picker was the same unit discussed by Knight and Albertin (1965). The machine was intended to be used in field observation of the trees at the Tree Research Center. Unfortunately the machine had a maximum exposure current of 10 mA's. Using the film worked with previously, the contrast was very poor despite repeated trials by the staff at the Michigan State University Veterinary Clinic and myself. Hence, while excellent radiographs of larvae were made during the fall, winter and spring of 1980-81 in the lab it was not possible to use the radiograph technique in the field.

SUMMARY

Birch dieback is a serious problem of most ornamental birches. It is the most serious problem of the European White Birch, the most popular of the ornamental birches. Birch dieback does not affect trees without warning and there are definite internal differences among trees in the various stages of dieback. Healthy trees tend to have higher levels of root starch, low reducing sugar to nonreducing sugar ratio and lower stem electrical resistance readings than their low vigor counterparts. They also have a higher percent of their feeder roots infected by ectomycorrhizae.

The bronze birch borer does not require dead inner bark tissue in order to complete its development. However, tissue frequently dies around the area where the pupal cell and emergence hole is formed. The bronze birch borer can survive from the second instar in healthy trees. Their gallery lengths are of similar lengths than their counterparts in less vigorous hosts. They complete sinuate galleries less than larvae in low-vigor trees. Sinuate gallery construction may not be a response to tree vigor but to localized turgidity and an avoidance of other larvae.

Parasitoids play an important role in regulating urban bronze birch borer populations. The most important parasitoids in forest situations are also the most important in urban areas. Cannibalism may also exist during the larval stage.

Pesticides should not be applied indiscriminately. The bronze birch borer does not attack trees at random, but instead selects trees for attack. While many of these selected trees may exhibit dieback, others may not. The most difficult task in birch dieback management is determining which of the apparently healthy trees are soon to be afflicted with dieback. Once these trees are identified, measures such as pesticides, fertilizer and watering could be taken to prevent or retard the onset of dieback. Few methods or procedures are available to identify these trees. Changes in the ratio of sugars generally precedes dieback but this is not an easy variable for an urban forest manager to measure. The Shigometer may be used to identify trees that will be attacked by the borer. Trees with a high ER generally are successfully attacked by the bronze birch borer. Other methods such as measuring root starch levels, percent infection of roots by ectomycorrhizae and observing fall color change cannot be used to predict the onset of dieback.

Birch dieback management should follow this procedure. Trees should have their stem electrical resistance measured every May. Trees that have a stem electrical resistance reading of 12 kohms or greater should be considered stressed and vulnerable to bronze birch borer attack. These trees should be sprayed with Lindane (20%) beginning when the horse-chestnut (Aesculus hippocastanum Linnaeus) reaches full bloom. Two additional sprays should be performed. All sprays should be spaced two weeks apart. The stressed trees should also receive pesticide protection against the birch leaf miner.

All trees, regardless of their vigor, should receive regular

watering during the summer (approximately 2.5 cm per week). The area around the base of the tree should be mulched to a distance of at least 1 m. Surface applications of nitrogen (3 kg of available nitrogen per 33 square meters) each spring is also recommended.

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APPENDICES

Appendix I.

August, 1980

Dear Homeowner,

Thank you for participating in this birch dieback research project. The information we obtain will be used in managing birch dieback. Here is a list of experiments to be performed on your tree along with the approximate dates. Let me assure you that these tests will not harm the tree.

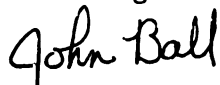
August 1980 - A check on the condition of the tree's canopy

- A small instrument known as a Shigometer will be used to measure the electrical resistance of the tree. A high reading may mean your tree is stressed.
- Two 1" diameter sections of bark will be removed from your tree. These will be used to determine the sugar ratio of the tree. A change in the ratio of sugars may mean the tree is stressed. Please do not paint the holes with tree wound dressing as this will interfere with the healing process.

August 1981 - A final check on the condition of the tree's canopy.

If you are interested in the results from your tree, I will be more than happy to provide them. If you ever have any questions, please feel free to call.

Thanks again.



John Ball

Office: Rm. 40

Natural Science Bldg.

ph. 355-3473

Appendix II.

August, 1981

Dear Homeowner,

Again let me express my thanks to all of you for participating in the birch dieback research project. The information derived from this project will provide new insight about birch dieback. I will pass along some of this new information in a letter next spring.

However, there is one bit of information I would like to pass along now. If your birch tree dies this winter please cut the tree down and burn it before next June. Trees that die during the winter generally contain a large borer population. If these trees are left standing the borers will emerge during June and fly to nearby birch trees to lay their eggs.

Next week I will be stopping by to examine your tree. This will mark the end of the research project. Again thank you for allowing me to study your tree. I have enjoyed talking with many of you. If any of your trees or shrubs have pest problems, please feel free to call me for recommendations.

Sincerely,



John Ball

Office: Rm 40
Natural Science Bldg.
ph: 355-3473

Appendix III.

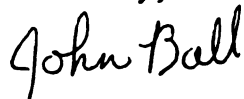
May, 1982

Dear Homeowner,

Thank you for participating in the birch dieback research project. The vigor of your tree(s) has been calculated and is marked in a box at the lower left-hand corner of this page. Also enclosed is our new bulletin about the borer problem. Please follow the recommendations for the vigor class of your tree(s). If your tree is in class 4 or 5, you may want to remove it as these trees rarely recover.

If you have any questions concerning the health of your tree, please feel free to call me at the number listed below.

Sincerely,



John Ball

Office: Rm. 40
Natural Science Bldg.
ph: 355-3473

Class 1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

Appendix IV. Analysis of covariance table for stem electrical resistance readings for Betula pendula among four classes of crown vigor (Table 2).

Source	df	SSx	SP	SS	residuals			
					df	SS	MS	F
among means	3	161.07	132.93	256.92	3	255.27	85.09	9.00**
within groups	48	2186.52	-51.11	445.38	47	444.09	9.45	

** F significant at 0.01 level

Appendix V. Analysis of variance for rate of wound closure of Betula pendula among five classes of crown vigor (Table 5).

source	degree of freedom	sum of squares	mean square	F
class	4	61165.67	15291.42	20.24**
error	55	41542.66	755.32	

** F significant at 0.01 level

Appendix VI. Analysis of covariance of stem electrical resistance among three different rates of wound closure.

source	df	SSx	SP	SS	residual			F
					df	SS	MS	
among means	2	59.59	101.71	198.31	2	195.63	97.81	9.32**
within groups	49	2288.00	-19.89	504.00	48	503.83	10.50	

** F significant at 0.01 level

Appendix VII. Analysis of variance for percentage of nonreducing sugar to total sugar for Betula pendula in each of the five crown vigor classes (Table 6).

source	degree of freedom	sum of squares	mean squares	F
Class	4	0.39	0.10	9.09**
Error	55	0.60	0.01	

** F significant at 0.01 level

Appendix VIII. Chi-square evaluation of the four possible combinations of forced and natural Agrilus anxius attack on Betula pendula.

Combination	observed	expected	X statistic
Attack both inside and outside cage	11	11	9.95*
No attack	28	11	
Attack only inside the cage	1	11	
Attack only outside the cage	4	11	

*X Significant at 0.02 level

Appendix IX. Analysis of variance of gallery length of Agrilus
anxius larvae among the four host treatment groups
 (Table 7).

Source	degree of freedom	sum of square	mean Square	F
treatment	3	1310.51	436.34	2.11 ^{ns}
error	29	6004.91	207.07	

^{ns}F not significant at 0.05 level

Appendix X. Analysis of variance of gallery length of implanted Agrilus anxius larvae among the four host treatment groups (Table 8).

Source	degree of freedom	sum of squares	mean squares	F
treatment	3	514.28	171.43	2.06 ^{ns}
error	17	1417.19	83.36	

^{ns}F not significant at 0.05 level

Appendix XI. Analysis of variance of the number of turns made by Agrilus anxius larvae among four host treatment groups (Table 9).

Source	degrees of freedom	sum of squares	mean squares	F
treatment	3	242.34	80.78	4.11*
error	29	569.54	19.64	

*F significant at 0.025 level

Appendix XII. Analysis of variance of number of turns made
by implanted Agrilus anxius larvae among four host
treatment groups (Table 10).

Source	degrees of freedom	sum of squares	mean squares	F
treatment	3	50.14	16.71	3.07 ^{ns}
error	17	92.43	5.44	

^{ns}F not significant at 0.05 level

Appendix XIII. Analysis of variance of changes in reducing sugar (% odw) of Betula pendula inner bark tissue in four treatment groups (Table 12).

Source	degree of freedom	sum of squares	mean squares	F
treatment	3	25.75	8.58	5.40**
larvae	2	4.57	2.28	1.44 ^{ns}
interaction	6	30.01	5.00	3.14*
error	32	50.84	1.58	

**F significant at 0.01 level

*F significant at 0.05 level

^{ns}F not significant at 0.05 level

Appendix XIV. Analysis of variance of stem electrical resistance readings of Betula pendula among four treatment groups before treatments were implemented (Table 13).

Source	degree of freedom	sum of squares	mean squares	F
treatment	3	97.88	32.63	2.43 ^{ns}
error	40	537.68	13.44	

^{ns}F not significant at 0.05 level

Appendix XV. Analysis of variance of stem electrical resistance readings for Betula pendula among four treatment groups and three levels of borer infestation (Table 14).

Source	degree of freedom	sum of squares	mean squares	F
treatment	3	16.10	5.37	0.00 ^{ns}
larvae	2	5.12	2.56	0.00 ^{ns}
interaction	6	88.44	14.74	0.01 ^{ns}
error	32	85741.66	2679.42	

^{ns}F not significant at 0.05 level

Appendix XVI. Analysis of variance of stem electrical resistance readings for Betula pendula among four treatment groups and two levels of borer infestation (Table 15).

Source	degree of freedom	sum of squares	mean squares	F
treatment	3	44.82	14.94	1.03 ^{ns}
larvae	1	181.79	181.79	12.53**
interaction	3	16.01	5.34	0.37 ^{ns}
error	36	522.48	14.51	

**F significant at 0.01 level

^{ns}F not significant at 0.05 level

Appendix XVII. Analysis of variance for root starch (% odw) for Betula pendula among four treatment groups and three levels of borer infestation (Table 16).

Source	degrees of freedom	sum of squares	mean squares	F
treatment	3	25.02	8.34	11.58**
larvae	2	10.01	5.00	6.95**
interaction	6	2.79	0.46	0.64 ^{ns}
error	32	23.03	0.72	

**F significant at 0.01 level

^{ns}F not significant at 0.05 level

Appendix XVIII. Analysis of variance of the total number of Agrilus anxius collected from the crowns of Betula pendula representing four different crown vigor classes (data transformed $\sqrt{\quad}$) (Table 21).

Source	degree of freedom	sum of squares	mean squares	F
classes	3	12.46	4.15	11.71**
error	16	5.68	0.35	

**F significant at 0.01 level

Appendix XIX. Analysis of covariance of stem electrical resistance readings for Betula pendula in four crown vigor classes.

Source	df	SSx	SP	SS	Residuals			
					df	SS	MS	F
among means	3	7.61	-4.35	34.20	3	33.15	11.05	0.29 ^{ns}
within groups	16	53.41	-55.47	633.60	15	575.99	38.40	

^{ns}F not significant at 0.05 level

Appendix XX. Analysis of variance of percent mycorrhizae infection of Betula pendula among four crown vigor classes (Table 23).

Source	degree of freedom	sum of squares	mean squares	F
class	3	16673.75	5557.92	11.09**
error	16	8020.00	501.25	

**F significant at 0.01 level

Appendix XXI. Analysis of variance of root starch content (% odw) for Betula pendula in four crown vigor classes (Table 24).

Source	degree of freedom	sum of squares	mean squares	F
treatment	3	30.8	10.27	15.75**
error	16	10.43	0.65	

**F significant at 0.01 level