THE ETIOLOGY OF THE DECLINE OF EASTERN WHITE PINE (*Pinus strobus* L.) ON VIRGINIA LANDSCAPES: A SURVEY OF STRESS FACTORS

by

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This work culminates the author's graduate program in plant pathology. He regrets that his father could not have lived to see its completion and wishes to dedicate this work to him as a gesture of sincere love and admiration.

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Chapter I

INTRODUCTION

Eastern white pine, *Pinus strobus* L., is the most extensively planted conifer on Virginia landscapes; it is planted in small and large groves, as screens (see Figure 1), and individually to provide privacy, shade, noise abatement, to ameliorate harsh weather factors (see Figure 2), and for its aesthetic value (see Figure 3). Landscape plantings are observed statewide with trees located around homes, schools, apartments, churches, airports, golf courses, cemeteries, historic shrines, business and commercial establishments, on the grounds of industries, along streets and highways, and around various other institutions. The loss of this species as a landscape planting could alter the landscaping industry, disappoint tree owners, and leave a large gap in the inventory of landscape tree choices.

The natural habitat of eastern white pine in Virginia, which includes those areas associated with the Appalachian Mountains, is rarely considered when planting the species on landscape sites (see Figure 4). Altitude plays a key role in its southern range where the species grows in areas with an average July temperature ranging from 18 to 24 degrees C (62 to 72 degrees F). In its natural habitat, *P. strobus* is

Figure 1: Typical screen of "healthy" eastern white pine at Martinsville, VA.

Figure 2: Eastern white pine sheared for use as a weather barrier near Radford, VA.

Figure 3: Eastern white pine planted for its aesthetic value in a home landscape at Martinsville, VA.

favored by sandy to loamy, well-drained soils with an acid pH range of 4.0 to 6.0. On natural sites, trees contribute to well aerated soils, moist root zones, and an acid pH by the annual deposition of fallen needles building a natural mulch layer under the crown. The artificial environment created by most landscaping activities precludes many of these natural site qualities.

A decline of eastern white pine has been observed for many years in landscape plantings (see Figure 5) and on some poor quality natural growing sites throughout Virginia and the eastern United States(USA) (R. J. Stipes, personal communication). The term "decline," which according to Webster's Unabridged Dictionary (180), means to deteriorate or fail gradually over time, and is usually associated with a complex of disease-causing agents, has not been used until recently to describe this aspect of white pine disease terminology. Other terms, including the names "white pine needle blight" and "white pine blight" (29), were used as early as 1908 (33, 40, 132, 133) to describe the decline-type symptoms associated with the syndrome under discussion within this dissertation. This terminology was eventually incorporated into the air pollution literature. The first use of the word decline, in a definitive sense, was associated with "white pine root decline" during the past 25 years (3, 4, 49, 89, 90, 93, 94, 106, 144, 148, 149, 167). Although

Figure 4: Eastern white pine planted for their aesthetic value around the Jefferson Memorial in Washington, DC.

the causal agent of this root disease appears, at times, to be a factor in the decline process, it is not the sole contributor to decline. The use of the word decline to describe this disease has confused the layman and scientist alike with many using the terms "white pine root decline" and "white pine decline" synonymously to describe this vascular wilt. It is the opinion of this writer that white pine root decline should have been named with some more accurately descriptive term perhaps associated with the suspected causal agent, Verticicladiella procera Kendrick. Others have also indicated that the disease has been misnamed and should be called "Verticicladiella wilt" or "white pine wilt". White pine decline (WPD) is used in the present study as a name for the long term chain of events leading to white pine death. The first use of the words "white pine decline" with this meaning appeared to have been by this writer (177, 178). The syndrome associated with WPD is reminiscent of the decline syndromes of other tree species in which several abiotic and biotic factors usually work in concert to cause the disorder (11, 88, 91, 92, 95, 149, 164).

The key to WPD seems to be environmental plant stress. Abiotic agents initiate the stress on an otherwise healthy host and other abiotic and biotic factors act as finishers

Figure 5: Declining eastern white pine on the Virginia Tech campus (tree code #1).

resulting in death of the host (108, 147). Houston (88, 91, 92) defined a dieback/decline situation as a "progressive disease condition that begins when trees are altered initially by stress and continues as they become invaded by organisms of secondary action". He stated that in forest tree declines, a stress/host-change/organism attack relationship exists. In many urban tree declines repeated and prolonged severe stress can by itself result in loss of tree vigor and even cause tree death. Both situations are visible with UPD.

Houston linked the onset of diebacks and declines with environmental stress. He defined "stress" as "an environmental pressure, sufficient to bring about changes in the physiology, form, or structure of a tree, that predisposes it to attack by organisms that it would resist under normal conditions." Stress includes biotic and abiotic factors. Biotic stress is caused by attacks on plant parts by insects, fungi, nematodes, and other living factors. Abiotic factors include extremes in weather, gaseous, liquid and solid chemicals, changes in soil physics and chemistry, various damages and modifications made by man and his activities, extremes in nutrient levels, and most importantly, in most cases, extremes in moisture levels.

Tattar (164), in 1978, also considered declines and diebacks to be synonymous, and described them as complex diseases where their causes can not be attributed to any one agent. He also indicated that a decline was initiated by one or more stresses that deteriorated the health of a tree to a point where any number of secondary pathogens or insects could kill the host.

Hargo (personal communication, 1980) described the contributors to decline as "initiators" and "finishers". The "initiators" started the deterioration of a host and the "finishers" became associated with its ultimate demise.

If plant disease principles are illustrated in the form of a plant disease triangle one can see a comparison between conventional diseases and declines. The traditional disease triangle, as illustrated in Figure 6, demonstrates the more familiar "one-cause, one-disease" philosophy. In Figure 6, a decline triangle is illustrated with the initiators (environmental factors) laying a path for the finishers (facultative pathogens) to kill the host.

Two syndromes are characteristically associated with declining white pines:

1. The acute decline syndrome (ADS) usually involves chlorotic foliage, wrinkled (desiccated) bark, wilting, resinosis, necrosis, and death within a period

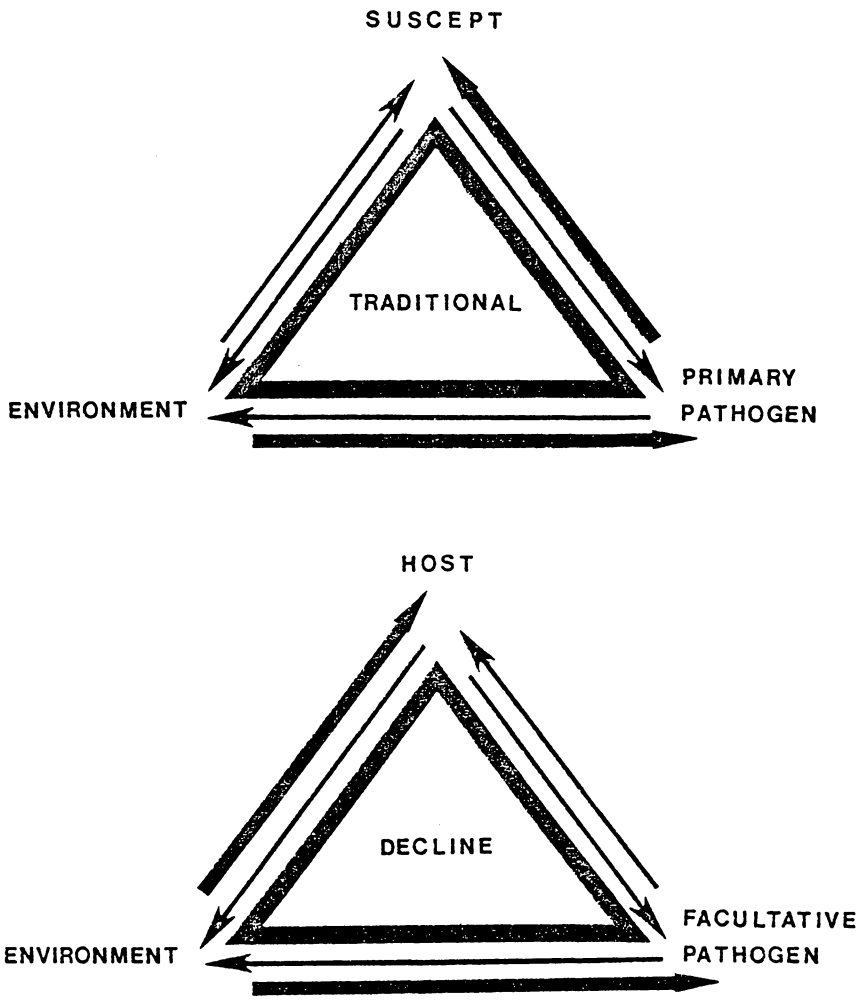


Figure 6: Comparison of a traditional disease triangle to a decline triangle.

of several months after expression of these symptoms.

2. The chronic decline syndrome (CDS) involves chlorosis, premature defoliation contributing to a thin crown, shortened internodal growth, wrinkled bark, necrosis, and death within a period of several years.

Within both syndromes all constituent symptoms may not be present, and in some cases ADS and CDS may appear the same until the time lapse from visible symptoms to death is taken into account. It is apparent that ADS and CDS should be considered together with trees that first appear to be declining slowly, dying suddenly, and trees which appear to be dying suddenly, recovering and declining slowly. This is typical of many declines, in that a period of stress initiated decline and further weakens the host which then falls prey to many secondary agents. Depending upon the ability of and acceleration at which these secondary agents are able to kill the host, one or the other of the syndromes may or may not be exhibited.

A similar situation has been documented by Heikkenen with Pinus taeda L. and the Southern pine beetle, Dendroctonus frontalis Zinn. (74, 75, 81). When trees were crowded within their growing area and became stressed, their chemistry changed, and they emitted volatile terpenes and other compounds that attracted the Southern pine beetle. These in-

sects acted as secondary biotic agents and killed the host along with many neighboring pines. Plant stress and other declines of trees will be discussed in further detail in chapter 2, section 2.2.

The purpose of this investigation has been to identify some of the suspected causal factors associated with WPD. As in similar studies (11, 91, 92), diagnosis of the causal factors of decline diseases using such conventional methods as Koch's Postulates was impossible unless one considered a study period of 25 to 50 years. Wallace (176) suggested, in a review of the "diagnosis of plant diseases of complex etiology", that a synoptic approach be followed to determine the cause and the eventual control of diseases of this nature; he indicated that the phenomenon of "one cause-one disease" is more the exception than the rule in plant disease diagnosis. His approach involved the systematic sampling of the host's environment to determine the variables influencing it. Then by use of various types of statistical analysis, the impact of these variables as disease incitants were determined both individually and in concert. Further testing of this diagnosis was then followed under controlled experimental conditions to confirm the hypothesis resulting from the systematic investigation. An approach of a similar nature was used here.

In this study, a systematic indexing method was developed with which over 100 white pines, in various stages of health, ranging from healthy trees in their natural forest habitat to completely dead trees on domestic or institutional landscapes, were throughly examined. The sample area for this investigation included western Virginia, the Washington, D. C. area, and one site in western Pennsylvania. The sample trees were located through referrals from county extension agents, with most referrals coming from western and west-central Virginia (see chapter 3, subsection 3.1.1, and Figure 8 for detailed information on site selection). Trees on landscapes were located throughout the sample area while trees growing in their natural habitat were located within the Jefferson National Forest in Montgomery County, Virginia, seven miles east of U. S. 460 along State Route 621 and Craig Creek. The information compiled was examined to determine if WPD is a typical decline or just a collection of different diseases grouped together for convenience or due to a lack of knowledge.

Chapter II

REVIEW OF THE LITERATURE

2.1 WHITE PINE DISEASES WITH SYMPTOMS SIMILAR TO WHITE PINE DECLINE

2.1.1 White pine needle blight and other early terminology

The use of the terminology "white pine decline" (WPD) was preceded by several terms describing the symptoms now associated with the decline. In early reports, symptoms of similarity to WPD were described under various names including: blight, leaf blight, pine blight, sunscorch, tipburn, short needle, sandburn, dwarf needle, and chlorotic dwarf. Campana (29) reviewed the literature from 1894 to 1952 using the terms, "white pine blight" and "white pine needle blight" to describe the syndrome.

The first description of a disease of seemingly similar nature to WPD was used by Hartig (69) in 1894. He described a blight of *Pinus sylvestris* L. in Europe which had also been found associated with *P. strobus*. The symptoms included browning of needles and premature defoliation. Hartig attributed this problem to drought as symptoms were usually observed on young shoots exposed to the wind.

Numerous reports of "needle blight" were documented in the early 1900's from New England. Clinton (33), in 1906,

described needle blight as death of needles in the crown, progressing downward. An example of one case was noted where the blight progressed downward until it killed the tree; in this case, death was attributed to the universal killing of roots and a Hymenomycetous fungus observed on both living and dead roots.

In 1908, in an anonymous report from the New Hampshire Agricultural Experiment Station (5) "pine blight" was described as a uniform browning of needles over the entire tree. Symptoms ranged from a tipburn attributed to late frost, to a progressive burning attributed to a combination of poor site and drought.

The blight was reported to occur generally throughout New England by Clinton (33) in 1908. He reported that older trees were more seriously affected, with no problems reported for nursery seedlings. Symptoms included stunted current season's needles, premature needle drop, and root death in severely diseased trees. Clinton felt that needle blight probably was initiated by adverse climatic conditions such as frost, drought, and low temperatures.

Dana (40), in 1908, reviewed all aspects of the blight and noted that it stood out as a distinct disease of white pine as early as 1904. He described symptoms, occurrence, and distribution of the disease and noted that:

1. Needle dieback always occurred from the tip.
2. The extent of the dieback varied from needle to needle and from tree to tree.
3. After the first year, new needles were usually stunted, bunched, under-developed, and were associated with dieback.
4. Once the tree was initially affected it rarely escaped blight the following year.
5. Difference in age, size and site did not seem to differ in the incidence of blight.
6. Soil characteristics and moisture in the root zones of trees did not seem to affect the incidence of the blight.
7. Only scattered trees were blighted, with adjacent trees unaffected even when coming in contact with blighted foilage of the others.
8. There was no progression of the disease during dormancy.
9. Little was known if trees recovered from the blight.
10. Damage from blight was small but could have been serious if the disease was proven to be infectious.
11. Speculation was not made as to the cause of the blight.

Morse (132, 133), in 1908, believed that adverse weather conditions associated with winter injury affected all conifers similarly in Maine. The blight there was widespread throughout the state and affected young trees more seriously than the older trees; it killed back twigs for several inches and seemed confined to the northern and northwestern parts of trees.

Spaulding (157, 158) mentioned a needle blight, occurring in 1909, with different symptoms from one reported the previous year in the same area; several types of blight were likewise later documented by Campana (29) in 1952. Spaulding attributed the blight to the extreme climatic conditions of the preceding winters. Blighted needles could be either stunted or normal in length, and the blight affected tops and/or bottoms of the large portions of trees.

Stone (162), in 1910, noted that the blight had been observed for 25 years and felt that the sudden attention others were giving to the disease may have been due to an outbreak caused by recent dry weather conditions. He called the disease "sunscorch" which was a common problem prevalent on dry sites. Many trees had needle burn, while those with poor root systems had chlorotic, shortened foliage, stunted growth and little, if any, needle burn. Stone concluded that the blight was caused by the killing of fine absorbing

rootlets in the winter followed by unusually dry, windy summers.

Clinton (34), in 1910, indicated that trees could recover from the blight, and again, as in 1908, suggested that blight was caused by adverse climatic conditions. He also concluded that needle blight was the result of late frosts.

Hartley (70), in 1913, reported that the blight was the result of drought injury. He stated that the injury was due to insufficient amounts of water during times of increased transpiration.

Burns (27), in 1916, reported a tipburn of white pine seedlings in the Vermont state forest nursery. Pines in several low lying areas were undamaged, but other seedlings were seared and brown. Wind velocity was the deciding factor in killing young leaves; temperature was not implicated, since the incident occurred in June.

Faull (60, 61, 62), in 1920 and 1922, also believed that white pine blight was the result of drought and related to root injury. Young trees growing under favorable conditions recovered while older trees recovered slowly although up to 5% died. This disease was prevalent over a large area of Ontario from 1917 to 1919.

Snell and Howard (155), in 1922, reported two non-parasitic diseases of white pines in New England. In Massachu-

setts, brick kiln gases, probably sulfur dioxide, were suspected to have caused needle injury on a 25 to 30 acre lot of white pines. In New Hampshire, calcium chloride stored in barrels under roadside pines, elms, and birches, killed the pines and partially defoliated the deciduous trees.

Gussow (67) attributed a severe outbreak of needle blight, in Ontario in 1928, to destruction of fine root hairs. This was the result of an abnormally wet summer causing the temporary cessation of water uptake by these rootlets.

Kimball (101), in 1930, reviewed the literature of what he referred to as "short needle" of P. strobus and described a new type of needle disturbance without the needle dieback symptoms described previously by others. In earlier notations of this type of needle blight on P. strobus and other Pinus species, possible causal agents included frost, drought and shade. Symptoms of short needle blight included: chlorotic, dwarfed needles, reduced numbers of rows of stomata, premature needle drop, a lack of rootlets and stunted growth. Kimball felt that deficiencies of inorganic nutrients and moisture were the only causal factors of significance. He indicated that short needle disease occurred more frequently in plantations than in natural stands, more often in open than in dense stands, and that it increased from north to south in the range of the white pine.

Lee (107), in 1931, investigated the possible causes of dwarfing and yellowing as they applied to white pine blight. Lee also conducted a plantation survey on the occurrence of disease and compared normal and blighted trees in another study. She concluded that high and low soil moisture, low inorganic nutrients, environmental imbalances and any injury or disturbance of the previous season were the factors contributing most to chlorosis and stunting of P. strobus. In her survey of plantations the needle blight occurred more often on poor-quality growing sites, usually without sufficient nutrients and good drainage, especially during years with severe droughts. Diseased trees had shallow, underdeveloped root systems with few rootlets. Lee felt that competition from grasses and weeds might play an important role in such a situation. All plant parts on blighted trees were smaller than normal size. Lee attributed blight to a water deficit within the needle tissue as the tree was unable to take up and hold water due to a lack of soil moisture and/or poor root system.

Deuber (44), in 1931, found it difficult to attribute the yellowing and stunting of foliage to unfavorable environmental factors alone as he leaned more toward hereditary and internal plant conditions. Deuber also recognized the same causes that Lee indicated in her investigation.

Baxter (15), in 1937, described a chlorotic dwarf condition which was usually preceded by yellowing and browning of needles. These symptoms lasted for several years before the tree died. He noted that roots all grew within a foot of the soil surface. Trees grew well in the plantations he surveyed until they reached a size where the shoots outnumbered the roots and required more water than was available in the upper soil layer. A similar situation occurred in wet seasons where roots suffered from a lack of oxygen due to poor aeration as water accumulated above a heavy clay subsoil.

In 1943, Spaulding and Hansbrough (159) reported that moisture deficiency was associated with sudden needle dieback. They thought that the blight was due to a combination of sudden climatic changes which occurred around the time of needle emergence when water requirements were greatest. In addition, trees were found to lack a sufficient amount of absorbing rootlets to survive these climatic conditions. Because many trees, even after blighting, recovered the next season, the problem was temporary and probably dependent upon the availability of water.

Swingle (163), in 1944, reported a "chlorotic dwarf" type disease similar to that described previously by Spaulding (157, 158) and Deuber (44) and indicated that this was the

most important disease of plantation-grown white pine in Ohio. Along with chlorosis, trees had a chronic reduction of internodal growth. Trees died after a period of gradual decline of three or more years. This was the first descriptive use of the word "decline" associated with any white pine disease. Symptoms were very similar to those described for the present decline. There were yellow-green discoloration of needles, shriveling of bark, raised pitch pockets on the lower sten and the usual foliar disturbances described by previous observers. In addition, roots were shallow, stunted and lacked fibrous rootlets. Swingle indicated that this was not due to a root rot, but to inhibited growth and development. There was no evidence of recovery from this disease, as was evident in previous white pine blight reports.

Hudson (96), in 1944, studied the relationship between soil moisture and needle blight symptoms of white pine. He reviewed the literature and did not consider the descriptions of the blight by Dana (40) and Spaulding (157, 158) to be the same as that described by Faull (60, 61, 62), Deuber (44), Spaulding and Hansbrough (159), Swingle (163), and his own descriptions. However, later workers (29, 166,) did not reach this conclusion when reviewing these articles. He was able to demonstrate under controlled conditions that blight

symptoms could be induced by duplicating natural environmental conditions. Hudson followed the hypothesis of Spaulding and Hansbrough (159) that a sudden change from low to high transpiration conditions occurred during greatest moisture requirements. He found that a saturated soil environment in the early spring could kill or inactivate mycorrhizae on feeder roots. This was the explanation for the occurrence of blight during hot, dry summers preceded by a wet spring.

Walker (175), in 1946, reported needle blight in Maryland affecting trees in a similar fashion as that described by Spaulding and Hansbrough (159). Walker attributed the disease to poor root development and adverse weather conditions. Trees that were severely affected became stunted when blight recurred for three to five years and some trees died. He reported the blight affected trees at random, a typical pattern. Out of a group, only one tree may have been severely affected with a few only slightly off color, while the rest remained healthy.

Doolittle (57), in 1948, concluded that white pine needle blight seemed to be more common in thinned than unthinned stands, and that the problem was more common on dry than moist sites. Its incidence was five times greater on thinned, dry sites than on unthinned, moist sites.

Marshall (128), in 1948, reported the occurrence of a heavy, white to buff-colored fungus growing as a saprophyte on the surface of the ground under a group of blighted white pines. These pines had yellowed needles and dwarfing symptoms. Marshall noted a white root rot destroying numerous feeder roots. The fungus was identified as Corticium galactinum (Fries) Burt. (182), and was the first report of a root rot fungus associated with white pine blight. He did not present evidence that the fungus was actually a pathogen capable of destroying the feeder roots of white pine.

Toole (166) gave a comprehensive report of white pine blight as it occurred in the southeastern USA in 1949. The blight was described as a syndrome similar to that described previously by Dana (40), Spaulding (157, 158), Faull (60, 61, 62), Gussow (67), Spaulding and Hansbrough (159), Walker (175), and Marshall (128). Swingle's report (163) of chlorotic dwarf symptoms also resembled some stages of white pine blight. It was Toole's opinion that Swingle (163) recognized that symptoms of white pine needle blight could be produced by a number of different and possibly unrelated causal factors.

Toole pointed out that the blight may have been confused with needlecast in previous reports and it was virtually impossible to determine if the previous reports, at other

times and places, were the same as that which he described in the Southeast. Toole also felt that there were many similarities between the blight and little leaf disease as described by Hepting et al. (78) in 1945. He discounted previous theories that blight was due to non-parasitic diseases, but did indicate that it was probably being caused by upset water relations or other factors.

Toole described blighted trees as first appearing reddish-brown in mid-summer due to dieback of the terminal portions of new needles. This usually occurred when the new needles completed their growth and could be observed usually all over a tree, although other times it was present only in the tops or in another portion of the crown. Trees blighted for several years had chlorotic dwarf symptoms along with premature defoliation and reduced shoot growth.

Toole indexed the condition of groups of trees in several different locations over a period of several years. His indexing system included scores for the degrees of needle color, needle length, needle dieback, and shoot length. Toole observed that dieback symptoms were only evident during a short period of time at needle emergence. Some trees had dwarfed needles with chlorosis for almost one-third of their length instead of a dieback. As the disease advanced the dieback symptoms disappeared, giving way to the chlorotic dwarf symptoms. He pointed out that these symptoms were so

different from the earlier dieback symptoms that one would suspect they were unrelated. However, in one year, Toole's observed trees changed from the dieback symptoms to the chlorotic dwarf stage.

Toole reported that stems of blighted trees, especially those in advanced stages of the disease, had shriveled or wrinkled bark and raised pitch pockets. He noted that this was previously reported by Swingle as a symptom of chlorotic dwarf. Toole examined healthy and blighted root systems and noted extensive feeder root dieback only on severely blighted trees. This root dieback seemed to follow top symptoms. Toole indicated that the lack of adequate feeder roots had been documented by earlier investigators. Also found on the roots of blighted, but not on healthy pines, were clusters of root aphids. Toole and his colleagues found these at several different locations and mentioned the possibility of these playing a role as virus vectors. He surveyed along North Carolina highways for over two consecutive years to determine if the blight was on the increase. He found that it was increasing in some areas, but not in others.

Toole summarized the findings of other workers as to the possible causes of the blight. He concluded that the blight was on the increase in the Southeast and in many cases death accompanied reduced growth rate and needle dieback. He

ruled out needle fungi as a possible cause, and felt that others needed to determine the significance of the root fungi and the root aphids. The aphids were linked to either the primary cause of the blight or as virus vectors.

Vermillion (171), in 1950, described the disease with the tip chlorosis symptom followed by the browning of needles from the tip back. Vermillion claimed to have fulfilled Koch's Postulates with a Pestalotia sp. and thus considered this fungus as the causal agent of white pine needle blight.

Linzon (110), in 1950, compared the blight symptoms to those caused by smelter fumes. He also reviewed many other possible causes of blight. This was the first report describing symptoms as an orange-red colored tipburn. When burning occurred during needle emergence it included more than half of the needle's length, while burning after needles matured included less than half of their length. Linzon's report also listed several previously undocumented symptoms including:

1. Blighted adventitious branches on the main trunk of otherwise healthy trees.
2. Swelling at the juncture of diseased and healthy needle tissue.
3. An increase in the number of stomata per unit area of diseased needles.

4. Enlarged vascular bundles.
5. Thickened cuticle on blighted needles.
6. Shedding of 2-year-old needles in the fall leaving only new needles and those one year old on the tree.
7. Tufted, chlorotic, dwarfed needles on perennially diseased trees attributed to a decrease of stored nutrients.

Linzon's observations concurred with Toole's theory (166) that a transition period occurred from the early dieback stage to the chlorotic dwarf stage after the blight progressed for several years.

Linzon (111), in 1958, found the blight uncorrelated with trunk rots, and concluded that it could have been caused by a variety of physiological factors as a result of some environmental disturbances or extremes. Linzon consistently implicated water deficiency and a reduction of the mycorrhizal populations.

Campana's 1952 review (29) of the early literature on white pine needle blight and white pine blight was summarized as follows:

1. There was much confusion and contradiction regarding the possible causes and symptoms of the disease.
2. There was no one consistent pattern of symptoms, but two different ones which included the needle dieback syndrome and the chlorotic dwarf syndrome.

3. There were no environmental factors constantly associated which could account for blight under all conditions.
4. There was no conclusive evidence of a parasitic causal factor.
5. The needle dieback syndrome was constantly associated with a lack of soil moisture.
6. The chlorotic dwarf syndrome was associated with a wider variety of adverse site conditions than just soil moisture.
7. Needle blight was probably the result of many different causal factors.
8. Since the disease was systemic the root system was probably involved in some way.

Campana (29, 30, 31) indicated that although the disease was most commonly known as white pine needle blight and white pine blight, it was also discussed under other names including pine blight, blight, leaf blight, sunscorch, tipburn, short needle, sandburn, dwarf needle, and chlorotic dwarf.

Campana (31), in 1954, investigated the possibility of the disease being caused by Corticium galactinum, a white root rot pathogen in many species of hardwoods and coniferous trees and known especially for its pathogenicity on Ha-

lus sp. Campana investigated the pathogenicity of the fungus on P. strobus, and after much work concluded that the fungus did not cause white pine needle blight. He also compared the foliage symptoms of diseased and healthy trees, which aided in supporting his findings. He failed to isolate the fungus from the roots of pine and could not successfully inoculate host tissue. He concluded that the disease was non-parasitic in nature, and divided the two syndromes, described by others, into the red needle blight (needle dieback syndrome) and the yellow dwarf blight (chlorotic dwarf syndrome).

Campana's review cited several unpublished reports which were unavailable to this writer. These included the works of Hansbrough, Welch, Michaelson, Eggertson, Wilson, and Han and Eggertson and are interpreted from Campana's review as follows.

In 1938, Hansbrough reported "dwarf needle disease" to be one of the most serious and widespread diseases of plantation-grown eastern white pine. Hansbrough recognized both chronic and sudden types of disease with both having shortened needles and excessive branching at the nodes. Needle dieback was only evident in the most advanced cases of needle blight where needle tips became brown and shriveled. Needles were retained from one to four years in the chronic

type of blight. In the sudden type of blight, previous year's needles dropped after shortened, current year's needles appeared. The blight was observed only in plantations and naturally seeded old field sites. Hansbrough indicated that roots of blighted trees were always found near the surface, regardless of site factors present, and were poorly branched, without many fibrous roots and poorly developed. He concluded that blight was initiated in the root system by one to several factors associated with poor site quality, thus contributing to poorly formed or distributed root systems.

In 1945, Welch reported the needle blight in a seven state area of the southern Appalachians. This was the first report from this geographic area and also the first one suggesting that needle blight had any pathogenic traits. He reported that the disease had increased from a few trees in 1934 to a general occurrence in 1943 in this area. His descriptions of the blight could be identified with those of Dana (40), Spaulding and Hansbrough (159), Gussow (67), and other workers, except for one difference not previously reported, the gradual and simultaneous appearance of dieback symptoms with needle emergence. In some cases this greatly inhibited growth, while in other cases needle length was barely different from normal. Welch believed that some form of parasitism existed as he reported evidence of a fungus

growing profusely on the fine rootlets possibly interfering with the development of mycorrhizae.

Michaelson reported chlorotic dwarf in those plantations he surveyed in Delaware. He observed excessive branching at the nodes, a symptom also reported by Hansbrough, with some trees showing no reduced growth even though foliage symptoms were present.

Wilson, in 1948, associated the root systems of blighted white pines with a definite lack of mycorrhizae. This was similar to the earlier findings of Hudson.

Eggertson, in 1949, observed needle blight in Ontario where needle dieback affected from 1/4 to 3/4 of the needle length during the period of needle emergence. Yellow dwarf symptoms were not mentioned, but a correlation was drawn between dry sites and the incidence of the blight.

Ham and Eggertson, in 1950, continued their work in Ontario where they produced more evidence that the blight was associated with dry sites. They also produced data on the correlation between the decrease in blight and the increase in rainfall during the critical growing period between June 15 and July 15. Also trees that survived the dry years, those more vigorous and with the most active root systems, were more susceptible the following year.

Ibberson and Streater (98), in 1952, were the first to test the response of blighted white pines to fertilizer applications. They found that the host had a definite and rapid response to the application of a 10:6:4 fertilizer at a rate of one to two pounds per inch DBH. Other treatments were either ineffective or were toxic.

Baldwin (13), in 1954, surveyed white pine needle blight in New Hampshire and confirmed reports of previous observers that the disease was related to poor root growth caused by drought injury. Soil texture appeared to be another factor associated with blight as only one-half of all trees were growing on sandy soils.

Pierson (138) reported needle blight to be widespread in Maine in 1954. Most blighted trees were found on dry sites with many roots killed apparently by drought; potassium and magnesium deficiencies were found in diseased needles.

Quirke (139, 140) reported from Canada, in 1954, that the disease killed white pines blighted annually over a period of several years. In a preliminary study blight reduced annual increment of tree ring growth. Needle blight was classified as a physiogenic disease with the causal factors involved unknown. Also in 1954, Davidson (41) reported a similar case of a decline in vigor of white pine in Ontario.

Stone et al. (161), in 1954, reported a malady of red pine on poorly drained soils in New York State and compared it to the resinosis disease of white and red pine. They were unclear as to descriptions made in an unpublished report by York in 1944 on the malady of red pine in New York State. York had reported this disease in that region since 1930.

In 1955, McKenzie (131) reported needle blight occurring in early summer all over Massachusetts. Symptoms included a reddening of new needles with tips commonly killed and at times whole needles affected. He found neither fungi nor insects consistently associated with blighted trees which appeared to usually recover naturally. McKenzie (130) referred to needle blight as the mystery disease of eastern white pine. He stated that even after 50 years of documented outbreaks, the disease was still poorly understood. McKenzie also indicated that trees recovered slowly and completely in a year or more without treatment, and that removal of affected trees should not be taken in haste since the blight was not contagious.

Wahlenberg (173), in 1955, surveyed a thinned plantation of 56-year-old white pine at Biltmore, North Carolina. Blight was a minor problem and seemed to be linked with a drier forest floor in the open areas where it reduced growth by one-third.

2.1.2 Reports and terminology, since 1957, of white pine diseases with symptoms similar to white pine decline

More recently, the accounts of pine diseases with symptoms similar to WPD have been reported as: semi-mature tissue needle blight, white pine emergence tipburn, resinosis disease, post-emergent chronic tipburn, basal canker, Leptographium root decline, white pine root decline, Verticicladiella wilt, pine wilt, and various types of air pollution injury. In the more recent literature, the old terms were changed to terms based on the "one-cause-one-disease" philosophy described by Wallace (176) in Chapter I. Many of the earlier reports of needle blight are now being attributed to air pollution damage or are being attributed to some other single causal factor. Most recently, the terms "Verticicladiella wilt" (a synonym of "basal canker", "root stain disease", "Leptographium root decline", "resinosis disease" and "white pine root decline") and "pine wilt", caused by the pinewood nematode, have been used in the literature to describe diseases with symptoms similar to WPD. The names used in the citations listed below have been gradually changed over time from the white pine needle blight terminology to this more recent terminology.

In a Southeastern Forest Experiment Station report (6), in 1957, it was noted that symptoms of needle blight and fume-damaged trees were very similar. Trees in an area of

Tennessee exposed to industrial fumes were compared to trees in fume-free areas of Virginia. There were little significant differences between the sulfur content of needles from trees from the two areas.

Linzon (112) studied a group of blighted and healthy trees in Ontario from 1949 to 1953. The blighted trees were significantly reduced in growth largely due to reduced size and number of functioning needles. Linzon indicated that trees affected for several successive years had progressively weaker foliage with extreme cases having dwarfed needles of the current year's growth only. He stated that the cause of the disorder was unknown. In a later study (113), he examined another group of healthy and blighted trees for a relationship between the disease and heart rot in the merchantable parts of the stem, but found none.

The chlorotic dwarf syndrome, first described by Baxter (15), has since been viewed as a separate condition from other needle blight symptoms. Campana (29) divided the blight into a needle dieback syndrome and a chlorotic dwarf syndrome. The chlorotic dwarf syndrome had since been called "chlorotic dwarf" and became a distinct designation from white pine needle blight.

In 1958, the Central States Forest Experiment Station (7) documented that chlorotic dwarf occurred in young white pine

plantations throughout the eastern USA; death occurred after pronounced characteristic symptoms.

Reid (141), in 1958, reported that chlorosis was distinct from white pine needle blight. He found only Lophodermium pinastri Schrad. ex Fr. consistently on attached chlorotic and fallen needles.

In 1958, Schmiege and Anderson (146) reported a disease with symptoms similar to chlorotic dwarf occurring commonly in 1957 in the Lake States. It damaged larger trees than previously reported for chlorotic dwarf and also occurred in natural stands. The decline they described resulted in tree death within several years of initial symptom expression. In Grand Rapids, Minnesota, a large number of trees developed the disease and died in the late 1950's.

Boyce (23), in 1959, reported that Scirrhia acicola (Dearn.) Siggers caused brown spot needle blight of white pine in western North Carolina, and was associated with the so-called "white pine blight".

Linzon (112, 113, 114), from 1958 to 1960, characterized needle blight occurring in Ontario as an orange-red discoloration of the distal portions of the current year's needles. This was only the second time that orange-red discoloration was used to describe the symptoms of the blight. Campana (29) indicated it was an unusual description when it was first noted by Linzon (110) in 1950. It was possible that

Linzon was describing an entirely different syndrome from that noted by other workers.

The first symptoms were faint, pinkish spots on the stomata-bearing faces of needles in semi-mature (ca. 4-wk-old) tissue. Spots developed rapidly into orange-red bands which within several days spread to the needle tips. Mature tissues were not susceptible, but younger tissues derived from basal meristems were affected by the disease. When needles were affected in early summer only limited areas at the tips of the needles were killed, but those infected when the needles were nearly fully grown involved most of their length. Outbreaks took place after a period of wet weather lasting from one to several days. Suddenly following the wet period was a period of continuous sunny weather. Linzon did not isolate any micro-organisms from the tissues of needle-blighted trees. He suspected that trees inherited the susceptibility to the unfavorable conditions which incited the blight. Susceptibility was suspected to vary among individuals and was not just a matter of varying local predisposition among uniformly susceptible individuals. Linzon indicated that the blight was initiated in semi-mature leaf tissues only, and spread distally throughout adjacent, more mature tissues following a similar pattern of breakdown. He compared the growth of healthy and needle-blighted white

pine saplings (115). Needle blight symptoms included reduction of needle and twig size, reduced height and diameter increments, fewer buds produced on shoots, and fewer shoots per whorl in the year following these buds. When these effects occurred annually only terminal buds were produced and with this lack of foliage the trees eventually died.

Dochinger (45), in 1960, examined white pine plantations in Ohio for chlorotic dwarf symptoms and found that most diseased trees were in 3- to 11-year-old plantations. About 7% of the trees in 43 plantations were diseased, with incidence varying from high to low. This incidence may have been due to certain management practices or plant/environment relationships.

Leaphart (106), in 1960, reported for the first time that eastern white pine were dying in two plantations in northwest Montana due to a root stain disease caused by Verticicladiella sp. This disease has since been called "white pine root decline".

Berry (16), in 1961, compared Boletes and other fungi from roots of blighted and healthy white pines and found 27 genera of fungi, none of which were associated consistently with blighted trees nor recognized as root pathogens. He found more dead tips and dead laterals on the roots of blighted trees than on healthy ones. Many of the main roots were also dead on diseased trees.

Berry (17), in 1961, referred to "white pine emergence tipburn" as a physiogenic disturbance. He tested the hypothesis that the disease, which he described as a blight which attacked developing needles in the early summer, was atmospheric and environmental in origin. He found that the number of live feeder roots in healthy trees was twice the number found in diseased trees. Berry considered the root condition a secondary factor, as he did not isolate any pathogens from the roots; no fungi were found associated with them. Seedlings were transplanted out of the area of disease incidence and the symptoms were reduced the following years. When healthy scions were grafted to diseased stock, the scions remained healthy; the opposite procedure produced diseased scions on healthy stock. Berry tested susceptible ramets (scions grafted on nursery-run, 2-year-old rootstocks) by exposing them for two hours to ten pphm of artifically-generated ozone. These developed typical tipburn symptoms 48 hours after treatment. He suggested that ozone was the cause of the disease since it commonly occurred in higher concentrations than those used in the test in unpolluted air. Also, a high incidence of tipburn in North Carolina, in 1961, could be correlated with abnormally high incidence of tobacco weather fleck, a disease associated with ozone.

Berry and Ripperton (19) reported white pine emergence tipburn occurring in Pocahontas County, West Virginia, in the summer of 1961. High concentrations of atmospheric oxidants were measured at 6.5 ppbm. The workers compared ramets protected in chambers, supplied charcoal-filtered air, to unprotected ramets growing in the greenhouse. Oxidants were produced artificially in concentrations and exposure times similar to field conditions. The symptoms produced appeared typical of the disease.

Hepting and Berry (79), in 1961, differentiated several needle blights caused by fungi from those caused by physiological disturbances and industrial fumes. Causal fungi included Bifusella linearis (Peck) Hohnel and Scirrhia acicola.

Linzon (117), in 1961, strengthened his hypothesis that susceptibility to the unfavorable conditions contributing to needle blight was inherent in the individual. He compared rooted cuttings from diseased and healthy mother trees. After rooting and development, cuttings were planted in a nursery 3 miles from the parent trees. When the susceptible parents developed initial needle-blight symptoms, the cuttings also developed blight on their new foliage simultaneously. The healthy cuttings and their mother trees remained healthy.

Linzon (118), in 1961, also grafted healthy scions to needle-blighted stock and needle-blighted scions to healthy stock; there was no disease transmission and the scions remained the same as their parent trees. This study was similar to that of Berry (16).

Linzon (116), in 1961, compared the movement of injected dye solutions in healthy and needle-blighted white pines. Acid fuchsin proved to be the best indicator of vascular movement of tree water supply. Healthy and needle-blighted trees were injected simultaneously, with blighted trees taking longer to absorb the same amount of solution. The solutions were absorbed the same height in both treatments. Linzon concluded that there appeared to be no occlusion of the water supply in the vascular system of blighted trees to prevent it from reaching the foliage. He also felt that the slower rate of absorption was related to the foliage injury.

Campana (32), in 1962, reaffirmed his earlier report of two definitive patterns of white pine needle blight. His study of 160 paired (blighted and healthy) trees indicated at least two distinct types of blight with separate, if not unrelated, causal factors. One type, yellow dwarf, was characterized by stunting and premature defoliation. The second type, red needle, characterized by needle dieback, had greener needles, retained year-old needles longer, and had greater stem growth than yellow dwarf trees. Red needle

types had more dead rootlets and fewer mycorrhizae than the yellow dwarf types.

Linzon (119), in 1962, described the process of needle blight of semi-mature needle tissue as it occurred at the cellular level. A distinguishing feature of the changing of the tissue was the start of suberization of the radial and transverse walls of the endodermal cells surrounding the stele, a stage which coincided with the onset of cellular breakdown (associated with the needle blight). For 7-8 weeks, the breakdown occurred at about the same distance from the basal meristem. As the blight progressed, the breakdown moved from the tips to the basal portion of the needles. After the needles stopped growing, the blight continued to progress until 3 weeks after cessation. By this time, the needles became mature and were no longer susceptible to blight.

Silverborg et al. (148), in 1962, reported a basal canker disease of white pine occurring in central New York state plantations. Cankers occurred from ground level to 30.5-61.0 cm (12-24 in) in height on trees growing on poorly drained soils, with a fragipan at a depth of 20.3-30.5 cm (8-12 in). These soils had a silty loam texture with low pH readings of 3.9 to 4.4 and had gleying and mottling present. Trees inoculated with fungi isolated from cankers did not

develop cankers. Trees began to decline on these soils from 20-25 years of age, when their roots reached the impervious layer. The workers felt that the fragipan and possibly root competition contributed to canker development.

Annan and Berry (2), in 1963, eliminated insects found associated with tip-burned white pines as a cause of the post-emergence chronic tipburn. At a research site located in eastern Tennessee they treated the foliage and the soil with insecticides. Control of aphids, **Pineus strobi** Hartig on the crown and **Prociphilus** sp. on the roots, failed to relieve the tipburn symptoms.

Dochinger and Seliskar (53, 54), in 1963, concluded a 5-year study of root and shoot grafts with no transmission of chlorotic dwarf. They indicated that the disease was not of a virus origin as earlier suspected but genetically controlled with the causal agent acting directly on the tree's foliage instead of the roots. Healthy scions were grafted on chlorotic dwarfed trees and developed not only larger crowns but better root systems. The workers also produced evidence that susceptibility to emergence tipburn was independent to susceptibility to chlorotic dwarf.

Dochinger (46), in 1963, later reproduced the effects of chlorotic dwarf on tree growth and vigor of 5-year-old white pines by artificial defoliation. This technique proved fa-

tal to most trees and also proved that the current year's needles were more important for shoot growth than older needles. He also, in 1964 (47), concluded that treatments with organic chelates, fertilizers, lime, and a mixture of fertilizers and lime, did not prevent the mottling and premature defoliation symptoms of diseased trees.

Berry and Hepting (18), in 1964, observed a general decline leading to white pine death during an aerial survey of the Cumberland Plateau in Tennessee. They attributed the disease to post-emergent chronic tipburn with no primary pathogens found to cause a decline in growth and vigor. They reported that fertilization and pruning sometimes improved vigor but did not eliminate tipburn symptoms. They also transplanted a group of diseased trees out of the areas, which were in the vicinity of industrial sites, and another group of diseased trees into adjacent sites within the same areas. The trees transplanted outside recovered from tipburn, but those transplanted within the same areas continued to decline. The workers conducted similar grafting tests to earlier studies and concluded that the disease was caused by air pollution and not a virus agent. They also concluded that resistance to the disease was genetically controlled. Although leaves they analyzed did not have high levels of sulfur or fluoride, they still regarded these pollutants as possible factors.

Houston and Eno (94), in 1965, summarized a study of basal canker of white pine in New York State, and reported that cankers were initiated by ants and by snow and ice damage. These agents damaged the lower branches and the basal areas of trees. Damaged tissues were then apparently colonized by many species of fungi. They reported a Fusarium sp. and a Leptographium sp. to cause annual lesions and an unidentified fungus to cause perennial cankers; this fungus was found in 50% of the lesions, and was capable of killing 8-year-old trees in less than one year. Death was found to be hastened by mice feeding on diseased tissues which caused trees to be girdled at a faster rate. The disease was also reported in this same year in the report of the Northeast Forest Experiment Station by an anonymous author (8).

Dochinger et al. (55), in 1965, reported that chlorotic dwarf was caused by gaseous pollutants which acted on susceptible foliage. When they placed diseased trees in chambers supplied with air filtered through activated charcoal, these trees recovered. Mottling was not present on trees in chambers receiving filtered air, but trees in chambers receiving unfiltered air or filtered air with particulate size over 0.3 microns in diameter still showed chlorotic dwarf symptoms.

Linzon (120), in 1965, studied the nature and etiology of semi-mature tissue needle blight. He confirmed earlier reports that the disorder was non-parasitic, was associated with unfavorable environmental conditions and that susceptibility to the disease was inherent in the individual.

Linzon (121), in 1966, reported that forests of white pine in Ontario were severely damaged by atmospheric sulfur dioxide, up to 40 km (25 mi) from large smelters in the Sudbury mining district. He also indicated that there was no correlation between the occurrence of semi-mature tissue needle blight and the presence of atmospheric ozone or sulfur dioxide. Symptoms of the blight were dissimilar to symptoms known to have been caused by these chemical pollutants on white pine.

Linzon (122), in 1967, studied the histological aspects of semi-mature tissue needle blight. He observed macro- and and microscopic symptoms and found that susceptible needles had tightly packed mesophyll cells with little intercellular space. These needles matured faster and stopped growing earlier than those on resistant trees. Linzon (123), in 1967, concluded in further study of his earlier experiments (121) that ozone was not an incitant of semi-mature tissue needle blight in the Chalk River, Ontario area.

Dochinger (48), in 1966, reported a root decline of white pine in Ohio, and in 1967 (49), reported that Leptographium root decline had occurred sporadically in six states since 1957. Symptoms included a delay in budbreak, a reduction in shoot growth, foliar discoloration, and a wilt. After this, growth stopped, needles turned reddish-brown, and remained attached indefinitely. Cankers occurred from the root crown extending around 45 cm upwards and caused tree death from a progressive root-cambium necrosis; the lesions consistently yielded an isolate of Leptographium sp. which was pathogenic when inoculated into susceptible tissues.

Smith (154), in 1967, studied a root disease of pines caused by Verticicladiella wagneri Kendrick (100) as it occurred in the western USA. The fungus was confined to the non-living mature tracheids of the primary and secondary xylem. The disease was similar to earlier accounts of white pine root decline, or Leptographium root decline, caused by Leptographium sp. (later called Verticicladiella procera). Smith found that the disease was very much similar to a vascular wilt.

Dochinger (50, 51), in 1968, stated that the susceptibility of white pine to chlorotic dwarf was inherited and a result of aerological agents acting directly on the foliage of susceptible trees. He summarized his earlier filter chamber

techniques to distinguish between polluted air, clean air and disease incidence. There were statistical correlations between seedling characteristics and disease development in plantation-grown white pine in Ohio. He found that out of 11 seedling characteristics, needle mottling was the best diagnostic character of the disease. This allowed for early diagnosis and roguing of affected plants from nursery beds.

Linzon (124), in 1968, identified needle fungi associated with semi-mature tissue needle blight and demonstrated no connection between the symptoms on new and old blighted needles and the growth of fungi when studied both histologically and in culture. He found no fungi on newly blighted needles, and could not connect the appearance of symptoms with the prevalence of fungal spores. Fungi found on older blighted needles included Lophodermium sp., Cenangium acuum Fr., and Hysterographium fraxinicolum Duby. Inoculations with these fungi produced negative results. The use of fungicides (Captan and Bordeaux mixture) aimed at controlling possible pathogenic fungi prevented the growth of saprophytes, but did not suppress needle blight symptoms.

Houston (89), in 1969, continued his previous studies of basal cankers occurring in north-central New York plantations. He inoculated healthy seedlings with fungi isolated from natural cankers, including Fusarium sp., Verticicla-

diella procera, and *Fragmopara pithya* (Fr.)Fr. The rarely isolated *Fusarium* sp. and *V. procera* were found to cause annual cankers, while *P. pithya* isolates caused perennial cankers which girdled and killed 8- to 10-year-old trees in less than one year; this fungus was isolated from nearly half of the cankers of inoculated test trees. In plantations having naturally infected trees, cankered trees were found associated with both ant mounds and certain types of stand topography allowing for insect damage along with ice and snow damage.

Costonis and Sinclair (39), in 1969, reported the relationship of atmospheric ozone to needle blight. They found that current season's needles were acutely sensitive to 3 ppha for 48 hours or 7 ppha for 4 hours ozone exposure. These were quantities that would occur in a rural stand of pines. Trees fumigated with ozone in the presence of a mist were more severely damaged that trees fumigated by ozone only. Acute symptoms included silver flecks on the needles which were caused by the collapse of individual mesophyll cells beneath the stomatal surfaces; these flecks could coalesce to form yellow to pink spots, necrotic bands and tips. Susceptibility was at its maximum during needle elongation, with individual trees varying considerably in susceptibility. Chlorosis, premature defoliation of older nee-

dles, and slow growth were associated with chronic exposure to ozone.

Dochinger et al. (52), in 1970, found that a possible ozone and sulfur dioxide synergism produced symptoms of chlorotic dwarf. They observed symptoms in the field and induced them experimentally by exposure to ozone and sulfur dioxide both separately and in combination. In combination the pollutants were suspected to act synergistically; thus a combination of gases may cause injury before any one gas could reach injurious levels. Sulfur dioxide alone was more effective than ozone as an incitant of symptoms. Chronic exposure resulted in growth reduction from loss of photosynthetic tissues.

Costonis (36), in 1970, exposed white pine ramets in controlled environment chambers to sulfur dioxide and ozone. This resulted in acute injury to current-year needles by sulfur dioxide at concentrations as low as 3.5-6.5 pphm for 1 hour. He indicated that certain strains of white pine were extremely sensitive to sulfur dioxide which was more phytotoxic than ozone. New needles were injured by exposure to either of the gases at 20-30 pphm for 2 hours. He did not find any histological differences that could have been used as diagnostic tools to differentiate between the two types of injury. He observed macroscopic differences (that

were not unlike those described by earlier workers) in injuries that developed in response to the two types of gas exposures.

Costonis (37), in 1971, later observed that symptoms of acute sulfur dioxide injury to white pine were similar to those described by Costonis and Sinclair (39). Symptoms of chronic sulfur dioxide injury included chlorosis of current and older needles with premature defoliation of the older ones. Sulfur dioxide of 6 ppha for 4 hours caused acute injury of new needles but ozone up to 4 ppha caused no injury.

Linzon (125), in 1971, reported on the annual occurrence and effects of semi-mature tissue needle blight on white pine, and studied the annual fluctuations in incidence in several separate plots in a localized area of Canada from 1957 to 1964. He found that major outbreaks were rare and often occurred after a heavy rainfall followed by a continuous sunny period. As a result of disease, growth was reduced and perennially blighted trees died prematurely.

Skelly et al. (151), in 1972, studied symptom expression of eastern white pine located near a source of oxides of nitrogen and sulfur dioxide. They studied four Pinus spp. and found that Pinus strobus seedlings and larger trees were the most severely affected by nearby industrial emissions of nitrogen oxides (at moderate levels) and sulfur dioxide (at

low levels). Acute symptoms included tufted needle growth with severe needle tipburn (orange) and stunting.

Botkin et al. (21), in 1972, observed the effects of ozone on suburban white pine seedlings by monitoring the variation in inhibition and recovery of net photosynthesis. Seedlings were monitored over an extended period of time using the small chamber technique as described earlier by Dochinger et al. (52). The threshold of ozone suppression was 50 ppbm for a minimum of 4 hours. Above this threshold, they found three categories of ozone sensitivity present: susceptible, intermediate, and resistant.

Costonis (38), in 1973, reported injury to white pine by sulfur dioxide and ozone alone and in mixtures. The most severe needle damage to susceptible clones was incited by 2-hour separate exposures to ozone and sulfur dioxide at 5 ppbm each, followed after 24 hours by a 2-hour exposure to a combination of ozone and sulfur dioxide at 5 ppbm. He also found that a single 2-hour sulfur dioxide treatment alone caused more damage than a combined ozone and sulfur dioxide treatment.

Houston and Stairs (87), in 1973, and Houston (86), in 1974, studied the reaction of tolerant and sensitive clones of P. strobus to sulfur dioxide and ozone. Clones were analyzed to estimate the upper limit of genetic control for

tolerance. After fumigation, clones were evaluated by needle elongation and two indices of direct needle damage. Tolerant and sensitive clones were later fumigated for 6 hours with different concentrations of ozone and sulfur dioxide alone and in combination. These fumigation chamber treatments correlated with field damage observed under ambient conditions. It was found that sensitive clones were injured by sulfur dioxide at 2.5 ppbm. Of the tolerant clones, 60% were injured by sulfur dioxide at a range of 5-15 ppbm, while 100% were injured at 45 ppbm. The synergistic effect of ozone and sulfur dioxide caused even more damage than either pollutant alone at similar levels.

Hill and Skelly (183), in 1974, found that fertilizers high in nitrogen could be used to alleviate air pollution damage to white pine. The fertilizers were applied in autumn on Christmas tree plantations to reduce the symptoms of tipburn and chlorosis. Recommendations were based on tree height. This was not the first report of this nature as earlier workers had experimented with the use of fertilizers to alleviate white pine blight symptoms (18, 47, 98).

Houston (93), in 1975, reported the occurrence of the basal canker disease complex of white pine in Maine. The disease was found in young white pines planted as living snow fences along an interstate highway. This situation was very

much similar ecologically to that reported previously in New York. The factors leading to the disease seemed to be more widespread and common than formerly thought. Several fungi were isolated from cankers, but none except a *Fusarium* sp. was suspected to have caused them. The isolate of *Fusarium* appeared morphologically similar to one associated with cankers in New York.

Houston (90) had previously used large scale aerial color photography for assessing this disease in the northeastern USA. He found that foliar symptoms could be easily detected on both color infrared and true color aerial films.

Phillips *et al.* (137), in 1976, found that white pine exhibited growth retardation caused by fluctuating air pollutant levels. They measured growth inhibition of asymptomatic trees over a 35-year-period subjected to 3 peaks of pollution levels. Since no significant growth rate differences were found between symptom classes during pollution peaks, growth of asymptomatic trees was reduced as much as that of injured trees during peak pollution periods.

Towers (167) reported the occurrence of *Verticicladiella procera* on white pine in Pennsylvania in 1976. He indicated that the disease associated with this pathogen, white pine root decline, had been killing 3- to 10-year-old white pines in that state since 1968. The disease was usually associated with shallow, heavy clay, poorly drained soils. He iso-

lated the fungus from discolored roots and basal cankers of 7-year-old white pines in a one acre stand in Chester County. The soils were poorly drained in this area and around 20% of the trees were dead or dying from the disease. Attempts to isolate the fungus from other locations with similar soil types proved futile. A species of Fusarium was isolated instead.

Hayes and Skelly (72), in 1977, reported the effects on white pine of ozone transported into Virginia from the northeastern USA. They monitored rural areas for one year and found increases in oxidant levels to be associated with the weather patterns moving air in from the Northeast. After oxidant levels either exceeded or equaled the national air quality standards from 39 to 104 hours on the sites, typical oxidant-induced symptoms were consistently observed on white pines following these exposures. A significant linear association was found between severity of needle injury of sensitive trees and levels of oxidants.

Few reports have been published since 1977 on air pollution injury to white pine except those covering the specifics of experimentation. Much of the initial work to investigate the suspected causal agent of white pine root decline is under way at this time.

Several workers (3, 129) have published methods for isolating the suspected causal fungus, Verticicladiella procera. Anderson (3), in 1980, developed a method for recovering the fungus from the basal cankers by placing chips of the host on wet filter paper. The conidiophores of the fungus were then transferred to potato-dextrose agar. McCall and Merrill (129), in 1980, developed a selective medium that contained cycloheximide in concentrations up to 100 ppm, in acidified malt agar for isolating the fungus.

Several workers have reported Verticicladiella procera causing disease in white pines both in the USA and New Zealand in 1980. Shaw and Dick (144) reported the pathogen causing a root disease of Pinus strobus on the North Island of New Zealand. They, like previous workers, associated the disease with poorly drained sites. Sinclair and Hudler (150) reported that V. procera caused a "root lesion disease" throughout New York State. These infected trees were also found on soils with poor internal drainage. In New York, the disease was found on trees up to 20 years old. In both of these reports, the authors did not use the name white pine root decline but referred to the disease as a "root disease" or "root lesion disease".

The most recent reports of a disease of pines with symptoms similar to WPD have been of the "pine wilt" disease. A review, by Holdeman (84), of the pinewood nematode, Bursa-

Bursaphelenchus lignicolus Mamiya & Kiyohara, and the associated "pine wilt" disease of Japan, summarized the present situation of this pathogen in the USA. The nematode possibly originated in the USA, since many of the native pines have a certain amount of resistance to the disease. The pinewood nematode was first identified in Japan in 1969 (127) and was not suspected to occur in the USA until its discovery in Missouri in 1979. The initial discovery in the USA was on *Pinus nigra* Arnold, but the pathogen has since been identified from *P. strobus*. The first report (179) of the nematode in Virginia was in February, 1980, from a Rockbridge County landscape. The host was a 17-year-old white pine from which samples were collected by this writer as part of this investigation.

Although the symptoms appear suddenly and are similar to those of the acute syndrome of WPD, the sudden death of pinewood nematode infested native pines in the USA may be related to predisposition by stress. This was indicated by Holdeman and apparently by others he consulted to compile the review. According to Holdeman's hypothesis, native pines would not normally be killed if they had not been under stress previous to infestation. This has seemed to have been the case in the USA since the disease has not presented a large threat to native pines except in stressed landscape and some forest and plantation situations. This discussion

by Holdeman of predisposition by stress strengthens the basis for this investigation of WPD, that when stressed trees are confronted by an opportunistic pathogen, the syndrome changes from a chronic situation to an acute situation.

2.2 COMPARISON OF DECLINES OF BROAD-LEAVED TREES WITH WHITE PINE DECLINE

Five examples of declines of forest and landscape tree species include: ash dieback, beech bark decline, maple decline, oak decline, and pin oak blight and decline. Ash dieback (25, 80, 88, 91, 92, 142) is a disease which begins with the death of the branch tips and proceeds inward and downward. Small chlorotic, sparse leaves are produced at the nodes resulting in a thin "tufted" crown, and the trees deteriorate until they die. Ash dieback in the Northeast is thought to be initiated by drought. Bark tissues are altered by drought to allow the entry of canker fungi. These cankers invade weakened tissues, girdling limbs and in some cases the main stem. According to most authorities, the disease is still not completely understood and other factors, such as viruses and other stress factors may also play a role in the dieback. Some symptoms of this disease are similar to WPD, e.g., the tufting of branches and chlorosis, but many symptoms are dissimilar.

Beech bark disease (92, 145) is a disease complex of American beech. The symptoms include a thin crown bearing small, sparse, chlorotic foliage and a general dieback. The initiating stress is biotic, Cryptococcus fagisuga Lindinger, a scale insect. The secondary agent or finisher is a canker fungus, Nectria coccinea Pers. ex Fr. var. faginata Lohman, Watson, and Ayres. These organisms attack the bole of the tree. Many factors still unknown may exist in this disease complex. Beech bark disease is similar to WPD particularly when certain insects such as the pine bark aphid become associated with the white pine. This part of the WPD syndrome is reminiscent of the beech bark scale association with beech bark disease.

According to Houston (92), there are two types of maple decline. The forest type is initiated by insect defoliation, while the roadside type is initiated by de-icing salt. Typical symptoms of maple decline include a terminal dieback accompanied by a progressive deterioration of the crown with small, sparse, chlorotic foliage on sprout origin tissue. Maple decline is most prevalent in the northeastern USA (181).

The forest type of maple decline, as described by Houston, (92) is initiated by insect defoliation followed by an invasion of the tree's roots by Armillaria mellea (Vahl ex

Fr.) Kummer, a root fungus. Defoliation causes dieback symptoms and rapid death and is associated with invasion by A. mellea, which is probably favored by a sharp decline in the starch levels yielding glucose and fructose sugars in the root tissues. Houston also indicates that certain amino acids and phenolic compounds may play a key role in the increase of susceptibility to attack by otherwise non-aggressive organisms.

The street tree variety of maple decline has similar symptoms to the forest type, with similar agents involved in some cases. Tattar (164) describes a decline of maples, primarily sugar maples, as their failure to succeed as shade trees. Like white pine, maple is intolerant of many of man's activities and site and environmental conditions present in landscape plantings (102). He states that many of these maples have been under stress for years with the magnitude, frequency and timing of stress determining tree response and whether they will be attacked by some secondary biotic agent.

Oak decline is very similar to maple decline in expression of disease symptoms and causal factors (91, 92, 164). Oaks are defoliated by such insects as the gypsy moth, Porthetria dispar L., the elm spanworm, Ennomos subsignarius Hubn., and certain leaf rollers and leaf tiers. These in-

sects initiate the decline, while **Armillaria mellea** and the two-lined chestnut borer, **Agrilus bilineatus** Weber, and drought conditions finally act to kill the host. Houston is currently trying to determine if the initial defoliation relates to the type of site, as certain ones seem more likely to be defoliated than others (92). This hypothesis also applies to other declines, including WPD. He found that trees on sites subjected to severe environmental perturbations were most likely to be defoliated by insects. However, trees growing on sites of poorer quality seemed not to succumb as easily to a certain level of defoliation as trees on higher quality sites (sites not disturbed or disturbed less frequently). Apparently, trees on poor quality sites had adapted to these conditions and were not as affected by certain levels of defoliation.

Howe (95) indicates that oak decline in some Midwestern areas may be different than that described by Houston (92) in the Northeast. He found that trees growing in northeastern Illinois are more susceptible to soil disturbance than in the Northeast due to the shallowness of the root systems. The often impervious, calcium-rich, dense, clay-underlayer of young oak forests in these areas of the Midwest provides an environment where the acidophilic oak must develop its root system close to the soil surface. In the Northeast, with its acidic well-drained soils of glacial origin, root

systems develop deeper and are less susceptible to surface soil disturbances. This situation, described by Howe in northeastern Illinois, is similar to the situation with WPD in Virginia.

Stipes and Phipps (160) first reported pin oak blight and decline killing mature *Quercus palustris* Muenchh. in Hampton, Virginia in 1971. The disease was associated with the fungus, *Endothia gyrosa* (Schw.) Fr., which caused a girdling stem canker. The disease was found to cause noticeable damage to mature pin oaks on water-stressed sites.

Appel (11) investigated the possible predisposition by water stress of urban pin oak plantings to pin oak blight and decline. Using Wallace's "synoptic" approach to the problem (176), Appel concluded from carefully monitored greenhouse experiments that susceptability to the blight was enhanced, if not necessitated, by water stress; decline and eventual death of the host resulted. This disease followed a typical decline pattern with water stress acting as the "initiator" and the fungus acting as the "finisher". Pin oak blight has general simularities to WPD although one specific biotic factor such a *E. gyrosa* has not been implicated as the finisher with WPD. However, a similarity that exists in both cases is the planting of pin oak and white pine outside their natural range. This practice of planting these

trees in poor site locations could possibly be an initiator of disease.

The various parameters of declines discussed by these writers are very similar to those of WPD. Although in each case the parameters may vary, the disease pattern is similar with initiators stressing trees to decline and other factors killing the host.

Chapter III

MATERIALS AND METHODS

3.1 SYSTEMATIC INDEXING METHOD

The objective of this investigation was to compare trees in various stages of health to determine the factors contributing to decline. The need for indexing disease symptoms, tree physiological factors, and site quality indicators was of primary importance to fulfill this objective. An information indexing form (see Figure 7) was developed in order to collect and compile data in an efficient and systematic fashion. The information collected was compiled and evaluated subjectively and statistically for indicators of decline. Various tree health factors were collected and compared with site factors and signs of stress and disease. The methods and materials used for each study and analysis are noted in the following sections.

WPD1

WHITE PINE DECLINE SURVEY FORM (IF FOUND RETURN TO: M.J.WEAVER-DEPT.PLANT PATHOLOGY & PHYS.-
417 PRICE HALL-VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIV.- BLACKSBURG, VA. 24061)

TREE#____ DATE_____COUNTY_____TOWN_____ IWD1____ IWD31____

ADDRESS_____OWNER_____ IWD2____ IWD32____

LOCATION_____ IWD3____ IWD33____

AGE____HEIGHT_____DMH_____DBH_____ NDLGTH(OLD)_____ NDLGTH(NEW)_____ IWD4____ IWD34____

BARK1 dark__ light__
BARK2 corky__ sound__
BARK3 hard__ soft__
BARK4 furrowed__ turgid __
COMMENTS_____

BOLE1 tapered__ cylinder__
BOLE2 forked__ unforked__
BOLE3 #forks above 1M_____
BOLE4 #forks below 1M_____
BOLE5 DMH forks below 1M ____
BOLE6 DMH forks below 1M ____
BOLE7 DMH forks below 1M ____
COMMENTS_____

IWD5____ IWD35____
IWD6____ IWD36____
IWD7____ IWD37____
IWD8____ IWD38____
IWD9____ IWD39____

CROWN1 thin__ normal__ none__ (FOLIAGE)
CROWN2 none__ few__ many__ (LARGE DEAD BRANCHES)
CROWN3 none__ few__ many__ (SMALL DEAD BRANCHES)
CROWN4 tufted__ full__ (FOLIAGE)
CROWN5 wilted__ not__ (FOLIAGE)
CROWN6 old__ new__ all__ (AMT.CHLOROSIS)
CROWN7 old__ new__ all__ (AMT.NECROSIS)
CROWN8 % chlorotic ____
CROWN9 % necrotic ____
CROWN10 mgchlorophyll(new needles)_____/g tissue
CROWN11 mgchlorophyll(old needles)_____/g tissue
COMMENTS_____

IWD10____ IWD40____
IWD11____ IWD41____
IWD12____ IWD42____
IWD13____ IWD43____
IWD14____ IWD44____
IWD15____ IWD45____
IWD16____ IWD46____

ROOTS1 depth of root zone ____
ROOTS2 area of theoretical root zone ____
ROOTS3 area of actual root zone ____
ROOTS4 volume of root zone ____
ROOTS5 soil depth over roots____
ROOTS6 % impeded laterally ____
ROOTS7 source of decay or discoloration_____

IWD17____ IWD47____
IWD18____ IWD48____
IWD19____ IWD49____
IWD20____ IWD50____

ASPECT1 % slope ____
ASPECT2 elevation ____
ASPECT3 long(100'+)___ moderate(10-50')___ short(10'-)___(SLPLGTH)
ASPECT4 level__knob__depression__slope__ toe slope__terrace__
well,level__well,depressed__well,sloped__well,knob__
well,inverted__other,specify_____
ASPECT5 % direct sunlight ____
ASPECT6 east__west__north__south__all(no shading)__other, specify___
(DIRECTION OF SUNLIGHT)
ASPECT7 source of shading_____

COMMENTS_____

IWD21____ IWD51____
IWD22____ IWD52____
IWD23____ IWD53____
IWD24____ IWD54____
IWD25____ IWD55____
IWD26____ IWD56____
IWD27____ IWD57____
IWD28____ IWD58____
IWD29____ IWD59____
IWD30____ IWD60____

Figure 7: Systematic disease indexing forms used to compile data.

WHITE PINE DECLINE SURVEY FORM (IF FOUND RETURN TO: M.J.WEAVER-DEPT.PLANT PATHOLOGY & PHYS.- 417 PRICE HALL-VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIV.- BLACKSBURG, VA 24061) WPD2

	type	%rz impeded(covered)	good	mod.	poor(%health)
COMPETITION1					
COMPETITION2					
COMPETITION3					
COMPETITION4					
COMPETITION5					
COMPETITION6					
COMPETITION7					
COMPETITION8					
COMPETITION9					
COMPETITION10					

DAMAGE COMMENTS_____

SYMPTOMS1_____
SYMPTOMS2_____
SYMPTOMS3_____
SYMPTOMS4_____
SYMPTOMS5_____
SYMPTOMS6_____ (LIST SEQUENCE IN CHRONOLOGICAL ORDER)
COMMENTS_____

ENVIRONS1 low__ moderate__ heavy__ SUBURBAN TRAFFIC FLOW(NEARBY)
ENVIRONS2 low__ moderate__ heavy__ URBAN TRAFFIC FLOW(NEARBY)
ENVIRONS3 low__ moderate__ heavy__ RURAL TRAFFIC FLOW(NEARBY)
ENVIRONS4 low__ moderate__ heavy__ HIGHWAY RIGHT-OF-WAY TRAFFIC FLOW
ENVIRONS5 private residence__ campus__ park__ cemetery__ golf course__ commercial(offices, businesses)__ industrial site: light__ moderate__ heavy__ other, specify_____

ENVIRONS 6 point source of pollution(excluding traffic & background)_____

	chemicals applied to site	date applied	freq. applied	amt.applied	where
CHEM1					
CHEM2					
CHEM3					
CHEM4					
CHEM5					
CHEM6					

COMMENTS_____

Figure 7: (continued)

WPDS

WHITE PINE DECLINE SURVEY FORM (IF FOUND RETURN TO: M.J.WEAVER-DEPT.PLANT PATHOLOGY & PHYS.-417 PRICE HALL- VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIV. - BLACKSBURG, VA 24061)

nematodes found	count/250cc soil	conc.= high medium low
NEMA1		
NEMA2		
NEMA3		
NEMA4		
NEMA5		
NEMA6		
NEMA7		
NEMA8		
NEMA9		

signs or symptoms	conc.= high medium low	suspected cause	time present
AGENTS1			
AGENTS2			
AGENTS3			
AGENTS4			
AGENTS5			
AGENTS6			
AGENTS7			
AGENTS8			
AGENTS9			
AGENTS10			

WHITE PINE WEEVIL terminal woobies #years=____ years nit_____

MYCORRHIZAE (FEEDER ROOTS) number present= many__ some__ few__ none__

WEATHER DATA:_____

1979_____

1978_____

1977_____

COMMENTS:_____

Figure 7: (continued)

WHITE PINE DECLINE SURVEY FORM (IF FOUND RETURN TO: M.J.WEAVER-DEPT.PLANT PATHOLOGY & PHYS.
417 PRICE HALL- VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIV.- BLACKSBURG, VA 24061)

	SOIL FACTORS			
FACTOR	HORIZON A	HORIZON B	FRAGIPAN	DISTURBED LAYER
volume				
depth				
color				
consistence				
structure				
compaction (resistance to penetration)				
% moisture				
PSA				
mottles				
abundance				
size				
contrast				
color				
foreign matter				
amount present?				
SOIL LAB DATA				
pH				
Ca				
Mg				
P				
K				
Mn				
Zn				
S.Salts				
%OM				
$N\text{-}NO_3$				

DEPTH TO C LAYER _____

PARENT MATERIAL _____
COMMENTS _____

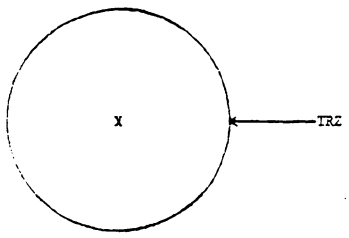
HORIZONTAL VIEW OF SITE (INCLUDING SOIL LAYERS)

_____ground level_____

Figure 7: (continued)

WHITE PINE DECLINE SURVEY FORM (IF FOUND RETURN TO: M.J.WEAVER-DEPT. OF PLANT PATHOLOGY & PHYS.-417 PRICE HALL-VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIV.-BLACKSBURG,VA 24061) WPDS

AERIAL MAP OF SITE: (X=TREE) (TRZ=THEORETICAL ROOT ZONE)



MAP OF LOCATION: (INCLUDE COUNTY ROAD NUMBERS AND LANDMARKS)

Figure 7: (continued)

3.1.1 Tree code designations and site locations

Codes were used for each tree for orderly designation of data. The sequence used for the systematic disease indexing study was from 1 to 104, with each tree assigned a number according to the date of recording.

Tree codes 1-50 and 60-100 were assigned to trees surveyed on landscape sites. These trees were designated under a group called "decline habitats". This name was not meant to imply that all trees on landscapes were declining nor were all trees surveyed from decline habitats in poor health. This designation was used for illustration purposes in this study. Tree codes 51-56 and 101-104 were assigned to trees surveyed on a site in the Jefferson National Forest 7 miles off US Route 460 on State Route 621 along Craig Creek in Montgomery County, Virginia. This group was referred to in this study as the "natural habitat" and was not meant to imply that trees did not decline in the forest.

Tree codes 105-110 were also located at this forest site, but were not used in the systematic disease indexing study. Instead, these 6 trees were part of a study of annual changes in foliar color described in the second sections of chapters 3 and 4.

Trees were located in various parts of Virginia according to the map in Figure 8. Observations are listed on the map

according to a location number (map code) with the specific location of each tree listed in Table 1.

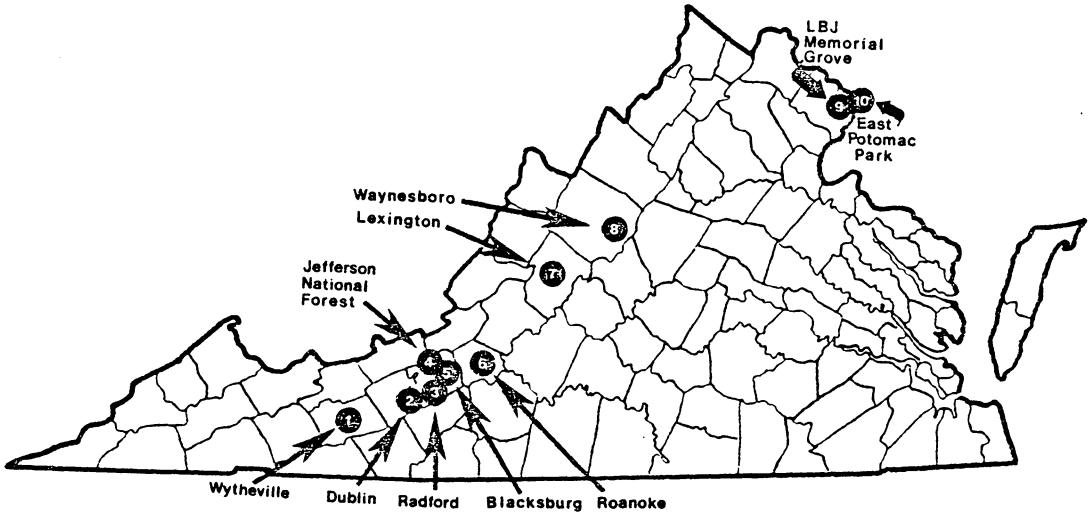


Figure 8: Map illustrating white pine decline sampling sites in Virginia for use with systematic disease indexing method.

TABLE 1

List of specific tree locations used in the systematic disease indexing study

Map* Code	Tree Code	Location
1	72-73	Wytheville, VA, Tazewell & North Sts.
1	74-77	Wytheville, VA, Rolling Hills Dr. & 11 St.
2	84-86	Dublin, VA, S end of Claytor Lake
3	64-66	Radford, VA, 1 mi. S on SR 664
4	51-56	Jefferson Nat. Forest- 7 mi. E on SR 621
	101-104	off US 460 W of Blacksburg, VA
5	1	VPI&SU campus, near Davidson Hall
5	2-3, 60	VPI&SU campus, near Newman Library
5	4	VPI&SU campus, near McBryde Hall
5	5-7	VPI&SU campus, near Patton Hall
5	8-15	VPI&SU campus, west of Schultz Hall
5	57-59	VPI&SU campus, north of Schultz Hall
5	16-36	VPI&SU campus, near Bldg.276 & Solitude
5	37-45	VPI&SU campus, near Biochemistry Bldg.
5	46-48	VPI&SU campus, near Hillcrest Dorm.
5	49-50	VPI&SU campus, near Wallace Hall
5	81-83	Blacksburg, VA, Grisson & Country Club Drs.
5	87	Blacksburg, VA, 1404 Giles Rd.
5	88-90	Blacksburg, VA, 1508-1510 W.Main St.
5	91	Blacksburg, VA, 726 Lucas Dr.
5	92-95	Blacksburg, VA, 601 Broce Dr.
6	61-63	Roanoke, VA, near Londonberry Dr.
7	78-80	Lexington, VA, 1 mi. W off SR 825
8	67-68	Waynesboro, VA, 3 mi. W off SR 828
8	69-71	Waynesboro, VA, 741 Guynne Ave.
8	99	Waynesboro, VA, Waynesboro Garden Ctr.
9	97-98	Washington, DC, LBJ Memorial Grove
10	96	Washington, DC, East Potomac Park
11	100	Greenville, PA, Salem Village (not on map)

* Refer to Figure 8 for a guide to map codes.

3.1.2 Tree health and growth indicators

AGE--Tree age was determined by counting the number of nodes or whorls of branches per tree. Although it has been documented that trees in certain circumstances can produce false branch whorls (136), this was the most reliable and convenient means available to evaluate this factor. This technique was mandatory for use on landscape sites where tree owners were sensitive about possible damage to their valuable trees by increment borers. However, older trees at times did present a problem due to the height and loss of the lower branches. Most of these measurements were 90 to 95% accurate. Age of tall trees was often determined more accurately by counting whorls on a more visible lower branch rather than from the top down. The whorls were counted from the branch tip back to the bole and down to the ground as illustrated in Figure 9. This method proved as accurate as counts made from the top.

HEIGHT--Height was measured by the use of a Blume-Leiss altimeter. After an especially designed measuring plaque was attached to the tree at eye level, the observer walked back on level ground a prescribed number of feet according to the number at eye level on the plaque. If the ground was not level, a correction factor was used to correct the reading. The observer would then sight through the viewfinder

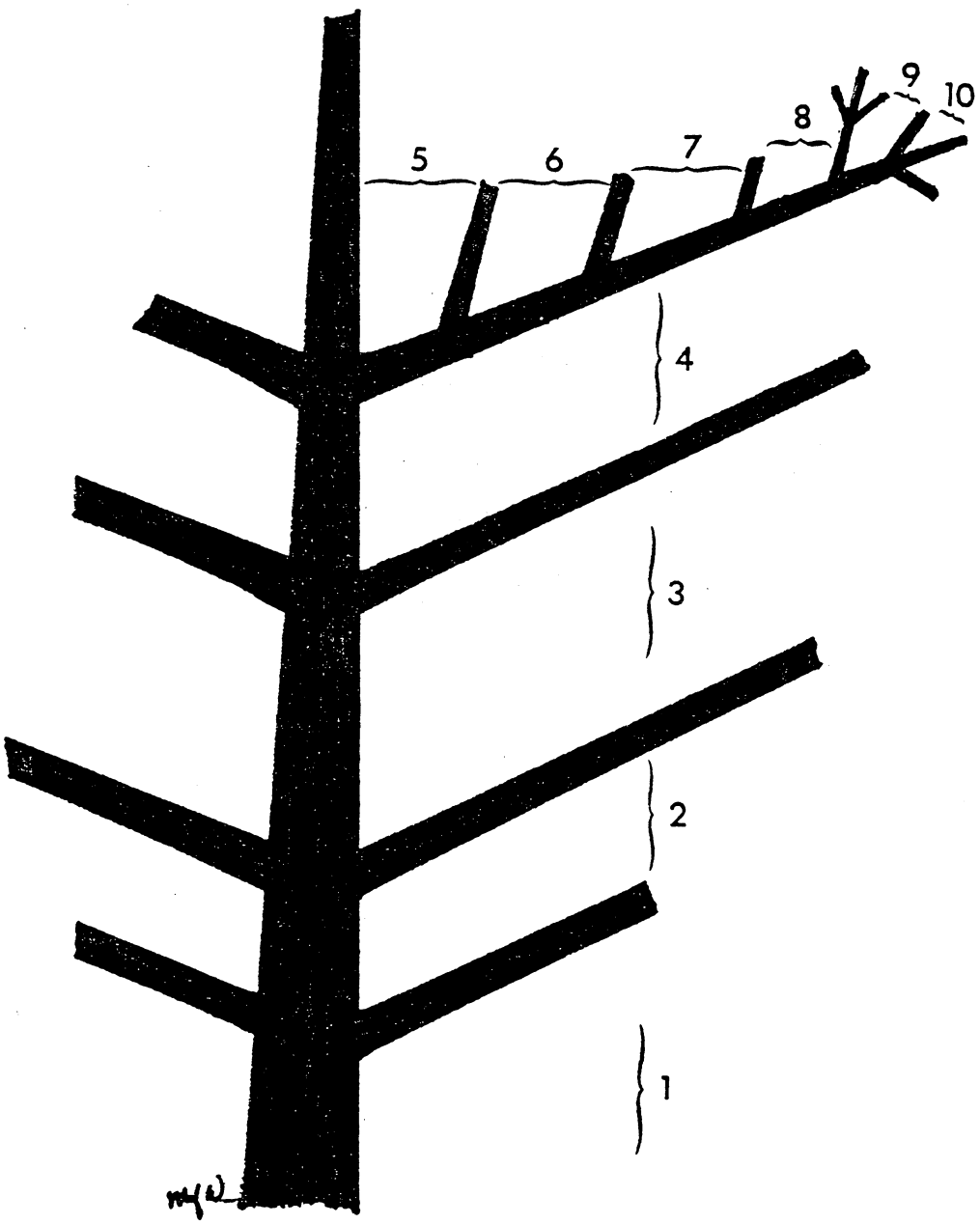


Figure 9: Technique used to count and measure distance between branch whorls of white pine.

of the instrument and stop walking when a split image in the viewfinder was lined-up. The next step was to sight on the tree through another viewer on the instrument and release a pendulum-like needle. The needle moved on a height scale and changed as the instrument was trained up the tree's bole to the top. When the observer sighted the top of the tree, the needle was locked and the height was read directly off the scale within the instrument according to the distance from the tree. This figure was added to the distance from the eye level point on the tree to the base of the tree and the total height was calculated.

DIAMETER--Diameter was measured with a metric DBH Tape on the bole at one meter in height and again at breast height (around 1.37 m or 4.5 ft). In forked trees the diameters were taken on all forks and entered separately in the data. The diameters of both forks were then added and multiplied by 0.75 to obtain a representation of bole diameter.

INTERNODAL MEASUREMENTS--The tree growth rate was determined by measuring the internodal (interwhorl) distances. With the technique illustrated in Figure 9, the distance between branch whorls was measured and recorded for analysis. The measurements were taken as far back the lowest branch as possible. Only intact branches were selected for measurement. Branches that had been damaged or trimmed were not

used for these data. Most trees under 50 years of age could be measured from the current year's growth to the first year's growth. This method was used to determine the average yearly growth rate. The measurements for the last ten years were collected, combined, and each year's measurement was divided by the total to obtain a percentage of total growth per year. Trees with branches too high to reach were sampled with an increment borer and analyzed by the Virginia Tech Forest Pathology Laboratory. The core readings were then added together for the last ten years and each year's reading was divided by the total yielding the % growth rate per year for a 10-year period. It was then able to compare the readings from increment borings with those obtained from interwhorl measurements on a similar scale. These ten yearly percentages were plotted on graph paper to obtain a curve of a tree's growth history. Each history was plotted and compared with others to determine how rate was affected by site quality.

GENERAL APPEARANCE OF TREE PARTS--Certain diagnostic characteristics of the bark, bole, crown and roots were noted to aid in the establishment of tree growth quality. The bark was scored for color (dark or light), integrity (corky or sound), succulence (hard or soft), and texture (furrowed or smooth). The bark information was used to detect signs of desiccation.

The bole was examined for shape (tapered or cylindrical), forking (forked or unforked), location of forks (above or below breast height), and if forked below this height, the diameter of each fork.

The crown was examined for the amount of foliage (normal, thin, or none), appearance of the foliage (tufted or full, wilted or unwilted), the percentage of chlorotic and necrotic foliage (current, old, or all needles) and which needles were chlorotic or necrotic (current or previous year's).

Roots were examined in order to estimate the health and the amount of roots supporting a tree. Root depth was determined by digging sample holes at several points around a tree at the outer edge of the drip line. Three to four sample holes were dug and two were used for measurements unless a marked difference in physical appearance was detected in each. Holes were dug to just under the root layer where root depth and root mat thickness were measured at this point. All soil samples for later laboratory analysis were taken here as well as root examinations for integrity and signs of decay and discoloration.

ROOT ZONE MEASUREMENTS--The root zone was evaluated for a variety of factors which related to the roots themselves as well as the environment in which they were growing. The distance from the tree center to the drip line was measured

and multiplied by 1.50. This value was the radius of the theoretical root zone (TRZ). The TRZ was the area where, theoretically, roots grew. The area (in square meters) of the TRZ was determined by using the formula pi times radius squared. A typical scoring form is illustrated in Figure 10.

The area of the actual root zone (ARZ) was determined by subtracting all competed and impeded areas within the root zones from the area of the TRZ. These areas were defined as those taken-up by other plant roots and man-made structures, respectively.

The volume of the root zone was determined by measuring the root depth and multiplying by the area of ARZ in order to obtain a value in cubic meters. It was hoped that volume could be a true indication of how much soil was available for a particular tree. Unfortuately, variation in depth throughout many root zones caused volume data to be of little use. Instead, approximate root mat thicknesses, average and maximum root depths and the area of the TRZ and ARZ were established.

The final data from these calculations were the percent of the TRZ that was or was not impeded or covered by various factors. These factors were catagorized and reported as follows: a). competition (competition from other trees and

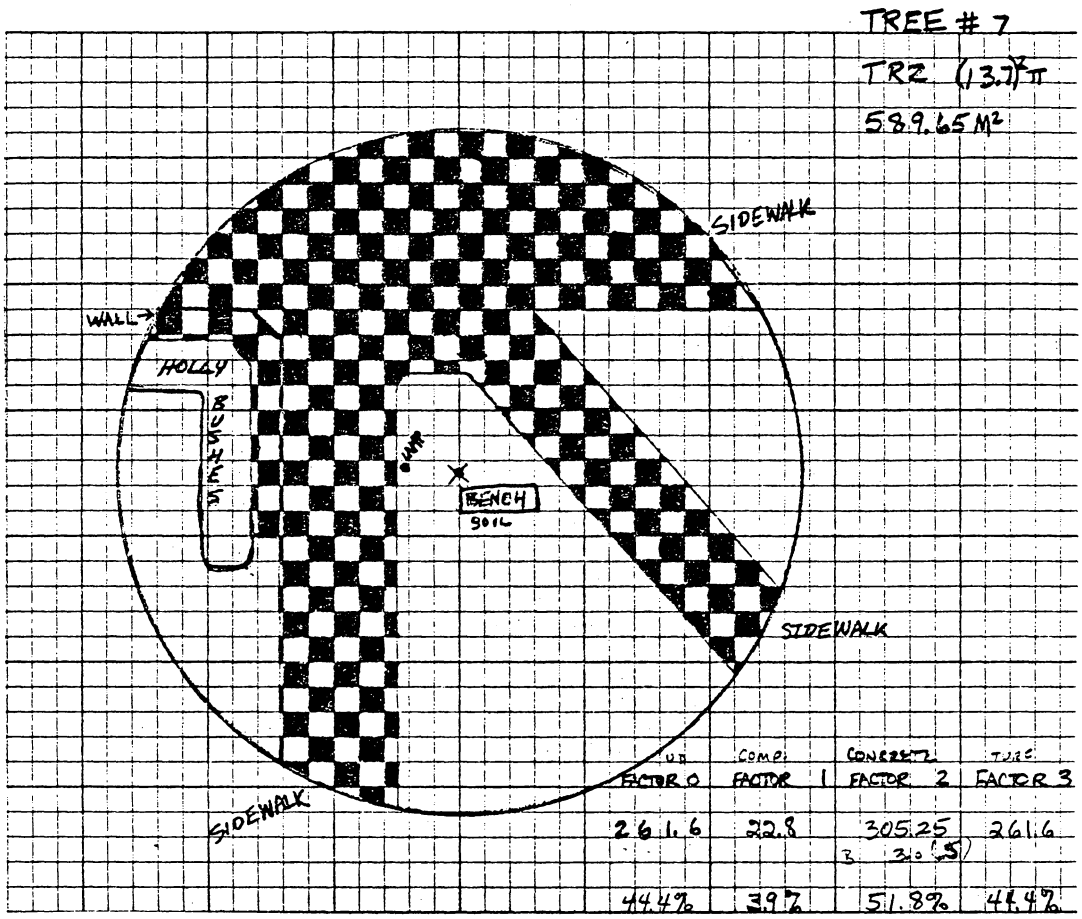


Figure 10: Form used to score the obstructions, competition and other theoretical root zone data of survey trees.

plants), b). turf (cover of the root zone by grasses grown for ornamental or erosion prevention), c). asphalt cover (cover of the root zone by asphalt, concrete, and other impermeable surfaces), d.) subterranean disturbance (disturbance of the root zone by sewers, gas lines, excavation, etc.), and e). unimpeded (areas of the root zone not disturbed or covered by asphalt or competition other than turf). In order to establish the percentages of these factors the area of each specific factor was divided by the area of the TRZ. These data were reported in chapter 4 and Appendix Table 3 as the % of the TRZ impeded, competed, or unimpeded. The ARZ was used in determining these final data.

Soil depth over the roots was measured to determine the possibility of root damage from a mechanical operation and/or from freezing. A lack of root cover was often a clue to the capability of roots to penetrate underlying layers. In such cases a traffic pan or unfavorable soil condition encouraged roots to push up to the surface for nutrition, water and growing space.

Decay and discoloration were noted on primary, secondary and fine feeder roots. If these signs of root rot were observed, samples were taken to the laberatory for diagnosis. Glucose-yeast extract agar was used for general isolations

of possible pathogenic fungi (168, 169). McCall's and Merrill's Medium (129) was used when there were signs and symptoms that Verticicladiella procera might be a causal agent. Whole roots were cut from badly diseased trees and chips were cut with a wood chisel from moderately healthy trees with signs of decay and discoloration. In some instances chips were placed in a moist chamber for 24-48 hours after surface sterilization with 10% Chlorox solution (3). No regimented program was used for isolations, as few signs of decay and discoloration were observed in a preliminary study.

The number of mycorrhizae were subjectively noted as many, some, few, or none. These were evaluated to determine if there was any change in numbers for trees in various stages of health.

3.1.3 Site quality factors

ASPECT--One factor of the aspect was the elevation which was determined by the use of topographical maps of the sample locations. Elevation was documented since it affected the mean annual temperature and apparently the natural distribution of the white pine in its southern range.

Slopes were visually estimated according to the number of feet dropped in 100 feet (30.48 m). The number of feet

dropped was directly read as the percent slope. The length of a slope was estimated according to approximate distance. A long slope measured approximately 75 (22.86 m) or more feet in length, a moderate slope measured between 10 (3.05 m) and 75 feet, and a short slope measured 10 feet or less. In most situations the percent slope could be estimated by looking at a site, however in a few cases slope was measured with the aid of a tape measure and altimeter.

The type of site or aspect was noted to determine the drainage quality and possible site disturbances. The site was categorized as being level, a knob, in a depression, on a slope (other than a toe slope), a toe slope, on a terrace, in a well on level ground, in a well in a depression, in a well on a sloped site, in a well on a knob, on an inverted well or a raised planting platform, and various miscellaneous sites were noted as well.

The percent of direct sunlight was determined by observing the direction a tree was exposed to the sun. If a tree was exposed from all four directions it was scored 100%, three ways (75%), two ways (50%) and one way (25% or less). The source of shading was noted in each case for later analysis.

ENVIRONMENT--A pattern of environmental quality was established by determining a site's relationship to vehicle

traffic flow patterns, point and non-point source chemical pollution, and other environmental factors.

Traffic flow patterns were scored as low, moderate or heavy in a suburban, urban, or rural area, or on a highway right-of-way. The site type was chosen as near or at a private residence, campus, park, cemetery, golf course, commercial area such as offices or businesses, or near a light, moderate, or heavy industrial site. Other factors were noted if exceptions to these. A point source of pollution was listed if different from the traffic or background (non-point) sources.

SOILS--Soils were analyzed both chemically and physically for patterns of poor site quality. The volume of soil was estimated using the methods noted under the estimate of actual root zone. To calculate the volume of each horizon or disturbed soil layer the soil depth was measured in the holes dug for root sampling. This was then multiplied by the actual root zone value to obtain the volume in cubic meters.

In this study soils were sampled where there was a marked difference in soil color or a distinct layer. Soils were disturbed in most cases and were not in natural soil horizons. Each soil sample was designated with a code letter according to the type of horizon or layer from which it was removed. Where these soil data were reported the soil let-

ter codes were combined with tree codes to designate information according to each observation.

After soil samples (which were approximately 500-1000 grams dry weight) were taken, they were returned to the laboratory for analysis. The following procedures were used to analyze the various soil qualities.

Soil color was evaluated by comparison of wet soil samples from each soil layer to a Munsell Soil Color Chart (9). A standard light source (a 100W tungsten microscope lamp) was used for color evaluation. Soil color was evaluated for matrices and mottles where present. Standard Munsell evaluation factors of hue, chroma, and value were used for documenting colors (explained in detail in section 3.2).

Consistence was measured visually and by feel using the standard soil testing procedures (104, 156). Consistence was checked for each soil layer when fresh soil was removed from the field.

Soil structure was measured visually according to standard soil testing techniques (104, 156). This quality was checked on fresh soil removed from each layer at a site.

Moisture content was determined by placing a 100 gram sample in a drying oven at 110 degrees C overnight. The oven dry weight was subtracted from the initial weight to obtain the percent moisture. This figure was important to

evaluate the other soil qualities as well as the site quality itself. However it should be emphasized that moisture content was of no value for comparison with other observations due to its variation with sampling time.

Mottles were observed for their abundance, size, contrast and color. Abundance was measured according to standards in Agricultural Handbook No. 436 (156), as were the other mottle factors. Their size was measured and evaluated as 0-5, 5-15, and more than 15 mm. Their contrast was determined according to the variation in color from the surrounding matrices. Mottle color was scored according to Munsell soil color charts (9).

Texture was evaluated by particle size analysis (104). Soil cylinders of 1150 ml in volume and soil hydrometers suspended in the soil solutions were used to measure the amount of clay, silt and sand falling out of solution. The soil was prepared by crushing and oven drying overnight at 110 degrees C and sifting through a 20 mesh (1:20) screen to eliminate gravel.

At this point the type of foreign matter and the percent coarse fragment were evaluated for each layer of soil. Foreign matter was evaluated to determine if a layer of soil had been disturbed and included in the weigh of the coarse fragments. The percent coarse fragment was measured to

evaluate the stoniness of the soil in each layer. Stoniness was determined by weighing the amount of coarse fragments per 100 g soil. This information was collected to determine if stoniness affected drainage and soil aeration.

After this, 50 g of the remaining soil sample was oven dried and re-weighed to determine the percent of moisture. The sample was then combined with 100 ml of a 5% Calgon solution and placed on a geometric shaker overnight. The samples were then poured in the cylinders and rinsed with distilled water to each cylinder until the volume of each was brought up to 1150 ml with a hydrometer in the solution. The hydrometer was removed and the solution was agitated for one minute. The hydrometer was replaced and read after 40 seconds. The temperature was taken at the beginning and end of the analysis. This figure was used as a correction factor, subtracting 0.2 g/l for every degree below 20 degrees C and adding for every degree above it. To keep down frothing three drops of wetting agent (dilute octanol) was added to each cylinder. After two hours another reading was taken and recorded to obtain the percent of clay left in solution.

A Calgon correction factor was obtained by calibrating each individual hydrometer in a 5% Calgon/distilled water mixture. To obtain this a 100ml aliquot of Calgon was mixed with distilled water and filled to 1150ml with the hydrome-

ter in the solution. Each hydrometer was read and this figure was added to the calibration as a correction factor. Another correction factor was the oven dry weight of each sample which was multipled times the other corrected factors to obtain the end result.

First the percent sand dropping out of solution was calculated by subtracting this corrected number from 100 (40 seconds reading). The percent clay was determined by multiplying the two hour reading by the oven dry weight. The percent of silt was calibrated by adding the percent of sand and clay and subtracting from 100 (sample calculations are available in most soil lab manuals, e.g., reference 104).

Chemical analysis of soil samples conducted by the Virginia Cooperative Extension Service Soil Testing Lab (56) included tests for pH, calcium, magnesium, phosphorus, potassium, manganese, zinc, soluble salts, and percent of organic matter. The % organic nitrogen was estimated by dividing the percent organic matter by 20 according to Brady p.156 (20). The type of parent material was noted from soil maps (28, 66) and by digging for fragments.

Compaction was measured in a few select sites to determine the impact of this factor on trees. A Proctor penetrometer was used to test the resistance to penetration. Soils were tested by measuring the resistance to penetration of a needle-like probe (see Figure 11). The spring-loaded

probe was pushed into the soil and a reading was taken on a scale of 0-120. Surface debris was cleared away to test the underlying layers and each probe was redone if the needle hit an object such as a rock or root or dropped into a void. Fourteen readings were taken per layer and averaged together. Each reading was multiplied by the reciprocal of the probe size to calculate the resistance in pounds per square inch (psi). Each distinct layer of a soil profile was tested for the study group. Sites were selected to represent each soil texture: clay, loam, and sand.

This testing method varied from the standard procedure which required the removal of samples to the laboratory. These procedures required the separation of coarse fragments and determination of soil moisture. The procedure followed here did not involve these tests but required the testing of materials intact in the field. These variations must be noted when evaluating results of this study.

Figure 11: Proctor penetrometer used for testing soil compaction.

3.1.4 Miscellaneous Factors

Also noted on the indexing form were various agents of disease, damage, and competition. Various types of competition and impedance were noted by type and percent in the root zone. If the root zone was impeded, the percent impedance was calculated, as outlined earlier. The health of competing trees was noted along with the DBH and the TRZ. The percentages of competition and impedance were determined by laying out a site map representing the TRZ to scale in square meters. The competition which included turf cover and competition from other trees was broken down in the results as % competition and % turf. The impedance was separated into % asphalt and the % subterranean disturbance. An example of a site map is illustrated in Figure 10.

Damage comments were noted to determine if a tree were damaged mechanically by man or weather.

Symptoms and their sequence were noted to determine how and to what extent they occurred.

Tree owners were asked about possible chemical exposure to each tree; material applied to the site, when, how often, the amount, and on what portion of the site or what part of the plant (172).

Agents of disease were noted either by their presence or by their signs or symptoms. Any concentration of these

agents were rated as high, medium, or low. The suspected cause of any signs or symptoms was noted along with the time of year and the time span for which they were thought to be present. The number of wobbles or crooks were counted from the top down to determine in which years damage to the terminal was incurred. This terminal damage could have been caused mechanically or by insects infesting the terminals, e.g., white pine weevil. The number of years and what years this occurred was noted. The roots were inspected for nematode damage and some assays were taken for soil-borne nematodes and the pinewood nematode. Sugar flotation was used to detect the presence of soil-borne nematodes. A water flush method was used to extract the pinewood nematode where wood from the bole and limbs was chopped up and placed in tap water overnight. All samples for both types of nematodes were examined under a dissecting microscope.

Any significant weather data, such as droughts or floods, were noted for the previous three years. In addition to the above information, any unique factors which might contribute to decline were noted.

STATISTICAL METHODS--Statistics applied to this investigation varied from those usually applied to plant disease studies. Through the advice of the Virginia Tech Statistical Consulting Center the method applied to this investigation was known as "discrim analysis". Discrim analysis was

based on procedures outlined by the Statistical Analysis System (SAS) in Raleigh, NC (143). The procedure was used to establish a model or classification criterion which was determined by a measure of generalized squared distance. The criterion in this study took into account prior probability of each site class (explained below). Once established the criterion or model could be applied to similar data to determine site quality and the probability of decline on a particular site.

The products of the analysis made it possible to determine whether one factor or a combined group of parameters warranted a particular observation belonging to the original designated group. For example, in this investigation the data have been divided into two groups, one called the decline habitat and the other called the natural habitat. This analysis was used to indicate which trees were of good quality vs. poor quality and separate those which might be considered in the wrong group. A sample discrim analysis program of combined site factors can be seen in Appendix B.

In addition to discrim analysis, the SAS procedures were used to run a general linear model (GLM) regression analysis where appropriate on plots of growth data.

It should be noted that the statistical analyses of the results were voluminous and have caused a problem in listing these in Chapter 4 and/or the appendix. Therefore, statis-

tical data have been abbreviated and only an example of a discrim analysis program was listed in Appendix B.

3.2 STUDY OF MONTHLY FOLIAR COLOR CHANGES OF POOR VS. GOOD QUALITY SITE TREES

This study was conducted to determine why and how much trees changed color on stressed vs. relatively unstressed habitat sites. A 15-foot pole pruner was used to sample from the periphery of each tree. Needles were selected from all sides of the trees and then selected from the total sample to obtain an average sample for each observation in the study. Needles were collected monthly for a period of 12 months from a group of six natural habitat trees in the Jefferson National Forest site. These trees were understory trees due to the inability to reach limbs of superior (dominant) trees and were separate trees from those surveyed in the systematic disease indexing study. These trees were numbered with tree codes 105-110. At the same time samples were obtained from seven trees on the Virginia Tech campus (decline habitat-both high and low quality sites). These were trees also used in the systematic disease indexing study and were coded 1, 2, 3, 4, 5, 18, and 19. The needles were scored using a Munsell color rating scale to detect any monthly changes in color (10). Colors were designated according to the Munsell system which used a three part designation to give a color's Hue, Value, and Chroma. A sample

designation, e.g., 7.0GY5/6, would include the following: where 7.0 = a specific Hue sub-division, GY = Green Yellow Hue names, 5/ = the Value or degree of lightness, and /6 = the Chroma or degree of saturation.

3.3 PINEWOOD NEMATODE STUDY

After the initial study had been completed, the pinewood nematode was discovered on some of the samples. This was the first time that this pathogen had been found in Virginia (179). Because of this finding study trees in Rockbridge and Pulaski counties were re-sampled and tested for the presence of the nematode. A water flush technique, as described in subsection 3.1.2, was used to sample for the pathogen. The nematode was identified by Dr. J. A. Fox of Virginia Tech's Nematology Laboratory (Dr. Fox is now at Mississippi State University).

Chapter IV

RESULTS AND DISCUSSION

4.1 ESTABLISHMENT OF SITE QUALITY USING THE SYSTEMATIC INDEXING METHOD

The data, indexed systematically from decline and natural habitat sites, were compiled to establish the site quality for each observation. The site quality for a natural habitat was established from the experimental data and the silviculture literature (64, 184, 186). Site quality for the decline habitats was established from the experimental data. This information is broken down by index parameters into habitat types (decline or natural) in the sections to follow. The habitats are compared in subsection 4.1.7.

4.1.1 Site quality for a natural habitat (tree health and growth indicators)

AGE--The age for the natural habitat trees ranged from 33 to 75 years. Tree ages for natural habitat trees are listed in Table 2.

HEIGHT--The tree height for natural habitat trees ranged from around 16 m (51 ft) to around 34 m (110 ft) (see Table 2). Tree height was uniform for natural habitat trees with little variation by age except that measurements were approximated due to the inability of obtaining an unobstructed view of tree tops in the forest.

TABLE 2

Growth data for natural habitat trees

Tree Code*	Age (yrs)	Height** (m)	DBH*** (mm)
51	33	16	245
52	75	34	693
53	66	34	790
54	50	34	520
55	53	34	505
56	54	34	430
101	49	31	445
102	58	31	385
103	55	31	402
104	57	31	455

* Tree Codes are not in sequence.
** Approximate height measured with Blume-Leiss altimeter.
*** DBH = diameter of bole at breast height.

DIAMETER--The DBH (diameter of the bole at breast height) of natural habitat trees varied by age (see Table 2).

INTERWHORL MEASUREMENTS--Due to tree height measurement of interwhorl distance was not possible on natural habitat trees. Increment borings were taken instead with measurements converted to the percent growth per year for the last ten years of growth. The % growth decreased for the 10-year period when all natural habitat observations were averaged together. These data, listed in Table 3, were then compared on a similar scale to internodal measurements.

GENERAL APPEARANCE OF TREE PARTS--The bark of natural habitat trees generally appeared a light color, with a sound integrity, and soft on younger limbs with a smooth texture. Because there was no shrinking of the bark, trees appeared to have had a sufficient supply of soil moisture.

The unforked boles of natural habitat trees were practically cylindrical in shape. The forest conditions contributed to a lack (natural pruning) of lower limbs.

The crown was generally concentrated in the upper one-third of the boles with "normal" amounts of foliage. The foliage was full with no chlorotic or necrotic areas, except where lower limbs were shaded out over time. Detailed tree appearance data are listed in Appendix Table 1. Also an attempt at tree crown rating is illustrated in Appendix Table 11.

TABLE 3

Annual growth in percent of a total 10-year period for natural habitat trees

Tree	% Growth/Year									
Code*	1979	1978	1977	1976	1975	1974	1973	1972	1971	1970
51	8.6	7.8	8.1	10.7	7.3	9.3	7.7	8.3	13.5	18.8
52	9.1	10.6	11.9	11.0	9.4	10.4	10.5	9.9	8.3	8.8
53	8.5	5.7	10.2	12.1	15.3	11.9	8.3	11.3	8.0	8.8
54	15.4	18.5	10.3	10.6	7.2	13.7	6.9	6.7	6.0	4.7
55	13.5	10.9	10.7	9.8	5.7	9.0	7.1	6.4	12.2	14.9
56	17.9	11.4	12.6	8.5	9.3	7.5	7.8	8.5	8.1	8.6
101	9.4	14.4	12.2	10.5	9.8	9.4	10.3	8.5	7.4	8.2
102	9.7	11.9	15.6	16.4	11.5	8.6	7.3	8.3	4.9	6.0
103	12.8	10.7	8.4	10.1	11.5	10.8	8.6	9.5	14.9	2.8
104	5.2	9.3	11.6	9.1	11.0	14.1	7.8	10.0	10.5	11.5
AVG	11.0	11.1	11.2	10.9	9.8	10.5	8.2	8.7	9.4	9.3

* Tree Codes are not in sequence.

The roots of these trees were unobstructed vertically with the average depth of roots on this site 30 cm (12 in) and the average root mat thickness 45 cm (18 in). The maximum depth for the feeder roots was 50 cm (20 in). Detailed data on root depth and root mat thickness are listed in Appendix Table 2.

These trees were not impeded by any factors, but competition was present from adjacent trees. Competitors included: other white pines, eastern hemlock (*Tsuga canadensis* (L.)Carr.), and flowering dogwood (*Cornus florida* L). Competition was rated at 100% for all natural habitat trees. There were neither weeds nor turfgrass on the natural habitat site to compete for water or nutrients. Detailed competition and impedance data are listed in Appendix Table 3.

Average root cover was 8 cm which included soil, humus, needle mulch and other litter. The roots of these natural habitat trees were healthy, without decay or discoloration. Signs of mycorrhizae, dichotomous branching and stubby feeder root tips, were numerous on this site (see details in Appendix Table 4).

An example of a natural habitat tree is illustrated in Figure 12.

Figure 12: A 75-yr-old natural habitat tree (#52) in the Jefferson National Forest, VA.

4.1.2 Site quality for a natural habitat (site quality factors)

ASPECT--The elevation of the natural habitat site was 1800 feet (548.6 m) above sea level. The site had no slope and thus the aspect was classified as level. The site was located in a narrow valley in a creek bottom with mountains of around 4000 feet (1219.2 m) elevation on each side. The valley was provided with cold air drainage from the surrounding mountains which could have changed the climate there to one similar to a location at a much higher elevation.

Natural habitat trees were shaded by neighboring trees with direct sun only reaching the upper crowns. Diffused sunlight filtered to the forest floor, but was apparently not enough to support the lower limbs of the white pines. This site was evaluated as receiving 50% direct sunlight. Detailed aspect data are listed in Appendix Table 5.

ENVIRONMENT--The environmental quality of this site was very high. The site was located off a forest road which connected to a lightly traveled rural road in the Jefferson National Forest. There was no local source of chemical pollutants to air, soil or water, since the nearest town was over ten miles away. Only distant sources of air pollutants such as Charleston, WV or the northeastern US could have been responsible for injury. The area was used occasionally

for camping with capacity for only one campsite here. Detailed data for the environment are listed in Appendix Table 6.

SOILS--The soils in this forest site had undisturbed natural profiles. Except for competition, tree root zones were unobstructed both vertically and laterally. The soil depths for each horizon are listed in Table 4.

Soil colors for the natural habitat were a fairly uniform 10YR3/3 (dark brown) for the A horizon and 10YR4/4 (dark, yellowish brown) for the B horizon (see Table 4). The soil structures for the A and B horizons in the natural habitat ranged from crumb to subangular blocky. The consistence of the A horizon on this site was loose to very friable and for the B horizon was loose to firm. The average percent moisture of the A horizon was 16.8 and of the B horizon was 14.5.

Since there were no mottles present in these soils, there was a free drainage pattern. Matrix colors and the absence of gleying were evidence of good soil aeration.

The textural class for most A horizons was a sandy loam and for most B horizons a loamy sand. The sand, silt, clay ratios are listed in detail in Appendix Table 7. Foreign matter was not present and coarse fragments were low to moderate in content (see detailed data in Appendix Table 8).

TABLE 4

Soil physical factors for natural habitat trees

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
51A	0-7	10YR3/3	SBAGBLKY	FRIABLE	16.4	25.1	SDCL
51B	8-	10YR4/3	SBAGBLKY	FIRM	15.9	27.1	SDCL
52A	0-7	10YR3/3	SBAGBLKY	FRIABLE	16.4	25.1	SDCL
52B	8-	10YR4/3	SBAGBLKY	FIRM	15.9	27.1	SDCL
53A	0-25	10YR3/2	CRUMB	LOOSE	8.9	12.9	SDYL
53B	26-	10YR5/4	CRUMB	LOOSE	6.1	11.9	LMSD
54A	0-25	10YR3/2	CRUMB	LOOSE	8.9	12.9	SDYL
54B	26-	10YR5/4	CRUMB	LOOSE	6.1	11.9	LMSD
55A	0-25	10YR3/2	CRUMB	LOOSE	8.9	12.9	SDYL
55B	26-	10YR5/4	CRUMB	LOOSE	6.1	11.9	LMSD
56A	0-25	10YR3/2	CRUMB	LOOSE	8.9	12.9	SDYL
56B	26-	10YR5/4	CRUMB	LOOSE	6.1	11.9	LMSD
101A	0-25	10YR3/2	CRUMB	LOOSE	8.9	12.9	SDYL
101B	26-	10YR5/4	CRUMB	LOOSE	6.1	11.9	LMSD
102A	0-7	10YR3/3	SBABLKY	FRIABLE	16.4	25.1	SDCL
102B	8-	10YR4/3	SBABLKY	FIRM	15.9	27.1	SDCL
103A	0-7	10YR3/3	SBABLKY	FRIABLE	16.4	25.1	SDCL
103B	8-	10YR4/3	SBABLKY	FIRM	15.9	27.1	SDCL
104A	0-25	10YR3/2	CRUMB	LOOSE	8.9	12.9	SDYL
104B	26-	10YR4/3	CRUMB	LOOSE	6.1	11.9	LMSD

* Tree Codes are not in sequence; A=A horizon soils, B=B horizon soils.

/1_ Color rated according to Munsell soil color ratings.

/2_ Structure abbreviations = SBAGBLKY (subangular blocky) according to standard soil classification.

/3_ Consistence ratings according to standard soil ratings.

/4_ Textural Class abbreviations include: SDCL=sandy clay loam, SDYL=sandy loam, LMSD=loamy sand (see Appendix Table 7 for % sand & silt).

Also general comments on soils are listed in Appendix Table 9.

Soil chemistry data included several factors which were important (see Table 5). The average soil pH reading here was 5.5, which was ideal for a high quality white pine site. Although nutrient levels were consistently low, plant growth quality did not produce evidence of any excesses or deficiencies. The high amounts of soil organic matter, due to the breakdown of litter to a rich humus, enhanced growth on the site. The site was apparently made up of a colluvium parent material which had originated from the soils developed in the sandstone and shale slopes of the watershed. Shale bedrock was not observed at this site due to the depth of the sandy soils and could not be seen until one sampled the surrounding slopes. A geologic map (28) of this area provided evidence that the parent material was the Braillier formation, a greenish-gray, silicaeous shale and a thin-bedded, greenish sandstone.

The soils for a few select trees on this site were tested for compaction using a Proctor penetrometer (see Figure 11). The resistance to penetration was measured in pounds per square inch (psi). The average reading for the A horizon was 138.35 psi and for the B horizon was 273.25 psi. This was evidence of little or no compaction except from natural weight of overlying soils and litter. Compaction readings

TABLE 5

Soil chemical factors for the natural habitat

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (%)	Organic Matter (%)	N (%) /1
51A	5.0	2	23	156	45	2.2	7.9	0.0	2.0	0.100
51B	4.9	3	20	108	35	1.3	16.1	0.0	1.3	0.065
52A	5.0	2	23	156	45	2.2	7.9	0.0	2.0	0.100
52B	4.9	3	20	108	35	1.3	16.1	0.0	1.3	0.065
53A	6.0	3	14	432	25	1.3	15.9	0.0	1.9	0.095
53B	5.9	3	9	144	13	0.5	8.3	0.0	0.8	0.040
54A	6.0	3	14	432	25	1.3	15.9	0.0	1.9	0.095
54B	5.9	3	9	144	13	0.5	8.3	0.0	0.8	0.040
55A	5.5	3	19	294	35	1.8	11.9	0.0	2.0	0.100
55B	5.4	3	15	126	24	0.9	12.2	0.0	1.1	0.055
56A	5.5	3	19	294	35	1.8	11.9	0.0	2.0	0.100
56B	5.4	3	15	126	24	0.9	12.2	0.0	1.0	0.050
101A	5.5	3	19	294	35	1.8	11.9	0.0	2.0	0.100
101B	5.4	3	15	126	24	0.9	12.2	0.0	1.0	0.050
102A	6.0	3	14	432	25	1.3	15.9	0.0	1.9	0.095
102B	5.9	3	9	144	13	0.5	8.3	0.0	0.8	0.040
103A	6.0	3	14	432	25	1.3	15.9	0.0	1.9	0.095
103B	5.9	3	9	144	13	0.5	8.3	0.0	0.8	0.040
104A	5.0	3	23	156	45	2.2	7.9	0.0	2.0	0.100
104B	4.9	3	20	108	35	1.3	16.1	0.0	1.3	0.065

* Tree Codes are not in sequence; A=A horizon soils, B=B horizon soils.

/1 % N (organic nitrogen) = % Organic Matter/20 see p.156 of Brady (20).

(PSI) for sites selected to represent a clayey, loamy and sandy soil texture are listed in Appendix Table 7.

4.1.3 Site quality for a natural habitat (miscellaneous factors)

There were no detrimental factors noted at this site. No harmful insects were observed or at least were not in numbers high enough to be noticed or cause significant damage. Root aphids, *Prociphilus* sp., were found in low numbers on a few trees. The only sign of mechanical damage to these trees was by man. A few trees were damaged by an overzealous woodchopper. This axe damage occurred within the last year and only to a few isolated trees, thus it did not affect their present overall appearance or growth rate. The rest of the stand was intact and had no signs of damage or disease. Comments on damage of individual trees are listed in Appendix Table 10.

4.1.4 Site quality for a decline habitat (tree health and growth indicators)

AGE--The tree age for the decline habitat trees ranged from 7 to 75 years. These ages are listed in Table 6.

HEIGHT--Tree height for the decline site trees ranged from 1.8 m (6 ft) to 26.8 m (88 ft). The heights, listed in Table 6, varied according to age and site quality.

TABLE 6

Growth data for decline habitat trees

Tree* Code	Age (yrs)	Height (m)	DBH** (mm)	Tree* Code	Age (yrs)	Height (m)	DBH** (mm)
1	46	20.7	513	42	23	9.5	275
2	70	22.0	850	43	22	8.8	204
3	75	21.3	745	44	23	9.8	312
4	56	22.3	900	45	23	6.4	283
5	60	21.0	1350	46	22	9.1	320
6	66	22.0	730	47	19	9.8	245
7	60	21.6	910	48	22	8.8	155
8	19	7.6	215	49	22	7.6	155
9	20	8.2	205	50	20	7.9	140
10	20	10.1	305	57	20	7.6	154
11	58	25.6	780	58	22	9.8	285
12	24	8.8	245	59	23	7.9	282
13	22	9.8	231	60	26	11.9	470
14	21	9.8	267	61	20	6.1	146
15	22	12.2	371	62	19	6.1	132
16	45	26.8	735	63	20	6.1	84
17	37	20.7	750	64	21	4.6	129
18	41	18.9	725	65	15	4.6	169
19	42	20.7	650	66	17	4.6	119
20	42	17.1	480	67	11	4.6	72
21	48	18.9	460	68	19	4.6	110
22	35	16.2	380	69	19	4.6	105
23	41	22.6	480	70	20	8.2	162
24	42	20.7	510	71	19	8.2	187
25	38	21.0	520	72	23	4.3	81
26	41	24.4	530	73	20	4.3	73
27	48	22.0	520	74	9	2.7	31
28	43	20.1	460	75	10	2.1	20
29	35	18.9	610	76	7	1.8	10
30	38	21.0	540	77	10	3.1	44
31	43	17.7	520	78	17	10.7	312
32	31	23.2	590	79	19	10.7	285
33	57	22.3	775	80	20	10.7	305
34	47	25.0	700	81	38	16.5	382
35	44	20.4	490	82	31	17.1	424
36	47	20.4	590	83	32	15.3	326
37	23	7.6	235	84	23	11.9	298
38	20	9.5	243	85	27	11.9	310
39	24	5.2	95	86	23	11.0	267
40	24	6.1	118	87	26	9.2	277
41	26	9.8	285	88	29	11.6	367

TABLE 6

(continued)

Tree* Code	Age (yrs)	Height (m)	DBH** (mm)
89	35	12.5	355
90	38	14.0	460
91	31	13.7	343
92	19	8.8	164
93	17	7.3	145
94	17	7.9	145
95	16	4.3	145
96	25	5.2	180
97	24	7.3	110
98	22	6.7	125
99	45	13.7	255
100	26	7.9	175

* Tree Codes are not in sequence.
** DBH = Diameter of bole at breast height.

DIAMETER--Diameter of the bole at breast height (DBH) varied from 10 mm (6.39 in) to 1350 mm (53.2 in) with age and site quality. These are listed in Table 6.

INTERNODE MEASUREMENTS--The distance between the nodes was measured on most trees except those where the lower branches could not be reached. These trees were measured by increment borings which were converted to percent growth/year over the last ten years. Percent growth for each year decreased over the 10-year period when all decline habitat observations were averaged together. These data are listed in Table 7.

GENERAL APPEARANCE OF TREE PARTS--The bark of decline habitat trees ranged in appearance according to the stage of decline. The more unhealthy the tree the darker, corkier, harder and more furrowed the bark. These factors were evidence of how badly trees had desiccated during the decline process.

The boles of decline habitat trees were generally tapered and many of these trees were forked. Tapering apparently related to the speed at which a tree was growing and the basal density of the area (stand) in which it grew. Due to the open nature of many landscape sites trees were not only tapered, but were forked and many lower limbs often remained attached longer. These lower limbs remained intact until removed by weather or man.

TABLE 7

Annual growth in percent of a total 10-year period for decline habitat trees

Tree	% Growth/Year									
Code*	1979	1978	1977	1976	1975	1974	1973	1972	1971	1970
1	1.3	9.8	6.4	5.8	7.7	9.5	10.3	18.0	16.1	15.1
2	6.4	9.0	15.1	9.1	9.5	10.5	11.9	10.2	10.2	8.2
3	10.6	5.6	5.8	11.8	8.1	8.8	11.6	12.4	12.0	13.3
4	13.1	10.3	9.8	12.1	11.8	9.7	8.1	7.5	9.0	8.7
5	6.8	8.8	8.3	6.5	12.1	15.9	12.9	9.1	10.0	9.6
6	8.0	9.7	6.5	9.7	7.1	12.7	9.9	10.3	10.6	15.6
7	9.5	11.5	8.4	13.8	11.6	6.9	9.4	6.3	9.1	13.5
8	3.6	8.2	3.9	6.4	5.5	11.8	8.6	17.8	17.1	17.1
9	12.8	13.3	11.1	14.6	14.2	10.6	8.9	11.5	9.7	7.5
10	10.7	4.4	3.6	5.8	9.3	11.6	12.4	15.1	16.4	10.7
11	5.9	12.0	12.1	10.5	11.3	12.3	12.5	9.7	6.5	7.4
12	6.0	9.2	9.2	8.1	10.5	8.5	11.0	10.0	13.3	14.3
13	10.7	8.9	10.7	6.9	7.6	11.0	13.8	9.0	8.2	13.2
14	5.9	9.9	4.0	3.5	12.0	11.3	17.8	9.9	12.2	13.4
15	7.3	7.3	7.5	10.6	9.4	9.2	8.3	9.4	12.3	18.7
16	7.3	6.6	5.4	22.0	12.5	7.3	9.5	7.0	12.5	10.0
17	12.7	9.0	13.4	17.9	11.0	6.2	6.5	10.0	6.0	7.5
18	10.4	10.7	11.3	10.7	6.7	12.2	9.8	10.4	9.2	8.6
19	11.0	6.8	7.1	10.5	10.2	10.4	7.5	6.6	18.1	12.0
20	14.1	15.1	13.7	6.9	8.9	8.9	8.6	10.6	6.9	6.4
21	14.6	8.7	9.6	7.8	7.8	7.3	8.2	10.5	13.7	11.9
22	12.3	8.6	5.5	8.2	5.1	10.4	9.4	14.1	11.5	14.8
23	9.5	4.7	8.4	12.5	8.8	8.3	8.2	14.2	9.9	15.5
24	6.7	7.0	10.8	4.3	9.2	11.8	8.6	14.0	16.9	10.8
25	8.6	7.8	9.3	12.2	10.6	10.3	12.8	10.0	7.6	10.7
26	11.2	9.5	6.6	10.1	9.6	8.7	9.4	9.9	9.9	15.2
27	10.8	7.5	8.8	5.2	9.5	13.3	13.0	12.2	9.5	10.1
28	5.9	10.6	15.3	10.3	11.1	8.5	7.5	13.3	13.1	4.4
29	8.5	8.4	5.4	12.4	7.0	15.5	12.1	9.3	11.6	9.8
30	5.3	6.1	7.8	10.8	7.4	9.1	10.8	9.4	15.7	17.7
31	9.5	10.8	12.5	12.8	4.7	7.8	6.4	10.5	13.0	12.2
32	9.4	16.5	10.6	10.7	7.8	6.3	4.9	6.2	10.7	17.0
33	13.2	8.9	8.9	7.7	7.9	7.4	9.9	13.8	9.2	13.3
34	2.2	3.4	6.6	10.1	9.8	15.0	7.4	12.5	15.2	17.7
35	13.9	8.5	8.0	9.3	11.8	9.3	15.8	10.8	7.0	5.7
36	15.7	6.1	4.8	10.1	11.2	13.7	13.2	8.8	8.1	8.4
37	13.2	10.1	6.8	6.5	8.9	8.6	7.9	11.2	13.6	13.2
38	9.9	7.3	4.1	3.7	7.8	11.8	14.0	13.2	16.9	11.5
39	8.0	4.8	4.6	4.0	13.4	8.9	12.7	19.9	18.1	5.8
40	13.4	5.6	4.6	3.4	7.0	5.1	12.4	18.3	19.0	11.3
41	9.7	9.8	8.8	5.7	11.8	13.4	11.3	8.7	12.3	8.5

TABLE 7

(continued)

Tree Code*	% Growth/Year 1979	1978	1977	1976	1975	1974	1973	1972	1971	1970
42	10.4	9.5	8.4	6.7	9.9	10.4	11.0	12.5	11.0	10.4
43	8.2	8.8	5.4	3.7	9.4	12.7	14.9	13.6	11.8	11.6
44	7.5	8.2	10.8	2.4	8.2	12.5	12.7	11.6	14.0	12.2
45	6.6	8.2	5.9	5.6	7.4	10.7	12.4	12.2	15.9	15.3
46	9.5	9.9	7.7	6.5	8.2	12.3	12.0	11.1	12.8	10.0
47	8.2	5.6	7.6	6.2	10.9	13.3	12.1	10.7	16.4	9.1
48	9.7	11.3	5.7	9.6	4.2	10.1	5.3	13.0	14.1	17.1
49	16.3	12.3	7.0	4.9	13.6	7.6	8.7	12.2	10.8	6.7
50	7.7	8.7	5.1	4.1	13.9	9.7	12.7	14.0	14.5	9.6
57	10.4	8.1	9.0	6.0	9.8	12.2	11.5	11.9	15.1	6.0
58	7.9	8.1	8.7	7.3	10.7	11.2	11.8	10.4	12.6	11.4
59	11.3	8.1	9.1	4.9	9.7	10.3	8.9	9.3	12.8	15.6
60	10.8	9.0	4.5	9.5	10.8	13.3	11.7	14.0	9.9	6.3
61	8.7	7.4	11.0	10.6	7.9	8.5	10.8	11.0	7.1	17.0
62	1.5	2.2	10.2	4.4	12.4	21.8	21.8	5.5	8.0	12.4
63	8.1	9.8	10.1	14.2	4.7	3.7	8.5	17.2	5.1	18.6
64	8.8	10.6	5.5	1.8	4.6	4.6	4.6	12.8	19.2	27.5
65	8.8	9.6	5.4	3.5	6.9	10.0	11.5	8.8	18.0	17.6
66	10.2	6.3	5.1	13.3	9.7	6.1	12.3	12.2	14.5	10.2
67	3.2	6.6	6.6	17.0	20.4	15.7	11.5	10.6	4.3	4.3
68	3.3	3.1	5.4	11.3	12.3	16.4	16.6	12.8	10.7	8.2
69	3.1	5.9	5.7	11.3	9.7	13.0	19.1	10.6	11.3	10.4
70	7.0	6.2	7.5	9.5	13.4	9.9	14.1	11.2	9.9	11.2
71	3.6	9.9	7.5	10.7	11.7	12.1	12.7	10.4	10.2	11.4
72	3.6	6.3	6.9	5.5	9.9	14.0	12.0	15.4	12.0	14.5
73	4.3	4.4	4.7	6.3	8.3	13.7	12.1	17.7	13.4	15.1
74	12.4	10.0	10.7	22.3	8.3	19.5	7.8	6.7	2.4	-
75	15.7	11.5	7.5	13.3	25.9	10.7	2.7	2.4	8.8	1.6
76	9.3	8.9	21.9	26.2	12.7	10.1	11.0	-	-	-
77	17.0	12.2	7.8	2.9	5.4	17.8	15.1	11.9	7.1	2.9
78	7.5	8.4	13.0	13.6	11.4	12.3	9.8	7.6	7.1	9.5
79	11.6	6.8	7.7	10.4	10.8	10.2	10.9	9.0	9.2	13.3
80	8.8	6.0	6.8	10.5	10.8	8.8	11.4	10.8	10.5	15.9
81	11.1	5.8	8.1	7.8	9.3	10.4	12.0	10.6	15.1	9.7
82	3.7	8.0	13.8	11.0	11.8	10.2	12.2	10.2	8.3	11.1
83	16.0	12.1	9.5	7.4	9.9	7.5	9.5	9.9	8.6	9.5
84	3.9	4.7	6.3	9.4	11.1	12.7	11.7	14.7	13.9	11.6
85	3.0	3.5	5.9	6.9	11.3	12.1	14.3	16.5	14.3	12.1
86	3.0	6.6	6.6	6.6	6.1	12.2	16.2	21.3	10.6	10.6
87	9.1	6.3	4.7	4.7	6.9	7.8	10.9	15.0	15.9	18.8
88	5.7	4.9	5.6	12.1	12.1	13.9	13.9	9.3	11.4	11.1
89	10.2	9.9	10.2	12.7	12.4	11.8	11.5	7.6	7.6	6.1

TABLE 7

(continued)

Tree Code*	% Growth/Year									
	1979	1978	1977	1976	1975	1974	1973	1972	1971	1970
90	10.0	6.6	7.9	8.2	9.8	10.5	11.8	13.1	10.5	11.6
91	9.5	9.1	5.5	5.2	8.5	9.1	7.8	10.1	16.9	18.2
92	6.9	5.3	9.5	9.5	8.8	13.4	14.5	12.6	10.3	9.2
93	3.3	13.7	8.8	9.8	15.8	12.7	13.7	9.4	6.5	6.5
94	6.8	10.8	8.2	12.3	7.1	10.0	13.9	10.4	11.9	8.7
95	5.4	10.0	7.2	8.7	15.5	11.3	14.0	8.1	10.0	9.9
96	2.7	4.7	6.7	2.7	9.3	37.3	6.0	7.3	13.3	10.0
97	2.7	1.9	1.8	2.0	12.7	13.9	14.8	7.8	20.7	21.7
98	7.2	5.7	3.8	4.3	12.3	15.7	15.1	15.9	12.7	7.3
99	1.6	2.4	4.1	9.0	10.6	13.8	11.4	13.0	13.0	21.1
100	5.8	3.3	6.4	5.6	10.4	14.2	12.7	11.7	17.3	12.7
AVG	8.5	8.1	7.9	8.9	10.0	11.3	11.2	11.5	11.8	11.8

* Tree Codes are not in sequence.
(.) = missing value or not available due to tree age.

The crowns of decline habitat trees were generally distributed throughout the upper 75% of the bole height. Depending upon the stage of decline, poorer quality trees had tufted, chlorotic foliage that gave the crowns a thin appearance. Detailed appearance data are listed in Appendix Table 1 and an attempt to rate crown quality is illustrated in Appendix Table 11. Examples of decline habitat trees in various stages of health are illustrated in Figure 13, 14, 15, and 16.

The root systems of the decline trees were generally obstructed from "normal" outgrowth, both laterally and vertically. The average depth of roots on these sites was 15 cm with a maximum depth of 25 cm. The average root mat thickness for decline habitat trees was 17.1 cm (see Appendix Table 2 for details on root depth and root mat thickness).

The root zones of these trees were generally impeded by a variety of obstructions. Competition from nearby trees was often present, but turfgrass seemed to be a more active competitor. Adjacent trees did not seem to be viable competitors by themselves, except in cases of extreme crowding. This type of crowding was often observed where trees were planted in screens or clusters. Tree competitors ranged in types from various hardwoods to other conifers (see Table 8).

Figure 13: Tree (#12) in the early stages of decline located on a poor quality site on the Virginia Tech campus.

Figure 14: Tree (#89) in the middle stages of decline along a Blacksburg, VA street.

Figure 15: Tree (#8) in the latter stages of decline on the Virginia Tech campus.

Figure 16: Close-up of decline habitat tree (#8) with inner limbs heavily infested by pine bark aphids and loss of foliage.

TABLE 8

List of competitors (associates) found at various decline habitat sites

Scientific Name*	Common Name	% Sites
Acer negundo L	boxelder	1
Acer platanoides L.	norway maple	7
Acer saccharum Marsh.	sugar maple	7
Ailanthus altissima/1	tree-of-heaven	2
Betula nigra L.	river birch	1
Broussonetia papyrifera/2	paper mulberry	1
Buxus sempervirens L.	boxwood	3
Cornus florida L.	flowering dogwood	6
Crataegus sp.	hawthorn	1
Forsythia sp.	goldenbells	5
Hibiscus syriacus L.	rose-of-Sharon	2
Juglans nigra L.	black walnut	8
Juniperus communis L.	common juniper	5
Juniperus virginiana L.	eastern redcedar	2
Liriodendron tulipifera L.	yellow poplar	1
Morus alba L.	white mulberry	1
Picea abies (L.) Karst.	norway spruce	3
Pinus strobus L.	eastern white pine	73
Pinus sylvestris L.	scotch pine	4
Prunus avium L.	sweet cherry	3
Quercus alba L.	white oak	1
Quercus phellos	willow oak	2
Robinia pseudoacacia L.	black locust	1
Rosa multiflora/3	multiflora rose	5
Syringa vulgaris L.	common lilac	9
Taxus cuspidata Sieb.& Zucc.	japanese yew	1
Thuja occidentalis L.	arbor-vitae	2
Tilia americana L.	american basswood	1
Tsuga canadensis (L.) Carr.	eastern hemlock	8
Ulmus americana L.	american elm	2
Miscellaneous species	turfgrass & weeds	70

* source = Terrell, E. E., 1977. A checklist of names for 3,000 vascular plants of economic importance. AHB No. 505. USDA-ARS. 201pp. (165).

/1_ authorities=(Mill.) Swingle

/2_ authorities=(L.) Vent.

/3_ authorities=Thunb. ex Murr.

Root covers varied from turfgrass, in most cases, to asphalt and concrete (see Figure 17) in others. The amount of impedance by concrete, asphalt and buildings seemed to be an important contributing factor to decline (see Appendix Table 3 for detailed competition and impedance data). In some cases roots were exposed to the surface. These roots were often subject to mechanical damage by lawnmowers and other man-made apparatuses.

A small group of trees expressed signs of decay and discoloration. This group amounted to less than 10% of the total decline habitat observations. Attempts to isolate pathogenic fungi from root tissues of this group yielded only saprophytes. However, a species of *Fusarium* which was consistently isolated from a number of these sites could have had pathogenic qualities. Pathogenicity tests were not run on this isolate. The trees in this group expressed the acute decline syndrome.

The mycorrhizae found on decline trees did not seem to change significantly from tree to tree. *Tricholoma saponaceum* (Fr.) Kumner and *Suillus americanus* (Pk.) Snell were observed fruiting around the dripline of decline habitat trees in the fall of 1979 (see Figure 18). These fungi were used as indicators of mycorrhizae on the feeder roots in a small study to determine their abundance on and the location of tree root tips. Younger trees and trees with root zones

Figure 17: Root disturbance and cover by concrete sidewalk around decline habitat tree (#6) on the Virginia Tech campus.

which were less compacted and higher in moisture had more of these mycorrhizal fungi. These fungi were not observed fruiting around older trees, ages 40 or more, at that time. **Tricholoma saponaceum** was particularly easy to detect as most younger (10-40 yrs) tree root zones were saturated with the telltale soapy smell of this fungus (see mycorrhizae data in Appendix Table 4).

Figure 18: Suspected mycorrhizal fruiting structures around the dripline and feeder root tips of decline habitat tree (#68).

4.1.5 Site quality for a decline habitat (site quality factors)

ASPECT--Sites varied in elevation from almost sea level to over 2000 feet (609.6 m) above sea level and from level to sloped in aspect. Slopes varied in the degree of steepness and in length with little consistency from site to site. Many of the decline trees were in crowded plantings (high basal density), while others were in the open. The amount of tree shading varied from site to site. Aspect data are listed in Appendix Table 5.

ENVIRONMENT--The environmental quality of the decline sites varied from site to site. No one consistently occurring factor was observed for decline sites. Air pollution damage was observed on a small number of trees but was not considered to be any more significant than any other stress factor in causing decline. No one recurring factor was found on any group of sites to indicate chemical damage either by air or through the soil water. Detailed environmental data are listed in Appendix Table 6.

SOILS--If any one group of factors played a role in the demise of decline habitat trees, it was the group of soil factors. The soil chemistry and physics of the decline sites were consistently poor in quality. Tree root zones were most often obstructed both vertically and laterally. Most sites were disturbed by construction activities before

and/or after planting. The % coarse fragments, mottle data and comments on foreign matter in the soils are listed in Appendix Table 8. Also see Appendix Table 9 for general soil comments. Soil layer depth is listed in Table 9.

Soil colors were fairly uniform among the sites. A few sites had soils with mottling and colors varying from site to site. An average soil color could not be obtained for decline habitat sites. These colors are listed by soil layer in Table 9.

The structure of the soil layers varied according to the site quality. The poorer the site the poorer the structure. Soil consistence also followed these patterns, with consistence becoming poorer as site quality decreased. Moisture content of these soils varied from site to site dependent upon time of sampling. Structure, consistence and moisture content are listed by layer in Table 9.

Soil texture was an important factor in the decline syndrome. As site quality became poorer the soil texture became heavier. Soils were very high in clay, up to 80%, in the poorer quality sites. Many of these high clay soils were transported into these sites from deeper subsoil layers by excavation equipment during construction activities (see Figure 19). Trees were then planted directly into these soils or in a thin topsoil layer above these excavated

TABLE 9

Soil physical factors for decline habitat trees

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
1DL	0-25	10YR3/3	GRANULAR	FRIABLE	12.7	39.1	CL
2AU	0-15	10YR4/4	GRANULAR	FRIABLE	12.5	28.1	CL
2BU	16-	10YR5/6	ANGBLKY	FIRM	12.2	32.1	CL
2AL	0-5	10YR4/3	SBAGBLKY	V.FIRM	15.8	42.3	C
2BL	6-	10YR5/4	ANGBLKY	V.FIRM	15.4	43.3	C
3AU	0-15	10YR4/6	SBANBLKY	FIRM	15.2	29.5	CL
3BU	16-	7.5YR4/6	SBANBLKY	FIRM	14.7	31.9	CL
3AL	0-15	10YR5/8	ANGBLKY	FIRM	14.4	33.9	CL
3BL	16-	10YR4/4	ANGBLKY	FIRM	13.8	40.0	CL
4AX	0-10	7.5YR5/8	ANGBLKY	V.FIRM	21.8	64.4	C
4DL	11-	10YR4/3	ANGBLKY	FIRM	15.9	40.4	SLTC
5A	0-10	10YR4/4	GRANULAR	FIRM	16.9	32.1	CL
5B	11-	10YR6/6	SBANBLKY	FIRM	16.5	29.0	CL
6DL	0-	10YR4/3	ANGBLKY	V.FIRM	17.7	33.9	CL
7ADL	0-20	10YR4/3	CRUMB	FRIABLE	19.4	35.4	CL
7BDL	21-26	10YR4/4	ANGBLKY	V.FIRM	19.1	42.0	C
7DL1	0-	7.5YR4/2	ANGBLKY	V.FIRM	14.6	32.3	CL
8ADL	0-15	10YR3/3	CRUMB	FRIABLE	22.3	30.8	CL
8BDL	16-	10YR6/6	ANGBLKY	V.FIRM	21.1	53.2	C
9ADL	0-20	10YR3/3	CRUMB	FRIABLE	21.0	31.6	CL
9BDL	21-35	10YR4/4	ANGBLKY	V.FIRM	21.3	49.9	C
10ADL	0-15	10YR3/3	GRANULAR	FRIABLE	17.1	41.0	C
10BDL	16-32	10YR6/8	ANGBLKY	V.FIRM	25.8	75.8	C
11ADL	0-14	10YR4/4	ANGBLKY	V.FIRM	20.6	44.8	C
11BDL	15-	10YR5/6	ANGBLKY	V.FIRM	30.9	67.6	C
12ADL	0-12	10YR4/3	SBANBLKY	V.FIRM	14.2	36.4	CL
12BDL	13-	10YR5/6	ANGBLKY	V.FIRM	14.2	45.3	C
13ADL	0-15	10YR3/3	CRUMB	FIRM	17.8	35.0	CL
13BDL	16-	10YR5/8	ANGBLKY	V.FIRM	18.6	55.5	C
14ADL	0-10	10YR3/1	ANGBLKY	V.FIRM	15.7	30.5	CL
14BDL	11-	10YR5/8	ANGBLKY	FIRM	19.5	57.9	C
15ADL	0-10	10YR3/1	ANGBLKY	V.FIRM	15.7	30.5	CL
15BDL	11-	10YR5/8	ANGBLKY	FIRM	19.5	57.5	C
16ADL	0-15	10YR3/3	GRANULAR	FIRM	10.0	25.5	SCL
16BDL	16-32	10YR4/3	GRANULAR	FIRM	10.6	27.8	L
17ADL	0-10	10YR3/2	ANGBLKY	V.FIRM	15.3	39.9	CL
17BDL	11-	10YR4/3	GRANULAR	FIRM	12.2	33.0	CL
18A	0-15	10YR4/3	GRANULAR	FRIABLE	11.7	30.8	CL
18B	16-	10YR5/6	SBAGBLKY	FIRM	10.9	26.7	CL
19ADL	0-15	10YR4/3	GRANULAR	FRIABLE	8.2	20.3	SCL
19BDL	16-	10YR3/3	GRANULAR	FRIABLE	10.3	28.9	CL

TABLE 9

(continued)

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
20ADL	0-12	10YR3/2	ANGBLKY	FIRM	26.6	39.5	CL
20BDL	13-	10YR4/3	GRANULAR	FIRM	17.3	32.1	CL
21ADL	0-15	10YR4/3	CRUMB	FRIABLE	26.6	39.1	SCL
21BDL	16-	10YR3/3	SBANBLKY	FIRM	17.3	34.8	CL
22A	0-15	10YR3/2	GRANULAR	FIRM	22.6	30.0	CL
22B	16-	10YR3/3	GRANULAR	FIRM	17.1	30.0	CL
23ADL	0-5	10YR4/4	GRANULAR	V.FIRM	16.2	36.1	CL
23BDL	6-	10YR4/2	ANGBLKY	V.FIRM	17.7	42.0	C
24A	0-15	10YR4/3	GRANULAR	FIRM	16.7	25.8	L
24B	16-23	10YR3/3	ANGBLKY	V.FIRM	19.7	38.3	CL
25ADL	0-7	10YR3/3	GRANULAR	FRIABLE	17.2	34.3	CL
25BDL	8-	10YR3/2	SBANBLKY	V.FIRM	15.8	25.0	L
26ADL	0-7	10YR3/3	GRANULAR	FRIABLE	17.2	34.3	CL
26BDL	8-	10YR3/2	SBANBLKY	V.FIRM	15.8	25.0	L
27ADL	0-7	10YR3/3	GRANULAR	FRIABLE	17.2	34.3	CL
27BDL	8-	10YR3/2	SBANBLKY	V.FIRM	15.8	25.0	L
27UDL	0-	10YR5/4	ANGBLKY	V.FIRM	21.7	53.9	C
27LDL	0-	10YR5/4	ANGBLKY	V.FIRM	21.7	53.9	C
28UDL	0-	10YR5/4	ANGBLKY	V.FIRM	21.7	53.9	C
28LDL	0-	10YR5/4	ANGBLKY	V.FIRM	21.7	53.9	C
29ADL	0-	10YR5/4	ANGBLKY	V.FIRM	21.7	53.9	C
29BDL	5-	10YR4/4	GRANULAR	FRIABLE	9.4	28.1	CL
30DL1	0-	10YR5/4	ANGBLKY	V.FIRM	21.7	53.9	C
30DL2	0-	10YR5/6	ANGBLKY	V.FIRM	18.3	48.3	C
31ADL	0-10	10YR3/2	ANGBLKY	V.FIRM	15.9	40.2	STCL
31BDL	11-	10YR4/2	GRANULAR	FRIABLE	18.2	27.0	L
32ADL	0-16	10YR3/2	GRANULAR	FRIABLE	19.2	29.2	CL
32BDL	17-34	10YR5/4	ANGBLKY	V.FIRM	16.8	42.3	STCL
32DL1	0-	10YR3/3	ANGBLKY	V.FIRM	16.4	14.0	STL
33DLU	0-	10YR3/3	GRANULAR	FRIABLE	18.9	27.1	L
33DLL	0-	10YR4/4	GRANULAR	FRIABLE	14.3	32.2	CL
34A	0-20	10YR3/2	GRANULAR	FIRM	17.6	29.2	CL
34B	21-	10YR3/3	SBANBLKY	FIRM	19.6	36.0	CL
35A	0-35	10YR3/3	GRANULAR	FRIABLE	17.7	30.2	CL
35B	36-	10YR5/6	ANGBLKY	FIRM	15.8	34.1	CL
36ADL	0-38	10YR3/3	GRANULAR	FRIABLE	15.0	30.2	CL
36BDL	39-	10YR5/6	ANGBLKY	FIRM	16.3	38.8	STCL
37AU	0-16	10YR4/3	GRANULAR	FRIABLE	16.6	36.1	STCL
37BU	17-	10YR5/6	ANGBLKY	FIRM	18.1	57.9	C
37AL	0-10	10YR4/4	GRANULAR	FRIABLE	17.8	44.9	C
37BL	11-	10YR6/6	ANGBLKY	FIRM	18.2	51.1	C

TABLE 9

(continued)

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
38ADL	0-15	10YR4/3	GRANULAR	FRIABLE	18.2	38.1	CL
38BDL	16-28	10YR5/6	ANGBLKY	V.FIRM	17.0	56.3	C
39A	0-18	10YR3/3	GRANULAR	FIRM	18.5	36.3	CL
39B	19-	10YR6/6	ANGBLKY	V.FIRM	16.0	46.5	C
40A	0-14	10YR4/3	GRANULAR	FRIABLE	19.5	42.1	C
40B	15-	10YR5/4	ANGBLKY	V.FIRM	16.7	52.6	C
41AU	0-15	10YR3/3	GRANULAR	FRIABLE	19.5	32.6	CL
41BU	16-	10YR6/6	PLATY	FIRM	13.2	39.0	SCL
41AL	0-15	10YR4/3	GRANULAR	FRIABLE	17.8	34.6	CL
41BL	16-	10YR5/6	ANGBLKY	V.FIRM	17.4	57.3	C
42AU	0-15	10YR3/3	GRANULAR	FRIABLE	18.4	32.7	CL
42BU	16-	10YR6/6	ANGBLKY	FIRM	21.1	62.4	C
42AL	0-15	10YR4/3	GRANULAR	FRIABLE	17.7	36.4	CL
42BL	16-	10YR6/6	ANGBLKY	V.FIRM	26.6	80.8	C
43AU	0-10	10YR4/3	CRUMB	FIRM	19.4	41.1	L
43BU	11-	10YR5/4	ANGBLKY	V.FIRM	17.6	47.7	C
43AL	0-12	10YR4/2	GRANULAR	FRIABLE	16.7	34.7	CL
43BL	12-	10YR6/6	ANGBLKY	V.FIRM	16.9	49.0	C
44AU	0-10	10YR5/3	GRANULAR	FRIABLE	18.3	37.9	SCL
44BU	11-15	10YR5/6	ANGBLKY	V.FIRM	16.7	44.3	SC
44AL	0-15	10YR4/4	GRANULAR	FRIABLE	20.4	40.2	SC
44BL	16-	10YR5/6	ANGBLKY	V.FIRM	20.2	62.1	C
45AU	0-18	10YR4/3	SBANBLKY	FIRM	18.7	35.8	SCL
45BU	19-	7.5YR5/6	ANGBLKY	V.FIRM	28.1	60.8	C
45AL	0-18	10YR4/4	GRANULAR	FRIABLE	19.4	32.7	SCL
45BL	19-	10YR5/6	ANGBLKY	V.FIRM	23.9	62.9	C
46ADL	0-15	10YR3/3	ANGBLKY	V.FIRM	17.4	43.5	SCL
46BDL	16-	10YR5/6	ANGBLKY	V.FIRM	27.2	65.2	C
47ADL	0-10	10YR4/3	GRANULAR	FRIABLE	19.1	42.8	SC
47BDL	11-	10YR5/6	ANGBLKY	V.FIRM	25.4	62.6	C
48ADL	0-10	10YR4/3	GRANULAR	FRIABLE	21.4	46.7	C
48BDL	11-	10YR5/6	ANGBLKY	V.FIRM	22.3	56.6	C
49ADL	0-20	7.5YR4/4	GRANULAR	FRIABLE	18.0	38.1	SCL
49BDL	21-	10YR5/6	ANGBLKY	V.FIRM	19.0	49.3	C
50ADL	0-20	10YR4/4	GRANULAR	FRIABLE	22.7	39.9	SCL
50BDL	21-	10YR5/4	ANGBLKY	V.FIRM	18.0	54.6	C
57ADL	0-15	10YR3/3	GRANULAR	FIRM	18.4	23.5	SL
57BDL	16-	7.5YR5/8	ANGBLKY	V.FIRM	17.8	55.8	C
58ADL	0-13	10YR3/3	GRANULAR	FIRM	18.4	23.5	SL
58BDL	14-	10YR4/4	ANGBLKY	V.FIRM	17.8	55.8	C
59ADL	0-12	10YR3/3	GRANULAR	FIRM	17.3	35.4	CL

TABLE 9

(continued)

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
59BDL	13-	10YR4/4	ANGBLKY	V.FIRM	18.8	41.7	SC
60AU	0-20	10YR4/4	GRANULAR	FRIABLE	16.7	40.2	SC
60BU	21-	10YR5/6	ANGBLKY	FIRM	18.8	57.9	C
60AL	0-18	10YR4/4	ANGBLKY	FRIABLE	15.1	39.6	SCL
60BL	19-	10YR5/8	ANGBLKY	FIRM	25.2	61.0	C
61AU	0-10	10YR3/2	GRANULAR	FRIABLE	19.1	41.5	C
61BU	11-	10YR4/4	SBANBLKY	FIRM	13.4	46.0	C
61AL	0-10	10YR3/3	GRANULAR	FRIABLE	14.7	40.0	CL
61BL	11-	5YR4/4	SBANBLKY	FIRM	14.6	40.4	C
62ADL	0-10	10YR3/3	GRANULAR	FRIABLE	25.5	43.9	SC
62BDL	11-	10YR4/4	CRUMB	FRIABLE	22.2	48.3	C
63ADL	0-10	10YR3/3	GRANULAR	FRIABLE	23.2	41.9	C
63BDL	11-	10YR4/4	ANGBLKY	FIRM	12.6	43.3	C
64ADL	0-10	10YR3/3	ANGBLKY	FIRM	21.1	45.3	C
64BDL	11-	10YR6/8	ANGBLKY	V.FIRM	22.9	69.7	C
65ADL	0-20	10YR5/4	ANGBLKY	V.FIRM	18.6	52.3	C
65BDL	21-	10YR4/4	ANGBLKY	V.FIRM	22.1	70.8	C
66A	0-15	10YR3/3	GRANULAR	FRIABLE	20.5	44.2	C
66B	16-	10YR6/6	ANGBLKY	FIRM	13.5	45.2	C
67A	0-10	10YR4/4	GRANULAR	FIRM	26.5	33.1	CL
67B	11-	10YR4/3	GRANULAR	FIRM	19.2	37.0	CL
68AU	0-12	7.5YR4/4	GRANULAR	FRIABLE	23.1	37.3	CL
68BU	13-	10YR4/6	GRANULAR	FRIABLE	24.3	34.0	CL
68AL	0-12	7.5YR4/4	GRANULAR	FRIABLE	18.1	40.3	C
68BL	13-	10YR5/4	GRANULAR	FIRM	18.5	36.1	CL
69A	0-15	10YR4/4	ANGBLKY	FIRM	19.5	33.2	CL
69B	16-	7.5YR5/8	GRANULAR	FRIABLE	17.9	43.0	SC
70A	0-10	7.5YR4/4	GRANULAR	FRIABLE	17.5	36.7	SCL
70B	11-	7.5YR5/8	ANGBLKY	FIRM	15.7	44.7	C
71A	0-10	7.5YR4/4	GRANULAR	FIRM	17.9	36.7	SCL
71B	11-	7.5YR4/4	PLATY	FIRM	17.1	36.7	SCL
72ADL	0-15	10YR4/3	GRANULAR	FRIABLE	18.4	38.6	CL
72BDL	16-	7.5YR4/4	GRANULAR	FRIABLE	13.7	44.5	C
73ADL	0-15	10YR3/3	GRANULAR	FRIABLE	17.6	40.7	C
73BDL	16-	10YR4/3	GRANULAR	FRIABLE	12.9	43.0	SC
74DL	0-	10YR6/4	ANGBLKY	FIRM	16.6	38.5	SCL
75DL	0-	10YR6/3	ANGBLKY	FRIABLE	14.9	32.3	SCL
76DL	0-	7.5YR5/8	ANGBLKY	V.FIRM	21.7	56.9	C
77DL	0-	10YR5/8	ANGBLKY	FIRM	18.7	45.8	SC
78A	0-20	10YR4/3	SBANBLKY	FRIABLE	28.0	43.9	SC
78B	21-	10YR6/6	PLATY	V.FIRM	18.7	47.6	SC

TABLE 9

(continued)

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
79A	0-25	10YR4/3	GRANULAR	FRIABLE	20.0	42.8	SC
79B	26-	10YR6/6	ANGBLKY	V.FIRM	17.9	47.5	SC
80A	0-15	10YR4/3	GRANULAR	FRIABLE	21.3	45.1	SC
80B	16-	10YR5/6	ANGBLKY	V.FIRM	18.5	52.3	SC
81A	0-10	10YR3/3	SBANBLKY	FIRM	16.1	38.9	SCL
81B	11-	10YR4/3	GRANULAR	FIRM	16.1	36.0	SCL
82A	0-10	10YR3/3	GRANULAR	FIRM	18.4	33.8	CL
82B	11-	10YR4/4	ANGBLKY	FIRM	16.3	35.8	SCL
83A	0-10	10YR4/2	GRANULAR	LOOSE	15.6	36.3	SCL
83B	11-	10YR4/3	GRANULAR	FRIABLE	14.4	36.0	SCL
84A	0-5	10YR6/4	GRANULAR	FRIABLE	12.8	24.4	L
84B	6-10	2.5YR6/4	GRANULAR	FRIABLE	11.6	27.4	CL
84B2	11-	10YR5/3	GRANULAR	FIRM	14.8	22.6	L
84DL	0-	10YR5/6	ANGBLKY	FIRM	17.6	47.1	STC
85A	0-20	10YR3/3	GRANULAR	FRIABLE	14.4	23.5	CL
85B	21-	10YR6/4	GRANULAR	FIRM	12.5	25.4	L
86A	0-20	10YR3/3	GRANULAR	FRIABLE	14.4	23.5	CL
86B	21-	10YR6/4	GRANULAR	FIRM	12.5	25.4	L
87A	0-25	10YR3/2	GRANULAR	FRIABLE	20.5	37.6	SCL
87B	26-	10YR4/3	GRANULAR	FIRM	18.5	39.6	SCL
88ADL	0-25	10YR3/3	GRANULAR	FIRM	17.4	37.1	SCL
88BDL	26-	2.5YR4/4	GRANULAR	FIRM	16.1	35.4	SCL
88DL	0-	7.5YR5/8	ANGBLKY	V.FIRM	16.8	64.8	C
89A	0-20	10YR3/3	GRANULAR	FRIABLE	22.6	37.7	SCL
89B	21-	10YR5/6	ANGBLKY	FIRM	26.3	44.6	SC
89DL	0-	10YR4/3	ANGBLKY	FIRM	27.9	37.5	C
90A	0-17	10YR3/3	CRUMB	FRIABLE	29.7	34.2	SCL
90B	18-	10YR4/4	ANGBLKY	FIRM	31.0	40.3	STC
91DL	0-20	10YR4/4	SBANBLKY	FRIABLE	15.9	41.0	C
92ADL	0-20	10YR5/4	CRUMB	FIRM	18.6	44.7	STC
92BDL	21-	10YR5/6	ANGBLKY	V.FIRM	19.5	52.7	C
93ADL	0-20	10YR4/4	ANGBLKY	FIRM	17.2	42.0	STC
93BDL	21-	10YR5/6	ANGBLKY	V.FIRM	20.0	54.9	C
94ADL	0-20	10YR5/4	ANGBLKY	FIRM	19.1	43.7	STC
94BDL	21-	10YR5/6	ANGBLKY	V.FIRM	19.9	54.2	C
95ADL	0-20	10YR5/4	CRUMB	FRIABLE	18.9	37.1	SCL
95BDL	21-	10YR5/6	ANGBLKY	V.FIRM	18.7	52.8	C
96DL	0-	10YR3/2	CRUMB	FRIABLE	24.1	27.1	SCL
97DL	0-	10YR3/3	ANGBLKY	V.FIRM	31.3	46.7	SC
98DL	0-	10YR3/3	ANGBLKY	FIRM	19.9	34.1	CL
99A	0-6	7.5YR4/4	GRANULAR	FRIABLE	6.0	-	SL

TABLE 9

(continued)

Tree Code*	Horizon Depth (cm)	Color /1	Structure /2	Consistence/3	Moisture (%)	Clay (%)	Textural Class/4
99B	7-	7.5YR4/4	GRANULAR	FRIABLE	6.0	-	CL
100A	0-16	10YR4/2	CRUMB	FIRM	21.6	32.6	CL
100B	17-	10YR4/4	SBANBLKY	FIRM	21.6	32.5	CL

* Tree Codes are not in sequence and listed by number for each tree and by soil codes for each layer or duplicate sample. DL=disturbed layer, A=A horizon or or upper layer, B=B horizon or deeper layer, X=traffic pan visible, U=sample taken from upper part of a slope, L=sample taken from lower part of a slope (if used with DL=DLL) 1=duplicate sample 1, 2=duplicate sample 2. Duplicate samples were averaged in with each other for analysis of results.

/1_ Color rated according to Munsell soil color ratings.

/2_ Structure abbreviations: SBANBLKY=subangular blocky, ANGBLKY=angular blocky; according to standard soil classification terminology.

/3_ Consistence ratings according to standard soil ratings (V.=very).

/4_ Textural Class abbreviations include: CL=clay loam, C=clay, SLTC=silty clay, SCL=sandy clay loam, L=loam, SC=sandy clay, STC=silty clay (see Appendix 7 for detailed soil texture data).

soils, and were expected to survive (see example in Figure 20). The textures are listed by the percent clay and class in Table 9 (see detailed soil texture data in Appendix Table 7).

Soil chemistry data (Table 10) also varied from site to site except for soil pH which was in the alkaline range for most sites. Poor quality sites had a pH ranging from 7.0 (neutral) to 8.5 (alkaline). Nutrients did not seem to play a significant role in the decline process. However, high nutrient levels may have played a detrimental role in mycorrhizal development as they were consistently high on decline sites (71, 152). High calcium and magnesium levels correlated with high pH levels and were probably the result of overfertilization and overliming on some sites. Soluble salt readings varied among all sites. According to Virginia Tech Soil Testing Laboratory personnel the readings obtained from these tests were not high enough to damage pines. Soil organic matter and % organic nitrogen readings also varied among sites with lower readings usually obtained from deeper and disturbed soil horizons. It should be noted that a deficiency of the study was that nitrate and ammonium ion levels were not established for these soils. This need was overlooked during planning and has hindered any conclusions being made on the effects of nitrogen levels on decline.

Figure 19: Disturbed soil profile made up of displaced clay subsoils under a declining tree (#4) on the Virginia Tech campus.

Figure 20: Declining white pine (#4) located in a well formed when subsoils were graded over the root zone.

The organic nitrogen readings could not be used for this purpose. Nutrients, pH, soluble salts, organic matter and organic nitrogen readings are listed in Table 10.

Several parent material types occurred on decline habitats with most trees in the study located over the Rome formation. These included trees located on the Virginia Tech campus (tree codes 1-50, 57-60), trees in the town of Blacksburg, VA (tree codes 81-83, 87-95), and trees in Waynesboro, VA (tree codes 67-71, 99). The Rome formation consisted of shale and sandstone variegated with dolomite. Other geologic formations which contributed to parent materials under decline habitats included the following. The Beekmantown formation consisted of Conococheague limestone and Elbrook dolomite and was found under trees in Wytheville, VA (tree codes 72-77). The Elbrook formation consisted of a thick-bedded, shaley, argillaceous, dolomite and some limestone. It was located under trees in Roanoke, VA (tree codes 61-63), Dublin, VA (tree codes 84-86), and Radford, VA (tree codes 64-66). The Ordovician formation was made up of Athens shale, Whitesburg limestone, and Holston limestone and was located under trees in Lexington, VA (tree codes 78-80). The Patuxent formation was made up of arkosic sandstone, gray to buff sandstone cross-bedded with interbedded clays, and gravel. It was located under trees in the Washington, DC area (tree codes 96-98). The Pocono forma-

TABLE 10

Soil chemical factors for decline habitat trees

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (ppm)	Organic Matter (%)	N (%) /1
1DL	7.6	84	19	1679	199	6.1	16.1	141	1.5	0.075
2AU	7.5	60	72	1200	120	2.8	16.1	179	3.0	0.150
2BU	7.7	44	51	1200	120	0.5	13.8	38	1.3	0.065
2AL	6.4	60	158	1080	120	6.1	16.1	794	5.5	0.275
2BL	7.3	60	158	1200	120	2.3	16.1	205	1.6	0.080
3AU	5.5	60	99	900	89	1.6	16.1	269	2.6	0.130
3BU	5.7	60	99	852	83	1.6	16.1	205	2.3	0.115
3AL	6.3	60	116	1200	120	2.3	13.7	179	3.3	0.165
3BL	6.8	27	88	816	116	0.7	5.0	64	1.3	0.065
4AX	7.4	12	158	1200	120	1.1	15.7	499	1.0	0.050
4BDL	7.5	60	158	1200	120	5.0	16.1	243	3.0	0.150
5A	6.3	64	135	1523	136	6.1	16.1	141	2.5	0.125
5B	7.0	16	141	705	96	0.4	8.8	64	0.2	0.010
6DL	7.5	60	82	1200	120	6.1	16.1	115	3.0	0.150
7ADL	7.0	60	109	1200	120	6.1	16.1	154	4.6	0.230
7BDL	5.9	34	103	852	65	1.9	16.1	154	2.3	0.115
7DL1	7.3	27	77	1200	120	2.3	16.1	51	2.5	0.125
8ADL	7.6	125	15	1679	199	6.1	16.1	230	3.4	0.170
8BDL	7.9	7	10	1679	199	5.2	14.6	256	0.7	0.035
9ADL	7.6	112	173	1679	122	3.4	16.1	128	2.0	0.100
9BDL	8.0	4	100	1679	199	6.1	13.4	179	2.6	0.130
10ADL	7.7	60	101	1200	120	5.0	16.1	141	3.4	0.170
10BDL	6.8	10	61	1200	120	0.6	6.4	230	1.1	0.055
11ADL	6.3	25	93	1188	120	3.8	16.1	141	2.9	0.145
11BDL	7.0	60	148	1200	120	3.4	16.1	166	3.3	0.165
12ADL	7.6	60	158	1200	120	6.1	16.0	192	5.0	0.250
12BDL	7.8	8	75	1200	120	1.5	16.0	192	1.5	0.075
13ADL	7.0	60	90	1200	120	4.2	16.0	243	4.1	0.205
13BDL	7.3	16	77	1140	120	0.8	11.5	64	1.0	0.050
14ADL	7.3	60	109	1200	120	6.1	16.0	166	4.8	0.240
14BDL	7.5	10	122	1200	120	3.5	16.0	141	1.3	0.065
15ADL	7.3	60	109	1200	120	6.1	16.0	166	4.8	0.240
15BDL	7.5	10	122	1200	120	3.5	16.0	141	1.3	0.065
16ADL	6.6	31	70	1024	122	2.1	16.1	0.0	2.7	0.135
16BDL	6.1	24	38	487	62	1.0	16.1	0.0	1.5	0.075
17ADL	7.4	57	62	1125	157	2.1	16.1	102	2.1	0.105
17BDL	7.7	72	51	1595	199	3.1	16.1	102	1.7	0.085
18A	7.6	125	79	1427	155	2.8	16.1	51	2.3	0.115
18B	7.4	31	120	957	116	1.1	16.1	38	1.0	0.050
19ADL	7.8	62	96	1679	179	2.0	16.1	128	1.8	0.090
19BDL	7.9	15	60	1679	148	6.1	3.2	192	7.4	0.370

TABLE 10

(continued)

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (ppm)	Organic Matter (%)	N (%) /1
20ADL	6.5	125	129	1209	110	4.6	16.1	102	3.4	0.170
20BDL	6.6	31	96	605	54	1.5	16.1	0.0	1.3	0.065
21ADL	8.1	44	66	1679	193	2.2	16.1	128	1.5	0.075
21BDL	8.0	21	68	1679	199	5.8	16.1	166	1.8	0.090
22A	7.6	125	87	1679	136	6.1	16.1	115	4.4	0.220
22B	7.7	118	70	1427	106	4.5	16.1	0.0	2.5	0.125
23ADL	7.3	60	103	1200	120	5.7	16.1	141	4.2	0.210
23BDL	7.6	35	78	1200	120	3.6	16.1	192	2.1	0.105
24A	6.5	60	96	1200	120	6.1	16.1	243	4.4	0.220
24B	6.8	29	77	1164	120	3.6	16.1	0.0	2.3	0.115
25ADL	6.2	60	158	1200	120	5.6	16.1	730	3.9	0.195
25BDL	6.9	60	82	1200	120	2.6	16.1	205	2.4	0.120
26ADL	6.2	60	158	1200	120	5.6	16.1	730	3.9	0.195
26BDL	6.9	60	82	1200	120	2.6	16.1	205	2.4	0.120
27ADL	6.2	60	158	1200	120	5.6	16.1	730	3.9	0.195
27BDL	6.9	60	82	1200	120	2.6	16.1	205	2.4	0.120
27UDL	5.4	60	112	1200	120	6.1	16.1	384	8.6	0.430
27LDL	7.2	56	158	1200	120	2.1	16.1	179	3.9	0.195
28UDL	6.7	13	111	1116	120	1.2	16.1	38	1.3	0.065
28LDL	5.4	60	112	1200	120	6.1	16.1	384	8.6	0.430
29ADL	5.2	21	64	672	81	1.7	16.1	102	2.9	0.145
29BDL	6.7	13	111	1200	120	1.2	16.1	38	1.3	0.065
30DL1	7.2	56	158	1200	120	2.1	16.1	179	3.9	0.195
30DL2	7.4	18	78	1200	120	1.2	14.5	102	1.0	0.050
31ADL	6.8	56	158	1200	120	2.1	16.1	179	3.9	0.195
31BDL	6.6	60	64	1200	120	6.1	16.1	256	3.0	0.150
32ADL	7.2	60	114	1200	120	6.1	16.1	435	3.7	0.185
32BDL	7.3	60	143	1200	120	6.1	16.1	333	2.3	0.115
32DL1	7.2	60	135	1200	120	6.1	16.1	346	4.8	0.240
33DLU	6.9	60	86	1200	120	6.1	16.1	243	3.6	0.180
33DLL	7.1	20	82	1200	120	6.1	16.1	384	2.6	0.130
34A	7.6	25	67	1200	120	3.7	16.1	474	4.1	0.205
34B	7.9	9	26	1200	120	2.4	16.1	320	2.6	0.130
35A	6.3	60	85	1200	120	6.1	16.1	243	3.1	0.155
35B	7.0	60	74	1200	120	3.5	16.1	154	1.4	0.070
36ADL	6.6	60	120	1200	120	6.1	16.1	384	3.7	0.185
36BDL	7.4	60	120	1200	120	2.8	16.1	154	1.1	0.055
37AU	6.5	35	122	1200	120	0.9	16.1	243	2.0	0.100
37BU	7.8	6	99	1200	120	2.6	16.1	294	1.2	0.060
37AL	7.4	43	93	1200	120	1.7	16.1	512	3.3	0.165
37BL	7.8	7	51	1200	120	0.2	16.1	243	1.0	0.050

TABLE 10

(continued)

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (ppm)	Organic Matter (%)	N (%) /1
38ADL	7.3	125	131	1679	199	3.4	16.1	166	4.4	0.220
38BDL	7.9	155	77	1679	199	0.9	16.1	256	1.2	0.060
39A	7.3	60	107	1200	120	4.0	16.1	422	2.7	0.135
39B	7.6	13	58	1200	120	1.0	16.1	320	1.3	0.065
40A	7.6	32	158	1200	120	3.0	16.1	730	2.6	0.130
40B	7.7	11	155	1200	120	1.3	16.1	486	1.2	0.060
41AU	6.3	60	95	1128	120	1.7	16.1	307	3.0	0.150
41BU	7.3	10	70	900	116	0.2	7.9	154	0.9	0.045
41AL	7.3	60	80	1200	120	2.3	16.1	422	3.6	0.180
41BL	7.8	8	48	1200	120	0.6	16.1	282	1.6	0.080
42AU	7.0	60	143	1200	120	0.5	16.1	397	3.3	0.165
42BU	7.1	9	82	960	120	0.2	2.4	140	1.0	0.050
42AL	7.6	55	104	1200	120	4.3	16.1	435	3.4	0.170
42BL	7.8	5	63	1200	120	1.6	15.4	320	1.5	0.075
43AU	7.5	50	148	1200	120	3.1	16.1	730	3.0	0.150
43BU	7.8	24	109	1200	120	1.6	16.1	448	1.7	0.085
43AL	7.4	32	66	1200	120	2.5	16.1	435	2.1	0.105
43BL	7.8	3	64	1200	120	0.4	16.1	294	1.1	0.055
44AU	7.1	51	155	1200	120	4.1	16.1	794	2.6	0.130
44BU	7.5	13	127	1032	120	1.1	16.1	307	0.9	0.045
44AL	7.3	24	101	1200	120	6.1	16.1	768	2.6	0.130
44BL	7.5	8	64	1200	120	0.9	16.1	410	0.8	0.040
45AU	6.5	41	158	1200	120	2.6	16.1	742	2.0	0.100
45BU	7.3	5	125	1200	120	0.7	10.3	269	0.7	0.035
45AL	7.0	33	93	1200	120	2.1	16.1	614	2.1	0.105
45BL	7.4	5	72	1152	120	1.3	16.1	448	0.6	0.030
46ADL	7.6	16	130	1200	120	4.3	16.1	218	2.3	0.115
46BDL	7.2	4	99	1164	120	0.8	6.7	230	0.7	0.035
47ADL	6.9	57	132	1200	120	2.6	16.1	333	2.1	0.105
47BDL	7.7	111	85	1200	120	0.7	16.1	192	0.7	0.035
48ADL	7.7	47	90	1200	120	5.7	16.1	358	2.7	0.135
48BDL	7.7	10	70	1200	120	6.1	16.1	512	0.9	0.045
49ADL	7.5	40	150	1200	120	0.8	16.1	141	2.1	0.105
49BDL	7.6	16	88	1200	120	0.5	15.9	115	0.9	0.045
50ADL	7.3	23	124	1200	120	2.0	16.1	346	2.5	0.125
50BDL	7.6	12	98	1200	120	0.8	16.1	294	0.7	0.035
57ADL	7.3	60	124	1200	120	5.8	16.0	179	5.2	0.260
57BDL	7.6	18	130	1200	120	1.5	16.0	141	1.2	0.060
58ADL	7.3	60	124	1200	120	5.8	16.0	179	5.2	0.260
58BDL	7.6	18	130	1200	120	1.5	16.0	141	1.2	0.060
59ADL	7.5	60	111	1200	120	2.5	16.0	166	3.1	0.155

TABLE 10

(continued)

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (ppm)	Organic Matter (%)	N (%) /1
59BDL	7.6	11	140	1200	120	1.5	16.0	128	1.4	0.070
60AU	7.2	60	86	1200	120	2.9	16.0	154	3.4	0.170
60BU	7.8	7	88	1200	120	2.0	16.0	154	1.3	0.065
60AL	6.3	41	106	1140	120	4.0	16.0	64	3.3	0.165
60BL	6.1	9	67	924	120	1.0	7.2	102	1.1	0.055
61AU	7.9	11	89	1679	199	6.1	16.1	179	5.0	0.250
61BU	8.3	9	43	1041	199	2.5	16.1	141	1.4	0.070
61AL	7.4	12	73	907	199	6.1	16.1	0.0	3.4	0.170
61BL	7.4	10	131	571	191	1.6	16.1	0.0	1.3	0.050
62ADL	7.6	20	120	1511	199	6.1	16.1	141	4.9	0.245
62BDL	7.7	12	129	722	199	2.3	13.2	0.0	1.5	0.075
63ADL	7.7	125	139	1679	199	6.1	16.1	209	5.0	0.250
63BDL	7.7	125	149	1679	199	6.1	16.1	155	2.9	0.145
64ADL	6.1	125	188	1679	199	6.1	16.1	256	6.8	0.340
64BDL	6.6	19	102	856	199	2.2	3.5	64	0.9	0.045
65ADL	7.0	118	188	1679	199	6.1	16.1	128	4.0	0.200
65BDL	7.2	17	161	1108	199	2.3	6.9	0.0	1.1	0.055
66A	7.8	125	188	1679	199	6.1	16.1	141	4.0	0.200
66B	7.9	51	188	1327	144	2.2	11.8	0.0	1.3	0.050
67A	6.5	13	91	1024	148	1.9	9.0	0.0	3.2	0.160
67B	6.4	8	36	588	94	1.0	6.7	0.0	1.4	0.070
68AU	6.3	10	51	974	116	2.0	5.3	0.0	3.3	0.165
68BU	6.5	7	30	554	84	0.8	5.6	0.0	1.0	0.050
68AL	6.2	8	112	806	134	1.7	3.6	0.0	2.9	0.145
68BL	6.1	5	38	554	100	0.9	6.1	0.0	1.5	0.075
69A	5.3	124	56	386	36	1.4	6.3	0.0	2.9	0.145
69B	4.9	23	108	268	28	0.8	3.0	90	0.6	0.030
70A	4.9	57	71	302	38	1.0	6.6	38	1.7	0.085
70B	5.0	22	77	319	32	0.7	4.6	0.0	0.9	0.045
71A	5.2	125	75	537	56	1.2	5.9	0.0	2.9	0.145
71B	5.4	21	64	269	18	0.9	4.2	0.0	1.5	0.075
72ADL	7.6	125	62	1679	199	6.0	16.0	64	3.5	0.175
72BDL	8.1	79	83	1679	199	6.0	16.0	115	1.7	0.085
73ADL	7.3	125	159	1679	199	6.0	16.0	102	3.1	0.155
73BDL	7.9	125	77	1679	169	6.0	16.0	230	2.6	0.130
74DL	6.4	25	32	420	84	3.3	9.2	64	2.0	0.100
75DL	6.5	28	41	336	66	3.2	6.6	0.0	1.4	0.070
76DL	5.7	12	45	454	98	3.2	7.3	0.0	2.2	0.110
77DL	5.9	9	45	605	120	4.6	11.1	0.0	1.5	0.075
78A	6.6	11	40	960	120	1.2	16.1	371	2.3	0.115
78B	6.7	4	15	540	63	0.8	16.0	128	0.8	0.040

TABLE 10

(continued)

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (ppm)	Organic Matter (%)	N (%) /1
79A	6.5	7	31	1068	93	0.7	16.1	166	2.2	0.110
79B	6.7	3	20	816	54	0.5	15.6	64	0.7	0.035
80A	6.1	4	48	720	66	0.7	16.1	154	1.5	0.075
80B	5.7	7	17	636	48	0.7	9.2	1	0.8	0.040
81A	7.8	6	23	1200	120	6.1	16.1	179	4.8	0.240
81B	7.9	10	15	1200	120	6.1	16.1	154	2.5	0.125
82A	6.8	12	37	684	120	4.4	16.1	102	3.2	0.160
82B	7.0	5	28	1080	74	0.6	16.1	0.0	1.6	0.080
83A	7.4	60	51	1200	120	3.5	16.1	218	4.8	0.240
83B	7.4	56	34	1200	120	1.2	16.1	102	2.9	0.145
84A	6.4	11	33	1200	105	3.0	11.5	90	2.5	0.125
84B	4.9	5	23	660	77	0.7	13.4	51	1.5	0.075
84B2	5.1	10	15	192	50	1.2	16.1	205	1.9	0.095
84DL	7.0	7	39	1200	120	0.9	16.1	0.0	2.0	0.100
85A	7.3	21	31	216	120	1.2	16.1	102	2.7	0.135
85B	7.5	8	29	1200	120	0.3	8.6	0.0	1.5	0.075
86A	7.3	21	31	216	120	1.2	16.1	102	2.7	0.135
86B	7.5	8	29	1200	120	0.3	8.6	0.0	1.5	0.075
87A	7.6	11	91	1200	120	6.1	16.0	192	4.2	0.210
87B	7.7	29	48	1200	120	6.1	16.0	102	2.7	0.135
88ADL	7.5	27	50	1200	120	2.6	16.0	141	3.6	0.180
88BDL	7.6	7	36	1056	120	0.7	16.0	0.0	1.5	0.075
88DL	7.9	4	47	1200	120	0.7	16.0	128	0.9	0.045
89A	7.2	6	109	1200	120	5.1	16.0	192	5.2	0.260
89B	7.2	4	66	744	114	0.4	11.1	0.0	1.1	0.055
89DL	7.5	7	63	1200	120	6.1	16.0	128	3.6	0.180
90A	7.7	60	72	1200	120	6.1	16.0	154	3.7	0.185
90B	7.6	60	59	1200	120	3.9	16.0	102	2.7	0.135
91DL	7.8	6	59	1200	120	1.7	16.0	128	2.0	0.100
92ADL	5.8	3	72	756	120	0.4	11.0	38	2.3	0.115
92BDL	4.9	4	63	504	120	0.4	1.3	0.0	1.1	0.055
93ADL	7.0	4	47	1080	120	0.7	15.3	0.0	2.0	0.100
93BDL	4.8	3	53	492	120	0.3	2.1	0.0	1.0	0.050
94ADL	6.7	4	64	936	120	1.0	16.1	0.0	2.1	0.105
94BDL	4.8	2	55	468	120	0.4	3.3	0.0	1.1	0.055
95ADL	6.2	3	42	732	120	0.6	16.1	0.0	1.8	0.090
95BDL	5.3	1	42	624	120	0.4	6.6	0.0	1.3	0.065
96DL	6.0	60	93	888	85	6.1	16.1	0.0	2.8	0.140
97DL	6.7	60	88	1200	120	6.1	16.1	102	3.6	0.180
98DL	6.4	21	53	1068	80	4.2	16.1	64	1.9	0.095
99A	6.3	15	81	722	78	0.7	16.1	64	1.1	0.055

TABLE 10

(continued)

Tree Code*	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Soluble Salts (%)	Organic Matter (%)	N (%) /1
99B	6.3	15	81	722	78	0.7	16.1	64	1.1	0.055
100A	6.8	28	66	1679	102	3.8	16.1	26	3.5	0.175
100B	7.2	35	79	1595	110	2.9	16.1	0.0	2.9	0.145

* Tree Codes are not in sequence and listed by number for each tree and by soil codes for each layer or duplicate sample. DL=disturbed layer, A=A horizon or or upper layer, B=B horizon or deeper layer, X=traffic pan visible, U=sample taken from upper part of a slope, L=sample taken from lower part of a slope (if used with DL=DLL) 1=duplicate sample 1, 2=duplicate sample 2. Duplicate samples were averaged in with each other for analysis of results.

/1_ % N (organic nitrogen) = % Organic Matter/20 see p.156 of Brady (20).

tion, made up of predominately gray, hard, massive, cross-bedded conglomerate, sandstone, and some shale, was located under tree number 100 in Greenville, PA (66). It was evident that the parent materials on decline habitat sites did not initate those on the natural habitat site. The parent material under the natural habitat was deficient of limestone and it should be emphasized that this difference may have biased the investigation as a whole. However, the parent materials under decline habitat sites did include sandstone and shale materials as well. Limestone layers broken-up by construction activities could have contributed to high soil pH on many of the decline sites. Many of the soils on poorer quality sites were moved by construction equipment from a subsoil layer to the surface. When trees were planted in these layers and the soils were exposed to the weather, broken-up limestone may have solublized to raise the pH into the alkaline range. Also a contributing cause to a rise in pH on some sites may have been overliming and overfertilization by tree owners.

When soils of decline sites were tested for compaction it was found that they were more compacted than soils of the natural site. Soils tested on decline habitats with a clayey texture were very highly compacted, with readings averaging around 1500 psi required to penetrate the soils. In

three decline habitat sites with soils high in clay, penetrometer readings averaged 1161.7 psi in upper layers and 1806.1 psi for the lower layers. There were no true A or B horizons in disturbed profiles and were only referred to here as upper and lower layers. Soils tested on decline habitat sites with a loamy texture were also highly compacted, with readings of around 700 psi required to penetrate the soil. Readings averaged 766.0 psi for the upper layers and 620.0 psi for the lower layers. Compaction by foot traffic and turf maintenance equipment added significantly to compaction (see detailed compaction data in Appendix Table 7). Concentrated foot traffic alone was estimated to increase compaction by nearly 90% on the loamy sites checked with the penetrometer. An example of foot traffic compaction to decline habitat root zone soils is illustrated in Figure 21.

At this site, feeder roots were found between the compacted layer and a clay layer in a limited root mat area. Roots found in this area were flattened by pressure from the compacted layer pushing them against the clay layer. The tree's foliage was chlorotic above the compacted root zone. This phenomenon was observed several times on decline habitat sites (see Figure 14).

Figure 21: Soils compacted by heavy foot traffic under a declining white pine (#15) on the Virginia Tech campus.

4.1.6 Site quality for a decline habitat (miscellaneous factors)

There were a number of insects associated with declining trees. These seemed to increase in number as trees became more unhealthy. The pine bark aphid (adelgid), **Pineus strobi** Hartig, heavily infested declining trees and was highly visible due to its conspicuous appearance on the bole and branches (see Figure 22). The white pine aphid, **Cinara strobi** Fitch, was also abundant on declining trees. These also seemed to increase as tree health deteriorated (see Figure 23). The pine needle scale, **Phenacaspis pinifoliae** Fitch, was present on trees in poor health, although not as consistently as the two "aphids" mentioned above. A root aphid identified as **Prociphilus** sp. was found on both decline and natural habitat trees. Due to the inability to estimate numbers throughout a tree's root system, it was impossible to determine if more of these were present on trees in poor health (see Figure 24).

Other potentially harmful insects (99) found on decline habitat trees included: Saratoga spittlebug (**Aphrophora saratogensis** Fitch), pine tube moth (**Argyrotaenia pinatubana** Kearfott), pine leaf chermid (**Pineus pinifoliae** Fitch), white pine weevil (**Pissodes strobi** Peck), and large lepidopterous larvae, probably those of the Cecropia moth (**Hyalophora cecropia** L).

Figure 22: Pine bark aphids concentrated on bole of fastigiate variety white pine on the Virginia Tech campus.

Figure 23: White pine aphids concentrated on limb of a decline habitat tree (#50).

Figure 24: Root aphids attached to roots of a decline habitat tree (#43).

There were no plant pathogens consistently associated with declining white pines. Fungi associated with decline habitat trees are listed in Table 11.

Nematode assays were not run on all decline habitat trees and conclusive evidence as to their impact on declining trees could not be obtained. Several decline habitat trees were assayed for nematodes of which those identified included: **Bursaphelenchus lignicolus** Mamiya & Kiyohara (pinewood nematode), **Hoplolaimus** sp., **Xiphenema** sp., and **Criconemoides** sp. Therefore, the information obtained could not be evaluated to determine whether nematodes, other than the pinewood nematode, played a role in the decline complex. Details of an investigation of the pinewood nematode can be found in section 4.3.

Mechanical damage of various types was present on many decline habitat trees. Cankers were created from repeated impact on lower limbs by tractor-driven and hand-pushed lawnmowers. Ice and wind played a role in mechanical damage on many decline habitat trees. Ice broke the tops out of many decline habitat trees and deformed many trees on open sites. Terminal deformation, which may also have been caused by white pine weevil damage, was evident by crooked boles on many open site trees, as illustrated in Figure 5 and 27. Other mechanical damage was inflicted on trees by

TABLE 11

Fungi isolated from decline habitat sites

Fungus	Roots	Bole	Limbs	Foliage
Armillaria tingens/1		X	X	
Botryosphaeria dothidea/2		X	X	
Cenangium ferruginosum/3		X	X	X
Chalara sp.	X	X	X	
Diplodia sp.			X	
Fusarium sp.	X			
Pestalotia sp.			X	X
Phytophthora sp.	X			
Pythium sp.	X			
Rhizoctonia sp.	X			
Scirrhia acicola/4				X
Verticillium sp.	X			

/1_ Authorities=Lohman & Cash
/2_ Authorities=Gross & Dug.
/3_ Authorities=Berk. & Curt.
/4_ Authorities=(Dearn.) Siggers

Sources: Boyce, J. S. 1961. Forest pathology. 3rd edition. McGraw Hill Book Co., Inc. New York. 572pp. (24).

Hepting, G. H. 1971. Diseases of forest and shade trees of the United States. AHB No. 386. USDA-FS 658pp. (77).

US Dep. Agric. 1970. Index of plant diseases in the United States. AHB No. 165. USDA-ARS 531pp. (170).

construction activities. This included damaged roots, broken limbs, and extensive damage to the bole. Poor planting techniques contributed to some mechanical damage as well (see Figure 25). Detailed damage reports are listed in Appendix Table 10.

Figure 25: Poor planting techniques attributed to this tree's (#74) decline on a home landscape in Wytheville, VA.

4.1.7 Summary of results obtained from the systematic indexing method

The data presented in the previous sections could have been treated in a variety of ways. Individual observations (trees) could have been compared with each other to determine which factors occurred in all trees of a similar habitat. Each variable from each tree of each habitat could have been compared with its counterpart from the other habitat. Still another alternative would have been to summarize the data from each habitat and compare the two habitat types. The later approach was chosen in this investigation with only factors viewed as important discussed in this subsection.

It is extremely difficult to interpret accurately field study data. This is mostly due to the fact that the field environment can not be manipulated and controlled to observe only those desired factors. Unlike the laboratory or greenhouse the field environment is extremely unpredictable.

For these reasons conclusions should not be based on any one factor. Only a consistently occurring group of factors from one habitat can be weighed against a corresponding group from another habitat. Each tree in the study had overall general similarities with other trees of similar habitat but still differed from these trees when specific similarities were sought. Yet even with the environmental situation and variation among the samples the natural habitat

trees and the decline habitat trees grossly differed in both growth and site quality.

COMPARISON OF GROWTH DATA--The more mature natural habitat trees were consistently taller than the more mature trees from the decline sites. A height vs. age index seemed to be the best indicator of growth quality. When compared on an age vs. height regression plot (see Figure 26) a group of more mature (>50 years) natural habitat trees separated from the more mature decline habitat trees. A general linear models (GLM) analysis was run with predicted values vs. actual values. The natural habitat trees were all to the left of the intercept line while most of decline habitat trees were either to the right or along the line. The R-squared value for this GLM procedure and other statistical data are listed in Table 12. Younger trees (<50 years) did not separate as easily as they apparently had not reached a point where the shoot:root ratio (63) had caused a noticeable reduction in height growth. This difference in height can be best illustrated if one compares Figure 27, a 75-year-old decline habitat tree (tree code 3), with Figure 12, a natural habitat tree of the same age (tree code 52). The declining tree had appeared to have reached its full growth capacity, with shortened interwhorl growth and stunted overall height. The natural habitat tree was still in

good health and appeared to have had many more years of growth ahead of it. There was a difference of 12.7 m (41 ft) in height between the shorter decline tree and the natural habitat tree. However, it must be emphasized that natural habitat trees were all closely grown trees in the forest habitat while decline habitat trees varied from open-grown to close-grown. The older decline habitat trees (> 50 years) were all open-grown. An exception to this was a group of decline habitat trees grown in close quarters similar to the forest site. These trees (tree codes 16-36) were also consistently shorter than natural habitat trees, and were grown at about the same basal density.

Other means of evaluation of tree growth quality were chosen to strengthen the height vs. age data and defend them against the argument that open-grown trees were shorter than close-grown counterparts regardless of health. However, these other growth factors were not as easily evaluated between the two groups. A regression plot of diameter at breast height, or DBH, vs. age (see Figure 28) illustrated that the DBH's of natural habitat trees were to the right or on the predicted intercept line for the groups as a whole. This evidence did not strengthen the argument against the value of height as a reliable indicator of growth between the two groups. This evidence is the opposite of that obtained by plotting height times age. The only question now

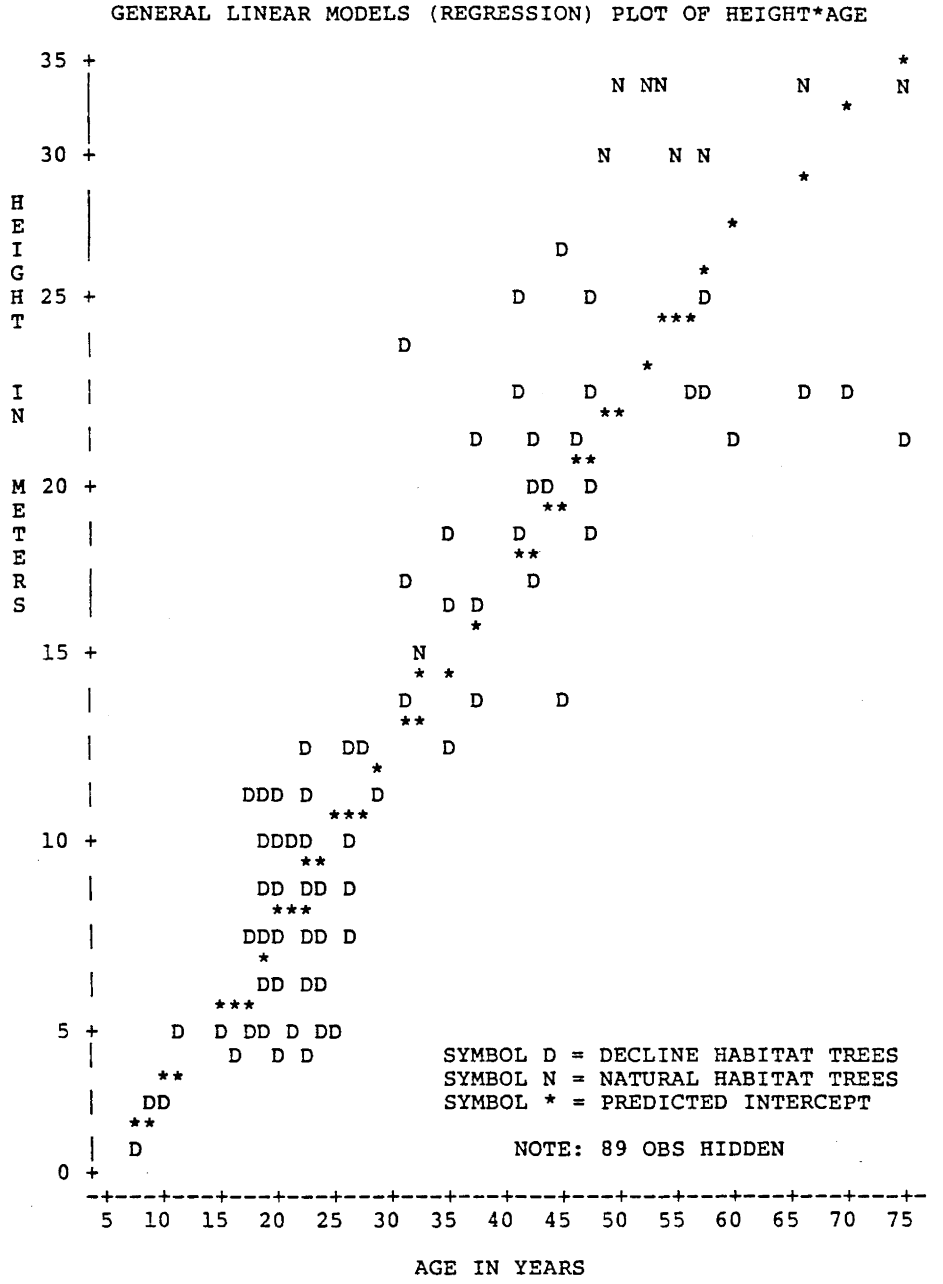


Figure 26: Comparison of height vs. age data for decline and natural habitat trees.

Figure 27: A 75-year-old decline habitat tree (#3) 12.7 m (41 ft) shorter in height than natural habitat trees of the same age.

TABLE 12

General linear models statistics for height vs. age of natural and decline habitat trees

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: HEIGHT (HEIGHT IN METERS)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	1	5899.26367506	5899.26367506
ERROR	102	1553.71017109	15.23245266
CORRECTED TOTAL	103	7452.97384615	

MODEL F = 387.28 PR > F = 0.0001

R-SQUARE	C.V.	STD DEV	HEIGHT MEAN
0.791532	27.6649	3.90287748	14.10769231

SOURCE	DF	TYPE I SS	F VALUE	PR > F
AGE	1	5899.26367506	387.28	0.0001

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
AGE	1	5899.26367506	387.28	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-1.31032628	-1.50	0.1360	0.87193412
AGE	0.47765086	19.68	0.0001	0.02427150

is which of these plots to rely upon the most for an indicator of growth quality. In the literature height vs. age indices have been weighed more heavily than DBH vs. age (1, 12, 58, 174). It should be realized that the natural habitat trees were in a highly competitive and shaded situation and should be expected to be taller and more slender than the decline habitat trees which were planted mostly in an open situation. The R-squared value and other statistical data for the GLM analysis of DBH vs. age of natural and decline observations are listed in Table 13.

An attempt to rate crowns by foliar color and appearance did not yield a reliable measure of decline (see Appendix Table 11). It was felt that this was caused by the latent symptoms so typical of declining white pines. A typical tree might have been declining for a period of several months to a year before there was visual expression of foliar symptoms. Only trees in the latter stages of decline and those in good health could be easily compared with a crown rating scale. An example of foliage from these two types of crowns is shown in Figure 29. The foliage to the left had all needles present while the foliage to the right had the previous year's needles missing.

Another index for growth quality, related to the height/age index, was the interwhorl or increment record measure-

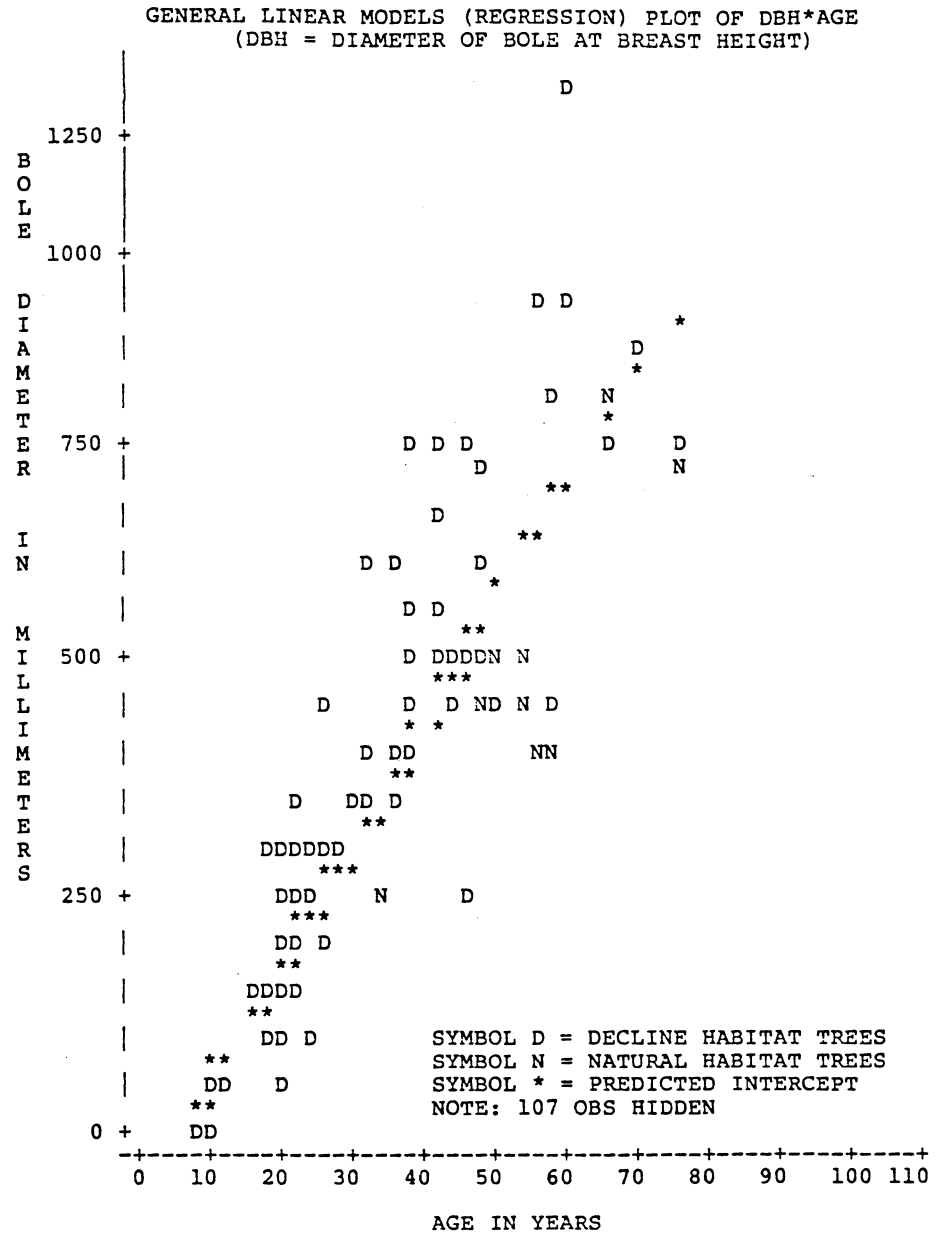


Figure 28: Comparison of diameter (DBH) vs. age for decline and natural habitat trees.

TABLE 13

General linear models statistics for DBH* vs. age of natural and decline habitat trees

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DBH (BOLE DIAMETER IN MILLIMETERS)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	1	4264565.41454284	4264565.41454284
ERROR	102	1739555.80661101	17054.46869226
CORRECTED TOTAL	103	6004121.22115385	

MODEL F = 250.06 PR > F = 0.0001

R-SQUARE	C.V.	STD DEV	DBH MEAN
0.710273	36.1339	130.59275896	361.41346154

SOURCE	DF	TYPE I SS	F VALUE	PR > F
AGE	1	4264565.41454284	250.06	0.0001

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
AGE	1	4264565.41454284	250.06	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-53.12711896	-1.82	0.0715	29.17546927
AGE	12.84248447	15.81	0.0001	0.81213973

* DBH = diameter of bole at breast height.

1=current year's needles 2=previous year's needles

Figure 29: A comparison of foliage from a high quality crown (left) and a poor quality crown (right).

ments. These measurements were of course a history of the annual growth rate of a tree. When converted to a standard, such as the percent of growth per year over a 10-year-period, both increment borings and interwhorl measurements could be compared on a similar index. A comparison of the average of decline vs. natural habitat growth rates over a 10-year-period is illustrated in Figure 30. Natural habitat trees generally increased in growth over the past 10 years, while the decline habitat tree growth decreased during this same period.

COMPARISON OF SITE QUALITY DATA--There were several site quality factors, which when occurring in concert and individually, varied consistently between the natural and decline habitats. Two of these factors were obtained from soil data and included soil pH and soil texture.

An average of soil pH differed significantly between the two habitat types. When evaluated using discrim analysis with Statistical Analysis System (143) "discrim procedure", soil pH separated between habitats as a single factor in 95.79% of the decline habitat observations and 66.67% of the natural habitat observations. Although by using SAS one was not able to classify as many of the natural habitat observations to the natural habitat group, it should be emphasized that the SAS program did not evaluate the pH readings as

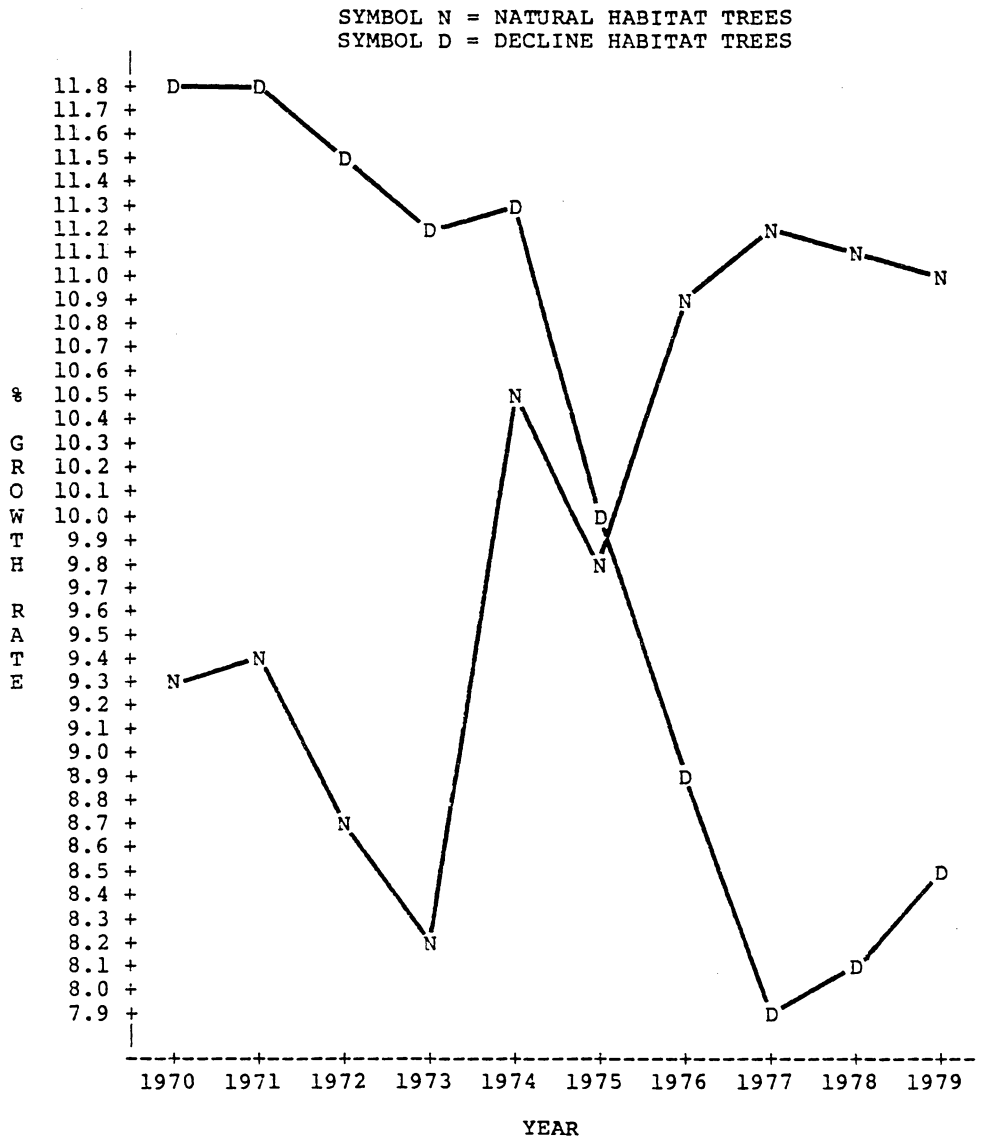
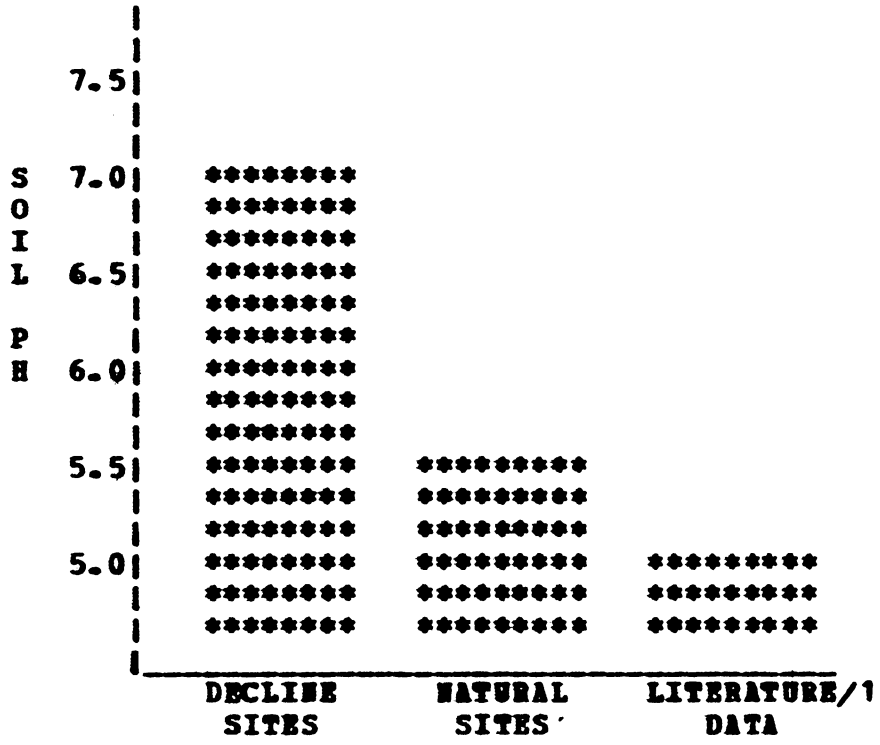


Figure 30: Combined interwhorl and increment core readings (means) of all natural vs. decline habitat trees over a 10-year period.

their actual chemical values. Due to this incapability, several of the natural habitat readings at the upper end of their range (6.0) were classified into the decline habitat group. It was evident from the averages of the two groups (see Figure 31) that there was a 50-fold difference between the pH values. This difference could not be detected using SAS and thus several observations were discounted by discrim analysis as belonging to the natural habitat group. The average pH for the decline habitat was 6.95 with a range of 5.9 to 8.1. The average pH of the natural habitat was 5.50 with a range 5.0 to 6.0. In the literature, the ideal pH for favorable white pine growth was between 4.0 and 6.0 (an average of 5.0) (64, 184).

Another reliable indicator of site quality was soil texture, particularly the clay content. The decline habitat soils were consistently high in clay, while the natural habitat soils were consistently low in clay (see Figure 32). When analyzed using SAS, the average clay content divided easily between the two habitat types. Using SAS one was able to classify 94.62% of the decline habitat observations as belonging to this group and 83.33% of the natural habitat observations as belonging to the natural habitat group. The average clay content in the soils above and in the root mat layer of decline habitat trees was 37.05% and for the natu-



/1_ LITERATURE DATA = Folwells, H. A. 1965. Silvics of forest trees of the United States. USDA-FS, AHB No. 271. p. 329-337. (64) and Yawney, H. E. and Trimble, G. R., Jr. 1958. West Virginia's unusual pine plantation. J. For. 56:849-851. (184).

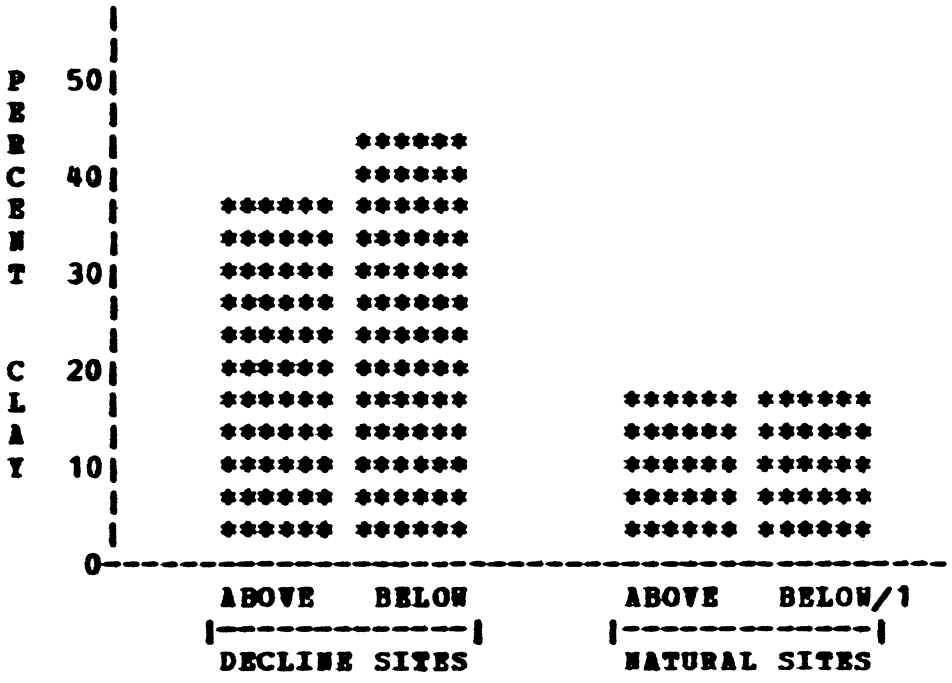
Figure 31: Average soil pH values for combined natural vs. decline habitats and the literature data.

ral habitat trees 17.76%. The average clay content in the soils directly beneath the root mat layer of decline habitat trees was 43.99% and for the natural habitat trees 17.95%. This difference between groups was obvious with 19.29% higher clay content in the area in and above the root mat area of decline trees and 26.04% more clay in the area beneath the root mat area in decline sites.

Soil chemistry varied between the two habitat types with consistently low nutrient levels in the natural habitat and consistently high levels in the decline group (perhaps due to over-fertilization). Using discrim analysis one was able to separate the observations into the prescribed group in 100% of the decline and natural observations in soils above and in the root zones as well as soils below the root zones.

It was hard to determine if this difference in nutrient levels played a significant role in decline. One factor which may have been affected by low nutrients in the natural habitat was the mycorrhizal population. Mycorrhizae are known to be favored by environments low in nutrients (71). High nutrient levels may have played a detrimental role in the mycorrhizal populations of decline habitat sites.

The amount of competition from other trees did not appear to differ between the two habitat types with all of the natural habitat trees being 100% ingressed by adjacent plants.



/1_ ABOVE = above and in the root zones, and
BELOW = below the root zones

Figure 32: The average of percent clay for decline vs. natural habitat sites.

However, turfgrass was not present on the natural habitat site while present on almost all of the decline sites. Turfgrass was viewed as a prime competitor with tree feeder roots for nutrients and water and as a major contributor to weakening decline habitat trees.

The forest environment did not have this turf layer present but instead had a layer of needle mulch and litter. This layer enhanced growth as it maintained an acid soil pH, held in moisture, increased the organic content of the soil and protected the soil from erosion, compaction and other disturbances.

A comparison of a typical soil profile of a natural vs. a decline habitat is illustrated in Figure 33. In the natural habitat, a duff layer protects the deep, sandy soils from compaction, protects the soil around the shallow feeder roots from freezing allowing nutrients and water to be taken up year round, and holds sufficient moisture for a longer period of time for uptake by the feeder roots. The soils in the natural habitat site allow plenty of room for rooting both vertically and laterally. Sandy soils drain easily and do not allow water to stand and reduce soil oxygen. These qualities are the exact opposite for the typical decline habitat site with shallow roots freezing in winter, being easily damaged, and competing with turf for nutrients and wa-

ter. Heavy, clay soils in the decline sites hold too much water, too long and hold water tenaciously when in low amounts.

Root mat thickness was a direct result of several soil factors which limited the depth and amount of water available to a tree root system. Clay content, soil compaction, and soil disturbance all played a key role in root mat thickness. Root mat thickness averaged only 17.1 cm for decline habitat trees and 45.5 cm for natural habitat trees (see Figure 34). A discrim analysis of root mat thicknesses enabled one to classify 100% of the observations from each habitat as belonging to the prescribed group.

Soils high in clay were more likely to have limited root mat areas. Clay layers beneath the root mats may have limited root depth by contributing to poor soil aeration (caused a lack of available oxygen), acting as a barrier to free soil water, and a physical barrier to feeder roots. Soil compaction both before and after planting compounded these problems and caused clay layers to become more impenetrable and in many cases created a traffic pan. Soil disturbance usually caused compaction and in many cases higher clay content by the displacement of subsoils into root zones. A typical root mat area of a decline habitat tree is illustrated in Figure 35. The roots in this drawing were

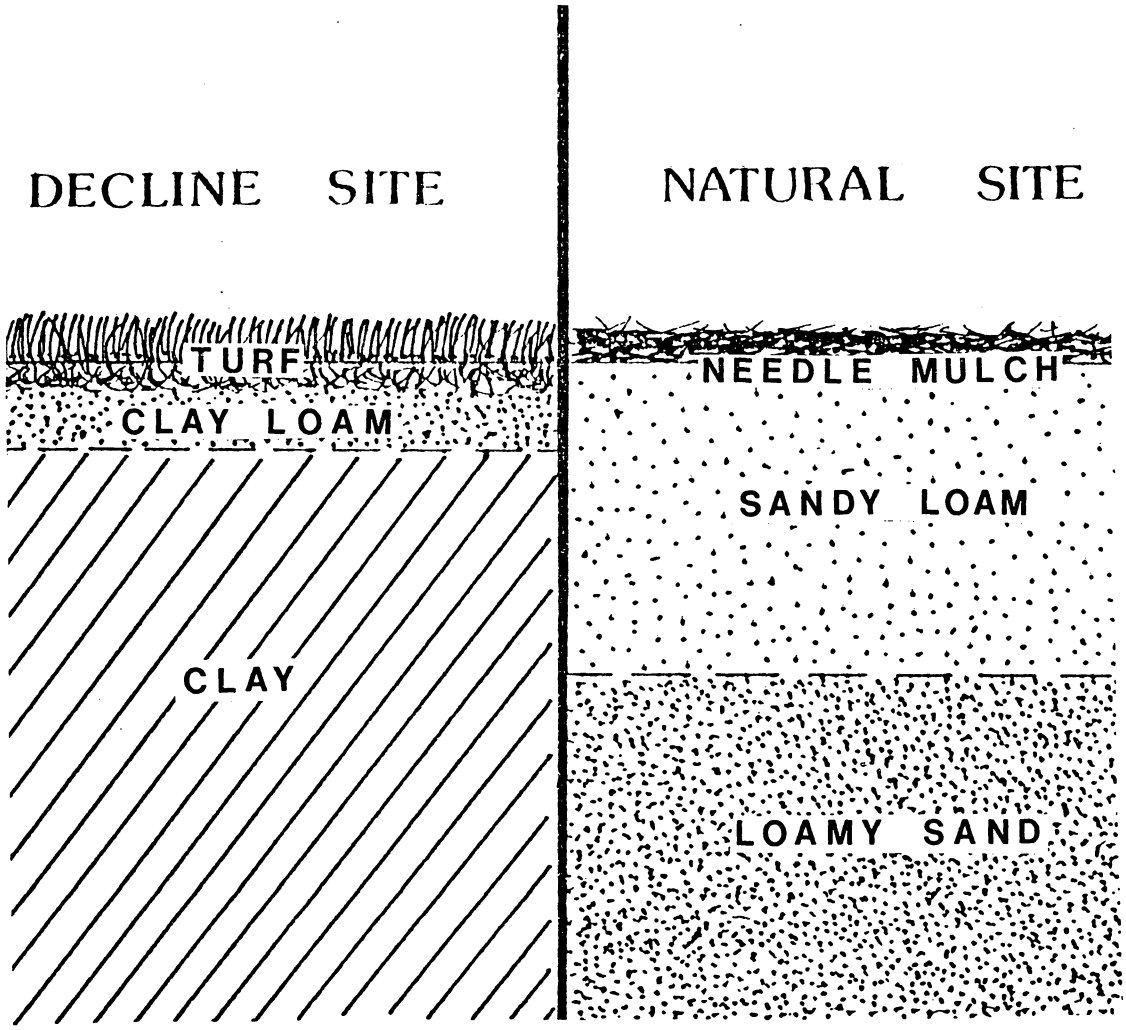
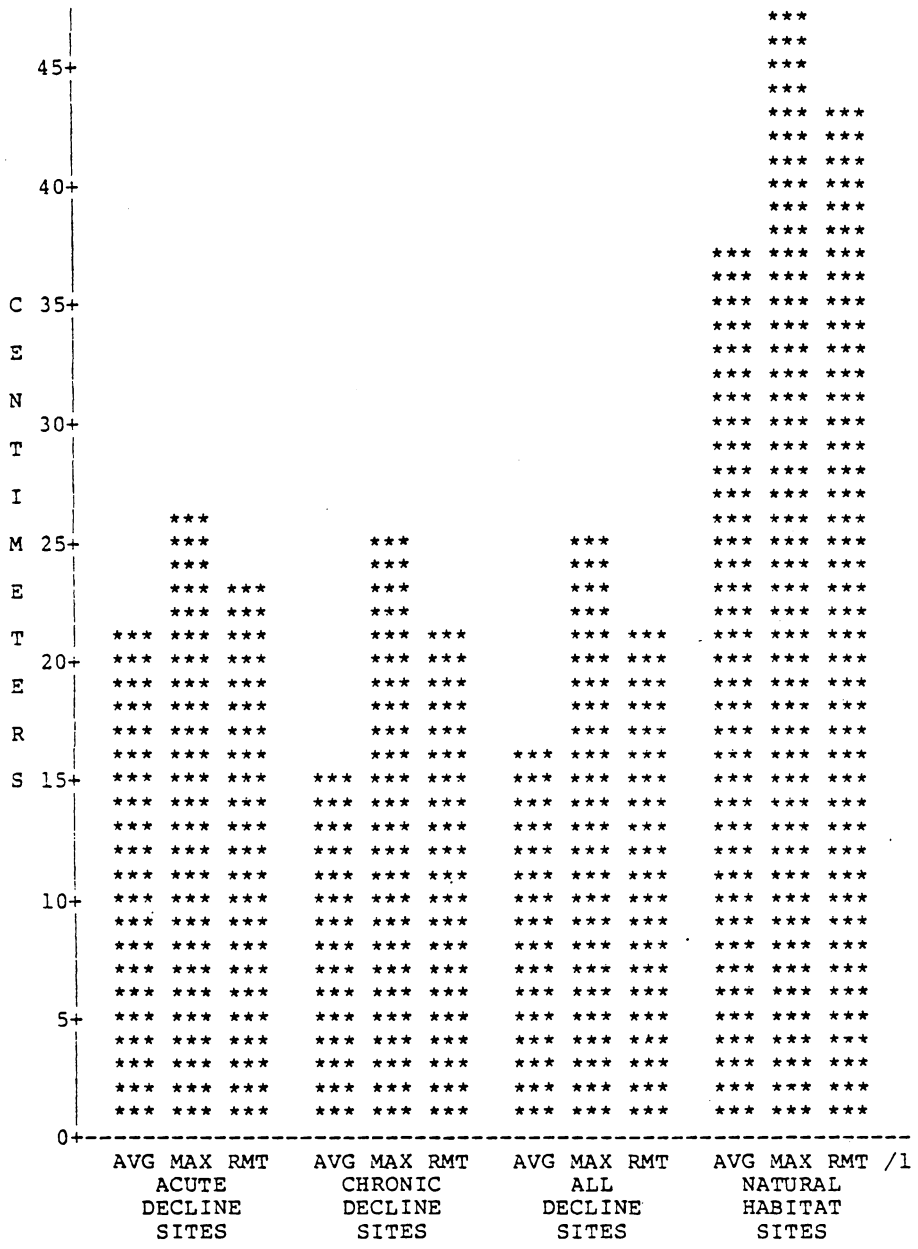


Figure 33: Comparison of typical soil profiles of a natural vs. a decline habitat.



1_ AVG=average rootmat depth
MAX=maximum rootmat depth
RMT=total rootmat thickness

Figure 34: Comparison of root depths and thicknesses for decline vs. natural habitats.

limited by an impervious layer of compacted clay, which stopped root growth due to the inavailability of oxygen and water. This illustration is a typical representation of many decline habitat sites.

Soil impedance (the amount of concrete, asphalt, compacted zones, and other disturbed areas) did not occur consistently from tree to tree. However, they were probably important when combined with the other factors listed above. Disturbance factors were evaluated using discrim analysis together and in sets of two with a variable difference between the groups. None of the natural habitat trees were classified into the decline group using the analysis, but many of the decline observations were classified wrong due to impedance factors not present on all trees.

When the most important site quality factors considered in this study (% clay for both above and below the roots, pH above and below the roots and root mat thickness), were combined, it was apparent that there was a very large difference between the two habitat groups. When combined in a discrim analysis dataset, these factors were classified as belonging to their previously assigned groups in 90.22% of the decline habitat observations and 100% of the natural habitat observations (see Appendix B for details).

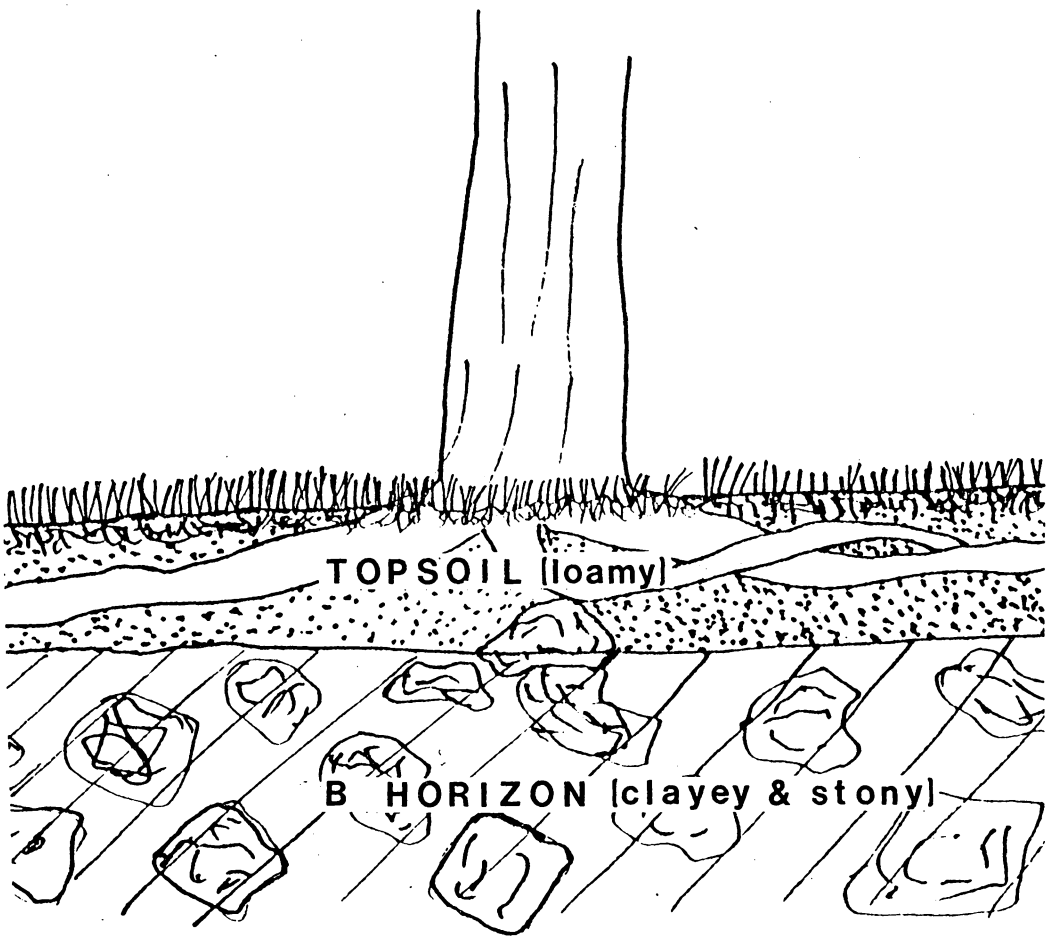


Figure 35: Typical rooting area observed in decline habitat sites.

Posterior probability that each observation belonged to its particular group varied, with 9 of the decline observations being classified into the natural habitat group. Tree code #'s 3, 16, 26, 69, 70, 71, 84, 96, and 99 were classified as fitting into the natural habitat criteria. This information did confirm that discrim analysis may be of future value as a modeling system to detect low and high hazard sites for planting white pines. With some refinement future workers could plug in tree growth and site data and be able to determine whether to plant white pine. Also, the fact that 9 observations were segregated from the decline habitat was an indication that higher quality sites could be detected using discrim analysis and they were useful in this study for comparison as controls if need be.

Although it appeared that these were the most significant factors affecting site quality in this investigation it must be emphasized that certain aspects of experimental design did favor these results. These included the parent material differences between the two habitat types and the way in which data were examined. However, the goal of this experiment was to compare a high quality natural habitat site to poor quality decline habitat sites. This goal has been achieved in that the extreme differences have been illustrated by the results of this study.

Other contributing factors of importance could not be analyzed using a statistical method. These included secondary biotic stress such as insects, especially the pine bark aphid and the white pine aphid. Also soil disturbance was a very important factor for which numerical data could not be assigned directly. However, all site quality data discussed and analyzed previously were an indirect way to measure soil disturbance.

Unfortunately, direct impedance and disturbance data could not be analyzed due to their variability from site to site. The amount of disturbance on natural habitat sites was minimal, this was not the case with decline sites. Damage by man and weather was also important in many of the decline observations, but likewise did not lend themselves to be analyzed as numerical data. The drought during the past five years in Virginia has probably affected the incidence of white pine decline. In addition, heredity of disease susceptibility was one factor which could not be evaluated to determine how it affected decline. When all these factors were considered with the major contributors to poor site quality, tree growth indicators produced the differences observed and discussed above.

4.2 STUDY OF MONTHLY FOLIAR COLOR CHANGES OF POOR VS. GOOD QUALITY SITE TREES

Needle color seemed to fluctuate normally throughout the growth cycle of the white pine (65, 135). However, this color usually remained in the blue-green area. This was not the case with declining trees which tended to lose their blue-green color and turned a chlorotic yellow as they declined.

Another early indication of the decline syndrome was yellowing over the winter months. This was probably caused by water stress since shallow-rooted trees, such as those on poor quality sites, had most of their roots in the upper 6 cm of the soil with very few sinker roots to enhance uptake of water (59, 97, 103, 109, 126). When the ground froze during the cold winter months the surface water table may have frozen as well. This may have made most of the water unavailable for uptake by the stressed, shallow-rooted pines and they yellowed. Probably the older the tree and larger the biomass, the more readily this yellowing may have occurred. It seemed that as the warmer spring months occurred the water was probably freed and the trees greened-up.

This phenomenon was more readily observed on trees located on poor quality sites than those growing on high quality sites. These poorer sites had the qualities discussed in the previous section which included clayey textures and dis-

turbed soil profiles (particularly those with shallow rooting areas). The higher quality sites had sandy to loamy soils with undisturbed profiles and deep rooting areas.

Although colors fluctuated from tree to tree throughout the year, trees had a marked change in color during the winter months if they were located on these poor quality growing sites. Typical plots of color readings, over a period of 12 months, for two trees, one on a good quality site (see Figure 36) and the other on a poor quality site (see Figure 37) are compared below. Please refer to the Appendix C for plots of other trees in the study. It was evident from these plots that trees located on good sites (tree codes 3, 18, 105, 106, 107, 109, and 110) maintained needle color during the winter months, while those on poor quality sites yellowed over winter. The plot lines for tree code 108 flucuated somewhat and could have been caused by a mis-reading of colors or some other factor such as the shallow root zone at this location. Other observations in this study (tree codes 1, 2, 4, 5, and 19) had a loss of green color in the winter months and were located on poor quality sites. Tree codes 3 and 18 were considered as part of the decline habitat group in the previous study but their needle color did not change over the winter months. Both of these trees had rooting areas deeper than the average decline habitat tree and this could explain this phenomenon. Also tree #3

was, after discrim analysis, apparently misclassified into the decline criterion model.

This loss in chlorophyll was undoubtedly detrimental to the tree's overall health. As this phenomenon was compounded over time (a loss in color annually) the affected tree declined due to a loss in food reserves.

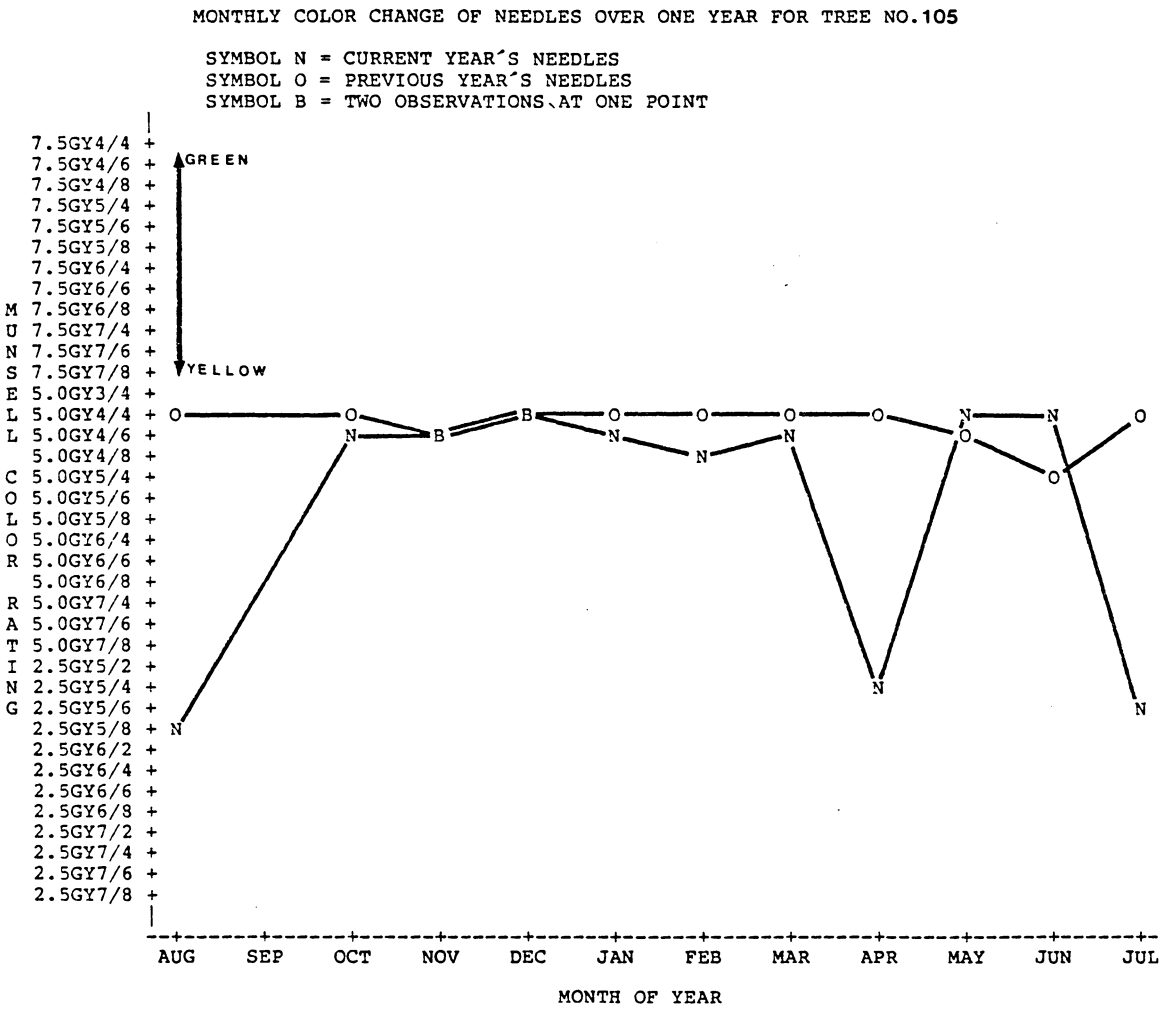


Figure 36: Needle color change over a 12-month period for a good quality site tree (#105).

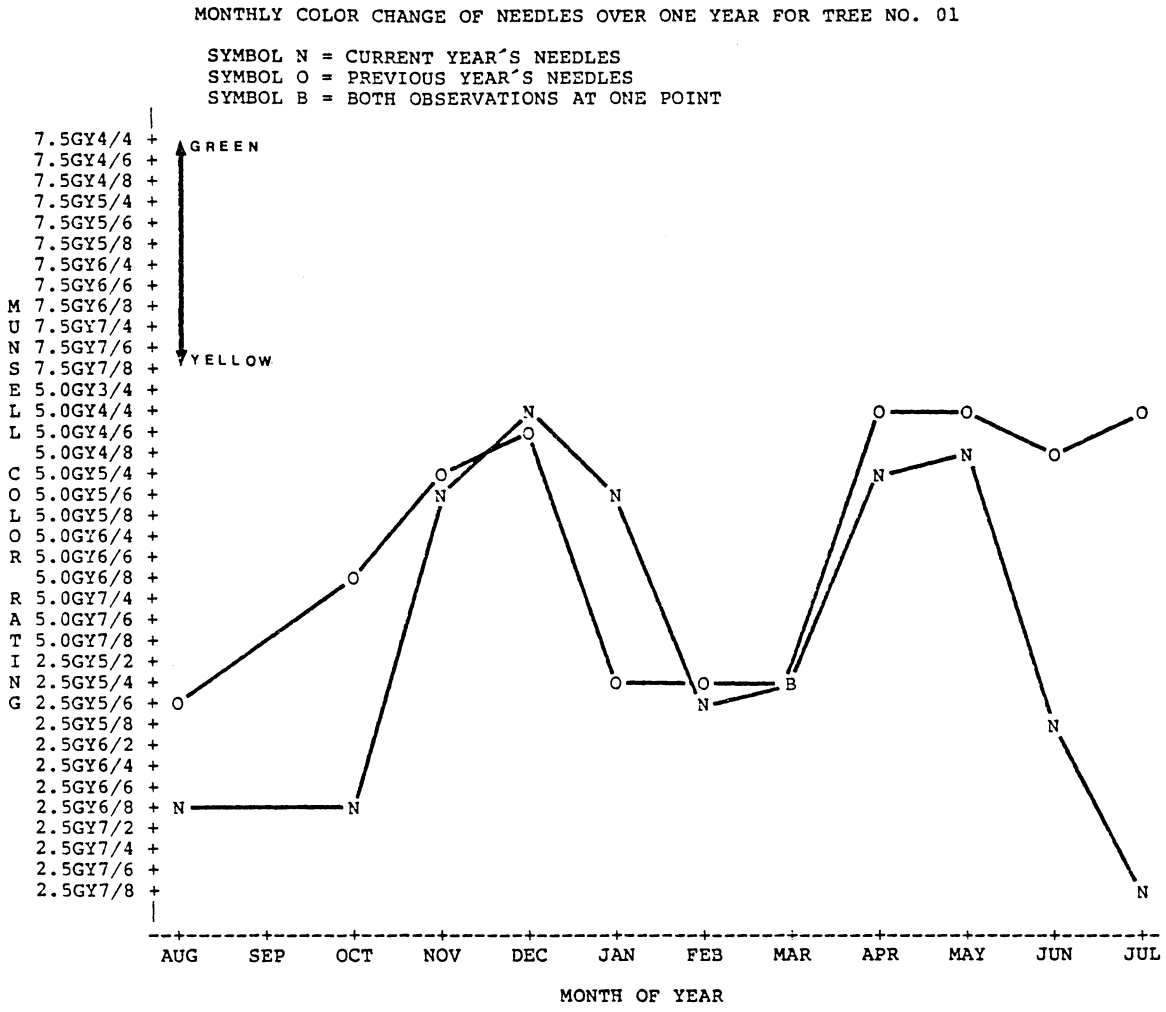


Figure 37: Needle color change over a 12-month period for a poor quality site tree (#1).

4.3 PINEWOOD NEMATODE STUDY

After trees in Pulaski and Rockbridge counties were assayed, the pinewood nematode was only found on samples from the original site (see Figure 38 and 39). There were counts of up to 1200 nematodes/100 g of wood chips from a 17-year-old white pine on the Rockbridge County site. The bole wood produced 35 nematodes per 100 g while counts ranged between 0-1 nematodes/100 g of wood chips from the stump.

These counts were not consistent with those recorded in the literature which included estimates in the 1000's on Japanese pine species (84). However, these data may have been appropriate for North American pines since they were suspected to be resistant to the pathogen. This resistance quality may aid to strengthened the hypothesis that the nematode was a secondary biotic agent similar to the white pine and pine bark aphids. It was suspected that the nematode may only be a threat to *P. strobus* when combined with other stress factors.

Other trees were sampled at the Rockbridge County site with nematodes found only in the stumps of several dead 30-40 year old white pines. These specimens were not positively identified as *Bursaphelenchus lignicolus*.

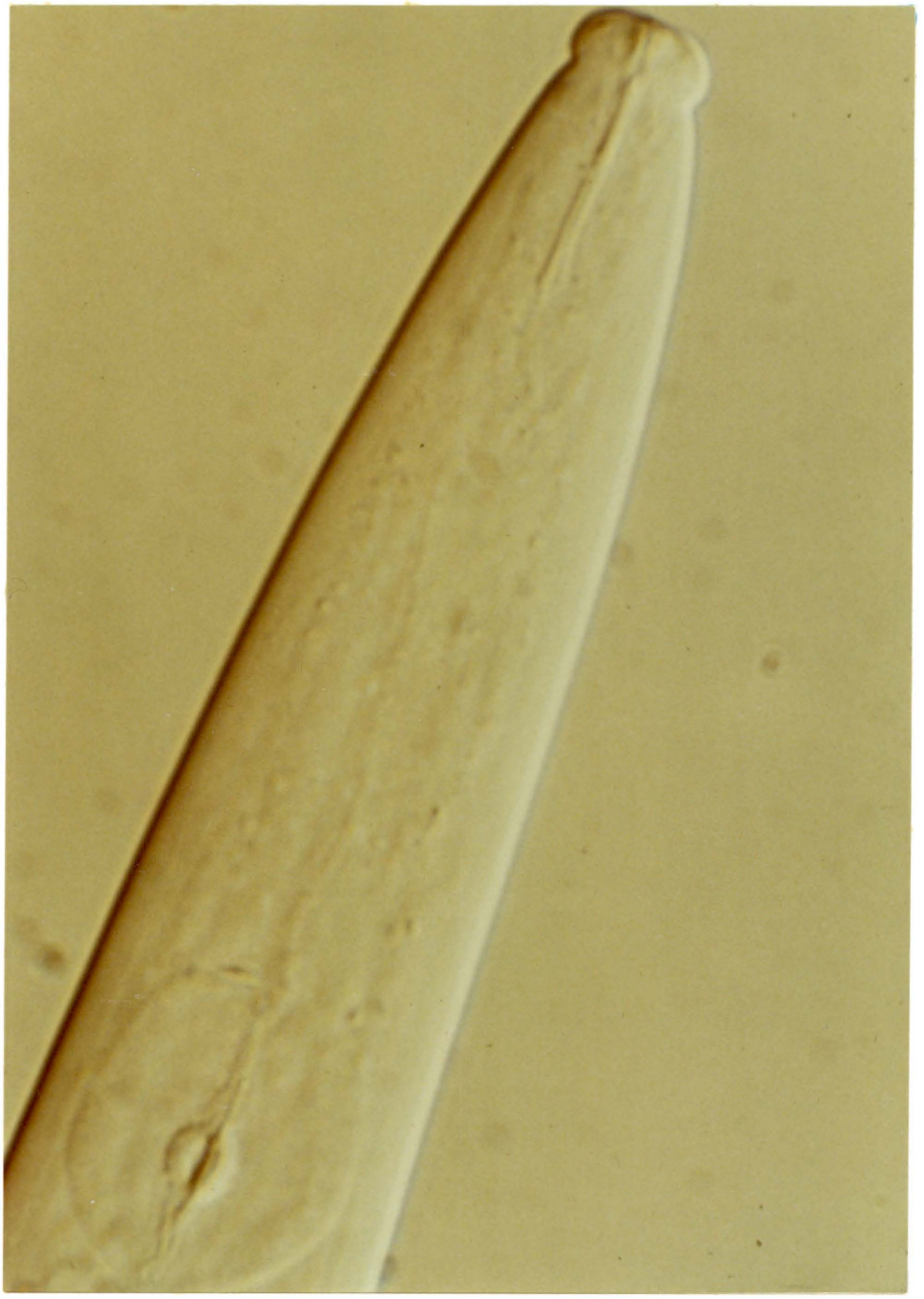


Figure 38: Anterior end of pinewood nematode specimen extracted from a Rockbridge County, VA. white pine (#78).

Figure 39: Posterior end of pinewood nematode specimen extracted from a Rockbridge County, VA. white pine (#78).

Chapter V

CONCLUSIONS AND SUMMARY

For over 80 years numerous investigators have attributed mysteriously dying and diseased *Pinus strobus* to a multitude of causal factors. In most reports, an attempt has been made to identify a single factor as the disease-causing agent. This "one-cause, one-disease" philosophy has been a traditional approach to plant disease diagnosis. Although many of the old reports of white pine diseases seem similar to WPD incidents, it is only speculation that these were the same problems observed on Virginia's landscapes today. However, this investigator is convinced that several of the disease incidents described in the early literature are similar to WPD.

On Virginia's landscapes WPD is a disease complex with an etiology similar to other decline syndromes. This decline can be divided into two syndromes which seem to work in concert dependent upon the presence of certain disease-causing factors. WPD has been subcategorized into an acute decline syndrome, which results in death within several months of visible symptoms (chlorosis, wilting, resinosis, and necrosis), and a chronic decline syndrome, which may take years for death to occur with a slow sequence of symptoms (chloro-

sis, shortened internodal growth, premature annual defoliation producing a thin crown, some needle drooping, especially in the winter, and eventual drying up of the tree producing shriveled bark). The separation of these two groups of symptoms is only artificial as in nature it is very hard, if not impossible, to predict the end results. The timespan in which these syndromes occur is dependent upon certain causal factors present and the environment interacting with the host.

After a systematic indexing method for collecting data from a group of natural and decline habitat trees was developed, these data were compiled to determine which factors were present on decline trees which were not present in a natural habitat. Several tree growth indicators were weighed against a group of site quality and disease indicators to determine a correlation. A height vs. age index seemed to be the most reliable indicator for tree growth quality. However, some consideration was given to the effect of shading on open-grown trees (such as some of those in decline habitats) vs. close-grown trees (such as those grown in the forest). There was some evidence that this hypothesis may have been unfounded since trees in the decline habitats were close-grown at about the same basal density as the natural habitat site and were still shorter than their forest counterparts of similar age. However, when a compar-

ison is made of the regression analyses for height vs. age and DBH vs. age it becomes evident that natural habitat trees are taller and more slender. The inter-whorl(-nodal) measurements plotted as percent growth per year over a 10-year-period seemed to be a reliable record of growth history. An index of seasonal foliar color changes over a period of years may have been another possible indicator of the rate of change in tree health. A single suitable indicator of growth quality for this type of study has not yet been found and only several indicators weighed together may prove reliable.

The following factors, after combining field observations with laboratory analyses, were found associated with decline sites and could be suspected as decline-causing factors (see Figure 40). Several of these factors were also present at times in the natural habitat but never occurred in concert.

1. Competition and shading were present on most decline sites with turfgrass being a major competitor with feeder roots for nutrients and water. Although shading and competition from other tree species were present in the forest, turfgrass was not and was considered a factor of great importance to initiation of decline.

2. Soils in decline sites had generally disturbed profiles both physically and chemically when compared to the natural habitat. A comparison of two soil profiles was illustrated earlier in Figure 33. Physical disturbances produced:
   a) Displaced subsoils which were high in clay (averaging 37.05% for soils above and in the root zones and 43.99% for soils beneath the roots vs. 17.76% and 17.95% respectively for the natural site) and generally had a high pH (averaging 6.95 for decline sites vs. 5.50 for the natural site).
   b) Highly compacted soils above and beneath tree root zones depending upon time of disturbance.
   c) Mechanical damage to tree roots when soils were disturbed on existing tree sites.
3. Soils were chemically disturbed by concentrations of salts from fertilizers, lime, de-icing chemicals, and pollutants of various types.
4. Roots were impeded both vertically and laterally from poor choice of planting locations and techniques, disturbances caused by construction activities reducing existing root zones and trees growing into areas restricted by physical barriers.

5. Abiotic stresses, other than those listed above, such as mechanical damage to the aerial tree parts by man and nature, chemical injury to the aerial parts by oxidants and off-target pesticides were involved.
6. It appeared that after these abiotic stress factors initiated decline, secondary biotic agents continued to weaken decline trees until they followed the course of the acute or chronic decline syndromes, dependent upon the ability of these agents to kill their hosts. Considered in this group were the white pine aphid, pine bark aphid, root aphids, and the pinewood nematode.

The quality of growth on decline sites was poor for the majority of trees observed in this study. There were a few exceptions to this observation since not all trees on the decline sites were declining. Several trees appeared in good health even though many site factors were poor. In these cases there were several factors at each site which favored better growth. Most of these trees had deeper root zones than declining trees. However in most cases, if trees were not currently in a visible state of decline their growth quality data gave evidence that they might be eventually. Trees on poor quality growing sites were treated with the philosophy that they all had the potential for eventual

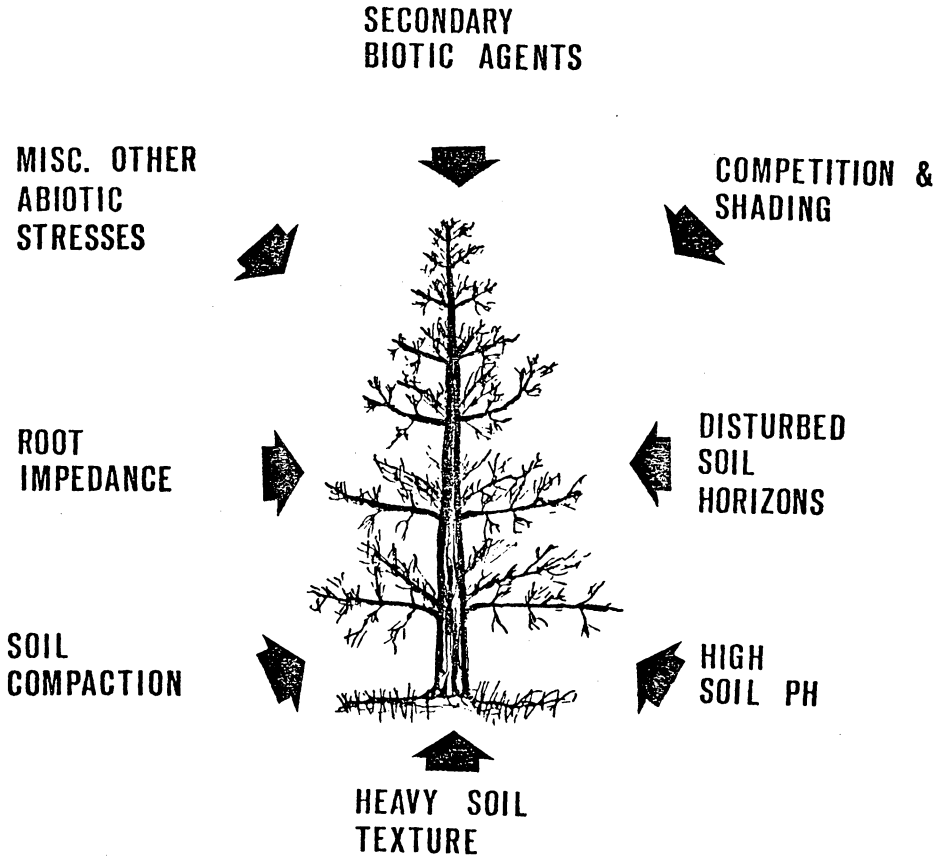


Figure 40: Summary of factors contributing to white pine decline.

decline and premature death. This time factor seemed to correlate with age and shoot to root ratio. It appeared that when trees grew older and larger they probably outgrew their rooting area, moisture may have became a limiting factor and they declined.

The major factor associated with poor quality growing sites was the changing of natural soil profiles by construction activities. When soils were disturbed the natural water table may have been altered resulting in poor distribution of needed water and nutrients throughout the rooting area.

The usual situation observed in this study was altering of the soils before planting. Trees were usually landscaped into an area after buildings and roads were constructed. Original tree inhabitants were either removed in this process or damaged to a point where they did not survive.

Soil disturbances followed several patterns. One was where deep subsoils were dug from a foundation and spread out over the original profiles to reshape a site. In this case these soils were extremely clayey, had broken-up parent material mixed-in, which may have raised the pH if it was a limestone, and were compacted by earth-moving equipment to a point where a traffic pan was formed. When sites were landscaped a thin layer of topsoil (usually 6-10 cm) was graded over these soils where turfgrass flourished (which in some

cases may have been due to heavy fertilization and liming) but white pines could not survive for a long period of time.

A second type of disturbance was where existing profiles were graded down, mixed-up, reshaped and landscaped. This also pulled up a deeper clayey layer which was often mixed-up with the lighter upper layers.

These situations may have created a physical barrier to water movement into tree root zones causing an inability for roots to grow in these layers. Except in extreme cases, roots may have been more likely prohibited from growth in these soils due to the unavailability of oxygen, nutrients and water rather than an inability of roots to penetrate the soils. Another problem was where water may not have percolated down as fast as it should during periods of high moisture and may have created an aeration problem to the roots (185). If these factors were present they were probably more important during times of moisture extremes and drought.

Other environmental disturbances and factors probably work in concert with the above factors to reduce the quality of growth in the traditional tree and turf landscape situation. This is not to indicate that all landscape sites are potential decline sites. If landscape sites are maintained in a manner similar to the natural habitat then white pines

and other sensitive plants should do well. However, if landscaping practices preclude the natural habitat factors, white pines planted in these sites may have a poor chance of long-term survival.

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Appendix A

APPENDIX TABLES

APPENDIX TABLE 1

General appearance data of decline and natural habitat trees

/1	BARK						BOLE		CROWN							
TREE CODE	DARK	LIGHT	COARSE	SOUND	HARD	SOFT	FURROWED	TAPERED	#FORKS	THIN	NOTCHED	NONE	WILTED	TUFTED	%CHLOROTIC	%NECROTIC /2	CHLOROTIC /3	NECROTIC
1	X		X		X		X	X	1	X			X		100	10	B	B
2		X	X			X	X	X	2	X			X		100	0	B	
3	X		X			X	X	X	0	X			X		40	0	B	B
4	X		X		X		X	X	0	X			X		100	15	B	B
5		X	X			X	X	X	1	X			X		100	10	B	B
6		X	X			X	X	X	5	X			X		75	10	N	B
7	X		X			X		X	5	X			X		100	5	N	B
8	X		X		X		X	X	0	X			X		90	5	B	B
9		X	X			X	X	X	0		X		X		70	1	B	
10	X		X			X	X	X	0	X			X		100	5	B	B
11		X		X		X		X	1	X					0	10		B
12		X	X			X	X	X	0	X			X		80	1	B	B
13		X		X		X	X	X	0	X					65	5	N	B
14		X		X		X	X	X	0		X				20	5	N	B
15		X		X		X	X	X	0		X				35	0	N	
16	X		X		X			X	0	X			X		50	10	B	B
17		X		X		X		X	1		X				25	5	N	B
18		X		X		X		X	3		X				0	0		
19	X		X			X		X	0	X			X		50	5	B	B
20		X		X		X		X	0		X				10	10	B	B
21	X		X			X	X	X	4	X					0	5		B
22		X	X			X	X	X	1	X			X		100	10	B	B
23		X	X			X		X	0		X				10	5	N	B
24		X		X		X	X	X	3	X					40	5	N	B
25		X		X		X	X	X	0		X				15	15	N	B
26		X		X		X	X	X	2	X					30	5	N	B
27		X		X		X	X	X	2		X				20	5	N	B
28	X			X	X		X	X	0	X					0	15		B
29		X		X		X	X	X	1		X				5	5	N	B
30	X			X		X	X	X	1		X				30	10	N	B
31		X		X		X	X	X	2	X			X		45	10	N	B

Appendix Table 1

(continued)

/1	BARK						BOLE			CROWN					/2	/3		
TREE CODE	DARK	LIGHT	COARSE	SOUND	HARD	SOFT	PUNKY	TAPERED	CYLINDRICAL	# FORKS	THIN	NORMAL	THICK	LIGHT	TUFTED	% CROWN	% CROWN	CHLOROTIC	NECROTIC
32		X		X		X		X		0		X				25	2	B	B
33		X	X			X		X		0	X				X	0	0		
34		X	X		X			X		1		X			X	70	5	N	
35	X		X		X		X	X		1	X				X	80	15	B	B
36		X		X		X	X	X		3		X				10	5	N	B
37		X		X		X	X	X		0		X				15	0	B	
38		X		X		X	X	X		0		X				0	5		B
39		X		X		X	X	X		0	X					50	5	B	
40		X	X			X	X	X		0	X				X	90	0	B	B
41		X		X		X		X		0		X				0	5		B
42		X		X		X	X	X		0		X				15	5	B	B
43	X		X			X	X	X		1	X				X	50	5	B	B
44		X		X		X	X	X		0		X				5	0	B	
45		X		X		X		X		0		X				10	0	N	
46	X		X			X	X	X		1		X		X	X	50	10	B	B
47		X		X		X		X		0		X				10	0	N	
48		X	X		X		X	X		0	X				X	75	10	B	B
49		X		X		X		X		0		X				0	5		B
50		X	X			X	X	X		0	X				X	100	5	B	B
51		X		X		X			X	0		X				0	0		
52		X		X		X			X	0		X				0	0		
53		X		X		X			X	0		X				0	0		
54		X		X		X			X	0		X				0	0		
55		X		X		X			X	0		X				0	0		
56		X		X		X			X	0		X				0	0		
57		X		X		X	X	X		0		X				35	5	N	B
58		X		X		X	X	X		0		X				30	5	N	B
59		X		X		X	X	X		1		X				35	0	N	
60		X		X		X		X		0		X				0	0		
61		X		X		X	X	X		1		X				25	5	N	N
62		X		X		X	X	X		2		X				40	10	N	N

Appendix Table 1

(continued)

/1	BARK						BOLE			CROWN					/2	/3	
TREE CODE	DARK	LIGHT	COARSE	SOUND	HARD	SOFT	FURROWED	TAPERING	CYLINDRICAL	#FORKS	THIN	MODERATE	THICK	THIN	MODERATE	THICK	% CROWN LOSS	% NECROTIC	CHLOROTIC	NECROTIC
63		X		X		X	X	X		1		X					30	0	N	
64		X		X		X	X	X		0		X		X			100	5	N	N
65		X		X		X	X	X		0		X		X			100	5	N	N
66		X		X		X	X	X		0		X					0	0		
67	X		X		X		X	X		0	X					X	100	100	B	O
68	X			X		X	X	X		0	X					X	100	5	B	B
69		X		X		X	X	X		0	X						100	10	B	B
70		X		X		X		X		0		X					40	0	B	
71	X			X		X	X	X		0	X					X	100	100	B	N
72	X		X			X	X	X		0	X					X	30	20	B	N
73	X			X		X	X	X		0	X					X	50	10	N	B
74		X		X		X	X	X		2		X					0	0		
75		X		X		X	X	X		0		X				X	100	100	B	O
76		X		X		X	X	X		0		X				X	50	10	O	O
77		X		X		X	X	X		1		X					0	0		
78	X		X		X		X	X		0			X			X	0	100		B
79		X		X		X	X	X		0		X				X	0	0		
80		X		X		X	X	X		1		X					0	0		
81		X		X		X	X	X		0	X					X	50	0	B	
82		X		X		X	X	X		2	X					X	75	0	B	
83		X		X		X	X	X		3		X				X	30	0	B	
84		X		X		X	X	X		0	X					X	0	0		
85		X		X		X	X	X		0	X					X	0	0		
86		X		X		X	X	X		0		X				X	0	0		
87		X		X		X	X	X		0	X					X	100	0	B	
88		X		X	X		X	X		0	X					X	75	10	B	B
89		X		X		X	X	X		0	X					X	50	5	B	B
90		X		X		X	X	X		2	X					X	30	5	B	B
91		X	X			X	X	X		0	X					X	100	5	B	B
92		X	X			X	X	X		0	X					X	50	0	B	
93	X		X		X		X	X		0			X			X	0	100		B

Appendix Table 1

(continued)

/1	BARK							BOLE			CROWN					/2		/3	
TREE CODE	DARK	LIGHT	CORKY	SOUND	HARD	SOFT	FURROWED	TAPERED	CYLINDER	# FORKS	THIN	NORMAL	NONE	WILTED	TUFTED	% CHLOROTIC	% NECROTIC	CHLOROTIC	NECROTIC
94	X		X		X		X	X		0			X			0	100		B
95		X		X		X	X	X		0	X				X	50	10	B	B
96	X		X		X		X	X		1	X				X	0	90		O
97		X	X			X	X	X		0	X				X	100	0	B	
98		X		X		X	X	X		0		X				100	0	B	
99	X		X		X		X	X		0			X			0	100		B
100	X		X			X	X	X		2	X				X	100	15	B	B
101		X		X		X			X	0		X				0	0		
102		X		X		X			X	0		X				0	0		
103		X		X		X			X	0		X				0	0		
104		X		X		X			X	0		X				0	0		

/1_ TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

/2_ PERCENT GIVEN IN AMOUNT OF TYPE OF SYMBOL (N, O, B): i.e.- 30% with the letter N to the right means 30% of new needles were either chlorotic and/or necrotic

/3_ SYMBOLS FOR CROWN DATA: N = new or current year's needles, O = old or previous years' needles, B = both or all needles

APPENDIX TABLE 2

Average and maximum root depths and root mat thicknesses for natural and decline habitat trees*

TREE CODE	AVERAGE ROOT DEPTH	MAXIMUM ROOT DEPTH	ROOT-MAT THICKNESS
1	17	25	10
2	16	27	10
3	15	25	15
4	.	.	.
5	13	15	13
6	20	20	5
7	15	20	18
8	21	25	15
9	26	30	15
10	20	25	15
11	13	30	18
12	22	25	15
13	15	20	15
14	21	25	10
15	21	25	10
16	43	50	30
17	50	50	30
18	25	25	25
19	35	35	15
20	35	35	12
21	16	16	15
22	30	30	15
23	23	25	15
24	15	30	15
25	25	30	20
26	25	30	20
27	25	30	20
28	14	21	14
29	14	15	14
30	14	15	14
31	10	25	15
32	25	30	17
33	25	32	15
34	37	50	15
35	35	35	20
36	33	38	25
37	6	15	13
38	25	27	15
39	20	30	18
40	27	32	15
41	15	25	15

APPENDIX TABLE 2

(Continued)

TREE CODE	AVERAGE ROOT DEPTH	MAXIMUM ROOT DEPTH	ROOT-MAT THICKNESS
42	18	25	15
43	26	38	11
44	26	35	13
45	18	30	18
46	4	14	14
47	20	30	10
48	15	20	10
49	20	35	30
50	20	38	30
51	30	40	40
52	30	40	40
53	40	50	50
54	40	50	50
55	40	50	45
56	40	50	45
57	15	25	18
58	15	25	19
59	15	25	20
60	20	30	25
61	20	20	18
62	25	45	23
63	18	18	16
64	15	15	13
65	15	25	23
66	20	20	18
67	30	30	26
68	15	25	21
69	20	25	23
70	15	15	13
71	20	25	23
72	15	30	15
73	15	30	20
74	10	10	10
75	10	10	8
76	15	17	13
77	20	25	23
78	20	35	32
79	23	23	19
80	20	20	17
81	19	27	24
82	19	28	25
83	18	25	22

APPENDIX TABLE 2

(Continued)

TREE CODE	AVERAGE ROOT DEPTH	MAXIMUM ROOT DEPTH	ROOT-MAT THICKNESS
84	15	25	23
85	10	20	18
86	10	20	18
87	20	30	25
88	20	20	15
89	15	28	23
90	15	28	23
91	-	-	-
92	15	25	18
93	10	25	23
94	10	15	5
95	15	25	15
96	5	20	15
97	10	10	10
98	5	5	5
99	31	36	7
100	5	12	10
101	40	50	45
102	40	50	50
103	40	50	50
104	30	40	40

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

(-) = data missing or not available

APPENDIX TABLE 3

Competition and impedence factors for natural and decline habitat trees*

TREE CODE	% COMPETITION/1	% TURF /2	% ASPHALT COVER/3	% SUBTERRANEAN DISTURBANCE/4	% UNIMPEDED/5
1	7.5	45.1	47.1	0.3	45.1
2	13.6	86.4	10.1	13.6	35.3
3	9.8	98.4	1.2	12.2	79.5
4	5.5	48.1	21.8	99.8	0.2
5	76.8	65.7	16.1	12.1	19.2
6	12.2	43.5	50.6	0.0	40.2
7	3.9	44.4	51.3	0.5	44.4
8	17.7	25.7	56.7	10.2	17.6
9	52.3	41.8	34.3	16.8	6.4
10	16.7	28.8	66.9	9.2	18.6
11	71.9	90.0	0.0	0.0	28.3
12	6.0	15.9	84.1	0.0	9.6
13	47.8	77.0	21.6	1.4	32.9
14	68.6	57.6	30.2	13.9	12.6
15	26.8	42.7	52.8	6.6	23.7
16	88.2	71.7	28.3	0.0	2.0
17	80.0	74.4	18.3	7.3	17.6
18	74.4	26.9	38.2	0.0	10.1
19	96.8	42.3	57.7	0.0	0.0
20	96.0	16.2	19.2	0.0	0.0
21	100.0	53.7	43.2	3.1	0.0
22	100.0	64.7	35.3	0.0	0.0
23	100.0	69.3	30.7	0.0	0.0
24	100.0	19.5	8.3	0.0	0.0
25	100.0	75.9	24.1	0.0	0.0
26	93.0	94.8	0.0	5.2	7.0
27	100.0	100.0	0.0	0.0	0.0
28	100.0	100.0	0.0	0.0	0.0
29	65.2	100.0	0.0	0.0	34.8
30	100.0	100.0	0.0	0.0	0.0
31	100.0	100.0	0.0	0.0	0.0
32	93.3	42.1	57.9	0.0	3.4
33	92.5	98.5	8.0	1.3	7.5
34	66.0	98.0	0.0	11.1	31.2
35	99.9	100.0	0.0	0.0	0.1
36	87.6	94.8	5.2	0.0	12.3
37	0.0	99.8	0.2	0.0	99.8
38	0.0	87.8	12.2	0.0	87.8
39	0.0	100.0	0.0	0.0	100.0
40	19.5	100.0	0.0	0.0	80.6

Appendix Table 3

(Continued)

TREE CODE	% COMPETITION/1	% TURF /2	% ASPHALT COVER/3	% SUBTERRANEAN DISTURBANCE/4	% UNIMPEDED/5
41	30.0	100.0	0.0	0.0	70.0
42	0.0	98.5	1.5	0.0	98.5
43	25.4	100.0	0.0	0.0	74.6
44	19.3	98.9	1.1	0.0	79.6
45	33.8	100.0	0.0	0.0	66.2
46	3.6	91.3	8.8	0.0	87.6
47	51.7	100.0	0.0	0.0	48.3
48	40.4	100.0	0.0	0.0	59.5
49	0.0	79.9	20.1	0.0	79.9
50	0.0	94.1	6.0	0.0	94.1
51	100.0	0.0	0.0	0.0	0.0
52	100.0	0.0	0.0	0.0	0.0
53	100.0	0.0	0.0	0.0	0.0
54	100.0	0.0	0.0	0.0	0.0
55	100.0	0.0	0.0	0.0	0.0
56	100.0	0.0	0.0	0.0	0.0
57	84.5	69.7	30.3	0.0	2.9
58	42.3	61.7	37.2	0.0	32.2
59	41.8	65.0	35.1	0.0	36.6
60	0.0	42.6	13.0	0.0	87.1
61	99.8	40.7	23.5	0.0	0.0
62	96.8	26.9	23.1	0.0	0.0
63	98.8	45.6	4.4	0.0	0.0
64	79.1	55.5	0.0	0.0	20.9
65	79.1	55.5	0.0	0.0	20.9
66	83.8	55.5	0.0	0.0	16.2
67	95.6	100.0	0.0	0.0	4.4
68	27.0	89.4	10.6	0.0	37.1
69	100.0	100.0	0.0	0.0	0.0
70	94.6	100.0	0.0	0.0	5.4
71	92.8	100.0	0.0	0.0	7.3
72	100.0	0.0	37.1	0.0	0.0
73	100.0	0.0	38.1	0.0	0.0
74	1.5	100.0	0.0	0.0	98.5
75	2.8	100.0	0.0	0.0	97.2
76	0.0	100.0	0.0	0.0	100.0
77	0.0	100.0	0.0	0.0	100.0
78	90.2	100.0	0.0	0.0	9.8
79	76.1	100.0	0.0	0.0	23.9
80	41.7	100.0	0.0	0.0	58.4
81	78.4	15.6	23.1	0.0	6.1

Appendix Table 3

(Continued)

TREE CODE	% COMPETITION/1	% TURF /2	% ASPHALT COVER/3	% SUBTERRANEAN DISTURBANCE/4	% UNIMPEDED/5
82	98.2	7.0	3.7	0.0	1.8
83	99.6	9.8	18.6	0.0	0.0
84	95.3	100.0	0.0	0.0	4.7
85	61.5	76.5	23.6	0.0	14.9
86	98.2	70.8	29.2	0.0	0.0
87	56.1	51.9	48.6	0.0	21.9
88	12.8	45.7	54.3	0.0	34.2
89	66.9	49.5	50.5	3.6	3.2
90	79.6	80.2	19.8	0.0	0.6
91	5.9	25.3	76.1	3.3	17.7
92	99.6	40.5	40.5	0.0	0.4
93	100.0	39.4	39.4	0.0	0.0
94	100.0	39.4	39.4	0.0	0.0
95	99.6	40.5	40.5	0.0	0.4
96	0.0	100.0	0.0	0.0	100.0
97	27.9	0.0	0.0	44.4	0.0
98	74.1	0.0	0.0	0.0	25.9
99	99.6	26.4	0.0	0.0	0.4
100	80.1	100.0	0.0	0.0	19.9
101	100.0	0.0	0.0	0.0	0.0
102	100.0	0.0	0.0	0.0	0.0
103	100.0	0.0	0.0	0.0	0.0
104	100.0	0.0	0.0	0.0	0.0

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

/1_ COMPETITION = competition from other trees and plants other than turfgrass.

/2_ TURF = cover of the root zone by grasses grown for ornamental or erosion prevention.

/3_ ASPHALT COVER = cover of the root zone by asphalt, concrete, and other impermeable surfaces.

/4_ SUBTERRANEAN DISTURBANCE = disturbance of the root zone by sewers, gas lines, excavation, etc.

/5_ UNIMPEDED = areas of the root zone not disturbed or covered by asphalt or competition other than turf.

APPENDIX TABLE 4

Mycorrhizal observations for natural and decline habitats*

TREE CODE	# ON ROOTS	FRUITING STRUCTURES	TREE CODE	# ON ROOTS	FRUITING STRUCTURES
1	some	none	43	some	S.a. /1
2	some	none	44	many	S.a., T.s./2
3	some	none	45	many	S.a.
4	none	none	46	many	S.a.
5	some	none	47	many	S.a.
6	many	none	48	some	S.a.
7	many	none	49	some	S.a., T.s.
8	some	none	50	some	S.a.
9	some	S.a.	51	some	none
10	some	Agaricus sp.	52	some	none
11	some	none	53	some	none
12	some	none	54	some	none
13	some	S.a.	55	some	none
14	some	none	56	some	none
15	some	none	57	some	Coprinus sp.
16	many	none	58	some	none
17	some	Amanita sp.	59	some	none
18	many	Amanita sp.	60	many	none
19	some	none	61	many	none
20	many	S.a.	62	many	none
21	some	none	63	many	none
22	some	none	64	some	none
23	many	none	65	some	none
24	some	none	66	many	none
25	many	none	67	some	none
26	many	none	68	few	none
27	some	none	69	few	none
28	many	none	70	some	none
29	many	none	71	some	Lycoperdon sp.
30	some	none	72	none	none
31	some	none	73	none	none
32	many	none	74	many	S.a.
33	some	none	75	some	none
34	many	none	76	some	none
35	none	none	77	some	none
36	many	none	78	some	none
37	many	S.a., T.s.	79	some	none
38	many	S.a., T.s.	80	some	none
39	some	S.a., T.s.	81	some	none
40	some	T.s.	82	many	none
41	many	S.a.	83	many	none
42	many	S.a., T.s.	84	many	none

Appendix Table 4

(Continued)

TREE CODE	# ON ROOTS	FRUITING STRUCTURES	TREE CODE	# ON ROOTS	FRUITING STRUCTURES
85	many	none			
86	many	none			
87	some	T.s.			
88	some	none			
89	many	none			
90	many	none			
91	none	none			
92	some	none			
93	none	none			
94	none	none			
95	some	none			
96	none	none			
97	few	none			
98	some	none			
99	some	none			
100	some	none			
101	some	none			
102	some	none			
103	some	none			
104	some	none			

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.
/1_ S.a. = Suillus americanus (Pk.) Snell
/2_ T.s. = Tricholoma saponaceum (Fr.) Kummer

APPENDIX TABLE 5

Aspect data for trees on decline and natural habitats*

TREE CODE	ELEVATION**	%SUNLIGHT	DIRECTION	ASPECT	% SLOPE	LENGTH OF SLOPE**
1	2032	75/1	WNS/2	LEVEL/3	0/4	
2	2060	90	WNS	SLOPE	2	75+/5
3	2060	90	WNS	SLOPE	2	75
4	2060	80	ENW	WELL,LEVEL	0	
5	2055	50	EW	SLOPE	1	75
6	2055	50	ES	LEVEL	0	
7	2060	100	EWNS	LEVEL	0	
8	2080	60	ENS	SLOPE	<1	<10
9	2080	75	ENS	SLOPE	<1	<10
10	2080	75	ENS	SLOPE	<1	<10
11	2070	100	EWNS	TOE SLOPE	<1	75
12	2080	90	EWNS	LEVEL	0	
13	2080	75	ENW	LEVEL	0	
14	2080	65	EW	LEVEL	0	
15	2080	60	EW	LEVEL	0	
16	2030	75	E	SLOPE	<1	75
17	2030	50	E	SLOPE	<1	75
18	2030	50	EW	SLOPE	<1	75
19	2030	50		SLOPE	<1	75
20	2030	50	W	SLOPE	<1	75
21	2030	50	E	SLOPE	<1	75
22	2030	15	W	LEVEL	0	
23	2030	10		LEVEL	0	
24	2030	10		LEVEL	0	
25	2030	10		LEVEL	0	
26	2030	10		LEVEL	0	
27	2030	50	W	SLOPE	<1	75
28	2030	30	W	LEVEL	0	
29	2030	35	WS	SLOPE	2	<10
30	2030	30		SLOPE	2	<10
31	2030	25		SLOPE	2	<10
32	2030	65	ENW	LEVEL	0	
33	2010	75	ENS	SLOPE	1	75
34	2010	75	WNS	LEVEL	0	
35	2030	40	EW	LEVEL	0	
36	2030	30	EW	LEVEL	0	
37	2095	100	EWNS	SLOPE	5+	10
38	2095	75	ENW	SLOPE	<1	75
39	2095	100	EWNS	SLOPE	<1	75
40	2095	100	EWNS	SLOPE	<1	10
41	2090	90	EWNS	SLOPE	5+	10
42	2087	100	EWNS	SLOPE	5+	10

APPENDIX TABLE 5

(Continued)

TREE CODE	ELEVATION**	%SUNLIGHT	DIRECTION	ASPECT	% SLOPE	LENGTH OF SLOPE**
43	2085	50	EW	SLOPE	5+	10
44	2080	45	WWS	SLOPE	5+	10
45	2095	50	EWS	SLOPE	2	75
46	2095	70	EWS	SLOPE	<1	10
47	2095	70	EWS	SLOPE	<1	75
48	2095	70	WWS	SLOPE	<1	75
49	2095	90	WWS	LEVEL	0	
50	2095	100	EWWS	LEVEL	0	
51	1800	0		LEVEL	0	
52	1800	0		LEVEL	0	
53	1800	0		LEVEL	0	
54	1800	0		SLOPE	4	10
55	1800	0		LEVEL	0	
56	1800	0		SLOPE	4	10
57	2080	50	WS	LEVEL	0	
58	2080	50	WS	LEVEL	0	
59	2080	75	EWS	LEVEL	0	
60	2055	80	WWS	SLOPE	<1	75
61	1120	25	E	SLOPE	5	75
62	1140	30	E	SLOPE	2	75
63	1160	20	E	SLOPE	<1	75
64	2100	60	EWS	SLOPE	<1	<10
65	2100	60	EWS	SLOPE	<1	<10
66	2100	50	E	SLOPE	<1	<10
67	1380	40	WS	LEVEL	0	
68	1400	75	EWW	SLOPE	1	75
69	1340	65	WS	LEVEL	0	
70	1340	75	WWS	SLOPE	<1	75
71	1340	50	WS	LEVEL	0	
72	2299	40	WS	TERRACE	0	
73	2299	30	WS	TERRACE	0	
74	2400	100	EWWS	LEVEL	0	
75	2400	100	EWWS	LEVEL	0	
76	2400	100	EWWS	SLOPE	1	<10
77	2400	100	EWWS	SLOPE	<1	<10
78	1100	60	EW	SLOPE	<1	75
79	1100	60	EW	SLOPE	<1	75
80	1100	60	EW	SLOPE	<1	75
81	2083	50	ES	SLOPE	<1	<10
82	2083	40	ES	SLOPE	<1	<10
83	2083	50	WW	SLOPE	<1	<10
84	1860	50	EWW	LEVEL	0	

APPENDIX TABLE 5

(Continued)

TREE CODE	ELEVATION**	%SUNLIGHT	DIRECTION	ASPECT	% SLOPE	LENGTH OF SLOPE**
85	1860	75	EN	LEVEL	0	
86	1860	50	W	LEVEL	0	
87	2083	75	ENW	SLOPE	<1	75
88	2083	85	ENS	SLOPE	2	<10
89	2083	75	WNS	LEVEL	0	
90	2083	50	NW	LEVEL	0	
91	2083	50	EN	SLOPE	<1	<10
92	2083	60	NS	LEVEL	0	
93	2083	60	NS	LEVEL	0	
94	2083	60	NS	LEVEL	0	
95	2083	60	NS	LEVEL	0	
96	100	100	ENWS	LEVEL	0	
97	100	75	ENWS	LEVEL	0	
98	100	50	S	LEVEL	0	
99	1381	40	EW	LEVEL	0	
100	1000	50	E	LEVEL	0	
101	1800	0		LEVEL	0	
102	1800	0		LEVEL	0	
103	1800	0		LEVEL	0	
104	1800	0		LEVEL	0	

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.
** elevation and length of slope in feet.
/1_ %SUNLIGHT = % direct sunlight reaching crown.
/2_ DIRECTION = direction of direct sunlight (symbols E, W, N, S = east, west, north, and south).
/3_ ASPECT = aspect of site included level ground, slopes, toe slopes, terraces, & in well on level.
/4_ % SLOPE = number of ft a site dropped in 100 ft.
/5_ LENGTH OF SLOPE = length in ft down a slope which was important in relation to drainage.

APPENDIX TABLE 6

Environmental data for decline and natural habitat trees*

TREE CODE	TYPE OF LOCATION	TRAFFIC FLOW /1	CHEMICALS PRESENT/2	COMMENTS /3
1	campus	sub-mod	a,b,c	cfp (<1mi)
2	campus	sub-mod	a,b,c	cfp (<1mi)
3	campus	sub-mod	a,b,c	cfp (<1mi)
4	campus	sub-low	a,b,c	cfp (<1mi)
5	campus	sub-low	a,b,c	cfp (<1mi)
6	campus	sub-mod	a,b,c	cfp (<1mi)
7	campus	sub-mod	a,b,c	cfp (<1mi)
8	campus	sub-hvy	a,b,c,d	cfp (<1mi)
9	campus	sub-hvy	a,b,c,d	cfp (<1mi)
10	campus	sub-hvy	a,b,c,d	cfp (<1mi)
11	campus	sub-mod	a,b,c	cfp (<1mi)
12	campus	sub-hvy	a,b,c	cfp (<1mi)
13	campus	sub-hvy	a,b,c	cfp (<1mi)
14	campus	sub-hvy	a,b,c	cfp (<1mi)
15	campus	sub-hvy	a,b,c	cfp (<1mi)
16	campus	sub-mod	a,b,c	cfp (<1mi)
17	campus	sub-mod	a,b,c	cfp (<1mi)
18	campus	sub-mod	a,b,c	cfp (<1mi)
19	campus	sub-mod	a,b,c	cfp (<1mi)
20	campus	sub-mod	a,b,c	cfp (<1mi)
21	campus	sub-mod	a,b,c	cfp (<1mi)
22	campus	sub-mod	a,b,c	cfp (<1mi)
23	campus	sub-mod	a,b,c	cfp (<1mi)
24	campus	sub-mod	a,b,c	cfp (<1mi)
25	campus	sub-mod	a,b,c	cfp (<1mi)
26	campus	sub-mod	a,b,c	cfp (<1mi)
27	campus	sub-mod	a,b,c	cfp (<1mi)
28	campus	sub-low	a,b,c	cfp (<1mi)
29	campus	sub-low	a,b,c	cfp (<1mi)
30	campus	sub-low	a,b,c	cfp (<1mi)
31	campus	sub-low	a,b,c	cfp (<1mi)
32	campus	sub-mod	a,b,c	cfp (<1mi)
33	campus	sub-low	a,b,c	cfp (<1mi)
34	campus	sub-low	a,b,c	cfp (<1mi)
35	campus	sub-mod	a,b,c	cfp (<1mi)
36	campus	sub-mod	a,b,c	cfp (<1mi)
37	campus	sub-low	a,b,c	cfp (<1mi)
38	campus	sub-low	a,b,c	cfp (<1mi)
39	campus	sub-low	a,b,c	cfp (<1mi)
40	campus	sub-low	a,b,c	cfp (<1mi)
41	campus	sub-low	a,b,c	cfp (<1mi)
42	campus	sub-low	a,b,c	cfp (<1mi)

APPENDIX TABLE 6

(Continued)

TREE CODE	TYPE OF LOCATION	TRAFFIC FLOW /1	CHEMICALS PRESENT/2	COMMENTS /3
43	campus	sub-mod	a,b,c	cfp (<1mi)
44	campus	sub-mod	a,b,c	cfp (<1mi)
45	campus	sub-mod	a,b,c	cfp (<1mi)
46	campus	sub-mod	a,b,c	cfp (<1mi)
47	campus	sub-low	a,b,c	cfp (<1mi)
48	campus	sub-low	a,b,c	cfp (<1mi)
49	campus	sub-low	a,b,c	cfp (<1mi)
50	campus	sub-low	a,b,c	cfp (<1mi)
51	forest	rur-low		
52	forest	rur-low		
53	forest	rur-low		
54	forest	rur-low		
55	forest	rur-low		
56	forest	rur-low		
57	campus	sub-hvy	a,b,c,d	cfp (<1mi)
58	campus	sub-hvy	a,b,c,d	cfp (<1mi)
59	campus	sub-hvy	a,b,c,d	cfp (<1mi)
60	campus	sub-low	a,b,c	cfp (<1mi)
61	street	sub-hvy	d	along suburban street
62	street	sub-hvy	d	along suburban street
63	street	sub-hvy	d	along suburban street
64	lawn	rur-low	e	highway (<1mi)
65	lawn	rur-low	e	highway (<1mi)
66	lawn	rur-low	e	highway (<1mi)
67	field	rur-low	f	small field planting
68	lawn	rur-low	f	
69	lawn	sub-low	g	
70	lawn	sub-low	g	
71	lawn	sub-low	g	
72	lawn	urb-low		
73	lawn	urb-low		
74	lawn	sub-low	h	
75	lawn	sub-low	h	
76	lawn	sub-low	h	
77	lawn	sub-low	h	
78	lawn	rur-mod	e,f,i	
79	lawn	rur-mod	e,f,i	
80	lawn	rur-mod	e,f,i	
81	lawn	sub-mod	d,j	cfp (2mi)
82	lawn	sub-mod	d,j	cfp (2mi)
83	lawn	sub-mod	d,j	cfp (2mi)
84	lawn	rur-low	j	

APPENDIX TABLE 6

(Continued)

TREE CODE	TYPE OF LOCATION	TRAFFIC FLOW /1	CHEMICALS PRESENT/2	COMMENTS /3
85	lawn	rur-low	j	
86	lawn	rur-low	j	
87	lawn	sub-low	j	
88	lawn	sub-mod	d	along street
89	lawn	sub-mod	d	along street
90	lawn	sub-mod	d	along street
91	lawn	sub-low		
92	lawn	sub-hvy	d	along street
93	lawn	sub-hvy	d	along street
94	lawn	sub-hvy	d	along street
95	lawn	sub-hvy	d	along street
96	park	urb-hvy	k	near airport & city
97	park	urb-hvy	k	near airport & city
98	park	urb-hvy	k	near airport & city
99	lawn	sub-hvy	d, k	next to nursery
100	lawn	rur-low		
101	forest	rur-low		
102	forest	rur-low		
103	forest	rur-low		
104	forest	rur-low		

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

/1_ traffic flow: sub=suburban, urb=urban, rur=rural low=low, mod=moderate, hvy=heavy

/2_ chemicals: a=14-14-14 fertilizer, b=ammonium nitrate, c=2,4,-D, d= road de-icing salts, e=10-10-10 fertilizer, f=lindane, g=orthene, h=weed-b-gon (2,4-D & silvex), i=chelated iron & copper, j=5-10-5 fertilizer, k=various unknown fertilizers & pesticides.

/3_ abbreviations: cfp = coal-fired power plant.

APPENDIX TABLE 7

Soil texture and compaction(psi) data for natural and decline habitats

TREE CODE*	% SAND	% SILT	% CLAY	PSI/1	TREE CODE*	% SAND	% SILT	% CLAY	PSI
1DL	22.3	38.6	39.1	1987	20ADL	22.1	38.4	39.5	
2AU	37.3	34.6	28.1	1192	20BDL	30.7	37.2	32.1	
2BU	31.3	36.5	32.1	1625	21ADL	18.3	42.6	39.1	
2AL	21.0	36.7	42.3	1192	21BDL	39.0	26.2	34.8	
2BL	21.4	35.3	43.3	1625	22A	28.5	41.5	30.0	
3AU	32.4	38.1	29.5		22B	27.7	42.3	30.0	
3BU	31.4	36.7	31.9		23ADL	26.7	37.2	36.1	
3AL	28.3	37.8	33.9		23BDL	18.8	39.2	42.0	
3BL	22.3	37.8	40.0		24A	35.3	38.9	25.8	
4AX	4.5	31.1	64.4	1132	24B	34.0	38.1	27.9	
4BDL	18.1	41.5	40.4	1132	24DL	25.8	35.9	38.3	
5A	21.5	46.4	32.1		25ADL	27.7	38.0	34.3	
5B	22.7	48.3	29.0		25BDL	34.5	40.6	25.0	
6DL	23.9	42.2	33.9		26ADL	27.7	35.9	38.3	
7ADL	27.5	37.1	35.4		26BDL	34.5	40.6	25.0	
7BDL	21.7	36.4	42.0		27ADL	27.7	38.0	34.3	
7DL1	30.7	37.0	32.3		27BDL	34.5	40.6	25.0**	
8ADL	24.6	44.6	30.8		28UDL	12.9	33.2	53.9	
8BDL	12.1	34.7	53.2		28LDL	12.9	33.2	53.9	
9ADL	27.3	41.1	31.6		29ADL	12.9	33.2	53.9	
9BDL	23.0	27.2	49.9		29BDL	35.1	36.8	28.1	
10ADL	24.2	34.9	41.0		30DL1	15.2	36.5	48.3	
10BDL	10.1	14.2	75.8		30DL2	12.9	33.2	53.9	
11ADL	19.5	35.7	44.8		31ADL	16.0	43.8	40.2	
11BDL	8.8	23.6	67.6		31BDL	33.7	39.3	27.0	
12ADL	25.0	38.6	36.4		32ADL	25.9	44.9	29.2	
12BDL	23.3	31.4	45.3		32BDL	17.6	40.1	42.3	
13ADL	25.1	40.0	35.0	1103	32DL1	35.0	51.0	14.0	
13BDL	17.8	26.7	55.5	864	33DLU	27.0	45.9	27.1	
14ADL	25.1	40.0	35.0	1103	33DLL	26.9	40.9	32.2	
14BDL	17.8	26.7	55.5	864	34A	23.2	47.6	29.2	369
15ADL	29.6	39.9	30.5		34B	24.8	39.2	36.0	376
15BDL	14.1	28.0	57.9		35A	24.4	45.4	30.2	
16ADL	34.7	39.6	25.5		35B	22.7	43.2	34.1	
16BDL	32.2	40.0	27.8		36ADL	23.4	46.4	30.2	
17ADL	25.9	34.2	39.9		36BDL	17.4	43.8	38.8	
17BDL	31.0	36.0	33.0		37AU	16.9	47.1	36.0	
18A	29.4	39.8	30.8		37BU	11.3	30.8	57.9	
18B	32.7	40.6	26.7		37AL	21.3	33.8	44.9	
19ADL	55.1	24.6	20.3		37BL	19.0	29.9	51.1	
19BDL	31.1	40.0	28.9		38ADL	22.6	39.3	38.1	

Appendix Table 7

(Continued)

TREE CODE*	% SAND	% SILT	% CLAY	PSI	TREE CODE*	% SAND	% SILT	% CLAY	PSI
38BDL	12.5	31.2	56.3		54A	82.1	5.0	12.9	
39A	21.7	42.0	36.3		54B	86.2	2.0	11.8	
39B	17.5	36.0	46.5		55A	82.1	5.0	12.9	
40A	19.0	38.9	42.1		55B	86.2	2.0	11.8	
40B	15.4	32.0	52.6		56A	82.1	5.0	12.9	
41AU	23.7	43.7	32.6		56B	86.2	2.0	11.8	
41BU	13.7	47.3	39.0		57ADL	26.5	50.0	23.5	
41AL	23.7	41.7	34.6		57BDL	16.3	27.9	55.8	
41BL	14.8	27.9	57.3		58ADL	26.5	50.0	23.5	
42AU	28.0	39.3	32.7		58BDL	16.3	27.9	55.8	
42BU	2.6	35.1	62.3		59ADL	27.2	29.4	43.4	
42AL	21.2	42.2	36.6		59BDL	11.0	47.3	41.7	
42BL	1.1	18.1	80.8		60AU	14.1	45.7	40.2	
43AU	16.9	41.9	41.1		60BU	10.4	31.8	57.9	
43BU	14.7	37.6	47.7		60AL	16.4	44.0	39.6	
43AL	24.7	40.6	34.7		60BL	4.5	34.4	61.0	
43BL	16.4	34.6	49.0		61AU	29.7	28.3	41.5	
44AU	17.0	45.1	37.9		61BU	17.5	36.5	46.0	
44BU	12.3	43.5	44.2		61AL	33.7	26.3	40.0	
44AL	14.8	45.0	40.2		61BL	34.7	24.9	40.4	
44BL	3.2	34.7	62.1		62ADL	15.7	40.3	43.9	
45AU	17.6	46.7	35.8		62BDL	12.1	39.6	48.3	
45BU	1.8	37.5	60.8		63ADL	25.2	32.9	41.9	
45AL	19.8	47.6	32.7		63BDL	27.2	29.4	43.4	
45BL	2.6	34.5	62.9		64ADL	18.1	36.7	45.3	
46ADL	19.4	37.0	43.5		64BDL	5.9	24.4	69.7	
46BDL	8.5	26.3	65.2		65ADL	15.3	32.4	52.3	
47ADL	16.2	41.0	42.8		65BDL	5.8	23.4	70.8	
47BDL	10.8	26.6	62.6		66A	19.4	36.4	44.2	
48ADL	14.4	38.9	46.7		66B	24.4	30.4	45.2	
48BDL	10.7	32.7	56.6		67A	24.6	42.3	33.1	
49ADL	15.4	46.5	38.1		67B	23.0	40.0	37.0	
49BDL	17.3	33.4	49.3		68AU	22.3	40.4	37.3	
50ADL	14.6	45.9	39.9		68BU	22.0	44.0	34.0	
50BDL	14.8	30.6	54.6		68AL	23.4	36.3	40.3	
51A	50.5	24.4	25.1	138	68BL	24.7	39.2	36.1	
51B	49.7	23.3	27.1	273	69A	20.5	46.3	33.2	
52A	50.5	24.4	25.1	138	69B	13.0	44.0	43.0	
52B	49.7	23.3	27.1	273	70A	19.0	44.4	36.6	
53A	82.1	5.0	12.9		70B	15.9	39.4	44.7	
53B	86.2	2.0	11.8		71A	17.9	45.4	36.7	

Appendix Table 7

(Continued)

TREE CODE*	% SAND	% SILT	% CLAY	PSI	TREE CODE*	% SAND	% SILT	% CLAY	PSI
71B	15.8	47.5	36.7		88BDL	12.0	52.5	35.4	
72ADL	23.1	38.3	38.6		88DL	5.5	29.7	64.8	
72BDL	20.4	35.1	44.5		89A	9.6	52.8	37.7	
73ADL	20.8	38.6	40.6		89B	4.8	50.6	44.6	
73BDL	15.1	41.9	43.0		89DL	12.2	50.3	37.5	
74DL	14.9	46.6	38.5		90A	18.7	47.1	34.2	
75DL	18.3	49.4	32.3		90B	11.6	48.1	40.3	
76DL	7.5	35.6	56.9		91DL	27.5	31.5	41.0	
77DL	9.4	44.8	45.8		92ADL	12.2	43.2	44.7	
78A	9.5	46.7	43.9		92BDL	9.4	37.9	52.7	
78B	10.0	42.4	47.6		93ADL	14.2	43.8	42.0	
79A	11.0	46.2	42.8		93BDL	10.4	34.7	54.9	
79B	8.9	43.7	47.5		94ADL	12.1	44.2	43.7	
80A	6.5	48.5	45.0		94BDL	11.4	34.4	54.2	
80B	4.4	43.3	52.3		95ADL	13.7	49.2	37.1	
81A	12.5	48.6	38.9		95BDL	9.4	37.9	52.8	
81B	12.7	51.3	36.0		96DL	48.9	24.0	27.1	
82A	21.8	44.4	33.8		97DL	3.4	50.0	46.6	
82B	11.7	52.5	35.8		98DL	26.8	39.2	34.0	
83A	11.8	51.8	36.3		99A	-	-	-	
83B	10.6	53.4	36.0		99B	-	-	-	
84A	39.3	36.3	24.4		100A	25.0	42.5	32.5	
84B	32.4	40.2	27.4		100B	24.6	42.9	32.5	
84B2	34.6	42.8	22.6		101A	82.1	5.0	12.9	
84DL	10.3	42.8	22.6		101B	86.2	2.0	11.8	
85A	33.2	43.4	23.4		102A	50.5	24.4	25.1	138
85B	31.3	43.3	25.4		102B	49.7	23.3	27.1	273
86A	33.2	43.4	23.4		103A	50.5	24.4	25.1	138
86B	31.2	43.3	25.4		103B	49.7	23.3	27.1	273
87A	7.0	55.5	37.6		103B	49.7	23.3	27.1	273
87B	10.0	50.4	39.6		104A	82.1	5.0	12.9	
88ADL	12.0	50.9	37.1		104B	86.2	2.0	11.8	

APPENDIX TABLE 7

(Continued)

(.) = data missing or not available.

* = TREE CODES are listed by number for each tree (codes 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees) and by soil codes for each layer or duplicate sample. DL=disturbed layer, A=A horizon or upper layer, B=B horizon or deeper layer, X=traffic pan visible, U=sample taken from upper part of a slope, L=sample taken from lower part of a slope (if used with DL=DLL), 1=duplicate sample 1, 2=duplicate sample 2. Duplicate samples were averaged in with each other for analysis of results.

** = 27UDL,27LDL not listed (duplicates of 28UDL, 28LDL).

/1_ PSI=pounds per square inch to penetrate the soil using a Proctor penetrometer.

APPENDIX TABLE 8

Coarse fragments, mottles, and foreign materials found in soils of natural and decline habitats

TREE CODE /1	COARSE FRAGMENT (%)	MOTTLES	FOREIGN MATERIALS
1DL	11.1	COMMON	COAL, CINDERS
2AU	12.5	COMMON	COAL, WIRE
2BU	4.8	COMMON	COAL, WIRE
2AL	2.3	NONE	COAL, WIRE
2BL	4.3	COMMON	COAL, WIRE
3AU	9.7	COMMON	CHARCOAL
3BU	5.4	COMMON	CHARCOAL
3AL	2.8	COMMON	CHARCOAL
3BL	1.6	COMMON	CHARCOAL
4AX	6.5	COMMON	COAL, CONCRETE
4BDL	0.3	COMMON	COAL, CONCRETE
5A	3.5	NONE	COAL
5B	3.0	NONE	COAL
6DL	2.9	COMMON	GRAVEL, GLASS, COAL, CINDERS
7ADL	2.3	COMMON	COAL, CHARCOAL
7BDL	1.3	COMMON	COAL, CHARCOAL
7DL1	3.7	COMMON	COAL, CHARCOAL
8ADL	5.4	COMMON	BUILDING MORTAR, CINDERS, COAL
8BDL	3.5	COMMON	CINDERS, COAL
9ADL	6.6	COMMON	CINDERS
9BDL	2.0	COMMON	CINDERS
10ADL	14.3	NONE	BUILDING MORTAR
10BDL	0.7	COMMON	BUILDING MORTAR
11ADL	7.9	COMMON	NONE
11BDL	0.2	COMMON	NONE
12ADL	6.1	COMMON	YELLOW ROAD PAINT
12BDL	5.8	COMMON	NONE
13ADL	12.9	COMMON	DRAIN TILE
13BDL	15.3	COMMON	DRAIN TILE
14ADL	11.4	COMMON	DRAIN TILE, GLASS, BRICK
14BDL	1.9	COMMON	DRAIN TILE, GLASS, BRICK
15ADL	11.4	COMMON	DRAIN TILE, GLASS, BRICK
15BDL	1.9	COMMON	DRAIN TILE, GLASS, BRICK
16ADL	14.2	NONE	NONE
16BDL	15.6	NONE	NONE
17ADL	5.5	COMMON	BUILDING MATERIALS, CONCRETE
17BDL	10.5	NONE	NONE
18A	0.7	NONE	COAL
18B	4.5	COMMON	COAL
19ADL	27.7	NONE	CINDERS

APPENDIX TABLE 8

(Continued)

TREE CODE /1	COARSE FRAGMENT (%)	MOTTLES	FOREIGN MATERIALS
19BDL	8.5	COMMON	CINDERS
20ADL	1.0	NONE	NONE
20BDL	5.1	COMMON	NONE
21ADL	1.0	COMMON	COAL, BRICK, GLASS, MORTAR
21BDL	5.1	COMMON	COAL, BRICK, GLASS, MORTAR
22A	1.6	NONE	NONE
22B	9.3	NONE	NONE
23ADL	7.9	COMMON	CINDERS
23BDL	6.1	COMMON	CINDERS
24A	6.5	NONE	CINDERS
24B	7.8	COMMON	CINDERS
25ADL	4.3	NONE	CINDERS
25BDL	5.5	FEW	CINDERS
26ADL	4.3	NONE	CINDERS
26BDL	5.5	FEW	CINDERS
27AU	4.3	NONE	CINDERS, IRON
27BU	5.5	FEW	CINDERS, IRON
27UDL	4.1	COMMON	CINDERS, IRON
27LDL	4.1	COMMON	CINDERS, IRON
28UDL	4.1	COMMON	CINDERS
28LDL	4.1	COMMON	CINDERS
29ADL	17.0	NONE	CINDERS
29BDL	4.1	COMMON	CINDERS
30DL1	4.1	COMMON	CINDERS, IRON
30DL2	2.6	COMMON	CINDERS, IRON
31ADL	2.4	COMMON	CINDERS
31BDL	6.1	NONE	CINDERS
32ADL	6.4	NONE	COAL, BRICK, GLASS, CINDERS
32BDL	4.2	COMMON	COAL, BRICK, GLASS, CINDERS
32DL1	13.1	COMMON	COAL, BRICK, GLASS, CINDERS
33DLU	7.6	NONE	BRICK, COAL, CINDERS
33DLL	11.5	FEW	BRICK, COAL, CINDERS
34A	0.7	NONE	NONE
34B	2.7	COMMON	NONE
35A	13.8	NONE	CINDERS
35B	6.5	FEW	CINDERS
36ADL	8.6	NONE	GLASS, METAL, COAL
36BDL	7.3	NONE	GLASS, METAL, COAL
37AU	4.0	NONE	CEMENT
37BU	5.0	NONE	CEMENT
37AL	8.6	NONE	CEMENT

APPENDIX TABLE 8

(Continued)

TREE CODE /1	COARSE FRAGMENT (%)	MOTTLES	FOREIGN MATERIALS
37BL	4.2	NONE	CEMENT
38ADL	10.1	NONE	NONE
38BDL	7.6	COMMON	NONE
39A	5.0	COMMON	COAL
39B	6.9	COMMON	COAL
40A	4.8	FEW	SLAG
40B	9.0	COMMON	SLAG
41AU	1.7	NONE	NONE
41BU	3.3	NONE	NONE
41AL	5.7	NONE	NONE
41BL	11.1	COMMON	NONE
42AU	4.9	NONE	NONE
42BU	0.3	FEW	NONE
42AL	8.2	NONE	NONE
42BL	0.4	COMMON	NONE
43AU	3.7	NONE	COAL, CINDERS
43BU	7.7	COMMON	COAL, CINDERS
43AL	5.7	FEW	COAL, CINDERS
43BL	4.6	COMMON	COAL, CINDERS
44AU	2.6	NONE	BRICK
44BU	2.4	COMMON	BRICK
44AL	2.3	NONE	BRICK
44BL	0.8	NONE	BRICK
45AU	2.7	NONE	TIN, OIL
45BU	0.1	COMMON	TIN, OIL
45AL	2.5	NONE	TIN, OIL
45BL	0.1	COMMON	TIN, OIL
46ADL	10.6	NONE	COAL
46BDL	0.4	COMMON	COAL
47ADL	6.2	NONE	NAILS, CINDERS
47BDL	2.4	COMMON	NAILS, CINDERS
48ADL	4.0	NONE	WIRE, CINDERS, COAL
48BDL	4.4	COMMON	WIRE, CINDERS, COAL
49ADL	5.7	NONE	CONCRETE, CINDERS
49BDL	6.0	COMMON	CONCRETE, CINDERS
50ADL	4.3	NONE	CONCRETE, BRICK
50BDL	8.4	COMMON	CONCRETE, BRICK
51A	0.2	NONE	NONE
51B	<0.1	NONE	NONE
52A	<0.1	NONE	NONE
52B	<0.1	NONE	NONE

APPENDIX TABLE 8

(Continued)

TREE CODE /1	COARSE FRAGMENT (%)	MOTTLES	FOREIGN MATERIALS
53A	<0.1	NONE	NONE
53B	<0.1	NONE	NONE
54A	<0.1	NONE	NONE
54B	<0.1	NONE	NONE
55A	<0.1	NONE	NONE
55B	<0.1	NONE	NONE
56A	<0.1	NONE	NONE
56B	<0.1	NONE	NONE
57ADL	3.9	NONE	ALUMINUM FOIL, COAL
57BDL	2.9	COMMON	ALUMINUM FOIL, COAL
58ADL	3.9	FEW	COAL
58BDL	2.9	FEW	COAL
59ADL	<0.1	FEW	COAL
59BDL	<0.1	FEW	COAL
60AU	1.4	NONE	CHARCOAL, COAL
60BU	2.3	COMMON	CHARCOAL, COAL
60AL	4.0	NONE	CHARCOAL, COAL
60BL	0.1	COMMON	CHARCOAL, COAL
61AU	28.5	NONE	NONE
61BU	26.4	FEW	NONE
61AL	37.9	NONE	NONE
61BL	37.5	NONE	NONE
62ADL	25.4	NONE	NONE
62BDL	25.9	NONE	NONE
63ADL	69.0	NONE	NONE
63BDL	67.2	NONE	NONE
64ADL	1.1	NONE	NONE
64BDL	2.5	FEW	NONE
65ADL	0.5	COMMON	GLASS
65BDL	1.1	COMMON	GLASS
66A	2.6	NONE	NONE
66B	5.4	COMMON	NONE
67A	1.9	NONE	NONE
67B	9.0	NONE	NONE
68AU	2.3	NONE	NONE
68BU	0.7	NONE	NONE
68AL	9.6	NONE	NONE
68BL	8.2	NONE	NONE
69A	5.9	NONE	NONE
69B	4.3	NONE	NONE
70A	7.1	NONE	NONE

APPENDIX TABLE 8

(Continued)

TREE CODE /1	COARSE FRAGMENT (%)	MOTTLES	FOREIGN MATERIALS
70B	1.8	NONE	NONE
71A	10.2	NONE	NONE
71B	9.6	NONE	NONE
72ADL	9.8	NONE	GLASS
72BDL	21.7	NONE	GLASS
73ADL	10.2	NONE	CINDERS, GLASS
73BDL	10.0	NONE	CINDERS, GLASS
74DL	9.5	NONE	NONE
75DL	8.7	NONE	BARK MULCH
76DL	1.6	COMMON	BARK MULCH
77DL	3.3	COMMON	BARK MULCH
78A	3.0	COMMON	NONE
78B	6.0	NONE	NONE
79A	3.0	FEW	NONE
79B	2.8	NONE	NONE
80A	3.1	COMMON	NONE
80B	1.3	NONE	NONE
81A	2.1	NONE	IRON
81B	9.1	NONE	IRON
82A	5.8	NONE	NONE
82B	14.7	NONE	NONE
83A	7.3	NONE	GLASS
83B	13.4	NONE	GLASS
84A	11.0	NONE	NONE
84B	12.9	NONE	NONE
84B2	9.5	NONE	NONE
84DL	3.6	NONE	NONE
85A	15.9	NONE	NONE
85B	9.8	NONE	NONE
86A	15.9	NONE	NONE
86B	9.8	NONE	NONE
87A	3.0	NONE	NONE
87B	8.7	NONE	NONE
88ADL	10.1	NONE	NONE
88BDL	11.0	NONE	BEDROCK ROAD BASE
88DL	17.5	COMMON	BEDROCK ROAD BASE
89A	5.3	COMMON	NONE
89B	1.1	NONE	NONE
89DL	7.0	COMMON	NONE
90A	4.3	FEW	NONE
90B	5.0	NONE	NONE

APPENDIX TABLE 8

(Continued)

TREE CODE /1	COARSE FRAGMENT (%)	MOTTLES	FOREIGN MATERIALS
91DL	21.3	NONE	STYROFOAM
92ADL	5.1	FEW	NONE
92BDL	1.6	NONE	NONE
93ADL	2.4	COMMON	NONE
93BDL	0.7	NONE	NONE
94ADL	8.8	FEW	NONE
94BDL	1.2	NONE	NONE
95ADL	2.4	FEW	NONE
95BDL	1.0	NONE	NONE
96DL	1.4	COMMON	NONE
97DL	0.8	FEW	GLASS
98DL	0.2	FEW	NONE
99A	.	NONE	NONE
99B	.	NONE	NONE
100A	8.6	NONE	COAL
100B	7.3	NONE	COAL
101A	<0.1	NONE	NONE
101B	<0.1	NONE	NONE
102A	<0.1	NONE	NONE
102B	<0.1	NONE	NONE
103A	<0.1	NONE	NONE
103B	<0.1	NONE	NONE
104A	<0.1	NONE	NONE
104B	<0.1	NONE	NONE

(.) = data missing or not available.

/1_ TREE CODES are listed by number for each tree (codes 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees) and by soil codes for each layer or duplicate sample. DL=disturbed layer, A=A horizon or upper layer, B=B horizon or deeper layer, X=traffic pan visible, U=sample taken from upper part of a slope, L=sample taken from lower part of a slope (if used with DL=DLL), 1=duplicate sample 1, 2=duplicate sample 2. Duplicate samples were averaged in with each other for analysis of results.

APPENDIX TABLE 9

Comments on soils for natural and decline habitat trees*

TREE CODE	GENERAL COMMENTS
1	ash & coal layer below 25 cm, limestone fill below 10 cm
2	highly compacted by foot traffic
3	none
4	highly compacted by foot traffic
5	none
6	gravel above & clay at 30 cm
7	clay layer below 25 cm
8	mortar at 20 cm (pH 8.1), sewer below 32 cm
9	sewer below 35 cm
10	sewer below 32 cm
11	none
12	none
13	none
14	highly compacted by foot traffic
15	highly compacted by foot traffic
16	none
17	none
18	none
19	disturbed layer(5 cm topsoil,10 cm cinders) roots under and above cinder layer
20	none
21	8 cm topsoil on disturbed layer
22	none
23	soil near parking lot highly disturbed
24	none
25	none
26	none
27	none
28	clay subsoil mixed-in
29	A horizon eroded away on slope
30	disturbed by sewer excavation
31	clay subsoil mixed-in
32	highly compacted near driveway
33	rocks & fill for sewer mixed-in
34	wet, black muck(old pond bottom), rock fill
35	none
36	none
37	none
38	none
39	none
40	none

APPENDIX TABLE 9

(Continued)

TREE CODE	GENERAL COMMENTS
41	none
42	none
43	appear undisturbed, but next to a road cut
44	none
45	large rock fill
46	none
47	none
48	none
49	clay layer impedes roots
50	none
51	very deep and sandy
52	very deep and sandy
53	very deep and sandy
54	very deep and sandy
55	very deep and sandy
56	very deep and sandy
57	none
58	none
59	none
60	none
61	old A & B horizons buried below 50 cm fill
62	old A & B horizons buried below 50 cm fill
63	none
64	puddled & compacted (disturbed)
65	clay subsoil from foundation graded in
66	natural soil horizons
67	undisturbed
68	none
69	none
70	undisturbed
71	none
72	1 m clay fill over old horizons (disturbed)
73	1 m clay fill over old horizons (disturbed)
74	disturbed old B horizon present
75	clay aggregates mixed-in (old B horizon)
76	clay subsoil mixed-in (disturbed)
77	clay subsoil mixed-in (disturbed)
78	relatively undisturbed
79	relatively undisturbed
80	relatively undisturbed
81	compacted by vehicles (disturbed)
82	none

APPENDIX TABLE 9

(Continued)

TREE CODE	GENERAL COMMENTS
83	none
84	none
85	gravel from leach bed
86	none
87	none
88	bedrock road base
89	gravel fill
90	none
91	gravel fill
92	none
93	surface layer too shallow to sample
94	none
95	none
96	none
97	fill from river bottom, compacted
98	fill from river bottom, compacted
99	none
100	none
101	very deep and sandy
102	very deep and sandy
103	very deep and sandy
104	very deep and sandy

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

APPENDIX TABLE 10
Comments on damage to natural and decline habitat trees*

TREE CODE	GENERAL COMMENTS
1	7/79 roots cut for parking lot, disturbed soils 2' deep N of tree
2	ice damage to many small & large limbs
3	ice damage to many small & large limbs
4	ice damage to many small & large limbs, tree hollow
5	ice damage to many small & large limbs
6	ice damage to many small & large limbs
7	ice damage to many small & large limbs
8	terminal foliage necrotic, topped by power company
9	none
10	damage to bole by vehicle, callus formed (fluxing)
11	ice damage to several large limbs
12	none
13	none
14	none
15	ice damage to a few large limbs
16	none
17	none
18	ice damage to several large limbs
19	ice damage to several small & large limbs
20	ice damage to several small & large limbs
21	roots damage by vehicle
22	none
23	none
24	ice damage to a few large limbs
25	none
26	none
27	ice damage to several large limbs
28	none
29	ice damage to many large limbs
30	ice damage to many large limbs
31	ice damage to a few large limbs
32	none
33	ice damage to several large limbs
34	ice damage to several small & large limbs
35	ice damage to several large limbs
36	none
37	none
38	none
39	none
40	none
41	none
42	none

APPENDIX TABLE 10

(Continued)

TREE CODE	GENERAL COMMENTS
43	none
44	none
45	ice damage - top broken out
46	ice damage to many small & large limbs
47	13 years of growth broken out of top
48	butt damage approx. 10 cm diameter area
49	appears to have been topped by power company
50	power line runs thru limbs - some abrasion
51	none
52	none
53	none
54	none
55	none
56	none
57	none
58	none
59	ice damage to several small & large limbs
60	ice & construction damage to a few limbs & roots
61	tree topped in 1969
62	tree topped in 1969
63	tree topped in 1969
64	none
65	none
66	none
67	none
68	ice damage - top broken in 1978
69	tree topped in 1978
70	none
71	ice damage to small limbs (initiated cankers)
72	none
73	none
74	none
75	girdled at base of trunk by plastic twine
76	none
77	topped damaged by white pine weevil
78	none
79	none
80	none
81	ice damage to a few small & large limbs
82	none
83	none
84	none

APPENDIX TABLE 10

(Continued)

TREE CODE	GENERAL COMMENTS
85	none
86	none
87	none
88	none
89	ice & guide wire damage to few small & large limbs
90	ice damage to many small & large limbs
91	root system covered by asphalt, possibly damaged
92	limbs removed 2-3 m above street on one side of tree
93	none
94	large area of bole damaged by car-callused & fluxing
95	ice damage removed top - up to 6 years growth
96	none
97	none
98	none
99	none
100	none
101	slight axe damage to bole
102	none
103	none
104	none

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

APPENDIX TABLE 11

Visual crown ratings of tree* growth quality using a class and rating system./1

TREE CODE	CLASS	RATING	TREE CODE	CLASS	RATING
1	B	2	42	A	5
2	B	3	43	B	3
3	A	4	44	A	5
4	B	2	45	B	3
5	B	3	46	B	3
6	B	3	47	A	5
7	B	3	48	B	2
8	C	1	49	B	3
9	B	2	50	B	3
10	C	A	51	A	5
11	B	3	52	A	5
12	B	3	53	A	5
13	B	3	54	A	5
14	A	4	55	A	5
15	A	4	56	A	5
16	B	3	57	A	4
17	A	4	58	A	4
18	A	5	59	B	3
20	A	4	61	B	3
21	B	3	62	B	3
22	B	2	63	B	3
23	A	4	64	B	2
24	B	3	65	B	2
25	A	4	66	A	5
26	B	3	67	C	1
27	A	4	68	B	3
28	B	3	69	C	1
29	A	4	70	B	3
30	A	4	71	B	2
31	B	3	72	B	3
32	A	4	73	B	3
33	B	3	74	A	4
34	B	3	75	B	2
35	B	2	76	B	3
36	A	4	77	A	4
37	A	4	78	C	0
38	A	4	79	B	3
39	B	2	80	A	5
40	B	2	81	B	3
41	A	5	82	B	3

APPENDIX TABLE 11

(Continued)

TREE CODE	CLASS	RATING	TREE CODE	CLASS	RATING
83	B	3	100	B	2
84	B	3	101	A	5
85	A	4	102	A	5
86	A	4	103	A	5
87	B	2	104	A	5
88	B	2			
89	B	3			
90	B	3			
91	C	1			
92	B	2			
93	C	0			
94	C	0			
95	B	2			
96	C	0			
97	B	2			
98	B	2			
99	C	0			

* TREE CODES 51-56 and 101-104 are natural habitat trees and the rest are decline habitat trees.

/1_ Tree ratings are as follows: 0=dead, 1=100% chlorotic, 2=50-75% chlorotic, 3=25-49% chlorotic, 4=5-24% chlorotic, 5=0-5% chlorotic. Classes: A=ratings 4 & 5, B=ratings 2 & 3, C=ratings 0 & 1.

Appendix B

SAMPLE DISCRIM ANALYSIS PROGRAM

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

OBS	SITE	CLAYA	CLAYB	PHA	PHB	RMTHICKM
1	DECLINE	39.11	39.11	7.6	7.6	10
2	DECLINE	35.24	37.72	7.0	7.5	10
3	DECLINE	31.70	35.91	5.9	6.3	15
4	DECLINE	40.44	64.38	7.4	7.5	.
5	DECLINE	32.08	29.01	6.3	7.0	13
6	DECLINE	33.92	33.92	7.5	7.5	5
7	DECLINE	33.83	37.11	7.2	6.6	18
8	DECLINE	30.76	53.23	7.6	7.9	15
9	DECLINE	31.56	49.85	7.6	8.0	15
10	DECLINE	40.97	75.76	7.7	6.8	15
11	DECLINE	44.77	67.63	6.3	7.0	18
12	DECLINE	36.37	45.27	7.6	7.8	15
13	DECLINE	34.96	55.48	7.0	7.3	15
14	DECLINE	34.96	55.48	7.3	7.5	10
15	DECLINE	30.47	57.90	7.3	7.5	10
16	DECLINE	25.54	27.82	6.6	6.1	30
17	DECLINE	39.88	32.98	7.4	7.7	30
18	DECLINE	30.80	26.72	7.6	7.4	25
19	DECLINE	20.28	28.91	7.8	7.9	15
20	DECLINE	39.47	32.08	6.5	6.6	12
21	DECLINE	39.06	34.82	8.1	8.0	15
22	DECLINE	30.00	30.00	7.6	7.7	15
23	DECLINE	36.05	42.01	7.3	7.6	15
24	DECLINE	32.01	33.08	6.5	6.8	15
25	DECLINE	34.30	24.95	6.2	6.9	20
26	DECLINE	34.30	24.95	5.8	6.2	20
27	DECLINE	34.30	24.95	6.3	6.5	20
28	DECLINE	53.92	53.92	6.1	6.1	14
29	DECLINE	53.92	28.12	6.7	5.9	14
30	DECLINE	53.92	53.92	7.3	7.3	14
31	DECLINE	40.16	26.97	6.8	6.6	15
32	DECLINE	29.15	42.26	7.3	7.3	17
33	DECLINE	27.14	32.21	7.0	7.0	15
34	DECLINE	29.21	35.96	7.6	7.9	15
35	DECLINE	30.18	34.14	6.3	7.0	20
36	DECLINE	30.18	38.84	6.6	7.4	25
37	DECLINE	40.46	54.49	7.0	7.8	13
38	DECLINE	38.10	56.27	7.3	7.9	15
39	DECLINE	36.28	46.48	7.3	7.6	18
40	DECLINE	42.10	52.55	7.6	7.7	15
41	DECLINE	33.56	48.14	6.8	7.6	15
42	DECLINE	34.54	71.58	7.3	7.5	15
43	DECLINE	37.93	48.32	7.5	7.8	11
44	DECLINE	39.02	53.16	7.2	7.5	13
45	DECLINE	34.23	61.85	6.8	7.4	18

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

OBS	SITE	CLAYA	CLAYB	PHA	PHB	RMTHICKN
46	DECLINE	43.52	65.20	7.6	7.2	14
47	DECLINE	42.81	62.62	6.9	7.7	10
48	DECLINE	46.73	56.63	7.7	7.7	10
49	DECLINE	38.14	49.30	7.5	7.6	30
50	DECLINE	39.86	54.61	7.3	7.6	30
51	NATURAL	25.10	27.10	5.0	4.9	40
52	NATURAL	25.10	27.10	5.0	4.9	40
53	NATURAL	12.86	11.85	6.0	5.9	50
54	NATURAL	12.86	11.85	6.0	5.9	50
55	NATURAL	12.86	11.85	5.5	5.4	45
56	NATURAL	12.86	11.85	5.5	5.4	45
57	DECLINE	23.46	55.77	7.3	7.6	18
58	DECLINE	23.46	55.77	7.3	7.6	19
59	DECLINE	35.35	41.70	7.5	7.6	20
60	DECLINE	39.88	59.43	6.8	7.0	25
61	DECLINE	40.73	43.20	7.7	7.9	18
62	DECLINE	43.93	48.25	7.6	7.7	23
63	DECLINE	41.89	43.37	7.7	7.7	16
64	DECLINE	45.30	69.66	6.1	6.6	13
65	DECLINE	52.34	70.82	7.0	7.2	23
66	DECLINE	44.20	45.17	7.8	7.9	18
67	DECLINE	33.11	36.25	6.5	6.4	26
68	DECLINE	38.79	35.05	6.3	6.3	21
69	DECLINE	33.15	42.97	5.3	4.9	23
70	DECLINE	36.65	44.72	4.9	5.0	13
71	DECLINE	36.65	36.72	5.2	5.4	23
72	DECLINE	38.63	44.45	7.6	8.1	15
73	DECLINE	40.65	42.98	7.3	7.9	20
74	DECLINE	38.54	38.54	6.4	6.4	10
75	DECLINE	32.31	32.31	6.5	6.5	8
76	DECLINE	56.92	56.92	5.7	5.7	13
77	DECLINE	45.81	45.81	5.9	5.9	23
78	DECLINE	43.87	47.56	6.6	6.7	32
79	DECLINE	42.83	47.47	6.5	6.7	19
80	DECLINE	45.06	52.33	6.1	5.7	17
81	DECLINE	38.91	35.98	7.8	7.9	24
82	DECLINE	33.78	35.80	6.8	7.0	25
83	DECLINE	36.34	36.01	7.4	7.4	22
84	DECLINE	24.44	27.39	6.4	6.0	23
85	DECLINE	23.46	25.43	7.3	7.5	18
86	DECLINE	23.46	25.43	7.3	7.5	18
87	DECLINE	37.58	39.60	7.6	7.7	25
88	DECLINE	50.96	50.13	7.7	7.8	15
89	DECLINE	37.57	41.06	7.3	7.4	23
90	DECLINE	34.23	40.28	7.7	7.6	23
91	DECLINE	41.02	41.02	7.8	7.8	.

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

OBS	SITE	CLAYA	CLAYB	PHA	PHB	RMTHICKN
92	DECLINE	44.69	52.69	5.8	4.9	18
93	DECLINE	41.98	54.69	7.0	4.8	23
94	DECLINE	43.69	54.22	6.7	4.8	5
95	DECLINE	37.09	52.79	6.2	5.3	15
96	DECLINE	27.10	27.10	6.0	6.0	15
97	DECLINE	46.65	46.65	6.7	6.7	10
98	DECLINE	34.05	34.05	6.4	6.4	5
99	DECLINE	25.00	34.10	6.3	6.3	7
100	DECLINE	32.56	32.53	6.8	7.2	10
101	NATURAL	12.86	11.85	5.5	5.4	45
102	NATURAL	25.10	27.10	6.0	5.9	50
103	NATURAL	25.10	27.10	6.0	5.9	50
104	NATURAL	12.86	11.85	5.0	4.9	40

DISCRIMINANT ANALYSIS

SITE	FREQUENCY	PRIOR PROBABILITY
DECLINE	92	0.90196078
NATURAL	10	0.09803922
TOTAL	102	1.00000000

WARNING: 2 OF THE 104 OBSERVATIONS WILL NOT BE INCLUDED IN THE ANALYSIS DUE TO MISSING VALUES.

DISCRIMINANT ANALYSIS SIMPLE STATISTICS

SITE = DECLINE

VARIABLE	N	SUM	MEAN	VARIANCE	STANDARD DEVIATION
CLAYA	92	3408.80000	37.0521739	55.165479	7.4273467
CLAYB	92	4047.34000	43.9928261	150.269106	12.2584300
PHA	92	637.90000	6.9336957	0.453248	0.6732368
PHB	92	645.40000	7.0152174	0.714271	0.8451458
RMTHICKN	92	1572.00000	17.0869565	34.322026	5.8585003

SITE = NATURAL

CLAYA	10	177.560000	17.7560000	39.9513600	6.32070882
CLAYB	10	179.500000	17.9500000	62.0166667	7.87506614
PHA	10	55.500000	5.5500000	0.1916667	0.43779752
PHB	10	54.500000	5.4500000	0.1916667	0.43779752
RMTHICKN	10	455.000000	45.5000000	19.1666667	4.37797518

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS WITHIN COVARIANCE MATRICES

SITE = DECLINE DF = 91

VARIABLE	CLAYA	CLAYB	PHA
CLAYA	55.16547874	43.48813445	-0.32148065
CLAYB	43.48813445	150.26910621	0.99362900
PHA	-0.32148065	0.99362900	0.45324773
PHB	-0.97816531	0.75963784	0.46838270
RHTHICKN	-2.18238892	-7.49365504	0.00582895

VARIABLE	PHB	RHTHICKN
CLAYA	-0.97816531	-2.18238892
CLAYB	0.75963784	-7.49365504
PHA	0.46838270	0.00582895
PHB	0.71427138	0.01954133
RHTHICKN	0.01954133	34.32202580

SITE = NATURAL DF = 9

VARIABLE	CLAYA	CLAYB	PHA
CLAYA	39.95136000	49.77600000	-0.27200000
CLAYB	49.77600000	62.01666667	-0.33888889
PHA	-0.27200000	-0.33888889	0.19166667
PHB	-0.27200000	-0.33888889	0.19166667
RHTHICKN	-2.72000000	-3.38888889	1.91666667

VARIABLE	PHB	RHTHICKN
CLAYA	-0.27200000	-2.72000000
CLAYB	-0.33888889	-3.38888889
PHA	0.19166667	1.91666667
PHB	0.19166667	1.91666667
RHTHICKN	1.91666667	19.16666667

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS POOLED COVARIANCE MATRIX DF=100

VARIABLE	CLAYA	CLAYB	PHA
CLAYA	53.79620805	44.05404235	-0.31702739
CLAYB	44.05404235	142.32638665	0.87370239
PHA	-0.31702739	0.87370239	0.42970543
PHB	-0.91461043	0.66077043	0.44347826
RMTHICKN	-2.23077391	-7.12422609	0.17780435

VARIABLE	PHB	RMTHICKN
CLAYA	-0.91461043	-2.23077391
CLAYB	0.66077043	-7.12422609
PHA	0.44347826	0.17780435
PHB	0.66723696	0.19028261
RMTHICKN	0.19028261	32.95804348

DISCRIMINANT ANALYSIS WITHIN COVARIANCE MATRIX INFORMATION

SITE	COVARIANCE MATRIX RANK	NATURAL LOG OF DETERMINANT OF THE COVARIANCE MATRIX
DECLINE	5	9.95814604
NATURAL	2	2.02595637 *

* WARNING: THIS COVARIANCE MATRIX IS NOT OF FULL RANK, THE ABOVE LOG(DETERMINANT) IS BASED ON A COVARIANCE MATRIX WITH THE FOLLOWING VARIABLES DELETED: CLAYB PHB RMTHICKN

POOLED	5	9.65705149

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS
TEST OF HOMOGENEITY OF WITHIN COVARIANCE MATRICES

NOTATION: K = NUMBER OF GROUPS
P = NUMBER OF VARIABLES
N = TOTAL NUMBER OF OBSERVATIONS
N(I) = NUMBER OF OBSERVATIONS IN THE I'TH GROUP

$$V = \frac{\prod |\text{WITHIN SS MATRIX}(I)|^{N(I)/2}}{|\text{POOLED SS MATRIX}|^{N/2}}$$

$$RHO = 1.0 - \left[\sum \frac{1}{N(I)-1} - \frac{1}{N-K} \right] \frac{2P^2 + 3P - 1}{6(P+1)(K-1)}$$

$$DF = .5(K-1)P(P+1)$$

UNDER NULL HYPOTHESIS: $-2\ RHO\ LN \left| \frac{N^{PN/2}}{\prod |N(I)|^{PN(I)/2}} V \right|$

IS DISTRIBUTED APPROXIMATELY AS CHI-SQUARE(DF)

TEST CHI-SQUARE VALUE = 39.07974413
WITH 15 DF PROB > CHI-SQ = 0.0006

SINCE THE CHI-SQUARE VALUE IS SIGNIFICANT AT THE
0.1000 LEVEL, THE WITHIN COVARIANCE MATRICES WILL
BE USED IN THE DISCRIMINANT FUNCTION.

REFERENCE: KENDALL,M.G. AND A.STUART. THE ADVANCED THEORY
OF STATISTICS VOL.3 P266 & 282.

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS
PAIRWISE SQUARED GENERALIZED DISTANCES BETWEEN GROUPS

$$D^2_{(I|J)} = (\bar{X}_I - \bar{X}_J)' \, COV_J^{-1} \, (\bar{X}_I - \bar{X}_J) + LN\,|COV_J| - 2\,LN\,PRIOR_J$$

GENERALIZED SQUARED DISTANCE TO SITE

FROM SITE	DECLINE	NATURAL
DECLINE	10.16451452	28.08364768
NATURAL	44.78641846	6.67073181

DISCRIMINANT ANALYSIS
CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.COMBSOIL

GENERALIZED SQUARED DISTANCE FUNCTION:

$$D^2_J(X) = (X-\bar{X}_J)' \, COV_J^{-1} \, (X-\bar{X}_J) + LN\,|COV_J| - 2\,LN\,PRIOR_J$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH SITE:

$$PR(J|X) = EXP(-.5\ D^2_J(X)) \ / \ SUM_K\ EXP(-.5\ D^2_K(X))$$

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

POSTERIOR PROBABILITY OF MEMBERSHIP IN SITE:

OBS	FROM SITE	CLASSIFIED INTO SITE		DECLINE	NATURAL
1	DECLINE	DECLINE		1.0000	0.0000
2	DECLINE	DECLINE		0.9993	0.0007
3	DECLINE	NATURAL	*	0.3601	0.6399
5	DECLINE	DECLINE		0.6195	0.3805
6	DECLINE	DECLINE		0.9999	0.0001
7	DECLINE	DECLINE		0.9997	0.0003
8	DECLINE	DECLINE		1.0000	0.0000
9	DECLINE	DECLINE		1.0000	0.0000
10	DECLINE	DECLINE		1.0000	0.0000
11	DECLINE	DECLINE		0.9975	0.0025
12	DECLINE	DECLINE		1.0000	0.0000
13	DECLINE	DECLINE		0.9995	0.0005
14	DECLINE	DECLINE		0.9999	0.0001
15	DECLINE	DECLINE		0.9986	0.0014
16	DECLINE	NATURAL	*	0.0702	0.9298
17	DECLINE	DECLINE		1.0000	0.0000
18	DECLINE	DECLINE		0.9999	0.0001
19	DECLINE	DECLINE		0.9998	0.0002
20	DECLINE	DECLINE		0.9972	0.0028
21	DECLINE	DECLINE		1.0000	0.0000
22	DECLINE	DECLINE		1.0000	0.0000
23	DECLINE	DECLINE		1.0000	0.0000
24	DECLINE	DECLINE		0.9478	0.0522
25	DECLINE	DECLINE		0.6386	0.3614
26	DECLINE	NATURAL	*	0.3376	0.6624
27	DECLINE	DECLINE		0.8798	0.1202
28	DECLINE	DECLINE		1.0000	0.0000
29	DECLINE	DECLINE		1.0000	0.0000
30	DECLINE	DECLINE		1.0000	0.0000
31	DECLINE	DECLINE		0.9996	0.0004
32	DECLINE	DECLINE		0.9996	0.0004
33	DECLINE	DECLINE		0.9858	0.0142
34	DECLINE	DECLINE		1.0000	0.0000
35	DECLINE	DECLINE		0.5654	0.4346
36	DECLINE	DECLINE		0.7651	0.2349
37	DECLINE	DECLINE		0.9999	0.0001
38	DECLINE	DECLINE		1.0000	0.0000

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS
CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.COMBSOIL

POSTERIOR PROBABILITY OF MEMBERSHIP IN SITE:

OBS	FROM SITE	CLASSIFIED INTO SITE		DECLINE	NATURAL
39	DECLINE	DECLINE		1.0000	0.0000
40	DECLINE	DECLINE		1.0000	0.0000
41	DECLINE	DECLINE		0.9920	0.0080
42	DECLINE	DECLINE		0.9992	0.0008
43	DECLINE	DECLINE		1.0000	0.0000
44	DECLINE	DECLINE		1.0000	0.0000
45	DECLINE	DECLINE		0.9834	0.0166
46	DECLINE	DECLINE		1.0000	0.0000
47	DECLINE	DECLINE		0.9999	0.0001
48	DECLINE	DECLINE		1.0000	0.0000
49	DECLINE	DECLINE		1.0000	0.0000
50	DECLINE	DECLINE		1.0000	0.0000
51	NATURAL	NATURAL		0.0000	1.0000
52	NATURAL	NATURAL		0.0000	1.0000
53	NATURAL	NATURAL		0.0000	1.0000
54	NATURAL	NATURAL		0.0000	1.0000
55	NATURAL	NATURAL		0.0000	1.0000
56	NATURAL	NATURAL		0.0000	1.0000
57	DECLINE	DECLINE		0.9608	0.0392
58	DECLINE	DECLINE		0.9585	0.0415
59	DECLINE	DECLINE		1.0000	0.0000
60	DECLINE	DECLINE		0.9994	0.0006
61	DECLINE	DECLINE		1.0000	0.0000
62	DECLINE	DECLINE		1.0000	0.0000
63	DECLINE	DECLINE		1.0000	0.0000
64	DECLINE	DECLINE		0.9946	0.0054
65	DECLINE	DECLINE		1.0000	0.0000
66	DECLINE	DECLINE		1.0000	0.0000
67	DECLINE	DECLINE		0.9261	0.0739
68	DECLINE	DECLINE		0.9928	0.0072
69	DECLINE	NATURAL	*	0.0389	0.9611
70	DECLINE	NATURAL	*	0.1720	0.8280
71	DECLINE	NATURAL	*	0.2576	0.7424
72	DECLINE	DECLINE		1.0000	0.0000
73	DECLINE	DECLINE		1.0000	0.0000
74	DECLINE	DECLINE		0.9934	0.0066
75	DECLINE	DECLINE		0.8550	0.1450
76	DECLINE	DECLINE		1.0000	0.0000
77	DECLINE	DECLINE		0.9985	0.0015
78	DECLINE	DECLINE		0.9989	0.0011

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS
CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.COMBSOIL

POSTERIOR PROBABILITY OF MEMBERSHIP IN SITE:

OBS	FROM SITE	CLASSIFIED INTO SITE		DECLINE	NATURAL
79	DECLINE	DECLINE		0.9998	0.0002
80	DECLINE	DECLINE		0.9994	0.0006
81	DECLINE	DECLINE		1.0000	0.0000
82	DECLINE	DECLINE		0.9947	0.0053
83	DECLINE	DECLINE		1.0000	0.0000
84	DECLINE	NATURAL	*	0.0952	0.9048
85	DECLINE	DECLINE		0.9932	0.0068
86	DECLINE	DECLINE		0.9932	0.0068
87	DECLINE	DECLINE		1.0000	0.0000
88	DECLINE	DECLINE		1.0000	0.0000
89	DECLINE	DECLINE		1.0000	0.0000
90	DECLINE	DECLINE		1.0000	0.0000
92	DECLINE	DECLINE		0.9834	0.0166
93	DECLINE	DECLINE		0.5342	0.4658
94	DECLINE	DECLINE		0.6351	0.3649
95	DECLINE	DECLINE		0.7684	0.2316
96	DECLINE	NATURAL	*	0.0912	0.9088
97	DECLINE	DECLINE		1.0000	0.0000
98	DECLINE	DECLINE		0.7500	0.2500
99	DECLINE	NATURAL	*	0.0472	0.9528
100	DECLINE	DECLINE		0.9866	0.0134
101	NATURAL	NATURAL		0.0000	1.0000
102	NATURAL	NATURAL		0.0000	1.0000
103	NATURAL	NATURAL		0.0000	1.0000
104	NATURAL	NATURAL		0.0000	1.0000

* MISCLASSIFIED OBSERVATION

DISCRIM ANALYSIS OF COMBINED ROOTZONE FACTORS

DISCRIMINANT ANALYSIS
CLASSIFICATION SUMMARY FOR CALIBRATION DATA: WORK.COMBSOIL

GENERALIZED SQUARED DISTANCE FUNCTION:

$$D^2_J(X) = (X-\bar{X}_J)' \, COV_J^{-1} \, (X-\bar{X}_J) + LN\,|COV_J| - 2\,LN\,PRIOR_J$$

POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH SITE:

$$PR(J|X) = EXP(-.5\,D^2_J(X)) \,/\, SUM_K\, EXP(-.5\,D^2_K(X))$$

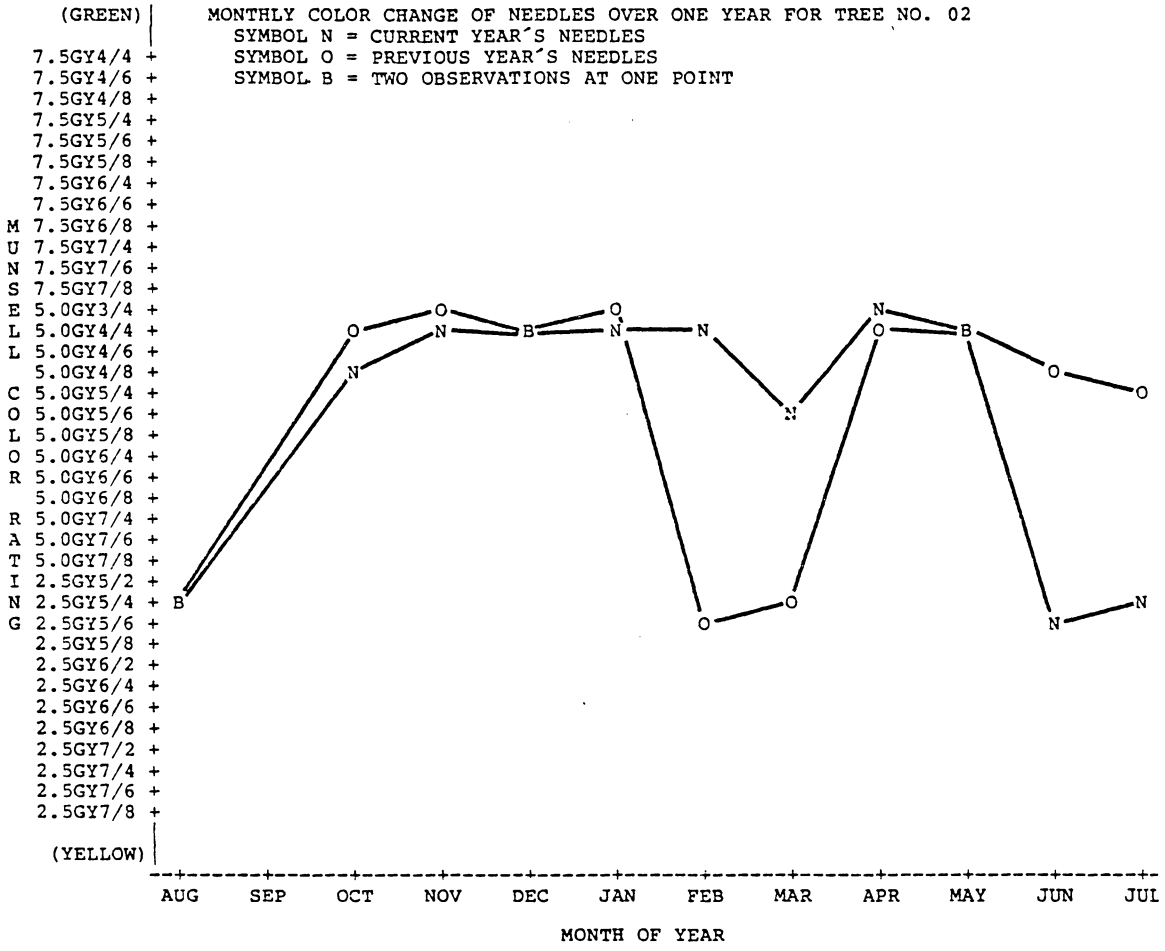
NUMBER OF OBSERVATIONS AND PERCENTS CLASSIFIED INTO SITE:

FROM SITE	DECLINE	NATURAL	TOTAL
DECLINE	83	9	92
	90.22	9.78	100.00
NATURAL	0	10	10
	0.00	100.00	100.00
TOTAL	83	19	102
PERCENT	81.37	18.63	100.00
PRIORS	0.9020	0.0980	

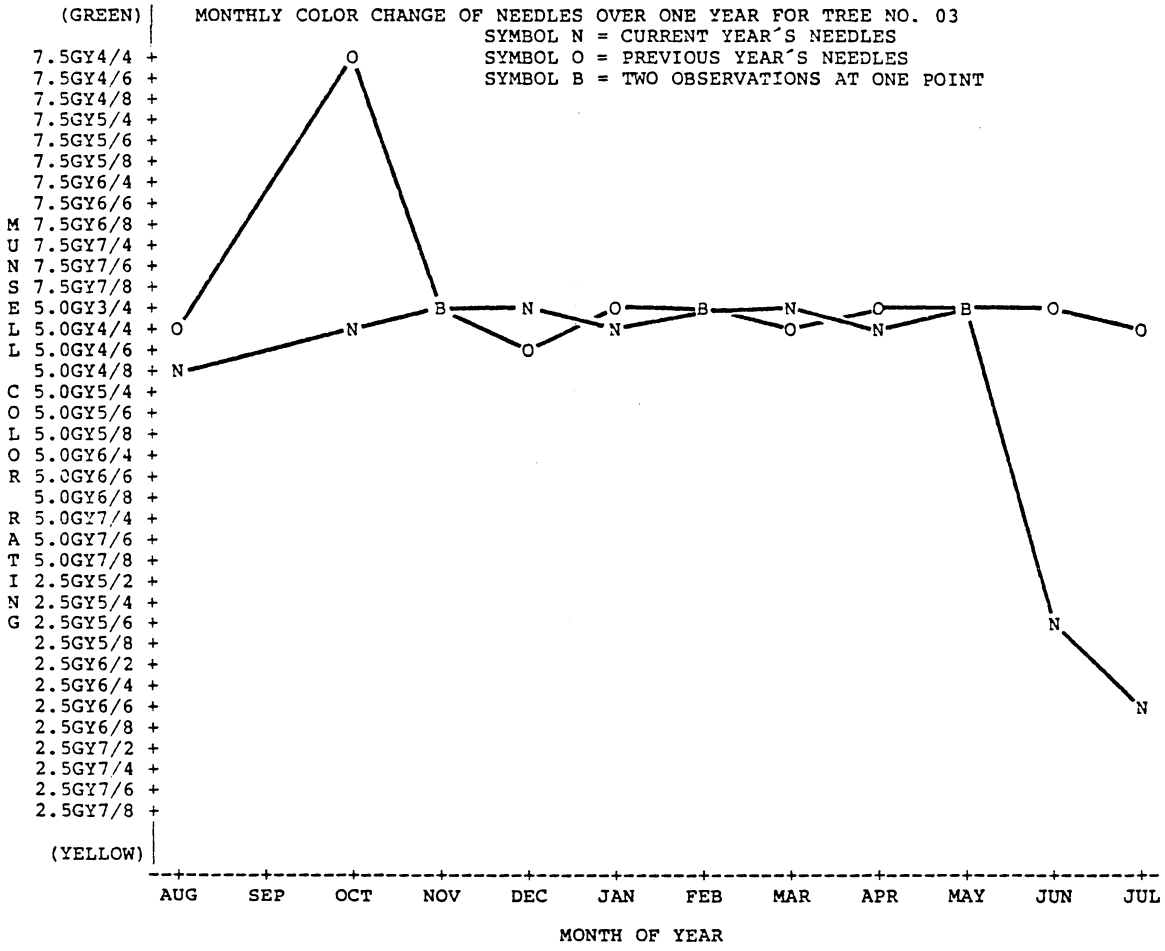
Appendix C

PLOTS OF SEASONAL FOLIAR COLOR CHANGE RATINGS

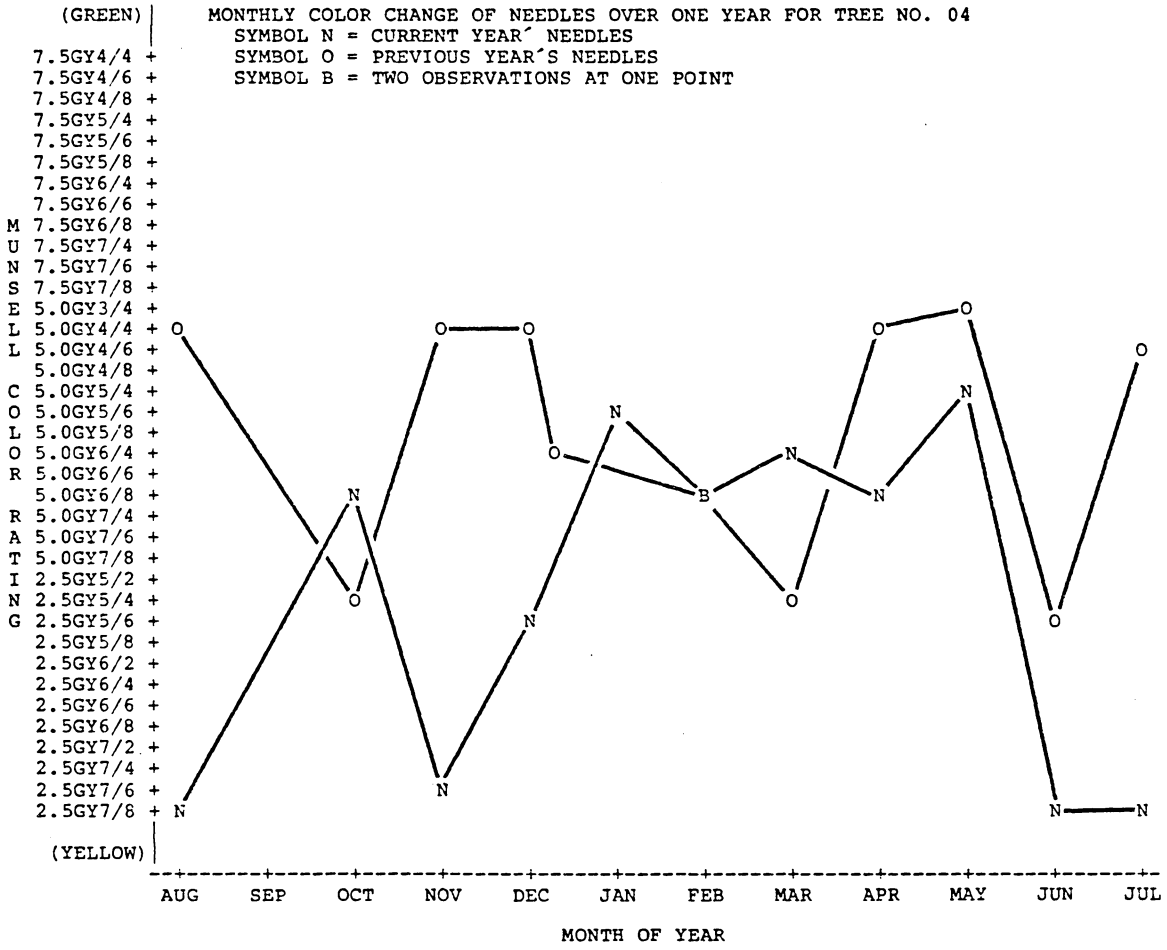
Tree codes 2, 3, 4, 5, 18, and 19 were decline habitat trees and part of the systematic indexing study. Trees 106-110 were natural habitat trees but were not part of the systematic indexing study. (see section 3.2 of chapter 3 for more information)



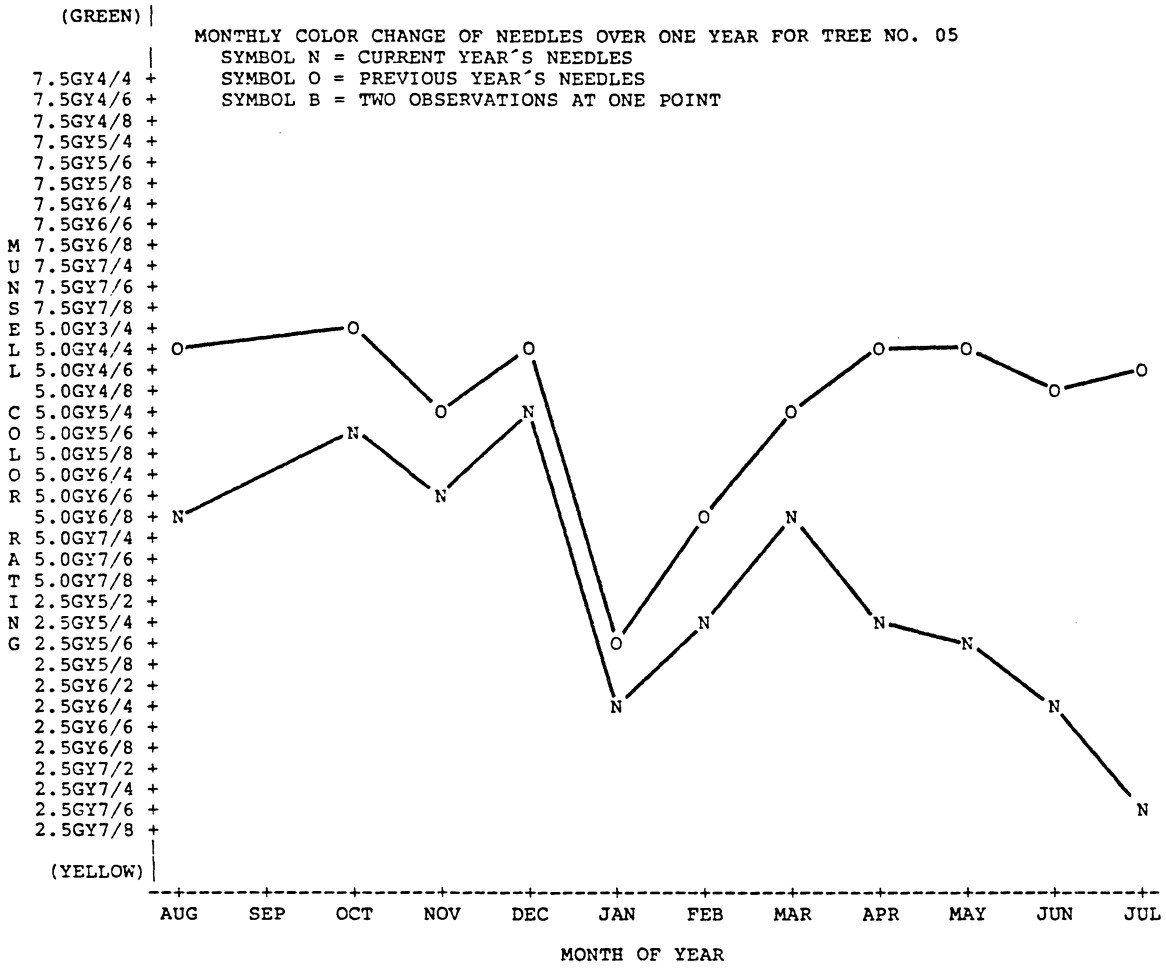
Plot of seasonal foliar color changes over a period of 12-months for a poor quality site tree (tree code #02).



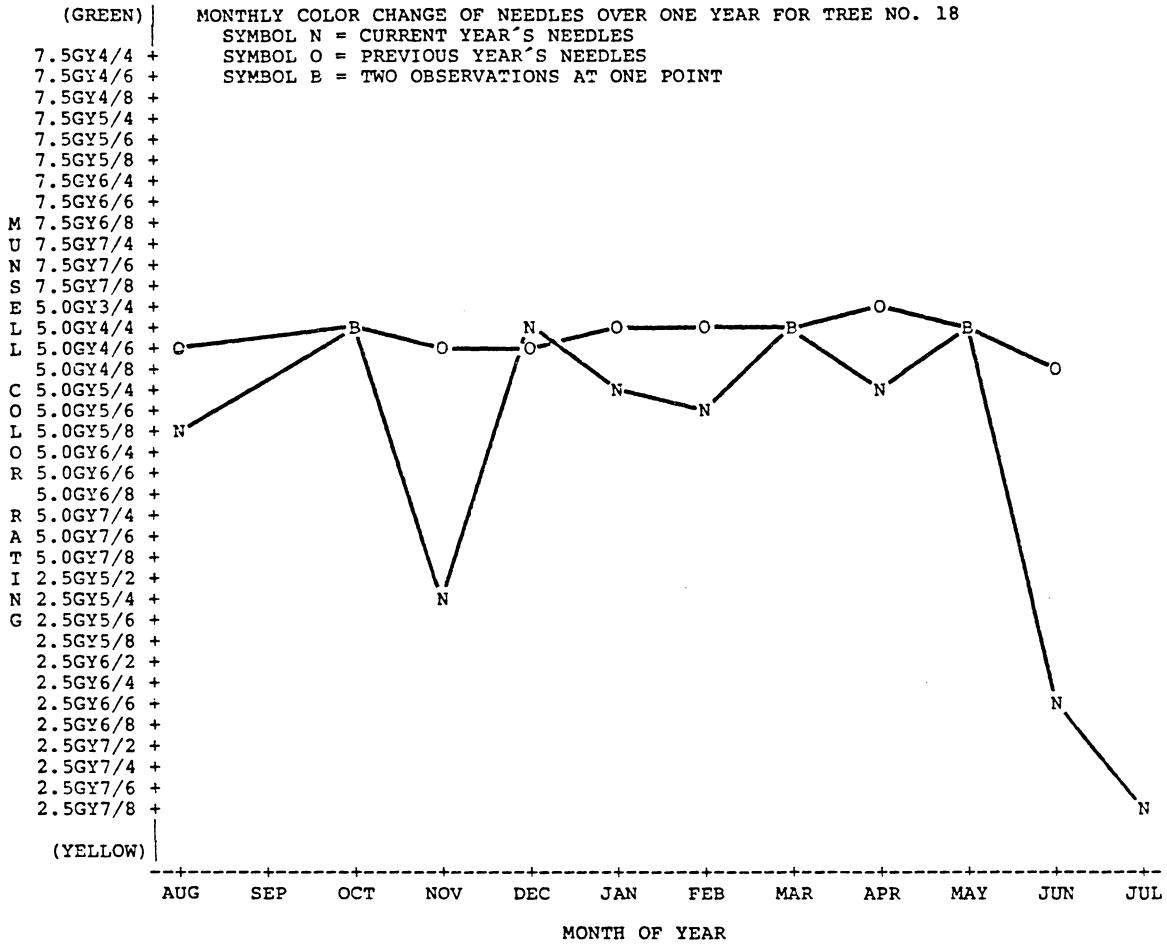
Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #03).



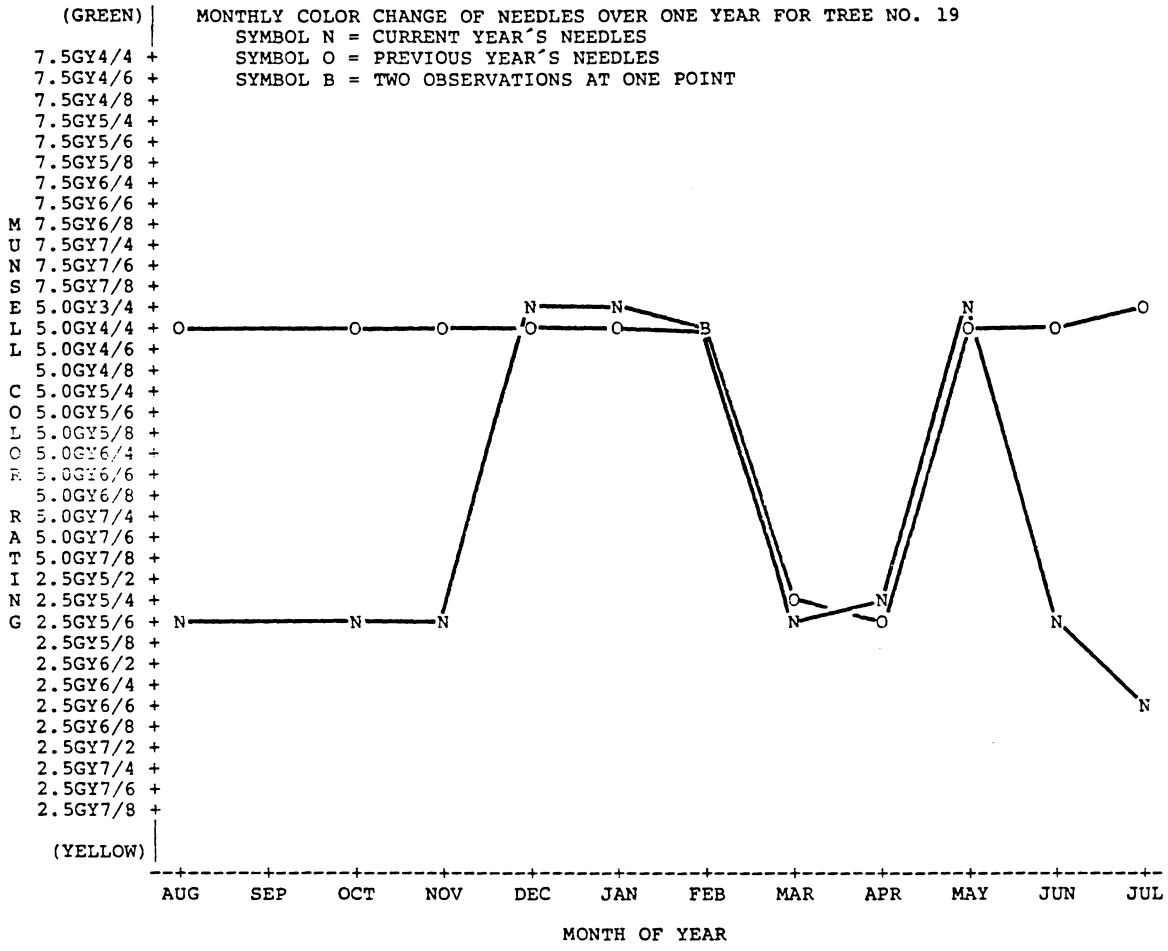
Plot of seasonal foliar color changes over a period of 12-months for a poor quality site tree (tree code #04).



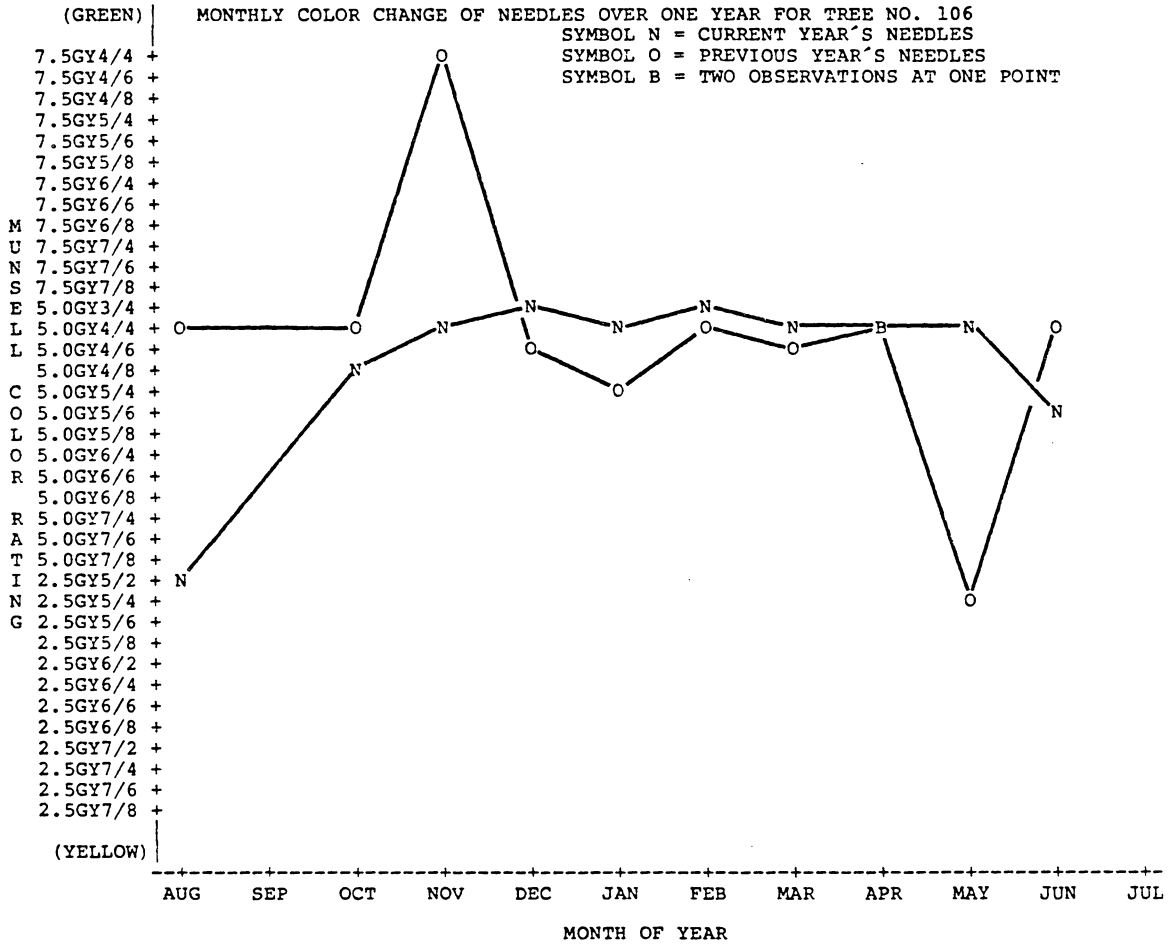
Plot of seasonal foliar color changes over a period of 12-months for a poor quality site tree (tree code #05).



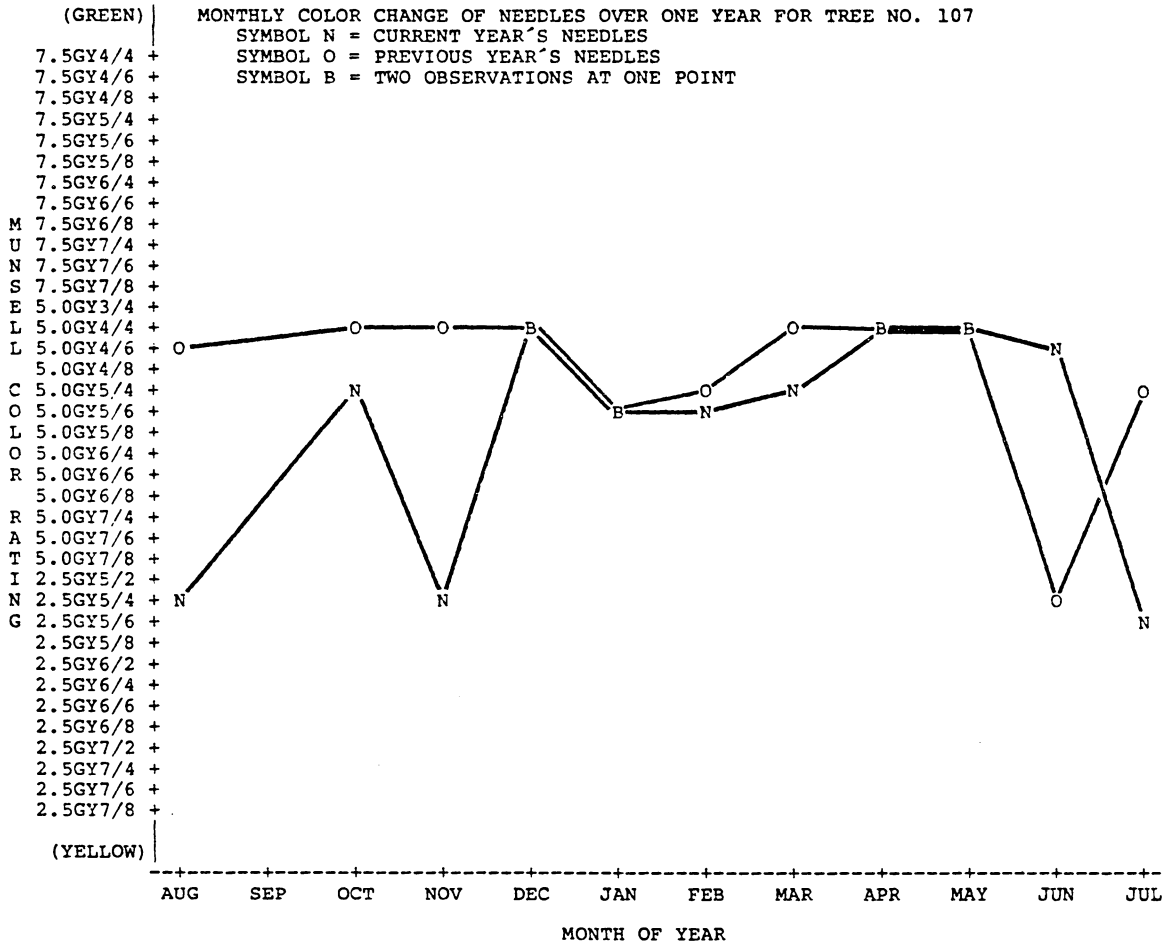
Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #18).



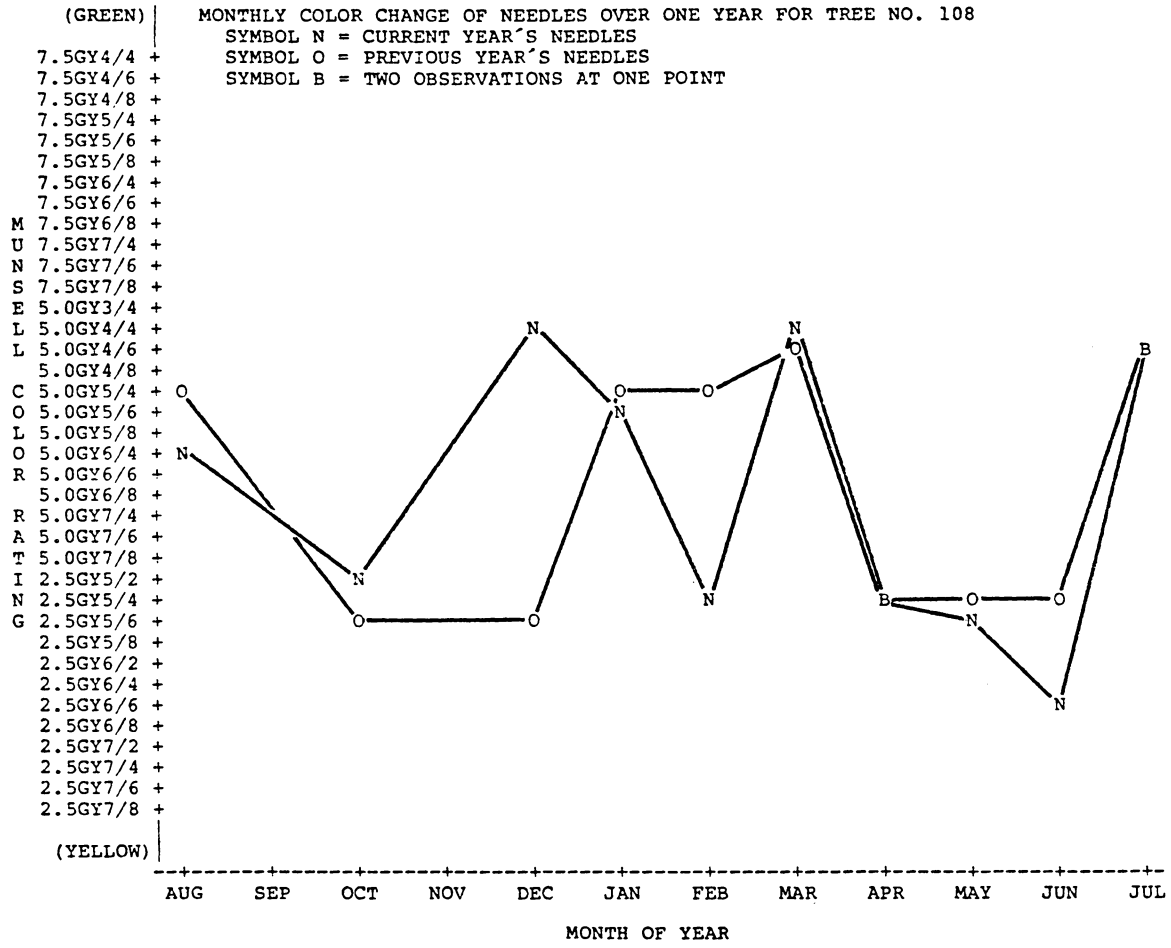
Plot of seasonal foliar color changes over a period of 12-months for a poor quality site tree (tree code #19)



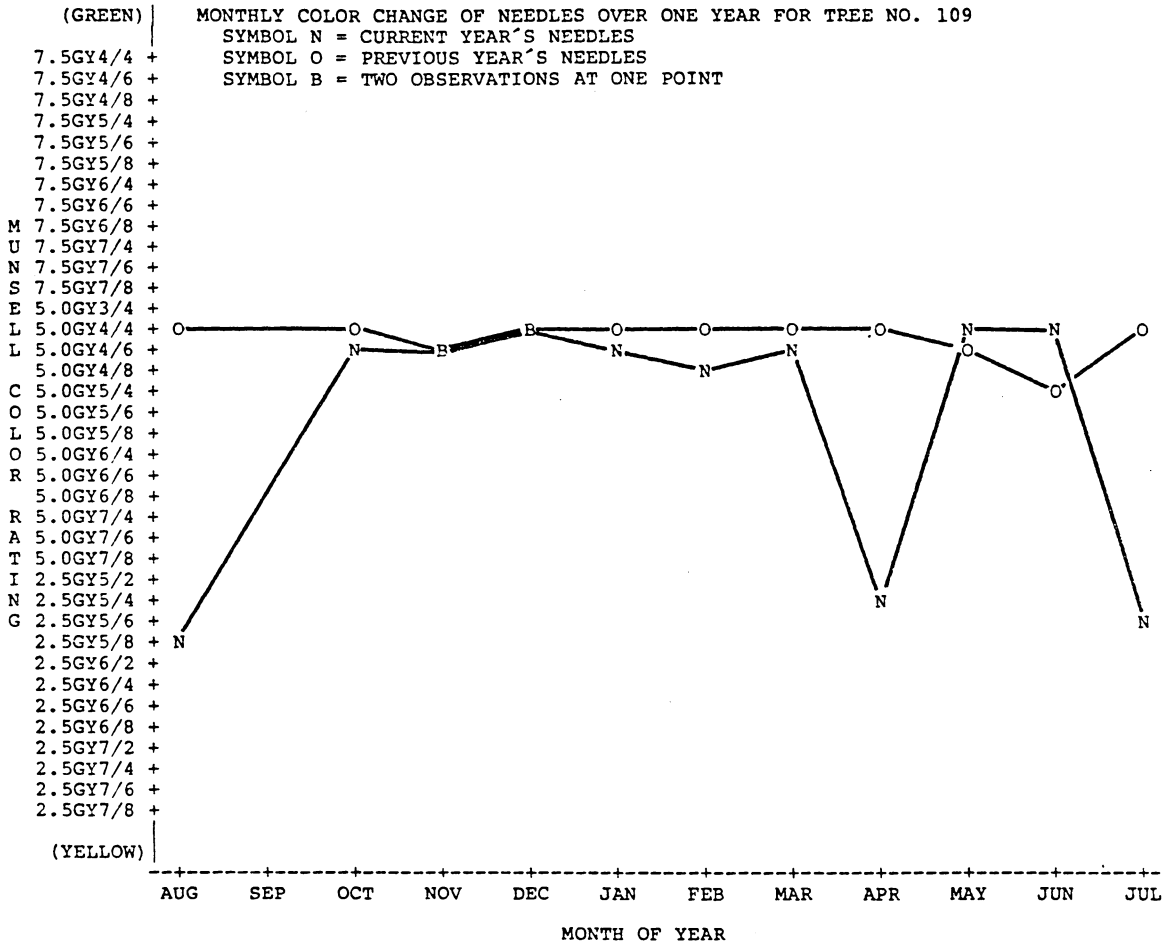
Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #106).



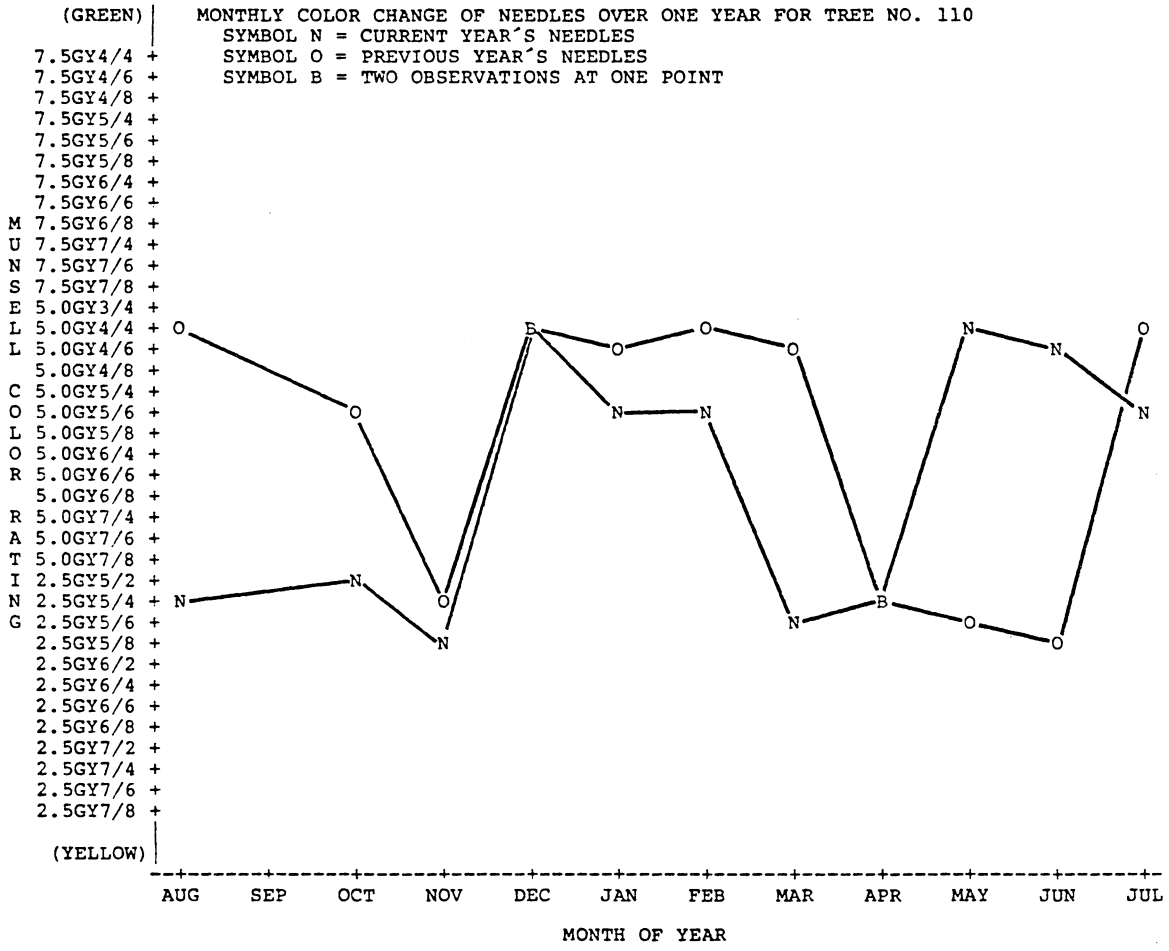
Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #107).



Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #108).



Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #109).



Plot of seasonal foliar color changes over a period of 12-months for a good quality site tree (tree code #110).

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THE ETIOLOGY OF THE DECLINE OF EASTERN WHITE PINE (*Pinus strobus* L.) ON VIRGINIA LANDSCAPES: A SURVEY OF STRESS FACTORS

by

Michael John Weaver

(ABSTRACT)

A decline of eastern white pine, *Pinus strobus* L., has been observed for over 80 years in the eastern United States. The syndrome has not always been discussed as a decline but reported under a variety of names.

Symptoms vary with time required for trees to die, but generally include chlorotic foliage, in many cases needle loss producing a tufted appearance, premature annual loss of needles, drooping of needles in some cases, shriveling of bark after a period of time, and eventual death after a period of months to years.

An investigation into the causes of decline on landscape sites in Virginia included an indexing technique to compile and analyze, systematically, pertinent data from good and poor quality sites. Over 300 variables were studied from

over 100 observations to narrow down the apparent causal factors for future investigation in a controlled environment. Observations were organized into two groups for analysis, one called the "decline habitat" and the other the "natural habitat." Natural habitat observations consisted of trees from a site in the Jefferson National Forest (VA) and decline habitat observations consisted of trees from mostly western Virginia landscapes.

After thorough study for a period of two years, a group of growth indicators were weighed against a group of site quality indicators. Growth quality indicators included: a height vs. age index, a 10-year compilation of tree ring increments and inter-branch whorl measurements converted to percent growth per year, and seasonal foliar color changes using a Munsell rating index.

Site quality indicators centered around the soils with soil pH, clay content, amounts of compaction and soil disturbance as the most prominent factors derived from the study. Soil pH averaged 6.95 with a range of 5.9-8.1 for decline habitats; while the pH averaged 5.50 with a range of 5.0-6.0 for the natural habitat. Clay content averaged 37.05% for decline sites vs. 17.76% for the natural site for soils above and in the root zones of white pines. Clay content averaged 43.99% for decline sites vs. 17.95% for the

natural site for soils beneath the root zones of white pines. Soils under decline habitat trees were highly compacted with measurements as high as 1806.1 psi to penetrate some decline habitat soils, while the natural habitat soils had little if any compaction, with readings of between 138 and 273 psi. Soil disturbance was not present in the natural site while present in most decline sites. The major cause of disturbance was construction and earth-moving activities around landscape sites.

Important abiotic factors which worked in concert with soil factors included poor planting practices, competition with tree feeder roots from turfgrass, chemical pollutants, and mechanical damage by weather and man. Biotic factors were viewed as secondary agents attracted to already weakened trees after initiation of decline by the previously discussed factors.

Separate studies of seasonal foliar color changes and the initial finding of the pinewood nematode in Virginia aided in identifying additional indicators of and contributors to decline.