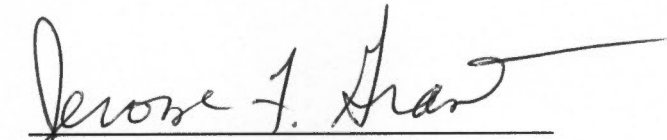


To the Graduate Council:

I am submitting herewith a thesis written by Robert Angelo Vance entitled "Incidence and Life History of Beech Scale, Initiator of Beech Bark Disease, in the Great Smoky Mountains National Park." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.

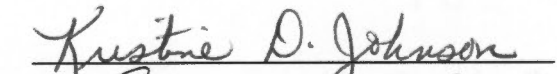


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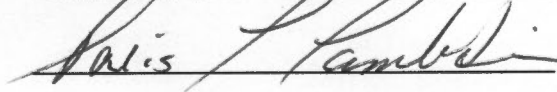


Mark T. Windham, Major Professor

We have read this thesis and
recommend its acceptance:







Accepted for the Council:



Associate Vice Chancellor
and Dean of the Graduate School

**INCIDENCE AND LIFE HISTORY OF BEECH SCALE,
INITIATOR OF BEECH BARK DISEASE, IN THE
GREAT SMOKY MOUNTAINS NATIONAL PARK**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Robert Angelo Vance

December 1995

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ABSTRACT

American beech, *Fagus grandifolia* Ehrlich, in eastern North America are currently threatened by the devastating beech bark disease. This disease is caused by the fungal pathogens, *Nectria coccinea* var. *faginata* Lohman, Watson and Ayers, and *Nectria galligena* Bres., which infect trees that are predisposed by infestations of beech scale, *Cryptococcus fagisuga* Lindinger. In 1993, beech bark disease was discovered in the Great Smoky Mountains National Park (GSMNP).

In 1994, a 2-year cooperative research project involving the National Park Service and the University of Tennessee Agricultural Experiment Station was initiated to study several aspects of beech bark disease in the GSMNP. One objective of this research was to initiate long-term monitoring of incidence and distribution of beech scale and beech bark disease in permanent plots in the GSMNP. Additional objectives of this research included monitoring the life history and seasonal incidence of beech scale, and identifying natural enemies of this insect present in the GSMNP.

Permanent plots were established for long-term monitoring, and plots were sampled twice in 1994 and once in 1995 for incidence and levels of beech scale and *Nectria* spp. The overall status of beech scale has not changed dramatically in the permanent plots during this investigation. However, the overall incidence and levels of *Nectria* spp. have consistently increased during this study.

Permanent plots also were monitored in 1994 and 1995 for incidence of *Xylococcus betulae* (Pergande) Morrison, another scale species that has been

associated with beech bark disease. This scale species was present in all permanent plots and at relatively high incidence in all but one plot.

Life history and seasonal incidence of beech scale were monitored at two locations in the GSMNP, from February 1994 to June 1995. During this investigation, the greatest number of beech scale eggs were collected in July and August 1994. The peak period for dissemination of beech scale occurred in September 1994, when the greatest number of crawlers were collected.

Few natural enemies of beech scale were observed in the GSMNP during this research. Monitoring for natural enemies of beech scale was conducted at four locations. Trapping for parasitoids of beech scale was conducted from May to September 1994, and no parasitoids were captured. Visual observations for arthropod predators of beech scale also were conducted from May to September 1994, and one predator, *Trombidium* sp., was documented to feed on beech scale.

The absence of parasitoids impacting beech scale populations, the limited diversity of predators of the scale, and the current success of this pest species indicate that beech scale will continue to threaten American beech in the GSMNP. Data from this research will provide base-line information needed for development and implementation of strategies for maintenance and control of beech scale in the GSMNP.

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CHAPTER I

INTRODUCTION

American beech, *Fagus grandifolia* Ehrlich, is an ecologically and economically important component of forests in eastern North America. Distribution of this tree species ranges from Nova Scotia southward to northern Florida and westward to Texas, Wisconsin, and Ontario (Hamilton 1955). Standing beech timber in the United States in 1943 was estimated to be more than seven billion board feet (Record and Hess 1943).

American beech can grow to a height greater than 36 m, a diameter greater than 2.1 m, and can live as long as 300 to 400 years (Hepting 1971, Hamilton 1955, Harlow 1935). American beech can live in a wide range of climatic conditions. This tree species can live with a daily normal mean precipitation ranging from 0.231 to 0.436 cm, and a yearly normal mean relative humidity of 67.5 to 85.2% (Hamilton 1955). The range of the normal frostless season for this tree is 95 to 281 days (Hamilton 1955). American beech also can grow on a wide range of soil conditions. This tree species is found on soil types ranging from sand to clay loam, and will grow on soils that range from calcareous to highly acidic, although the ideal soils for beech have a neutral or slightly alkaline pH (Hamilton 1955). American beech grows best in deep soil, but the root system of this tree can adapt to grow in shallow soil as well (Hamilton 1955).

American beech reproduce by seed as well as stump sprouts and root suckers (Hepting 1971, Harlow 1935). Large crops of seed are often produced, and reproduction

by seed is usually successful (Hepting 1971, Hamilton 1955). Reproduction by root suckers is quite substantial and often results in the growth of dense thickets beneath the parent tree, but reproduction by stump sprouts is usually not as effective (Hepting 1971, Harlow 1935).

American beech had limited economic value in earlier wood industry operations because of difficulties and potential losses encountered in seasoning the timber (Houston 1975, Shigo 1972). Improved drying methods developed during the 1950s and 1960s, and the increased use of beech as a pulpwood, have made the use of this tree species profitable (Twery and Patterson 1983, Houston 1975, Shigo 1972, Baker and McMillen 1955). Some uses of beech timber include furniture, heavy duty wood flooring, plywood, turning stock, dowels and containers (Mayer and Allen 1983, Twery and Patterson 1983, Titmuss 1971). American beech also is an important source of fuelwood (Twery and Patterson 1983).

The American beech plays an essential role in the natural ecological systems of eastern forests. Beech trees provide suitable habitat for numerous animal species and are an important food source for many birds and mammals (Martin et al. 1961). Leaf buds and the triangular seeds, or beechnuts, produced by these trees are an excellent source of food for many upland game birds, such as wild turkey, ring-necked pheasant and ruffed grouse (Martin et al. 1961). Many song birds, including the rose-breasted grosbeak, white-breasted nuthatch, northern blue jay, tufted titmouse and several woodpecker species, also feed on beechnuts (Martin et al. 1961).

Several forest mammals, such as the gray fox, red fox, raccoon, beaver and several squirrel species, use beechnuts as part of their diet (Martin et al. 1961). The flying squirrel and porcupine have been reported to acquire from 10 to 25 % of their diet from beechnuts. Black bear in Pennsylvania have been documented to obtain between 25 and 50% of their diet from beechnuts, and white-tailed deer in New York have been reported to feed on the foliage, twigs and nuts of American beech (Martin et al. 1961). One season of low beech mast production can have substantial negative effects on animals which depend on beechnuts for a sizeable portion of their diet (Martin et al. 1961). Any forest changes involving the American beech could have dramatic effects on the population dynamics of these animal species.

Some common fungal diseases associated with American beech include wood rots such as *Fomes igniarius* (L.) Gill., *F. applanatus* (Bers.) Wallr., and *Ployporus glomeratus* Peck (Hepting 1971, Hamilton 1955). Two foliage diseases of this tree are *Gloeosporium fagi* Westend and *Phyllosticta faginea* Peck (Hepting 1971). One root disease commonly associated with beech is *Armillaria mellea* Karst (Hepting 1971).

The American beech is currently threatened by beech bark disease, a devastating stem disease. The first outbreak of this disease in North America was discovered in Canada near Halifax, Nova Scotia, around 1920 (Ehrlich 1934). Beech bark disease was first found in the United States in Maine in 1931 (Ehrlich 1934). The disease has since been identified as far south as Tennessee and North Carolina (Figure 1), where it was discovered in the Great Smoky Mountains National Park (GSMNP) in 1993 (Houston 1994b; K. D. Johnson, personal communication).

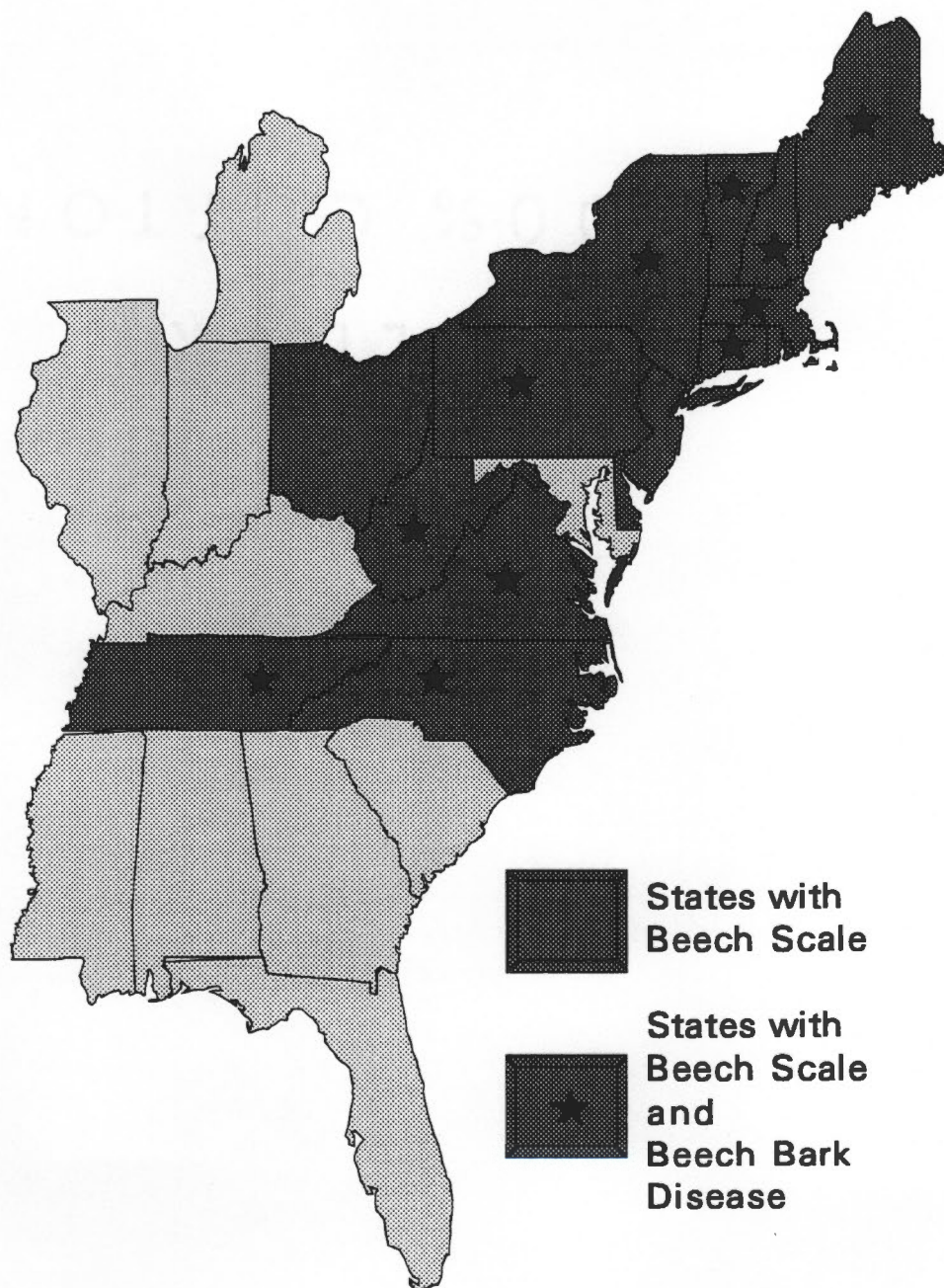


Figure 1. Distribution of beech scale and beech bark disease in the northeastern United States (modified from Houston 1994b).

Beech bark disease is primarily attributed to interactions between the beech scale, *Cryptococcus fagisuga* Lindinger (*Coccus fagi* Baerensprung) [family Eriococcidae, superfamily Coccoidea, suborder Sternorrhyncha and order Homoptera (Miller and Miller 1993, Borror et al. 1989, Stoetzel 1989)], and certain species of the fungus *Nectria* Fries (Houston 1994a, Ehrlich 1934). This epiphytotic is initiated when beech scale feed on living bark tissues, which weakens the natural defenses of the beech tree and renders it susceptible to infection by *Nectria* spp. (Houston 1994b, Manion 1991, Perrin 1983). The death of predisposed bark tissues infected by the fungus often leads to tree mortality (Manion 1991, Houston 1975). Mortality occurs when trees are completely girdled by the fungus or when partially girdled trees are subsequently broken by the wind (Shigo 1972).

Merchantable timber losses resulting from beech bark disease can be substantial. In a 1975-77 survey, a volume loss of almost 300 million board feet of timber was attributed to tree mortality and damage caused by this disease in Vermont (Houston 1994b, Miller-Weeks 1983). Timber volume losses of 3,383 board feet per-hectare were recorded in a 1981 survey of areas with prevalent beech bark disease in the Monongahela National Forest in West Virginia (Mielke and Houston 1983). The amount of damage and losses caused by beech bark disease can vary in proportion to the density of beech trees in a given forest. For example, 36% of the basal area of the forest stand in the West Virginia survey was composed of American beech (Mielke and Houston 1983).

The spread of beech bark disease into a non-diseased area can cause substantial changes in the forest ecosystem. The development of this epiphytotic is divided into three categories, the “advancing front,” “killing front” and the “aftermath stage” (Houston and

O'Brien 1983, Shigo 1972). The advancing front forests are characterized by newly-established beech scale colonies and only rare occurrence of the fungal pathogens (Houston and O'Brien 1983, Shigo 1972). The second stage, or killing front, has well established scale colonies, high incidence of the pathogen and prevalent tree mortality (Shigo 1972). Forests in the disease aftermath stage have damaged, disfigured and dead trees, healthy resistant trees, and abundant young beech saplings that are primarily root sprouts from infected and dying trees (Houston 1975, Shigo 1972). These thickets of beech saplings are genetic clones of the disease-susceptible stalk from which they sprouted, and this trend could lead to high tree mortality in the future when the saplings are subsequently attacked by beech scale and *Nectria* spp. (Houston 1975).

The beech scale is believed to have been accidentally introduced into North America from Europe in the late 1800s (Ehrlich 1934). The first records of this insect in North America were published in 1914 and referred to infestations identified in 1911 and 1913 near Bedford and Halifax, Nova Scotia (Houston 1994a, Ehrlich 1934). The beech scale is believed to have been imported on stocks of European beech, *Fagus sylvatica* L., the host of the insect in Europe (Ehrlich 1934, 1932). The beech scale was first discovered in the United States in 1929 in Boston, Massachusetts, in the Arnold Arboretum (Ehrlich 1934, 1932). Whether the insect was introduced into the United States from Canada or transported directly from Europe is not known (Ehrlich 1934). A beech scale infestation discovered in 1931, in Liberty, Maine, is suspected to have spread from infestations in Canada (Ehrlich 1934).

The beech scale has spread from Nova Scotia to other Canadian provinces including New Brunswick, Quebec, Cape Breton Island, and Prince Edward Island (Lachance 1983, Magasi and Newell 1983, Houston et al. 1979a). In the United States, the beech scale has spread throughout New England and south to West Virginia and Virginia and west to Ohio (Figure 1) (Houston 1994b, Mielke et al. 1985). Infestations of the insect also are present in the GSMNP in Tennessee and North Carolina (Houston 1994b).

The long-range dispersal of beech scale is accomplished primarily by wind when the insect is in the first-instar or crawler stage (Wainhouse and Gate 1988). The beech scale has spread in North America at a rate of 6 to 16 km per year (Wainhouse and Gate 1988). Human activities may sometimes be involved in the dispersal of beech scale because infestations have been discovered in highly traveled vacation sites located beyond the known range of the insect (Houston 1994b). An infestation identified near an arboretum in Ohio also implicates humans as a means of insect dispersal (Houston 1994b). The migration of birds and activities of several forest mammals also may contribute to the spread of this pest (Houston 1994b, Ehrlich 1934).

After dispersal onto beech, the insect pierces the bark with its stylet and feeds intercellularly on the parenchyma cells below the bark surface (Manion 1991, Wainhouse and Gate 1988, Lonsdale 1983a). Feeding by the insect is believed to induce changes which inhibit the ability of the tree to produce wound periderm, a natural defense to invasion by insects and pathogens (Houston 1994b, Manion 1991). Certain pectinases produced by beech scale are believed to promote susceptibility to infection by *Nectria* spp., but the overall weakening of natural defenses of the tree may involve combined

interactions between beech scale, *Nectria* spp., and the beech tree host (Houston 1994b, Perrin 1983).

Beech bark disease in North America is primarily associated with two species of *Nectria*, *Nectria coccinea* var. *faginata* Lohman, Watson, and Ayers, and *Nectria galligena* Bres. (Houston 1994a). These pathogens are members of the family Nectriaceae, order Hypocreales, series Pyrenomycetes, subclass Euascomycetes, and class Ascomycetes (Farr et al. 1989, Ehrlich 1934). The origin of *N. coccinea* var. *faginata* is unknown, but occurrence patterns suggest this pathogen was introduced into North America from Europe (Houston 1994a, 1994b). *Nectria coccinea* var. *faginata* is closely related to *N. coccinea* var. *coccinea* which is the fungal pathogen associated with beech bark disease in Europe (Houston 1994b). Beech bark disease is well distributed throughout Europe, and found in several countries including Great Britain, France, Germany and Denmark (Houston et al. 1979b).

Nectria galligena, native to North America, is often found on several hardwood tree species, including red maple, *Acer rubrum* L.; sugar maple, *Acer saccharum* Marsh.; yellow birch, *Betula alleghaniensis* Britt.; and red oak, *Quercus rubra* L. (Houston 1994a). Research suggests that American beech forests infested with beech scale may first develop beech bark disease when infected with the native *N. galligena* from the inoculum load present on these alternative hardwood hosts (Houston 1994a). *Nectria coccinea* var. *faginata*, which appears to be a better competitor than its native counterpart, is often a

secondary invader and replaces *N. galligena* as the pathogen of beech bark disease (Houston 1994a, 1994b).

Nectria spp. have both perfect (sexual) and imperfect (asexual) stages (Houston 1994b). The perfect stages produce ascospores within red perithecia which can be observed on the bark surface of infected trees (Houston 1994b, Kenaga 1986). The imperfect stages produce macroconidia on conidiophores within sporodochia, and microconidia when the organism grows saprophytically (Houston 1994b, Kenaga 1986). Microconidia are primarily dispersed by water, but ascospores and macroconidia are spread by either wind or water (Houston 1994b).

The discovery of beech bark disease in the GSMNP has prompted research into several aspects of this disease. A 2-year cooperative research project involving the National Park Service (NPS) and the University of Tennessee Agricultural Experiment Station was initiated in 1994. This research was funded in part through a cooperative agreement with the NPS, and all field work was conducted in the GSMNP. Objectives of this research included: 1) the initiation of long-term monitoring of incidence and distribution of beech scale and beech bark disease in permanent plots in the GSMNP, 2) monitoring the life history and seasonal incidence of beech scale, and 3) monitoring of natural enemies of beech scale in the GSMNP.

The initiation of long-term monitoring will establish base-line data necessary to document temporal changes in incidence and distribution as well as the impact of the spread of beech scale and beech bark disease in the GSMNP plots. These data will

provide essential information for the development and implementation of strategies for management of beech bark disease in the GSMNP.

Monitoring the life history and seasonal incidence of beech scale will provide insight into seasonality and life stage development, and document the seasonal incidence of the mobile first-instar stage. These data will allow researchers to identify the optimum time for dispersal of beech scale in the GSMNP.

Monitoring of natural enemies is an important aspect of this research. This study will investigate the relative diversity and abundance of natural enemies of *C. fagisuga* in the GSMNP. This information will indicate the presence or absence of niches for potential biological control of this pest species.

CHAPTER II

INFESTATION AND DISTRIBUTION OF BEECH SCALE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

i. Introduction

American beech, *Fagus grandifolia* Ehrlich, is a unique component of the diverse forest system of the Great Smoky Mountains National Park (GSMNP). Three races or genotypes of American beech are found in the GSMNP. The “white” beech trees are found in cove forests at lower elevations, while the “red” beech race is found in upper cove forests between 1067 m (3500 ft) and 1372 (4500 ft) (Stupka 1964, Hamilton 1955). At elevations above 1372 m, “gray” beech are primarily found in beech gap forests (Stupka 1964). Beech trees are an important food source and habitat for many animals (Martin et al. 1961).

American beech in the GSMNP is currently threatened by beech bark disease. This disease is primarily associated with the beech scale, *Cryptococcus fagisuga* Lindinger, and two species of fungi, *Nectria coccinea* var. *faginata* Lohman, Watson, and Ayers, and *Nectria galligena* Bres. (Houston 1994b). Beech bark disease is initiated when beech trees are infested with beech scale, which insert their stylet through the bark to feed on parenchyma cells beneath the surface of the bark (Houston 1994b, Manion 1991, Lonsdale

1983a). Predisposed bark tissues are then infected and killed by *Nectria* spp., and this infection often leads to the death of the entire tree (Manion 1991, Wainhouse and Gate 1988).

Long-term monitoring of beech scale and beech bark disease in the GSMNP is necessary to document temporal changes in distribution and incidence of the insect and disease. This monitoring will document the impact of the spread of beech scale and beech bark disease. American beech trees that were resistant to infestation by beech scale were observed in aftermath stage forests in New England and Canada (Houston 1983a). The chemistry of the bark is believed to be an important factor in this resistance (Houston 1994b). Resistance to beech scale also was observed in Europe in planted forests of European beech. The mechanism of this resistance is believed to be the physical structure of the bark (Houston 1994b). Long-term monitoring in the GSMNP may enable researchers to identify trees that exhibit similar types of resistance.

The primary objective of this research is to establish base-line data for long-term monitoring of beech scale and beech bark disease in permanent plots in the GSMNP. An additional objective is to monitor the incidence of the predaceous mite, *Trombidium* sp., and *Xylococcus betulae* (Pergande) Morrison, another scale species that has been associated with beech bark disease (Manion 1991, Shigo 1972).

ii. Materials and Methods

Nine new permanent plots (20 m x 20 m) were established during the spring and summer of 1994 (May-July) to evaluate long-term spread and impact of beech bark disease in the GSMNP (Table 1, Figure 2). One additional plot from previous research on American beech was included for data collection because of the abundance of beech trees within this plot. Based on preliminary visual observations by National Park Service personnel, three plots were established in areas where beech scale had not previously been found, and three plots were established in areas having low infestations of scale (newly-established beech scale populations present on trees in the area). The last three new plots and the one plot from previous research were located in areas with reportedly high beech scale infestations (well-established beech scale populations present on trees in the area).

Each plot was adjusted for slope correction using a clinometer. The four corners of each plot were marked with 75 cm rebar driven approximately 30 cm into the ground. These marker bars were painted bright orange before installation to ensure good visibility. One 45 cm rebar marker was added to each side of the plot, along the perimeter, centered between the corner markers. Another 45 cm marker was placed at the center of the plot. The 45 cm markers were driven about 25 cm into the ground. Elevation, aspect and slope of each plot were determined using an altimeter, compass, and clinometer, respectively. Methods used for plot design and data collection were derived from the Site Classification and Field Measurements, Methods Manual (Durr et al. 1988).

Table 1. Permanent plots established for research on beech bark disease in the Great Smoky Mountains National Park.

Plot	Location	n ^a	Preliminary Beech Scale Classification ^b	Elevation
A	Gregory Bald	45	None	1420 m (4660 ft)
B	Jenkins Knob	54	Low	1341 m (4400 ft)
C	Forney Ridge	77	High	1670 m (5480 ft)
D	Trillium Gap	55	None	1451 m (4760 ft)
E	Deep Creek	31	None ^c	1378 m (4520 ft)
F	Indian Gap	55	Low	1596 m (5235 ft)
G	Chimney Trail	20	Low	1109 m (3638 ft)
H	Sweat Heifer	28	High	1778 m (5834 ft)
I	Fork Ridge	35	High	1451 m (4760 ft)
J	Newfound Gap	49	Low	1596 m (5240 ft)

^a n = Number of beech trees at establishment of each permanent plot (20 m x 20 m).

^b None = scale not found, Low = newly-established scale populations on trees in the area, and High = well-established scale populations on trees in the area.

^c Beech scale was found in Plot E after the plot was established.

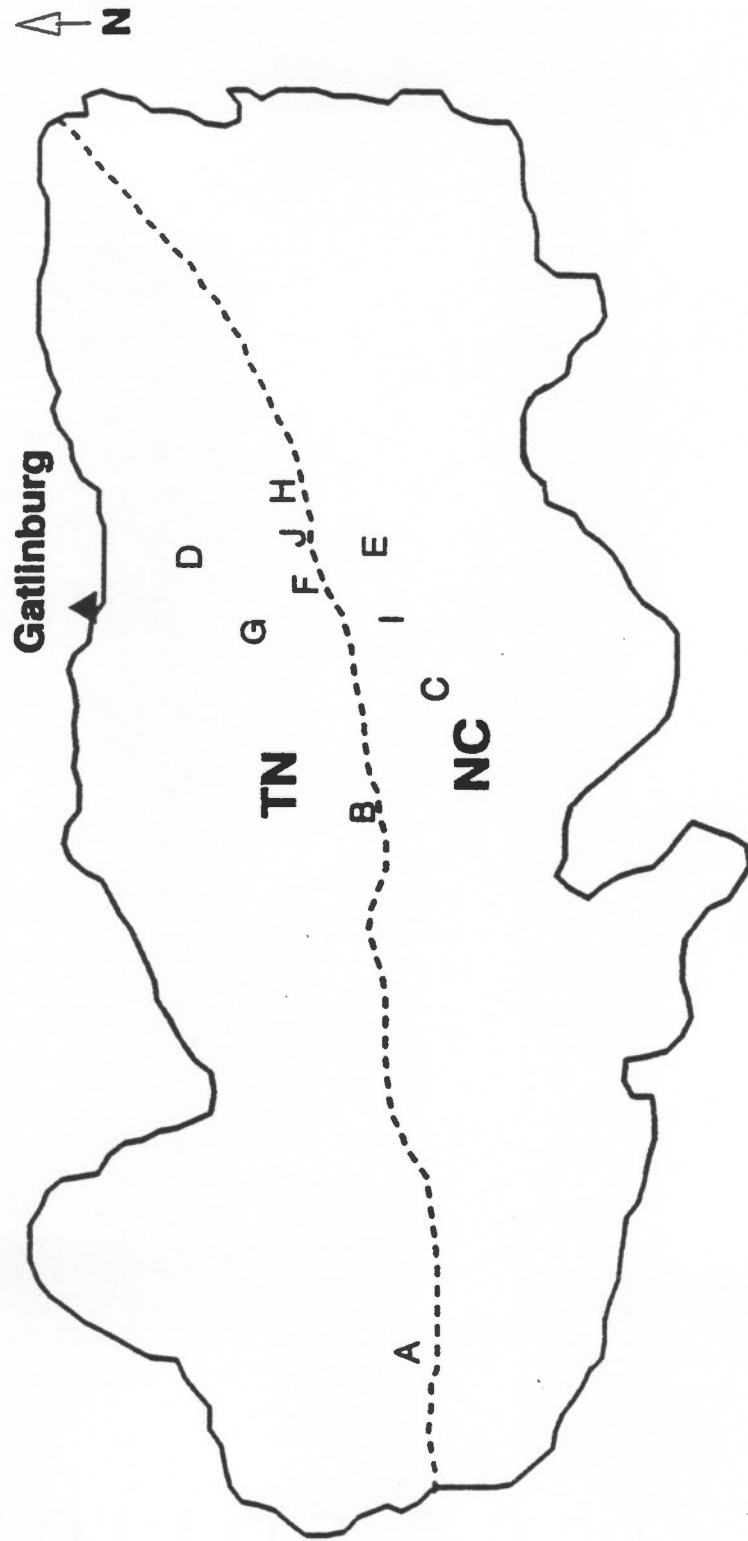


Figure 2. Location of permanent plots (A-J) established for research on beech bark disease in the Great Smoky Mountains National Park.

All trees in the plot with a diameter at breast height (dbh) of 3.5 cm or greater were identified and tagged, and dbh measurements were recorded. Each beech tree at or above the minimum dbh was marked with an aluminum tag (2.5 cm x 7 cm) indicating the plot number, research number and tree number. Aluminum tags were attached to the trees using aluminum sinker head nails (55 mm) at a height of approximately 137 cm.

Beech trees were evaluated for crown class, crown condition and bark condition. The crown class and crown condition rating systems used were from the Site Classification and Field Measurements, Methods Manual (Durr et al. 1988). The trees were rated for crown class as S = suppressed, I = intermediate, C = codominant, and D = dominant. The crown condition rating for defoliation and die-back was 1 = 0-10%, 2 = 11-50%, 3 = greater than 50%, 4 = recent dead, and 5 = old dead (Durr et al. 1988). The bark condition was rated as S = smooth, C = coarse, or R = rough. Each plot was rated for crown class, crown condition, and bark condition during the spring/summer 1994.

Each beech tree was then evaluated for beech scale. Ratings were made on the north and south sides of each tree using a rating square (33 cm x 33 cm) centered at 122 cm above the ground surface. Each tree also was rated for overall levels of beech scale and for levels and incidence of *Nectria* spp. Overall ratings were made by examining the bole of each tree from ground level up to about 2 m. The rating scale used for beech scale or *Nectria* spp. was 0 = no signs of beech scale infestation or *Nectria* spp. perithecia; 1 = low/scattered; 2 = low/uniform; 3 = moderate/scattered; 4 = moderate/uniform; 5 = high/scattered; and 6 = high/uniform. Each plot was rated three times for beech scale and *Nectria* spp., once during the spring/summer of 1994 (May-July), again in the fall of 1994

(September-November), and a third time in the spring of 1995 (May). On each date, the percent incidence of infested and infected trees was recorded for each plot. Incidence of beech scale or *Nectria* spp. denotes the presence or absence of the organisms, while the rating scale indicates the severity of insect infestation or fungal infection.

Beech trees at each plot also were evaluated for incidence of *X. betulae* and *Trombidium* sp. during permanent plot data collections in the spring/summer 1994, fall 1994, and spring 1995. The lower 2 m of each beech tree was examined (for 30-60 seconds) for the presence or absence of *X. betulae* and *Trombidium* sp. The percent of *X. betulae* or *Trombidium* sp. infested trees was recorded for each plot.

Data were analyzed using correlation coefficients and Proc GLM (SAS 1989). When significant differences were found, Duncan's multiple range test was performed to determine significant differences among means. Unless otherwise noted, significant effects were documented at the 0.05 level of probability.

iii. Results and Discussion

Incidence of Beech Scale

During this study, approximately 50% of all beech trees (n=449, 455, and 452, on first, second and third sampling dates, respectively) examined were infested with beech scale. The overall incidence of beech scale on beech in the permanent plots in the GSMNP was similar among sampling dates (Figure 3), ranging from about 47 to 49% of

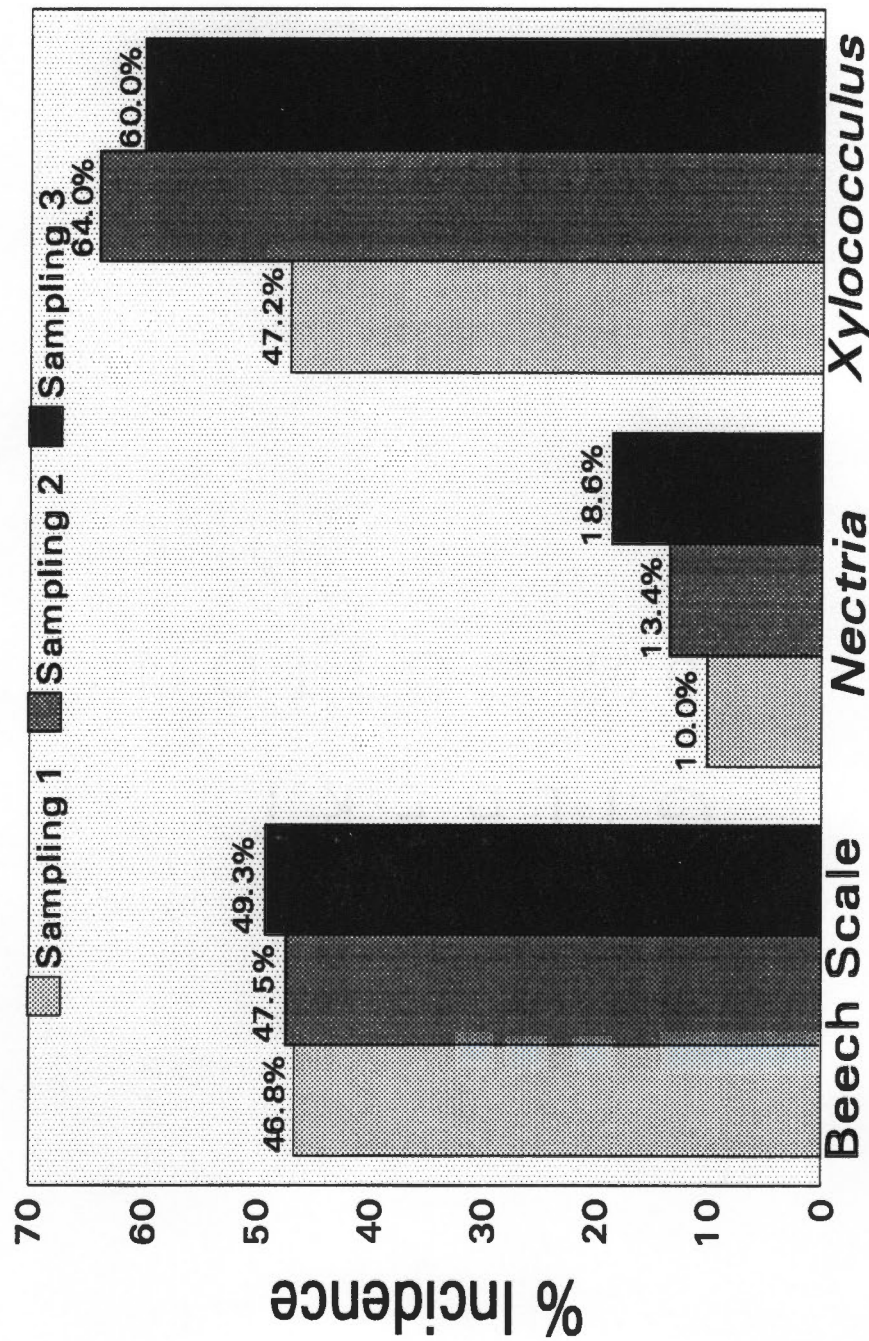


Figure 3. Total percent incidence of beech scale, *Nectria* spp., and *Xylococcus betulae* on the first, second, and third sampling dates.

all trees infested with beech scale on the first (spring/summer 1994), second (fall 1994), and third (spring 1995) sampling dates.

During 1994 and 1995, incidence of beech scale on beech trees on each sampling date was relatively high (near or above 60%) in six of the ten plots (Figure 4). These data were somewhat expected since these six plots were selected because they had been reported to have low or high densities of beech scale. Of the three 'no scale' plots, two of these [Gregory Bald (Plot A) and Trillium Gap (Plot D)] had no scale, while beech scale was present at low levels at the other one [Deep Creek (Plot E)]. Incidence of beech scale at this plot increased dramatically from the first to last sampling date (6.4, 16.1, and 25.8% on the first, second, and third sampling dates, respectively) (Figures 4 and 5). On the first sampling date, the incidence of beech scale was limited to one (4 m x 4 m) subplot (Figure 5). However, by the third sampling date, the insect had spread to five additional subplots. This trend can be expected to continue if the insect continues to disseminate throughout the plot. The relatively rapid increase in incidence of beech scale observed in this plot could be attributed to the availability of many trees suitable for colonization of the scale as it spread into this previously non-infested area. This rapid increase also could be influenced by the relative susceptibility of individual trees to infestation by beech scale.

The Forney Ridge plot (Plot C) is located in an area reported to have a high level of beech scale infestation. However, the incidence of beech scale within this plot was relatively low on all sampling dates (Figure 4). On the first and second sampling dates, beech scale was found on 29.8 and 22.0% of the beech trees, respectively. However, the incidence of beech scale (14.8%) on beech trees had declined dramatically by the third

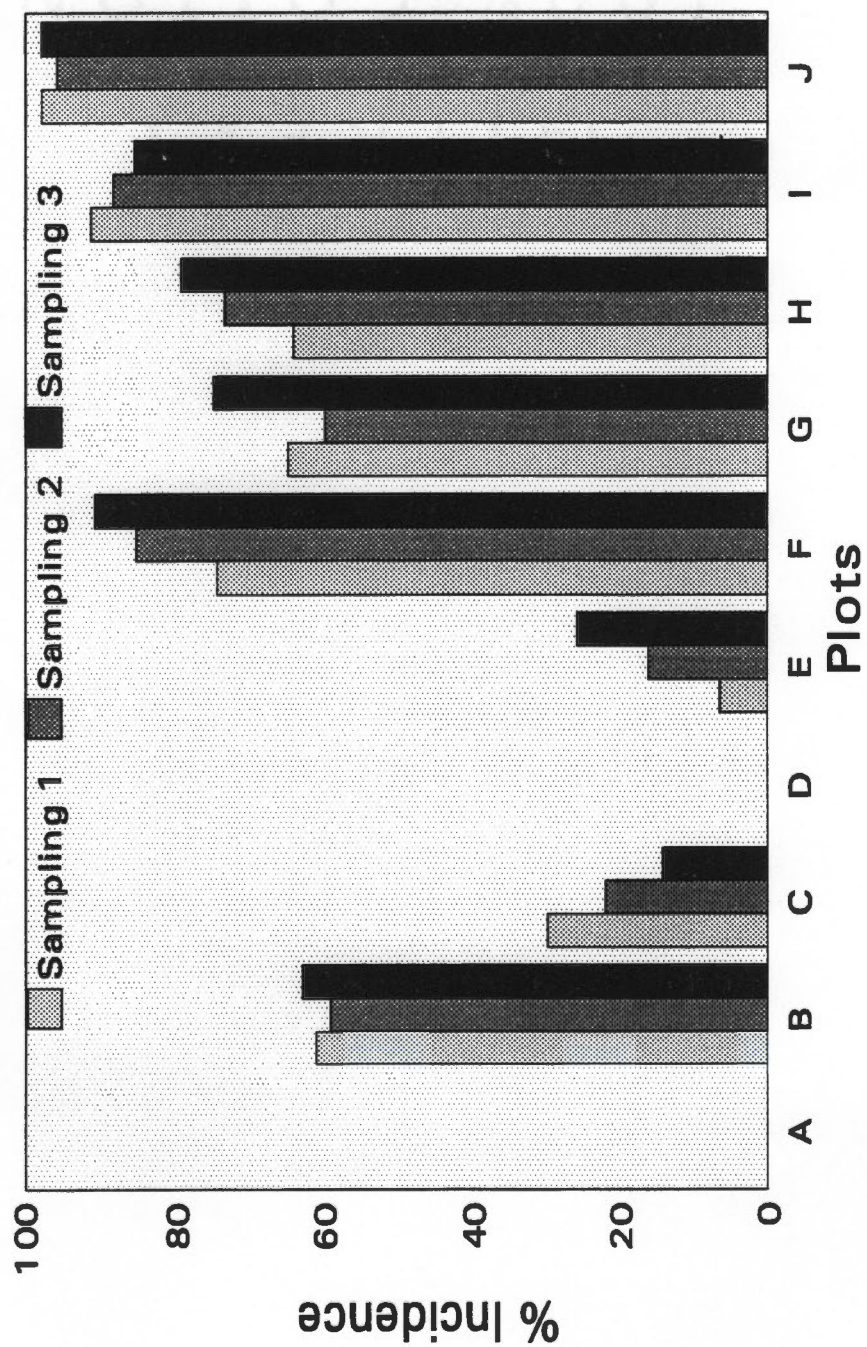


Figure 4. Percent incidence of beech scale per plot on the first, second, and third sampling dates.

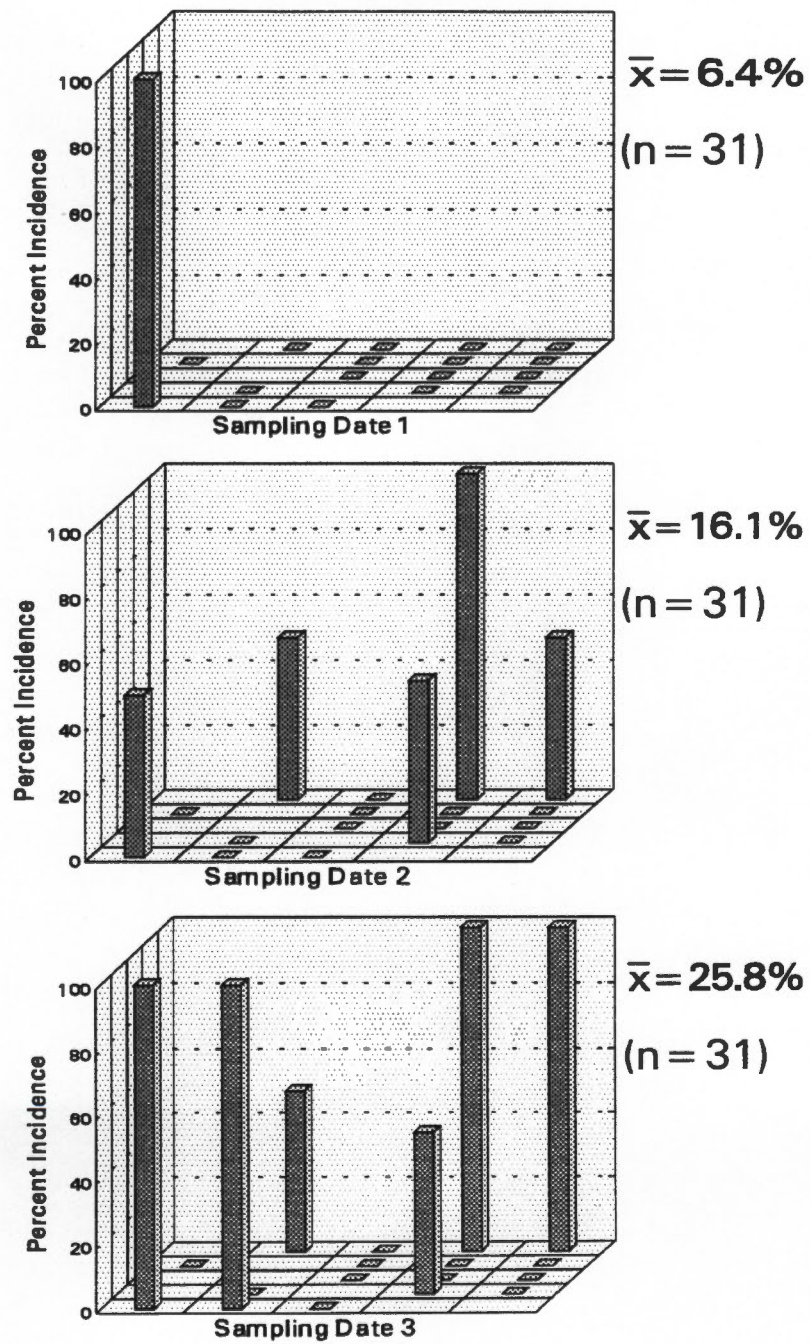


Figure 5. Incidence of beech scale in subplots (4 m x 4 m) on each sampling date at Deep Creek (Plot E).

sampling date (Figures 4 and 6). The low incidence of beech scale in this plot is partially attributed to the high level of tree mortality, which gradually increased from the first (71.0%), to the second (78.0%), to the third sampling date, when 83.7% of all trees were dead. This tree mortality is due to infection by *Nectria* spp. A decrease in beech scale incidence is expected when tree mortality increases, because beech scale cannot survive on dead trees.

The incidence of beech scale on the north and south sides of the trees was similar on each sampling date and among sampling dates (Figure 7). Although no significant differences were documented, the incidence of beech scale on the north side of the tree was slightly higher than those on the south side on all sampling dates. These numerical differences in incidence of scale on the north and south sides of the tree may be related to differences in temperature and moisture that could exist between the north and south sides.

Incidence of *Nectria* spp.

Nectria spp. were present in six of the ten plots on the first sampling date and in seven and eight plots on the second and third sampling dates, respectively. On the first sampling date, 10% of all trees had signs of *Nectria* spp. (Figure 3). The incidence of *Nectria* spp. increased from the first to third sampling date, when *Nectria* spp. were present on about 19% of the trees. At the Forney Ridge plot, *Nectria* spp. were present on 46.7 and 57.1% of the trees on the first and second sampling dates, respectively (Figure 8). Incidence of *Nectria* spp. increased dramatically by the third sampling date, when about 88% of the trees were infected. High incidence of signs of *Nectria* spp. at the

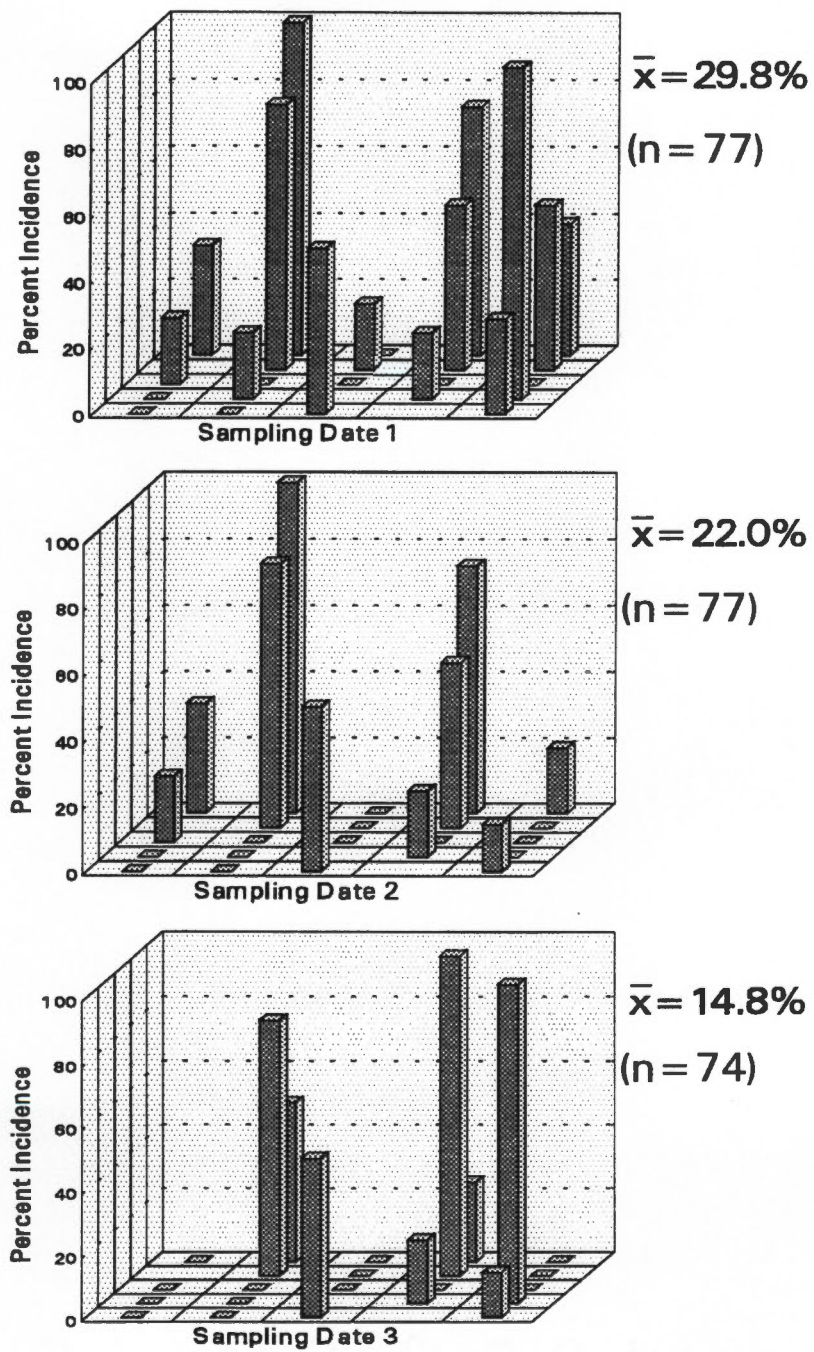


Figure 6. Incidence of beech scale in subplots (4 m x 4 m) on each sampling date at Forney Ridge (Plot C).

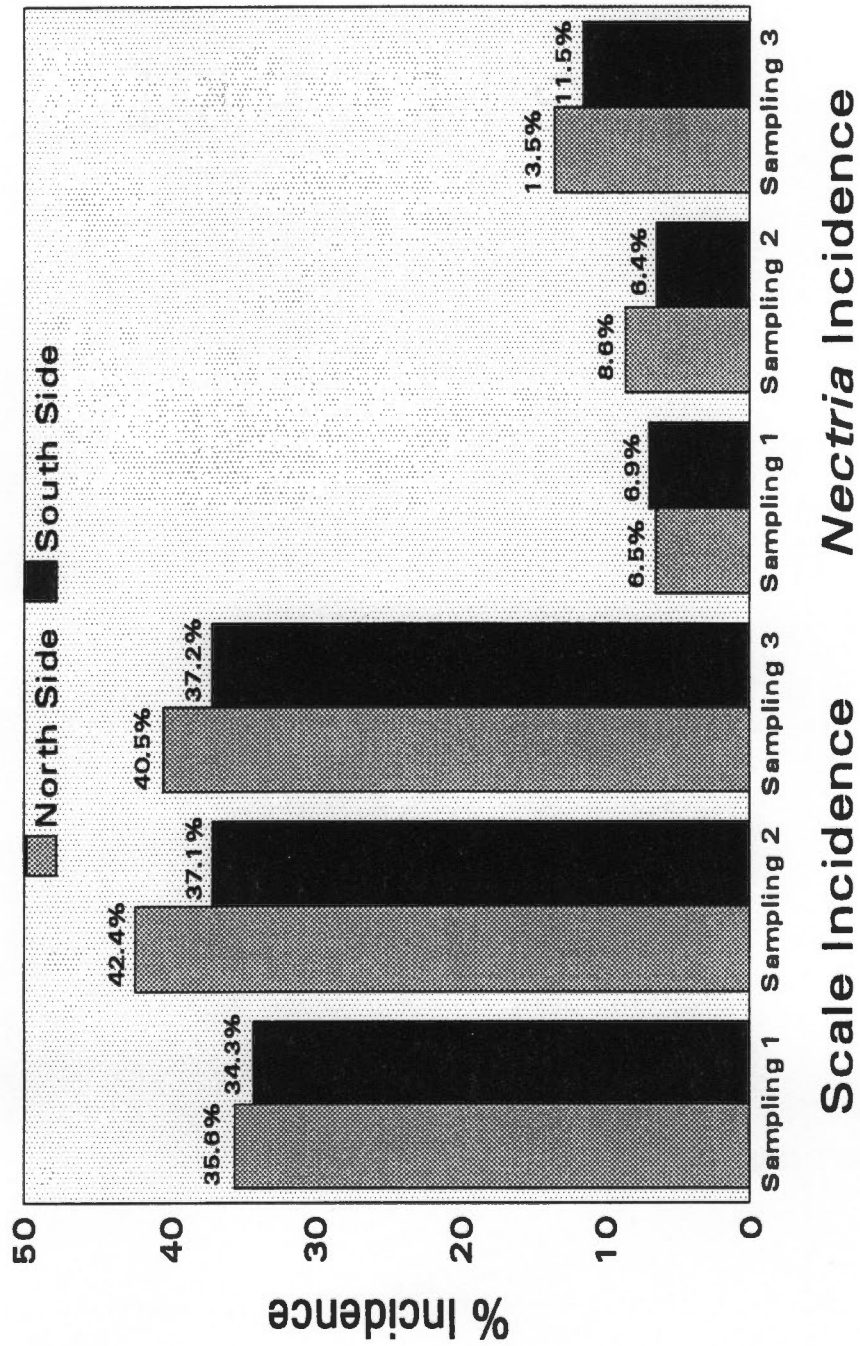


Figure 7. Percent incidence of beech scale and *Nectria* spp. on the north and south sides of beech trees on the first, second, and third sampling dates.

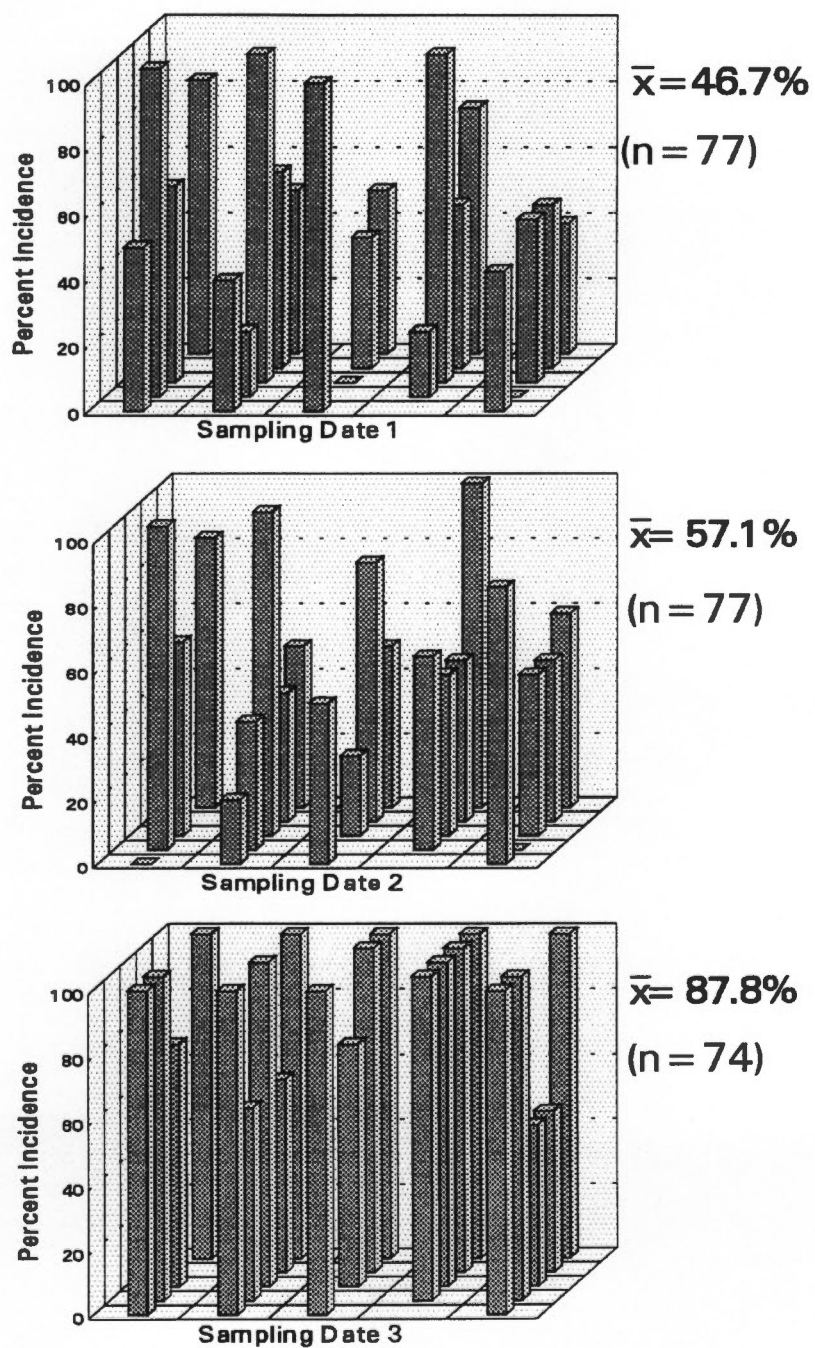


Figure 8. Incidence of *Nectria* spp. in subplots (4 m x 4 m) on each sampling date at Forney Ridge (Plot C).

Forney Ridge plot is directly related to high tree mortality in this plot (83.7% tree mortality on the third sampling date), because perithecia are only observed on dead bark tissue. As more trees are killed by the disease, more dead bark tissue becomes available for the sexual reproduction of *Nectria* spp., and the amount of living bark tissue on which beech scale survive decreases.

Incidence of *Nectria* spp. on the north and south sides of the trees was similar on all sampling dates (Figure 7). On the first sampling date, incidence of *Nectria* spp. was slightly higher numerically on the south side than on the north side of the trees (Figure 7). On the second and third sampling dates, incidence of *Nectria* spp. was slightly higher numerically on the north side than on the south side of the trees.

Rating of Beech Scale

The mean overall rating of all plots for beech scale was relatively similar among sampling dates (Figure 9). No statistical differences were observed between overall ratings for beech scale on the first and second sampling dates, or between the first and third sampling dates. However, the scale rating on the second sampling date was significantly lower than that on the third sampling date. The mean ratings for beech scale on the north and south sides of the trees were similar on all sampling dates, suggesting that the rating location on the tree is not critical. Among sampling dates, no statistical differences were observed for the north and south ratings.

Correlation analysis was conducted on data for all ten permanent plots. In general, no strong correlation existed between overall ratings for beech scale and plot elevation (Table 2), suggesting that beech scale populations may be equally successful at various

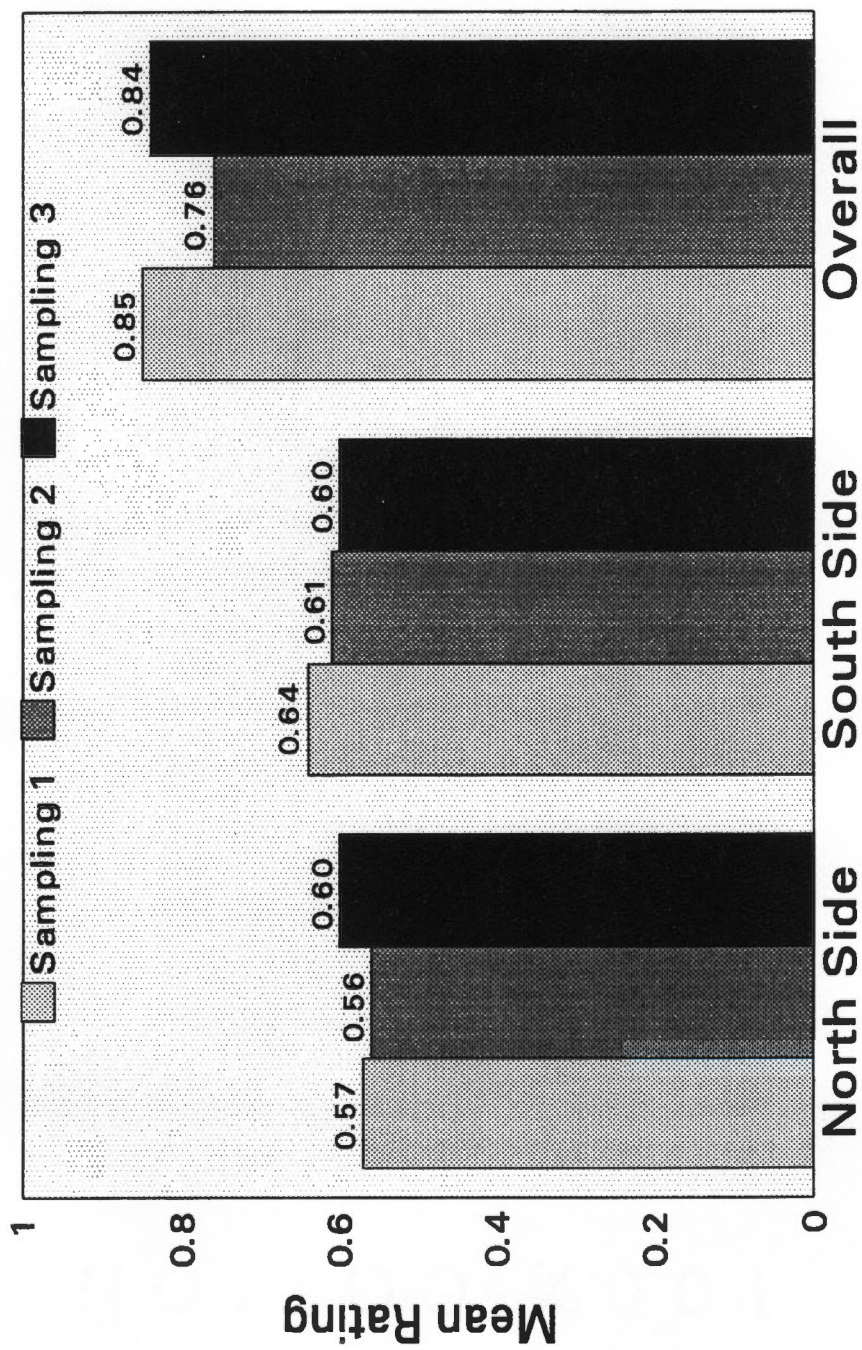


Figure 9. Mean ratings for beech scale on the first, second, and third sampling dates.

Table 2. Correlation analysis of ratings for beech scale and *Nectria* spp. vs. plot elevation, average aspect, and tree dbh^c.

Correlation Analysis						
Rating	Elevation		Average Aspect		dbh ^c	
	Corr. Coef. ^a	Prob. ^b	Corr. Coef.	Prob.	Corr. Coef.	Prob.
Scale North 1	0.17579	0.0002	-0.08889	0.0598	-0.02760	0.5597
Scale North 2	0.12904	0.0058	-0.25268	0.0001	-0.00439	0.9256
Scale North 3	0.09834	0.0366	-0.23885	0.0001	-0.02661	0.5726
Scale South 1	0.05223	0.2694	-0.14346	0.0023	0.04818	0.3083
Scale South 2	0.05626	0.2310	-0.21368	0.0001	0.09278	0.0479
Scale South 3	0.02535	0.5909	-0.18530	0.0001	0.07492	0.1117
Scale Overall 1	0.10778	0.0224	-0.19660	0.0001	0.10536	0.0256
Scale Overall 2	0.02706	0.5648	-0.25929	0.0001	0.16880	0.0003
Scale Overall 3	-0.01586	0.7366	-0.28375	0.0001	0.15124	0.0013
<i>Nectria</i> North 1	0.25581	0.0001	0.12323	0.0090	-0.14603	0.0019
<i>Nectria</i> North 2	0.25213	0.0001	0.09546	0.0418	-0.14097	0.0026
<i>Nectria</i> North 3	0.33803	0.0001	0.15521	0.0009	-0.18248	0.0001
<i>Nectria</i> South 1	0.24501	0.0001	0.09796	0.0380	-0.12764	0.0068
<i>Nectria</i> South 2	0.25133	0.0001	0.09194	0.0500	-0.12618	0.0070
<i>Nectria</i> South 3	0.29789	0.0001	0.12380	0.0084	-0.16021	0.0006
<i>Nectria</i> Overall 1	0.28352	0.0001	0.10959	0.0202	-0.16091	0.0006
<i>Nectria</i> Overall 2	0.27432	0.0001	0.11571	0.0135	-0.11452	0.0145
<i>Nectria</i> Overall 3	0.34953	0.0001	0.14949	0.0014	-0.19902	0.0001

^a Correlation coefficient. ^b Probability. ^c Diameter at breast height.

elevations in the GSMNP. Some correlation was observed between elevation and the north side ratings for beech scale. However, no significant correlation was found between elevation and the south side ratings for scale. A slight negative correlation was detected between ratings for beech scale and average aspect of the plots, implying that as the average aspect increased, the scale ratings slightly decreased. No notable correlation was observed between tree dbh and ratings for scale, although each overall scale rating was slightly correlated with dbh.

In general, no substantial correlation existed between the ratings of beech scale and *Nectria* spp. (Tables 3, 4, and 5). In a few instances, some of the overall beech scale ratings were slightly negatively correlated with *Nectria* spp. ratings. A negative correlation between beech scale and *Nectria* spp. ratings can be expected because beech scale will only survive on living bark tissue, while perithecia of the fungus is only found on bark tissue that is dead. However, over a long period, the presence of *Nectria* spp. should be positively correlated with the earlier presence of beech scale.

At Forney Ridge, the mean rating for beech scale declined substantially from the first (0.74) to the third (0.16) sampling date (Figure 10). This relatively rapid decline in beech scale populations could be typical of forests in the latter stages of beech bark disease, due to the presence of high levels of *Nectria* spp. which kill the host beech trees and indirectly cause the demise of the pest insect populations. While beech scale ratings have decreased in this plot, ratings for *Nectria* spp. and tree mortality have continued to rise, illustrating the relationship between the insect, fungus and host tree species.

Table 3. Correlation analysis of ratings for beech scale and *Nectria* spp. on sampling date one vs. ratings on the first, second, and third sampling dates.

	Correlation Analysis (correlation coefficients)					
Rating	Scale North 1	Scale South 1	Scale Overall 1	<i>Nectria</i> North 1	<i>Nectria</i> South 1	<i>Nectria</i> Overall 1
Scale North 1	1.0000**	0.7270**	0.7660**	0.0171	0.0060	0.0389
Scale North 2	0.7162**	0.5621**	0.6011**	-0.1059*	-0.0942*	-0.1039*
Scale North 3	0.5899**	0.5250**	0.5696**	-0.1366*	-0.0998*	-0.1137*
Scale South 1	0.7270**	1.0000**	0.8678**	-0.0256	-0.0228	-0.0149
Scale South 2	0.6305**	0.7562**	0.7274**	-0.1061*	-0.0939*	-0.1150*
Scale South 3	0.5746**	0.7082**	0.6978**	-0.1155*	-0.0915	-0.1131*
Scale Overall 1	0.7660**	0.8679**	1.0000**	-0.0348	-0.0220	-0.0205
Scale Overall 2	0.6048**	0.7073**	0.7597**	-0.1163*	-0.1050*	-0.1232*
Scale Overall 3	0.5601**	0.6864**	0.7066**	-0.1471*	-0.1199*	-0.1486*
<i>Nectria</i> North 1	0.0171	-0.0256	-0.0348	1.0000**	0.6560**	0.8056**
<i>Nectria</i> North 2	0.1376*	0.0590	0.0318	0.4361**	0.4093**	0.5067**
<i>Nectria</i> North 3	0.1881**	0.0629	0.0513	0.5734**	0.5081**	0.6401**
<i>Nectria</i> South 1	0.0060	-0.0228	-0.0220	0.6560**	1.0000**	0.8434**
<i>Nectria</i> South 2	0.1121*	0.0396	0.0366	0.3533**	0.4556**	0.5210**
<i>Nectria</i> South 3	0.1963**	0.1093*	0.0989*	0.4792**	0.5331**	0.5918**
<i>Nectria</i> Overall 1	0.0389	-0.0149	-0.0205	0.8056**	0.8434**	1.0000**
<i>Nectria</i> Overall 2	0.1555*	0.0330	0.0676	0.4561**	0.5129**	0.5903**
<i>Nectria</i> Overall 3	0.1748*	0.0623	0.0548	0.5163**	0.4987**	0.6266**

* Significantly correlated at 0.05 level of probability.

** Significantly correlated at 0.0001 level of probability.

Table 4. Correlation analysis of ratings for beech scale and *Nectria* spp. on sampling date two vs. ratings on the first, second, and third sampling dates.

	Correlation Analysis (correlation coefficients)					
Rating	Scale North 2	Scale South 2	Scale Overall 2	<i>Nectria</i> North 2	<i>Nectria</i> South 2	<i>Nectria</i> Overall 2
Scale North 1	0.7162**	0.6305**	0.6048**	0.1376*	0.1121*	0.1555*
Scale North 2	1.0000**	0.7036**	0.7186**	-0.0782	-0.0690	-0.0487
Scale North 3	0.7719**	0.6140**	0.6295**	-0.1419*	-0.1029*	-0.1504*
Scale South 1	0.5621**	0.7562**	0.7073**	0.0590	0.0396	0.0330
Scale South 2	0.7036**	1.0000**	0.8525**	-0.0840	-0.1068*	-0.0976*
Scale South 3	0.6600**	0.7978**	0.7620**	-0.1058*	-0.0930*	-0.1346*
Scale Overall 1	0.6011**	0.7274**	0.7597**	0.0318	0.0366	0.0676
Scale Overall 2	0.7186**	0.8525**	1.0000**	-0.0898	-0.0874	-0.0879
Scale Overall 3	0.6715**	0.7991**	0.8138**	-0.1149*	-0.1266*	-0.1683*
<i>Nectria</i> North 1	-0.1059*	-0.1061*	-0.1163*	0.4361**	0.3533**	0.4561**
<i>Nectria</i> North 2	-0.0782	-0.0840	-0.0898	1.0000**	0.6784**	0.7369**
<i>Nectria</i> North 3	-0.0826	-0.0984*	-0.1104*	0.6963**	0.5736**	0.6668**
<i>Nectria</i> South 1	-0.0942*	-0.0939*	-0.1050*	0.4093**	0.4556**	0.5129**
<i>Nectria</i> South 2	-0.0690	-0.1068*	-0.0874	0.6784**	1.0000**	0.7133**
<i>Nectria</i> South 3	-0.0363	-0.0681	-0.0778	0.5637**	0.6459**	0.6314**
<i>Nectria</i> Overall 1	-0.1039*	-0.1150*	-0.1232*	0.5067**	0.5210**	0.5903**
<i>Nectria</i> Overall 2	-0.0487	-0.0976*	-0.0879	0.7369**	0.7133**	1.0000**
<i>Nectria</i> Overall 3	-0.0564	-0.0770	-0.0983*	0.6671**	0.6127**	0.6953**

* Significantly correlated at 0.05 level of probability.

** Significantly correlated at 0.0001 level of probability.

Table 5. Correlation analysis of ratings for beech scale and *Nectria* spp. on sampling date three vs. ratings on the first, second, and third sampling dates.

	Correlation Analysis (correlation coefficients)					
Rating	Scale North 3	Scale South 3	Scale Overall 3	<i>Nectria</i> North 3	<i>Nectria</i> South 3	<i>Nectria</i> Overall 3
Scale North 1	0.5899**	0.5746**	0.5601**	0.1881**	0.1963**	0.1748*
Scale North 2	0.7719**	0.6600**	0.6715**	-0.0826	-0.0363	-0.0564
Scale North 3	1.0000**	0.7619**	0.7481**	-0.1776**	-0.1363*	-0.1776**
Scale South 1	0.5250**	0.7082**	0.6864**	0.0629	0.1093*	0.0623
Scale South 2	0.6140**	0.7978**	0.7991**	-0.0984*	-0.0681	-0.0770
Scale South 3	0.7619**	1.0000**	0.8759**	-0.1446*	-0.1185*	-0.1454*
Scale Overall 1	0.5696**	0.6978**	0.7066**	0.0513	0.0989*	0.0548
Scale Overall 2	0.6295**	0.7620**	0.8138**	-0.1104*	-0.0778	-0.0983*
Scale Overall 3	0.7481**	0.8756**	1.0000**	-0.1840**	-0.1524*	-0.1868**
<i>Nectria</i> North 1	-0.1366*	-0.1155*	-0.1471*	0.5734**	0.4792**	0.5163**
<i>Nectria</i> North 2	-0.1419*	-0.1058*	-0.1449*	0.6963**	0.5637**	0.6671**
<i>Nectria</i> North 3	-0.1776**	-0.1446*	-0.1840**	1.0000**	0.7706**	0.9150**
<i>Nectria</i> South 1	-0.0998*	-0.0915	-0.1199*	0.5081**	0.5331**	0.4987**
<i>Nectria</i> South 2	-0.1029*	-0.0930*	-0.1266*	0.5739**	0.6459**	0.6127**
<i>Nectria</i> South 3	-0.1363*	-0.1185*	-0.1524*	0.7706**	1.0000**	0.8478**
<i>Nectria</i> Overall 1	-0.1137*	-0.1131*	-0.1486*	0.6401**	0.5918**	0.6266**
<i>Nectria</i> Overall 2	-0.1504*	-0.1346*	-0.1683*	0.6668**	0.6314**	0.6953**
<i>Nectria</i> Overall 3	-0.1776**	-0.1454*	-0.1868**	0.9150**	0.8478**	1.0000**

* Significantly correlated at 0.05 level of probability.

** Significantly correlated at 0.0001 level of probability.

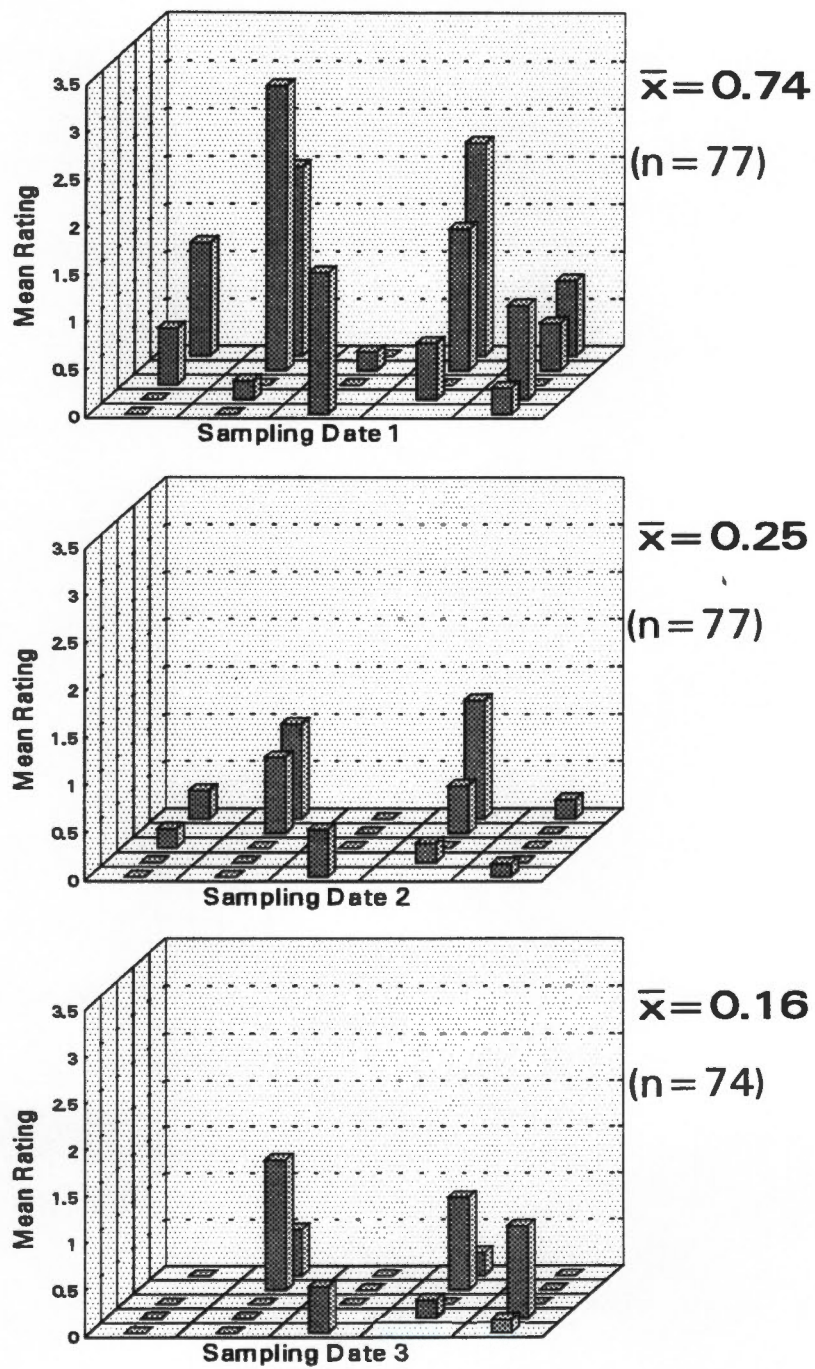


Figure 10. Mean ratings for beech scale in subplots (4 m x 4 m) on each sampling date at Forney Ridge (Plot C).

Rating of *Nectria* spp.

The mean overall rating for *Nectria* spp. was not significantly different on the first and second sampling dates. However, the rating for *Nectria* spp. on the third sampling date was significantly greater than ratings on the two previous sampling dates. The mean ratings for *Nectria* spp. were similar on the north and south sides of the trees on all sampling dates. This similarity implies that the rating location on the trees is not critical. Among sampling dates, the north and south ratings for *Nectria* spp. on the first two sampling dates were statistically similar. However, the north and south ratings on the third sampling date were significantly greater than those on the first and second sampling dates.

Some correlation was observed between elevation and overall ratings for *Nectria* spp. (Table 2), suggesting that the amount of *Nectria* spp. may be slightly influenced by elevation, and as elevation increases, the incidence of *Nectria* spp. increases. Increased elevation may initiate changes in the amount of available moisture, and these changes may influence the development of *Nectria* spp. Similar correlation also was found between elevation and the north and south side ratings for the fungus. No strong correlation was observed between the ratings for *Nectria* spp. and the average aspect of the plots, and *Nectria* spp. were only slightly negatively correlated with tree dbh. These results suggest that the average aspect and tree dbh are not notable factors affecting the ratings for *Nectria* spp.

At Forney Ridge, the mean rating for *Nectria* spp. on the third sampling date was significantly greater than those on previous sampling dates (Figure 11). The increase in ratings for *Nectria* spp. in this plot is likely to be linked to the amount of tree mortality (83.7%) in this plot as well as other factors, such as weather conditions and the length of time available for the development of perithecia after the trees have died.

Incidence of *Xylococculus betulae*

On the first sampling date, *X. betulae* was found on 47.2% of all trees sampled (Figure 3). However, incidence of *X. betulae* increased to about 60% on the second and third sampling dates. The incidence of *X. betulae* was relatively high (greater than 40%) in nine of ten permanent plots (Figure 12). The only plot with relatively low incidence (less than 20%) of this scale was Forney Ridge (Plot C). As with the beech scale incidence in this plot, the low incidence of *X. betulae* is due in part to the high level of tree mortality. The highest percent incidence of *X. betulae* was found at Jenkins Knob (Plot B), where about 90% of all trees in the plot were infested with *X. betulae* on the third sampling date.

Damage caused by *X. betulae*, resulting in cracks, fissures, and the growth of callus tissue on the bole of beech, is reported to provide suitable habitat for colonies of beech scale (Houston 1994b, 1975, Shigo 1964). This type of injury is reported to be common in aftermath forests in the northeastern United States (Houston 1975). During this research, *X. betulae* was often observed in fissures and deformed areas of tree bark, but the cause of the damage was not determined. Beech scale was often found in close

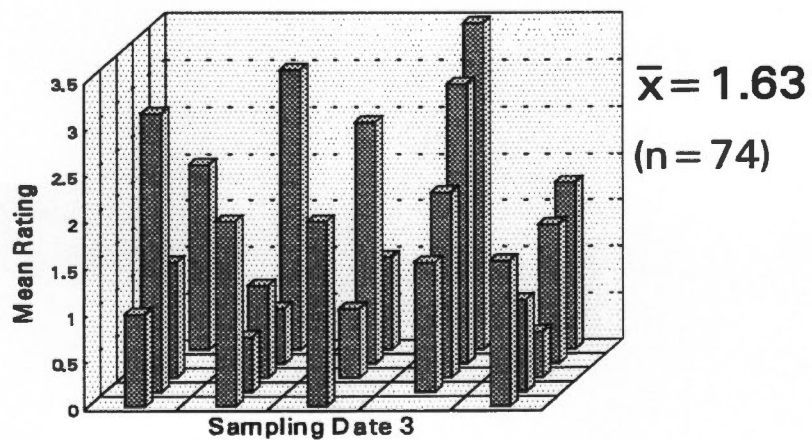
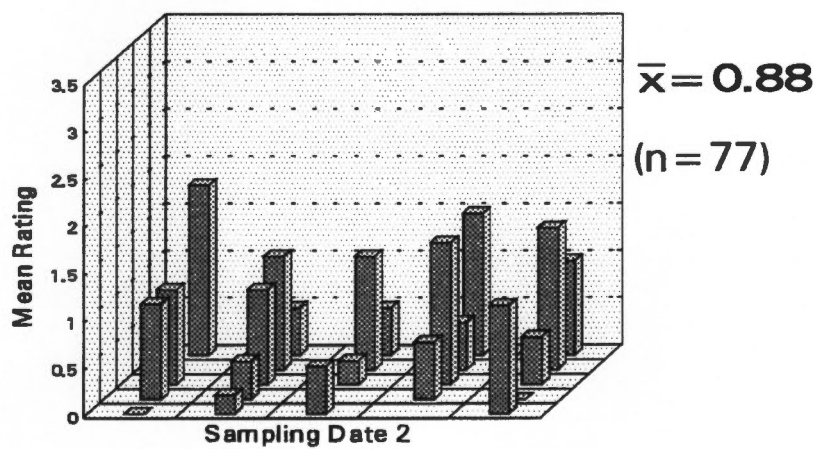
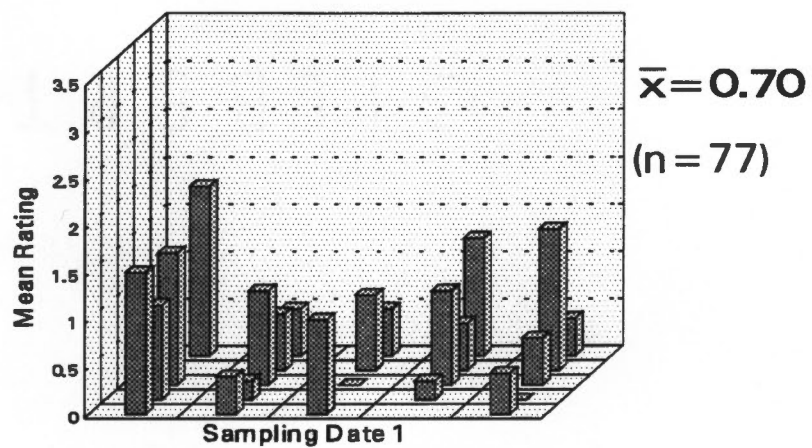


Figure 11. Mean ratings for *Nectria* spp. in subplots (4 m x 4 m) on each sampling date at Forney Ridge (Plot C).

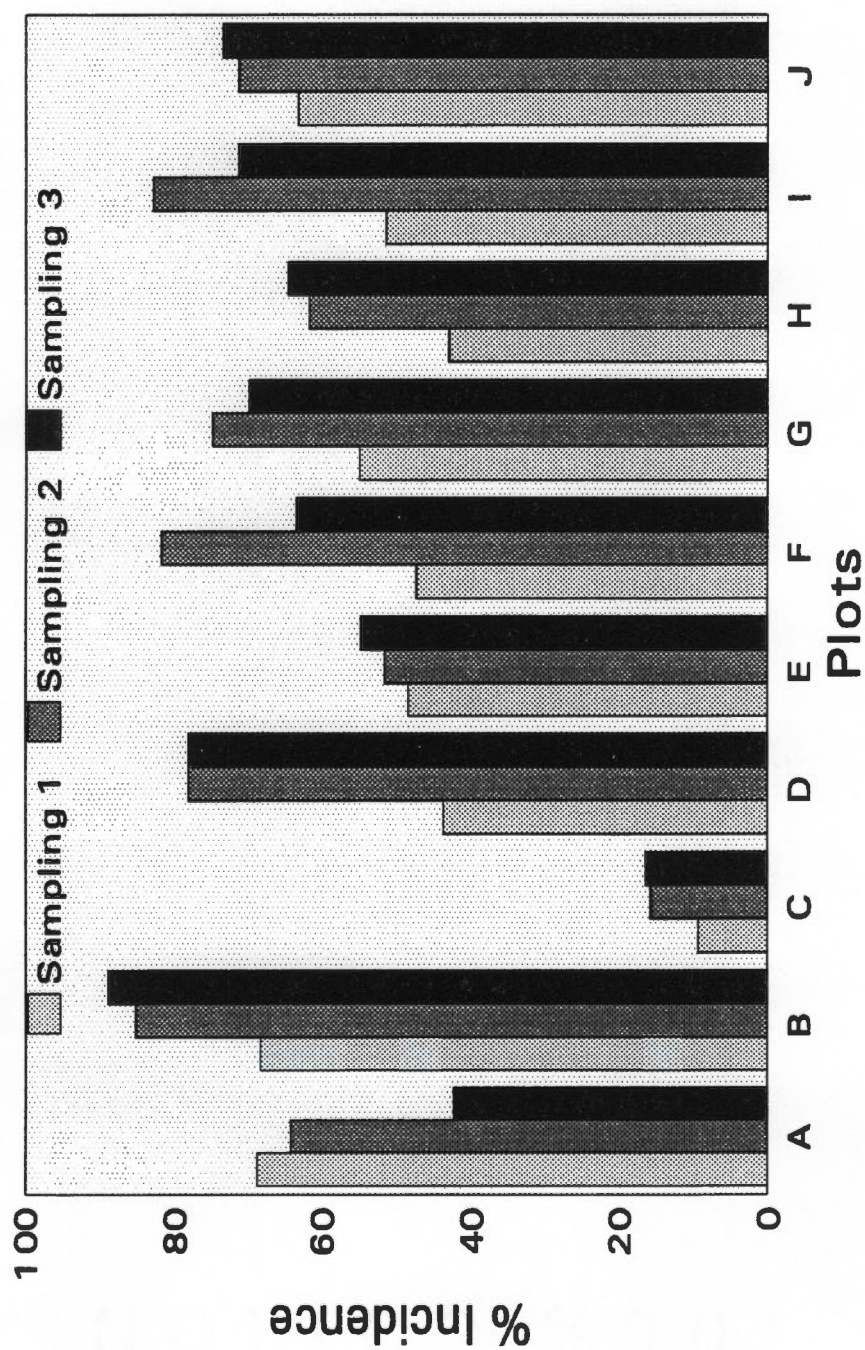


Figure 12. Percent incidence of *Xylococcus betulae* per plot on the first, second, and third sampling dates.

proximity to *X. betulae*, but a direct relationship between the two organisms could not be determined.

Incidence of *Trombidium* spp.

The predaceous *Trombidium* sp. was present in six permanent plots in 1994 and in five plots in 1995. On the first and second sampling dates, the mite was observed on 7.8 (n=449) and 4.4% (n=455), respectively, of all trees examined. The incidence of *Trombidium* sp. increased to 18.8% on the third sampling date (n=452). Several factors could be involved in inconsistencies in the number of *Trombidium* sp. observed among plots and sampling dates. Air temperature, weather conditions, time of year, time of day when the plots were sampled, and the life cycle and behavioral habits of *Trombidium* sp. are all factors that could influence the number of active mites in a plot during sampling.

iv. Summary

Beech scale is established in the GSMNP. During 1994 and 1995, beech scale was present in eight of ten permanent plots and at relatively high incidence in six plots. Of the plots with beech scale present, Forney Ridge (Plot C) had the lowest incidence of the insect. Total percent incidence of beech scale for all plots was relatively consistent on all three sampling dates.

The mean overall ratings for beech scale were relatively similar among sampling dates, with only a small statistical increase from the second to third sampling date. The

percent incidence and the mean ratings for beech scale on the north and south sides of trees were similar on each sampling date and among sampling dates, suggesting that the rating location on the tree is not critical. In general, no strong correlation was found between beech scale ratings and plot elevation, tree dbh, or average plot aspect.

The relative similarity in overall incidence and ratings for beech scale among sampling dates suggests that the overall status of beech scale in the GSMNP permanent plots has not changed dramatically during the period of this investigation. This similarity is not true for individual plots which are under transition. For example, populations of beech scale at Forney Ridge (Plot C) demonstrated a relatively rapid decline as tree mortality increased in that plot. Transition also is occurring at Deep Creek (Plot E) where beech scale populations are exhibiting a rapid increase as the insect moves into a previously noninfested area of forest.

Nectria spp. were found in seven permanent plots in 1994 and in eight plots in 1995. The percent incidence of *Nectria* spp. on the north and south sides of trees for all plots was similar among sampling dates, indicating that the rating location on the tree is not critical. Percent incidence of *Nectria* spp. was highest at Forney Ridge (Plot C), where 83.7% of the trees were dead on the third sampling date.

The mean overall rating for *Nectria* spp. was not significantly different on the first two sampling dates, but the rating on the third sampling date was significantly greater than those on the previous two sampling dates. Ratings of *Nectria* spp. on the north and south sides also were significantly greater on the third sampling date than those on the two

previous sampling dates. Ratings of *Nectria* spp. and plot elevation were slightly correlated; however, no significant correlations were detected with tree dbh and average plot aspect.

The consistent increases among sampling dates, in incidence and ratings of *Nectria* spp., suggest that the amount of *Nectria* spp. present in the GSMNP permanent plots has increased significantly during this investigation. The most dramatic increase in *Nectria* spp. occurred at Forney Ridge (Plot C), where tree mortality was greater than 80%.

The incidence of *X. betulae* was greater than 40% in nine of ten plots in 1994 and 1995. The incidence of this scale was relatively low at Forney Ridge (Plot C). No direct relationship between *X. betulae* and beech scale could be determined.

Beech scale, *Nectria* spp., and *X. betulae* are all well established in the GSMNP. The overall status of beech scale within the permanent plots has been somewhat static during 1994 and 1995, while the inoculum load for *Nectria* spp. appears to be increasing. This increase of inoculum, coupled with the spread of beech scale into new forest locations, may signify the continued demise of American beech in the GSMNP.

CHAPTER III

LIFE HISTORY OF BEECH SCALE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

i. Introduction

Beech bark disease is initiated when beech scale, *Cryptococcus fagisuga* Lindinger, feeds on bark tissues and predisposes the beech tree to infection by *Nectria* spp. (Houston 1994b, Manion 1991, Houston et al. 1979a). The beech scale has a univoltine life cycle and exhibits parthenogenetic reproduction (Wainhouse and Gate 1988, Houston and O'Brien 1983). In England, Canada and the northeastern United States, oviposition of beech scale primarily occurs from June or July through September, and eggs usually hatch about 25 days later (Houston 1994b, Wainhouse and Gate 1988, Wainhouse 1980, Ehrlich 1934). The legs and antennae of newly-emerged first-instars (crawlers) are well-developed, and this stage is the only mobile form of the insect (Houston and O'Brien 1983, Shigo 1972). Active crawlers of the beech scale are usually found in England from July through November (Wainhouse and Gate 1988, Wainhouse 1980). In Canada and New England, crawlers are primarily active from July or August through September (Ehrlich 1934).

After emergence, the crawlers may insert their stylet into the tree bark to feed at their present location, or move to more suitable feeding sites on the tree (Houston and O'Brien 1983, Shigo 1972). Once the insect begins to feed, it becomes permanently

immobile (Manion 1991, Wainhouse and Gate 1988). The beech scale is dispersed primarily during the crawler stage, although eggs also may be transported (Wainhouse 1980). Wind is the prominent factor involved in the long-range spread of beech scale, but birds, mammals, and human activities also are suspected modes of dissemination for this pest (Houston 1994b, Wainhouse 1980, Ehrlich 1934).

Determination of the presence of beech scale crawler in the forest is necessary because the pest is most often dispersed in this stage. The objective of this research is to monitor the life history and seasonal incidence of the beech scale in the Great Smoky Mountains National Park (GSMNP). Establishment of adult ovipositional periods and seasonality of crawler activity will provide base-line data for development of tools to predict optimum periods of dispersal of beech scale in the GSMNP. This knowledge can be coupled with long-term monitoring data to assist in future disease management efforts.

ii. Materials and Methods

The life history and seasonal incidence of beech scale were monitored at two sites, Chimney Trail (Plot G) and Sweat Heifer (Plot H), in the GSMNP in 1994 and 1995 (Figure 2). Samples of beech scale-infested bark were collected at approximately 2-week intervals from February to September 1994 and about once per month from September 1994 to April 1995. Biweekly sample collections were resumed from May to June 1995. On each sampling date, two bark samples (3.8 cm sq) were collected with a wood chisel from each of two trees selected at each site. Samples were collected from the lower 2 m

of the bole of the tree. Samples were placed in petri dishes (50 mm x 9 mm) and taken to the laboratory for processing.

All bark samples were examined using a stereoscope for life stages (egg, crawler, second-instar and adult) of beech scale. Characters used to identify crawlers were slender body shape and the presence of functional legs which enable this life stage to be mobile. Second-instars were characterized by the lack of mobility and a wider body shape. Adult beech scales (which are all females) were identified by the circular body shape, relatively large size, and/or the presence of eggs in or beneath their bodies.

Quantitative estimates of each life stage present on each sample were conducted. Using forceps, excess layers of wax, secreted by the insects while feeding, were removed from the sample to expose the beech scales, which were then counted. These layers of wax were then inverted in a petri dish so that attached scales also could be counted. Sections of loose bark and loosely attached lichens were removed to expose beech scales. The bark and lichens also were inverted so attached beech scales could be counted. The number of each stage of beech scale were recorded.

The air temperature was recorded daily at Newfound Gap by the National Park Service. The high and low monthly means of these temperatures were compared with the activity periods of beech scale crawlers during this investigation.

iii. Results and Discussion

General Overview of Life History

From February 1994 to May 1994, only non-mobile second-instar or adult beech scales were collected (Figure 13). The first eggs were collected at the end of May 1994 and were continually present until mid November, when only a few eggs were observed on one sample. Crawlers were first observed in early August 1994 and then found on all collection dates through mid November 1994. No beech scale eggs or crawlers were observed in mid December 1994.

In 1995, only non-mobile second-instar or adult beech scale were found in February through May (Figure 13). The first eggs were collected in early June 1995, and the first crawlers were collected in mid June 1995. Crawlers were collected about 1½ months earlier in 1995 than in 1994, possibly due in part to the relatively mild weather conditions in 1995.

Life Stage Quantification

The mean number (1.1) of beech scale eggs per sample was low in May 1994 (Table 6). By June, however, this number had increased to 16.0 eggs per sample, and during July and August, the number of eggs were excessively high and could not be counted accurately. The mean number of eggs per sample in September 1994 was 116.8 and decreased dramatically in October (6.8 eggs) and November (1.3 eggs). From December 1994 through May 1995, no beech scale eggs were observed. Eggs were observed again in June 1995 and averaged 13.8 eggs per sample.

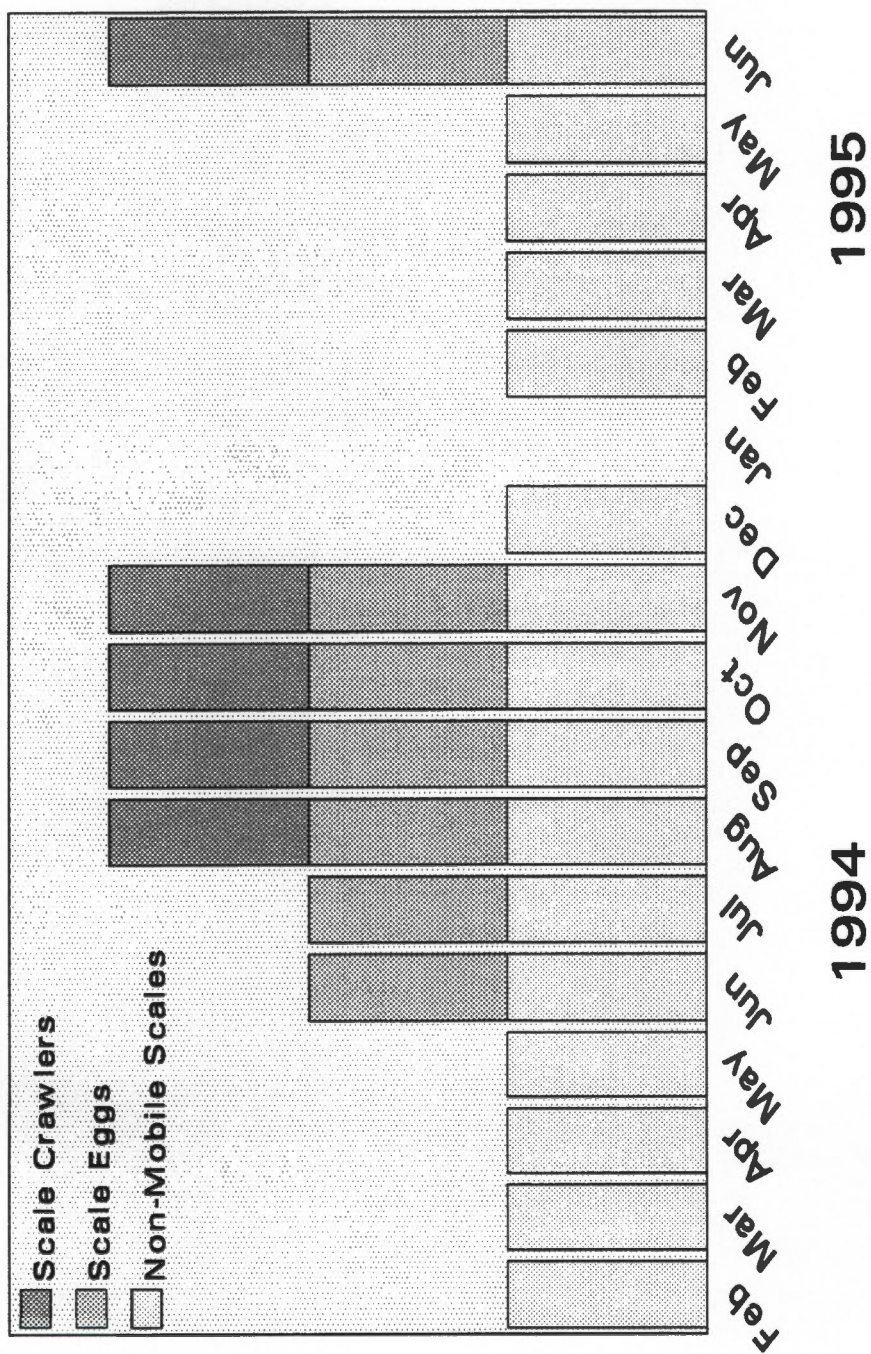


Figure 13. Incidence of beech scale life stages during 1994 and 1995. (Samples were not collected in January 1995.)

Table 6. Mean number of individuals within a life stage per sample (3.8 cm sq) at locations in the Great Smoky Mountains National Park.

Month/Year	n ^a	Eggs	Crawlers	Second-Instars	Adults
1994					
Feb	8	0	0	646.0	3.9
Mar	16	0	0	294.3	2.9
Apr	8	0	0	386.8	3.4
May	16	1.1	0	192.8	1.2
Jun	16	16.0	0	155.9	1.4
Jul	16	N/A ^b	0	1.2	112.2
Aug	16	N/A ^b	77.6	0.1	87.1
Sep	8	116.8	223.6	0	74.6
Oct	8	6.8	116.1	0	213.4
Nov	8	1.3	0.3	109.6	4.5
Dec	8	0	0	96.9	1.4
1995					
Jan	N/A ^c	N/A ^c	N/A ^c	N/A ^c	N/A ^c
Feb	8	0	0	77.6	1
Mar	8	0	0	86.6	1
Apr	8	0	0	92.0	0.3
May	8	0	0	48.5	2.3
Jun	16	13.8	0.2	49.4	7.2

^a Number of samples collected each month.

^b Egg masses were excessively numerous and could not be counted accurately.

^c No bark samples were collected in January 1995.

In 1994, crawlers were not observed until August when they averaged 77.6 crawlers per sample (Table 6). In 1994, density of crawlers peaked at 223.6 crawlers per sample in September. Crawler density was low (0.3 per sample) in mid November, and no crawlers were observed from December 1994 through May 1995. Crawlers were again collected in mid June 1995 and averaged 0.2 crawlers per sample.

In 1994, the mean number of second-instars were greatest from February through June (Table 6) and lowest from July through October. In 1995, the greatest number of second-instars were observed from February through April.

Adult beech scale were found in each month during data collections. The greatest mean number of adult beech scales were found on bark samples from July through October 1994 (Table 6). Mean numbers of adults were considerably lower on other collection times during 1994 and 1995.

These data are relatively consistent with life history research conducted in northeastern United States and Canada (Houston 1994b, Ehrlich 1934). However, the ovipositional period and the period of activity for crawlers in the GSMNP may be somewhat longer than that of beech scale populations in the Northeast. Researchers in Canada have reported beech scale eggs from mid July through September and in New England from June through September (Houston 1994b, Ehrlich 1934). In contrast, eggs were collected in the GSMNP as early as the end of May and as late as mid November. The active period for crawlers has been reported by researchers in Canada and New England to occur from July or August through September or October (Houston 1994b, Ehrlich 1934), while crawlers were collected in the GSMNP as early as mid June and as

late as mid November. In this research, a few eggs and crawlers were found in early spring and late fall, but the greatest number of eggs and crawlers were collected during times relatively consistent with periods of oviposition and crawler activity reported by previous researchers in the Northeast.

Beech Scale Mobility and Mean Air Temperature

During 1994, the mean high and low air temperatures recorded at Newfound Gap in the GSMNP peaked in June (Figure 14). The mean high temperature declined slightly in July, but both the mean high and low temperatures did not begin to drop dramatically until September 1994. Beech scale crawlers were first observed during August while air temperatures were still near their peak. The greatest mean number of crawlers per sample were collected in September 1994. As air temperatures declined in October 1994, the number of crawlers also declined, and the mean number of beech scale crawlers had dropped dramatically by November 1994 to 0.3 crawlers per sample.

The average air temperature may be a significant factor influencing the ovipositional period of the beech scale. In 1994, the crawler activity peaked in September, which suggests that the peak ovipositional period occurred in August when air temperatures in the mountains had been near their peak for about two months. The air temperature also is likely to play a role in determining the length of time that crawlers are active and therefore the time available for the dissemination of the insect. In 1994, as air temperatures dropped in the fall, the number of crawlers declined rapidly. Crawlers are more active in warmer weather conditions, and upward movements by crawlers on

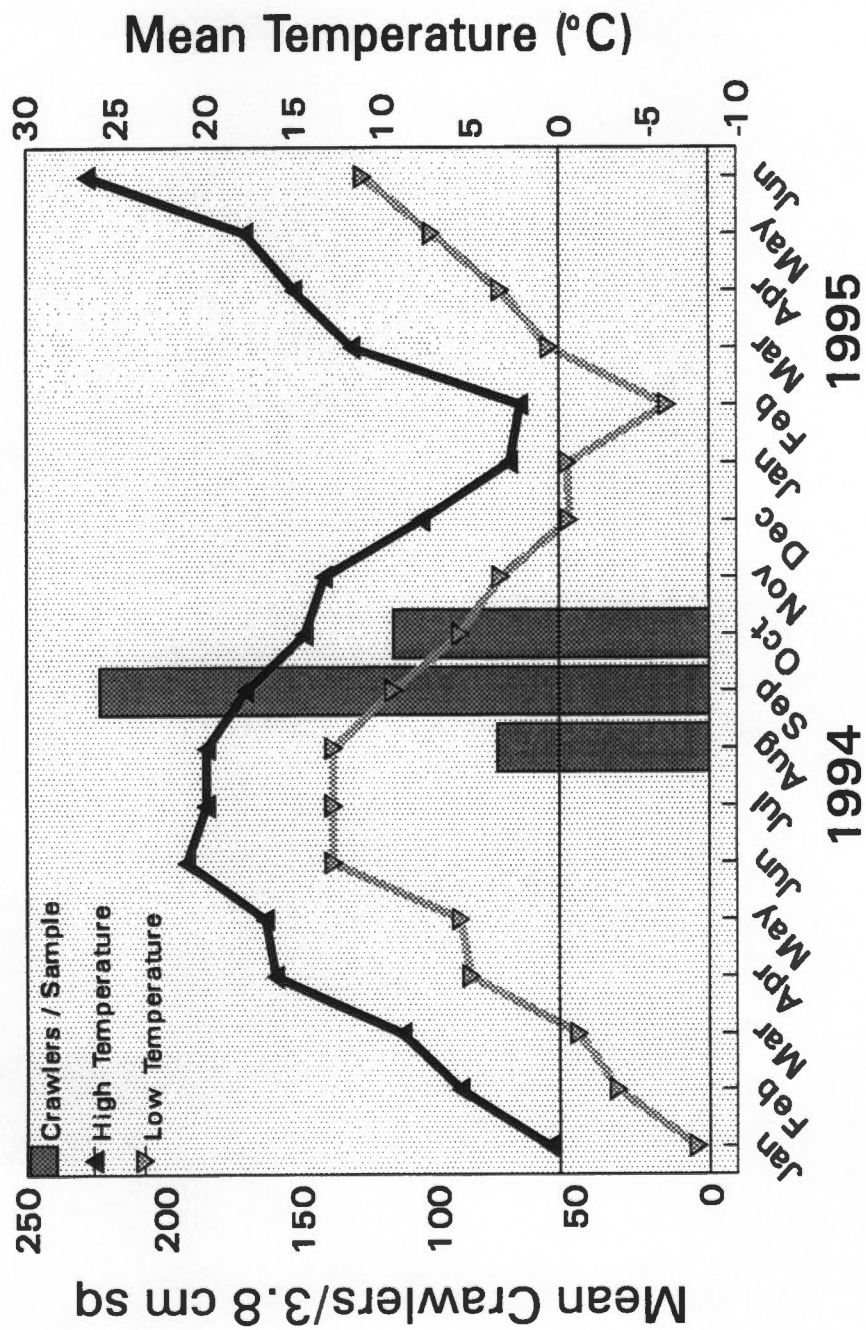


Figure 14. Mean crawlers per sample (3.8 cm sq) vs. monthly mean air temperature recorded at Newfound Gap in the Great Smoky Mountains National Park.

beech trees increase the chance of dissemination by wind (Wainhouse 1980, Ehrlich 1934). These factors suggest that the mean air temperatures in the GSMNP could influence the amount of dissemination as well as the time of dissemination.

iv. Summary

During this 2-year study, beech scale eggs were first found during late May to early June, and crawlers were first observed during mid June to early August. In 1994, beech scale eggs were collected from late May through mid November, with the greatest number of eggs found in July and August. Crawlers were collected from the beginning of August 1994 through mid November 1994, with the greatest number of crawlers found in September. In 1995, eggs were first collected in early June, and crawlers were first found in mid June.

During this research, the greatest number of crawlers were observed in late summer to early fall 1994 after mean air temperatures had started to decline. This observation suggests that the greatest chance for dissemination of beech scale occurs during late summer to early fall in the GSMNP. Crawlers were first observed about 1½ months earlier in 1995 than in 1994, indicating that the number of crawlers could peak earlier in 1995. If the number of crawlers peak earlier, the time period for dissemination as well as the chances of dissemination of beech scale could be significantly increased in 1995. The presence of high numbers of crawlers earlier in the season would suggest a longer

period of time with warmer weather conditions that may increase crawler activity and the probability of dissemination.

The peak periods of beech scale oviposition and crawler activity documented by this research provide base-line information needed to estimate the optimum time for the spread of beech scale in the GSMNP. These base-line data provide information that can be compared with future beech scale life history research to document temporal changes involving the dissemination of this insect. These data will provide basic information needed for future development of beech scale and beech bark disease management strategies.

CHAPTER IV

ASSESSMENT OF NATURAL ENEMIES OF BEECH SCALE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

i. Introduction

American beech, *Fagus grandifolia* Ehrlich, is an important component of forests in eastern North America. This tree species is a substantial source of pulpwood, fuelwood and lumber and plays an important role in eastern forests, providing food and habitat for many animal species (Mayer and Allen 1983, Twery and Patterson 1983, Martin et al. 1961). American beech is currently threatened by beech bark disease. This fungal disease is characterized by tree mortality resulting from infection by species of *Nectria* Fries, following infestation by the beech scale, *Cryptococcus fagisuga* Lindinger (Houston 1994b, Manion 1991).

Close association of beech scale with beech bark disease warrants the necessity for identification of natural enemies of this insect. The most common documented natural enemy of the beech scale in North America is the twicestabbed lady beetle, *Chilocorus stigma* (Say) (Shigo 1964). This coccinellid is native to North America, and the adult and all immature stages of this beetle are predaceous on beech scale (Mayer and Allen 1983, Shigo 1964). Behavior studies of *C. stigma* at two beech scale-infested sites in New York

indicate the beetle is an opportunistic predator and has only limited effectiveness in controlling the pest (Mayer and Allen 1983). Research in beech bark disease-infected forests in New Hampshire show that *C. stigma* is capable of transporting conidial inoculum of *Nectria* spp. while searching for food and could be a factor in long-range dissemination of this disease (Shigo 1964).

Calvia quatuordecimguttata var. *similis* Randall, another coccinellid, is a known predator of beech scale in New York and Pennsylvania (Mayer and Allen 1983). Several species of mites also are reported to be predators of beech scale. The predaceous mite *Anystis* sp. is known to feed on all life stages of the scale, and *Tydeus* spp. mites have been reported to feed on beech scale eggs (Mayer and Allen 1983). Other mites observed to feed on beech scale include *Abrolophus* sp. and *Leptus* sp. (Mayer and Allen 1983). Trapping for parasitoids of beech scale was conducted in 1976 at sites in Maine, Vermont and Pennsylvania (Houston 1982). During this research, no parasitoids of the beech scale were captured, and currently no known parasitoids of this scale have been reported (Wainhouse and Gate 1988, Houston 1983b, 1982).

In Europe, beech bark disease has caused considerable damage to forests of European beech, *Fagus sylvatica* L., and the beech scale is endemic to much of the range of this tree species (Wainhouse and Gate 1988). Several insects are reported to be predators of beech scale in Europe (Houston 1983b). Some of these are coccinellids in the genera *Exochomus* and *Chilocorus*, and larval forms of various Neuroptera in the families Chrysopidae and Hemerobiidae (Wainhouse and Gate 1988, Houston 1983b). Larvae of

the cecidomyiid, *Lestodiplosis* sp., have been confirmed to feed on all stages of beech scale in European forests (Wainhouse and Gate 1988, Houston 1983b).

These insects are all generalist predators and have limited effectiveness in the control of beech scale. Predators have been observed to reduce beech scale populations on individual beech trees, but this reduction only occurs when predator populations are high (Wainhouse and Gate 1988, Houston 1983b). The predators are not often found on trees with low populations of beech scale and therefore do not prevent the initial build-up of scale populations (Wainhouse and Gate 1988).

Natural enemies of beech scale in the Great Smoky Mountains National Park (GSMNP) are unknown. Thus, the objective of this research is to monitor the occurrence/incidence of parasitoids and predators of beech scale in the GSMNP. This information will enable scientists to develop better management efforts against beech scale and provide data necessary for the development of future biological control projects against beech scale.

ii. Materials and Methods

The parasitoid complex of beech scale was investigated at four sites in the GSMNP: Forney Ridge (Plot C), Chimney Trail (Plot G), Sweat Heifer (Plot H) and Fork Ridge (Plot I) (Figure 2). At each site, 12 beech trees were selected for parasitoid trapping. Of the 12 trees, six trees were less than 15.2 cm diameter at breast height (dbh) and six were greater than or equal to 15.2 cm dbh. Film canister (3 cm x 5 cm) parasitoid emergence

traps, developed by Christine Nalepa, North Carolina Department of Agriculture (Nalepa 1987), were used on trees less than 15.2 cm dbh, while a larger modified version (6 cm x 7 cm) of these traps was used on the larger diameter trees. The smaller film canister traps also were used on a few larger diameter trees, due to sealing problems with the larger traps on some trees. Each trap is designed with a collection vial (12 mm x 35 mm) attached to one side. If parasitoids emerge inside the canister, they are attracted to the light entering the hole (5 mm) which connects the collection vial to the canister. After the parasitoids enter the collection vial, they can be collected by removing and capping the vial, which is then replaced with a new vial.

Trap installation involved sealing the traps over areas of scale-infested bark. Traps were installed on the bole of the tree anywhere from about 30 to 200 cm above the ground surface. Each trap was cut to fit the contour of the tree using a pocketknife. Traps were sealed to the tree by lining the edge of each trap with rope caulk before installation. Traps were secured to the tree with 20 gauge galvanized wire.

Beginning in mid May 1994, one trap was placed on each selected tree at all sites. One new trap was added to each tree at approximately one month intervals through September 1994. This procedure resulted in five traps per tree and 60 traps per site, except for the Forney Ridge site where the last set of traps was not installed. Each trap remained on the tree until trapping was concluded. However, about 80 traps were removed early due to leakage problems and animal damage. Traps were removed from Chimney Trail and Sweat Heifer in December 1994. However, the traps at Fork Ridge

and Forney Ridge were not removed until January and March 1995, respectively. All traps removed in 1995 had leakage problems or were damaged by animals.

Each trap was monitored for captured parasitoids at approximately 2-week intervals. On monitoring dates, the collection vial on the side of each trap was inspected for the presence of parasitoids. If anything was observed in the vial, the vial was removed from the trap, capped, labeled and stored in a plastic container (4.5 cm x 6.5 cm) for transport to the laboratory. Each vial was labeled with the date, tree number and site number. Removed collection vials were immediately replaced with new vials. In the laboratory, vials were inspected for parasitoids using a stereoscope.

To increase the chances of success in capturing parasitoids, cardboard container emergence traps (8.5 cm x 9 cm) were used in the laboratory. Sections (ca. 6 cm long, 1 to 2 cm diam) of beech scale-infested branches were collected from beech trees at two trapping sites (Fork Ridge and Forney Ridge) once per month during July, August and September 1994. On each sampling date, branch sections from each sampling site were sealed in an emergence trap using clear plastic tape around the edge of the trap lid. Traps were placed near an outside window in the laboratory (ca. 18 to 32°C) where they received normal daylight. Traps were monitored weekly for emergence of parasitoids.

During parasitoid collections, visual observations were conducted on each beech tree to determine arthropod predators that feed on beech scale. All trees used in the parasitoid trapping investigation were monitored biweekly from May to September 1994 for predators of beech scale. On each sampling date, the lower 2 m of each tree were examined for approximately 1 to 2 minutes per tree. If active arthropods were observed,

a hand lens (9 mm diam) was used to monitor for predation of beech scale. Predators observed to feed on beech scale were collected and taken to the laboratory to be identified.

iii. Results and Discussion

Beech Scale Parasitoid Investigation

Throughout the season, 61 of 228 parasitoid traps were removed from beech trees at four sites in the GSMNP because of water leaking under the sealer. These leaks were sometimes caused by a poor seal between the traps, rough or uneven bark surfaces, or snails or millipedes feeding on the sealer. Eighteen additional traps were damaged or destroyed by animals (probably black bears). After five months of parasitoid trapping in 1994, no parasitoids were captured. The six cardboard container emergence traps used in the laboratory were monitored until December 1994, and no parasitoids had emerged from beech scale.

No parasitoids of beech scale were documented in this study or in previous parasitoid trapping studies conducted in Vermont and Pennsylvania (Houston 1982). These data unfortunately suggest that beech scale populations in North America are not impacted upon by parasitoids. However, the absence of established parasitoids that attack beech scale suggests the presence of a niche that could be exploited as a measure for biological control of this pest species.

Beech Scale Predator Investigation

Of the 48 beech trees examined biweekly from May to September 1994, only one arthropod predator, the predaceous mite, *Trombidium* sp., was observed to feed on beech scale. This predator was first observed to feed on second-instar beech scale in the field in May 1994 at the permanent plot at Newfound Gap. This feeding behavior was later verified when two mites were taken to the laboratory and placed on samples of beech scale-infested bark and examined under the stereoscope. The mites were observed to feed upon beech scale, which consisted primarily of non-mobile second-instars.

Monitoring for the incidence of *Trombidium* sp. on American beech trees also was conducted during beech scale permanent plot ratings in 1994 and 1995 (see Chapter II). *Trombidium* sp. were found in six permanent plots in 1994 (Forney Ridge, Gregory Bald, Indian Gap, Jenkins Knob, Newfound Gap, and Trillium Gap) and in five plots in 1995 (Forney Ridge, Gregory Bald, Jenkins Knob, Newfound Gap, and Sweat Heifer) (Table 1, Figure 2). During the spring/summer and fall 1994, the mite was observed on 7.8 (n = 449) and 4.4% (n = 455) of all trees monitored, respectively. However, the mite was found on about 18.8% (n = 452) of the trees during spring 1995. The number of mites on each tree were not recorded. When *Trombidium* sp. were present, only one or two mites were usually observed on each tree, but on rare occasions three or four mites were present on the same tree. Several variables (e.g., temperature, weather, time of day, and the time of the year) may be involved in the inconsistencies among plots and sampling dates. The life cycle and behavioral habits of this predator also are factors that could influence the observed activity of this mite. Additional research to evaluate the impact of

these variables is needed to acquire a more extensive view of the role of *Trombidium* sp. on the regulation of beech scale populations in the GSMNP.

iv. Summary

Few natural enemies of beech scale were found in the GSMNP during 1994. No parasitoids of beech scale were captured after five months of parasitoid trapping in 1994. During 1994, one arthropod predator was observed to feed on beech scale both in the field and in the laboratory. The absence of parasitoids, and the limited diversity of predators of beech scale, coupled with the current success of this pest species, imply that beech scale will continue to threaten American beech in the GSMNP. The shortage of natural enemies of beech scale could represent opportunities for the implementation of biological control measures for this pest.

The introduction of exotic natural enemies of beech scale is one option that could be considered. Predators of beech scale from Europe, if introduced into North America, may have advantages that could enable these species to exhibit a greater impact on beech scale. Previously introduced predators, such as the coccinellid, *Harmonia* spp., already common in the United States, also could be evaluated as potential control agents of beech scale.

Two microbial pathogens, *Cladosporium cladosporioides* (Fres.) de Vries and *Verticillium lecanii* Viegas, have been found in association with beech scale (Houston 1983b, Lonsdale 1983b). *C. cladosporioides* is known to degrade the protective coating

of wax on beech scale colonies and increase susceptibility to environmental conditions, and *V. lecanii* is a known entomogenous fungus (Houston 1983b, Lonsdale 1983b). The impact on beech scale populations by these fungal species has not been determined, and the development of these species as biological control agents warrants further investigation (Houston 1983b, Lonsdale 1983b). Additional research in the GSMNP is needed to determine if these or other microbial pathogens of beech scale are present, and if so, how they can be enhanced as agents of biological control.

Methods to enhance the success of *Trombidium* sp. could be employed to increase the impact of this native predator on beech scale populations. Investigation of the feasibility of rearing and releasing these mites is one potential method to amplify the impact of the mite on beech scale. The twicestabbed lady beetle, *Chilocorus stigma* (Say), the most common predator of beech scale in the Northeast, also could be evaluated for rearing and releasing to enhance the impact of this predator on the scale. Research to find biological controls that target the beech scale during peak crawler activity, when the scale may be more vulnerable, also should be considered.

Beech scale is likely to continue to be a problem in the GSMNP. However, the severity of this problem may be reduced by the impact of natural enemies of the scale. Efforts to increase the success of natural enemies already present, or by introducing new biological control agents, may lead to the eventual maintenance or control of this pest species.

CHAPTER V

CONCLUSIONS

American beech, *Fagus grandifolia* Ehrlich, is an ecologically and economically important component of forests in eastern North America. American beech is a substantial source of pulpwood, fuelwood and lumber and plays an essential role in eastern forests, providing food and habitat for many animal species (Mayer and Allen 1983, Twery and Patterson 1983, Martin et al. 1961). This tree species is currently threatened by the devastating beech bark disease.

Beech bark disease is a fungal disease caused by species of *Nectria* Fries, which can infect and kill beech trees that are predisposed by infestations of beech scale, *Cryptococcus fagisuga* Lindinger (Manion 1991, Houston et al. 1979a). Beech bark disease has advanced as far south as Tennessee and North Carolina since it was first discovered in North America near Halifax, Nova Scotia, during the 1920s (Houston 1994b, Ehrlich 1934). In 1993, beech bark disease was discovered in the Great Smoky Mountains National Park (GSMNP) (Houston 1994b; K. D. Johnson, personal communication).

In 1994, a 2-year research project was initiated to investigate several biological aspects of beech bark disease in the GSMNP. One goal of this research was to initiate long-term monitoring of incidence and distribution of beech scale and beech bark disease in the GSMNP. Other objectives of this research included monitoring the life history and

seasonal incidence of beech scale, and monitoring for natural enemies of beech scale in the GSMNP.

The overall status of beech scale in the GSMNP permanent plots has not changed dramatically during this research in 1994 and 1995. For example, the total percent incidence and total mean ratings for beech scale were found to be relatively similar on the three sampling dates in 1994 and 1995. However, some individual plots are undergoing substantial changes in incidence and population levels of beech scale. At Deep Creek, percent incidence and mean ratings for beech scale consistently increased during 1994 and 1995, as the beech scale moved into this previously noninfested area. During this research, the percent incidence and mean ratings for beech scale at Forney Ridge consistently decreased, primarily because of increased tree mortality in that plot.

The continuous increases in percent incidence and mean ratings for *Nectria* spp. on all sampling dates in 1994 and 1995 suggest that the overall levels of this pathogen are increasing. The most dramatic increases were observed at Forney Ridge, where the highest levels of *Nectria* spp. were recorded.

The rating location on beech trees was not a critical factor during this investigation. The total percent incidence and mean ratings for beech scale and *Nectria* spp. were similar on the north and south side of the trees on all sampling dates in 1994 and 1995.

Xylococcus betulae is well established in the GSMNP. This scale was present in all permanent plots and at more than 40% incidence in nine of ten plots on all sampling dates. On the third sampling date, seven plots had greater than 60% incidence of this scale.

During this research, the optimum time for dissemination of beech scale in the GSMNP occurred in late summer to early fall, when crawler activity peaked. In 1994, the greatest number of crawlers were collected during September. The peak time for beech scale oviposition occurred in mid to late summer. In 1994, the greatest number of beech scale eggs were collected in July and August.

Few natural enemies of beech scale were observed in the GSMNP during this investigation. After one five-month season of trapping in 1994, no parasitoids of beech scale were captured, and only one predator of beech scale was documented. This predator, *Trombidium* sp., was observed to feed on the scale both in the field and in the laboratory under the stereoscope. *Trombidium* sp. could be a potential candidate for biological control of beech scale in the future. The absence of parasitoids impacting upon beech scale in the GSMNP could indicate a possible niche that could be exploited for biological control of this pest. The low diversity of arthropod predators of beech scale, the absence of parasitoids of the scale, and the current success of this pest suggest that beech scale will continue to be a problem in the GSMNP.

Data from this research provide base-line information needed for development and implementation of strategies for maintenance and control of beech scale. Base-line data initiated during this research also will help future researchers document temporal changes in distribution and incidence of beech scale and beech bark disease in the GSMNP. These data also provide the basis for documentation of temporal changes in the life history of beech scale. Continued monitoring will document the impact of the spread of beech scale

and beech bark disease. This monitoring also may identify genetic resistance to beech scale that may be present in American beech trees in the GSMNP.

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