EFFECTS OF SPECIES COMPOSITION AND SITE FACTORS ON THE SEVERITY OF BEECH BARK DISEASE IN WESTERN MASSACHUSETTS AND THE WHITE MOUNTAINS OF NEW HAMPSHIRE: A PRELIMINARY REPORT[1]

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Abstract.--The extent of beech bark disease was examined on permanent inventory plots in western Massachusetts and on Bartlett Experimental Forest in New Hampshire. The amount of disease-caused defect was correlated with a reduction in the proportion of beech in a stand. Sites on lower slopes and with greater abundance of hemlock contained more defective beech.

INTRODUCTION

Beech (Fagus grandifolia) is a major component of the northern hardwood forests of New England. Although it is of less commercial importance than its companion species, sugar maple (Acer saccharum) and yellow birch (Betula alleghaniensis), beech is a valuable timber tree used for furniture parts, turning stock, fuelwood, and pulp. Beech mast is of great value to wildlife in the northern hardwood forests. The beech bark disease (BBD) has caused widespread destruction of mature beech stands resulting in lost value of standing timber and forest production. The true extent of this loss is unknown. Different species mixtures and environmental factors have been suggested as important potential sources of variation in the disease (Houston 1980). Conversely, the disease is a potential major influence on future species composition and stand structure (Filip 1978). This paper is a preliminary report on a study designed to examine both of these problems and to determine some of the specific causes and effects of variations in BBD.

BBD in North America is generally accepted to be a complex of the scale insect Cryptococcus fagisuga Lindinger, and the fungus Nectria coccinea var. faginata, as described by Ehrlich (1934). The insect was first noted in the western hemisphere in Halifax, Nova Scotia in 1890. The first disease outbreak in the United States occurred in Maine about 1930. The disease has since spread throughout New England, parts of eastern Canada, New York, and into Pennsylvania (Houston et al. 1979). Shigo (1972) described the progress of the disease as consisting of three stages: the advancing front, the killing front, and the aftermath zone. Most of New England is now in the aftermath zone, and BBD is endemic throughout (Houston 1975).

Diseases have been shown previously to be causes of considerable changes in forest composition. Davis (1981) has postulated that a disease of yet undetermined origin destroyed widespread hemlock stands about 4800 B.P. and caused changes in forest species composition (as determined by pollen analysis) that lasted for several hundred years. More recently, the destruction of chestnut (Castanea dentata) in the early 20th century substantially altered species composition of oak hardwood stands of the northeastern United States (Aughanbaugh 1935 e.g.). During the past two to three decades, Dutch elm disease (Ceratocystis ulmi) has also changed stand make-up (Eyre 1980). Similar effects might be expected from BBD. Beech, however, because of its ability to reproduce vegetatively by root suckers, has in some areas increased in basal area and density after destruction of overstory individuals by BBD (Houston 1975).

Few studies have examined the factors affecting the intensity of BBD within a stand. Mize and Lea (1974) found the highest

[1] Paper presented at the IUFRO Beech Bark Disease Working Party Conference, Hamden, CT. USA, 27 Sep to 7 Oct 1982.

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probability of beech mortality among trees of large diameter and low vigor. Parker (1980) found that competition within a stand lowers host resistance and increases risk of mortality for European beech (F. sylvatica). Lonsdale (1980) found that drought was an agent of stress which contributed to more severe disease symptoms. Parker (1974) and Lonsdale et al. (1979) also detected a correlation between depth of soil over chalk and amount of chalk incorporated into soils and the incidence of BBD in England. Topographical influences have also been found important in previous studies. Those trees likely to be first affected were found by Houston et al. (1979 and 1979a) and Parker (1974) to be ones on midslope or ones downwind of large, old, infested trees. Site conditions and soils are also recognized as significant influences on the ability of beech to compete with other species (Leak 1978, 1980) and may influence the impact of BBD on a stand.

STUDY AREAS

Because part of this study is an attempt to document changes in forest compositions attributable to beech bark disease, we needed stands with available data regarding the composition prior to infection. The most readily accessible data are from the Massachusetts Continuous Forest Inventory (CFI), for which permanent plots have been sampled periodically since the early 1960's. Because BBD mortality did not occur in substantial amounts in Massachusetts until the late 1960's, these records were considered acceptable. In order to examine differences over a wider geographical area and to include areas where BBD has been present longer, we also studied permanent inventory plots in the Bartlett Experimental Forest in NH. The plots in Bartlett were established initially in the 1930's and the BBD killing front passed through the area in the 1950's (Filip 1978).

Initially, we selected all plots on which beech made up at least 20% of the stems with a diameter at breast height (DBH) ≥ 5 inches (13 cm). Those plots with recent cutting were subsequently omitted.

The CFI plots sampled in Massachusetts are well distributed over state forest lands in four western counties. They vary in elevation from 600 to 2900 ft (180 m to 900 m). We sampled 41 plots during the summers of 1981 and 1982 from 94 which met the initial criteria. CFI plots are circular and cover an area of 0.20 acre (0.08 ha).

Bartlett Experimental Forest is in the eastern part of the White Mountains National Forest in New Hampshire. It occupies 2600 acres (1053 ha) on a generally northeast facing slope. Elevation varies from 700 ft to 3000 ft (210 m to 930 m). The plots sampled were from both the lower, gentler slopes and the upper, steeper slopes ranging from 800 to 2000 ft (240 m to 610 m) elevation. The inventory plots on Bartlett are 0.25 acre (0.10 ha) squares. A total of 25 plots were sampled for this study out of 47 which met the initial criteria. Time constraints and accessibility (< 1 mi from a road) limited the number of plots we could sample. Selection was subjective, with an attempt to distribute samples over a wide range of elevation, physiography, and geographical location (Figure 1).

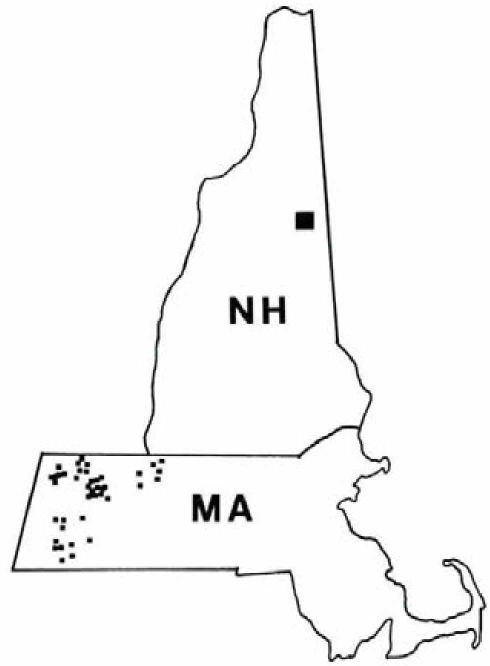

Figure 1.--Locations of sample plots in Massachusetts and New Hampshire.

PROCEDURES

On each plot, all woody stems ≥ 2 inches (5 cm) dbh were recorded by species, diameter class (to the nearest inch), crown class (dominant, codominant, intermediate, or suppressed), and condition (good, fair, poor, or dead). On beech ≥ 2 in dbh, variables relating to the incidence of BBD were also recorded according to the systems developed cooperatively by the USDA Forest Service and the British Forestry Commission (Houston et al. 1979a; Houston personal communication). These include the amount of wax present (as an indicator of scale population) by height zones and aspect, presence of Ascodichaena rugosa, abundance and aspect of algae and lichens, and the amount of fruiting of N. coccinea var. faginata present by height zones. Because current fruiting was considered insufficient to describe the amount of Nectria attack over a prolonged period, we added an index of visible defect due to old infections, using the same scale as for fruiting (0 to 4 for none to very heavy, respectively) of Nectria. Each tree was divided into three height zones: 0 to 2 m, 2 to 4 m, and over 4 m. We also recorded the number of tarry spots present, the number of Xylococculus betulae present, and the presence or absence of callusing. Site data recorded for each plot included 11 variables: aspect, percent slope, slope position (1=ridge and upper slope, 2=midslope, 3=lower slope, 4=bottom), elevation, canopy closure, canopy height, and percent cover of hardwood litter, softwood litter, bare soil, exposed rock, and fallen wood.

All analyses described in this paper were performed only on 1981 data, on 10 plots each from Massachusetts and New Hampshire. Results and the hypotheses generated will be tested against the 1982 data when they are available.

RESULTS

The first question to be addressed was whether the data recorded provided a meaningful index of the severity of the disease on any given plot. The amount of current fruiting of Nectria was deemed inappropriate, for much of the damage had occurred up to 25 years ago and often little fruiting was present in obviously damaged stands. The appropriate index appeared to be evidence of both past and present Nectria activity provided by the defect variable, which was recorded on each beech by intensity in each of three height zones. A total defect index for each tree was arrived at by summing the scores for each zone (possible scores 0-12 for live trees). A tree apparently killed by BBD was given a score of 13. The mean defect score for trees ≥ 5 in dbh on each plot was used as an index of BBD severity on that plot.

The six most important species found were beech, sugar maple, red maple (Acer rubrum), yellow birch, black birch (Betula lenta), and hemlock (Tsuga canadensis). These six species accounted for at least 80% of stocking on almost all plots. Total density and basal area in trees ≥ 5 in dbh were computed, as were the relative proportions of each of the six species. These figures were then used in analysis of composition of the plots. Important variables are summarized in Table 1.

Table 1.--Defect, stand, and site parameters on plots in Massachusetts (all digits) and New Hampshire (lettered plots).

Plot	Average Defect	Net Change Beech BA	Percent Hemlock BA	Slope Position
R-28	9.25	-26.0	51.4	4
M-28	7.96	-0.7	22.8	3
T-28	7.89	-28.4	24.0	4
V-11	7.80	-5.2	15.4	2
1026	7.67	-12.6	2.9	3
1057	7.65	-8.4	10.8	2
O-28	7.09	-31.0	62.9	3
V-13	6.22	-18.3	27.7	2
1087	6.00	10.3	0.8	1
83	5.88	-4.9	32.3	1
1037	5.88	20.1	41.4	2
Y-34	5.79	-9.4	17.7	3
1018	5.67	-7.6	32.4	2
X-12	5.39	-16.6	10.7	2
89	5.15	-8.3	0	1
1022	5.15	5.2	6.9	2
Z-32	5.00	25.9	0.8	2
915	4.53	0.4	0	2
V-28	3.94	18.1	0	4
1045	1.46	7.5	0	1

The total defect of each tree was compared to its diameter and crown class to determine whether this produced results similar to those described elsewhere (Mize and Lea 1979, Ehrlich 1934, Shigo 1972). Diameters were grouped into four classes: saplings (2 to 4 inches; 5 to 12 cm), poles (5 to 9 in; 12 to 23 cm), small sawlogs (10 to 14 in; 25 to 36 cm), and large sawlogs (over 14in; 36 cm). Saplings had significantly less defect than the poles, which had significantly less defect than the sawlogs (Table 2). The two sawlog classes, however, were not significantly different.

Crown class also had a significant effect on defect (Table 3). All crown classes were significantly different from each other, with dominant having the most defect, codominant next, then intermediate, and suppressed trees showing the least defect.

Severity of BBD varied significantly among the plots (Table 1). That variation was along a continuum and separation of plots into meaningful discrete groups by amount of defect alone was not possible. Average defect was significantly negatively correlated with the change in the percentage of total basal area in beech (Figure 2).

Table 2.--Average Nectria defect by diameter class, live trees only.

Diameter Class	*Number of trees*	*Mean Defect*
Saplings	248	2.02
Poles	203	3.84
Small sawlogs	91	5.73a
Large sawlogs	38	6.24a
Total	580	3.52

[a]Values followed by the same letter are not significantly different at p = 0.05.

Table 3.--Average Nectria defect by crown class, live trees only.

Crown Class	Number of trees	Mean *Defect*
Dominant	20	6.75
Codominant	169	5.33
Intermediate	105	3.46
Suppressed	286	2.24
Total	580	3.52

The current beech density was significantly negatively correlated with average defect by plot (Table 4). Average defect was not significantly correlated with either total density or total basal area. However, average defect was significantly correlated with the proportion of basal area in hemlock (Figure 3). Average fruiting was very highly correlated to average defect. Average defect was significantly correlated *with slope position. Analysis of variance* showed no overall difference by slope position, but an a priori contrast of the two upper positions vs. the two lower ones did indicate significantly more defect on the lower slopes.

None of the other site variables were significantly correlated with the severity of BBD. *An additional variable, solar radiation* index (SRI), was derived from a combination of aspect and slope (Frank and Lee 1966), but it was correlated only with total density, and had no relation to the disease. Abundance of the scale was almost totally independent of defect (R=0.01). Elevation was the only plot variable which showed a significant correlation with the scale.

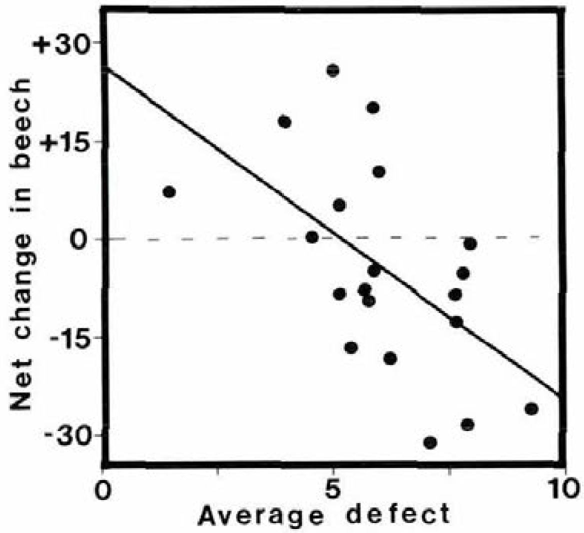

Figure 2.--Regression plot of change in percent basal area beech vs. average defect.

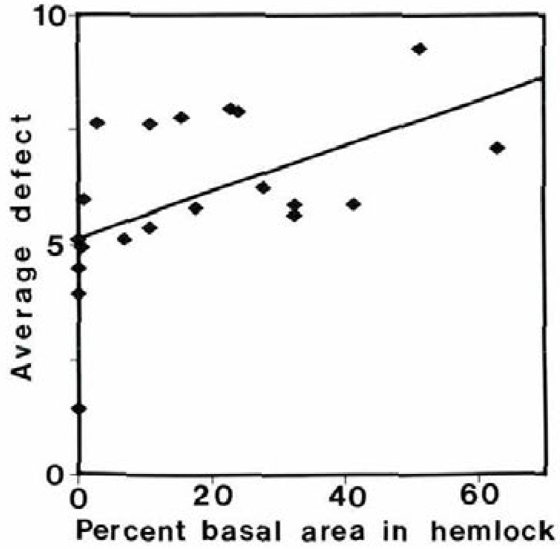

Figure 3.--Regression plot of average defect vs. percent basal *area in hemlock*.

Table 4.--Correlations of average defect with various site characteristics.

Variable	Correlation Coefficient(R)	Significance Level
Current Hemlock Density(%)	.5521	.006
Current Hemlock Basal Area(%)	.5195	.009
Average Fruiting Index	.8913	.001
Slope Position	.4858	.015
Net Change in Beech Basal area(%)	-.5688	.004
Net Change in Beech Basal Area(absolute)	-.4564	.022
Current Beech Density(%)	-.4199	.033
Net Change in Beech Density(%)	-.3836	.048

Stepwise multiple regression techniques produced the following equation:

$$Y=1.187(X_1)-0.698(X_2)+0.656(X_3)+0.590(X_4)$$

$$R=.816 \quad R^2=.665 \quad p=.002$$

where Y = predicted average defect

X_1 = current proportion of basal area in beech

X_2 = current proportion of stems in beech

X_3 = current proportion of basal area in hemlock

X_4 = slope position

and all coefficients are standardized. Figure 4 illustrates the goodness-of-fit of this prediction equation. The standardization of the coefficients allows comparison of their magnitudes despite differences in scale of the original variables.

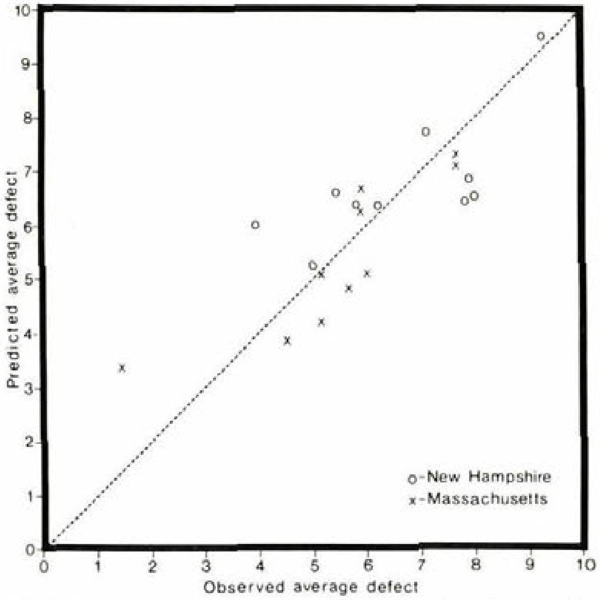

Figure 4.--Plot of predicted vs. observed values from the multiple regression equation. A perfect prediction would lie on the diagonal.

DISCUSSION

Beech bark disease has had a major impact on the composition of some northern hardwood stands in this study. An undisturbed stand of northern hardwoods in New England tends to increase its proportion of beech (Forcier 1975). Those stands where intensity of BBD is high, however, have experienced a reduction in beech generally in proportion to the intensity. This net loss of beech either through mortality or growth loss is important to the forest manager, who must decide how to deal with the effects of the disease.

The multiple regression equation is a remarkably good predictor of defect based on so few cases. If the final results of this study confirm these findings, it should prove useful and practical for management use because it involves only four easily measured variables.

In the part of New England where this study was conducted the most virulent attacks appear to be over. Those stands which have been only lightly attacked are less susceptible, due in part to composition or site characteristics. In those areas such as Pennsylvania or West Virginia, where the killing front has not yet passed, a classification of risk by composition and site could be very useful in deciding which stands to cut in advance of BBD attack. The fact that BBD attacks in a similar manner in this study area and in other previously mentioned areas suggests that our results may be applicable elsewhere.

Variation in the severity of BBD and its impact on a stand can be due to a number of factors. The lesser severity of BBD on plots with many small trees, as evidenced by the negative correlation of defect with beech density, implies that younger stands may not have catastrophic dying-off of beech. Ingrowth of small trees may account for increases found in beech stocking despite heavy disease of the larger trees, as on plot 1087. Other unrelated stand dynamics, such as the deaths of overmature paper birch (Betula papyrifera) may also lessen the noticeable impact of BBD on percent composition, as on plot M-28. The high correlation between fruiting and defect implies that the activity of Nectria has persisted on those sites where it has established itself. The scale is present in some numbers on all plots. The lack of correlation between defect and scale population may be due to the lag time involved between infestation and infection or to the cumulative nature of the defect index. The population dynamics of the scale in the aftermath zone appear to be based on some factors other than those measured in this study.

Those factors which had the most influence on the severity of BBD , aside from the presence of large beech, were the amount of hemlock and the slope position. Both of these factors appear to be explicable as increasing the protection which the site affords to the disease agents. Protected sites such as these would be subject to less extreme fluctuations of temperature and would maintain higher humidities. The presence of hemlock would serve to shade the trunks of the beech all winter, when alternate freezing and thawing might otherwise have a detrimental effect on the scale population.

CONCLUSIONS

This study found greater average defect in the presence of greater proportions of hemlock and on lower slopes. Other variations in species composition were not significant. Other site factors such as soil texture and drainage have not yet been examined. Nor has the additional data from the second field season been analyzed to determine whether it might confirm these hypotheses.

One outgrowth of the effect of increased hemlock on the severity of BBD is that where beech and hemlock are mixed presently, the hemlock appears to be taking a large share of the stocking and may eventually reduce beech to a minor species on these sites. On those upper slopes where hemlock is not present, BBD appears much less severe and beech is maintaining its proportion in the stand.

If these observations are confirmed by further study, they should prove useful as quick indicators to the forest manager of whether beech should be discriminated against because of high risk of BBD.

ACKNOWLEDGEMENTS

Many thanks are due to B.F. Wilson for advice and guidance in preparation of this manuscript, to D.R. Houston for help in designing the study, to W.B. Leak and the Northeast Forest Experiment Station for providing logistical support and access to inventory records, to J.C. Mawson and Bill Rivers for providing Mass. CFI records, to Andrew Backman and Won-Chin Liao for field assistance, and to Dee Ann Civello for typing the manuscript. This research is supported by Massachusetts Experiment Station Project McIntyre-Stennis 42.

RÉSUMÉ

L'importance de la maladie de l'écorce du hêtre (Fagus grandifolia) a été examinée sur les parcelles d'inventaire permanent dans l'ouest du Massachusetts et dans la forêt experimental de Bartlett au New Hampshire. La quantité de défaut causé par la maladie a été corelée à la reduction de la proportion de hêtre dans un peuplement. Les endroits situés au bas des pentes et avec une plus grande abondance de Tsuga canadensis sont couverts de hêtre plus susceptible à être attaqués par cette maladie.

ZUSAMMENFASSUNG

Das Ausmass der Buchen-Rindennekrose wurde auf Dauerbeobachtungsflächen im westlichen Massachusetts und im Bartlett Experimental Forest in New Hampshire untersucht. Es zeigte sich, dass eine Beziehung zwischen dem Ausmass der Schäden und dem Rückgang des Buchenanteils in den Beständen besteht. Flächen im unteren Teil von Hängen und solche mit höherem Anteil an Tsuga canadensis enthielten mehr geschädigte Buchen.

LITERATURE CITED

Aughanbaugh, J.E. 1935. Replacement of the chestnut in Pennsylvania. Penn. Dept. of Forests and Waters No. 54, 38 p.

Davis, M.B. 1981. Outbreaks of forest pathogens in Quaternary History. Proc. IV Intern. Conf. Palynology, Lucknow (1976-1977) 3:216-227.

Ehrlich, J. 1934. The beech bark disease: a Nectria disease of Fagus following Cryptococcus fagi. Can. J. Res. 10: 593-692.

Eyre, F.H. 1980. Forest Cover Types of the United States and Canada. Soc. Am. For., Washington, D.C.

Filip, S.M. 1978. Impact of beech bark disease on uneven-age management of a northern hardwood forest. USDA For. Serv. Gen Tech. Rep. NE-45. 7 p.

Forcier, L.K. 1975. Reproductive strategies and co-occurrence of climax tree species. Science 189:808-810.

Frank, E.C. and R. Lee. 1966. Potential solar beam irradiation on slopes: Tables for 30 to 50 latitude. USDA For. Ser. Res. Pap. RM-18. 116p.

Houston, D.R. 1975. Beech bark disease: the aftermath forests are structured for a new outbreak. J. For. 73: 660-663.

Houston, D.R. 1980. Beech bark disease: what we do and do not know. Ann. Sci. Forest. 37: 269-274.

Houston, D.R., E.J. Parker, R. Perrin, and K.J. Lang. 1979. Beech bark disease: a comparison of the disease in North America, Great Britain, France, and Germany. Eur. J. For. Path. 9: 199-211.

Houston, D.R., E.J. Parker and D. Lonsdale. 1979a. Beech bark disease: patterns of spread and development of the initiating agent Cryptococcus fagisuga. Can. J. For. Res. 9: 336-344.

Leak, W.B. 1978. Relationship of species and site index to habitat in the White Mountains of New Hampshire. USDA For. Serv. Res. Pap. NE-397.

Leak, W.B. 1980. Influences of habitat on silvicultural prescriptions in New England. J. For. 78: 329-333.

Lonsdale, D. 1980. Nectria Coccinea infection of beech bark: variations in disease in relation to predisposing factors. Ann. Sci. Forest. 37: 307-317.

Lonsdale, D., J.E. Pratt, and F.G. Aldsworth. 1979. Beech bark disease and archaeological crop marks. Nature 277:414.

Mize, C.W. and R.V. Lea. 1979. The effect of the beech bark disease on the growth and survival of beech in northern hardwoods. Eur. J. For. Path. 9: 243-248.

Parker, E.J. 1974. Beech bark disease. Forestry Commission, Forest Record No. 96.

Parker, E.J. 1980. Population trends of Cryptococcus fagisuga Lindinger following different thinning intensities of young beech. Ann. Sci. Forest. 37:299-306.

Shigo, A.L. 1972. The beech bark disease today in the northeastern United States. J. For. 70: 286-289.