THE SIGNIFICANCE OF VISIBLE PATHOLOGICAL INDICATORS IN ESTIMATING THE EXTENT OF DECAY IN A SPRUCE-BALSAM FOREST

by

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THE SIGNIFICANCE OF VISIBLE PATHOLOGICAL INDICATORS IN ESTIMATING THE EXTENT OF DECAY IN A SPRUCE-BALSAM FOREST

INTRODUCTION

In British Columbia, the Forest Surveys and Inventory Division of the B. C. Forest Service is currently undertaking a complete inventory of all forest resources within the province. With the aid of aerial photographs the work is now proceeding at the rate of approximately twenty-five million acres per year. Because of the increased attention to the establishment of forest management licenses and public working circles, this inventory is of vital importance to management planning. An essential part of this inventory is the compilation of net volumes of commercial standing timber. Among the many variables affecting the net volumes of stands, the determination of defect in standing trees is the most difficult. Defect may result from decay, insect damage, or a variety of other characteristics causing loss in volume. Of these, decay is probably the greatest contributor to the amount of defect in trees and stands.

At the present time there are two methods commonly employed in allowing for defect in standing timber. They are:

1. Direct appraisal of net volume in individual trees

or forest stands based on familiarity with the species and conditions in a region by an experienced estimator.

2. The application of an overall cull percentage to the gross volume estimates.

These methods are suitable for intensive surveys of a limited area but the problem is more complex when planning an extensive provincial inventory covering millions of acres. In a survey of this nature it is necessary to cover a wide range of forest types, site and age classes before a proper evaluation of the forest resources is possible. A field procedure designed to cover all of these conditions must be broad enough to include the essential information and at the same time be applied easily in the field. It is important to remember that in all forest inventory work the intensity of examination must be balanced against the practical limitations of field work in order that the total objective may be completed. The question of manpower is another important consideration. Each year the Forest Surveys and Inventory Division employs approximately 200 field men, most of whom have had very little forestry training or experience. After assignment to the regions in which they will be working, they receive intensive training in forest inventory practices by an experienced party chief. Following the training, high standards of work are maintained during the field season by periodic checking, by both the party chief and divisional supervisors. With these points in mind, the need for simple standardized procedures is obvious.

As a basis for dealing with defect the Unit of Forest Pathology of the Dominion Science Service prepared a classification of observable tree characteristics which had proven of value in previous work as indicators of pathological decay. In this system individual trees are segregated into classes based on the presence or absence of visible abnormalities which indicate or serve as an entrance for decay. It was expected that the incidence of these abnormalities occurring in a stand might be used to establish the amount of defect present in the stand. This system of tree classification has now been adopted as an integral part of the forest inventory program for the purpose of appraising the general condition of forest stands.

PURPOSE AND SCOPE OF STUDY

The provincial inventory was initiated in 1951 and planned to extend over a period of five years. The purpose of the project is to obtain a complete record of all the forest resources of the province. The facts are presented on forest cover maps and tabulations of wood volumes. Many of the timber types, especially the overmature classes, are subject to large volume losses because of fungous decays. The extent of decay is very difficult to estimate in the standing timber, especially by inexperienced field observors as previously mentioned. Included in the inventory project therefore, is a sub-project designed to supply the means of estimating extent of decay in all of the major types and subtypes recognized in the typing classifications. The field work of this sub project consists of two parts:

1. The application of the tree classification to the standing timber on sample plots, for the purpose of appraising its general condition.
2. Subsequent felling and bucking of all the trees on the plots and measurement of the actual amount of defect in the sample trees.

In order that the method of analysis may be clearly understood it will be necessary to include some details of the work entailed in the above procedures. The main emphasis will be placed on the tree classification system and how it may be adapted to the problem of determining defect in standing timber.

The purpose of this study is to supplement the work initiated by Browne, Foster and Thomas (4)(6) by analyzing actual field data and determining the significance of the tree classification system. The method of study is a statistical analysis of data which has been provided by the Forest Surveys and Inventory Division. The specific objectives are:

1. To determine the significance of visible pathological indicators in estimating decay in a forest stand.
2. To determine the relative importance of each of the defect classifications.
3. To outline a method of analysis which may be adapted to further studies of this nature.

The data for this thesis is confined to one broad spruce-balsam forest type of uniform age and site. The sample plots are located in the Crooked River area of Central British Columbia. Because of the lack of any previous work or information on this forest type the results of this study must be accepted with the understanding that it represents only a small contribution to the wide and important field of decay in forest stands.

REVIEW OF LITERATURE

Many attempts have been made to determine the presence and extent of decay in individual trees and stands. One of the first investigators to consider visible malformations and injuries was Boyce (2).

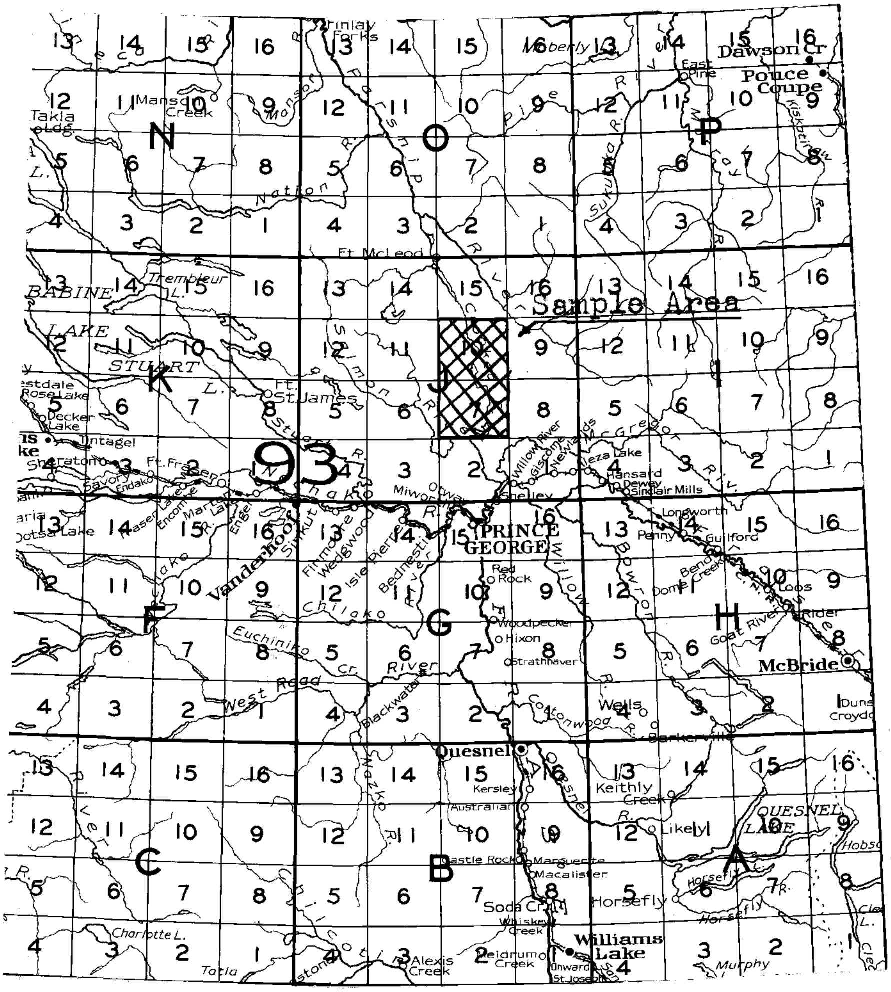


Figure 1. Location of Sample Plots in the Crooked River Area of Central British Columbia.

After investigations of Douglas-Fir in Washington and Oregon he concluded that scars, branch fans, dead limbs, burls and frost cracks failed to provide reliable indications of hidden defect. Sporophores and swollen knots provided reliable indicies to approximately 80 percent of the total decay in trees infected with Fomes pini (2, p.89). He points out the longitudinal extent and amount of decay which may be expected by the position of these defects in the tree. After studying the defect in Engelmann spruce, lodgepole pine and alpine fir, Hornibrook (8, p.408-417) developed a procedure for making reliable estimates in these species. His method applies standard scaling deductions and ocular appraisal of visible abnormalities in trees. For accurate results such a method requires experienced personnel and appears to be too detailed for application to extensive surveys.

In British Columbia, Foster, Thomas and Browne (4) conducted studies in the western hemlock (Tsuga heterophylla (Raf.) Sarg.), amabilis fir (Abies amabilis (Dougl.) Forbes) forest type in the upper Kitimat region. The forest type studied was a deteriorating old growth stand in which heavy losses from decay were occurring each year. In tallying the trees, the classifications of residual, suspect or dead were used to indicate the general condition of each tree. Residual trees are defined as all living trees which bear no visible signs indicative of decay. The suspect classification includes all living trees which bear one or more abnormalities indicative of decay. Dead trees are evident by the lack of green foliage. It was suggested that tree tallies based on these three classes might lead to the determination of average cull factors applicable to each class. Further investigations showed that sporophores, frost cracks, swollen knots, scars, dead tops, rotten branches, forked forms and trunk infections of mistletoe could be classed as abnormalities significant of decay. Sporophores and swollen knots produced following the development of decay are regarded as reliable indicators. The remaining abnormalities, however, do not indicate substantial amounts of decay in every instance. Scars and broken tops of recent origin contain very little decay compared to similar defects which have been present for a longer period of time. Characteristics such as exposed roots, dead branches, crook or burls were of minor significance in the study conducted in the Upper Columbia Region. It is possible that these classes may be valuable indicators in other areas or in other forest types. In extensive inventory work, however, it is desirable to maintain a uniform classification of indicators. As work continues certain modifications may be applied in local areas or revision of existing classes may be justified.

Further studies have been undertaken in a variety of forest types and stand conditions to verify the reliability of the classification. Work has been conducted in western hemlock and amabilis fir in the Kitimat region, hemlock in the Upper Columbia region and Engelmann spruce and alpine fir in the Bolean Lake area (Kamloops Forest District). The following is a summary of the important facts established from these projects.

1. The classification does not attempt to designate sound trees or cull trees.
2. Minimum cull losses of 50 percent are to be anticipated in dead trees.
3. The classification provides for the segregation of trees into classes of high and low susceptibility to disease.
4. The classification is of value in designating tree classes having more or less than average defect.
5. Results derived for one tree species are not applicable to a different species in the same region.
6. Results appear to confirm the reliability of the classification for the species and in the

region to which it has been applied. Further experience may indicate the need for modification to meet various conditions of forest growth and stand disturbance, however, it seems possible to apply the classification in its present form to mature coniferous stands throughout British Columbia. Revisions, if necessary, would become apparent following the subsequent examination of representative trees and the estimation of cull factors applicable to the specific region under consideration.

The classification is intended to supplement, but not replace, other pertinent variables such as site, age and diameter. Further reductions in error are to be anticipated through multiple correlations including these latter variables.

PATHOLOGICAL CLASSIFICATION OF TREES

In mature stands or stands approaching maturity it would be an advantage to know which classes of trees are likely to contain decay. On the basis of recent pathological studies by Foster, Thomas and Browne (4), living trees are classified into two broad groups which indicate the presence or absence of external signs of decay. These tree classifications are referred to as "Residual" and "Suspect" and have been previously defined in the review

Figure 2. Suspect Indicators

1. Sporophores.

2. Trunk Infection of Dwarf Mistletoe

of literature. To clarify the relationship between these two classifications and the presence of decay, the following section of the field manual is of interest: (2, Pt. III, Sec. 3, p. 3).

"Residual trees contain only hidden defect whereas Suspect trees contain hidden defect plus defect which is indicated by the presence of visible external signs. It is not implied that Residual trees are entirely free of decay, or that Suspect trees, as a class, are more defective than Residual trees, due in part to their associated defects which may have provided entrance for wood rotting fungi. It is important to remember that we are concerned with <u>classes</u> of trees, rather than individual trees."

The eight suspect classifications which are used on a province-wide basis are given hereunder with brief remarks about each.

1. Conks - sporophores or fruiting bodies are the most certain and reliable indicators of decay.
2. Swollen Knots - are analogous to conks as indicators of decay and usually result from an abortive conk.
3. Scars - any wound which has healed or any open wound which shows weathered wood tissue.
4. Forked Tree (Schoolmarm) or Pronounced Crook - includes forked trees and pronounced crook appearing in the merchantable portion of the trunk.

Figure 3. Suspect Indicators

3. Basal Frost Crack.

4. Schoolmarm or Forked Tree.

5. Frost Cracks - usually originate at the base of the tree and may extend several feet up the trunk. They are common in areas which are subject to extremes of temperature.

6. Mistletoe Trunk Infections - includes infections which are confined to the merchantable portion of the trunk. Branch infections are excluded unless such infection has clearly extended to the trunk.

7. Large Rotten Branches - includes large branches which are broken off short and are clearly rotten. Small dead branches only one to two inches in diameter occuring just below the live crown are not included.

8. Dead or Broken Tops - broken tops which are not of recent origin.

In the field each living tree 3.1 inches and larger in diameter at breast height is classified as being residual, suspect or dead. The pathological defect indicators comprising the suspect class are the most important factors influencing the presence and amount of decay in a stand. By proper evaluation of these indicators it is hoped that the incidence and extent of decay may be

Figure 4. Suspect Indicators

5. Scars.

6. Broken Top.

assessed within practical limits of accuracy.

The illustrations of the suspect indicators were donated by the Dominion Science Service and are not representative of the spruce-balsam forest type. They were included to illustrate typical defects as they are observed in the field. For a detailed description of the method of tree classification, the Forest Surveys Tally Manual (3) should be consulted.

FIELD PROCEDURE FOR DECAY ANALYSIS PROJECT

The provincial forest survey is being conducted with the aid of aerial photographs having an approximate scale of two inches to the mile. Mapping and coding of the forest types are done by crews carefully trained for the work. To facilitate the compilation and summary of the data the province is divided into Regions and Compartments. A compartment may be 10,000 acres or larger in size and several compartments comprise a Region. All data within a compartment including productive and non-productive forest land are summarized by an intricate coding system. A preliminary working map is printed for each compartment showing the final acreage and description of each type.

In determining the areas which are to be sampled for volume and decay work, the supervisory staff give first consideration to the amount of information required for various species and types. Using the preliminary working maps of areas which have been previously mapped and summarized they plan the project in detail. Field crews are supplied with duplicate aerial photographs and all available information on the area before proceeding with the field work.

In the field the location of sample plots for intensive analysis of volume and decay may be determined by three methods:

(a) By using existing inventory sample plots.

(b) By random selection of sample plots.

(c) By mechanical selection of sample plots.

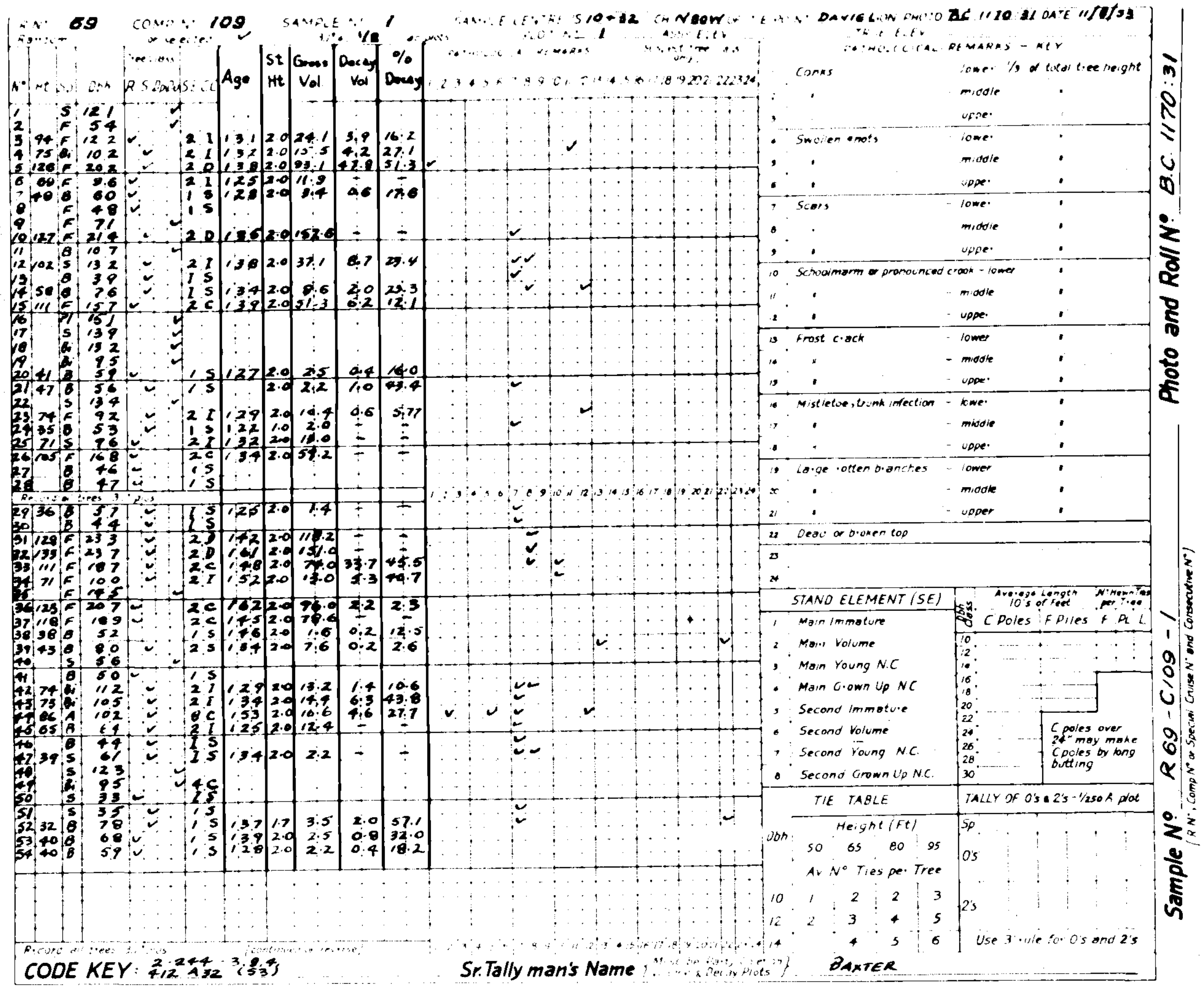
Whenever possible, existing inventory sample plots are used for volume and decay work. In many cases these plots are not suitable because they are inaccessible or they are not representative of the forest type for which information is required. If a sample is located by a random or selection method it is marked on an aerial photograph. The compass course and distance is then plotted on a map and a crew sent out to establish the sample in the field. If future examination of the plot is desired it may be relocated easily by referring to the aerial photograph and the compass and tally sheets which contain all the details of the sample. The samples used in this thesis were mechanically selected as being representative of a mature spruce-balsam forest type.

After locating the sample on the ground with the aid of a hand compass and chain, a sample-center is established by tagging a tree with four aluminum foil markers. Each sample consists of four circular plots laid out at right angles, and at a distance of two chains, from the sample center. Each of the four plots has a plot center and all trees, 3.1" D. B. H. and larger are measured within a specified radius of the plot center. In determining the plot size the governing factor is the requirement of approximately one hundred trees for each sample . All trees are identified by numbered paper tags stapled to the tree.

PRELIMINARY CLASSIFICATION OF TREES

Illustration 5 is a typical field sheet containing the information which is recorded for each plot. Suspect trees have one or more check marks in the columns headed by "Pathological Remarks" where defects are observed. Every tree within the plot is viewed from all sides and carefully appraised for defect indicators.

While each plot is not permanent it is possible to identify the plot centers and trees two to three years after establishment. The aluminum tags on the sample center tree should remain for several years to aid in relocating the sample if a resurvey is desired.



FIELD TALLY SHEET

FIGURE 5

ANALYSIS OF DEFECT

After the sample plot location has been determined and the preliminary tree classification has been completed, all trees, 5.1" D. B. H. and larger, are felled and bucked into sections in order that actual decayed portions may be observed. Intermediate bucking of logs is sometimes necessary to facilitate the longitudinal measurement of decay. The following table illustrates the specifications for bucking.

Table 1

Specifications For Bucking Trees

D. B. H. Range	Maximum Log Length	Maximum Top D. I. B.
5.1-11.0 inches	8 feet	4.0 inches
11.1 inches and larger	16 feet	8.0 inches

CLASSIFICATION AND MEASUREMENT OF DECAY

The classification and measurement of decay in the field is conducted under the supervision of a graduate forester. Since this is one of the most important aspects of the work it is essential that the crews be well trained and a responsible person placed in charge. Field crews make no attempt to classify the defect according to the type of decay prevalent in the stand. Recognition of the type of decay is difficult when no sporophores are present and in the incipient stage it may be necessary to run a culture test for positive identification. This requires the services of a trained pathologist and is not readily adapted to extensive survey work.

In the interest of being practical and consistent in field work, decay is classified as either white rot or brown rot. The white rots are those which decompose all components of the wood including the lignin. The wood is reduced to a stringy, fibrous or spongy mass or in some cases to white pockets or streaks. The affected wood is usually white but may be yellowish or light brown. White rots are described as:

(a) White pocket rot.

(b) White stringy rot.

(c) White spongy rot.

(d) White ring rot.

Brown rots attack chiefly the cellulose leaving the lignin more or less intact and reducing the wood to a brown carbonaceous mass. The wood has a dry burnt appearance which suggests the term, "dry rot." Brown rots are described as:

(a) Brown pocket rot.

(b) Brown stringy rot.

(c) Brown spongy rot.

(d) Brown ring rot.

(c) Brown cubical rot.

Brown cubical decays are the most common of the brown rots. Decays are further classified as either "heart rot" or "sap rot" according to the type of wood infected. Heart rot is by far the more common in living trees while sap rots occur more frequently in dead trees.

Decay measurements in trees include both the incipient and advanced stages. The incipient stage is the most difficult to recognize and measure. It is generally indicated by a change in colour and later by a general softening of the affected wood. When tested by a knife or an axe it usually has a punky or brashy texture. The advanced stage visibly changes appearance, structure and strength properties of the wood. It may result finally in a crumbly mass to complete hollowing of the infected part of the tree.

Diameters of rot are measured to the nearest inch and lengths to the nearest foot. In computing the volume of decay the defective portions are regarded as cylinders or cones. The diameter and length of the decay is equal to the average of the observed measurements of the defect. The total tree volumes and decay volumes for the data used in this thesis were compiled in cubic feet by use of the Smalian Formula.

DESCRIPTION OF DATA

The basic data for this thesis are taken from sample plots established in the Spruce-Balsam (Picea glauca (Moench) Voss), (Abies lasiocarpa (Hook.) Nutt.) forest type of the North Central Interior of British Columbia. This forest type represents one of the principal timber reserves of the province with an estimated total merchantable stand in excess of thirty-three billion board feet (4, p.7). The two main sub-types in this forest are: (a) a climax type, uneven aged and characterized by a heavy stand of advanced growth occurring as an understory and, (b) a more or less even-aged type with a lack of advanced growth, containing remnants of the original deciduous nurse crop. This study deals with the latter type. The ages throughout this forest type vary from 75 to 230 years. The majority of the trees are within the 121-140 year age class. The approximate height of the forest type is 100 feet and the average diameter from 14 to 20 inches.

METHOD OF ANALYSIS

Preliminary work in examining the data was essentially to determine if there were possible associations of decay with factors such as age and diameter. Work by Browne, Foster and Thomas (4, p.24) in relating age to decay showed that in amabilis fir the incidence of measurable amounts of decay increased from zero percent at age class 125 to 100 percent at age 425. They also report that diameter may have some useful applications in decay estimating. The application of this latter principle in overmature stands requires verification by further sampling. Initial examination of the data indicated the range of average diameters and ages of the stands involved were so narrow as to preclude the use of these factors in the present project.

Following this preliminary work it was decided to analyze the residual and suspect classifications to determine their significance and reliability in estimating decay in individual trees and stands. The study is limited to the spruce and balsam data only. Although minor volumes of Douglas-fir, lodgepole pine, aspen and birch are present, they do not constitute a part of the main stand and are of minor concern.

In tabulating the data it was found that of the eight pathological classifications used in the field, only five were present in sufficient number to be used in the analysis. The type and frequency of defects were found to be similar for the spruce and balsam. The suspect defects in order of frequency of occurrence are:

1. Scars.
2. Dead Tops.
3. Forked Trees.
4. Frost Crack.
5. Swollen Knots.

Of the remaining three classifications, conks are a positive indication of the presence of decay. In older stands the inclusion of this indicator is very important, however, as only one sporophore was recorded, this defect was omitted. Similarly mistletoe and rotten branches could not be included in the analysis for lack of sufficient cases.

When each defect is recorded in the field it is checked off in the column of the field sheet which refers to its position on the tree. Three positions were recognized, the lower, middle and upper third of the tree. From the preliminary tabulation of data it was noticed that in each of the five classifications, with the exception of broken tops, the greatest number of defects occurred on the lower one third of the tree. This may be partially explained by the unrestricted view of this section of the tree which facilitates a positive identification of the indicators. The position of the defect in the tree was not considered in this study but it may be of importance as far as volume of decay is concerned.

The analyses which follow cover only the following pathological indicator classes: Residual, Swollen Knots, Scars, Forked Trees, Frost Crack, and Dead or Broken Tops.

Preliminary Analyses

From general inspections of the computed field tally sheets several important facts were established:

1. Some of the trees possessing defect indicators proved to be entirely sound after being felled and bucked.
2. Some of the residual trees on the other hand were found to contain some defect when felled and bucked.
3. Some of the classifications seemed to be more reliable as indicators than others.
4. There was some evidence that those indicators most reliable for one species might be of minor significance for another species.

In order to gain a clearer insight into these general observations summaries of the tree data were made as in Table 2, which show the number of trees infected in each of the defect classes. A summary was made for each species, spruce and balsam, and also another which combined both species.

TABLE 2

CHI SQUARE TESTS OF SUSPECT CLASSIFICATIONS

(A) Spruce

Defect	x	y	Total	p
Swollen knots*	2	9	11	.18
Scars	52	60	112	.46
Forked stem	10	15	25	.40
Frost crack	13	2	15	.87
Broken tops	7	23	30	.33
Total	84	109	193	.43

Results of Test
X^2 = 29.90 significant at 0.01 level

(B) Balsam

Defect	x	y	Total	p
Swollen knots*	1	5	6	.16
Scars	39	39	78	.50
Forked stem	10	3	13	.77
Frost crack	8	7	15	.53
Broken tops	11	6	17	.65
Total	69	60	129	.534

Results of Test
X^2 = 7.4 not significant at the 0.05 level

(C) Spruce and Balsam Data Combined

Defect	x	y	Total	p
Swollen knots	3	14	17	.17
Scars	91	99	190	.48
Forked stem	20	18	38	.55
Frost crack	21	9	30	.70
Broken tops	18	29	47	.38
Total	153	169	322	.475

Results of Test
X^2 = 14.17 significant at the 0.01 level

Definition of Symbols:

x = number of infected of trees
y = number of trees not infected
Total = x y
p = proportion = $\frac{x}{x + y}$

*When separated by species the total number of trees in the swollen knots group is so small as to result in values of less than 5 when expected values are computed in the Chi-Square test, but for an approximate test such as being made here, the limitation has been ignored.

To determine if differential significances existed among the classes, Chi-Square tests were applied to the summaries. For the spruce data the Chi-Square value was significant at the 0.01 level, implying that the class proportions were not a homogeneous group of values. For the balsam data Chi-Square was not significant at the 0.05 level, but for the two species combined Chi-Square was again significant at the 0.01 level. From these analyses there is reason to believe that some of the indicator classes are of greater importance than others, at least as far as spruce is concerned. It is also of interest to note the small proportion of trees with swollen knots that were not infected in both the spruce and balsam data, and the relatively large proportion for frost cracks, especially spruce.

The latter test of the combined data illustrates the need for testing individual species rather than combined data. A high significance in spruce has offset a low significance in balsam and the effect of the test of combined data does not give a true evaluation of the species. For this reason further work was restricted to the analysis of individual species.

Regression Analysis

The preceding summaries and tests indicate a relatively wide variation among the proportions of trees actually infected in the five defect classes. The proportions of infected trees in spruce vary from 0.18 to 0.87 and in balsam from 0.16 to 0.77. From this it would follow that differential effects might be expected among the classes on the amount of defect in a tree or stand when expressed on a volume basis. In order to evaluate the effect of each classification in terms of volume some form of regression analysis seemed to be in order.

Some previous attempts have been made by the Dominion Laboratory of Forest Pathology to develop a formula for predicting decay in stands by means of readily measureable stand statistics. In analyzing hemlock data a multiple regression equation was developed expressing percentage of decay in a stand in terms of age, site index and the proportion by volume of suspect trees. This method was not used in analyzing the spruce-balsam data because of the lack of variation within the stand variables. It was also necessary to consider a method which would test the significance of each of the defect classes and determine their relative importance in predicting stand decay.

After completing the preliminary Chi-Square tests and with the above points in mind it was decided to seek the advice of the Statistical Service of the Agricultural Experimental Station. The method suggested was the fitting of constants by the method of least squares. This method may be used to predict decay in individual trees or stands and it is not necessary to summarize the data on an acre basis.

To understand the method of analysis it will be necessary to illustrate the procedure by a working example. The overall results are based on observations from 347 balsam trees and 467 spruce trees, all of which were 5.1" D. B. H. or larger.

Table 3 illustrates the form used in summarizing the basic data for balsam. Here, each tree recorded on the sample plots is reviewed in order and recorded according to a classification code number as defined under Table 3. Thus tree number one is a residual tree and possesses no decay indicators. Tree number three possesses scars only, number ten possesses scars and frost cracks. After completion of this summary for the 347 balsam trees, a count is made of the trees in each classification group, and also in each and every combination of groups as designated in Table 4. Herein n designates the count on number of trees and the numerals following indicate the classification. A single numeral indicates a single classification and

TABLE 3

BASIC DATA FOR OBSERVATION MATRICES - BALSAM

Tree No.	Percent decay (Y)	Defect class 1	2	3	4	5	6
1	25.0	x					
2	0.0	x					
3	0.0			x			
4	29.3				x		
5	34.4			x			
6	5.0					x	
7	72.0			x			
8	0.0	x					
9	1.1	x					
10	57.4			x		x	
11	30.0			x		x	
12	64.3		x	x			
13	0.0		x				
14	0.0			x	x		
15	50.0			x			
16	17.3				x	x	
17	5.6						x
.	.						
.	.						
.	.						
347	.						
	Sn	121	17	152	40	44	43

Definition of Symbols:

1 = residual trees
2 = swollen knots
3 = scars
4 = forked stem
5 = frost crack
6 = dead or broken tops
x = indicating the presence of each defect class
Sn = summation of trees in each defect class
Y = decay percentage of tree

Summation of Combinations of Defect:

Sn12 = 0
Sn23 = 6
Sn35 = 17

Sn46 = 8
.
.
.
Sn6 = 43

TABLE 4

Form Used in Summarizing Observation Data

	b1 (Residual)	b2 (Swollen Knots)	b3 (Scars)	b4 (Schoolmarm)	b5 (Frost Crack)	b6 (Dead or Broken Top)	Y (% Decay)
	x1	x2	x3	x4	x5	x6	Y
x1	n1	n12	n13	n14	n15	n16	(S)Y1
x2		n2	n23	n24	n25	n26	(S)Y2
x3			n3	n34	n35	n36	(S)Y3
x4				n4	n45	n46	(S)Y4
x5					n5	n56	(S)Y5
x6						n6	(S)Y6

multiple numerals indicate combinations of classifications. The results of these counts are presented in Tables 5 and 6 for balsam and spruce respectively. It should be noted that all the combinations involving number one classification (residual trees) are zero, since such a tree is free from all defect indicators.

In tables 5 and 6 the sum of the decay percentages for the trees in each of the six basic classifications are recorded in the Y column.

The upper portion of tables five and six is termed the "a" matrix. It represents a standard form of presentation of the normal observational equations required to establish a regression equation expressing percentage of decay in terms of the six classifications recognized.

The lower portion of the same tables is termed the "c" matrix and represents the second stage in the solution of the normal equations according to the Doolittle method of Matrix inversion (1, pp. 197-203). Further details in computation of the regression Coefficients (b constants), sum of squares due to regression, and the multiple correlation coefficients are shown by the following basic equations:

TABLE 5

SPRUCE DATA

Calculation of "a" and "c" matrices

<u>"a" matrix</u>

x1	x2	x3	x4	x5	x6	Y	Check
202	0	0	0	0	0	56.81	258.81
	25	8	3	0	5	13.38	54.38
		180	24	1	24	151.60	380.60
			55	1	4	39.06	126.06
				9	1	4.37	16.37
					57	36.15	127.15

<u>"c" matrix</u>

.0049505	0	0	0	0	0	1.0000010
	.0411745	-.0012366	-.0015011	.0006370	-.0029982	.9999994
		.0062563	-.0024891	-.0001577	-.0023486	1.0000027
			.0193945	-.0018619	-.0001487	.9999991
				.1115372	-.0018156	.9999996
					.0188380	.9999982

TABLE 6

BALSAM DATA

Calculation of "a" and "c" matrices

<u>"a" matrix</u>

x1	x2	x3	x4	x5	x6	Y	Check
121	0	0	0	0	0	146.63	267.63
	17	6	0	3	2	18.02	46.02
		152	15	17	14	238.59	442.59
			40	3	8	78.02	144.02
				44	7	74.52	148.52
					43	74.28	148.28

Note - Y values coded for convenience.
Y1 = 1466.3
Y2 = 180.2 etc.

<u>"c" matrix</u>

.0082645	0	0	0	0	0	1.0000045
	.0603021	-.0019892	.0013610	-.0031334	-.0019002	.9999999
		.0072725	-.0022592	-.0022842	-.0014831	1.000002
			.0267227	-.0003674	-.0042396	1.000001
				.0243262	-.0030023	1.0000029
					.0251046	1.0000011

(a) Calculation of tho b3 constant for spruce from the matrices of Table 5.

$b_i = S_j c_{ij} g_j$ (g decoded).

$= (0x568.1) + (-.0012366x133.8) + (.0062563x 1516.0) + (-.0024891x390.6) + (-.0001577x 43.7) + (-.0023486x361.5)$

$= 7.4913$

(b) Calculation of Sum of Squares for b1 constant Spruce - Tables 5 and 7. Sum of Squares of Regression on the i^{th} variate, adjusted for all other variates.

$$SS = \frac{b_i^2}{c_{ii}}$$

$$= \frac{(2.8124)^2}{.0049505}$$

$= 1598$

(c) Calculation of Regression Sum of Squares Spruce - Tables 5 and 7.

SS Regr. $= S_i b_i g_i$

$= (2.8124x568.1) + (1.9967x133.8)$
$(7.4913x1516.0) + (3.4660x390.6)$
$(3.3367x43.7) + (2.7109x361.5)$

$= 15,701$

(d) Calculation of Multiple Correlation Coefficient Spruce - Table 7.

TABLE 7

SPRUCE DATA

Summary of Regression Coefficients and Sums of Squares Due to Regression Terms

Indicator class	Reg. coeff. (% decay)	Sum of squares
1-(Residual)	2.8124	1598**
2-(Swollen Knots)	1.9967	98
3-(Scars)	7.4913	8970**
4-(Schoolmarm)	3.4660	619*
5-(Frost Crack)	3.3367	100
6-(Dead or Broken Top)	2.7109	390

Total S. S. 87,351

Regression S. S. 15,701

Error M. S. (s^2) $\frac{71,650}{461} = 155$ (461 d.f.).

F (s^2) = 598 (.05)

= 1037 (.01)

(R^2) = 0.180

$$R^2 = \frac{\text{SS Regr.}}{\text{SS Total}}$$

$$= \frac{15,701}{87,351}$$

$$= 0.180$$

The symbols used in the above equations are defined as follows:

b_1 = constant for residual trees.

S = summation of.

i = row.

j = column.

c = "c" matrix.

g = Y value (% Decay) from "a" matrix.

R^2 = multiple correlation coefficient.

The regression coefficients obtained from solution of the observation equations, the sums of squares due to the respective regression constants, and tests of significance are contained in Table 7 for the spruce species. The tests herein indicate that the b2, b5 and b6 coefficients are not significantly different from zero. In other words, the percentage of decay indicated by each of these factors may have occurred by chance and their inclusion in the analysis is not justified. The spruce data was recalculated by eliminating the x2 factor (Tables 8 and 9) and recalculated for the third time by deleting the x2 and x5 variables.

TABLE 8

SPRUCE DATA

Recalculation of "c" Matrix by Deleting x2 (Swollen Knots).

x1	x3	x4	x5	x6
.0049505	0	0	0	0
	.0062193	-.0025341	-.0001386	-.0024385
		.0193398	-.0017937	-.0002581
			.1115273	-.0017692
				.0186197

TABLE 9

Summary of Regression Coefficients and Sums of Squares Due to Regression Terms (After Deleting x2)

Indicator class	Reg. Coeff. (% decay)	Sum of squares
1-(Residual)	2.8124	1598**
3-(Scars)	7.5511	9168**
4-(Schoolmarm)	3.5407	648*
5-(Frost Crack)	3.3234	99
6-(Dead or Broken Top)	2.7045	393

Regression S. S. = 15,551

Error M. S. (s^2) = 155 (462 d.f.)

F · (s^2) = 598 (.05)

= 1037 (.01)

R^2 = .178

TABLE 10

SPRUCE DATA

Recalculation of "c" Matrix by Deleting x2 (Swollen Knots) and x5 (Frost Crack).

x1	x3	x4	x6
.0049505	0	0	0
	.0062191	-.0025363	-.0024405
		.0193110	-.0002866
			.0185916

TABLE 11

Summary of Regression Coefficients and Sums of Squares Due to Regression Terms (After Deleting x2 and x5)

Indicator class	Reg. coeff. (% decay)	Sum of squares
1-(Residual)	2.8124	1598**
3-(Scars)	7.5552	9178**
4-(Schoolmarm)	3.5942	669*
6-(Dead or Broken Top)	2.9091	445

Regression S. S. = 15,507

Error M. S. (s^2) = 155 (463 d.f.)

(R^2) = 0.178

The final results (Table 11) indicate that the b1 and b3 coefficients are significant at the one percent level and the b4 coefficient is significant at the five percent level. Although the b6 coefficient (broken tops) did not prove significant this factor was retained because it was larger than would be expected by chance. The square of the multiple correlation coefficient for spruce in the first analysis was 0.180. This was reduced to 0.178 in the second and third analyses. This means that 18 percent of the variation in the data may be explained by the factors under consideration. For a better correlation, other factors influencing the presence of decay must be considered in the analysis.

Table 12 is a summary of the results of the first analysis of the balsam data. All variables are significant at the one percent level with the exception of x2 (swollen knots) which was not significant within the prescribed limits. The balsam data were recalculated by omitting the x2 variable with the result that there was very little change in the values of the remaining constants (Table 11). The square of the multiple correlation coefficient was 0.340 in the first analysis and 0.339 in the final calculation.

The values for the b constants in each case refers to the percentage of decay which may be expected

TABLE 12

BALSAM DATA

Summary of Regression Coefficients and Sums of Squares Due to Regression Terms

Indicator class	Reg. coeff. (% decay)	Sum of squares
1-(Residual)	12.1182	17,769**
2-(Swollen Knots)	3.4358	196
3-(Scars)	12.4265	21,233**
4-(Schoolmarm)	12.2811	5,644**
5-(Frost Crack)	9.5966	3,786**
6-(Dead or Broken Top)	9.2217	3,387**

Total S. S. 210,878

Regression S. S. 71,619

Error M. S. $(s^2) = \frac{139,259}{341} = 408$

$(R^2) = 0.340$

$F \cdot (s^2) = 1579\ (.05)$
$= 2746\ (.01)$

TABLE 13

BALSAM DATA

Recalculation of "c" Matrix by Deleting x2 (Swollen Knots).

x1	x3	x4	x5	x6
.0082645	0	0	0	0
	.0072069	-.0022143	-.0023876	-.0015458
		.0266920	-.0002967	-.0041967
			.0241364	-.0031010
				.0250447

TABLE 14

Summary of Regression Coefficients and Sums of Squares Due to Regression Terms (After Deleting x2)

Indicator class	Reg. Coeff. (% decay)	Sum of squares
1-(Residual)	12.1182	17,769**
3-(Scars)	12.5399	21,819**
4-(Schoolmarm)	12.2036	5,579**
5-(Frost Crack)	9.7550	3,943**
6-(Dead or Broken Top)	9.3299	3,476**

Total S. S. 210,878

Regression S. S. 71,409

Error M. S. (s^2) $\frac{139,469}{342} = 408$

$R^2 = 0.339$

in association with each defect. Having determined these values it is now possible to determine the percent decay for an individual tree by applying the following formula:

(a) Regression Equation to Predict Decay in a Single Tree.

$$Yt = b1X1 + b2X2 + \cdots + b6X6$$

Where X1 = 0 when tree is suspect.

X1 = 1 when tree is residual.

X2 = 0 when tree does not have swollen knots.

X2 = 1 when tree does have swollen knots.

.
.
.
.

X6 = 0 when tree does not have a dead or broken top.

X6 = 1 when tree does have a dead or broken top.

Yt = percent decay for an individual tree, b1, b2 .... b6 are constants as determined before.

Using the balsam data as an example the formula may be applied by substituting the final values of the b constants. Since swollen knots did not prove significant the b2 constant is omitted. The equation then becomes:

$$
\begin{aligned}
Yt &= b1 + b3 + b4 + b5 + b6 \\
&= 0 + 12.54 + 12.20 + 9.75 + 9.33 \\
&= 43.82\%
\end{aligned}
$$

This equation refers to the percent decay in a single balsam tree which has the four significant visible suspect characteristics. The b1 constant in this case is zero because it is not a residual tree. Table 12 summarizes the percentage of decay associated with each defect and combinations of defect. It will be observed in Table 12 that some of the constants are lower than the b1 value. An assumption may be made that trees having a suspect characteristic would be expected to have at least the same percentage of decay as residual trees or possibly more. A lower value may be partly attributed to the fact, that in the analysis, the suspect defect classes are influenced by the combinations with other defects. If trees having only one suspect characteristic were considered in the analysis, then the resulting values for the suspect constants would be higher.

The confidence limits may be calculated for each defect class or combinations of defects. It must be emphasized at this point however, that the confidence limits do not hold for individual trees because the frequency of distribution of percent decay in trees is

TABLE 15

Predicted Decay for Individual Spruce and Balsam Trees

A. Spruce Data

No. of trees (n)	Path. defect	% Decay (Y)
202	1	2.81
180	3	7.55
55	4	3.59
57	6	2.91
24	34	11.15
24	36	10.46
4	46	6.50
3	346	14.06
549		

B. Balsam Data

No. of trees (n)	Path. defect	% Decay (Y)
121	1	12.12
152	3	12.54
40	4	12.20
44	5	9.75
43	6	9.33
15	34	24.74
17	35	22.29
14	36	21.87
3	45	21.95
8	46	21.53
7	56	19.08
1	345	34.49
1	356	31.62
0	456	31.28
0	3456	43.82
466		

not normal. For large stands of trees the confidence limits should be satisfactory as normality is approached.

The percent decay for a stand and the confidence limits may be predicted when the sample consists of 100 trees or more. The following equations apply:

(a) Regression Equation to Predict Stand Decay.

$$Y = \frac{S(nYt)}{N} \quad \text{Where } N = S(n)$$

$$= \frac{1}{N}\left[n1Y1 + n2Y2 + \cdots + n23456Y23456\right]$$

$$= \frac{1}{N}\left[n1b1 + n2b2 + \cdots + n23456(b2+b3+b4+b5+b6)\right]$$

$$= \frac{1}{N}\left[n1b1 + (n2+n23+n24+n25+n26+\cdots+n23456)\, b2 + (n3+\cdots)b3 + \cdots\ ()b6\right]$$

Y = percent decay for the stand, Yt = percent decay for an individual tree, S = summation of, n = number of trees in an indicator class, N = S(n) = total number of trees, Y1 = percent decay in residual trees only, Y2 = percent decay in trees having swollen knots •••• Y6 = percent decay in trees having dead or broken tops, n1Y1 = number of residual trees multiplied by the percentage of decay, n2Y2 = number of trees having swollen knots multiplied by the percentage of decay ••••n23456 = number of trees having a combination of swollen knots, scars, forked stem,

TABLE 16

Equation to Predict Stand Decay for Balsam

$$Y = \frac{1}{N}\Big[n1b1 + (n3 + n34 + n35 + n36 + n345 + n356 + n3456)b3 + (n4 + n34 + n45 + n46 + n345 + n456 + n3456)b4 + (n5 + n35 + n45 + n56 + n345 + n356 + n456 + n3456)b5 + (n6 + n36 + n46 + n56 + n356 + n456 + n3456)b6\Big]$$

$$= \frac{1}{466}\Big[(121)12.12 + (200)12.54 + (67)12.20 + (73)9.75 + (73)9.33\Big]$$

$$= \frac{1}{466}\Big[6184.76\Big] = 13.27$$

frost crack and dead or broken top, b1, b2 ....b6 = regression constants.

(b) Equation to Determine the Confidence Limits for the Percentage of Decay in a Stand.

$$L = \frac{\pm ts}{N} \sqrt{Sn^2_i C_{ii} + 2SSn_i n_j C_{ij}} \qquad \text{Where } i < j$$

$$= \frac{\pm ts}{N} \sqrt{n^2 C_{11} + n_2^2 C_{22} + \cdots n_6^2 C_{66} + 2n_1 n_2 C_{12} + 2n_1 n_3 C_{13} + \cdots 2n_{56} C_{56}}$$

L = Confidence limit, t = tabular value from "t" table, s = error mean square, N = total number of trees (Table 12), n_1 = number of residual trees, n_{34} = number of trees having scars and schoolmarm, C_{11} = value from "c" matrix in row 1 column 1, C_{66} = value from "c" matrix in row 6 column 6, SS = double summation of, S = summation of.

The values of the final constants were applied to the formulas to predict the percent decay and confidence limits in both spruce and balsam stands. The final results indicate that the percent decay in spruce is 5.24 ± 1.11 percent. The percent decay in balsam is 13.27 ± 1.98. Because of the low values of the multiple correlation coefficients it must be concluded that there are other factors which have an important influence on the presence of decay. Inclusion of these unknown factors would result in greater accuracy of prediction for

TABLE 17

Calculation of Confidence Limits on Percent Decay for Balsam

$$L = \frac{\pm ts}{N} \sqrt{n^2 1C11 + n^2 3C33 + n^2 4C44 + n^2 5C55 + n^2 6C66 + 2n34C34 + 2n35C35 + 2n36C36 + 2n45C45 + 2n46C46 + 2n56C56}$$

$$= \frac{\pm ts}{N} \sqrt{(121)^2(.0082645) + (200)^2(.0072069) + (67)^2(.0266920) + (73)^2(.0241364) + (73)^2(.0250447) + 2(200)(67)(-.0022143) + 2(200)(73)(-.0023876) + 2(200)(73)(-.0015458) + 2(67)(73)(-.0002967) + 2(67)(73)(-.0041967) + 2(73)(73)(-.0031010)}$$

$$= \frac{\pm 1.97\ (\sqrt{408})}{466} \sqrt{539.976}$$

$$= \frac{\pm 1.97 \times 20.2}{466} \times 23.237$$

$$= \frac{\pm 39.794 \times 23.237}{466}$$

$$= \frac{\pm 924.993}{466}$$

$$= \pm 1.9849$$

percent decay in a forest stand.

Tables 16 and 17 illustrate the procedure in calculating decay and confidence limits for balsam.

FINAL REMARKS AND LIMITATIONS

Before the final results of the analysis may be stated it is necessary to clarify the application and limitations of the data which were under consideration and to interpret observations which became evident.

The results of this study are sufficient to warrant setting up an equation to predict percent decay for this spruce-balsam forest type within the limits of accuracy given. It should be checked with further data from the same forest type for verification. It is understood that the results are confined to the two species under consideration and do not necessarily apply to other species.

In applying the equation for predicting decay in forest stands the sample should consist of 100 trees or more, all of which must be 5.1" or larger in diameter. The formula for predicting decay in individual trees in this stand has a very low accuracy because the distribution of decay in individual trees is not normal. For this reason the equation for predicting decay in individual trees for these data should not be used.

Of all the suspect classifications used in the analysis the swollen knots class deserves special consideration. Since swollen knots did not prove significant in any test it is possible that there is a misunderstanding in classifying this defect in the field. It is pointed out in the field manual that swollen knots are analagous to conks and should be positive indicators of decay. From personal observation in the field the writer would consider this defect one of the most difficult to assess. Field supervisors should emphasize and clarify the importance of this defect so that consistent recordings are possible. It is a valuable decay indicator if properly classified. Further studies of this nature in other species will aid in determining the relationship between the defects and possibly justify elimination of certain classes. No conclusions of this sort are possible from the results of this limited study.

CONCLUSIONS

For this particular forest type the percentage of decay in spruce is 5.24 ± 1.11 percent. The percentage of decay in balsam is 13.27 ± 1.98 percent. The multiple correlation coefficients for both species are low. Further consideration of age, site and inclusion of other pathological defects should improve the accuracy of prediction. A better correlation may be expected in older stands where all eight pathological defect classes are present and age is a significant factor.

In both the spruce and the balsam the scars were the most highly significant defect. The majority of scars were recorded on the lower third of the tree. Since the spruce-balsam forest type in this region is generally logged by a selection system it is important silviculturally that damage by scarring the standing trees be kept to a minimum.

The method of statistical analysis may be readily adapted and is recommended for use in further studies of this nature. Because of the importance and scope of the provincial inventory further studies of this nature would materially aid in the final evaluation of the forest resources of British Columbia.

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APPENDICES

APPENDIX I

Legend of Symbols Used in Working Data

Regression Coefficients		Pathological Defect
b1	-	Residual
b2	-	Swollen Knots
b3	-	Scars
b4	-	Schoolmarm
b5	-	Frost Crack
b6	-	Dead or Broken Top

"a" matrix - observation matrix.

"c" matrix - inverse of the observation matrix.

Error M. S. (s^2) - error mean square.

F (s^2) - tabular value of F multiplied by the error mean square.

95% L - 95 percent confidence limit.

S. S. - sum of squares.

S - summation of.

R^2 - multiple correlation coefficient squared.

d.f. - degrees of freedom.

**- significant at the one percent significance level.

* - significant at the five percent significance level.

APPENDIX II

Supplementary Information to Field Tally Sheet

To facilitate understanding of the field tally sheet, (Figure 5) the following abbreviations are defined:

NO. - Corresponding to tree tag number

Ht. - Height of the tree in feet

D.B.H. - Diameter Breast Height

Tree Class.

R - Residual

S - Suspect

Dp - Dead Potential

Du - Dead Useless

S. E. - Stand Element

C. C. - Crown Classification

Age - Total age of the tree determined by stump count plus correction factor taken from age-stump height curves.

St. Ht. - Stump Height

Gross Vol. - Gross volume in cubic feet - computed from the Smalian formula applied to felled and bucked logs.

Decay Vol. - Decay volume if present measured in cubic feet

% Decay - Decay volume expressed as a percentage of the gross volume

Pathological Remarks - Classification of suspect trees. Check marks indicate the tree has one or more of the pathological defects listed under the pathological remarks key

Code Key - Forest Type Mapping Code Classification

e.g. 1953 Code Key - 543A1-1-5-24-34-5
6-184-52-7-3

543 - Coder identification number

A - Major type classification

1 - Code sheet no. 1 for Coder 543

Type Description - Main Type

1 - Immature type

5 - Spruce

24 - 61-100 year old

34 - 57½' - 87½' in height

5 - Stocking Class 5 (over 100% stocked)

Secondary Type

6 - Secondary Volume

184 - Lodgepole Pine, Aspen type

52 - 81 - 120 year old

7 - 66' - 95' in height

3 - Stocking Class 3 (over 31 trees per acre of a size 13" and greater)

APPENDIX III

Description of Sample References

The field samples were located in the Summit Lake area in the Fort George Forest District. The following summary is included as a reference to the basic sample data.

Region number	Compartment number	Sample number	Photo reference number
69	105	1	B.C. 1169:106
69	110	7	B.C. 1170: 84
69	105	2	B.C. 1170: 40
69	103A	3	B.C. 1169: 79
69	103A	2	B.C. 1169: 78
69	109	1	B.C. 1170: 31
69	110	15	B.C. 1170: 30
69	110	1	B.C. 1170: 81
69	103A	1	B.C. 1169: 77