

**A SURVEY OF THE INCIDENCE  
AND SEVERITY OF ROOT DISEASES  
AND THEIR IMPLICATIONS FOR  
MANAGEMENT IN THE  
VANCOUVER FOREST REGION**

By

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December, 1987

Vancouver Forest Region  
British Columbia Ministry of Forests,  
Burnaby, B.C.

Forest Service Internal Report PM-V-10

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## ABSTRACT

A large-scale ground survey for root diseases was run in second growth Douglas-fir type forests of the Vancouver Forest Region during 1982-1983. Laminated root rot, [*Phellinus weirii*, (Murr.) Gilbn.], was observed to be the most damaging disease. Results indicate areas of visible *P. weirii* infection damage to Douglas-fir stands at 80 years, to be 20%, 18% and 3% respectively for medium, good and poor site classes. Significantly different levels of infection were observed between: biogeoclimatic subzone variants, CDFb and CWHal; type groups, Fir and Fir-hemlock; site classes, good, medium and poor and between some age classes. Application of the survey results to forest management include formulation of T.S.A. Plan issues statements, management objectives, disease guidelines, adjustments to yield tables, and harvest regulation. Major recommendations focus on the incorporation of accurate disease simulation functions into timber supply models used for A.A.C. determinations, in Timber Supply Areas and Tree Farm Licenses.

## ACKNOWLEDGEMENTS

Many people in the B.C. Ministry of Forests and Canadian Forestry Service have aided and contributed to the Vancouver Region root disease survey. In particular, I would like to thank Dr. Bill Bloomberg, Dan Hall and George Reynolds, C.F.S., Victoria, for their inspiration and assistance, especially in getting the project off the ground and in analyses; Peter Fuglem and Dave Gilbert, Protection Br. B.C.M.F., Victoria, for technical assistance and planning; Gary Sutherland and Nelson Harrison, Planning, B.C.M.F., Vancouver, for aid in T.S.A. Planning applications; Dr. A. Kozak, Faculty of Forestry, U.B.C., for the 1984 contract survey analysis; Ms. Wendy Bergerud, Research Br. B.C.M.F., Victoria, for extensive aid in the 1985 survey analysis; Paul Wood, Pest Management Coordinator, B.C.M.F., Vancouver and Drs. Bob De Boo and John Muir, Protection Br., B.C.M.F., Victoria for their spirited and insightful support of the survey; Don Heppner, Protection, B.C.M.F., Vancouver for aid in survey preparations and analysis; the B.C.M.F., Vancouver Research section for their keen interest and support in training; and most importantly to the large crew of keen root disease surveyors in the Duncan, Port Alberni, Campbell River and Powell River Forest Districts.

A SURVEY OF THE INCIDENCE AND SEVERITY OF ROOT DISEASES  
AND THEIR IMPLICATIONS FOR MANAGEMENT IN THE  
VANCOUVER FOREST REGION

I. INTRODUCTION

Throughout the history of forest management in Canada and in particular British Columbia, forest protection has focused on forest fires and insect pest control. Forest disease management has been neglected, but is now coming of age as disease damages are being recognized and as control methods evolve.

In B.C. three major forest diseases contribute to reduced forest production: (i) stem decays, (ii) dwarf mistletoes and, (iii) root diseases. It is estimated that they cause losses in the order of 21%, 7% and 7% respectively of the 25 million cubic metres lost annually to insects, diseases and fire (B.C. Min. of Forests, 1985a). Provincially, losses to root diseases are estimated to be 1 366 000 m<sup>3</sup>/yr (B.C. Min. of Forests, 1986). Root diseases clearly have a substantial impact on the forest; but if controlled, would present a good opportunity for increasing forest productivity and mitigating timber supply short-falls.

Forest root diseases occur widely throughout the forests of British Columbia. Generally, root diseases occur randomly, causing isolated pockets of mortality and growth reduction at all ages. In coastal forests root diseases are particularly damaging in second growth forests. While causing damage, root diseases also play a role as a biological thinning and forest successional agent. This latter role is as yet unevaluated, but is likely important for disease management strategies (Lawson 1985).

Compared to forest insect pests, root diseases are much less spectacular. They are usually long-lived, slow-acting organisms that are manifested in ways difficult to observe and measure. These characteristics of root disease have hampered out recognition of their damage and impact and hence our ability to manage them.

In the Vancouver Forest Region several root diseases are considered to be, or have the potential to be causing significant damage to the commercial forest resource. *Phellinus weirii* (Murr.) Gilbertson, the causal pathogen of laminated root rot is considered to be the most serious root disease in south coastal B.C. forests.

In order to evaluate and initiate disease management at stand and forest estate levels, the affects and impacts of root diseases on regional timber supply functions would need to be demonstrated. In 1982 the Vancouver Forest Region initiated a large scale root disease survey to assess the affects and impacts of root diseases. The survey, or inventory of root diseases has become the basis for many forest and disease management decision-making functions in the Vancouver Forest Region. The survey; its inception, development, analysis, results and management implications are the subject of this report.

## II. PROBLEM ANALYSIS

### A. The Biology and Manifestation of the Major Root Diseases in the Vancouver Forest Region

In coastal B.C. five major forest root pathogens are considered to be economically important. They are, in order of estimated importance: Laminated root rot, *Phellinus* (*Poria*) *weirii* (Murr.) Gilbn.; Annosus root disease, *Heterobasidion annosum* (Fr.) Bref.; Armillaria root disease, *Armillaria ostoyae* (Romagn.) Herink; Black stain root disease, *Ceratocystis wagneri* Goheen and Cobb (anamorph *Verticicladiella wagneri* Kendrick); and Schweinitzii butt rot, *Phaeolus* (*Polyporus*) *schweinitzii* (Fr.) Pat. Although all the pathogens are broadly infective to most conifers and some broadleaved species in B.C., there are distinct host susceptibilities to each of the pathogens. Refer to Table 1 of Host Susceptibilities and Disease Biology.

Following the logging patterns of the late 1800's in the Vancouver Forest Region, Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, western hemlock, *Tsuga heterophylla* (Raf.) Sarg. and western red cedar, *Thuja plicata* Donn. have regenerated to comprise extensive second growth forests. It is these forests that are known to be most susceptible and damaged by the major root diseases, and are therefore the subject of the root disease survey.

#### Laminated Root Rot

*Phellinus weirii* was first observed in the Vancouver Forest Region in 1929 at the Cowichan Lake Forest Experimental Station (Mounce et al. 1940). Subsequent B.C. Forest Service forest inventory work and Federal research assessments found *P. weirii* to occur throughout the range of Douglas-fir in B.C., but most significantly in coastal forests (Bier and Buckland 1947; Buchanan 1948; and Buckland et al. 1954). Bier and Buckland (1947) reported that significant damage and losses occurred in second growth, predominantly Douglas-fir forests. The forms of damage they report are mortality, increment loss, and density and stocking reductions. They felt that the disease was of high enough significance that "...any measures to minimize the importance of such a disease should be incorporated as part of the management policy for immature stands", and "Unless depletion from this cause is provided for as part of the management policy, grossly inaccurate figures may be obtained for all estimates of growth and yield."

*Phellinus weirii* continues to be a major threat in this Region for several reasons:

- (i) The pathogen is widespread throughout second growth Douglas-fir type forests (Wallis 1976).
- (ii) Most coniferous species are susceptible to infection and damage, especially Douglas-fir, true firs and western hemlock (Wallis 1976).
- (iii) Spread occurs when healthy roots contact ectotrophic (root surface) inoculum sources, ie. infected roots or stumps (Wallis 1976).
- (iv) Above ground visible spread (infection center boundary symptoms), advances at approximately 35 cm/yr (Bloomberg 1983a).
- (v) The fungus can remain a viable inoculum source for decades, approximately 50 years in harvested and untreated stands (Hansen 1979).

- (vi) Replanting infected sites with susceptible species will only exacerbate the incidence and severity of laminated root rot in subsequent rotations. (Wallis 1976; Hadfield and Johnson 1977).

#### Annosus Root Disease

Annosus root rot is a cause of root and butt rot in western hemlock, true fir *Abies* spp., Douglas-fir, western red cedar and sitka spruce, *Picea sitchensis* (Bong.) Carr. (Morrison 1979). The disease was first reported in the Franklin River area on Vancouver Island (Buckland et al. 1949). Concern over *H. annosum* in managed forests is about the year round susceptibility of freshly cut western hemlock and true fir stump-tops in thinned stands (Morrison and Johnson 1970; Wallis and Reynolds 1970). Some workers predict a rapid build-up of inoculum, new disease centers and increasing volume losses in subsequent rotations if preventative treatment is not made (Chavez et al. 1980; Morrison and Johnson 1978; and Wallis and Morrison 1975). Results reported by Goheen et al. (1980) do not seem to reflect this view of increasing losses in managed western hemlock forests. Conflicting evidence of this sort requires that further study be carried out on this pathogen.

#### Armillaria Root Disease

The armillaria root disease affects most coniferous and deciduous species in B.C. It is most commonly the cause of low incidence mortality in young conifer plantations in coastal regions. *A. ostoyae* is not known to cause much mortality and butt rot of large older trees on the coast, as is common in the Interior of B.C. (Morrison 1981).

#### Black Stain Root Disease

More recently a new root pathogen, black stain *Ceratocystis wagneri* Goheen and Cobb (anamorph *Verticicladiella wagneri* Kendrick) has been reported on hard pines and Douglas-fir, each with their own specific pathotype in B.C. (Hunt and Morrison 1980). Little has been reported on the occurrence and damage of the Douglas-fir pathotype in B.C. It is expected the losses due to the pathogen will increase as the pathogen vector is reported to be an insect root weevil.

#### Schweinitzii Butt Rot

The pathogen *Phaeolus schweinitzii* causes a cubical brown rot commonly found in many species of mature trees. It also occurs in younger trees, but less frequently (Foster and Wallis 1974). This pathogen is not expected to cause serious damage to second growth forests, but may be associated with the more serious root rots such as *P. weirii*.

### **B. The Need for a Root Disease Survey**

A strong new directive was provided for forest insect and disease management in the Province of B.C. as a result of the B.C. Forest Services' reorganization in 1978 and its' new mandate outlined in the Ministry of Forests Act (1978), and the subsequent formation of a Pest Management section at the Protection Branch and Regions in 1980.

Basic to the development and implementation of all Ministry of Forests' programs are the Resource Analysis and Forest and Range Resource Program reviews. Sutton (1979) headed up the Resource Analysis and Programs Task Force for the Protection program in the Vancouver Forest Region. In their

Final Background Report they identified, analysed and recommended alternatives for forest protection investments with the goal of maximizing forest productivity by reducing wood losses to root diseases. Wood loss estimates used in the 1979 analysis were based on subjective estimates made by experts and researchers from the B.C. Forest Service (B.C.F.S.) and the Canadian Forestry Service (C.F.S.) - Pacific Region. The report concluded that; (i) significant opportunities for reducing wood losses were possible through root disease management, and (ii) quantifying the pest loss data base was fundamental to the development of regional protection objectives and programs.

As the Vancouver Pest Management section evolved through 1980 and 1981 the requirement of quantitative pest data become more apparent. The Sutton (1979) report was unable to distinguish between wood losses caused by different pathogens - though the major pathogen was known to be *Phellinus weirii*. A review of the C.F.S. Forest Insect and Disease Survey (F.I.D.S.) annual reports found few subjective or quantitative root disease data for the Vancouver Forest Region (Wood and Beale 1981). The B.C.F.S. had even less information, though local knowledge indicated that root disease problems were evident. The situation in 1981 made it impossible to accurately predict disease hazards, damage or impacts to the Regional Timber Supply Areas.

As a result the Vancouver Forest Regions' Five Year Pest Management Plan 1982/83 - 1986-87 (Wood and Beale 1981) concluded that quantification of pest problems was a mandatory prerequisite to effective pest management.

The prime disease management objective then, was to determine the distribution and intensity of the major pathogens affecting the Region and to assess their respective impacts on the short and long term timber supplies; with program goals and objectives to follow. The five year plan outlined a region-wide root disease survey to meet quantification requirements, thus providing invaluable damage and impact data for disease management.

### C. The Goals of the Root Disease Survey

The stated goals for the root disease survey outlined in the Regional 5-year plan were:

- (i) To determine the damage (incidence and severity) of five major root diseases, particularly for laminated root rot (*P. weirii*) in the Vancouver Forest Region.
- (ii) To determine the affects of *P. weirii* on the short and long-term timber supplies of one or more Timber Supply Areas, (T.S.A.'s), including the affects on allowable annual cut (A.A.C.) determinations.
- (iii) To aid in establishing the level of root disease programs to help uphold target A.A.C.'s for the Regions' T.S.A.'s.
- (iv) To aid in the development of general and ecosystem-specific regional root disease management guidelines to meet protection program commitments.
- (v) To investigate for possible disease - forest ecosystem relationships.

The goals of the survey necessarily reached beyond what the survey results in themselves could provide. The survey results were able to meet goals (i) and (iv) quite adequately. In order to determine goals (ii) and (iii) the survey results and disease program treatment options would have to be run through T.S.A. timber supply models and other T.S.A. planning

functions. The survey results were derived through several statistical analyses programs.

### III. SURVEY DESIGN AND SAMPLING METHODS

The survey design and sampling methods were critically evaluated well in advance of initiating the survey in the spring of 1982. The survey design provided a workable balance for achieving the five major goals.

The co-operators and designers of this survey were Dr. W.J. Bloomberg, C.F.S., Victoria; Dr. J.M. Muir and Dr. H. Stauffer, Protection Br. and Research Br., B.C.F.S., Victoria, respectively; Mr. D. Fligg, Inventory Br. B.C.F.S., Victoria; Mr. P.M. Wood, Pest Management Coordinator, B.C.F.S., Vancouver; Ms.

C.A. Ray and the Ecology group (Dr. K. Klinka, P.J. Courtin, R.N. Green, F.C. Nuszdorfer and G. Shishkov.) in Vancouver Region, and myself, J.D. Beale. The survey was run cooperatively between the B.C.F.S. Pest Management, Vancouver Region, Research Branch, Victoria and the C.F.S. Forest Pathology - Root Diseases group in Victoria.

#### A. The Survey Domain and Stratification

##### 1. The Survey Domain

The following list of characteristics were used to select the survey domain:

- (i) Areas generally known to be affected by root diseases, particularly *Phellinus weirii*,
- (ii) Commercial, second growth Douglas-fir type forests,
- (iii) Areas viable for intensive forest management,
- (iv) Areas of good accessibility, and
- (v) Areas where the biological-ecological relationships between the forest and disease were more likely to be evident.

The survey domain was then defined as all forested, Crown administered lands of the Campbell River, Port Alberni, Duncan and Powell River Forest Districts lying within the Quadra T.S.A. and the Alberni valley portion of the Nootka T.S.A. The survey domain was ideal for developing disease management inputs for the Quadra T.S.A. yield analyses functions (Figs. 1 and 2), or subsequent T.S.A. boundary adjustments.

##### 2. The Survey Stratification

The following strata were selected to meet the forest planning and disease management goals:

- (i) Biogeoclimatic Subzone Variants: The Wetter Maritime Coastal Douglas-fir - leeward and windward (CDFb); and the Drier Maritime Coastal Western Hemlock - Vancouver Island (CWHal) were used to provide the ecological framework for management guidelines, hazard ratings and future research (Fig. 2), (Klinka et al. 1979).

- (ii) Forest Inventory Type-groups: Originally three type groups were to be investigated; Fir (Douglas-fir), Fir-cedar and Fir-hemlock, as defined by the B.C.F.S. Inventory Branch, (1979). These types comprise a large proportion of the productive land base in the Quadra T.S.A. and are highly susceptible to *P. weirii* infection. The Fir-cedar type group was later dropped from the survey design.
- (iii) Forest Site Classes: Three site classes were used; good, medium and poor, as defined by the B.C.F.S. Site Index Curves, Inventory Branch (1979).
- (iv) Forest Age Classes: Four age classes were used, 2 (21-40 years), 3 (41-60 years), 4 (61-80 years), and 5 (81-100 years), as defined by the B.C.F.S. Inventory Branch (1979).

## B. The Survey Design

The survey domain was divided into three blocks to maintain spatial distribution of the strata replicates, and to aid in crew work distribution and logistics. Seventy-two strata, later reduced to forty-eight, were sampled. The total survey sample size was set at 584 disease survey samples. The sample size was determined on the basis of projected budgets, field crew sizes and estimated survey productivity. The samples were allocated proportionally to stratum size in each survey block, (Table 2). A minimum of one randomly selected sample per stratum per block was required. A root disease survey sample was defined as a 20±2 ha contiguous block within a single stratum. An example of a survey stratum is:

CDFb - Fir-hemlock - Good Site - Age Class 3

To accomplish the analysis requirements the survey data would be analysed using unbalanced, randomized three-block, three-way analysis of variance (ANOVA) and covariance (ANCOVA) and linear regression models. The survey design is illustrated in Figure 3.

## C. The Root Disease Survey and Analysis Method

The survey method used was the Intersection Length Method plus Mapping option (Bloomberg et al. 1980 a & b), modified for systematic grid-transect start points (Beale and Wood 1985). The survey was carried out by running a series of transects through a stand and recording the distance passed through disease infection centers. Multiple-disease situations were recorded in each survey (Bloomberg 1983b). Quantitative field data was entered into computer files and analyzed using the RRSAMP analysis program (Bloomberg et al. 1980b). Average area infected estimates for each pathogen, were standardized to a 20 ha basis, and used in subsequent statistical analyses. Examples of a root disease survey field record and an RRSAMP survey analysis are shown in Figures 4 and 5 respectively.

The Intersection Length Method was selected for its simplicity and high accuracy, and flexibility for incorporating other required sub-sampling methods (Bloomberg et al. 1980a).

## D. Sub-Sampling Methods

Three separate sub-sampling procedures were carried out during each survey. The objective of sub-sampling was to improve sample stratum allocation, and

to provide useful mensurational, historical and ecological variables for subsequent statistical analyses.

1. Stand Mensuration Sampling

Method: Standard point sampling cruise plots were established at representative locations (approximately 4 points/survey), measuring:

- (i) Species composition by volume,
- (ii) Stems per hectare,
- (iii) Age, and age class, and
- (iv) Site index and site class (B.C.F.S. Inventory Branch, 1979).

2. Stand History Sampling

Method: Large BAF prism sweeps were established at representative locations, (approximately 4-6 points/survey), measuring:

- (i) Species composition of old-growth stumps.

3. Mapping Ecological Associations or Site Units

Method: A continuous line transect mapping method was used to identify the ecological site units along the root disease survey grid. The site units (Klinka et al. 1979, Klinka et al. 1984) were primarily identified by physiographic and topographic features, humus forms and indicator species and associations. Soil pits were dug infrequently.

E. Stand Selection

Within the survey domain, forested lands in the CDFb and CWHa1 biogeoclimatic subzone variants were found to be administered by the B.C.F.S. and two Tree Free Farm Licenses. Crown Forest Industries (then Crown Zellerbach) was tenure of T.F.L. 47 with the Duncan Bay blocks falling within survey block 1, and the Nanaimo River blocks falling within survey block 3. MacMillan Bloedel has tenure of T.F.L. 44 (Port Alberni area) within survey block 2.

Stand inventory listings summarized by the stratification parameters were obtained from the Licensees and the B.C.F.S.

Stand listings were numbered uniquely for each survey block by subzone variant combination. Random number listings (computer generated) were produced for each of the above listing combinations. Stands were then selected using the random number lists.

Stands were rejected for sampling when the stand was found to be:

- (i) Harvested,
- (ii) Less than the 20\*2 ha,
- (iii) Precommercial or commercially thinned (these conditions could make disease recognition and measurement very difficult),
- (iv) Inaccessible by vehicle, or not within reasonable walking distance, and
- (v) Incorrectly forest typed.

Stand selection for the fiscal year 1982/83 was largely done by Vancouver Regional staff and a contractor. Stand selection later switched to the District offices for the fiscal year 1983/84.

#### F. Survey Training

With the root disease survey investigating a complexity of forest, disease, and ecological parameters, it was important to establish a high calibre staff to execute the project.

In cooperation with the C.F.S. root disease group and Vancouver Region Protection and Ecosystem Training staff a comprehensive 10-day training session was held in May, 1982 at the Cowichan Lake Forest Experimental Station. The following topics and procedures were covered:

- (i) Survey objectives and familiarization,
- (ii) Disease symptoms,
- (iii) Survey theory (indoors),
- (iv) Survey method (outdoors),
- (v) Inventory/cruising procedures review,
- (vi) Stand history sampling,
- (vii) Ecosystem identification for the CDFb and CWHa1 subzone variants,
- (viii) Office preparations, photos, maps, layouts,
- (ix) Check-surveying procedures.

A shorter session was repeated in the spring of 1983, as most of the crews were experienced from the 1982 survey season.

#### G. Check-Surveying

This procedure was the responsibility of the Regional Forest Pathologist. Approximately 20% of the survey blocks were checked; for the most part in tandem with the crews. This appeared to develop a keener crewman and pathologist alike, and proved to be a mutually beneficial way of getting a better feel for disease behaviour and the multiplicity of survey problems that arose.

### IV. SURVEY ANALYSIS

#### A. Descriptive Statistics

In total, 290 20ha sample units were surveyed. The survey sample allocation was not met. Many of the survey sample combinations (strata) were missed because they did not exist; especially so with age class 5 and Fir-hemlock strata. Field sample stand characteristics, coupled with the conversion to Bruces' Douglas-fir site indices created a major re-allocation of samples. The result was an unbalanced data set, dominated by Fir, with many missing cells in the Fir-hemlock type group. With an unbalanced design, cautious interpretation of the significance of factors affecting *P. weirii* was required, especially when considering Fir-hemlock in an analysis. For this reason separate analyses were carried out on the Fir type group, which had no missing cells (survey strata).

Results for disease incidence and severity for the pathogens observed are described and tabled separately. Too few observations were made for *Schweinitzii* butt rot and the combinations of the four other root diseases to be reported.

Disease incidence is the estimate of all greater-than-zero disease observations. Several important trends of disease incidence were observed (Tables 3-9), and are described below:

- (i) Incidence of all pathogens generally decreased from good to poor site classes, (Tables 3-8), with little detectable trend with age classes (Tables 3-6).
- (ii) The incidence of *P. weirii* is more than double that of the other pathogens in both subzone variants and type groups. The ranking of disease incidence in all combinations of subzone variant and type group is consistent:  
  
*P. weirii* > *A. ostoyae* > *H. annosum* > *C. wagneri* > *P. schweinitzii*, (Tables 3-9)
- (iii) Disease incidence is similar between subzone variants within the same type group (Table 9), with the exception of *P. weirii* being substantially less frequent in CWHal-Fir-hemlock.
- (iv) Incidence for all pathogens with the exception of *H. annosum* is higher in the CDFb than in the CWHal variant (Tables 7-9).

Disease severity trends (average infection) were similar to disease incidence trends. Several important severity trends for second growth Douglas-fir forests are:

- (i) The severity of *P. weirii* is substantially greater than that of the other root diseases. The ranking of disease severity is identical to the incidence ranking. The weighted proportions of the total disease infection (combined variants, sites and age classes) shows that greater than 80% of the total infection is due to *P. weirii*, (Fig. 6).
- (ii) Disease severity is affected by type group; greater levels of *P. weirii*, *A. ostoyae*, and *C. wagneri* were observed in the Fir type group, while greater levels of *H. annosum* were observed in Fir-hemlock type group (Table 10, Figs. 7-10).
- (iii) There are trends in disease severity with age. For *P. weirii* and *H. annosum*, disease severity increases with age, but for *A. ostoyae* and *C. wagneri* there is a decrease in severity with age (Tables 11-14, Figs 11-18).
- (iv) There is an increase of disease incidence and severity with increasing site quality for all pathogens (Tables 7-8, Figs. 7-10).

## B. Sample Survey Statistics

Mean proportion of areas infected with laminated root rot at 95% confidence limits were calculated for the Fir type group by site and age class for the Quadra T.S.A., (Table 15). Mean proportion infected, and areas (ha) affected by site class are, respectively: good site, 0.103, 1 497\*233 ha; medium site, 0.082, 3 017\*589 ha; poor site, 0.025, 346\*221 ha and a total mean proportion of 0.075, with 4 887\*652 ha infected in 65 156 ha of Fir type in the Quadra T.S.A. Figures 19 and 20 illustrate the mean proportion and standard errors used in these calculations. The data presented in Fig.

20 will be the basis for setting minimum infection thresholds required for early harvest decision-making. Of particular importance is the higher mean infection proportion of the medium site class over the good site, and the overlap of standard errors in the 61-80 year age class.

### C. Analysis of Variance and Regression Analysis

Two major analyses of the survey data were undertaken, the first in 1984, and the second in 1985.

The 1984 analysis had a broad objective of developing infection prediction functions for both type groups for inputs into the T.S.A. yield analysis process. The 1985 analysis built on the previous analysis, had a narrower objective of developing infection functions for the Fir type group only, with and without stand history variables. Both analyses sought to determine significant effects of the variables on *P. weirii* using analysis of variance techniques.

#### ANOVA: F & FH and F-only 1984 analyses

Two major points were observed about the survey data set, (Table 16, Summary of Observations). Firstly, infection variance was observed to increase with infection severity. A cube root transformation produced a near homogeneity of variance, which satisfied ANOVA assumptions. Secondly, substantially lower average infection levels were observed for survey block 1, and also its combinations with subzone variant, type group, site and age class factors as compared to survey blocks 2 and 3.

The variation between samples within a survey strata or analysis unit or cell was termed the sampling error. For both analyses the experimental error variation was significantly greater than the sampling error.

All the main effect sources of variation, (survey block, subzone variant, forest type group, site class and age class) and the subzone-site class and type group-site class interactions were significant at the ( $p=.05$ ) or (95%) probability level (Tables 17 and 18). With the exception of the type group and type group-site interaction effects, similar trends and levels of significance were observed in the Fir-only ANOVA, (Tables 19 and 20).

The conclusions of the 1984 analyses are summarized below:

- o Mean infection levels between survey blocks are significantly different. Mean infection in block 1 was significantly lower than for survey blocks 2 or 3. No significant difference was found between survey blocks 2 and 3, ( $p=.05$ ).
- o In the F & FH analysis there was strong evidence for differences between subzone variants ( $p=.05$ ), the mean infection level of the CDFb variant being greater than the CWHal variant. In the Fir-only analysis there was weak evidence for difference between variants ( $p=.20$ ), again with the CDFb greater than the CWHal variant.
- o The mean infection level of the Fir type group was significantly greater than the level of the Fir-hemlock type group. The mean infection level of Fir was more than double that of Fir-hemlock.
- o Mean infection levels between good and medium site classes are moderately different at  $p=.10$ , while the difference between the good and medium and the poor site classes are strongly different at ( $p=.05$ ).

- o The mean infection levels of the subzone-site class interactions indicate a linear decrease of infection levels from good through poor sites in the CWHal variant. In the CDFb variant no significant difference was observed between good and medium sites, but both were significantly greater than poor site class infection levels resulting in a weaker linear relationship.
- o The mean infection levels of the type group-site class interaction indicates a linear decrease of infection levels from good through poor sites for the Fir type group. For the Fir-hemlock type group no significant differences in mean infection levels were found between any of the site classes.
- o The mean infection levels between the age classes indicate some significant differences. Age class 2 (21-40 years) had a lower mean infection level as compared to age classes 3 to 5. No significant differences were found between age classes 3 to 5.

In general all the main effects of the survey analysis model influence the level of root disease infection. The effects of the survey block are important for developing T.S.A. infection prediction functions, while subzone, type group, site and age class differences are recognizable and useful for local management purposes and investigating biological relationships.

#### Multiple Regression Analysis

Based upon the distinct differences between subzone variants and type groups, multiple regression equations were fitted to four subsets of the survey data, as follows:

| <u>Variant</u> | <u>Type Group</u> |
|----------------|-------------------|
| CWHal          | Fir               |
| CDFb           | Fir               |
| CWHal          | Fir-hemlock       |
| CDFb           | Fir-hemlock       |

Regression variables used in the functions were Bruces' site index, stand age, and site index-stand age interaction. Predicted proportion infected per hectare (Y), equations provided significant fits, although the proportion of variation explained ( $R^2$ ) was low. Because of low  $R^2$  values and the general inappropriateness of subzone-type group classes for T.S.A. yield analyses, two more regressions were fitted; one to the whole data set and a second to the whole data set plus fifteen Fir-cedar observations. The resulting fit of the sixth equation was equally good as the fifth, with a lower standard error. A series of residual variance tables (percent difference between actual and estimated infection) were developed for various groupings of data to evaluate the usefulness of the sixth regression function (Table 21: Summary of the Residual Variance Tables).

Equation six estimates infection proportion best for the whole data set, CDFb-Fir-all blocks, and CWHal-Fir-all blocks (Table 21; ref. Table 1, 2 and 4 respectively, in Table 21). Figure 21 illustrates the estimated vs. actual infection proportion. Estimates for good and medium sites were very good, while the poor site was overestimated. This was not considered serious, as small residual variances about low infection values result in high percent residual variance. Good estimates were also made for CWHal or CDFb-Fir-block 2 and 3 (Table 21; ref. Tables 10 and 12) respectively, and CDFb-Fir-block 1 (Table 21; ref. Table 8). Generally the FH type group is substantially overestimated.

This is probably because 71% of the samples were from the Fir type group. The CDFb variant was consistently underestimated, but this is a reflection of the higher average infection for the variant and the non-linear subzone-site relationship. Survey block 1 was generally overestimated as a result of its lower mean infection levels.

#### Infection Prediction Equations

- (1) CWHal F ( Y ) =  $[-1.452 + 0.00128 (\text{AGE})(\text{SITE INDEX})] / 20$   
 $r^2 = 0.498$       SE = 0.056
- (2) CDFb F ( Y ) =  $[-0.0995 + 0.000716 (\text{AGE})(\text{SITE INDEX})] / 20$   
 $r^2 = 0.178$       SE = 0.058
- (3) CWHal FH ( Y ) =  $[-1.969 + 0.0642 (\text{SITE INDEX})] / 20$   
 $r^2 = 0.139$       SE = 0.074
- (4) CDFb FH ( Y ) =  $[-0.428 + 0.0167 (\text{AGE})] / 20$   
 $r^2 = 0.170$       SE = 0.034
- (5) ALL DATA F & FH  
( Y ) =  $[-0.477 - 0.0134 (\text{AGE}) + 0.00108 (\text{AGE})(\text{SITE INDEX})] / 20$   
 $r^2 = 0.231$       SE = 0.062
- (6) ALL DATA F & FH & FC  
( Y ) =  $[-0.436 - 0.0146 (\text{AGE}) + 0.00108 (\text{AGE})(\text{SITE INDEX})] / 20$   
 $r^2 = 0.228$       SE = 0.061

On the basis of the 1984 analysis it appears that disease infection varies considerably with subzone variant, forest type group, site quality, stand age and location (survey block). If management requirements were defined to these grouping levels, infection prediction functions would be best developed for each different level, or combinations thereof. The size limitation of this survey data base at this point is not quite sufficient for that objective, except perhaps for the Fir type group. For broad T.S.A. management objectives the sixth regression function provides the most reasonable estimates of *P. weirii* infection.

#### ANOVA Fir-only 1985 analysis

Analysis objectives were to test the significance of (i) survey blocks, particularly the effect of the CWHal variant-block 1 observations, (ii) subzone variants and subzone variant-site class interactions, (iii) stand histories; the old-growth species composition, and (iv) to determine the best predictive model of *P. weirii* behaviour in the Fir type group; primarily for management purposes but, also as a basis for further root disease research.

Several changes were made to the data set to meet the objectives.

- (i) Only the Fir type group was used in this analysis.

- (ii) Analyses were run with and without the CWHal-survey block 1 to contrast the effect on *P. weirii* infection levels.
- (iii) Most analyses were run without age class 5 (81-100 years), due to an insufficient sample size and the highly variable data in those analysis units.
- (iv) Old-growth stand history data (composition of Fir expressed as (%) of total sph of Fd, Cw, and Hw stumps) was included as a covariate.
- (v) The data set was not transformed for ANOVA's using SAS-GLM models, since the distribution of the residuals was reasonably normal.

In order to contrast the effect of survey blocks and subzone variants ANOVA's were run according to point (ii) above. Survey blocks and subzone variant were shown to be significant at  $p=.0003$  and  $p=.0798$  probability levels, respectively, when the CWHal-block 1 data was included, (Table 22). In contrast, survey block and subzone variant were significant at  $p=.06$  and  $p=.24$  respectively, when the CWHal-block 1 data were not included (Table 23). The coefficients of determination were 0.476 and 0.472 respectively for the two analyses. It is evident that this area (CWHal-block 1, a portion of the Sayward Forest) is distinctive from the rest of the survey area. Possible factors affecting disease levels in this area will be discussed later.

Due to the lack of a high level of significance ie.  $p < .05$ , survey block and subzone variants were dropped from management oriented models.

The effect of the old-growth Douglas-fir stand history, on the level of *P. weirii* was examined. In several analyses of covariance, the covariate, percent species composition of old-growth Fir, was found to be highly significant; 0.0064 (Table 24) and 0.0029 (Table 25). Coefficients of determination were 0.418 and 0.465, respectively.

Ignoring the effects of survey block and subzone variant, a reasonably simple model was developed. The main effects of the model were site class, age and an age-site class interaction, (Table 26). The coefficient of determination for this model was 0.423. The resultant functions for each site class show a low slope for poor sites, and two steeper sloped functions for medium and good sites intersecting at 60 years. The medium site has a lower intercept but rises more steeply than for good sites, perhaps indicating a faster rate of spread and development of *P. weirii* on medium sites. It may also indicate a higher than average initial inoculum potential, resulting in a rapid increase of disease severity (Fig. 22).

The regression equations for the three site classes are as follows:

Equation No.

|      |                                             |   |   |                             |
|------|---------------------------------------------|---|---|-----------------------------|
| 85-1 | GOOD SITE                                   | Y | = | -0.017595 + 0.0022376 (AGE) |
| 85-2 | MEDIUM SITE                                 | Y | = | -0.1137 + 0.0038522 (AGE)   |
| 85-3 | POOR SITE                                   | Y | = | 0.017367 + 0.0000457 (AGE)  |
| 85-4 | ALL SITES & SUBZONE VARIANTS (See Table 24) |   |   |                             |

All sites were significantly different from each other.

The conclusions of the 1985 analyses are summarized below:

- o Survey block and subzone variant are not significant at  $p=.05$  when the CWHal-block 1 samples are not included for analysis. When included, both factors are significant at  $p=.08$  or greater.
- o Old-growth stand history had a highly significant and positive effect on the levels of *P. weirii*.

## V. SYNTHESIS AND APPLICATION TO FOREST MANAGEMENT

### A. General Evaluation of the Results

#### 1. Disease Ranking

Within the context of the survey domain, and probably other similarly forested ecosystems, *P. weirii* is by far the most serious root disease pathogen affecting coastal second growth Douglas-fir forests. The other pathogens, *A. ostoyae*, *H. annosum*, *C. wagneri* and *P. schweinitzii* were observed to cause less damage by 2-3 orders of magnitude. The damage the latter pathogens cause is much less dramatic and is very spotty in incidence.

#### 2. Type Group Relationships

Western hemlock and Douglas-fir are respectively, the most susceptible and damaged hosts to *H. annosum* and *P. weirii* (Morrison 1979, Wallis 1976), (ref. Table 1). It follows then that type groups with a greater composition of western hemlock would likely suffer more damage to *H. annosum*. Similarly with Douglas-fir and *P. weirii*. This can be shown to be a most likely conclusion.

The difference in incidence and severity of all pathogens between type groups was striking. *P. weirii*, *A. ostoyae* and *C. wagneri* were observed more frequently and at higher levels in the Fir type group. *H. annosum* had greater incidence and severity in Fir-hemlock as compared to the Fir type group.

Although the incidence of *H. annosum* is nearly identical between the type groups (Tables 7 & 8), disease severity is much higher in the Fir-hemlock type group (Figs. 9, 13 and 17). Similarly, infection levels of *P. weirii* in the Fir type group were shown to be more than double those in the Fir-hemlock type group.

Hazard ratings for inventory given type group are then dependent upon the proportion of the most susceptible tree species. The hazard ratings for the Fir and Fir-hemlock type groups could then be as follows:

| PATHOGEN               | HAZARD |        |
|------------------------|--------|--------|
|                        | High   | Medium |
| <i>P. weirii</i>       | F      | FH     |
| <i>A. ostoyae</i>      | F      | FH     |
| <i>H. annosum</i>      | FH     | F      |
| <i>C. wagneri</i>      | F      | FH     |
| <i>P. schweinitzii</i> | F      | FH     |

### 3. Age and Age Class Relationships

A trend of increasing disease severity with age was evident for *P. weirii* and *H. annosum*. Infection prediction functions in both analyses for *P. weirii* used age or age class as highly significant variables. Empirical disease dynamics data are useful for projecting the effects of the disease in the remainder of the Regions' unmanaged second growth forests. Age relationships may also be used in modelling disease effects in managed stand models.

Due to other biological factors and disease expression, there is much less concern of sharply increased damaged from annosus root rot as compared with laminated root rot.

A trend of decreasing disease severity with age was found for *A. ostoyae* and *C. wagneri*. Too few observations were made of *Schweinitzii* butt rot to report more about its age relationships. *Armillaria* root disease damage has been reported to be not much of a problem on conifers beyond the age of 15 on the coast (Morrison 1981). The incidence and severity estimates tend to confirm his reports.

The survey did find higher than expected levels of *A. ostoyae* on older trees. Two possible explanations for this might be: (i) some of the observations were actually secondary to incipient or difficult to detect infections of *P. weirii*, *C. wagneri* or *P. schweinitzii*, and (ii) on older trees *A. ostoyae* develops very slowly on roots, with a consequent long lag time between initial infection and symptom observation at the root collar. Morrison (1985) reports that coastal isolates of *A. ostoyae* may be less pathogenic than interior B.C. isolates, which would explain the decline in severity with age observed in the survey.

### 4. Site Relationships

Root rot infection levels were observed to be significantly different between sites. For all pathogens there was generally a decrease in incidence and severity from good to poor sites. *P. weirii* prediction functions used site class or site index-age interactions as a variable.

The site-subzone variant interaction was not shown to be highly significant (at least for management purposes), though it is useful for explaining biological variation (Tables 22 & 23).

The general conclusions from the site, site-age and site-subzone variant effects are that the higher the site quality, the greater the infection level, and thus a higher priority for management, in fact the good and medium sites can be treated identically. The fact that possible differential rates of *P. weirii* spread or inoculum potentials exist between the good and medium site classes, should not pose a serious management concern. The differences are probably related to the variation observed between site units, as shown by Bloomberg and Beale, (1985) in the CDFb. The factors controlling this phenomena are worth investigating as there may be associated biological disease suppressive factors affecting pathogen virulence and survival (Hutchins and Rose 1984).

### 5. Biogeoclimatic Subzone Variants and Survey Block Relationships

Strong to weak evidence of different infection levels between subzone variants was shown (ranging from  $p=.05$  to  $p=.24$ ). The strongest

differences were shown when both type groups were considered. Moderate evidence of subzone variant differences were shown when the Fir-only data was considered, and the weakest when the CWHal-block 1 data was not included. From a biological interpretation viewpoint this level of significance is intriguing.

One of the major reasons for stratifying the survey using Biogeoclimatic subzone variants, was that they are an excellent ecological framework with distinct forest successional patterns for ecosystems (Klinka and Nuszdorfer 1977). Successional patterns were hypothesized to strongly affect the incidence and severity of laminated root rot through the historical patterns of susceptible or non-susceptible host species. Ecosystems with climax or stable vegetation susceptible to *P. weirii*, (Fir in the CDFb), that succeeds from *P. weirii*-susceptible seral species (Fir), are more likely to be seriously affected by laminated root rot. Conversely, ecosystems with stable vegetation less, or non-susceptible to *P. weirii* (western hemlock and western red cedar in the CWHal), succeeding from *P. weirii*-susceptible seral species are less likely to be seriously affected by laminated root rot. This scenario is particularly well illustrated in the CWHal-block 1 area (Sayward Forest), where there is a higher component of western hemlock in the Fir and Fir-hemlock stand inventory. Furthermore, there is some evidence that western white pine was a large component in the previous forest. Both species are much less susceptible to *P. weirii* than Douglas-fir and thus help explain the lower incidence and severity of the disease.

The evidence of the analyses clearly indicates an overall significant difference between subzone variants, with the CDFb variant having a greater mean infection level. Although far from conclusive the survey results favour the hypothesis of a dynamic equilibrium of *P. weirii* control by forest successional patterns. This implicates the long-term control benefits of species less susceptible to *P. weirii*. Conversely, the evidence indicates the affects of continuous succession of Douglas-fir in the CDFb. The consequences of continuous short crop rotations of Douglas-fir in these areas is therefore likely to effect an increase of disease incidence and severity if measures are not taken to control *P. weirii*.

The differences found between the CDFb and CWHal variants using root disease infection as the diagnostic parameter, exemplify the interpretive quality of the Biogeoclimatic Ecosystem Classification System as an excellent tool for resource management.

## B. Implications and Applications for Forest Management

### 1. Rating of Disease Importance

The survey evidence clearly shows the importance of laminated root rot far exceeds that of the other four major coastal pathogens in second growth coastal Douglas-fir forests. Management emphasis must be directed towards *P. weirii*, and secondarily to the other pathogens, particularly when in association with *P. weirii*. The magnitude of losses to laminated root rot indicates that it should be considered at the T.S.A. Planning and Yield Analysis levels in the Quadra and other T.S.A.'s with substantial Douglas-fir inventories.

## 2. Ecologically Based Disease Management

Ecologically based disease management can presently focus on two areas:

- (i) hazard rating: zones, subzones, variants or site units, and,
- (ii) prescribing disease control treatments with the aid of ecologically based silvicultural site prescription guides.

Presently, hazard rating of zone or subzone variants is not done at the T.S.A. Yield Analysis level, but could be at the T.S.A. management plan level. From these results a *P. weirii* hazard rating for subzone variants would rank the CDFb above the CWHal. Because the hazard is in part a function of the proportion of type group in a variant, the ranks would be reversed for *H. annosum*. A small study of the variation of *P. weirii* within the CDFb site units has indicated some potential for hazard rating site units (Bloomberg and Beale 1985). The practical value of the site unit level of hazard rating is likely to be only one of disease awareness at this time.

Silvicultural site prescription guidelines can aid in disease control treatment decision making. Site, soil and vegetation analysis aid in determining whether mechanical root rot treatment is feasible and/or what alternate tree species are suitable for infected sites. Alternate tree species for planting in root rot areas are described by subzone variant and site unit for *P. weirii* (Green et al. 1984, Beale and Wood 1986, Beale et al. 1986).

## 3. Disease Management Guidelines

Results of the root disease survey are directly applicable to the development of management guidelines and are incorporated into the Vancouver Region Root Disease Management Guidelines, (Beale 1986). Ranking of disease importance has aided in setting management priorities for guidelines and elsewhere in the pest management program.

The differences in disease incidence and severity between type groups and site classes are useful for determining type group hazard ratings and assigning management priorities. Site classes are prioritized for management, with good sites highest and poor sites lowest in priority.

The variation of damage severity between subzone variants, type groups and host species, confirmed host susceptibility classifications reported by other forest pathologists. Host susceptibilities and damage classes to various pathogens are important for crop regeneration and stand tending on sites infected with root diseases.

The level of disease incidence and severity by age classes has two important implications for silviculture management: (i) the incidence and severity of *P. weirii* at precommercial thinning ages (ie <20 years in good and medium sites) is generally very low and not a major concern, and (ii) the incidence and severity in harvest-aged stands is high, and thus warrants mandatory root disease assessments before harvest, and treatment plans if infection is greater than established minimums. The pre-harvest silviculture prescriptions for the Vancouver Forest Region (under Pest Concerns, etc.) address this latter issue.

#### 4. Opportunities for Yield Enhancement

As a result of the root disease survey a crucial question became apparent to forest managers. Were the disease damages in the second growth included or not included into the empirical volume-age curves (VAC's)? It has since been determined that root disease losses in the form of stocking reductions are included in the VAC's (B.C. Ministry of Forests 1986). This meant that the VAC's were in fact not indicating the full site potential of timber productivity. If root diseased areas (infection centers) are assumed to be non-productive; then an opportunity for yield enhancement lies in the treatment and maintenance of production in those areas. For the Quadra T.S.A. the opportunity yield is substantial. For example, for the Quadra T.S.A. Fir type, see (Table 15), the total estimated area damaged by laminated root rot is about 5 000 ha. The approximate annual opportunity harvest that could be derived from root disease treatment would be: (4 500 ha good/medium sites) x (14.7 m<sup>3</sup>/ha/yr) = 66 150 m<sup>3</sup>/yr; assuming Bruce's site index 40, MSYT's (Mitchell and Cameron 1985). Estimates for the Arrowsmith, Strathcona and Sunshine Coast T.S.A.'s will be developed in 1988/89.

Yield gains of this magnitude will aid in (i) mitigating the projected timber shortfalls, and (ii) provide volumes of timber to the small business industry in the T.S.A.

Root disease management opportunity gains can also be included into T.S.A. supply models by upward adjustment of the yield curves (volume tables). Conversely, managed stand yield curves that do not account for such losses can be adjusted downwards. In both cases prediction equation (6) has been used to reflect these situations.

#### 5. T.S.A. Planning & Yield Analysis

The T.S.A. planning process purposes to aid in the determination of the annual allowable cut (AAC) through the yield analysis process, and to choose forestry program options that will optimally support the selected AAC (Sutton et al. 1985).

For the Quadra T.S.A., laminated root rot (*P. weirii*) was identified as an issue (B.C.M.F., 1985). As an issue, pest managers were required to provide inputs to the yield analysis process. Several key pest management inputs evolved as a result of the survey.

(i) T.S.A. inventory data is aggregated into Analysis Units and are often done so on the basis of issues. In the Quadra they were largely driven by the issue of root rot in Fir type groups, and the availability of managed stand yield tables for Douglas-fir (Mitchell and Cameron 1985). Six analysis units, one each of good, medium and poor site, Fir-leading type group aggregations for the Mainland and Vancouver Island portions of the T.S.A. were defined.

(ii) The yield curves for the six Fir analysis units were adjusted because of laminated root rot as follows:

Empirical VAC's - yield curves for existing natural stands did not require adjustment because root rot losses are assumed to be accounted for in the VAC's.

Managed Stand Yield Tables (MYST's) - yield curves for managed stands, untreated for *P. weirii* was reduced for predicted disease losses using equation (6). MYST's were not adjusted for areas treated for *P. weirii*.

Problems arose in the way supply models handle root rot losses in untreated stands beyond the first managed stand rotations. In successive rotations untreated, managed stands and untreated managed stands which revert to empirical VAC growth, are "grown" on reduced

MYST's and empirical VAC's, respectively. The reduced MYST's and normal VAC's do not reflect predicted cumulative root disease damages over several rotations. As an example, the damage at 80 years is 12.3% in Analysis Unit 2 (Reduced MYST). Because of the persistence and rapid spread of *P. weirii* in Fir-type forests, the predicted cumulative damages without treatment, are more likely to be 25% and 35% at the end of the second and third rotations. Damage in the fourth rotation would likely be less, as the *P. weirii* dies out.

The issue is that the models cannot simulate the predicted disease behaviour. The implication of Fir type dominated T.S.A.'s, is that supply models will be over estimating timber supply. It also means that the full benefits of selecting Protection (Disease Management) Options in a Yield Analysis, are not able to be properly evaluated. Failure to incorporate a more accurate simulation of disease behaviour will prevent the selection of Protection Options. With the recognition of these modelling deficiencies, managers are well advised to continue aggressive disease management in conjunction with other silviculture and timber programs, as stated in several coastal T.S.A. Management Plans. It is likely that increased Pest Management funding could be made available when more accurate disease simulation is included in timber supply models to show the real benefits of root disease control.

- (iii) Yield Analysis Options - Three root disease management Protection Options for the Quadra T.S.A. were developed to measure their effect on the timber supply (p. 41, Quadra T.S.A. Timber Supply Analysis, Information Report, B.C.M.F. Planning and Inventory Br., June 1985). The Options were defined to treat fixed proportions of affected Analysis Units harvested annually. The areas are treated by a mix of mechanical and silvicultural methods (alternate less susceptible species), each with a prorated treatment cost per hectare. Treatment levels could be adjusted to budget projections.

An unknown implication of the alternate (less susceptible) species disease control options is the effect of changing the forest composition on the long-run sustainable yield. This is yet to be assessed, but a shift to more western hemlock, western red cedar and

western white pine is likely as they are preferred species. A small drop in productivity may occur insome situations, but may be more than off-set by higher product values. This would require the supply models to evaluate value (\$/m<sup>3</sup>) as well as timber supply. Such a capability would facilitate an excellent benefit: cost analysis for root disease management programs. In all likelihood, a significant positive benefit: cost ratio would be realized for disease management program.

6. T.S.A. Management Plans and Vancouver Region Disease Management Programs.

The root disease survey has clearly identified laminated root rot as a management concern. To that end the Quadra T.S.A. Management Plan states that where feasible disease treatments will be done as recommended in Regional disease management guidelines (B.C. Ministry of Forests 1985b).

Other action which is required to meet the concerns are: (i) the adoption of appropriate volume reduction factors for use in timber supply analyses (previously discussed), (ii) harvesting of second growth stands prior to culmination age where the level of infection warrants, (iii) restructuring age class imbalances by harvesting root diseased stands, and (iv) further investigation into alternate species conversion and stump extraction control methods.

These management concerns are incorporated in the Vancouver Region's Pest Management programs in the following ways: (i) Yield table adjustments described earlier were applied to the 1985 Quadra T.S.A. yield analysis process, and are being applied to the Arrowsmith, Strathcona and Sunshine Coast T.S.A.'s, with adjustments to reduction factors for the Soa and Fraser T.S.A.'s; (ii) regional procedures for laminated root rot management are outlined in Vancouver Circular Letter VR85-476 and management guidelines. Specific criteria and priorities are set out for harvesting infected Fir types less than the minimum cutting age of 81 years, in Circular Letter VR85-470. The prerequisites are that at least 10% root disease infection by area be demonstrated by a ground survey, and that the timber be required for other reasons as well, eg. restructuring age class imbalances.

The minimum infection level (10%), can effectively be used as a harvest rate regulator (of the < 81 yr age timber) by raising and lowering the minimum infection level. Currently, using the survey statistics for age class 4 (61-80 yr), we find the average infection of the 40 samples to be 12.7%, with an 99.9% confidence interval with 8.1% to 17.3% area infected. The 10% minimum, in fact results in 80% of the Fir type group stands being eligible for harvest. Clearly, shifts in the minimums can regulate harvests.

A large proportion of the Douglas-fir timber sales harvested for root disease will continue to be administered under the Small Business Enterprise Program (SBEP). Increased funding will be required to fulfill survey and treatment prescriptions as the volume of second growth Douglas-fir harvest increases.

A continuing program of establishing and monitoring stump extraction and alternate species conversion trials is under way in the Vancouver Forest Region.

Benefits of meeting the goals and objectives of the Quadra T.S.A. Management Plan, other subsequent T.S.A. Plans, and the Regional Pest Management program are:

- (i) Preventing a further erosion of the Douglas-fir timber supply, as would occur due to laminated root rot.
- (ii) An opportunity to enhance the yield and value of the highly productive coastal forests and aid in mitigating the projected timber supply shortfall in the T.S.A.
- (iii) An opportunity to prioritize and regulate the correction of age class imbalances, and to provide second growth volume for the SBEP.

## VI. CONCLUSION

A number of conclusions can be made about root diseases in second growth coastal Douglas-fir.

- o Laminated root rot, *P. weirii*, was by far the most damaging disease affecting Douglas-fir type forests.
- o The other pathogens, *A. ostoyae*, *H. annosum*, *C. wageneri*, and *P. schweinitzii* were minor in importance, causing two to three orders of magnitude less damage than *P. weirii*.
- o For laminated root rot: significant differences of infection incidence and severity were observed between (a) survey blocks, block 2 & 3 > block 1, (b) subzone variants, CDFb > CWHal, the level of significance was analysis dependent, (c) type groups, Fir > FH, (d) site classes, in the CWHal; good > medium > poor and in the CDFb; good = medium > poor and (e) there is an increase in infection with age. Infection prediction/yield reduction functions include most of the above factors, depending on the management objectives. Presently, equation (6) is used for T.S.A. and regional stand management objectives.
- o The greater levels of *P. weirii* infection in the Fir type group, and of *H. annosum* in the Fir-hemlock type group confirm the host susceptibility rankings; Douglas-fir > western hemlock for *P. weirii* and western hemlock > Douglas-fir for *H. annosum*. Cedar was never observed to be infected with any pathogen except *A. ostoyae*.
- o The greater levels of *P. weirii* infection in the CDFb subzone variant and in the Fir type group, plus the significant positive effect of old-growth Fir composition on *P. weirii* infection lend strength to the hypothesis of a dynamic equilibrium of *P. weirii* strongly affected by forest successional patterns.

The value of the survey can be measured by its use in, and its' effects on the T.S.A. Planning and Yield Analysis process, and the Regional Pest Management programs and silvicultural practices.

The Vancouver Region root disease survey provided the first large - scale quantitative pest damage input for a T.S.A. Yield Analysis in B.C. The survey clearly identified laminated root rot as a major issue, and was instrumental in the definition of the Quadra T.S.A. Analysis Units. Furthermore empirical yield tables were determined to include root disease losses, and yield table reduction factors were developed for Douglas-fir managed stand yield tables as per equation (6). Site relationships formed the basis of disease management Protection Options, used in the Quadra T.S.A. Yield Analysis. And, although the Protection Option was not selected in the 1985 Yield Analysis, the positive effect of opportunity yield gains were noticeable by a slightly

increased long-run sustainable yield. The potential for aggressive disease management in the Quadra and other Fir-dominant areas is thus well identified.

The incorporation of root disease losses along with associated disease control Protection Options are now an integral part of coastal T.S.A. yield analyses.

Partly as a result of the survey, root disease management is currently the major emphasis of the Vancouver Forest Region Pest Management program. The data base enables cost and benefit projections for treatment of laminated root rot. It also provides the basis for a method of harvest regulation, particularly for less than culmination age timber infected by *P. weirii*. Disease hazard ratings can now be approached more confidently, and management concerns and actions can be better developed for Fir-dominated T.S.A.'s.

The wealth of disease trends and relationships provides the basis for the Regional root disease guidelines. They will hopefully aid in maximizing opportunity yields and in minimizing any further spread and persistence of laminated root rot. Root disease assessment prior to harvest is now required, and areas being treated for root rot are increasing each year. Mechanical and silvicultural disease control treatments are both used in the Vancouver Forest Region.

## VII RECOMMENDATIONS

The following recommendations are made; with particular reference to further applications of the survey data, and an expansion of the data base for this Region, and similarly for other Forest Regions in British Columbia.

1. Adopt survey findings into the Vancouver Forest Region root disease management guidelines.
2. On the basis of the survey findings, develop Pest Management goals and objectives for the Vancouver Forest Region to integrate with the Timber and Silviculture programs.
3. Adopt the use of root disease infection severity as a rate of harvest regulator for harvesting below minimum cutting age Fir types in the Vancouver Forest Region. And, to monitor the effectiveness of the regulation method for restructuring age class imbalances and fiscal control of treatment expenditures.
4. Incorporate root disease losses into the T.S.A. Yield Analysis process for T.S.A.'s with substantial inventories of Douglas-fir type forests; Fraser, Soa, Sunshine Coast, Arrowsmith and Strathcona T.S.A.'s.
5. Use of the *P. weirii* damage prediction equation No. 6 for deriving managed stand yield table (M.S.Y.T.) disease reduction factors is recommended in 4. above. The Sunshine Coast and Arrowsmith T.S.A.'s do not require any loss factor revisions, while the others will.
6. Submit revised yield table reduction factors and disease control Protection Options, to the T.S.A. yield analysis process where and when sufficient impact data is available.

7. Integration of Protection Options with Timber and Silviculture Options is required to maximize forest productivity, and is recommended for the T.S.A. yield analysis process too.
8. An accurate simulation of cumulative effects of *P. weirii* root rot damage for untreated natural and managed Douglas-fir yield functions should be incorporated into T.S.A. timber supply models.
9. Laminated root rot loss factors should be incorporated into Tree Farm Licence A.A.C. determinations, whether or not A.A.C.'s are estimated by a supply model.
10. Prediction Equations 85-1, 2 and 3 should be used for developing T.S.A. management plan concerns and objectives solely for the Fir type group in the Nanaimo, Cowichan, Powell River and Sechelt Timber Supply Blocks in the Vancouver Forest Region. Prediction Equation 85-4 (Table 22), is recommended for use in the Sayward Timber Supply Block.
11. The survey data base should be broadened to, (a) complete the assessment of the Fir-hemlock strata, and (b) sample other ecological strata in other T.S.A.'s in the Region.
12. Similar surveys should be initiated in the other Forest Regions to provide T.S.A. Planning and Yield Analysis inputs for regionally important root diseases.

TABLE 1. HOST SUSCEPTIBILITIES AND HOST BIOLOGIES

| Host Damage Class            | Host Susceptibilities                                                                                                      |                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                           | Host Biology                                                                                                                                                    |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              | Laminated Root Rot<br><i>P. weirii</i>                                                                                     | Annosus Root Rot<br><i>H. annosum</i>                                                                                                          | Amillaria Root Rot<br><i>A. ostoyae</i> - coastal                                                                                                                                                                                                                                                                                                                     | Black Stain Root Disease<br><i>G. wageneri</i>                                                                                                                                                                                            | Schweinitzii Butt Rot<br><i>P. schweinitzii</i>                                                                                                                 |
| - Severe                     | Fd, Bg, Ba, Hm                                                                                                             | Hw, Ss                                                                                                                                         | N/A                                                                                                                                                                                                                                                                                                                                                                   | Fd (Douglas-fir pathotype Harrington & Cobb 1984)                                                                                                                                                                                         | Fd, Ss                                                                                                                                                          |
| - Moderate                   | Hw, La, Se, Ss, Bl                                                                                                         | Ba                                                                                                                                             | Fd, Hw, Bg                                                                                                                                                                                                                                                                                                                                                            | N/A                                                                                                                                                                                                                                       | N/A                                                                                                                                                             |
| - Least                      | Pl, Py, Pw, Cw, Dec. App.                                                                                                  | Fd, Cw                                                                                                                                         | Pinus spp., Picea spp., Cw                                                                                                                                                                                                                                                                                                                                            | N/A                                                                                                                                                                                                                                       | Other conifers                                                                                                                                                  |
| Mode of Transmission         | Ectotrophic mycelium, on root to root contacts                                                                             | Root to root grafting<br>Airborne spore infection on fresh cut susceptible stumps and bole wounds                                              | Root to root contact, or Rhizomorph to root infection                                                                                                                                                                                                                                                                                                                 | Root to root grafting and Root feeding scolytid beetles or weevils                                                                                                                                                                        | Airborne spores into wounds and scars, and Root to root contacts                                                                                                |
|                              |                                                                                                                            |                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                           |                                                                                                                                                                 |
| Damage Expression            | Thinning chlorotic crowns<br>Distress cone crops<br>Windthrown trees, root balls<br>Small to large, often discrete centres | Crown symptoms not common<br>Often one to several trees per center<br>Commonly tears up large root mass - Hw particularly<br>Root and butt rot | Thinning chlorotic crowns<br>Distress cone crops<br>Basal retnosis<br>Mycetial fans under the bark, often with rhizomorphs<br>Usually single to several trees per center<br>Often found as secondary to <i>P. weirii</i> , <i>H. annosus</i> , <i>C. wageneri</i> and <i>P. schweinitzii</i><br>On coast most common in young plantations<br>Uncommon in older stands | Thinning chlorotic crowns<br>Longitudinal dark brown to black stain in 1 to 3 yr old xylem of roots and lower bole<br>Very fast killing disease, crown symptoms not common<br>Standing dead and firm<br>The pathogen does not cause decay | Thinning chlorotic crowns<br>Sporophores around tree base on forest floor on boles and fallen trees<br>Cubical brown root and butt rot<br>Mortality, windthrown |
|                              |                                                                                                                            |                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                           |                                                                                                                                                                 |
| Period of Disease Expression | When stand age greater than 20 years                                                                                       | Optimum 40 years plus                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                       | Plantation age to maturity                                                                                                                                                                                                                | Late-mature to mature                                                                                                                                           |
| Sporophore                   | Resupinate, reddish brown structure on underside of logs                                                                   | Irregular bracket-like conk usually found in root crotches<br>Top black, cream coloured undersurface<br>Perennial                              | Tufted top honey mushrooms in late August through September                                                                                                                                                                                                                                                                                                           | None visible                                                                                                                                                                                                                              | Clusters of stalked or bracket-like polypore caps<br>Annual sporophores; initially yellow-green in colour turning to red-brown                                  |

TABLE 2.

VANCOUVER FOREST REGION 1982-83  
ROOT DISEASE SURVEY SAMPLE ALLOCATIONS

| Biogeoclimatic Subzone Variant |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
|--------------------------------|------------|---|---|---|----|---|---|---|-------|---|---|---|----|---|---|---|
| Age Class                      | CDFb       |   |   |   |    |   |   |   | CWHa1 |   |   |   |    |   |   |   |
|                                | Type Group |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
|                                | F          |   |   |   | FH |   |   |   | F     |   |   |   | FH |   |   |   |
|                                | 2          | 3 | 4 | 5 | 2  | 3 | 4 | 5 | 2     | 3 | 4 | 5 | 2  | 3 | 4 | 5 |
| <u>Block 1</u>                 |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
| Site Class:                    |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
| Good                           | 2          | 2 | 2 | 1 | 2  | 2 | 1 | 1 | 2     | 2 | 2 | 1 | 2  | 2 | 1 | 1 |
| Medium                         | 4          | 4 | 2 | 1 | 2  | 2 | 2 | 1 | 5     | 5 | 2 | 1 | 3  | 3 | 2 | 1 |
| Poor                           | 4          | 4 | 2 | 1 | 2  | 2 | 2 | 1 | 5     | 5 | 2 | 1 | 3  | 3 | 2 | 1 |
| <u>Block 2</u>                 |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
| Site Class:                    |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
| Good                           | 3          | 3 | 2 | 1 | 1  | 1 | 1 | 1 | 3     | 3 | 2 | 1 | 1  | 1 | 1 | 1 |
| Medium                         | 5          | 5 | 5 | 1 | 1  | 1 | 1 | 1 | 4     | 4 | 3 | 1 | 1  | 1 | 1 | 1 |
| Poor                           | 5          | 5 | 5 | 1 | 1  | 1 | 1 | 1 | 4     | 4 | 3 | 1 | 1  | 1 | 1 | 1 |
| <u>Block 3</u>                 |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
| Site Class:                    |            |   |   |   |    |   |   |   |       |   |   |   |    |   |   |   |
| Good                           | 2          | 2 | 2 | 1 | 1  | 1 | 1 | 1 | 2     | 2 | 2 | 1 | 1  | 1 | 1 | 1 |
| Medium                         | 5          | 5 | 5 | 1 | 1  | 1 | 1 | 1 | 3     | 3 | 2 | 1 | 1  | 1 | 1 | 1 |
| Poor                           | 5          | 5 | 5 | 1 | 1  | 1 | 1 | 1 | 3     | 3 | 2 | 1 | 1  | 1 | 1 | 1 |

TABLE 3.

RELATIVE FREQUENCY (INCIDENCE) TABLES FOR THE  
MAJOR ROOT DISEASE PATHOGENS

CDFb Fir-Hemlock

|           |     | Root Disease Pathogens |           |            |            |             |
|-----------|-----|------------------------|-----------|------------|------------|-------------|
| Class     |     | OBS.                   | P. weirii | A. obscura | H. annosum | C. wageneri |
| Site      | Age |                        |           |            |            |             |
| Good      | 2   | 4                      | 4 (100) * | 1 (25)     | 3 (75)     | 0           |
|           | 3   | 6                      | 5 (83)    | 2 (33)     | 2 (33)     | 1 (17)      |
|           | 4   | 4                      | 2 (50)    | 1 (25)     | 0          | 0           |
|           | 5   | 1                      | 1 (100)   | 1 (100)    | 1 (100)    | 0           |
|           |     | 15                     | 12 (80)   | 5 (33)     | 6 (40)     | 1 (7)       |
| Medium    | 2   | 2                      | 2 (100)   | 1 (50)     | 1 (50)     | 1 (50)      |
|           | 3   | 4                      | 4 (100)   | 1 (25)     | 1 (25)     | 0           |
|           | 4   | 3                      | 3 (100)   | 0          | 0          | 0           |
|           | 5   | 3                      | 3 (100)   | 0          | 1 (33)     | 0           |
|           |     | 12                     | 12 (100)  | 2 (17)     | 3 (25)     | 1 (8)       |
| Poor      | 2   | 1                      | 0         | 1 (100)    | 0          | 0           |
|           | 3   | 2                      | 1 (50)    | 0          | 1 (50)     | 0           |
|           | 4   | 4                      | 3 (75)    | 2 (50)     | 2 (50)     | 0           |
|           | 5   | 3                      | 2 (67)    | 2 (67)     | 1 (33)     | 0           |
|           |     | 10                     | 6 (60)    | 5 (50)     | 4 (40)     | 0           |
| All Sites |     | 37                     | 30 (81)   | 12 (32)    | 13 (35)    | 2 (5)       |

\* Observed Frequency and (Percent Frequency)

TABLE 4.

RELATIVE FREQUENCY (INCIDENCE) TABLE FOR THE  
MAJOR ROOT DISEASE PATHOGENS

CWHal Fir-Hemlock

|           |     | Root Disease Pathogens |           |            |            |             |
|-----------|-----|------------------------|-----------|------------|------------|-------------|
| Class     |     | OBS.                   | P. weirii | A. obscura | H. annosum | C. wageneri |
| Site      | Age |                        |           |            |            |             |
| Good      | 2   | 5                      | 2 (40) *  | 2 (40)     | 3 (67)     | 0           |
|           | 3   | 7                      | 4 (57)    | 3 (43)     | 3 (43)     | 0           |
|           | 4   | 2                      | 2 (100)   | 1 (50)     | 1 (50)     | 0           |
|           | 5   | 0                      | 0         | 0          | 0          | 0           |
|           |     | 14                     | 8 (57)    | 6 (43)     | 7 (50)     | 0           |
| Medium    | 2   | 7                      | 3 (43)    | 2 (29)     | 1 (14)     | 0           |
|           | 3   | 5                      | 5 (100)   | 0          | 0          | 0           |
|           | 4   | 1                      | 1 (100)   | 1 (100)    | 1 (100)    | 0           |
|           | 5   | 2                      | 0         | 0          | 1 (50)     | 0           |
|           |     | 15                     | 9 (60)    | 3 (20)     | 3 (20)     | 0           |
| Poor      | 2   | 4                      | 1 (25)    | 1 (25)     | 0          | 0           |
|           | 3   | 0                      | 0         | 0          | 0          | 0           |
|           | 4   | 6                      | 3 (50)    | 2 (33)     | 3 (50)     | 0           |
|           | 5   | 2                      | 0         | 0          | 0          | 0           |
|           |     | 12                     | 4 (33)    | 3 (25)     | 3 (25)     | 0           |
| All Sites |     | 41                     | 21 (51)   | 12 (29)    | 13 (32)    | 0           |

\* Observed Frequency and (Percent Frequency)

TABLE 5.

RELATIVE FREQUENCY (INCIDENCE) TABLE FOR THE  
MAJOR ROOT DISEASE PATHOGENS

CDFb Fir

|           |     | Root Disease Pathogens |                  |                   |                   |                    |
|-----------|-----|------------------------|------------------|-------------------|-------------------|--------------------|
| Class     |     | OBS.                   | <u>P. weirii</u> | <u>A. obscura</u> | <u>H. annosum</u> | <u>C. wageneri</u> |
| Site      | Age |                        |                  |                   |                   |                    |
| Good      | 2   | 15                     | 15 (100) *       | 8 (53)            | 5 (63)            | 2 (13)             |
|           | 3   | 23                     | 23 (100)         | 9 (39)            | 14 (61)           | 4 (17)             |
|           | 4   | 13                     | 13 (100)         | 5 (38)            | 6 (46)            | 4 (31)             |
|           | 5   | 2                      | 2 (100)          | 1 (50)            | 1 (100)           | 0                  |
|           |     | 53                     | 53 (100)         | 23 (43)           | 26 (49)           | 10 (19)            |
| Medium    | 2   | 7                      | 6 (86)           | 5 (71)            | 1 (14)            | 2 (29)             |
|           | 3   | 12                     | 12 (100)         | 3 (25)            | 4 (33)            | 2 (17)             |
|           | 4   | 8                      | 8 (100)          | 1 (13)            | 0                 | 0                  |
|           | 5   | 9                      | 9 (100)          | 3 (33)            | 4 (44)            | 0                  |
|           |     | 36                     | 35 (97)          | 12 (33)           | 9 (25)            | 3 (11)             |
| Poor      | 2   | 1                      | 1 (100)          | 1 (100)           | 0                 | 0                  |
|           | 3   | 8                      | 4 (50)           | 2 (25)            | 1 (13)            | 1 (13)             |
|           | 4   | 6                      | 5 (83)           | 1 (17)            | 2 (33)            | 0                  |
|           | 5   | 4                      | 4 (100)          | 1 (25)            | 0                 | 0                  |
|           |     | 19                     | 14 (74)          | 5 (26)            | 3 (16)            | 1 (5)              |
| All Sites |     | 108                    | 102 (95)         | 40 (37)           | 38 (35)           | 15 (14)            |

\* Observed Frequency and (Percent Frequency)

TABLE 6.

RELATIVE FREQUENCY (INCIDENCE) TABLE FOR THE  
MAJOR ROOT DISEASE PATHOGENS

CWHal Fir

|           |     | Root Disease Pathogens |                |                |            |             |  |
|-----------|-----|------------------------|----------------|----------------|------------|-------------|--|
| Class     |     | OBS.                   | P. weirii      | A. obscura     | H. annosum | C. wageneri |  |
| Site      | Age |                        |                |                |            |             |  |
| Good      | 2   | 13                     | 12 (92)*       | 7 (35)         | 3 (25)     | 3 (23)      |  |
|           | 3   | 13                     | 11 (85)        | 7 (54)         | 5 (39)     | 2 (15)      |  |
|           | 4   | 11                     | 11 (100)       | 5 (45)         | 6 (55)     | 1 (9)       |  |
|           | 5   | <u>1</u>               | <u>1 (100)</u> | <u>1 (100)</u> | <u>0</u>   | <u>0</u>    |  |
|           |     | 38                     | 35 (92)        | 20 (53)        | 14 (37)    | 6 (16)      |  |
| Medium    | 2   | 20                     | 14 (70)        | 12 (60)        | 5 (25)     | 1 (5)       |  |
|           | 3   | 13                     | 12 (92)        | 0              | 2 (15)     | 0           |  |
|           | 4   | 8                      | 5 (63)         | 5 (63)         | 3 (38)     | 0           |  |
|           | 5   | <u>2</u>               | <u>2 (100)</u> | <u>0</u>       | <u>0</u>   | <u>0</u>    |  |
|           |     | 43                     | 33 (77)        | 17 (40)        | 10 (23)    | 1 (2)       |  |
| Poor      | 2   | 3                      | 2 (67)         | 1 (33)         | 0          | 0           |  |
|           | 3   | 1                      | 0              | 0              | 0          | 0           |  |
|           | 4   | 2                      | 0              | 0              | 0          | 0           |  |
|           | 5   | <u>2</u>               | <u>0</u>       | <u>0</u>       | <u>0</u>   | <u>0</u>    |  |
|           |     | 8                      | 2 (25)         | 1 (13)         | 0          | 0           |  |
| All Sites |     | 89                     | 79 (89)        | 38 (43)        | 24 (27)    | 7 (8)       |  |

\* Observed Frequency and (Percent Frequency)

TABLE 7.

RELATIVE FREQUENCY (INCIDENCE) TABLE FOR THE  
MAJOR ROOT DISEASE PATHOGENS

CDFb and CWHal--Fir

| Class     | OBS. | Root Disease Pathogens |                   |                   |                    |  |  |  |  |
|-----------|------|------------------------|-------------------|-------------------|--------------------|--|--|--|--|
|           |      | <u>P. weirii</u>       | <u>A. obscura</u> | <u>H. annosum</u> | <u>C. wageneri</u> |  |  |  |  |
| Good      | 91   | 88 (97)*               | 43 (47)           | 40 (44)           | 16 (18)            |  |  |  |  |
| Medium    | 79   | 68 (86)                | 29 (37)           | 19 (24)           | 5 (6)              |  |  |  |  |
| Poor      | 27   | 16 (60)                | 6 (22)            | 3 (11)            | 1 (4)              |  |  |  |  |
| All Sites | 197  | 172 (87)               | 78 (40)           | 62 (31)           | 22 (11)            |  |  |  |  |

TABLE 8.

RELATIVE FREQUENCY (INCIDENCE) TABLE FOR THE  
MAJOR ROOT DISEASE PATHOGENS

CDFb and CWHal - Fir-Hemlock

| Class     | OBS. | Root Disease Pathogens |                   |                   |                    |  |  |  |  |
|-----------|------|------------------------|-------------------|-------------------|--------------------|--|--|--|--|
|           |      | <u>P. weirii</u>       | <u>A. obscura</u> | <u>H. annosum</u> | <u>C. wageneri</u> |  |  |  |  |
| Good      | 29   | 20 (69)                | 11 (38)           | 13 (45)           | 1 (3)              |  |  |  |  |
| Medium    | 27   | 21 (78)                | 5 (19)            | 6 (22)            | 1 (4)              |  |  |  |  |
| Poor      | 22   | 10 (45)                | 8 (36)            | 7 (32)            | 0                  |  |  |  |  |
| All Sites | 78   | 51 (65)                | 24 (31)           | 26 (33)           | 2 (3)              |  |  |  |  |

\* Observed Frequency and (Percent Frequency)

TABLE 9.

RELATIVE FREQUENCY (INCIDENCE) TABLE FOR THE  
MAJOR ROOT DISEASE PATHOGENS

All Sites

| <u>Sites</u> |    | <u>Root Disease Pathogens</u> |                  |                   |                   |                    |  |
|--------------|----|-------------------------------|------------------|-------------------|-------------------|--------------------|--|
|              |    | <u>OBS.</u>                   | <u>P. weirii</u> | <u>A. obscura</u> | <u>H. annosum</u> | <u>C. wageneri</u> |  |
| CDFb         | FH | 37                            | 30 (81)*         | 12 (32)           | 13 (35)           | 2 (5)              |  |
| CWHal        | FH | <u>41</u>                     | <u>21 (51)</u>   | <u>12 (29)</u>    | <u>13 (32)</u>    | <u>0</u>           |  |
|              |    | 78                            | 51 (65)          | 24 (31)           | 26 (33)           | 2 (3)              |  |
| CDFb         | F  | 108                           | 102 (95)         | 40 (37)           | 38 (35)           | 15 (14)            |  |
| CWHal        | F  | <u>89</u>                     | <u>79 (89)</u>   | <u>38 (43)</u>    | <u>24 (27)</u>    | <u>7 (8)</u>       |  |
|              |    | 197                           | 181 (92)         | 78 (40)           | 62 (31)           | 22 (11)            |  |

\* Observed Frequency and (Percent Frequency)

NB Many of the CWHal FH samples came from block 1 where  
levels are significantly lower.

TABLE 10.

MEAN INFECTION LEVELS: ALL STRATA

| <u>Disease Pathogen</u> | <u>Type Group</u> | <u>SITE CLASS</u> |               |             |
|-------------------------|-------------------|-------------------|---------------|-------------|
|                         |                   | <u>Good</u>       | <u>Medium</u> | <u>Poor</u> |
| P. weirii               | F                 | 9.02 %            | 5.76 %        | 2.22 %      |
|                         | FH                | 3.51              | 2.38          | 0.99        |
| A. obscura              | F                 | 0.81              | 0.69          | 0.10        |
|                         | FH                | 0.62              | 0.30          | 0.13        |
| H. annosum              | F                 | 0.22              | 0.19          | 0.04        |
|                         | FH                | 0.25              | 0.06          | 0.11        |
| C. wagneri              | F                 | 0.05              | 0.04          | 0.002       |
|                         | FH                | 0.024             | 0.002         | 0.004       |

See also Figs. 7-10.

TABLE 11. MEAN INFECTION TABLES BY TYPE GROUP: *P. weirii*

| TYPE GROUP: F  | Site   | Age Class (Years) | Number | <i>P. weirii</i> | SDERR | VAR    | CV      | MIN    | MAX    |
|----------------|--------|-------------------|--------|------------------|-------|--------|---------|--------|--------|
| TYPE GROUP: F  | Good   | 21-40             | 28     | 5.005            | 0.956 | 25.564 | 101.013 | 0.000  | 16.400 |
|                |        | 41-60             | 36     | 8.911            | 1.163 | 48.709 | 78.320  | 0.000  | 23.400 |
|                |        | 61-80             | 24     | 12.767           | 1.635 | 64.140 | 62.732  | 0.100  | 30.900 |
|                | Medium | 81-100            | 3      | 17.833           | 5.521 | 91.453 | 53.625  | 7.700  | 26.700 |
|                |        | 21-40             | 27     | 1.344            | 0.314 | 2.670  | 121.548 | 0.000  | 5.600  |
|                |        | 41-60             | 25     | 5.212            | 0.985 | 24.240 | 94.464  | 0.000  | 19.750 |
|                | Poor   | 61-80             | 16     | 12.563           | 2.191 | 76.839 | 69.777  | 0.000  | 31.200 |
|                |        | 81-100            | 11     | 8.005            | 1.521 | 25.457 | 63.033  | 0.600  | 13.500 |
|                |        | 21-40             | 4      | 0.325            | 0.170 | 0.116  | 104.721 | 0.000  | 0.000  |
|                |        | 41-60             | 9      | 2.783            | 1.513 | 20.599 | 163.063 | 0.000  | 12.600 |
|                |        | 61-80             | 8      | 1.712            | 0.748 | 4.481  | 123.605 | 0.000  | 6.200  |
|                |        | 81-100            | 6      | 2.875            | 1.299 | 10.121 | 110.654 | 0.000  | 8.350  |
| TYPE GROUP: FC | Good   | 21-40             | 3      | 0.783            | 0.306 | 0.281  | 67.652  | 0.300  | 1.350  |
|                |        | 41-60             | 3      | 5.133            | 3.358 | 33.826 | 113.299 | 0.000  | 11.450 |
|                |        | 61-80             | 1      | 0.300            |       |        |         | 0.300  | 0.300  |
|                | Medium | 81-100            | 2      | 1.875            | 1.875 | 7.031  | 141.421 | 0.000  | 3.750  |
|                |        | 21-40             |        |                  |       |        |         |        |        |
|                |        | 41-60             |        |                  |       |        |         |        |        |
|                | Poor   | 61-80             |        |                  |       |        |         |        |        |
|                |        | 81-100            |        |                  |       |        |         |        |        |
|                |        | 21-40             |        |                  |       |        |         |        |        |
|                |        | 41-60             |        |                  |       |        |         |        |        |
|                |        | 61-80             |        |                  |       |        |         |        |        |
|                |        | 81-100            |        |                  |       |        |         |        |        |
| TYPE GROUP: FH | Good   | 21-40             | 9      | 3.672            | 2.799 | 70.526 | 228.689 | 0.000  | 25.750 |
|                |        | 41-60             | 13     | 2.377            | 1.183 | 18.189 | 179.430 | 0.000  | 15.400 |
|                |        | 61-80             | 6      | 4.067            | 1.941 | 22.596 | 116.889 | 0.000  | 12.350 |
|                | Medium | 81-100            | 1      | 13.550           |       |        |         | 13.550 | 13.550 |
|                |        | 21-40             | 9      | 1.000            | 0.593 | 3.164  | 117.887 | 0.000  | 5.500  |
|                |        | 41-60             | 9      | 2.628            | 0.827 | 6.161  | 94.455  | 0.200  | 6.450  |
|                | Poor   | 61-80             | 4      | 1.563            | 0.792 | 2.511  | 101.408 | 0.450  | 3.900  |
|                |        | 81-100            | 5      | 5.070            | 2.522 | 31.806 | 111.236 | 0.000  | 13.150 |
|                |        | 21-40             | 5      | 0.030            | 0.030 | 0.004  | 223.607 | 0.000  | 0.150  |
|                |        | 41-60             | 2      | 0.225            | 0.225 | 0.101  | 141.421 | 0.000  | 0.450  |
|                |        | 61-80             | 10     | 0.995            | 0.442 | 1.953  | 140.453 | 0.000  | 3.800  |
|                |        | 81-100            | 5      | 2.250            | 1.986 | 19.730 | 197.415 | 0.000  | 10.150 |

TABLE 12. MEAN INFECTION TABLES BY TYPE GROUP: *A. ostoyae*

| TYPE GROUP: F  | Site   | Age Class (Years) | Number | <i>A. ostoyae</i> | STD   | STDER | VAR    | CV      | MIN   | MAX    |
|----------------|--------|-------------------|--------|-------------------|-------|-------|--------|---------|-------|--------|
| TYPE GROUP: F  | Good   | 21-40             | 28     | 0.970             | 1.649 | 0.312 | 2.720  | 170.072 | 0.000 | 6.200  |
|                |        | 41-60             | 36     | 0.585             | 1.147 | 0.191 | 1.316  | 196.178 | 0.000 | 4.100  |
|                |        | 61-80             | 24     | 0.565             | 0.969 | 0.198 | 0.939  | 171.656 | 0.000 | 2.950  |
|                | Medium | 81-100            | 3      | 4.083             | 6.900 | 3.984 | 47.611 | 168.981 | 0.000 | 12.050 |
|                |        | 21-40             | 27     | 1.539             | 3.151 | 0.606 | 9.931  | 204.783 | 0.000 | 14.950 |
|                |        | 41-60             | 25     | 0.130             | 0.452 | 0.090 | 0.205  | 347.930 | 0.000 | 2.000  |
|                | Poor   | 61-80             | 16     | 0.456             | 0.704 | 0.176 | 0.496  | 154.407 | 0.000 | 2.000  |
|                |        | 81-100            | 11     | 0.264             | 0.556 | 0.168 | 0.309  | 210.866 | 0.000 | 1.700  |
|                |        | 21-40             | 4      | 0.188             | 0.239 | 0.120 | 0.057  | 127.657 | 0.000 | 0.500  |
|                |        | 41-60             | 9      | 0.117             | 0.235 | 0.078 | 0.055  | 201.018 | 0.000 | 0.600  |
|                |        | 61-80             | 8      | 0.037             | 0.106 | 0.037 | 0.011  | 282.843 | 0.000 | 0.300  |
|                |        | 81-100            | 6      | 0.100             | 0.245 | 0.100 | 0.060  | 244.949 | 0.000 | 0.600  |
| TYPE GROUP: FC | Good   | 21-40             | 3      | 1.383             | 0.861 | 0.497 | 0.741  | 62.220  | 0.700 | 2.350  |
|                |        | 41-60             | 3      | 0.817             | 1.414 | 0.817 | 2.001  | 173.205 | 0.000 | 2.450  |
|                |        | 61-80             | 2      | 0.000             |       |       |        |         | 1.200 | 1.200  |
|                | Medium | 21-40             | 9      | 0.622             | 0.953 | 0.318 | 0.909  | 153.212 | 0.000 | 2.300  |
|                |        | 41-60             | 13     | 0.735             | 1.210 | 0.336 | 1.463  | 164.678 | 0.000 | 3.550  |
|                |        | 61-80             | 6      | 0.408             | 0.665 | 0.272 | 0.442  | 162.892 | 0.000 | 1.550  |
|                | Poor   | 81-100            | 1      | 0.350             | 1.520 | 0.507 | 2.309  | 268.176 | 0.000 | 0.350  |
|                |        | 21-40             | 9      | 0.567             | 0.783 | 0.261 | 0.614  | 300.000 | 0.000 | 4.600  |
|                |        | 41-60             | 9      | 0.261             | 0.375 | 0.188 | 0.141  | 200.000 | 0.000 | 2.350  |
|                |        | 61-80             | 4      | 0.188             | 0.000 | 0.000 | 0.000  | 0.000   | 0.000 | 0.750  |
|                |        | 81-100            | 5      | 0.060             | 0.134 | 0.060 | 0.018  | 223.607 | 0.000 | 0.000  |
|                |        | 21-40             | 5      | 0.060             | 0.389 | 0.275 | 0.151  | 141.421 | 0.000 | 0.300  |
| TYPE GROUP: FH | Good   | 41-60             | 2      | 0.275             | 0.084 | 0.027 | 0.007  | 140.546 | 0.000 | 0.350  |
|                |        | 61-80             | 10     | 0.060             | 0.616 | 0.276 | 0.380  | 205.480 | 0.000 | 0.200  |
|                |        | 81-100            | 5      | 0.300             |       |       |        |         | 0.000 | 1.400  |
|                | Medium | 21-40             | 9      | 0.622             | 0.953 | 0.318 | 0.909  | 153.212 | 0.000 | 2.300  |
|                |        | 41-60             | 13     | 0.735             | 1.210 | 0.336 | 1.463  | 164.678 | 0.000 | 3.550  |
|                |        | 61-80             | 6      | 0.408             | 0.665 | 0.272 | 0.442  | 162.892 | 0.000 | 1.550  |
|                | Poor   | 81-100            | 1      | 0.350             | 1.520 | 0.507 | 2.309  | 268.176 | 0.000 | 0.350  |
|                |        | 21-40             | 9      | 0.567             | 0.783 | 0.261 | 0.614  | 300.000 | 0.000 | 4.600  |
|                |        | 41-60             | 9      | 0.261             | 0.375 | 0.188 | 0.141  | 200.000 | 0.000 | 2.350  |
|                |        | 61-80             | 4      | 0.188             | 0.000 | 0.000 | 0.000  | 0.000   | 0.000 | 0.750  |
|                |        | 81-100            | 5      | 0.060             | 0.134 | 0.060 | 0.018  | 223.607 | 0.000 | 0.000  |
|                |        | 21-40             | 5      | 0.060             | 0.389 | 0.275 | 0.151  | 141.421 | 0.000 | 0.300  |

TABLE 13. MEAN INFECTION TABLES BY TYPE GROUP: *H. annosum*

TYPE GROUP: F

| Site   | Age Class<br>(Years) | Number | <i>H. annosum</i> | STD   | STDErr | VAR   | CV      | MIN   | MAX   |
|--------|----------------------|--------|-------------------|-------|--------|-------|---------|-------|-------|
| Good   | 21-40                | 28     | 0.130             | 0.377 | 0.071  | 0.142 | 289.364 | 0.000 | 1.850 |
|        | 41-60                | 36     | 0.269             | 0.423 | 0.070  | 0.179 | 156.850 | 0.000 | 2.100 |
|        | 61-80                | 24     | 0.267             | 0.406 | 0.083  | 0.165 | 152.192 | 0.000 | 1.400 |
| Medium | 81-100               | 3      | 0.050             | 0.087 | 0.050  | 0.007 | 173.205 | 0.000 | 0.150 |
|        | 21-40                | 27     | 0.057             | 0.141 | 0.027  | 0.020 | 245.996 | 0.000 | 0.650 |
|        | 41-60                | 25     | 0.092             | 0.204 | 0.041  | 0.042 | 222.251 | 0.000 | 0.850 |
| Poor   | 61-80                | 16     | 0.275             | 0.791 | 0.198  | 0.625 | 287.480 | 0.000 | 3.000 |
|        | 81-100               | 11     | 0.614             | 1.011 | 0.305  | 1.022 | 164.709 | 0.000 | 2.650 |
|        | 21-40                | 4      | 0.000             | 0.000 | 0.000  | 0.000 | 300.000 | 0.000 | 0.000 |
|        | 41-60                | 9      | 0.083             | 0.250 | 0.083  | 0.063 | 233.673 | 0.000 | 0.750 |
|        | 61-80                | 8      | 0.037             | 0.088 | 0.031  | 0.008 |         | 0.000 | 0.250 |
|        | 81-100               | 6      | 0.080             | 0.000 | 0.000  | 0.000 |         | 0.000 | 0.000 |

TYPE GROUP: FC

|      |       |   |       |       |       |       |         |       |       |
|------|-------|---|-------|-------|-------|-------|---------|-------|-------|
| Good | 21-40 | 3 | 0.250 | 0.278 | 0.161 | 0.077 | 111.355 | 0.000 | 0.550 |
|      | 41-60 | 3 | 0.267 | 0.462 | 0.267 | 0.212 | 173.205 | 0.000 | 0.800 |
|      | 61-80 | 1 | 0.700 |       |       |       |         | 0.700 | 0.700 |
| Poor | 61-80 | 2 | 0.250 | 0.354 | 0.250 | 0.125 | 141.421 | 0.000 | 0.500 |

TYPE GROUP: FH

|        |        |    |       |       |       |       |         |       |       |
|--------|--------|----|-------|-------|-------|-------|---------|-------|-------|
| Good   | 21-40  | 9  | 0.650 | 0.830 | 0.277 | 0.689 | 127.355 | 0.000 | 2.100 |
|        | 41-60  | 13 | 0.265 | 0.598 | 0.166 | 0.358 | 163.676 | 0.000 | 1.650 |
|        | 61-80  | 6  | 0.258 | 0.633 | 0.258 | 0.400 | 244.949 | 0.000 | 1.550 |
| Medium | 81-100 | 1  | 0.450 |       |       |       |         | 0.450 | 0.450 |
|        | 21-40  | 9  | 0.028 | 0.565 | 0.019 | 0.003 | 203.470 | 0.000 | 0.150 |
|        | 41-60  | 9  | 0.033 | 0.100 | 0.033 | 0.010 | 300.000 | 0.000 | 0.300 |
| Poor   | 61-80  | 4  | 0.188 | 0.375 | 0.188 | 0.141 | 200.000 | 0.000 | 0.750 |
|        | 81-100 | 5  | 0.040 | 0.055 | 0.024 | 0.003 | 136.931 | 0.000 | 0.100 |
|        | 21-40  | 5  | 0.000 | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|        | 41-60  | 2  | 0.125 | 0.177 | 0.125 | 0.031 | 141.421 | 0.000 | 0.250 |
|        | 61-80  | 10 | 0.210 | 0.274 | 0.087 | 0.075 | 130.313 | 0.000 | 0.700 |
|        | 81-100 | 5  | 0.030 | 0.067 | 0.030 | 0.004 | 223.607 | 0.000 | 0.150 |

TABLE 14. MEAN INFECTION TABLES BY TYPE GROUP: *C. wagneri*

| TYPE GROUP: F  | Site   | Age Class (Years) | Number | <i>C. wagneri</i> | STD   | STDEV | VAR   | CV      | MIN   | MAX   |
|----------------|--------|-------------------|--------|-------------------|-------|-------|-------|---------|-------|-------|
| TYPE GROUP: F  | Good   | 21-40             | 28     | 0.064             | 0.210 | 0.040 | 0.044 | 326.473 | 0.000 | 1.050 |
|                |        | 41-60             | 36     | 0.036             | 0.144 | 0.024 | 0.021 | 398.026 | 0.000 | 0.850 |
|                |        | 61-80             | 24     | 0.044             | 0.100 | 0.020 | 0.010 | 229.026 | 0.000 | 0.300 |
|                | Medium | 81-100            | 3      | 0.080             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 21-40             | 27     | 0.115             | 0.379 | 0.073 | 0.143 | 329.850 | 0.000 | 1.900 |
|                |        | 41-60             | 25     | 0.006             | 0.022 | 0.004 | 0.000 | 366.414 | 0.000 | 0.100 |
|                | Poor   | 61-80             | 16     | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 81-100            | 11     | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 21-40             | 4      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 41-60             | 9      | 0.006             | 0.017 | 0.006 | 0.000 | 300.000 | 0.000 | 0.050 |
|                |        | 61-80             | 8      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 81-100            | 6      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
| TYPE GROUP: FC | Good   | 21-40             | 3      | 0.033             | 0.058 | 0.033 | 0.003 | 173.205 | 0.000 | 0.100 |
|                |        | 41-60             | 3      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 61-80             | 1      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                | Medium | 81-100            | 2      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 21-40             | 9      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 41-60             | 13     | 0.054             | 0.194 | 0.044 | 0.038 | 360.555 | 0.000 | 0.700 |
|                | Poor   | 61-80             | 6      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 81-100            | 1      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 21-40             | 9      | 0.006             | 0.017 | 0.006 | 0.000 | 300.000 | 0.000 | 0.050 |
|                |        | 41-60             | 9      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 61-80             | 4      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 81-100            | 5      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
| TYPE GROUP: FH | Good   | 21-40             | 9      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 41-60             | 13     | 0.054             | 0.194 | 0.044 | 0.038 | 360.555 | 0.000 | 0.700 |
|                |        | 61-80             | 6      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                | Medium | 81-100            | 1      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 21-40             | 9      | 0.006             | 0.017 | 0.006 | 0.000 | 300.000 | 0.000 | 0.050 |
|                |        | 41-60             | 9      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                | Poor   | 61-80             | 4      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 81-100            | 5      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 21-40             | 5      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 41-60             | 2      | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 61-80             | 10     | 0.000             | 0.000 | 0.000 | 0.000 |         | 0.000 | 0.000 |
|                |        | 81-100            | 5      | 0.020             | 0.045 | 0.020 | 0.002 | 223.607 | 0.000 | 0.100 |

TABLE 15.

VANCOUVER REGION ROOT DISEASE SURVEY 1982-83  
SAMPLE SURVEY RESULTS AS APPLIED TO THE FIR TYPE  
GROUP IN THE QUADRA TIMBER SUPPLY AREA

| Age Class  | SITE CLASS            |             |           |             |
|------------|-----------------------|-------------|-----------|-------------|
|            | Good                  | Medium      | Poor      | Total       |
| 2          |                       |             |           |             |
| 21-40 yrs  | 0.059 <sup>a</sup>    | 0.015       | 0.004     | 0.021       |
|            | 0.011 <sup>b</sup>    | 0.004       | 0.002     | 0.003       |
|            | 2 460 <sup>c</sup>    | 6 468       | 3 083     | 12 011      |
|            | 145 ± 54 <sup>d</sup> | 97 ± 52     | 12 ± 12   | 252 ± 72    |
| 3          |                       |             |           |             |
| 41-60 yrs  | 0.098                 | 0.067       | 0.028     | 0.066       |
|            | 0.012                 | 0.013       | 0.015     | 0.008       |
|            | 7 428                 | 17 065      | 6 302     | 30 795      |
|            | 728 ± 378             | 1 143 ± 444 | 176 ± 189 | 2 032 ± 492 |
| 4          |                       |             |           |             |
| 61-80 yrs  | 0.128                 | 0.155       | 0.017     | 0.134       |
|            | 0.016                 | 0.019       | 0.007     | 0.013       |
|            | 3 921                 | 9 254       | 1 365     | 14 540      |
|            | 502 ± 126             | 1 434 ± 352 | 23 ± 20   | 1 948 ± 378 |
| 5          |                       |             |           |             |
| 81-100 yrs | 0.178                 | 0.087       | 0.043     | 0.078       |
|            | 0.055                 | 0.015       | 0.015     | 0.011       |
|            | 723                   | 4 001       | 3 086     | 7 810       |
|            | 129 ± 80              | 348 ± 120   | 133 ± 98  | 609 ± 173   |
| Total      | 0.103                 | 0.082       | 0.025     | 0.075       |
|            | 0.008                 | 0.008       | 0.008     | 0.005       |
|            | 14 532                | 36 788      | 13 836    | 65 156      |
|            | 1 497 ± 233           | 3 017 ± 589 | 346 ± 221 | 4 887 ± 652 |

<sup>a</sup> Sample mean proportion infected

<sup>b</sup> Sample standard error

<sup>c</sup> Site class area (hectares)

<sup>d</sup> Total mean area infected with 95% confidence limits.

TABLE 16.

SUMMARY OF OBSERVATIONS

(N=No. of Observations, M=Mean (Hectares out of 20) S=Standard Dev., E=Standard Error of Mean)

|                         |   |   | ZONE C W H A |       |      |         |       |       | ZONE C D F B |       |       |         |       |       |
|-------------------------|---|---|--------------|-------|------|---------|-------|-------|--------------|-------|-------|---------|-------|-------|
| Site Class<br>Age Class |   |   | Type F       |       |      | Type FH |       |       | Type F       |       |       | Type FH |       |       |
|                         |   |   | G            | M     | P    | G       | M     | P     | G            | M     | P     | G       | M     | P     |
| Block 1                 | 2 | N | 5            | 10    | 1    | 2       | 6     | 3     | 6            | 1     | 0     | 3       | 1     | 1     |
|                         |   | M | 0.156        | 0.292 | 0.04 |         | 0.112 |       | 0.942        | 0.47  |       | 0.177   | 0.04  |       |
|                         |   | S | 0.18         | 0.509 |      |         | 0.185 |       | 1.106        |       |       | 0.081   |       |       |
|                         | 3 | E | 0.081        | 0.161 |      |         | 0.076 |       | 0.451        |       |       | 0.047   |       |       |
|                         |   | N | 5            | 7     | 0    | 4       | 4     | 0     | 4            | 4     | 4     | 3       | 2     | 1     |
|                         |   | M | 0.442        | 0.393 |      | 0.202   | 0.187 |       | 1.205        | 1.43  |       | 0.05    | 0.025 |       |
|                         |   | S | 0.317        | 0.465 |      | 0.405   | 0.144 |       | 0.781        | 1.258 |       | 0.062   | 0.035 |       |
|                         | 4 | E | 0.142        | 0.176 |      | 0.202   | 0.072 |       | 0.391        | 0.629 |       | 0.036   | 0.025 |       |
|                         |   | N | 0            | 3     | 0    | 0       | 0     | 6     | 4            | 2     | 1     | 2       | 0     | 4     |
|                         |   | M |              |       |      |         |       | 0.075 | 1.915        | 2.165 | 0.23  | 0.165   |       | 0.385 |
|                         | 5 | S |              |       |      |         |       | 0.098 | 1.6          | 1.138 |       | 0.233   |       | 0.376 |
|                         |   | E |              |       |      |         |       | 0.04  | 0.8          | 0.805 |       | 0.165   |       | 0.188 |
|                         |   | N | 0            | 1     | 2    | 0       | 2     | 2     | 0            | 1     | 0     | 0       | 1     | 1     |
|                         | 6 | M |              | 0.12  |      |         |       |       |              | 0.48  |       |         | 1.63  |       |
|                         |   | S |              |       |      |         |       |       |              |       |       |         |       |       |
|                         |   | E |              |       |      |         |       |       |              |       |       |         |       |       |
| Block 2                 | 2 | N | 6            | 10    | 1    | 3       | 1     | 1     | 5            | 4     | 1     | 1       | 0     | 0     |
|                         |   | M | 0.983        | 0.213 | 0.06 | 1.73    | 0.03  | 0.03  | 1.862        | 0.337 | 0.16  | 0.89    |       |       |
|                         |   | S | 0.941        | 0.226 |      | 2.962   |       |       | 1.101        | 0.24  |       |         |       |       |
|                         | 3 | E | 0.384        | 0.071 |      | 1.71    |       |       | 0.492        | 0.12  |       |         |       |       |
|                         |   | N | 7            | 0     | 0    | 2       | 0     | 0     | 8            | 2     | 1     | 3       | 3     | 1     |
|                         |   | M | 2.727        |       |      | 0.135   |       |       | 2.177        | 1.225 | 1.57  | 0.623   | 1.127 | 0.09  |
|                         | 4 | S | 1.635        |       |      | 0.163   |       |       | 1.386        | 0.488 |       | 0.376   | 0.266 |       |
|                         |   | E | 0.618        |       |      | 0.115   |       |       | 0.49         | 0.345 |       | 0.217   | 0.153 |       |
|                         |   | N | 6            | 4     | 0    | 2       | 1     | 0     | 6            | 2     | 2     | 1       | 1     | 0     |
|                         | 5 | M | 2.985        | 3.05  |      | 1.635   | 0.78  |       | 1.353        | 2.59  | 0.315 | 1.28    | 0.23  |       |
|                         |   | S | 1.631        | 1.055 |      | 1.181   |       |       | 1.004        | 0.693 | 0.445 |         |       |       |
|                         |   | E | 0.666        | 0.527 |      | 0.835   |       |       | 0.41         | 0.49  | 0.315 |         |       |       |
|                         | 6 | N | 1            | 1     | 0    | 0       | 0     | 0     | 1            | 5     | 1     | 1       | 1     | 1     |
|                         |   | M | 5.34         | 2.7   |      |         |       |       | 1.54         | 1.892 | 1.67  | 2.71    | 0.81  | 2.03  |
|                         |   | S |              |       |      |         |       |       |              | 0.88  |       |         |       |       |
|                         | 7 | E |              |       |      |         |       |       |              | 0.393 |       |         |       |       |
| Block 3                 | 2 | N | 2            | 0     | 1    | 0       | 0     | 0     | 4            | 2     | 0     | 0       | 1     | 0     |
|                         |   | M | 0.33         |       |      |         |       |       | 1.432        | 0.56  |       |         | 1.06  |       |
|                         |   | S | 0.269        |       |      |         |       |       | 1.012        | 0.792 |       |         |       |       |
|                         | 3 | E | 0.19         |       |      |         |       |       | 0.506        | 0.56  |       |         |       |       |
|                         |   | N | 2            | 5     | 1    | 0       | 3     | 0     | 12           | 5     | 3     | 0       | 0     | 0     |
|                         |   | M | 1.76         | 0.746 |      |         | 4.013 |       | 1.527        | 2.038 | 1.143 |         |       |       |
|                         | 4 | S | 2.489        | 0.378 |      |         | 4.012 |       | 1.145        | 1.325 | 1.217 |         |       |       |
|                         |   | E | 1.76         | 0.169 |      |         | 2.316 |       | 0.331        | 0.593 | 0.703 |         |       |       |
|                         |   | N | 5            | 1     | 2    | 0       | 0     | 0     | 3            | 3     | 3     | 0       | 2     | 0     |
|                         | 5 | M | 3.376        | 3.47  |      |         |       |       | 3.567        | 3.527 | 0.627 |         | 0.12  |       |
|                         |   | S | 1.609        |       |      |         |       |       | 1.535        | 2.542 | 0.532 |         | 0.042 |       |
|                         |   | E | 0.719        |       |      |         |       |       | 0.886        | 1.468 | 0.307 |         | 0.03  |       |
|                         | 6 | N | 0            | 0     | 0    | 0       | 0     | 0     | 1            | 2     | 3     | 0       | 1     | 1     |
|                         |   | M |              |       |      |         |       |       | 3.82         | 2.185 | 0.593 |         | 2.62  | 0.22  |
|                         |   | S |              |       |      |         |       |       |              | 0.262 | 0.285 |         |       |       |
|                         | 7 | E |              |       |      |         |       |       |              | 0.185 | 0.165 |         |       |       |

TABLE 17.

1984 ANALYSIS OF VARIANCE FOR BOTH  
TYPES (F AND FH)

| SOURCE OF VARIATION             | DF         | SS            | MS    | F      |
|---------------------------------|------------|---------------|-------|--------|
| Block (B)                       | 2          | 7.762         | 3.881 | 22.05* |
| Subzone (Z)                     | 1          | 2.753         | 2.753 | 15.64* |
| Type Group (T)                  | 1          | 4.347         | 4.347 | 24.70* |
| Age Class (A)                   | 3          | 6.304         | 2.101 | 11.94* |
| Site Class (S)                  | 2          | 9.948         | 4.974 | 28.27* |
| Z * T                           | 1          | 0.229         | 0.229 | 1.30   |
| Z * A                           | 3          | 0.967         | 0.323 | 1.84   |
| Z * S                           | 2          | 1.188         | 0.594 | 3.38*  |
| T * A                           | 3          | 0.054         | 0.018 | 0.10   |
| T * S                           | 2          | 1.130         | 0.565 | 3.21   |
| A * S                           | 6          | 1.380         | 0.230 | 1.31   |
| Z * T * A                       | 3          | 0.809         | 0.270 | 1.53   |
| Z * T * S                       | 2          | 0.327         | 0.164 | 0.93   |
| Z * A * S                       | 6          | 1.717         | 0.286 | 1.63   |
| T * A * S                       | 6          | 1.098         | 0.183 | 1.04   |
| Z * T * A * S                   | 4          | 1.028         | 0.257 | 1.46   |
| Experimental Error <sup>a</sup> | 46         | 8.106         | 0.176 | 1.49*  |
| Sampling Error                  | <u>180</u> | <u>21.193</u> | 0.118 |        |
| Total <sup>b</sup>              | 273        | 75.381        |       |        |

\* Significant at the 0.05 probability level.

<sup>a</sup> Experimental Error is the interaction between Blocks and the other Factors.

<sup>b</sup> Because of the general least square technique, the sums of squares do not exactly add to the Total.

TABLE 18.

SUMMARY OF SIGNIFICANT FACTORS FOR BOTH  
TYPES - 1984 (Units = Hectares/20 hectares)

| BLOCK | 1                  | 2     | 3     |
|-------|--------------------|-------|-------|
| N     | 109 <sup>a</sup>   | 97    | 68    |
| M     | 0.415 <sup>b</sup> | 1.516 | 1.711 |
| SE    | 0.071 <sup>c</sup> | 0.143 | 0.207 |

---

| SUBZONE | CWHa1 | CDFb  |
|---------|-------|-------|
| N       | 131   | 143   |
| M       | 0.967 | 1.272 |
| SE      | 0.136 | 0.102 |

---

| TYPE GROUP | F     | FH    |
|------------|-------|-------|
| N          | 195   | 79    |
| M          | 1.347 | 0.582 |
| SE         | 0.100 | 0.140 |

---

| AGE CLASS | 2     | 3     | 4     | 5     |
|-----------|-------|-------|-------|-------|
| N         | 82    | 96    | 66    | 30    |
| M         | 0.547 | 1.194 | 1.635 | 1.377 |
| SE        | 0.099 | 0.111 | 0.204 | 0.245 |

---

| SITE CLASS | Good  | Medium | Poor  |
|------------|-------|--------|-------|
| N          | 120   | 105    | 49    |
| M          | 1.522 | 1.049  | 0.323 |
| SE         | 0.137 | 0.136  | 0.082 |

---

| SUBZONE * SITE | Good  | CWHa1<br>Medium | Poor  | Good  | CDFb<br>Medium | Poor  |
|----------------|-------|-----------------|-------|-------|----------------|-------|
| N              | 52    | 59              | 20    | 68    | 46             | 29    |
| M              | 1.574 | 0.751           | 0.029 | 1.483 | 1.432          | 0.525 |
| SE             | 0.246 | 0.186           | 0.014 | 0.153 | 0.187          | 0.125 |

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| TYPE GROUP * SITE | Good  | F<br>Medium | Poor  | Good  | FH<br>Medium | Poor  |
|-------------------|-------|-------------|-------|-------|--------------|-------|
| N                 | 93    | 75          | 27    | 27    | 30           | 22    |
| M                 | 1.778 | 1.144       | 0.424 | 0.641 | 0.811        | 0.198 |
| SE                | 0.155 | 0.149       | 0.123 | 0.221 | 0.298        | 0.097 |

<sup>a</sup> N = Number of observations  
<sup>b</sup> M = Mean  
<sup>c</sup> SE = Standard error of the mean

TABLE 19.

1984 ANALYSIS OF VARIANCE FOR TYPE F ONLY

| SOURCE OF VARIATION             | DF         | SS     | MS    | F      |
|---------------------------------|------------|--------|-------|--------|
| Block (B)                       | 2          | 4.396  | 2.198 | 10.42* |
| Subzone (Z)                     | 1          | 2.199  | 2.199 | 10.42* |
| Age Class (A)                   | 3          | 5.666  | 1.889 | 8.95*  |
| Site Class (S)                  | 2          | 9.506  | 4.753 | 22.53* |
| Z * A                           | 3          | 0.321  | 0.107 | 0.51   |
| Z * S                           | 2          | 1.585  | 0.792 | 3.75*  |
| A * S                           | 6          | 1.171  | 0.195 | 0.92   |
| Z * A * S                       | 6          | 1.449  | 0.241 | 1.14   |
| Experimental Error <sup>a</sup> | 30         | 6.321  | 0.211 | 1.87*  |
| Sampling Error                  | <u>139</u> | 15.751 | 0.113 |        |
| Total <sup>b</sup>              | 194        |        |       |        |

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\* Significant at the 0.05 probability level.

<sup>a</sup> Experimental Error is the interaction between Blocks and the other Factors.

<sup>b</sup> Because of the general least square technique, the sums of squares do not exactly add to the Total.

TABLE 20.

SUMMARY OF THE SIGNIFICANT FACTORS FOR TYPE F  
ONLY - 1984 (Units = Hectares/20 Hectares)

| BLOCK          | 1                  | 2      | 3     |       |        |       |
|----------------|--------------------|--------|-------|-------|--------|-------|
| N              | 61 <sup>a</sup>    | 74     | 60    |       |        |       |
| M              | 0.628 <sup>b</sup> | 0.678  | 0.670 |       |        |       |
| SE             | 0.115 <sup>c</sup> | 0.167  | 0.197 |       |        |       |
| SUBZONE        | CWHa1              | CDFb   |       |       |        |       |
| N              | 89                 | 106    |       |       |        |       |
| M              | 0.617              | 1.512  |       |       |        |       |
| SE             | 0.162              | 0.123  |       |       |        |       |
| AGE CLASS      | 2                  | 3      | 4     | 5     |        |       |
| N              | 59                 | 70     | 47    | 19    |        |       |
| M              | 0.617              | 1.360  | 2.123 | 1.646 |        |       |
| SE             | 0.108              | 0.153  | 0.248 | 0.325 |        |       |
| SITE CLASS     | Good               | Medium | Poor  |       |        |       |
| N              | 93                 | 75     | 27    |       |        |       |
| M              | 1.778              | 1.144  | 0.424 |       |        |       |
| SE             | 0.155              | 0.149  | 0.124 |       |        |       |
| SUBZONE * SITE |                    | CWHa1  |       |       | CDFb   |       |
|                | Good               | Medium | Poor  | Good  | Medium | Poor  |
| N              | 39                 | 42     | 8     | 54    | 33     | 19    |
| M              | 1.854              | 0.715  | 0.013 | 1.724 | 1.691  | 0.597 |
| SE             | 0.286              | 0.167  | 0.008 | 0.171 | 0.233  | 0.160 |

<sup>a</sup> N = Number of observations  
<sup>b</sup> M = Mean  
<sup>c</sup> SE = Standard error of the mean

TABLE 21.

SUMMARY OF RESIDUAL VARIANCE TABLES

| <u>Number</u> | <u>Title</u>          | <u>OBS.</u> | <u>Good</u><br>(%) | <u>Medium</u><br>(%) | <u>Poor</u><br>(%) | <u>All</u><br>(%) |
|---------------|-----------------------|-------------|--------------------|----------------------|--------------------|-------------------|
| 1             | All data              | 273         | 1.3                | -1.5                 | 67.6               | 3.9               |
| 2             | CWHal F               | 89          | -15.0              | 3.4                  | 2623.2             | 7.2               |
| 3             | CWHal FH              | 41          | 47.0               | 391.7                | 1520.9             | 151.9             |
| 4             | CDFb F                | 106         | -10.7              | -36.9                | -20.1              | -20.5             |
| 5             | CDFb FH               | 37          | 224.8              | 74.1                 | 80.1               | 129.1             |
| 6             | CWHal F Block 1       | 34          | 274.9              | 185.0                | 3707.0             | 239.0             |
| 7             | CWHal FH Block 1      | 29          | 685.8              | 671.2                | 1525.0             | 819.0             |
| 8             | CDFb F Block 1        | 27          | 27.7               | -33.0                | 724.7              | 10.3              |
| 9             | CDFb FH Block 1       | 19          | 1282.9             | 214.6                | 219.2              | 468.9             |
| 10            | CWHal F Blocks 2 & 3  | 55          | -28.2              | -32.0                | 1943.9             | -27.9             |
| 11            | CWHal FH Blocks 2 & 3 | 12          | 3.5                | 98.2                 | 766.7              | 15.0              |
| 12            | CDFb F Blocks 2 & 3   | 79          | -20.1              | -37.8                | -35.9              | -27.5             |
| 13            | CDFb FH Blocks 2 & 3  | 18          | 66.5               | 45.1                 | -16.3              | 45.1              |

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Negative numbers denote a percent residual under-estimation. Positive numbers denote percent residual overestimation.

TABLE 22.

ANOVA TABLE - Fir

Dependent Variable: Infection Proportion of *P. weirii*

| <u>Source</u>   | <u>DF</u> | <u>Sum of Squares</u> | <u>R-Square</u> | <u>Root MSE</u> |
|-----------------|-----------|-----------------------|-----------------|-----------------|
| Error           | 166       | 0.4655                | 0.476           |                 |
| Corrected Total | 176       | 0.8886                |                 | 0.053           |

| <u>Source</u>   | <u>DF</u> | <u>Type III S Squares</u> | <u>Pr &gt; F</u> |
|-----------------|-----------|---------------------------|------------------|
| Block           | 2         | 0.0988                    | 0.0003           |
| Site Class      | 2         | 0.0869                    | 0.0745           |
| Age             | 1         | 0.1865                    | 0.0001           |
| Age * Site      | 2         | 0.0364                    | 0.0021           |
| Subzone Variant | 1         | 0.0047                    | 0.0798           |
| Site * Subzone  | 2         | 0.0098                    | 0.1773           |

Prediction Equation for Block 1: 85-4

$$Y = [0.060699 + \{(-0.039748)\} + (-0.0769 \text{ Good}) + (-0.1095 \text{ Medium}) + (0.0 \text{ Poor})]$$

$$+ [-0.000344 + (0.00266 \text{ Good}) + (0.00327 \text{ Medium})] * \text{Age} + (0.0 \text{ Poor})$$

$$+ (-0.035 \text{ CWHa1}) + [0.03893 \text{ G} * \text{CWHa1}] + [0.01075 \text{ M} * \text{CWHa1}] + [0.0 \text{ All others}]$$

TABLE 23.

ANOVA TABLE - Fir

Dependent Variable: Infection Proportion of *P. weirii*

| <u>Source</u>   | <u>DF</u> | <u>Sum of Squares</u> | <u>R-Square</u> | <u>Root MSE</u> |
|-----------------|-----------|-----------------------|-----------------|-----------------|
| Error           | 135       | 0.4068                | 0.472           |                 |
| Corrected Total | 145       | 0.7712                |                 | 0.0549          |

| <u>Source</u>   | <u>DF</u> | <u>Type III S Squares</u> | <u>Pr &gt; F</u> |
|-----------------|-----------|---------------------------|------------------|
| Block           | 2         | 0.1734                    | 0.0598           |
| Site Class      | 2         | 0.0320                    | 0.0060           |
| Age             | 1         | 0.0778                    | 0.0001           |
| Age * Site      | 2         | 0.0489                    | 0.0005           |
| Subzone Variant | 1         | 0.0041                    | 0.2435           |
| Site * Subzone  | 2         | 0.0137                    | 0.1065           |

TABLE 24.

ANOVA TABLE - Fir

Dependent Variable: Infection Proportion of *P. weirii*

| <u>Source</u>   | <u>DF</u> | <u>Sum of Squares</u> | <u>R-Square</u> | <u>Root MSE</u> |
|-----------------|-----------|-----------------------|-----------------|-----------------|
| Error           | 117       | 0.3884                | 0.459           |                 |
| Corrected Total | 131       | 0.7179                |                 | 0.0576          |

| <u>Source</u>    | <u>DF</u> | <u>Type III S Squares</u> | <u>Pr &gt; F</u> |
|------------------|-----------|---------------------------|------------------|
| Block            | 2         | 0.0127                    | 0.1526           |
| Site Class       | 2         | 0.0617                    | 0.0002           |
| Age Class        | 2         | 0.0346                    | 0.0068           |
| Site & Age Class | 4         | 0.0387                    | 0.0242           |
| Subzone Variant  | 1         | 0.0003                    | 0.7645           |
| Site & Subzone   | 2         | 0.0123                    | 0.1606           |
| Fir              | 1         | 0.0256                    | 0.0064           |

TABLE 25.

ANOVA TABLE - Fir

Dependent Variable: Infection Proportion of *P. weirii*

| <u>Source</u>   | <u>DF</u> | <u>Sum of Squares</u> | <u>R-Square</u> | <u>Root MSE</u> |
|-----------------|-----------|-----------------------|-----------------|-----------------|
| Error           | 122       | 0.4179                | 0.4179          |                 |
| Corrected Total | 131       | 0.7179                |                 | 0.0585          |

| <u>Source</u>    | <u>DF</u> | <u>Type III S Squares</u> | <u>Pr &gt; F</u> |
|------------------|-----------|---------------------------|------------------|
| Site Class       | 2         | 0.0708                    | 0.0001           |
| Age Class        | 2         | 0.0462                    | 0.0017           |
| Site & Age Class | 4         | 0.0384                    | 0.0286           |
| Fir              | 1         | 0.0317                    | 0.0029           |

TABLE 26.

ANOVA TABLE - Fir

Dependent Variable: Infection Proportion of *P. weirii*

| <u>Source</u>   | <u>DF</u> | <u>Sum of Squares</u> | <u>R-Square</u> | <u>Root MSE</u> |
|-----------------|-----------|-----------------------|-----------------|-----------------|
| Error           | 140       | 0.4378                | 0.432           |                 |
| Corrected Total | 145       | 0.7712                |                 | 0.0559          |

| <u>Source</u> | <u>DF</u> | <u>Type III S Squares</u> | <u>Pr &gt; F</u> |
|---------------|-----------|---------------------------|------------------|
| Site Class    | 2         | 0.0285                    | 0.0120           |
| Age           | 1         | 0.0902                    | 0.0001           |
| Age * Site    | 2         | 0.0456                    | 0.0010           |



**FIGURE 5.**

## AN EXAMPLE SURVEY RRSAMP ANALYSIS OUTPUT

[illegible]

FIGURE 6.

## INFECTION PROPORTION BY PATHOGEN

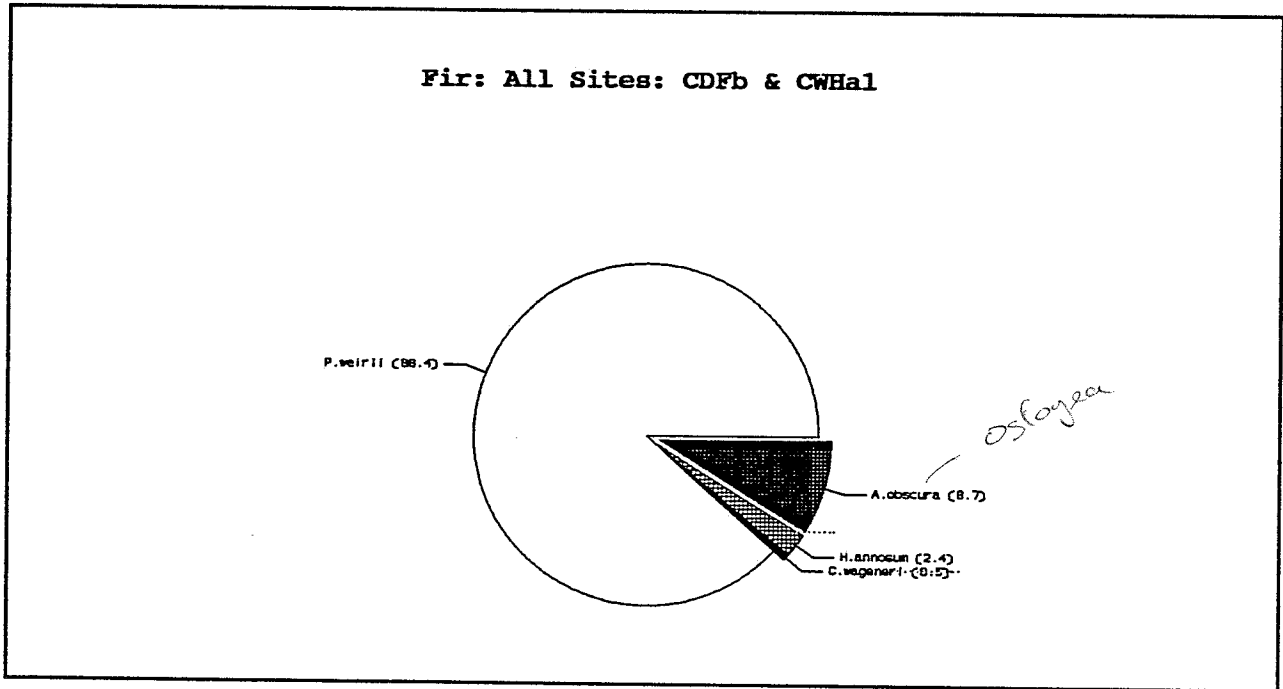
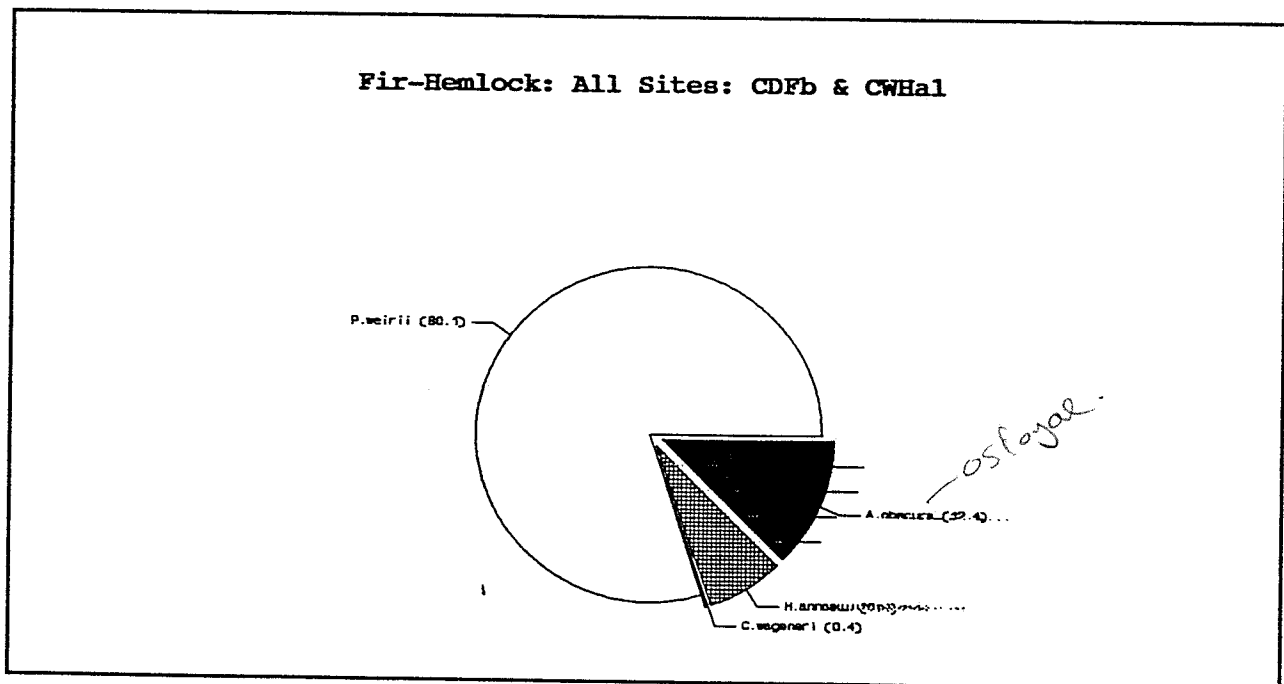


FIGURE 7.

ROOT DISEASE SURVEY: ALL STRATA  
Average Infection of *P. weirii*

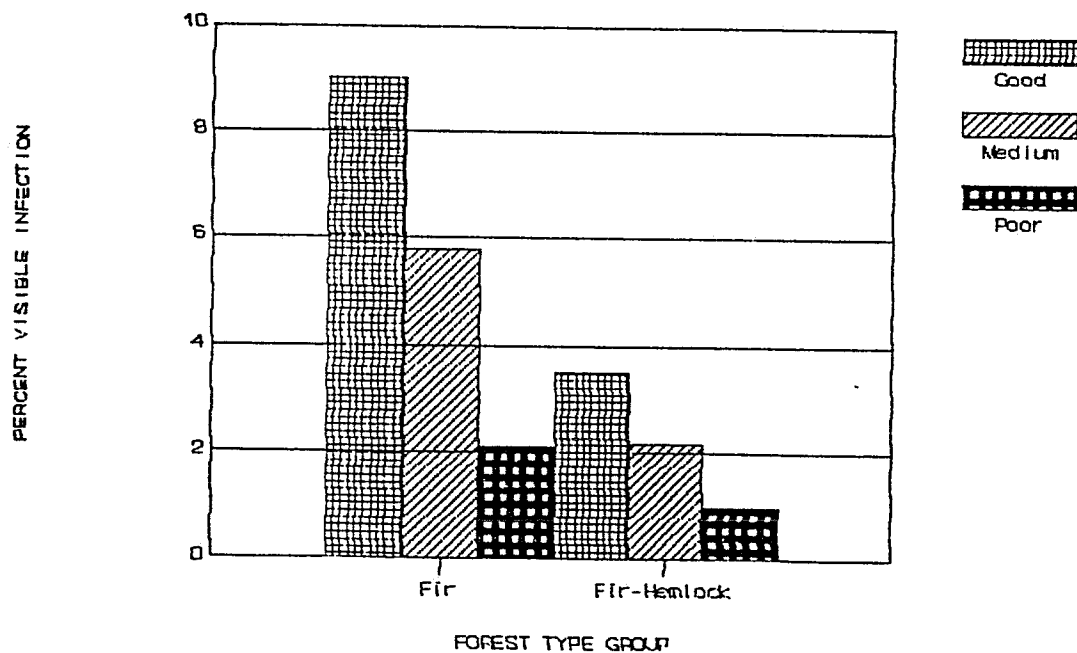


FIGURE 8.

ROOT DISEASE SURVEY: ALL STRATA  
Average Infection of *A. ostoyae*

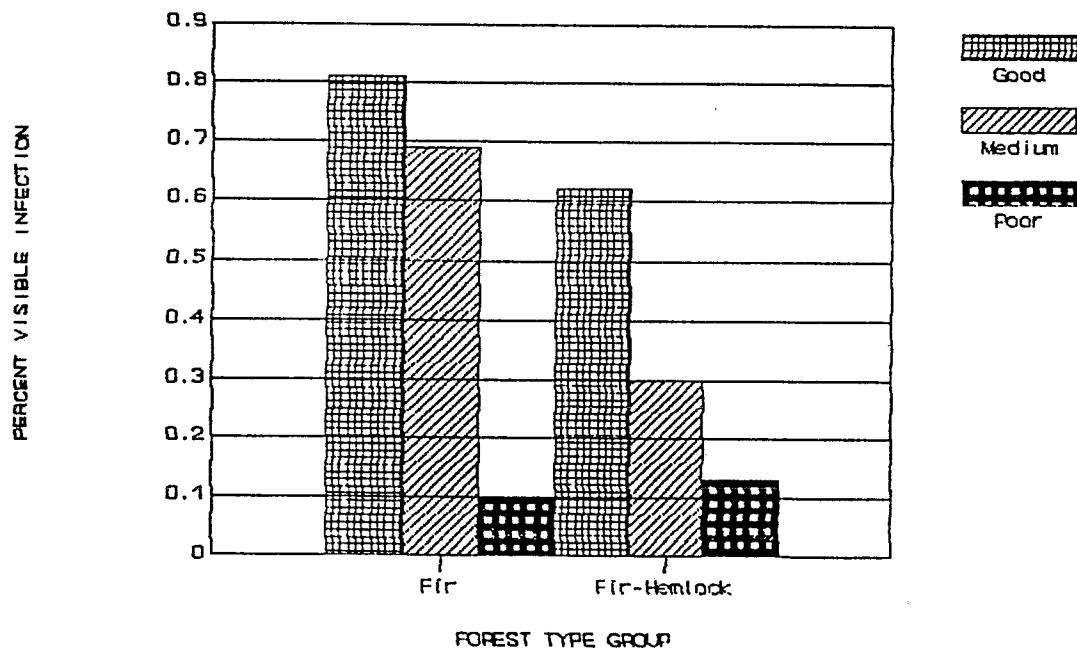


FIGURE 9.

ROOT DISEASE SURVEY: ALL STRATA  
Average Infection of *H. annosum*

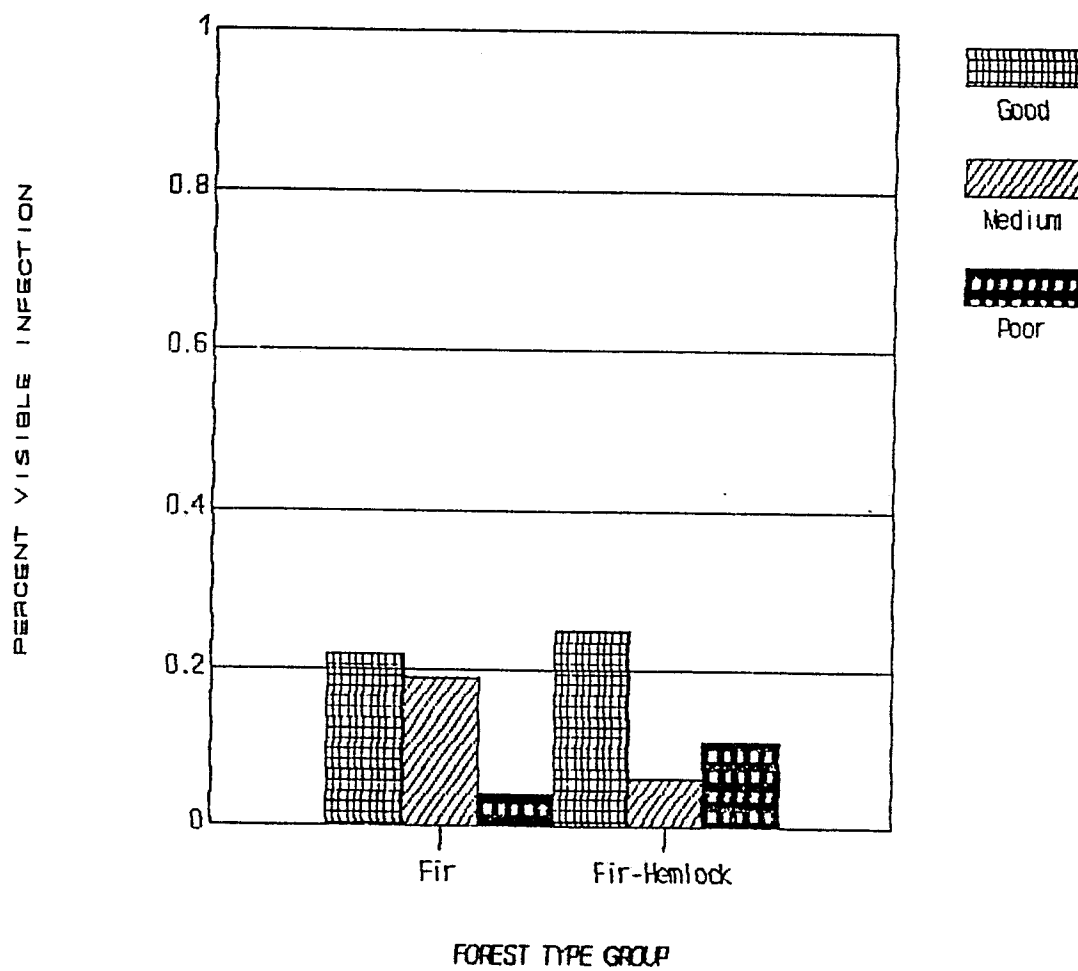


FIGURE 10.

ROOT DISEASE SURVEY: ALL STRATA  
Average Infection of *C. wagneri*

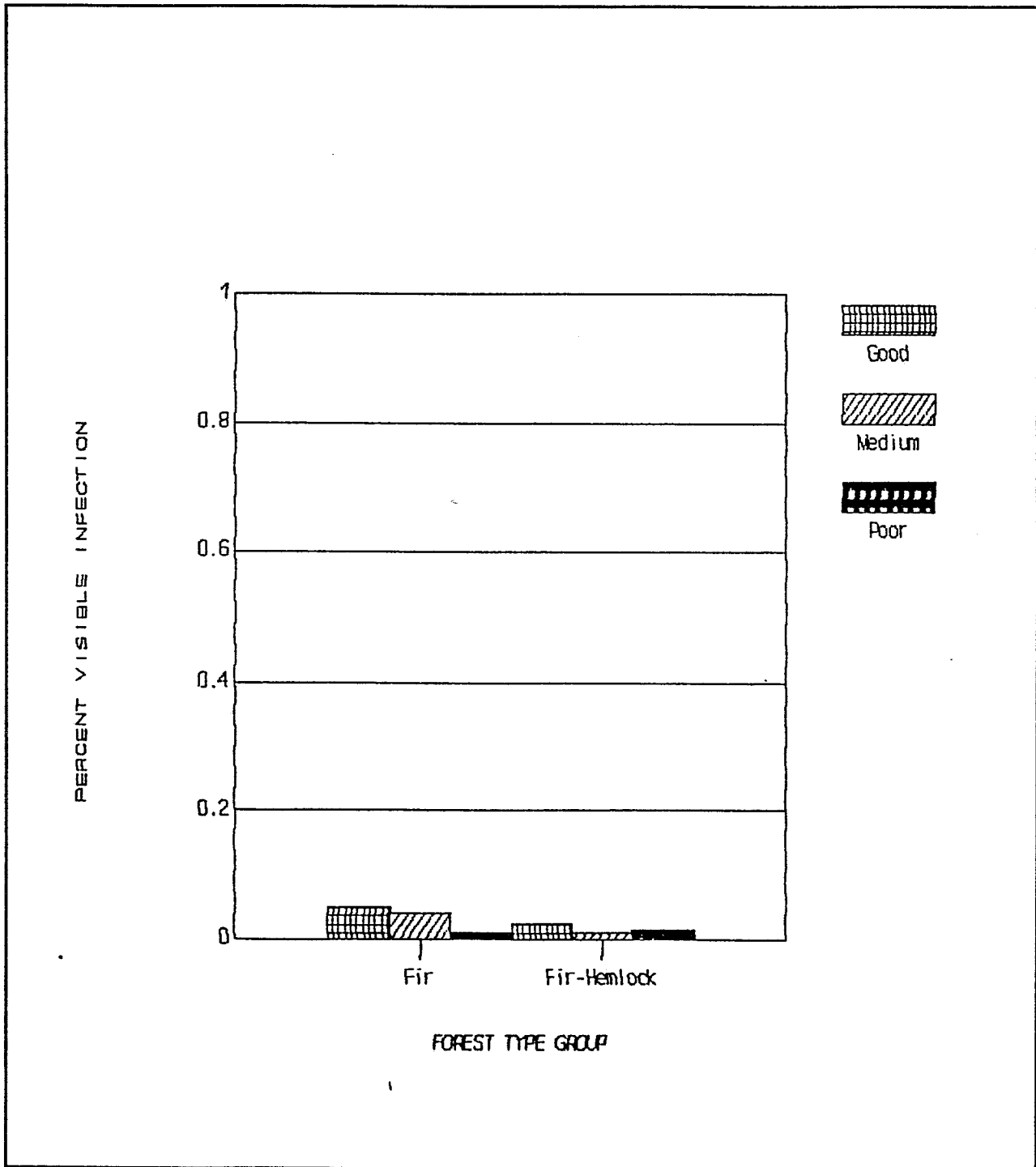


FIGURE 11.

DISEASE SURVEY: Douglas-Fir  
Mean Infection Level *P. weirii*

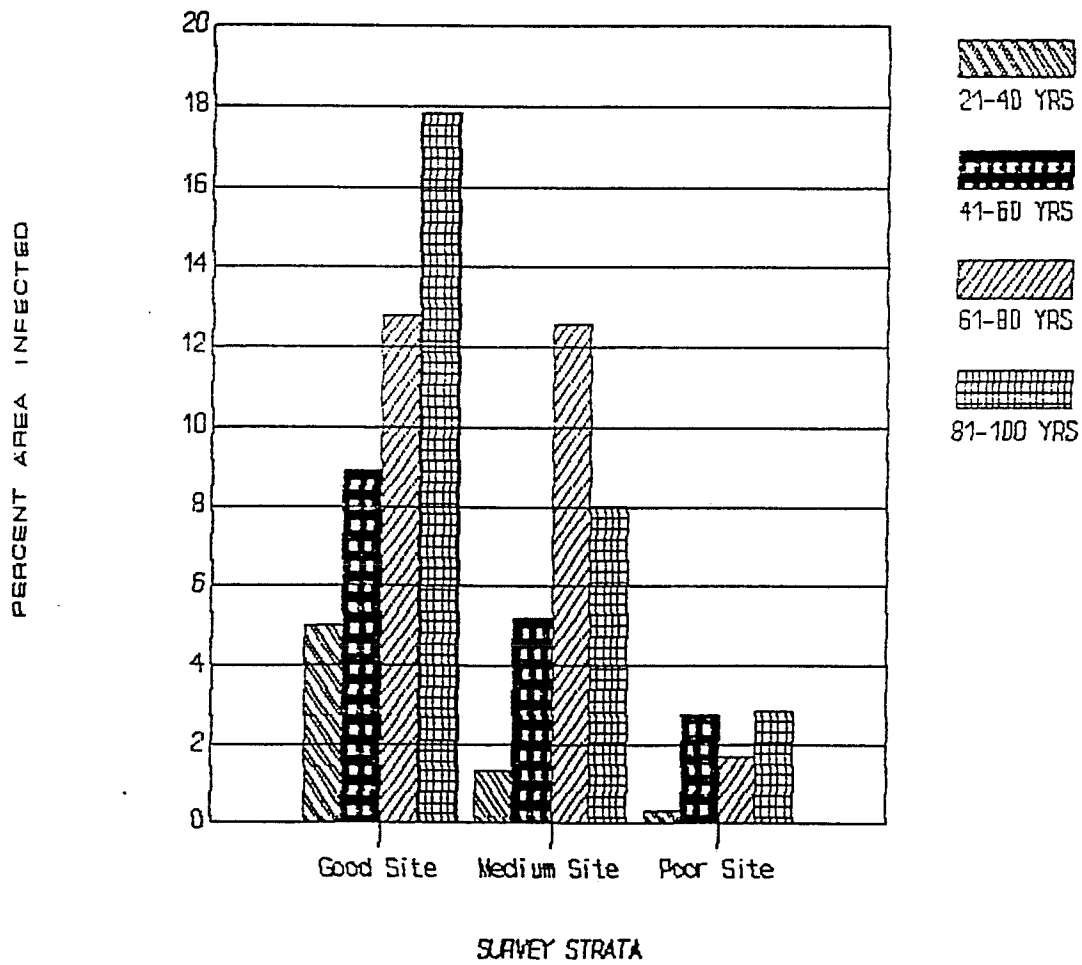


FIGURE 12.

**DISEASE SURVEY: Douglas-Fir**  
**Mean Infection Level *A. ostoyae***

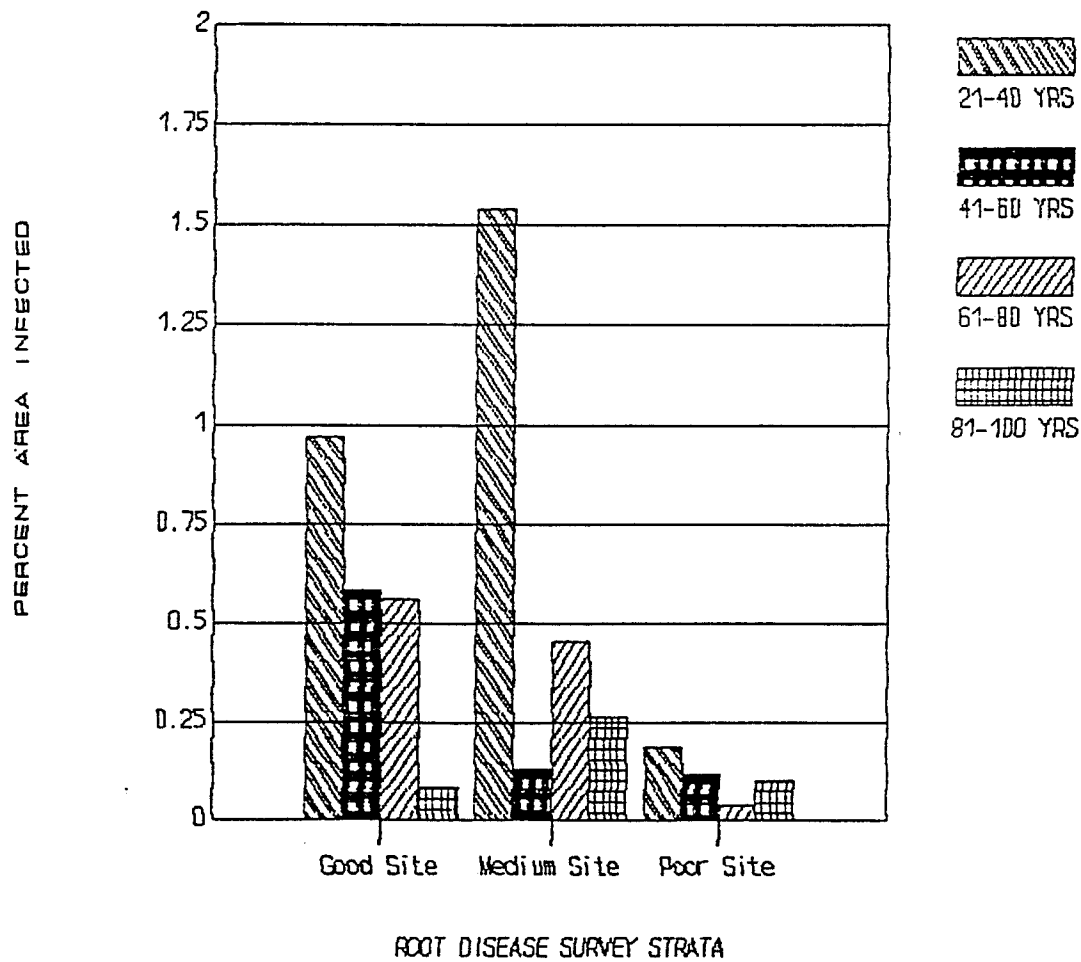


FIGURE 13.

**DISEASE SURVEY: Douglas-Fir**  
**Mean Infection Level *H. annosum***

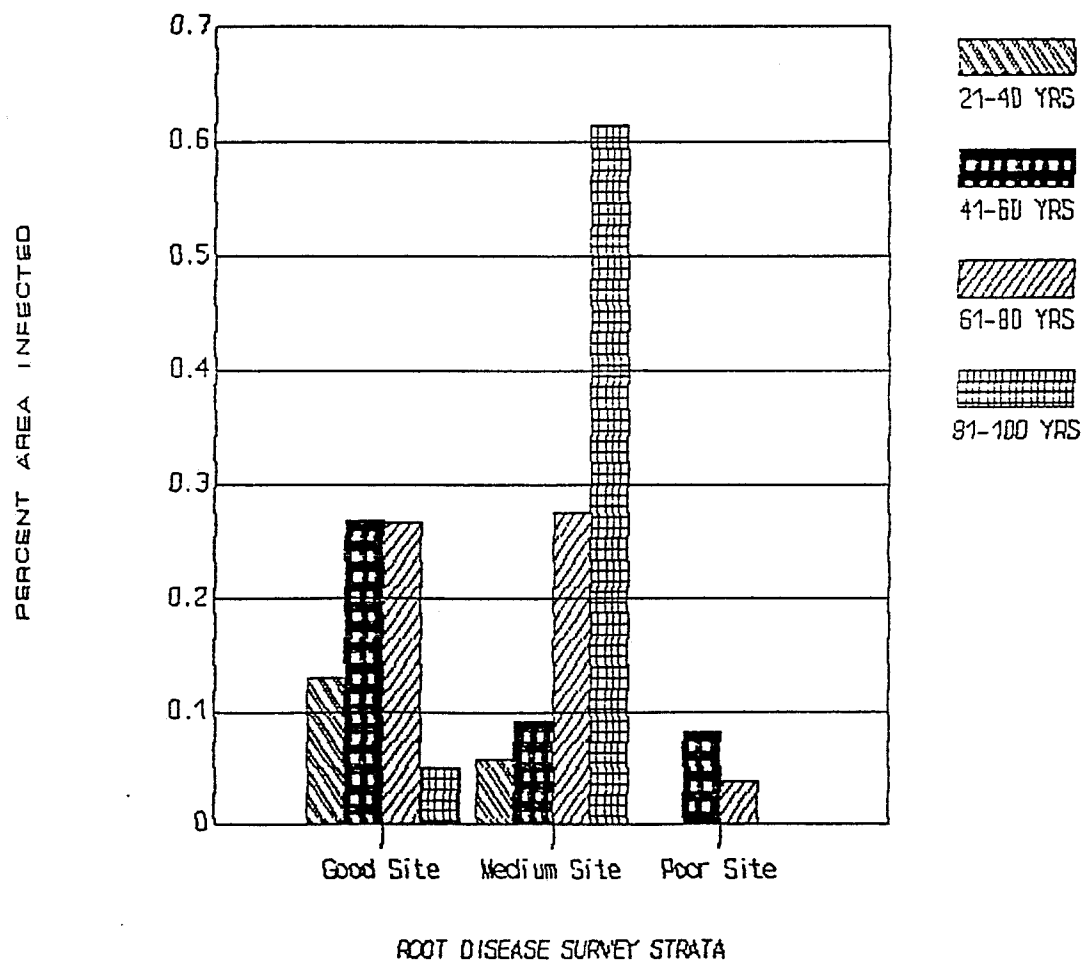


FIGURE 14.

**DISEASE SURVEY: Douglas-Fir**  
**Mean Infection Level *C. wagneri***

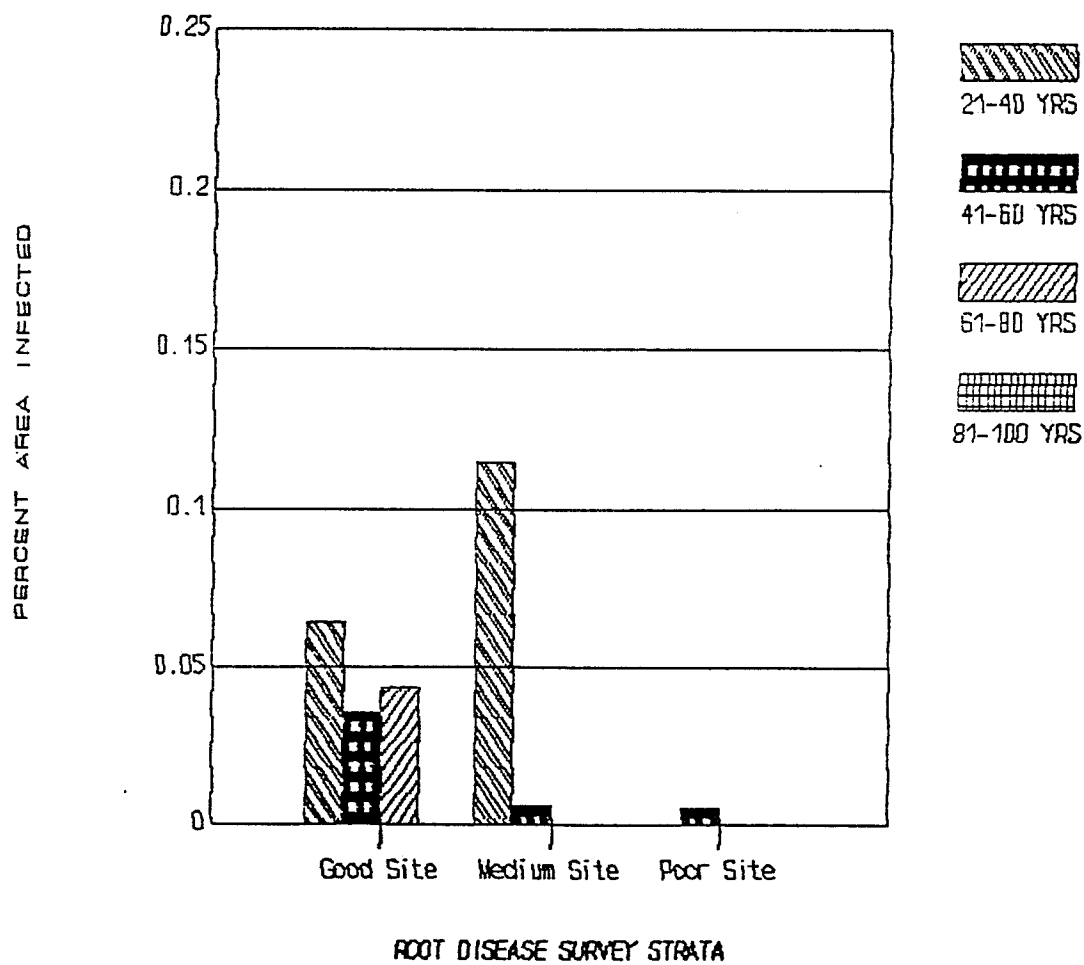


FIGURE 15.

DISEASE SURVEY: Fir-Hemlock  
Mean Infection Level *P. weirii*

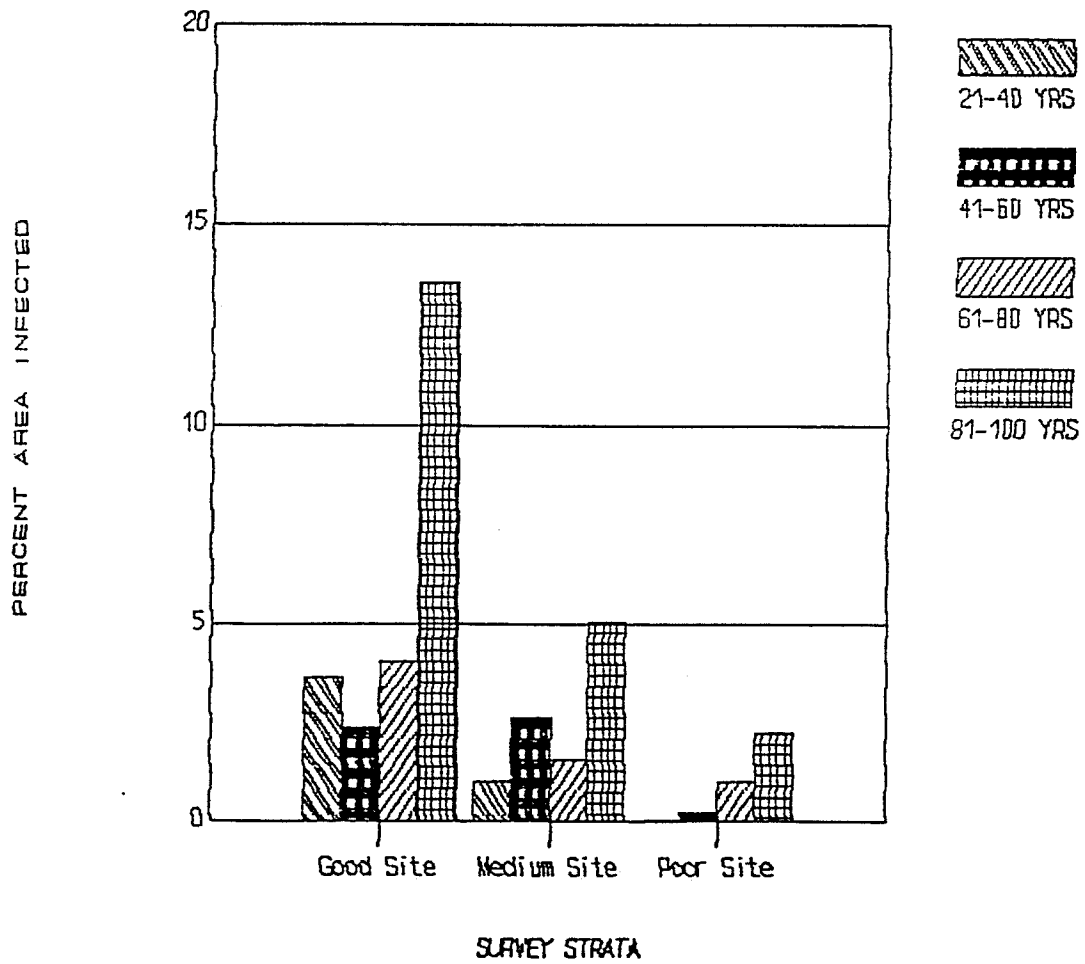


FIGURE 16.

**DISEASE SURVEY: Fir-Hemlock**  
**Mean Infection Level *A. ostoyae***

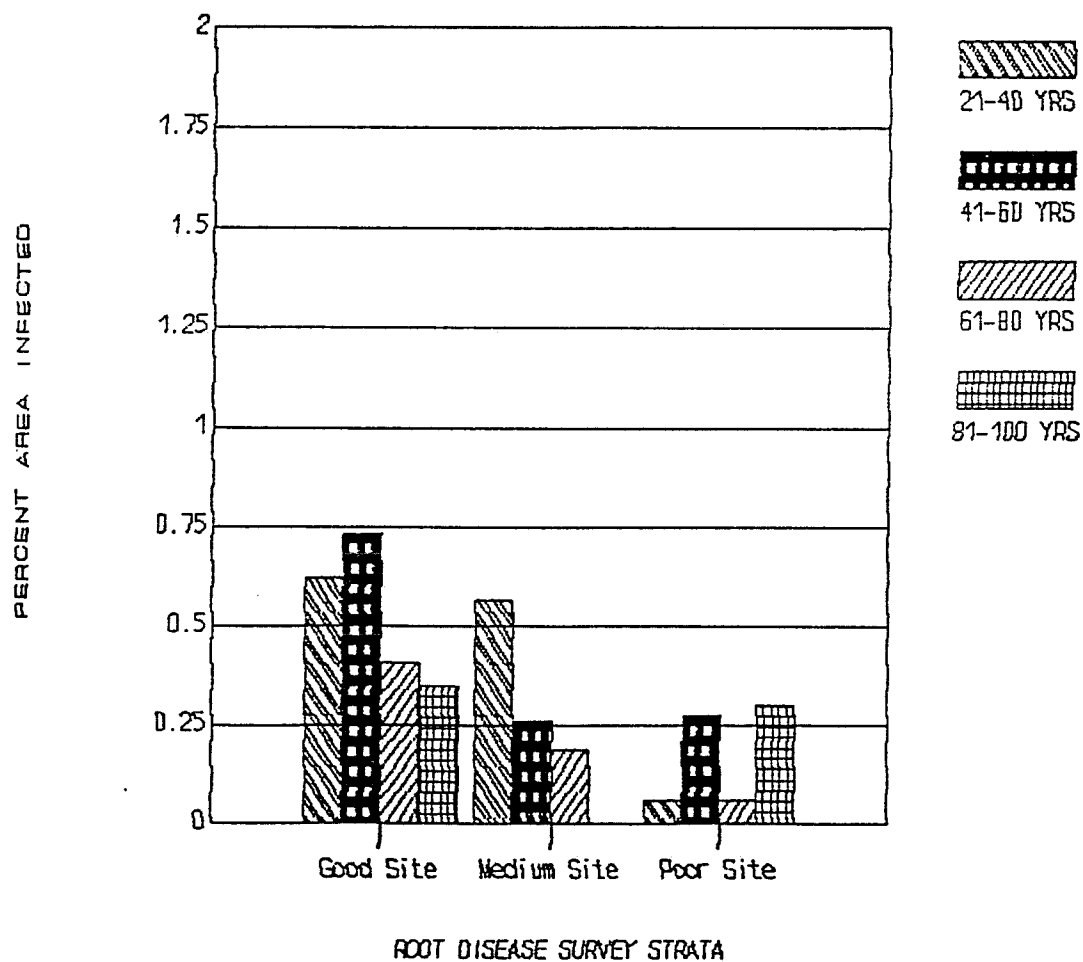


FIGURE 17.

DISEASE SURVEY: Fir-Hemlock  
Mean Infection Level *H. annosum*

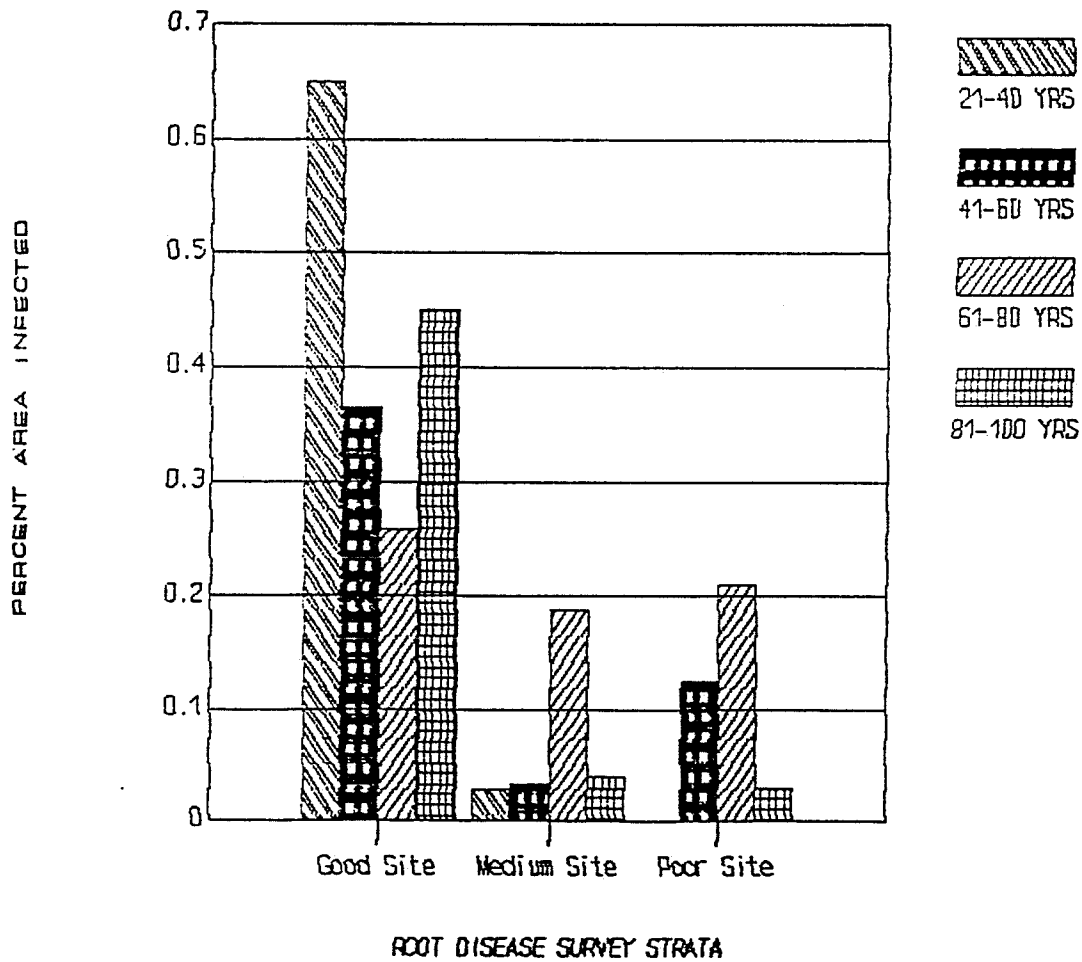


FIGURE 18.

**DISEASE SURVEY: Fir-Hemlock**  
**Mean Infection Level *C. wagneri***

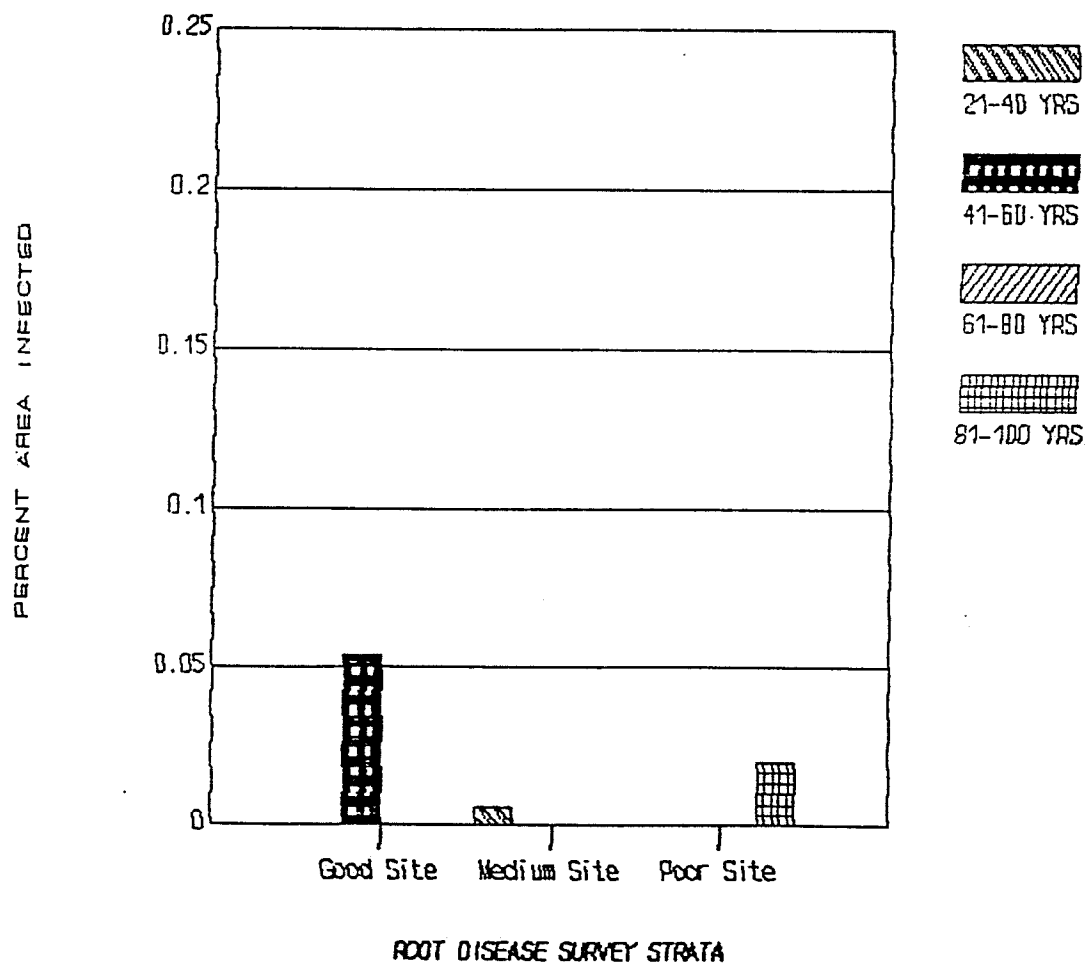


FIGURE 19.

SAMPLE SURVEY RESULTS, FIR-ONLY, QUADRA T.S.A.

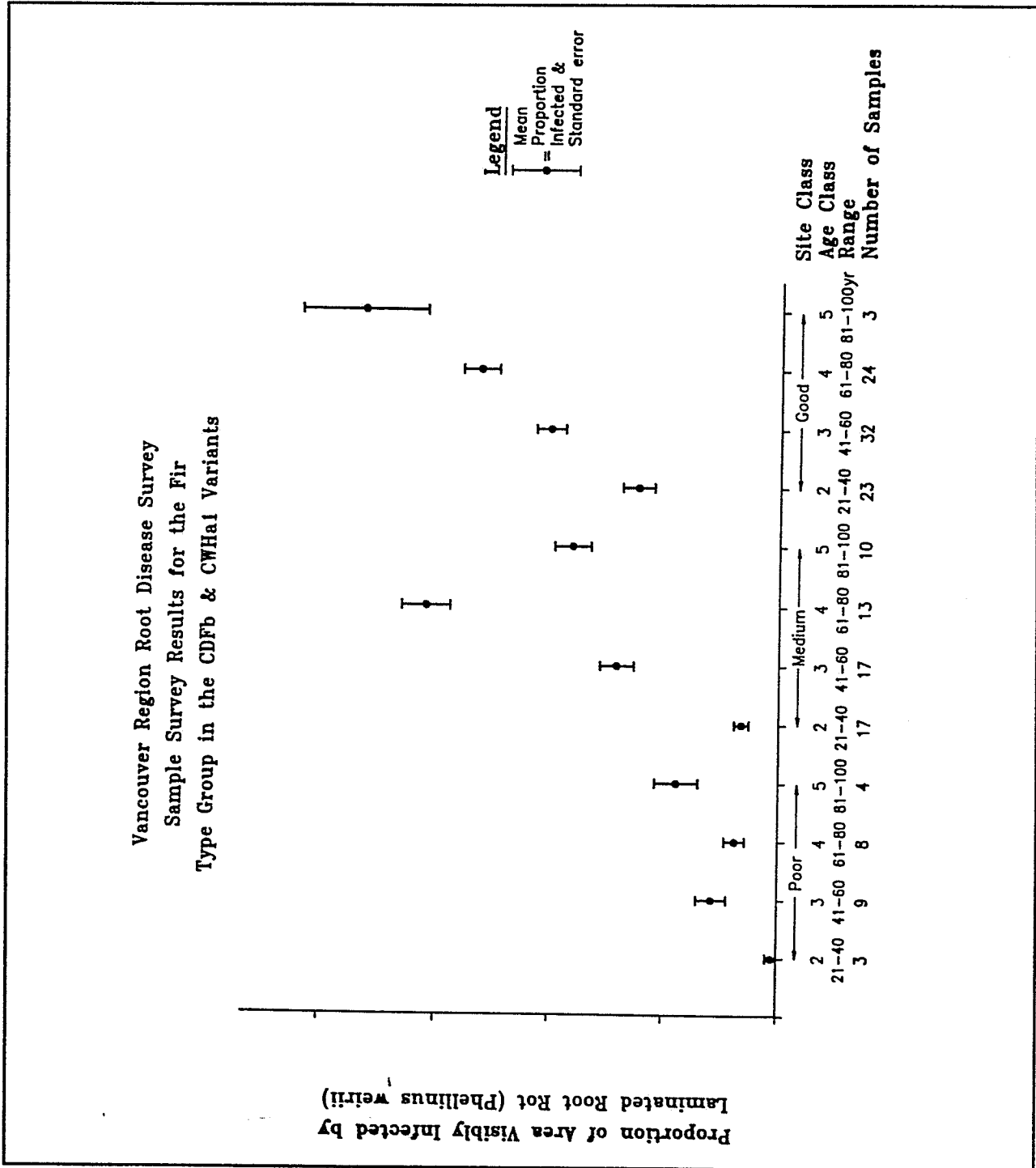


FIGURE 20.

SAMPLE SURVEY RESULTS, FIR-ONLY, QUADRA T.S.A.

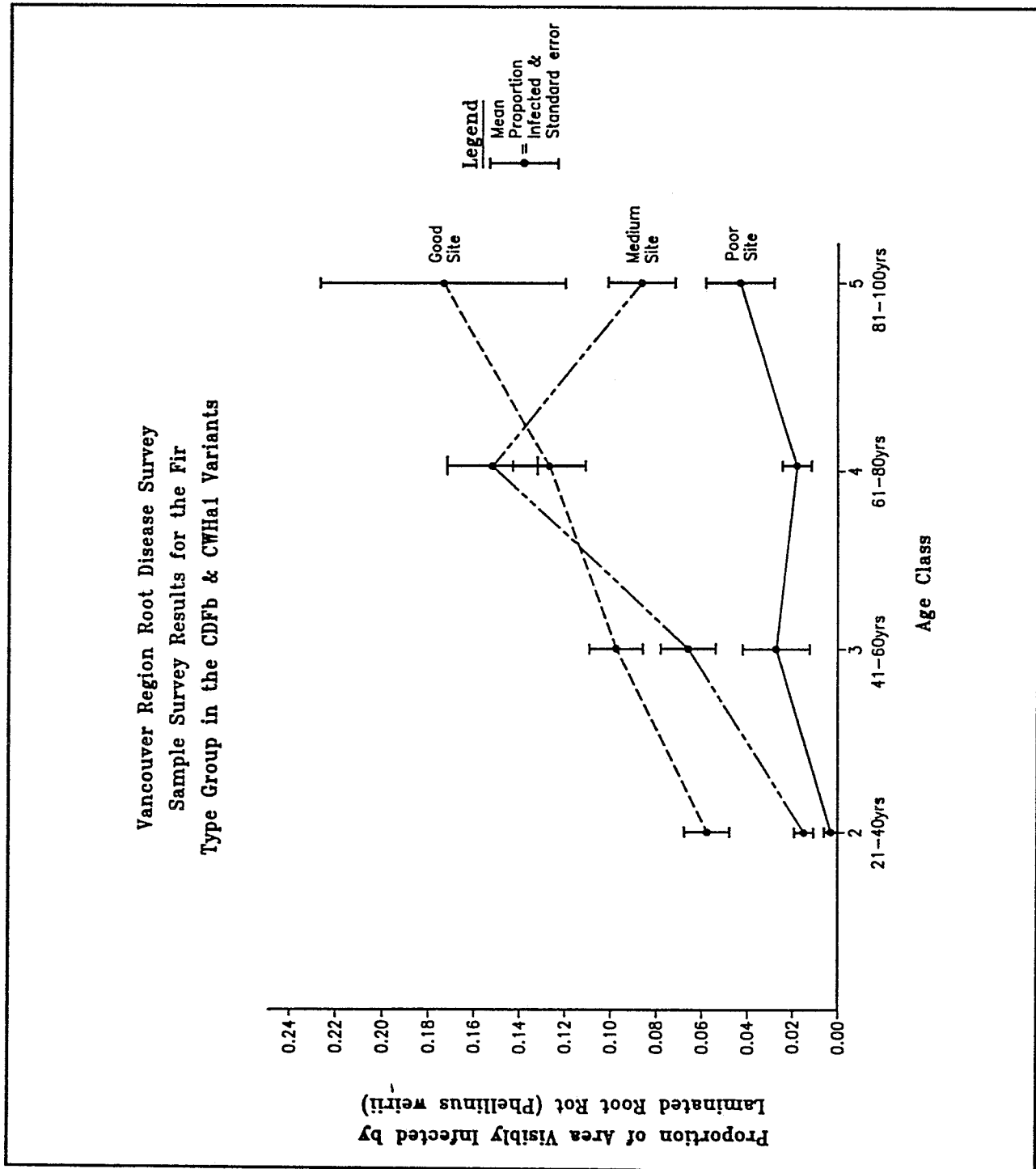


FIGURE 21.

ESTIMATED vs ACTUAL INFECTION PLOT  
FOR THE WHOLE DATA SET

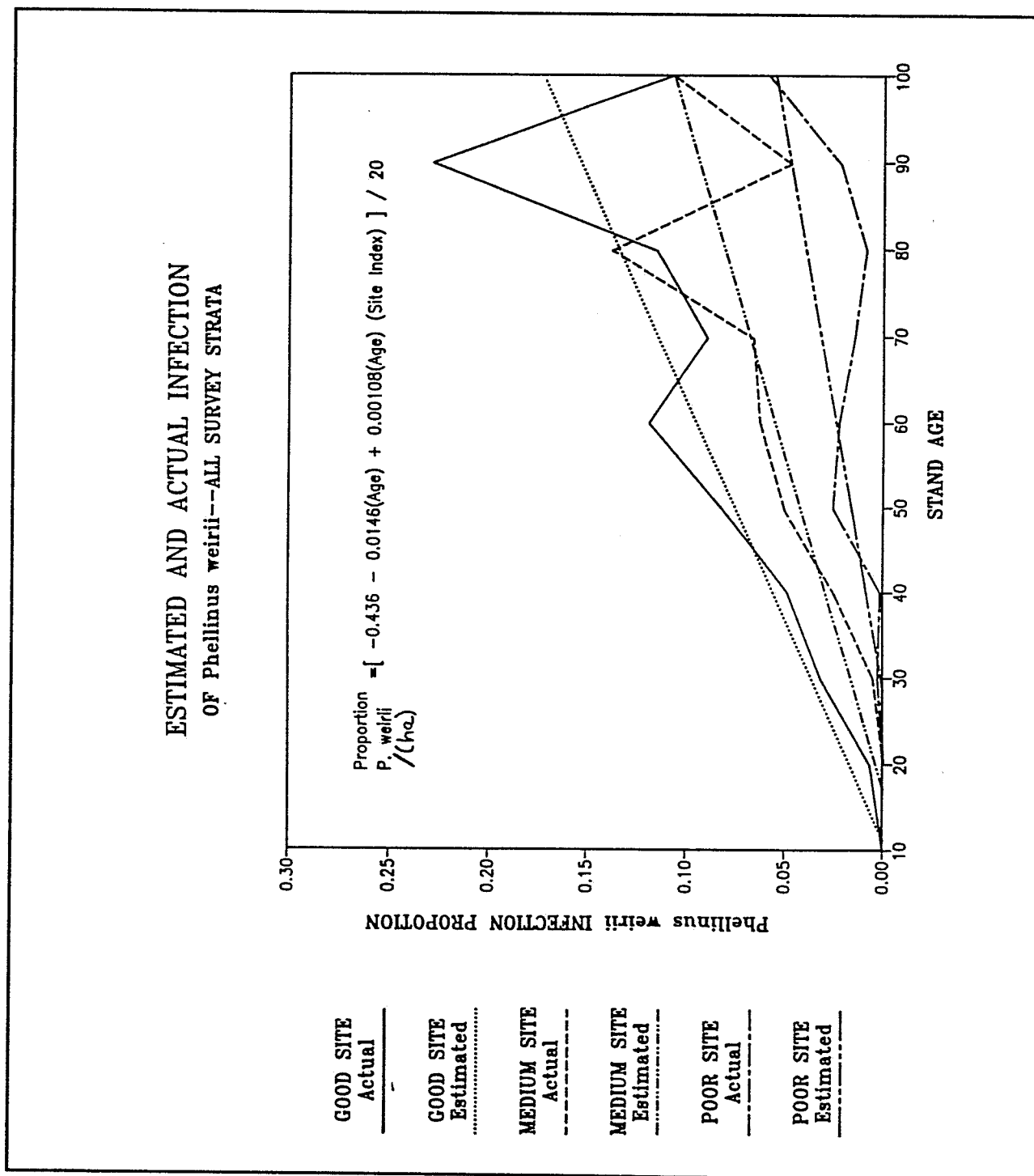
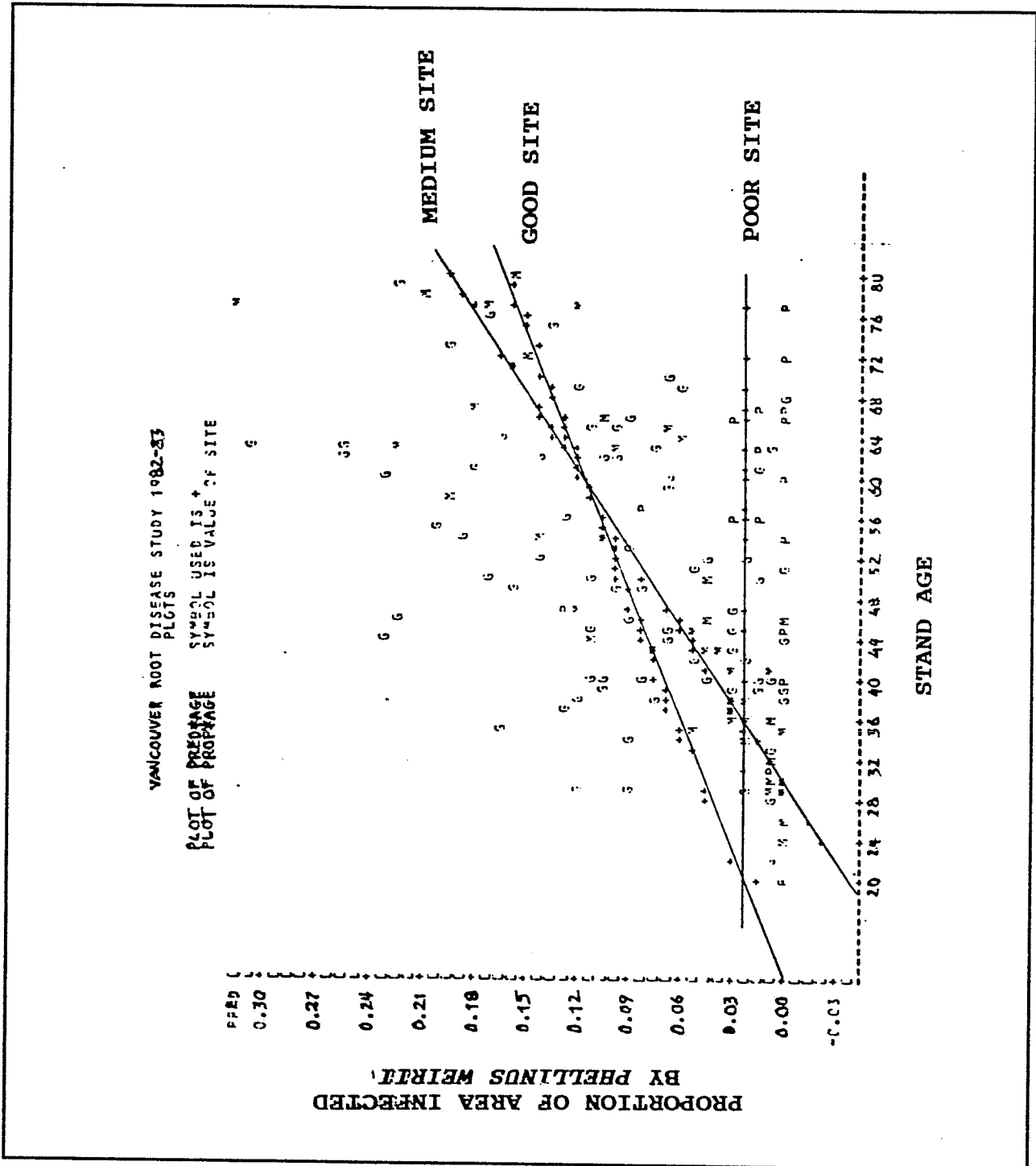


FIGURE 22.

PLOT OF TABLE 24 ANOVA FIR-85



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FIGURE 1.

TIMBER SUPPLY AREAS USED IN THE  
ROOT DISEASE SURVEY

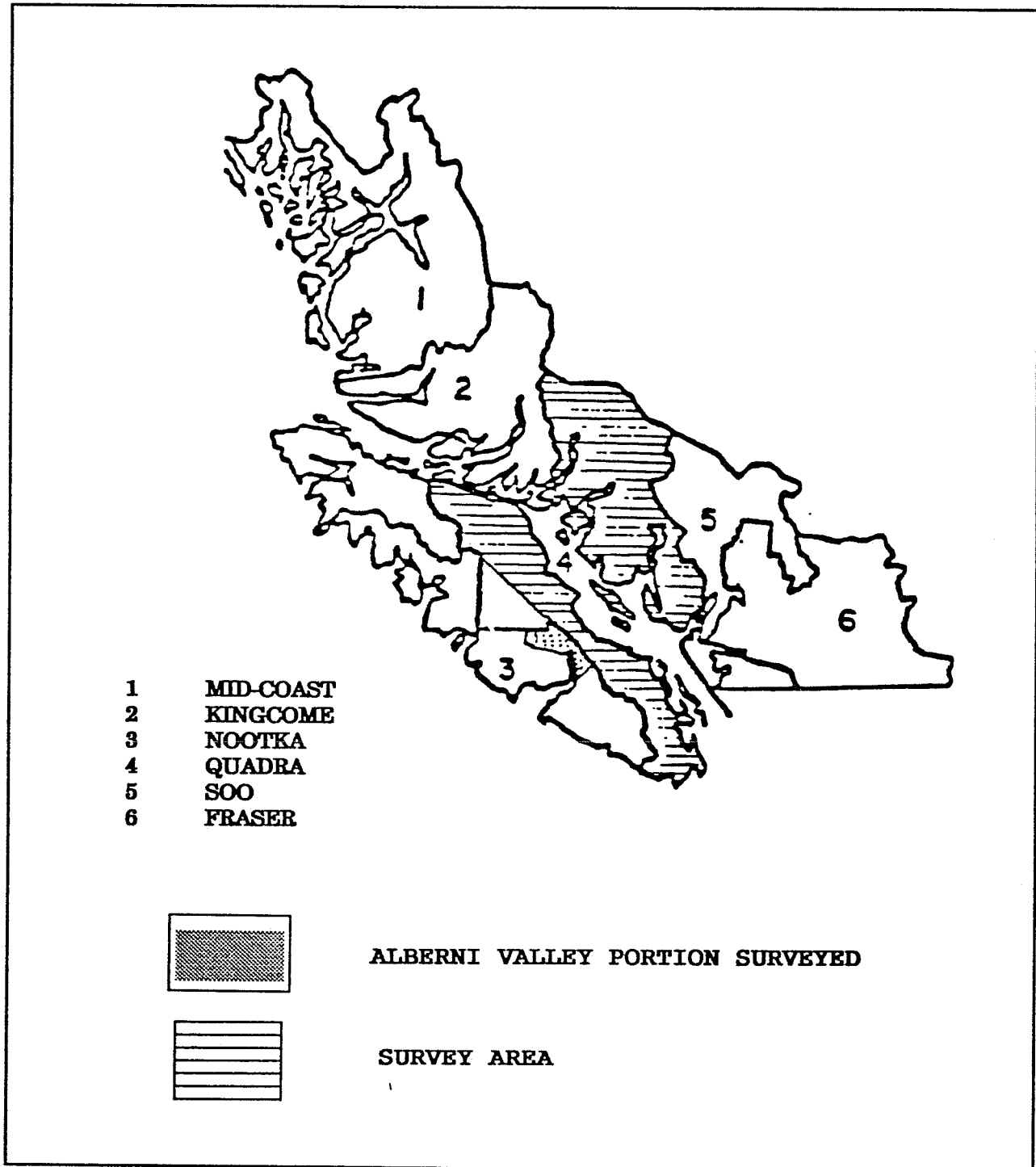


FIGURE 2.

VANCOUVER REGION ROOT DISEASE  
SURVEY: Survey Domain

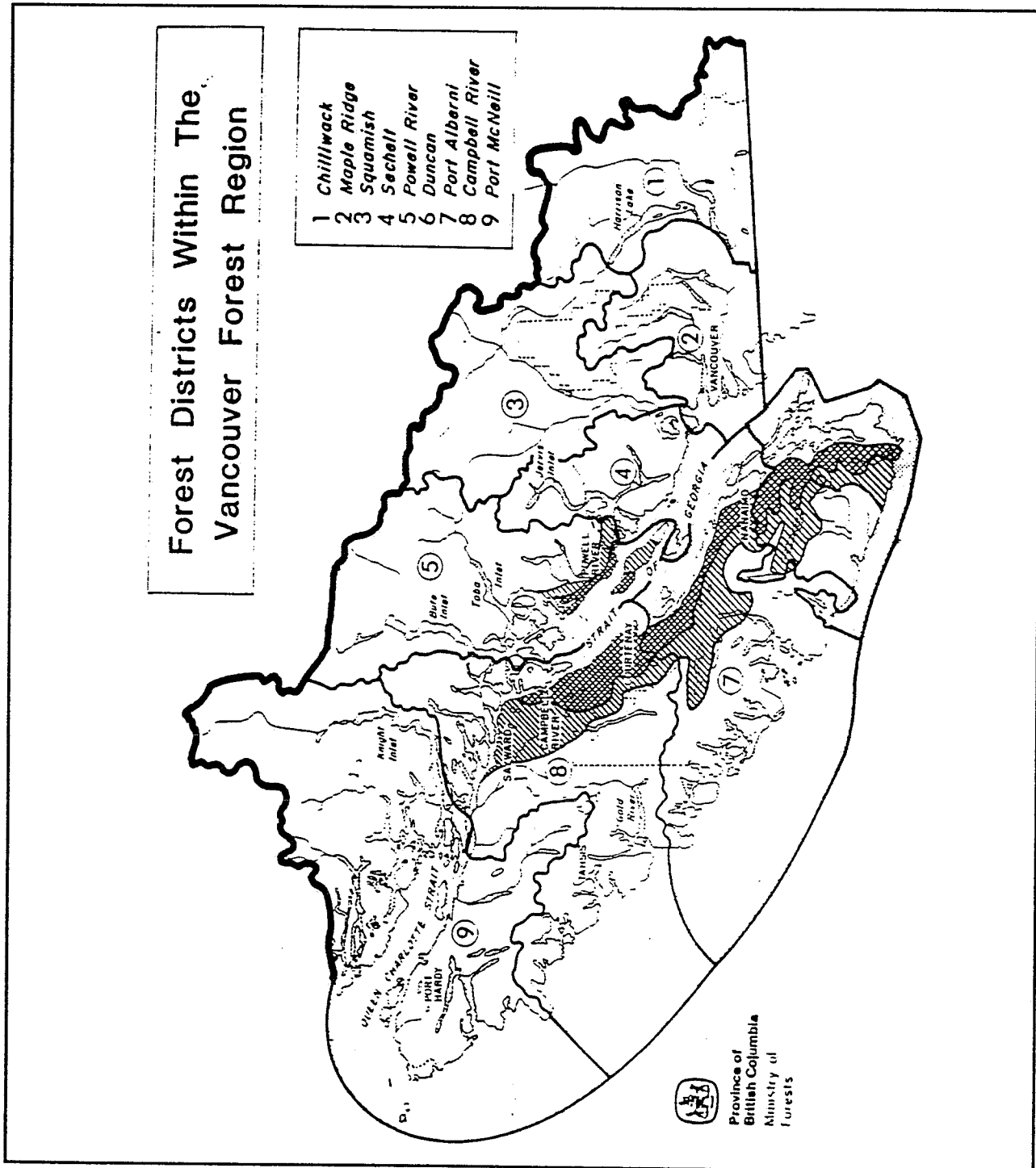
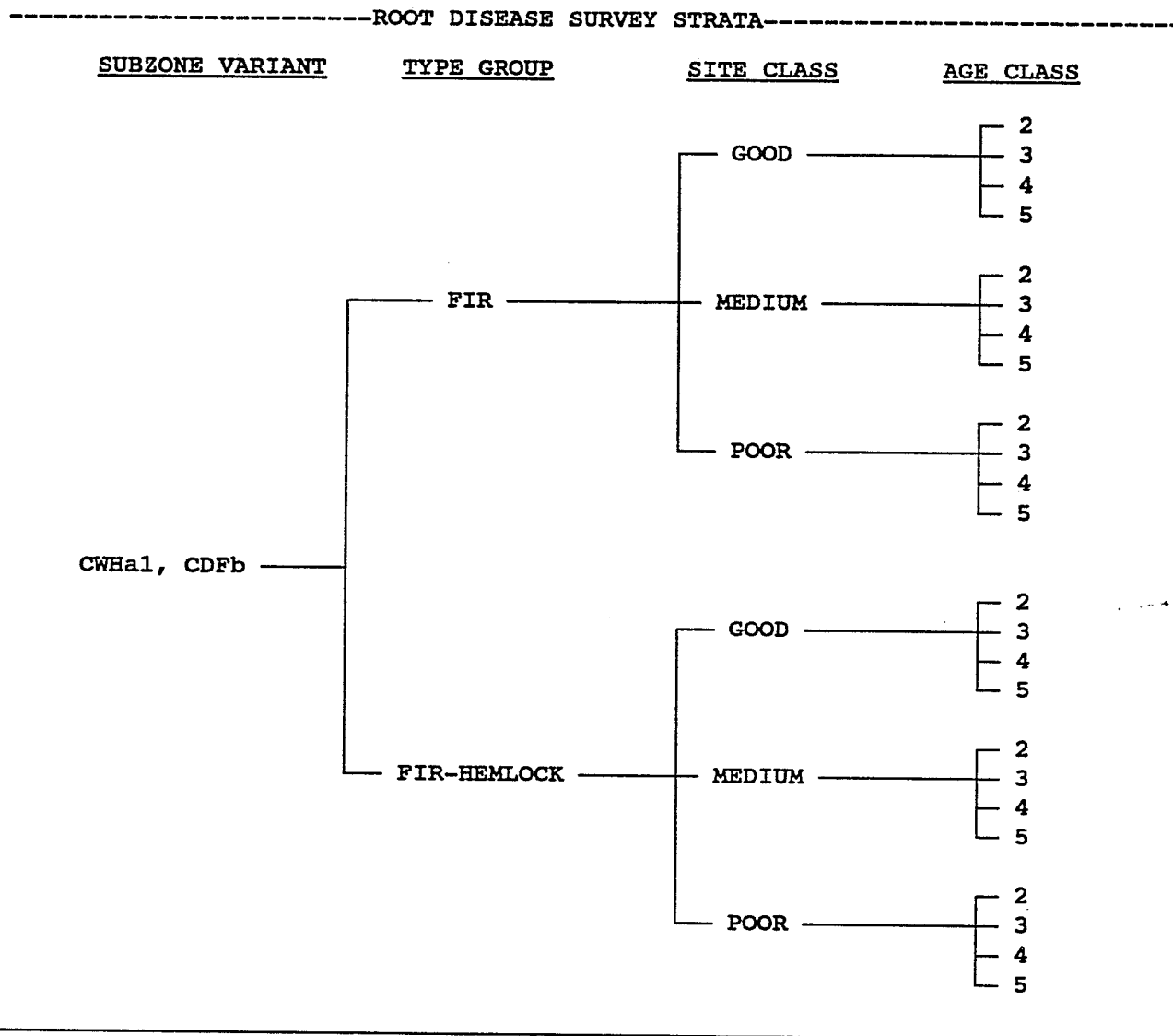


FIGURE 3.

VANCOUVER FOREST REGION 1982-83 ROOT DISEASE SURVEY DESIGN



1982-83 Vancouver Forest Region Root Disease Survey Design.  
The number of strata, 48, is calculated by multiplying the number  
of levels per stratum; ie.  $2 \times 2 \times 3 \times 4 = 48$ .