

LAMINATED ROOT ROT:
ECOLOGICAL RELATIONSHIPS AND STAND PRODUCTIVITY
IMPACTS IN COASTAL DOUGLAS-FIR ECOSYSTEMS OF
BRITISH COLUMBIA

by

JEFFREY DAVID BEALE

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Jeffrey David Beale

Department of Forestry

The University of British Columbia
2075 Wesbrook Place
Vancouver, B.C., Canada
V6T 1W5

August 10, 1990

ABSTRACT

The effect of laminated (*Phellinus*) root rot in coastal second growth Douglas-fir ecosystems of southeastern Vancouver Island was investigated in 139 ecosystems centered around 215 growth and yield permanent sample plots (PSP's). The impact of *Phellinus* root rot on stand productivity was estimated from PSP records and a percent basal area reduction (%BAR) parameter estimate determined using variable-radius plot sampling. The methods involved ecological site characterization to Biogeoclimatic Ecosystem Classification system units, sampling of root rot incidence and severity, and calculation of root rot damage intensity, sampling of old growth stand conditions (stand density and species composition), determination of second growth stand origin, and summaries of second growth stand conditions and growth and yield from the 30 to 35 yr long PSP records.

Phellinus root rot was present in 87% of the 139 sample survey units, while the incidence in the PSP's was 37%. Root rot damage intensity varied significantly between the CDFmm and CWHxm subzones, respectively 5.94% and 11.11%. Generally, root rot did not vary much between subzone variants, plant alliances and associations and site associations. The highest root rot intensity was in the mesic conditions and tailed off in the drier and fresher soil moisture regimes. Only stand density (stems/ha) of old growth Douglas-fir and western hemlock were significantly and negatively correlated with *Phellinus* root rot intensity. It appears that the nearly two-times greater density of old growth Douglas-fir in the CWHxm contributed to nearly double the damage intensity, as

compared to the CDFmm subzone. Trends in the old growth species composition indicated a natural, host-pathogen dynamic equilibrium is part of the ecosystem. That is, *Phellinus* kills-out susceptible, shade intolerant pioneer seral species by creating infection center gaps, making way for less-susceptible, shade tolerant mid-late seral species. In doing so, the inoculum is reduced but rarely eliminated, therefore keeping it in equilibrium with its hosts. Elevation (m asl), slope (%), mineral soil pH and coarse fragment content (% by volume) varied substantially between subzones, and likely play some role in the disease incidence and damage intensity. No other ecological site or stand attributes were correlated to damage intensity.

Second growth stand attributes (stand density (stems/ha), relative density and species composition) had similar distribution patterns to damage intensity, although no meaningful relationships were determined in multiple linear regression models. Second growth less- to non-susceptible host species composition was found to increase by about 4% in *Phellinus* infected conditions (both in temporary variable-radius %BAR sampling and PSP's) compared to a 0.2% increase in healthy conditions, strongly suggesting *Phellinus* acts as a biogenic successional agent that induces species shifts as part of the host-pathogen equilibrium.

Root rot damage intensities were highest in second growth stands of wildfire origin, followed by logged-only, then logged-and-slashburned stands. Although stand origin class ages varied significantly (they were positively related to the damage intensity) there was an indication that logging and logging-and-slashburning could have played a role in

reducing the inoculum levels particularly through fire.

Ecosystem hazard and *Phellinus* risk were approximated for ecosystem units on the basis of root rot incidence and intensity estimates. The site association taxon model (climax species potential) was found to accurately estimate *Phellinus* risk when the host *Phellinus* susceptibility patterns are considered in light of the postulated host-pathogen dynamic equilibrium.

Within a set of comparable PSP's, yield reductions ranged up to 30% depending on stand age and damage intensity. Yield models estimated volume reductions to range between 4.97 - 8.86% at age 80, or site height 35 m, depending on ecological and age 10 stand density stratifications. Percent basal area reductions ranged from 8.25 - 9.99%, depending on the species and diameter class stratification of the estimate parameter.

Management at the stand and forest level must consider the pervasive nature of *Phellinus* root rot. The significant ecological role the disease appears to play in inducing a species shift, has direct implications on the use of less-susceptible species in control and management strategies. Stand yield impacts appear to be substantial enough to warrant treatment where timber production objectives are primary.

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LIST OF SYMBOLS

Topographic Variables

<u>Name</u>	<u>Description</u>	<u>Measurement Unit(s)</u>
ELEV	Elevation above sea level	m
SLOPE	Percent slope	%
ASPECT	Slope aspect	Azimuth degrees

Mineral Soil Variables

ROOTDP	Major rooting zone depth	cm
RRLADP	Root restricting layer depth	cm
MOTDP	Depth to mottling zone	cm
SEEPDP	Depth to seepage	cm
CF20	Coarse fragment content by volume (ocular) for soil depth 10 to 30 cm horizon	(% or porportion of volume)
MSBDT	Total bulk density (coarse & fine fraction)	g/cm ²
MSBDF	Bulk density (fine fraction, <2 mm)	g/cm ²
PORF	Percent porosity (% volume occupied by air spaces)	%
SMR	Relative soil moisture regime categorical values (Klinka <i>et al.</i> 1984)	0 to 9
SNR\$	Relative soil nutrient regime categorical values (Klinka <i>et al.</i> 1984)	A-E
MSPH	Soil hydrogenion activity (pH) for 10 to 30 cm horizon	
MSC	Percent carbon (c) content for 10 to 30 cm horizon	%
MSN	Percent nitrogen (N) content for 10 to 30 cm horizon	%
MSCN	Carbon: Nitrogen ratio for 10 to 30 cm horizon	proportion
MEQCA	Milliequivalents calcium (Ca) for 10 to 30 cm horizon	meq
MEQMG	Milliequivalents magnesium (Mg) for 10 to 30 cm horizon	meq
MEQK	Milliequivalents pottassium (K) for 10 to 30 cm horizon	ppm
MSMN	Mineralizable nitrogen for 10 to 30 cm horizon	Kg/ha
MSMNK	Mineralizable nitrogen for 10 to 30 cm horizon	

Forest Floor Variables

FFPH	Hydrogen ion activity	pH
FFC	Percent carbon (c)	%
FFN	Percent nitrogen (N)	%
FFMN	Mineralizable nitrogen	ppm

Old Growth Mensuration Variables

SPHFH	Stems or stumps/ha of Douglas-fir and western hemlock	Sample plot mean
SPHCW	Stems or stumps/ha of western red cedar	Sample plot mean
COMPFH	Proportion of total species composition-- Douglas-fir and western hemlock	(proportion 1-1.0)
COMPCW	Proportion of total species composition - western red cedar	

Stand (History) Origin Variables

BURN	Wildfire origin
LOG	Logged-only origin
LOG & BURN	Logged and slashburn origin

Second Growth Mensuration Variables (PSP-based)

FSUS/LSUS	First/Last measurement; highly susceptible species (Fd, Bg) composition	Proportion of Total Composition (PropTC)
FINT/LINT	First/Last measurement; intermediately susceptible species (Hw) composition	PropTC
FRES/LRES	First/Last measurement; resistant species (Pl, Pw & Cw) composition	PropTC
FDEC/LDEC	First/Last measurement; deciduous species (Ar, Mb, Dr, Bi, Dw, Ch, Qg, Ac)	PropTC
FSUSINT	Sum of FSUS and FINT species composition	PropTC
FRESDEC	Sum of FRES and FDEC species composition	PropTC
FST4/LST4	First/Last measurement; stems/ha ≥ 4.0 cm dbh diameter limit	(stems/ha)
FBA4/LBA4	First/Last measurement; basal area/ha ≥ 4.0 cm dbh diameter limit	(m ² /ha)
FVL4/LVL4	First/Last measurement; volume/ha ≥ 4.0 cm dbh diameter limit	(m ³ /ha)
CRD1	Curtis' relative density, at first measurement	1-20
CRD87	Curtis' relative density at last measurement	1-20
CRDINCR	Change in relative density first to last measurement	1-20
AGE1	Total age (years since germination) at first measurement	yr
AGE87	Total age (years since germination) adjusted to 1987	yr
SI	Douglas-fir site index; top height at breast-height age 50 (Bruce 1981)	m
RRIN	<i>Phellinus</i> root rot incidence inside permanent sample plots	
STHGHT	Site height, average total height of site trees (sampling procedures vary but often largest diameter trees disease and damage-free)	m
STHGHT2	Site height squared for linear modelling purposes	

DSTHGHT1	Annual site height increment	m/yr
VOL4	Gross volume (≥ 4.0 cm) per hectare; observed and predicted	m^3/ha
DVOL4	Annual volume increment (≥ 4.0 cm) per hectare, per year; observed and predicted	$m^3/ha/yr$

Phellinus Root Rot Survey Statistics

%BAR	Percent basal area reduction, due to root rot, from the healthy condition	
S	Susceptible species to <i>Phellinus</i> root rot (Fd, Bg and Hw)	%
N	"Non-susceptible" species to <i>Phellinus</i> root rot (PI, Pw, Cw & Deciduous spp.)	
NS	"Non-susceptible" and susceptible species	
NSBAR	NS species %BAR statistic for ≥ 4.0 cm dbh diameter limit variable-radius samples	
SBAR	S species %BAR statistic for ≥ 4.0 cm dbh diameter limit variable-radius samples	(sample plot mean %)
BARS	S species %BAR statistic for $\geq 12.0/17.5$ cm dbh diameter limit variable-radius samples	(sample plot mean %)
BARNS	NS species %BAR statistic for $\geq 12.0/17.5$ cm dbh diameter limit variable-radius samples	(sample plot mean %)
NSSEV	NS species, ≥ 4.0 cm diameter limit, %BAR statistic for severity, or relative basal area reduction between healthy and infected variable-radius basal area estimates within a 25-plot sample survey, (see also Table 3)	(sample plot mean %)
SSEV	S species, ≥ 4.0 cm diameter limit, %BAR statistic for severity, or relative basal area reduction between healthy and infected variable-radius basal area estimates within a 25-plot sample survey, (see also Table 3)	
SEVS	S species, $\geq 12.0/17.5$ cm diameter limit, %BAR statistic for severity, or relative basal area reduction, (see also Table 3)	
SEVNS	NS species, $\geq 12.0/17.5$ cm diameter limit, %BAR statistic for severity, or relative basal area reduction, (see also Table 3)	
SALH	Severity sub-component; ≥ 4.0 cm diameter limit healthy condition, susceptible species	
NALH	Severity sub-component; ≥ 4.0 cm diameter limit healthy condition, non-susceptible species	
NSALH	Severity sub-component; ≥ 4.0 cm diameter limit healthy condition, non-susceptible and susceptible species	
SALI	Severity sub-component; ≥ 4.0 cm diameter limit infected condition, susceptible species	
NALI	Severity sub-component; ≥ 4.0 cm diameter limit infected condition, non-susceptible species	
NSALI	Severity sub-component; ≥ 4.0 cm diameter limit infected condition, non-susceptible and susceptible species	

SLSH	Severity sub-components; ≥ 4.0 cm < 12.0/17.5 cm diameter limit, healthy condition, susceptible species
NLSH	Severity sub-components; ≥ 4.0 cm < 12.0/17.5 cm diameter limit, healthy condition, non-susceptible species
NLSLH	Severity sub-components; ≥ 4.0 cm < 12.0/17.5 cm diameter limit, healthy condition, non-susceptible and susceptible species
SLSI	Severity sub-components; ≥ 4.0 cm < 12.0/17.5 cm diameter limit, infected condition, susceptible species
NLSI	Severity sub-components; ≥ 4.0 cm < 12.0/17.5 cm diameter limit, infected condition, non-susceptible species
NLSLI	Severity sub-components; ≥ 4.0 cm < 12.0/17.5 cm diameter limit, infected condition, non-susceptible and susceptible species
SGRH	Severity sub-components; $\geq 12.0/17.5$ cm diameter limit, healthy condition, susceptible species
NGRH	Severity sub-components; $\geq 12.0/17.5$ cm diameter limit, healthy condition, non-susceptible species
NSGRH	Severity sub-components; $\geq 12.0/17.5$ cm diameter limit, healthy condition, non-susceptible and susceptible species
SGRI	Severity sub-components; $\geq 12.0/17.5$ cm diameter limit, infected condition, susceptible species
NGRI	Severity sub-components; $\geq 12.0/17.5$ cm diameter limit, infected condition, non-susceptible species
NSGRI	Severity sub-components; $\geq 12.0/17.5$ cm diameter limit, infected condition, non-susceptible and susceptible species
N1	≥ 4.0 cm, non-susceptible species-only, healthy condition species composition
N2	≥ 4.0 cm, non-susceptible species-only, infected condition species composition
S1	≥ 4.0 cm, susceptible species-only, healthy condition species composition
S2	≥ 4.0 cm, susceptible species-only, infected condition species composition
N3	12.0/17.5 cm, non-susceptible species-only, healthy condition species composition
N4	12.0/17.5 cm, non-susceptible species-only, infected condition species composition
S3	12.0/17.5 cm, susceptible species-only, healthy condition species composition
S4	12.0/17.5 cm, susceptible species-only, infected condition species composition

DNBA	≥4.0 cm, non-susceptible species-only species composition, net of infected
DSBA	≥4.0 cm, susceptible species only species composition, net of infected
DBAN	≥12.0/17.5 cm, non-susceptible species-only species composition, net of infected
DBAS	≥12.0/17.5 cm, susceptible species-only species composition, net of infected

Biogeoclimatic Ecosystem Classification Variables

SUBZONE VARIANT	CDFmm, CWHxm CDFmm, CWHxm1, mx2
PORD p.all.	Plant alliance Plant alliance: Full (and abbreviated) names were; <i>Pseudotsuga-Mahonia</i> (<i>PseudMahonia</i>), <i>Tsuga-Mahonia</i> (<i>same</i>), and <i>Thuja-Tiarella</i> (<i>Thuja-Tiarlea</i>)
PASS p.a.	Plant association Plant association: Full (and abbreviated) names were; <i>Pseudotsuga-Arbutus</i> (<i>PseudArbutus</i>), <i>Pseudotsuga-Gaultheria</i> (<i>PseudGaulthr</i>), <i>Tsuga-Mahonia</i> (<i>TsugaMahonia</i>), and <i>Pseudotsuga-Achlys</i> (<i>PseudoAchlys</i>)
SASS s.a.	Site association Site association: Full (and abbreviated) names were; <i>Fd-Salal</i> (<i>Fsalal</i>), <i>FdBg-Oregon grape</i> (<i>FBoregrape</i>), <i>FdHw-Salal</i> (<i>FHsalal</i>), <i>HwFd-Kindbergia</i> (<i>HFKindberg</i>), and <i>Cw-Foamflower</i> (<i>CWfoamflowr</i>)

Tree Species (Common Names)

Fd	Douglas-fir
Bg	grand fir
Hw	western hemlock
Cw	western red cedar
Pl	lodgepole pine
Pw	western white pine
Ar	Pacific madrone (arbutus)
Qg	Garry oak
Ch	cherry
Dw	Flowering dogwood
Bi	paper birch
Mb	bigleaf maple
Dr	red alder
Ac	back cottonwood

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1.0 INTRODUCTION

Laminated root rot, a forest root disease caused by the pathogen *Phellinus weirii* (Murr.) Gilbertson, is considered to be the most damaging pest of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) second growth coastal forests of western North America (Childs 1963, Childs and Shea 1967, Wallis 1976). The effects of the disease are variable, but generally stand density and productivity falls below that of healthy stands over time (Mounce *et al.* 1940, Bier and Buckland 1947, Childs 1970, Johnson and Wallis 1972, Nelson 1980, Bloomberg and Reynolds 1985).

Forest pathologists have observed the incidence and intensity, of several root diseases to vary with certain forest, ecological and environmental site factors (Buckland *et al.* 1954, Williams and Marsden 1982, Hobbs and Partridge 1979, Reynolds and Bloomberg 1982, Whitney 1978, Shields and Hobbs 1978, Bloomberg and Beale 1985, Nilsen 1983, Huse 1983, MacDonald *et al.* 1987a, 1987b, Wilks *et al.* 1985), although causal relationships are difficult to quantify and confirm (Childs 1963, 1970). The possibility of patterns in the laminated (or *Phellinus*) root rot pathosystem of second growth coastal Douglas-fir ecosystems in British Columbia is of interest to forest pathologists, ecologists, silviculturists and forest managers alike. A study directed to assess whether ecological site factors influence or control the *Phellinus* root rot pathosystem, and to assess the impact on forest productivity would aid management of the coastal Douglas-fir ecosystem and provide direction for *Phellinus* root rot control research efforts.

British Columbia's ecosystem-based forest management using the system of Biogeoclimatic Ecosystem Classification (Pojar *et al.* 1987), provides the ideal basis for investigating and reporting on the epidemiological patterns of laminated root rot and its effects on forest productivity in second growth Douglas-fir ecosystems.

Specifically the objectives of the study are:

- (1) To assess *Phellinus* root rot damage intensity levels in coastal Douglas-fir ecosystems, particularly at the site classification level of the Biogeoclimatic Ecosystem Classification (BEC) system;
- (2) To develop a *Phellinus* root rot hazard and risk classification for BEC system units in coastal Douglas-fir ecosystems;
- (3) To develop a model of the relationships between *Phellinus* root rot and significant ecological, site and stand history factors in coastal Douglas-fir ecosystems;
- (4) To determine the effects on forest productivity attributable to *Phellinus* root rot in coastal Douglas-fir ecosystems through examination of species dynamics, stand growth and yield, and root rot damage intensity estimates;
- (5) To compare two *Phellinus* root rot sampling methods; (1) fixed-radius and (2) variable-radius plots;

- (6) To compare two damage expression terms (1) land-area diseased, and (2) stand-parameter diseased and;
- (7) To compare two disease dynamics relationships (1) incidence-severity and (2) incidence-intensity.

2.0 LAMINATED ROOT ROT BIOLOGY AND BEHAVIOUR

Disease development begins in a newly regenerating stand when healthy roots of susceptible tree species contact infected stumps and roots (inoculum sources) from the previous stand (Wallis and Reynolds 1965). Host tree species in coastal Douglas-fir ecosystems are in order of decreasing susceptibility: grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir, western hemlock (*Tsuga heterophylla* Bong.), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), and western white pine (*Pinus monticola* Dougl.). Western red cedar (*Thuja plicata* Donn. ex D. Don in Lamb) and all deciduous tree species are resistant to *P. weirii* (Wallis 1976, Hadfield 1985). Subsequent tree to tree infection spread occurs radially between living trees through root contacts. Both ectotrophic and endotrophic mycelial spread are involved in *P. weirii* transmission. Ectotrophic spread is more frequent and successful compared to endotrophic spread and is relatively unaffected by site or root factors (Bloomberg and Reynolds 1982). Fungal advancement continues proximally and distally along the roots causing decay and root death, resulting in reduced water and nutrient uptake and weakened structural support to the tree. Dependent upon tree age at infection, crown symptoms may appear 1 to 15 years later, with time-to-mortality inversely related to the tree's age at initiation of infection (Wallis 1976). Crown symptoms associated with laminated root rot are reduced terminal leader and branch growth, chlorotic and thinning foliage, and frequently observed distress cone crops (Mounce *et al.* 1940). The length of time until death or windthrow of crown symptomatic trees is variable, but is probably no greater than 15 years (Bloomberg 1983).

Laminated root rot is first manifested in young stands in one-to-two-tree infection centers five to twenty years after stand establishment. In coastal stands, laminated root rot appears to have a random, but often aggregated pattern of fairly discrete infection centers (Childs 1963, 1970, Foster and Johnson 1963). The likelihood of infection centers coalescing increases with stand age (Foster and Johnson 1967, Wallis and Reynolds 1965). Infection centers expand radially at approximately $30 \text{ cm/yr} \pm 15 \text{ cm}$ (Childs 1970, Nelson and Hartman 1975, Bloomberg 1984, McCauley and Cook 1980). Trees infected around the advancing perimeter of infection centers undergo increment reduction for several years before death. Continuing infection in stands of susceptible species will gradually reduce susceptible species stand density (basal area and stems per hectare) through tree growth reduction, usually followed by premature mortality and/or windthrow, leaving stands poorly stocked, often with non-productive openings (infection centers). Significant stand productivity losses, in terms of tree mortality, basal area, volume and periodic increment have been demonstrated in second growth Douglas-fir (Mounce *et al.* 1940, Bier and Buckland 1947, Buckland *et al.* 1954, Gillette 1975, Ford 1977, Bloomberg and Wallis 1979, Nelson 1980, Thies 1983, Bloomberg and Reynolds 1985).

Differential resistance to damage of Douglas-fir, first reported by Buckland *et al.* (1954), has important implications in damage detection and appraisal, and in the creation of inoculum sources. Trees showing no resistance are said to have "no formation of callus tissue or adventitious roots, as the disease spreads too rapidly for healing or compensation to occur", (Buckland *et al.* 1954). Such trees are killed by fungal growth solely in the sapwood. Trees showing resistance usually exhibit no visible distress

symptoms as the decay of roots is compensated for by callus tissue production and adventitious roots, thus maintaining vigour with marginal structural support, (Bloomberg and Hall (1986) have observed this phenomena in 30 to 40 yr old Doulgas-fir stands on Vancouver Island. "Resistant trees" can essentially maintain normal growth in protected, well stocked stand conditions for many years. It is still unknown if the differential resistance reported by Buckland *et al.* (1954) is genetically controlled (e.g., tree-age-at-infection response), environmentally site controlled, or a combination of these factors. The mechanisms which impede fungal development and decay actually aid in the pathogens' persistence in stumps and roots for periods exceeding 50 years. However, "resistant tree" inoculum likely poses a less serious threat as inoculum sources because the lower infected stump volume is usually well contained inside the callused stump (Buckland *et al.* 1954). These or other resistance mechanisms also aid in masking above-ground symptoms, which confounds disease detection and damage assessments.

As stand infection continues, reduction of *P.weirii* inoculum sources may occur in several ways: (1) windthrow and uprooting of inoculum; (2) amount and viability of ectotrophic *P. weirii* declines to near zero in forty years on old growth Douglas-fir stump and root systems (Hansen 1979); (3) succession to more disease tolerant tree species such as western hemlock, western red cedar, western white pine, lodgepole pine and many deciduous species. (Wallis 1976, McCauley and Cook 1980, Cook 1980, Williams and Marsden 1982, Dickman and Cook 1989); (4) tree resistance factors (Buckland *et al.* 1954); (5) reduction of root contacts over time due to stand density-related self-thinning and premature disease-related windthrow (Buckland *et al.* 1954); (6) activity of

antagonistic soil microbiological factors (Childs 1970, Rose *et al.* 1980, Hutchins and Li 1981, Hutchins and Rose 1984); (7) genetic variation of *P. weirii* clones in terms of pathogenic virulence hypothesised by Childs (1963, 1970), and demonstrated by Hansen *et al.* (1983).

The persistence and potential for carry-over into subsequent rotations is largely dependent on the presence, number, size and spatial distribution of inoculum sources (Childs 1970, Tkacz and Hansen 1982, Hansen *et al.* 1983). The role of basidiospore spread and infection in the disease epidemiology has been considered, but is not thought to be large (Childs 1970). Clearly basidiospores must play a role in at least long distance spread and infection to account for the pathogens extensive range, however infrequent or inefficient the means (Dickman and Cook 1989). Attempts to inoculate intact and wounded trees and stumps with basidiospores have failed (Nelson 1971).

In summary, the epidemiology of *Phellinus* root rot disease intensification and persistence, must consider clonal genetic variation of the pathogen (Hansen *et al.* 1983, Angwin 1985), mechanisms of tree resistance and disease persistence, the combined effects of site history (tree species succession, harvesting and fire patterns), stand attributes such as density and species compositions, and various ecological site conditions. Apparently the disease is under the influence of site factors, in fact it can be considered a disease of the site (Hadfield 1985). These factors are of utmost importance in assessing the hazard (stand susceptibility) and risk (probability and intensity of damage) of disease on forest sites.

3.0 A REVIEW OF SITE ECOLOGICAL RELATIONSHIPS OF *PHELLINUS WEIRII*

Evidence for the effect of site factors on the spread and persistence of *P. weirii* has been variable but generally indicates some correlations and relationships. Bier and Buckland (1947) report that *Phellinus* root disease occurred as abundantly on good as on poor sites of second growth Douglas-fir on southeastern Vancouver Island. Later, Buckland *et al.* (1954) observed that extensive disease spread appeared related to dense growth of shallow roots and high frequency of root contacts; root contact frequency rises from 20 to 60 years then drops-off. They also observed the most rapid spread and heaviest damage was in good, well stocked sites 20 to 60 yr old. Shallow soils induce shallow radiating root systems with a high frequency of root contacts, and therefore significantly contributes to disease spread and damage. Sites with deep, dry soils have lower disease spread rates since the roots are small, fibrous, and grow downwards, minimizing root contact frequency (Buckland *et al.* 1954). Childs (1970) reported that laminated root rot was common from sea level upwards, on good to poor sites, and on many kinds of soils from deep loams to gravels, but with no distinction between any geographic or site variables. Childs (1970) further stated that beyond stand history, stand density would most significantly affect the level of the pathogen on a site. More recently, Reynolds and Bloomberg (1982) reported the probability of intertree root contact is positively related to increasing d.b.h., percent slope, soil gravel content and stand density, while inversely related to rooting depth. Bloomberg (1990) has shown stand density to be positively related to disease spread rates in long-term monitoring plots.

In Oregon, experiments to assess the effects of soil factors (pH, nitrogen, moisture, temperature, bulk density and microorganisms) on *P. weirii* inoculation and ectotrophic growth response, suggest that soil environment does influence the rate of mycelial growth (Hansen *et al.* 1983, Angwin 1985). Several key responses of *P. weirii* to adjusted site factors found by Angwin (1985), summarised below, tend to support some site factor control on *P. weirii*. Maximum inoculation success and mycelial growth was observed at 15% soil water content, decreasing with higher or lower water content. Similarly with soil temperature, maximum growth, and to a lesser degree inoculation success peaked at 20 to 25°C levels, dropping by more than 50% for higher and lower soil temperatures. Increasing soil pH affected mycelial growth positively to pH 6.0 then dropped. It should be noted that soil pH above 5.5 stimulates bacteria and actinomycetes, some possibly antagonistic to *P. weirii*, and below pH 5.5 mineralization of immobilized nitrogen to ammonium is reduced, (the nitrogen form ammonium is useable by *P. weirii*). Finally, additions of urea-nitrogen fertilizer strongly reduced mycelial growth, possibly indicating a positive effect on host vigor, or antagonistic microorganisms and/or the indirect effect of lowering soil pH. All these factors, among others, are likely involved in the success and growth of *P. weirii*.

In a large scale root disease survey of coastal second growth Douglas-fir in B.C., laminated root rot damage intensity was found to vary significantly between biogeoclimatic subzone variants, forest cover type group and site quality (Beale 1987). Disease intensity was also strongly correlated with stand age and site index. The wetter maritime Coastal Douglas-fir subzone variant (CDFb), now CWHxm1, was 30 to 50% more severely infected

than the drier Coastal Western Hemlock subzone variant (CWHa1), now CWHxm2. The Douglas-fir inventory type group was infected at more than double the intensity of the Fir-Hemlock type group. Disease intensity predictions for the Douglas-fir type group estimate the Medium site quality to have the greatest intensity at harvest ages (80 yr, plus), followed closely by the Good sites and distantly by the Poor sites (Beale 1987).

In another study of root disease survey data, Bloomberg and Beale (1985) reported *P. weirii* infection intensity varied significantly ($p < .10$) between several ecological site unit classifications in the CDFb (now CWHxm1) subzone variant. Significantly lower damage intensity was observed in forest cover types containing western red cedar and lodgepole pine, and less so with types containing western hemlock. Several other root disease pathosystems, discussed below, are illustrative of these types of patterns too.

In northern Idaho, the occurrence of *P. weirii* and *Armillaria mellea* (Vahl. ex Fr.) Quel. *sensu lato*, is directly related to the occurrence of Douglas-fir and grand fir, and inversely related to elevation (Williams and Marsden 1982, Hobbs and Partridge 1979). Furthermore, significant slope-aspect, soil-aspect and habitat type-age interactions are important predictors for estimating the probability of root disease center occurrences (Williams and Marsden 1982). In northern Idaho, the incidence of pathogenic *Armillaria spp.* decreases as habitat type productivity increases, and further depends on specific combinations of habitat type and stand development history (McDonald *et al.* 1987a and 1987b). In other *Armillaria spp.* pathosystems, sites found to be most susceptible are low in pH (Singh 1983); low in pH, N, P, and Ca and high in K (Shields and Hobbs 1979); and

have high soil surface compaction (Ono 1970).

Whitney (1978), reported that tomentosus root rot (*Inonotus (Polyporus) tomentosus* (Fr.) Teng.) and *Armillaria mellea, sensu lato*, are positively affected by high soil moisture and fine soil texture. Van Groenewoud (1956) found *I. tomentosus* infection centers were in association with near-surface impermeable soil layers, or sandy soil veneers over very well-drained subsoils, causing more shallow-rooting than in healthy portions of stands. He also found that *I. tomentosus* infection centers are associated with acidic soil pH; centers were never found in soil pH greater than 7.0, and the damage was most severe in soils down to pH 4.5. Van Groenewoud (1956), concluded that the *white spruce (Picea glauca* (Moench.)) *Voss.-Hylocomium-Calliergonella* plant association is the most conducive to tomentosus root disease development. Low organic horizon pH, low nutrient content of the major rooting zone, and high stand density was common to the stand disease caused by *I. tomentosus* in spruce forests of northern Saskatchewan (Van Groenewoud and Whitney 1969). Spread of black stain root disease (*Leptographium wageneri* Goheen & Cobb (anamorph *Verticidiella wageneri* Kend.)) in the ponderosa pine (*Pinus ponderosa* Laws.) pathosystem of the Sierra Nevada in California is strongly related to high soil water potential, indicating spread is favoured on wetter sites (Wilks *et al.* 1985).

In Norway, Huse (1983), reported that the frequency of annosus butt rot, causal pathogen *Heterobasidion annosum* (Fr.) Bref., on Norway spruce (*Picea abies* (L.) Karst.), is positively correlated to tree diameter, increasing maturity class, soil depth, clay content

and slope, while negatively correlated to forest floor thickness and the extent of soil podsolization. The frequency of butt rot increases from poorer to richer site plant communities. In a similar Norwegian study of *H. annosum* butt rot frequency on older aged Norway spruce, no relationship with site class was found (Nilsen 1983). Nilsen (1983), also reported that butt rot was apparently more frequent in the *Melico-piceetum typicum* vegetation type (moderately poor site type), in good-drainage soils (they appear to be mesic), and in the 150 to 300 m elevation band. No strong relationships were found between butt rot frequency and soil chemical properties and pH (Nilsen 1983).

In summary, it is apparent from observations in the laminated root rot pathosystem and other related root rot pathosystems, that some combination of ecological factors either influences, controls, responds to, or is spuriously correlated with disease incidence and intensity patterns. Similarly, tree species susceptibility to infection, and past and present stand compositions (which are related to ecosystem-specific tree species successional chronosequences) are also shown to reflect the damage intensity of *P. weirii*, as also appears to be the case for other root rot pathosystems. By extension, the demonstrated reductions to forest productivity by *P. weirii* may also vary by some combination of ecological criteria or classification.

The literature suggests further studies are needed to understand *Phellinus* root rot damage and its effects on productivity, and its ecological role in different coastal Douglas-fir ecosystems. Such a study should consider evaluating the effects and interactions of ecosystems and their component variables, stand origin, and past and present stand

conditions (species composition and stand density (stems/ha, basal area/ha) on *Phellinus* root rot epidemiology.

Furthermore, in B.C. there is a critical and legal requirement to assess stand hazard (stand susceptibility) and pest risk (probability and intensity of damage) during certain phases of forest management to aid silvicultural decision making. Also, it is increasingly important to accurately reflect the effects of *Phellinus* root rot on growth and yield for stand and forest level planning, as the competition for scarce forest resources increases.

In order to achieve the study objectives, a sensitive and accurate estimator of root rot damage incidence, severity and intensity must be used to evaluate the relationship of *Phellinus* root rot to ecosystem site components, ecosystem classification taxon, stand history, past and present stand attributes, stand dynamics' parameters and its effects on forest productivity. The question of an appropriate damage intensity estimator is dealt with in the following section.

4.0 MEASUREMENT OF ROOT ROT INCIDENCE AND DAMAGE – A REVIEW

4.1 A Review of Measurement Methods

Measuring the effects of root rot on forest productivity remains a difficult task because there appears to be a lack of standardized and acceptable disease measurement terminology and sampling methodologies, that can provide accurate damage estimates with a direct (or even indirect) linkage to forest inventories and/or growth and yield projection systems. Furthermore, disease estimates are prone to large measurement errors because of difficult diagnostics due to highly variable tree susceptibilities and symptom expression, the decay and disappearance of killed trees over time, and observer experience.

Disease measurement terms such as incidence, intensity, frequency, severity and prevalence have been poorly defined and used interchangeably, in practice and in the literature, thus creating confusion in measurements and interpretation. To lend clarity to the selection of appropriate measurement terms consider that pests in general, and root rots in particular, have clumped distribution patterns of infection centers, with varying levels of damage within infection centers. It follows then, that measurement terms and sampling methods should attempt to describe/estimate the *degree of infection center coverage*, and the *degree of damage within infection centers*--which is analogous to, "How much root rot is there, and how is it affecting the crop?" A third measurement term

might be used to describe the combined-term *overall damage condition in a sample population*. Seem (1984), eloquently addresses these three disease measurement concepts in light of historical definitions and usage, and concludes with three pathometry (disease and damage measurement) definitions for:

- (i) degree of infection center coverage,
- (ii) degree of damage within infection center areas, and
- (iii) overall damage condition for a sample population.

The *degree of infection center coverage* is best described by the term incidence, which is defined as the proportion (0 to 1) or percentage (0 to 100) of diseased entities within a sampling unit (Seem 1984). Incidence is measured as present or absent (a binomial or quantal response), (Zadoks and Sehein 1979). Incidence is quickly and easily measured and generally more accurate and reproducible than other quantitative measures (Horsfall and Cowling 1978). These features of incidence measurement make it a favoured measure for detection and enumerations of disease spread patterns (Pearce 1976).

The *degree of damage within infection centers* is defined as severity, or the quantity of disease affecting entities within a sampling unit (Seem 1984). Severity also can be expressed as a proportion or percentage.

The *overall damage estimate* is defined by Seem (1984) as intensity, which is a product of incidence and severity (Moore 1953).

In Seem's (1984) definitions he stated that "... an entity is the plant part or plant population that is measured. A sampling unit is a group of entities that form a single composite or average measure. This distinction must be made when incidence and severity are compared because disease incidence on a single entity cannot be compared to severity." Relationships between incidence and severity can only be derived when entities are grouped into sampling units that are defined in a spatial hierarchy. For example, the spatial hierarchical levels for this study might be (from high to low spatial resolution); root, tree, fixed-radius plot/variable-radius plot (prism sweep), 1 ha sample survey, biogeoclimatic site series, site association, variant, subzone and zone. Sampling units are used to define the spatial hierarchical level in which incidence and severity measures are made. The sampling unit hierarchy is also necessary because an incidence measure at one level can become a severity measure at a higher level. As an example, incidence may be measured as the proportion of trees infected, and severity as the average number of roots infected per tree -- the sampling unit is in both cases the tree. If then, the incidence were measured as the proportion of 0.01 ha plots infected (the sampling unit is now 0.01 ha plots) the severity measure would become the number of infected trees in 0.01 ha sample plots.

Measurement of root rot incidence, severity and intensity generally falls into one of two damage expression estimates; (1) *land-area-diseased* per unit area (e.g., proportion

or percent), and (2) *stand-parameter-diseased* per unit area (e.g., stems/ha, basal area/ha or volume/ha) (Filip 1980). The choice of the sampling unit and sampling entity will determine the damage expression term, or conversely the choice of damage expression, based on end use objectives, will determine the sampling units and entities. Filip (1980) recognized four survey sampling methods for estimating *land-area-diseased*: (i) fixed-radius plots, (ii) variable-radius plots, (iii) line-intercept (Bloomberg *et al.* 1980), and (iv) aerial photography; and two sampling methods for estimating *stand-parameter-diseased* (e.g., inventory plots, growth and yield plots): (i) fixed-radius plots, and (ii) variable-radius plots.

4.2 Evaluation and Selection of an Appropriate Root Rot Measurement Method

The pathometry terms incidence, severity and intensity can be used as criteria for evaluating *land-area* and *stand-parameter-diseased* measurement expressions.

The *land-area-diseased* expressions appear best used for incidence, although given various spatial hierarchy sampling units (transects, swaths or plots), damage severity and intensity estimates can be derived. A disadvantage of the *land-area-diseased* expression is that it only samples land (Is it infected or not infected?), without providing a direct linkage measure or expression relating to stand attributes/parameters. This is unfortunate since *land-area-diseased* can only be determined by assessing disease incidence by looking at trees, the very parameter used for estimating *stand-parameter-*

diseased damage expressions.

The stand-parameter-diseased expression, given the same spatial hierarchy sampling unit restrictions, can provide incidence, severity and intensity estimates. Incidence is assessed on the basis of disease occurrence on a sampled stand parameter (trees), and severity is quantified on the basis of disease expression on some stand parameter (density or volume), with intensity multiplicatively derived from the two. The stand-parameter-diseased expression term provides a direct linkage to forest inventory and/or growth and yield. Interestingly, if incidence is also simultaneously determined on a land-area-diseased basis, incidence-severity, and incidence-intensity relationships (land-based to stand-based severity, or intensity) can be determined. The latter relationship could potentially simplify sampling methods and reduce costs, by estimating disease intensity from cheaper and easier to perform land- or stand-based disease incidence sampling.

Selection of a disease sampling method should then be based on; (a) the desired terms of disease expression, land- and/or stand-parameter-diseased, (b) the sampling objectives (e.g., general detection, stand or forest level damage appraisal, silvicultural treatment decision making or silvicultural treatment layout), (c) sampling costs, and (d) ease of use. Other sampling method factors to be considered are: (i) surveyors' proficiency in detection, diagnosis and delineation of disease conditions, (ii) variability of the sampling methods (usually not known), and (iii) the efficiency of the sampling method to estimate a land-area or stand-parameter-diseased.

Recall that the stated objectives of this thesis (see pg. 2) require an efficient and accurate sampling method to assess incidence and damage in land- and stand-based expressions so that ecological and stand dynamics relationships, and stand productivity responses to *Phellinus* root rot can be determined. A short review of various root rot sampling methods in use today follows.

The intersection length sampling method for root rots (Bloomberg *et al.* 1980) is a flexible set of survey options for making land-area-diseased assessments which can include a mapping option. It has been used extensively for disease incidence sampling in coastal British Columbia (Bloomberg 1983, and Beale 1987). Essentially the proportion of the line/grid transect lengths in root disease centers, defined by above ground disease symptomology, is the estimate of the land-area diseased (incidence or intensity estimate) per sample block. No estimate of disease severity is made using this method. Filip (1980), ranked this method second to fixed-radius plot sampling for accuracy, but twice as fast for assessing the land-area-diseased.

Fixed-radius plot sampling to estimate the land-area-diseased appears to be the most accurate and compatible for sampling small, irregularly shaped areas (Filip 1980). Filip's fixed-radius plot sampling method required surveyors to estimate the area infected within plots. The method is definitely slow, but it is highly accurate. Alternatively, the sampling could be much faster by only estimating disease presence or absence. This method can also be used to estimate stand-parameter-diseased terms, but is known to be less efficient than the variable-radius plot sampling discussed below.

Variable-radius plot sampling was least accurate for estimating land-area-diseased in Filip's (1980) study. However, simultaneous acquisition of stand-parameter-diseased data may offset the loss in accuracy of estimating the land-area-diseased using this method. Variable-radius plot sampling compared to fixed-radius plot sampling "is simpler...without sacrificing accuracy, reduces personal errors and provides a better balanced sample of the various diameter classes within the stand" (Dilworth and Bell 1979). In terms of simplicity "variable plot sampling does not require measurement of the plot radius or tree diameters to compute the basal area per hectare as with fixed-radius plots. Stem counts are made, with each tree contributing equally, without regard to diameter, to the basal area estimate" (Dilworth and Bell 1979). Similarly, disease conditions are tallied on a tree by tree basis. The principle of tree selection differs markedly between the two methods: Grosenbaugh (1952) states, "In (fixed-radius) plot sampling the probability of tree selection is proportional to tree frequency; in point sampling (variable-radius) it is proportional to tree basal area". These concepts are important for disease sampling because the impact of diseases on the basal area growing stock contributes the most to volume production. The latter can easily be computed from sample-based basal area/ha which is then factored by a sampled/or known volume:basal area ratio (VBAR), (Dilworth and Bell 1979). Although variable-radius plots are ideally suited to estimate disease severity (i.e., if basal area or volume is the desired parameter), the notion of disease incidence is most easily captured by stratifying sample plots on the basis of disease presence/absence. The proportion of the plots infected, to any degree (one or more trees), is termed disease incidence.

Forest disease surveys using variable-radius plots to estimate damage to stand parameters have been successfully conducted in the Pacific Northwest (Goheen 1979, Goheen and Worrel 1979). On Vancouver Island, B.C., Blair *et al.* (1975) used variable-radius plots in a sequential sampling scheme to estimate *percent basal area infected* in stands managed by MacMillan Bloedel Limited.

Several studies based on *growth and yield permanent sample plots or stem analysis plots* have also provided direct linkage to the effects of *Phellinus* root rot on stand productivity (Mounce *et al.* 1940, Bier and Buckland 1947, Buckland *et al.* 1954, Johnson *et al.* 1972, Nelson 1980, Thies 1983, Bloomberg and Reynolds 1985, and Bloomberg 1990). Recognition of pest activities in growth and yield or forest inventory permanent sample plots (PSP's) could allow for comparison of: (a) root rot incidence and, (b) growth and yield rates between PSP's affected and not-affected by root rots, given comparable initial stand and site conditions. These types of comparisons are basic to the hypotheses being examined in this thesis. Generally, sets of growth and yield PSP's might be suitable for extrapolation of damage effects on local stand productivity, whereas forest inventory PSP's would more likely be representative of forest conditions.

Based on the discussion of disease measurement terminology and sampling methodology, I propose a new comprehensive approach to root rot sampling that will include: (a) ecological characterization and stratification of sampling units, (b) land-area and stand-parameter disease incidence estimates, (c) stand-parameter-diseased estimates for damage severity and intensity using two different diameter limits and, (d)

land-area-diseased incidence estimates for growth and yield permanent sample plots. This methodology would provide the basis for studying ecological and stand dynamics relationships, development of incidence-severity and incidence-intensity relationships, and provide a direct linkage measure to forest inventory and growth and yield for assessing stand productivity responses to *Phellinus* root rot.

5.0 STUDY LOCATION

5.1 Geography

The study was conducted on the southeastern half of Vancouver Island between Union Bay and Shawnigan Lake; on the eastern slopes and coastal plain of the Beaufort Mountains, and the lower elevations around Port Alberni and south along the Alberni Inlet. Some additional PSP's were sampled in the lower elevations at the west end of Cowichan Lake. The study area is illustrated in Figure 1, and is better defined by the southern two-thirds of the shaded biogeoclimatic subzone variants in the figure.

5.2 Physiography

The study area lies within two major physiographic areas of the Western Canadian Cordilleran system: the Coastal Trough and the Outer Mountain Area.

The eastern portion of the study area lies within the Nanaimo Lowland of the Georgia Depression which rises to 600 m asl in the Vancouver Island Ranges, westwards from the Georgia Strait. The area is largely underlain by the Nanaimo Group of Upper Cretaceous sedimentary rocks (hard sandstone, conglomerate, shales and softer rocks), giving rise to differential erosion potential and soil parent materials. The Nanaimo Lowland was intensively glaciated during the Pleistocene, reducing relief and leaving behind a complex of glacial and glaciofluvial blankets and veneers (Holland 1976).

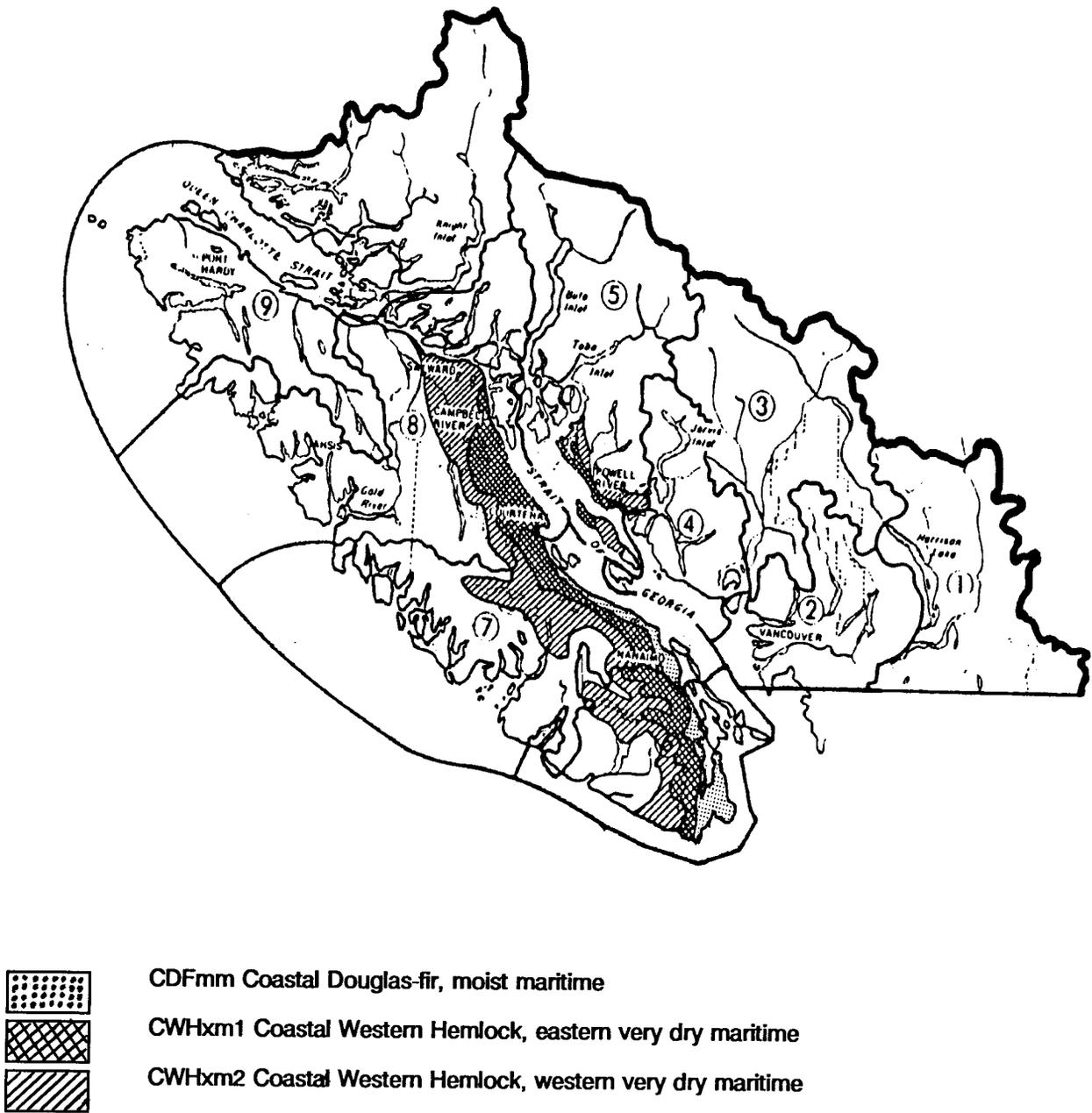


Figure 1 Study area and biogeoclimatic unit map. Note, the area from just south of Courtenay southwards comprised the study location. Source: Ministry of Forests, Vancouver Forest Region, Burnaby, B.C.

The western portion of the study area lies within the the Insular Mountains, comprised of the Port Alberni Basin and the Vancouver Island Ranges. The Port Alberni Basin is a low lying area extending northwestward from Port Alberni about 40 km with widths between 8 and 13 km. Its elevational boundary runs to about the 300 m contour on the north, west and southern flanks of the basin. The eastern flank is bounded by the scarp of the western slopes of the Beaufort Range. The basin is also underlain by Upper Cretaceous sedimentary rocks (Holland 1976). A third but very small portion of the study area lies within the Vancouver Island Ranges. The ranges are composed of a heterogenous group of pre-Cretaceous sedimentary and volcanic rocks with numerous granitic batholiths that run on a northwest-southeast axis (Holland 1976). The combination of alpine, valley and continental ice-sheet glaciation during the Pleistocene has produced soil parent materials of a very heterogenous nature on southern Vancouver Island, particularly in the study area (Jungen *et al.* 1985).

5.3 Soil Parent Materials--Surficial Deposits

Two periods of glaciation 18,500 and 11,500 years ago resulted in extensive deposition of fluvial and morainal materials, as well as marine deposits (Jungen *et al.* 1985). Fluvial deposits consist of glaciofluvial and contemporary fluvial deposits; its materials are sorted and less heterogenous than morainal deposits (Howes and Kenk 1988). Common glaciofluvial landforms are old river terraces or raised estuaries composed of coarse sands to sandy gravels. Finer textured, fluvial and glaciofluvial deposits are found at lower elevations and near active rivers (Jungen *et al.* 1985). Glacial

morainal deposits are composed of an unsorted heterogenous mixture of sands, silt and clay with variable amounts and sizes of coarse fragments (Howes and Kenk 1988). Morainal deposits (tills) are generally very compacted, coarse textured and bouldery. Some finer textured tills derived from shales and volcanic rock, are found near Courtenay, Nanaimo and Port Alberni. Sandy tills are derived from sandstone bedrock and interglacial sands (Jungen *et al.* 1985). Marine deposits found at elevations below 100m in the Nanaimo Lowland (Jungen *et al.* 1985) were formed as a result of land submergence and uplifting following glaciation (Howes and Kenk 1988). Colluvial deposits, resulting from mass wasting (Howes and Kenk 1988) are usually found on, or at the base of, steep slopes or in areas of interspersed exposed bedrock. Colluvial deposits are composed of angular, nonuniform sized coarse materials ranging from bouldery to sandy gravel, thus generally well drained (Jungen *et al.* 1985).

5.4 Climate

The study area is completely within the rainshadow effect of the Olympic Mountain Ranges in western Washington State and the Vancouver Island Ranges to the west of the Alberni Basin and to the west of the Nanaimo Lowlands. Thus, the area is in a leeward position to the westerly prevailing moist Pacific weather systems. This is indicated in the naming of the regional climates (biogeoclimatic subzones) within B.C. (Klinka *et al.* 1984). The climate according to Koppen, as described by Trewartha (1968), ranges from Csb to Cfb. This indicates a mild, temperate, rainy climate with a cool summer, with a minor distinction of a dry summer (s), *versus* a no-distinct dry season (f). The dry summer

climate (Csb) is found near the Georgia Strait and the Alberni Basin, while the no-distinct dry season climate (Cfb), is primarily a feature of increasing elevation and westward geographic location. Klinka *et al.* (1979) reports that three distinct regional climates can be identified for the climatic gradient within the study area. These are listed by their revised BEC unit names (Banner *et al.* 1990) as:

- CDFmm (CDFa1) = Moist Maritime Coastal Douglas-fir subzone variant,
 CWHxm1 (CDFb1) = Eastern Very Dry Maritime Coastal Western Hemlock subzone variant,
 CWHxm2 (CWHa2) = Western Very Dry Maritime Coastal Western Hemlock subzone variant (see Fig. 1).

Further analysis of climatic data by (Courtin 1990) has confirmed the presence of three regional climates, which are a major basis for differentiating ecosystems in the biogeoclimatic ecosystem classification system (Klinka *et al.* 1984; Pojar *et al.* 1987) (see Table 1).

Climatic Property	Subzone Variant		
	CDFmm	CWHxm1	CWHxm2
Mean Annual Precipitation (mm)	873	1215	2123
% Percipitation As Snow	6	9	7
Precipitation Of Driest Month (mm)	18	28	35
Warmest Month Mean Temperature (°C)	16.8	17.4	17.4
Growing Degree Days > °C	3550	3459	3360

5.5 Forest Cover and Stand History--Past and Present

The study area is under an extensive cover of predominantly naturally regenerated, second growth, even-aged, Douglas-fir forests. These forests regenerated largely as a result of the forest industry which began at Chemainus, B.C. in 1862. Expansion of the industry, particularly up and down the Vancouver Island coastline, occurred because of the construction of the Esquimalt and Nanaimo (E&N) Railroad in 1886 (Jungen *et al.* 1985). The coal mining industry, centered in and south of Nanaimo, also cut extensively from the local forest for mining timber peaking between 1901-1930's (Jungen *et al.* 1985). The historical progression of logging from the coastline westwards, across the Nanaimo Lowlands and into the Alberni Basin, is seen in the decreasing average PSP age across the biogeoclimatic subzone variants; CDFmm, CWHxm1, and CWHxm2, have an average age of 76, 70 and 59 years, respectively.

These second growth forests are generally pure Douglas-fir (>80% species composition by volume), with minor mixtures of western hemlock, western red cedar, grand fir, western white pine, lodgepole pine, red alder (*Alnus rubra* Bong.), bigleaf maple (*Acer macrophyllum* Pursh.), arbutus (*Arbutus menziesii* Pursh.), and Garry oak (*Quercus garryana* Dougl.), depending on the ecological and historical conditions affecting stand development. The second growth Douglas-fir forests are now in a mid-seral condition, with a mean age of 70 years. The majority of stands regenerated following harvest of predominantly old-growth Douglas-fir forests containing sizeable components of western red cedar and likely some western hemlock, depending on ecological site conditions and

6.0 METHODS

6.1 General Approach

This study was observational in nature, and was aimed at collecting data and determining relationships between *Phellinus* root rot incidence, severity and intensity and the following datasets: growth and yield, ecological characteristics, stand history, and old growth and second growth stand attributes within the coastal Douglas-fir ecosystems of B.C.

6.2 Sampling Design

This study was focused on a set of 215 PSP's located on southeastern Vancouver Island, within the CDFmm, CWHxm1 and CWHxm2 biogeoclimatic subzone variants. With the exception of 11 PSP's near Cowichan Lake, the core set of 204 PSP's are the property of MacMillan Bloedel Limited. The PSP's are located on either Managed Forest Unit No. 19, or Tree Farm Licence No. 44 in several forest operations divisions: Cameron, Sproat, Northwest Bay, Chemainus and Shawnigan. The 11 PSP's near Cowichan Lake are on Managed Forest Unit No. 7, owned by Canadian Pacific Forest Products Limited.

Historically, most growth and yield PSP's were located to meet "normal forest" condition sampling objectives (i.e., avoiding disturbances such as poor stocking, rock outcrops, windthrow conditions and insect and disease damage (Iles 1987)). In the past,

a small proportion of PSP's, about 15%, were established randomly (Northway 1990). Most natural, unmanaged Douglas-fir PSP's were established between 1955 to 1965, in 30 to 40 yr old stands. Both the date, and stand age at PSP establishment make it likely that some PSP's were located on infected sites. Root rots were not widely known or understood at that time, and the first major wave of root rot symptoms and mortality would have just begun in stands of those ages. The small area of the PSP's, generally 0.04ha, makes it difficult to assess root rot dynamics (not a study objective *per se*), but due to plot locating procedures, any root rot incidence in the plots is most likely due to incursion from nearby root rot centers rather than to PSP establishment in infection centers.

A vast amount of soils data had been collected in the past decade in many of the PSP's, which could aid in ecological correlation and classification work, saving significant soil sampling and analytical costs (Kumi 1987, and Beese 1987). Both owners of the PSP's knew that an undetermined but sizeable number of Douglas-fir PSP's were infected with *Phellinus* root rot, and that there was an opportunity cost to not determining the damage effects due to the disease. It was felt the value of 30 to 40 years of connected plot growth data on a fairly wide range of sites, in over 200 PSP's, should override any concern over using PSP's located for different objectives. Intensive stand-parameter-diseased root rot sampling as proposed, in such close proximity to the PSP's would also provide for the best possible linkage to growth and yield, and perhaps to the forest inventory, if the study results could be corroborated with large-scale root disease surveys

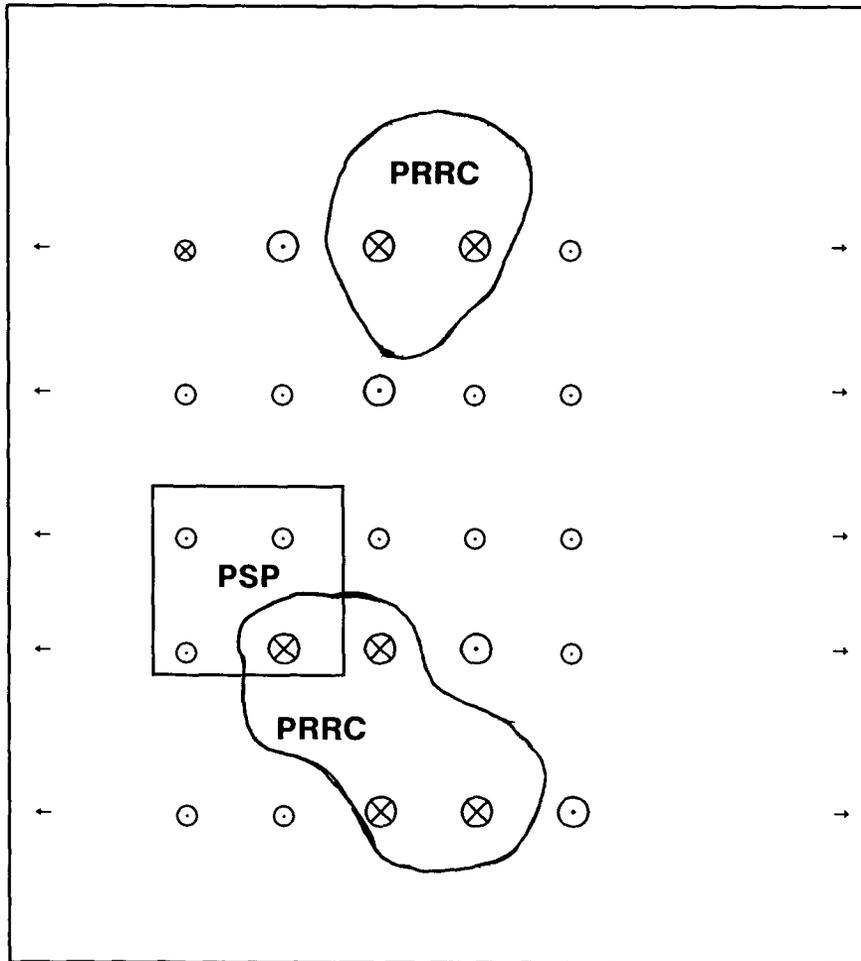
such as that reported by Beale (1987).

All unlogged, pure Douglas-fir (>80% by volume at PSP establishment), naturally regenerated (5% turned out to be planted), non-silviculturally treated PSP's in 30 to 120 year old stands were selected for sampling from MacMillan Bloedel's growth and yield database. The PSP's selected from Canadian Pacific Forest Products were selected similarly, but focused solely on very high site qualities only. This latter selection was an attempt to fill a gap in site association coverage that was recognized after field sampling and preliminary ecological analyses were done. Random selection of PSP's would have been considered if some level of site classification were known. PSP selection would then have been made equally or weighted proportionally to the representation of PSP's across the distribution of site associations/series or types, thereby reducing sampling costs. Since the biogeoclimatic classification was not available, all 215 PSP's were visited during the study.

The sampling design and procedures for all datasets were centered on a 1 ha sample of the contiguous ecosystem identified at each selected PSP location. A contiguous ecosystem was first defined at the site type level (Banner *et al.* 1990), but was found too impractical given significant soils variability. A more reliable and easier definition for the 1 ha sample survey was set at the site series level of the BEC system. The generalized sampling procedures were:

1. Ecological characterization to the site series level was done in, or as close to the selected PSP as possible. This included description of vegetation, physiography, soils and forest floor. Aggregation of ecologically similar PSP's within growth and yield installations was done where appropriate.
2. Sampling for root rot incidence and severity, and old growth stand history (stems/ha and species composition) was conducted simultaneously on a systematic, 20 m-grid interval (25 plots) within the contiguous ecosystem as identified at the PSP, with the PSP located centrally where the PSP location and ecotone allowed, (Fig. 2).
3. At each of the 25 plot centres, root rot incidence was sampled using; (i) a land-area-diseased estimate based on 0.005 ha fixed-radius plots and, (ii) a stand-parameter-diseased estimate using variable-radius plots, (Fig. 2).
4. At each of the 25 plot centres, root rot severity was sampled using the stand-parameter-diseased expression by establishing two separate diameter limit (≥ 4.0 cm and $\geq 12.0/17.5$ cm), same basal area factor variable-radius plots. Two diameter limits were used to sample ingrowth due to *Phellinus* root rot disturbances, (Fig. 2).
5. At each of the 25 plot centres, old growth stand conditions (stems/ha and species composition) were estimated from 0.01 ha fixed-radius plots.

6. Each PSP was assessed for incidence of *Phellinus* root rot, (Fig. 2).
7. Permanent sample plot growth and yield data collected by the PSP owners, provided stand origin, mensuration and species dynamics data.



LEGEND:

PSP = A *Phellinus* Infected Permanent Sample Plot; RRIN = 1

 PRRC = *Phellinus* Root Rot Centre

 Healthy Fixed-Radius and Variable-Radius Plot; DSPT=0, DSWP=0

 Healthy Fixed-Radius and Infected Variable-Radius Plot; DSPT=0, DSWP=1

 Infected Fixed-Radius Plot and Healthy Variable-Radius Plot; DSPT=1, DSWP=0

 Infected Fixed-Radius Plot and Infected Variable-Radius Plot; DSPT=1, DSWP=1

 Example Sampling Transect

Figure 2 Sample plot layout centered about a permanent sample plot within a contiguous, homogenous ecosystem as defined at the site association level. Under optimal conditions a 5 by 5 sample plot grid (25 point) layout was located. Example transects illustrate all possible disease incidence conditions; RRIN and DSPT/DSWP (0)=Healthy, (1)=Infected.

6.3 Measurement Of Root Rot Incidence, Severity and Calculation of Intensity

Incidence of *Phellinus* root rot was sampled for, estimated and expressed in three ways; one method for PSP's and two methods for the Percent Basal Area Reduction (%BAR) sample surveys:

Permanent Sample Plot--*Phellinus* Incidence

- (1) The presence/absence of *Phellinus* root rot was assessed in each PSP (a land-area-diseased expression, variable name is RRIN), and was used at the whole-study level as a measure of incidence, (Fig. 2). The PSP buffer extending 10 m, was assessed similarly, (variable name is RRBF).

%BAR Sample Surveys--*Phellinus* Incidence

- (2) Land-Area-Diseased Expression. The presence/absence of *Phellinus* root rot was assessed in each of 25 fixed-radius 0.005 ha plots. A plot was defined "infected" when the incidence of *P. weirii* was confirmed in the second growth stand component. The proportion of infected plots was termed incidence (variable name is DSPT).

- (3) Stand-Parameter-Diseased Expression. The presence/absence of *Phellinus* root rot was assessed in each of 25 variable-radius plots. A plot was defined "infected" when one or more *Phellinus* "infected" trees (living or dead) were counted "in", (Figs. 2; and 4 see pg. 41). The proportion of plots infected with *P. weirii* was termed incidence (variable name is DSWP). Note, an incidence measure was made for each of the two separate diameter limit sweeps. Incidence was estimated simultaneously in the prism sweep and tally procedure for damage severity, discussed below.

Damage severity of *Phellinus* root rot was sampled for, estimated and expressed in one method for the Percent Basal Area Reduction (%BAR) sample surveys:

%BAR Sample Surveys--*Phellinus* Damage Severity

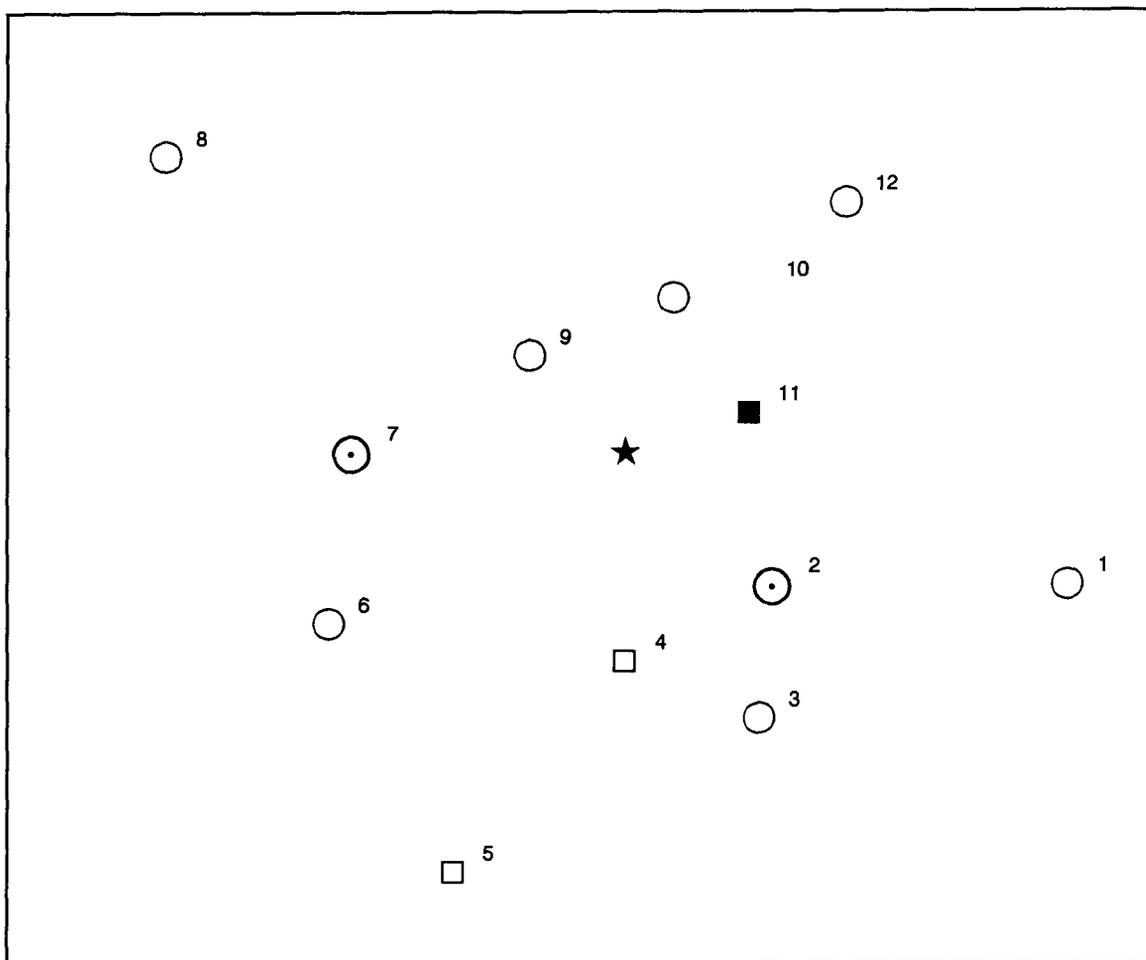
- (1) Two full-circle sweeps were made using the same basal area factor (baf) prism, to provide two "in" tree tallies; one each for ≥ 4.0 cm and $\geq 12.0/17.5$ cm diameter limits. The ≥ 12.0 cm diameter limit was only used in stands where 7 to 11 trees could not be selected at the 17.5 cm limit (e.g., in young or poor quality stands). All "in" trees were tallied, except *Phellinus* infected trees, thus the tallies were always healthy trees only that were distinguished by *Phellinus* incidence (DSWP) notations and diameter limit classes (Fig. 2).

Two diameter limits were used to sample ingrowth due to *Phellinus* disturbance and to impose an artificial "age class" structure; the latter assumes that diameter is strongly related to age. This is borne out by the fact that tree counts and basal areas are generally inversely related to the diameter limit size. Thus, the larger and smaller diameter limits are analogous to an "older" and "younger" age class respectively. If all trees are truly even-aged then the size differences attributed to age are more likely due to sampling of dominant/codominant versus intermediate/suppressed crown class trees. Observations by forest pathologists consistently indicate the phenomena of new ingrowth into root rot centers that implies younger tree ages. Aging of ingrowth was not conducted in this study. The diameter class/age class stratification would enable a view into stand dynamics and variations in productivity response to disease condition.

Calculation of *Phellinus* damage severity parameters (and subsequent %BAR intensities) required one further post-sampling stratification to separate out the susceptible species (Douglas-fir, grand fir and western hemlock) from the less-to-non-susceptible species. This enabled a comparison of the "worst case" root rot damage scenario with lesser damage conditions. Following the calculation procedures outlined in 6.3.1 and illustrated in Figures 3 and 4, the severity parameter for a given diameter limit class and species susceptibility class combination

is determined for a sample survey (25 plots/ha), by calculating the basal area reduction of *Phellinus* infected prism sweeps relative to the basal area of healthy prism sweeps and expressed as a proportion. The severity parameter names are shown in Table 3, and severity subcomponent variables in Table 5.

Note, prior to this study several pilot %BAR surveys were tested and compared against operational root rot surveys in the Port Alberni Forest District. Field and calculation methods were revised following the pilot sampling.



LEGEND:

- = Susceptible > Diameter Limit - Healthy ■ = Non-Susceptible > Diameter Limit - Healthy
 ⊙ = Susceptible < Diameter Limit - Healthy □ = Non-Susceptible < Diameter Limit - Healthy
 ★ Plot Centre

"IN" TREE COUNTS BY %BASAL AREA REDUCTION PARAMETER

≥ 4.0 cm Tree No.'s

≥ 12.0/17.5 cm Tree No.'s

NSBAR (1 through 12) $\Sigma = 12$

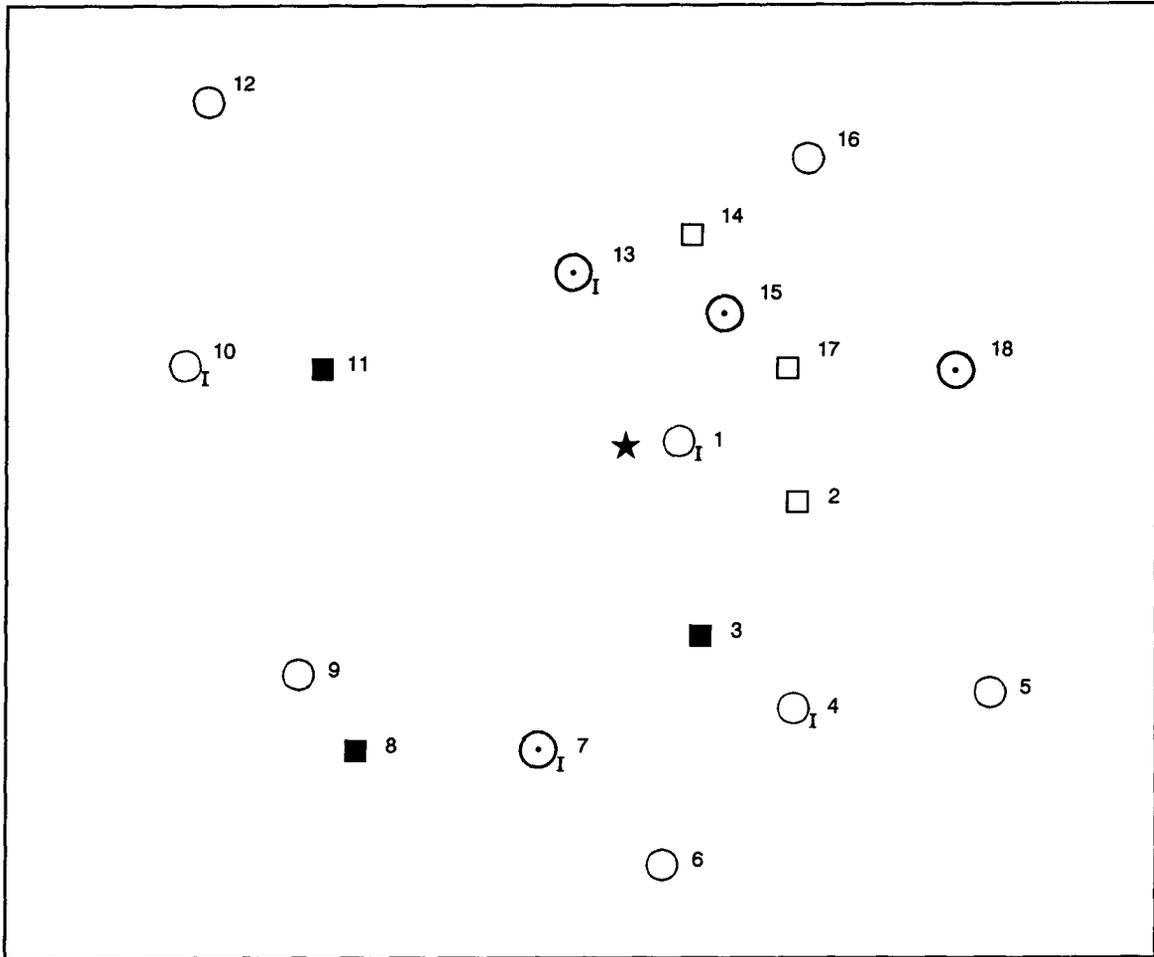
BARNS (1,3,4,5,6,8,9,10,11,12) $\Sigma = 9$

SBAR (1,2,3,5,6,7,8,9,10,12) $\Sigma = 10$

BARS (1,3,5,6,8,9,10,12) $\Sigma = 8$

Figure 3

Healthy variable-radius plot condition. Root rot incidence is null or DSWP=0.



LEGEND:

- = Susceptible > Diameter Limit - Healthy
- = Non-Susceptible > Diameter Limit - Healthy
- ⊙ = Susceptible < Diameter Limit - Healthy
- = Non-Susceptible < Diameter Limit - Healthy
- ★ Plot Center

"IN" TREE COUNTS BY %BASAL AREA REDUCTION PARAMETER

<u>≥ 4.0 cm Tree No.'s</u>	<u>≥ 12.0/17.5 cm Tree No.'s</u>
NSBAR (2,3,5,6,9,11-18) Σ = 11	BARNs (3,5,6,8,9,11,16) Σ = 7
SBAR (5,6,9,15,16,18) Σ = 6	BARS (5,6,9,16) Σ = 4

Figure 4 Infected variable-radius plot condition. Root rot incidence is positive or DSWP=1. Note visibly infected trees (I) 1, 4, 7, 10 and 13 are not counted as "in" trees in the sampling design described. Also, Tree 12 is considered "out".

TABLE 3 MATRIX OF DAMAGE SEVERITY VARIABLES AND CONSEQUENT %BAR DAMAGE INTENSITY PARAMETERS (in Parentheses)		
Species Class	Diameter Limit	
	≥ 4.0 cm	≥ 12.0/17.5 cm
Non-susceptible & Susceptible species	NSSEV (NSBAR)	SEVNS (BARNS)
Susceptible species	SSEV (SBAR)	SEVS (BARS)
Non-susceptible species =	western red cedar, white pine, shore pine, Sitka spruce, red alder, birch, cherry, flowering dogwood, cottonwood, arbutus and Garry oak.	
Susceptible species =	Douglas-fir, grand fir, and western hemlock.	

6.3.1 Calculation Methods For %BAR Percent Basal Area Reduction Variables

The generic %BAR calculation follows:

$$\text{Intensity} = ((\text{Severity}) \times (\text{Incidence})) \times 100$$

The %BAR calculation for SBAR, (Susceptible species only, ≥4.0 cm):

$$\%SBAR = (SSEV \times DSWP) \times 100$$

$$\%SBAR = \left(\frac{\overline{BA}_h - \overline{BA}_i}{\overline{BA}_h} \right) \times (\text{proportion DSWP}) \times 100$$

\overline{BA}_h - is the mean tree count multiplied by the sample stand Basal Area Factor (BAF) of the healthy/noninfected point sample sweeps; i.e., with no infected "in" trees. For example, from Fig. 3 the SBAR tally is 10 trees, multiplied by BAF=8, equals 80 m²;

\overline{BA}_i - is the mean tree count multiplied by the sample stand Basal Area Factor (BAF) of the infected point sample sweeps; i.e., with one or more infected "in" trees, and where "in"

trees are not counted in the tally. For example, from Fig. 4 the SBAR tally is 6 trees, multiplied by BAF=8, equals 48 m²;

BAF - is the stand sample Basal Area Factor, eg., BAF 8 is 8 m²;

DSWP - is the proportion of the point sample sweeps having visibly infected "in" trees in the tally--infected "in" trees were not tallied in this study. For example, from Fig. 3 and 4, the proportion of infected point samples is 1 out of 2, or 0.50;

¹ - Variables are severity subcomponents and are respectively **SALH** and **SALI** in this example (See Table 5 pg. 46).

E.g.,

$$\text{SBAR} = \left(\frac{80\text{m}^2 - 48\text{m}^2}{80\text{m}^2} \right) \times 0.50 \times 100$$

$$\text{SBAR} = 20\% \text{ Basal Area Reduction}$$

6.3.2 Assumptions of the Percent Basal Area Reduction (%BAR) Sampling Method

6.3.2.1 Expected Relationships For the %BAR Damage Intensity Parameter

The calculated %BAR damage intensity parameters shown in Table 4, illustrate the expected relationships between the parameters. Parameters that account for *non-susceptible plus susceptible* species (NSBAR, BARNS), would in most cases have higher stem counts and basal areas as compared to variables that only account for *susceptible species* (SBAR, BARS), since the former account for greater, near total tree species diversity. The result is that NSBAR & BARNS reflect lower damage intensity as compared to SBAR & BARS. Similarly, parameters with the lower diameter limit, ≥ 4.0 cm (NSBAR & SBAR), must have higher stem counts and basal areas than the higher diameter limits, ≥ 12.0 or 17.5 cm (BARS & BARNS), with the result that NSBAR & SBAR parameters may reflect lower percent damage than the BARS & BARNS parameters.

Sampling outside of the conditions found in this study (points (a)-(h) in Table 4), may tend to equilibrate the estimated relationships between %BAR parameter estimates, and may even cause a reversal of the expected relationship.

TABLE 4		EXPECTED RELATIONSHIPS BETWEEN %BAR DAMAGE INTENSITY PARAMETERS		
NSBAR	≤	≤	≤	
	SBAR	≤	≤	
		BARS	≥	
			BARNS	
<p>Several very important assumptions are of concern in comparing Basal Area Reduction estimation methods. Each relationship above, is dependent upon the following generalized sample stand conditions:</p> <ul style="list-style-type: none"> a) stand species composition, (Douglas-fir > 70% by volume); b) site and ecological conditions, (BEC units; e.g., CDFmm, CWHxm) c) primarily naturally regenerated, unmanaged/nonspaced; d) mid-seral stand age, (approx. 40 to 80 yr); e) moderate stand density (approx. 800-3 000 stems/ha) at 10 yr; f) variable plot sampling diameter limits (≥ 4.0 cm and ≥ 17.5 cm); g) intensity of root rot and, h) diameter class ingrowth rates <p>NOTE: Items in (parentheses) indicate the general conditions found in this study.</p>				

6.3.2.2 Testing The Homogeneity Of Species Compositions And The Decomposition Of The %BAR Severity Parameters

An assumption in stand selection was that species composition did not vary significantly between the ecological units, so that there was enough similarity in susceptible species composition to detect responses to *Phellinus* root rot with near-equal probability between BEC units using the %BAR damage intensity parameter estimates. In order to test the hypothesis of species composition similarity between subzone variants, site associations and site series, the %BAR severity parameters were decomposed to provide all possible combinations of species susceptibility, diameter class and disease incidence status (Table 5). For testing, a new, third diameter class,

intermediate to the upper and lower classes was created through subtraction of the upper from the lower diameter classes. This process also provided the required %BAR components to assess species shifts/dynamics in response to *Phellinus* root rot.

TABLE 5		DECOMPOSITION OF %BAR DAMAGE SEVERITY VARIABLES TO SUBCOMPONENTS	
≥4.0 cm Diameter Limit & Healthy Sweeps		SALH = Susceptible spp. NALH = Non-susceptible spp. NSALH = Non-susceptible and Susceptible spp.	
≥4.0 cm Diameter Limit & Infected Sweeps		SALI = Susceptible spp. NALI = Non-susceptible spp. NSALI = Non-susceptible and Susceptible spp.	
≥4.0 cm <17.5 cm Diameter Limit & Healthy Sweeps (determined by subtraction)		SLSH = Susceptible spp. NLSH = Non-susceptible spp. NSLSH = Non-susceptible and Susceptible spp.	
≥4.0 cm <17.5 cm Diameter Limit & Infected Sweeps (determined by subtraction)		SLSI = Susceptible spp. NLSI = Non-susceptible spp. NSLSI = Non-susceptible and Susceptible spp.	
≥12.0/17.5 cm Diameter Limit & Healthy Sweeps		SGRH = Susceptible spp. NGRH = Non-susceptible spp.	
≥12.0/17.5 cm Diameter Limit & Infected Sweeps		SGRI = Susceptible spp. NGRI = Non-susceptible spp. NSGRI = Non-susceptible and Susceptible spp.	

Healthy condition, susceptible (SALH) and non-susceptible (NALH) species compositions, ≥4.0 cm, are shown to be very stable about the all-samples means of 91.52% and 8.48%, respectively, when plotted across site associations (Figs. 65-66, pg. 132). The variability of susceptible and non-susceptible species across site associations

is minimal and not significant ($p > .05$); also see Table 22, p.119.

6.4 Ecological Assessments

Ecological assessments were done to characterize regional climate (geographic location), physiography, vegetation, soils, forest floor, tree and stand measurements. The integration of these climatic and site parameters enables classification of sample stands to levels of most interest in the Vegetation, Zonal (Climatic) and Site Classifications of the BEC system (Pojar *et al.* 1987).

In general, the procedure for ecological assessments at each PSP was to confirm the geographic location on the forest cover maps (1:20 000 scale) and then determine the indicated subzone variant (regional climate) from the biogeoclimatic unit map (1:500 000 scale), (Nuszdorfer *et al.* 1984). Subsequently, the sites' physiography, vegetation, soils and forest floor were described using the procedures outlined by Walmsley *et al.* (1980). Since this study has a strong operational basis, site description modifications lean towards the Site Diagnosis procedures described by Klinka *et al.* (1984) and Green *et al.* (1984).

6.4.1 Site: Physiography

Site physiography was described for the general site conditions identified at the PSP, which included elevation, slope position (crest, upper, middle, lower, toe or level), slope

shape (straight, concave, convex or irregular/hummocky), percent slope, and aspect.

6.4.2 Site: Vegetation

In a 0.04 ha relevé plot, the percent cover of vegetation in 3 tree layers, 2 shrub layers, 1 herb layer and 1 moss layer was described and classed on the Domin-Krajina 6-class cover class scale, after Walmsley *et al.* (1980). The relevé plot usually conformed to the PSP dimensions, if not, then the most representative location near the PSP was described.

6.4.3 Site: Soils

Soils were described on the basis of two soil pits dug outside the PSP at representative locations (to avoid damage to the PSP), following the Canadian System of Soil Classification (CSSC 1978) and Walmsley *et al.* (1980). Physical soil parameters of particular interest were: rooting depth (cm); type of root restricting layer (none, fragmental, compacted, cemented, or rock); major rooting zone soil texture (≤ 2 mm); major rooting zone coarse fragment content (> 2 mm), root restricting layer depth (cm); depth to mottling (cm); depth to seepage water (cm); total and fine fraction bulk density (g/cm^3).

Two mineral soil bulk density samples of about $1\ 000\ \text{cm}^3$ were taken for the 10 to 30 cm depth, at each of the soil pits per PSP. Volume was measured by replacement

with fine, dry playsand (after Klinka *et al.* 1981). Two soil chemistry samples were also taken from the 10 to 30 cm mineral soil depth and composited at the MacMillan Bloedel, Nanaimo environmental laboratory.

6.4.4 Site: Forest Floor

Forest floor described and classed to the Group level as described by Klinka *et al.* (1981). Separate forest floor samples were taken for bulk density and chemistry at four randomly located points within the PSP. At each point, two 225 cm² square blocks of forest floor were cut out to mineral soil depth. The first block at each point was used for forest floor chemistry, and the second block was measured for depth. Forest floor depth was based on the mean of four representative depths taken from each side. Samples for each of bulk density and chemistry were composited at the MacMillan Bloedel, Nanaimo environmental laboratory.

6.4.5 Site: Old Growth Stand History

Stand history was estimated from the PSP database, confirmed by ecological assessment, and further assessed via the fixed-radius plot old growth stump survey. Information available from the PSP data base pertained to logging and fire history, regeneration method and presence of old growth veteran trees. Old growth stump survey procedures involved estimating the old growth species composition and stems/ha by species. Only Douglas-fir and western red cedar were easily identifiable from stumps 30

to 120 years old. Western hemlock was extremely difficult to identify so long after harvest and consequently very few hemlock were tallied. Systematically located 0.01 ha (5.64 m fixed-radius) stump survey plots were established on the same 25-plot sampling grid as the %BAR survey.

6.4.5.1 Old Growth Stand History (Stand Density & Species Composition) Estimates Using Fixed-Radius Plots

Stems/ha were estimated separately for susceptible and non-susceptible species, Douglas-fir/western hemlock (SPHFH) and western red cedar (SPHCW), respectively, as follows:

$$\text{SPHFH} = \frac{(\sum \text{FD} + \sum \text{HW})}{\text{No.Plots}} \times 100$$

$$\text{SPHCW} = \frac{(\sum \text{CW})}{\text{No.Plots}} \times 100$$

Where: FD is Douglas-fir, HW is western hemlock, CW is western red cedar, No.PLOTS is the sample size and, 100 is the sample size expansion factor to 1 ha.

The old-growth species composition was calculated as follows:

$$\text{COMPFH} = \frac{\sum \text{FH}}{\sum \text{FH} + \sum \text{CW}} \quad \text{COMPCW} = \frac{\sum \text{CW}}{\sum \text{FH} + \sum \text{CW}}$$

Where: COMPFH and COMPCW are species compositions for Douglas-fir/western hemlock, and western red cedar, respectively.

6.5 Site: Stand Mensuration

Tree and stand measurement data were obtained exclusively from the PSP summary data files provided by MacMillan Bloedel Limited, Woodlands Services, in Nanaimo, BC, and Canadian Pacific Forest Products Limited, Saanichton Forestry Centre. No additional measurements were undertaken in PSP's or the surrounding sampling area. Note, that since the growth and yield remeasurement cycle is five years for both firms, the data is not all representative of the 1987 field season in which the rest of the study occurred.

6.6 Laboratory Analyses And Data Preparation

As part of previous ecological studies conducted by MacMillan Bloedel Limited on the PSP database, many of the mineral soil and forest floor physical and chemical property data required for this study were available (Kumi 1987, and Beese 1987). The soils data, stored on the BC Ministry of Environments' Soils Information System, was summarised for the 10 to 30 cm mineral soil depth and for the F and H layers of the forest floor.

Laboratory analyses for various mineral soil and forest floor physical and chemical properties collected as part of this study were conducted by the Environmental Lab. at the MacMillan Bloedel Limited, Woodlands Service's office in Nanaimo, BC.

6.6.1 Mineral Soil And Forest Floor Physical Properties

Bulk density for mineral soil and forest floor were of interest in order to estimate nutrient levels on a per hectare basis, and to provide an estimate of root penetrability of mineral soils. Soil porosity was calculated from the bulk density to provide an estimate of aeration and its possible effects on fungal (*P.weirii*) ecology.

Bulk density samples were air dried for up to 48 hours on trays after arrival at the laboratory. Samples were paper bagged and oven dried for 24 hr at 105°C. Total dry weights were then recorded. Samples were then separated into the coarse and fine fractions (>2 mm, and ≤2 mm, respectively) by passing the materials through a 2 mm sieve and the fractional weights' recorded. Since the organic content of the Brunisols and Podzols common to the study area are known to be low (CSSC 1978), only obvious organic matter was removed manually.

Mineral soil bulk density was calculated for the total sample and the fine fraction (coarse-fragment free), after Klinka *et al.* (1981). Coarse-fragment free volumes were calculated prior to bulk density calculations using the standard 2.65 g/cm³ for estimating the volume of coarse fragments in the samples.

$$\begin{aligned} \text{MSBDT (g / cm}^3\text{)} &= \text{MSTOT} / \text{MSVOLtot} \\ \text{MSBDF (g / cm}^2\text{)} &= \text{MSFIN} / \text{MSVOLfin} \end{aligned}$$

Where: MSBDT is the total sample mineral soil bulk density (coarse and fine fractions); MSTOT is the dry weight of the total sample; MSVOLtot is the volume of the excavated, total soil bulk density sample; MSBDF is the fine fraction mineral soil bulk density; MSFIN is the dry weight of the fine fraction sample; and MSVOLfin is the estimated volume of the fine fraction.

Forest floor bulk density was calculated similarly, as follows:

$$\text{FFBD (g / cm}^3\text{)} = \text{FFTOT} / \text{FFVOL}$$

Where: FFBD is the forest floor, fine fraction bulk density; FFTOT is the four-sample composite dry weight of the forest floor, fine fraction; FFFVOL is the four sample composite volume of the forest floor.

Mineral soil porosity, or the proportion of the soil volume occupied by air or water, was calculated for the fine fraction using the following formula from Armson (1977):

$$\text{PORF} = 1 - (\text{MSBDF} / \text{particle density})$$

Where: PORF is the mineral soil fine fraction porosity; MSBDF is the mineral soil fine fraction bulk density; particle density is taken to be 2.65 g/cm³ unless local data indicates other lower values (Armson 1977).

6.6.2 Mineral Soil And Forest Floor Chemical Properties

Mineral soil and forest floor chemical properties were composited and air dried prior to fine fraction (≤ 2 mm) separation. Mineral soil samples were passed through a 2 mm sieve to obtain the fine fraction. Forest floor samples were coarse ground then fine ground, and sieved through a 2 mm screen to obtain the fine fraction. Mineral soil and forest floor pH were determined with a pH potentiometer probe in a 1:1, soil (or forest floor):water suspension (Peech 1965). Total carbon was determined using the Walkley-Black wet oxidation method (Walkley 1947). Total nitrogen (N) was determined colorimetrically by Technicon Autoanalyzer II after the 60-mesh samples were digested in a semimicro Kjeldahl digest (Lavkulich 1981). Mineralizable nitrogen (N) was determined colorimetrically (by Technicon Autoanalyzer II) from a 1 N KCl extractant, following a 2-week (30°C) anaerobic incubation (Waring-Bremner method) (from Keeney 1982). Exchangeable cations (Ca, Mg and K) were determined by atomic absorption spectrophotometry preceded by the ammonium acetate (pH 7) extraction method (Black 1965).

6.6.3 Conversion Of Chemical Property Concentrations To Kg/ha

Conversion of nutrient concentrations in the < 2 mm fraction to kg/ha was done to provide a better estimate of chemical nutrient availability to ecosystems. (Also, see Appendix A). Kilogram per hectare estimates are sensitive to bulk density and coarse-fragment content estimates. Also, the measures provide a reference with which others

may wish to make comparisons.

6.6.4 PSP Stand Attribute Data Preparation

Some of the PSP summary data required manipulation to be meaningful for statistical analyses, particularly regarding species composition and shifts in species composition over time, and averaging procedures for PSP's. The following variables were summarised and/or calculated on the basis of first and last PSP measurement:

- Total age in 1987
- Breast-height age,
- Species composition and percent composition (1ST, 2ND, & 3RD order),
- Stems/ha ≥ 4.0 cm,
- Basal area/ha ≥ 4.0 cm,
- Volume/ha ≥ 4.0 cm,
- Stems/ha ≥ 17.5 cm,
- Basal area/ha ≥ 17.5 cm,
- Volume/ha ≥ 17.5 cm,
- Curtis' relative density (metric) ≥ 4.0 cm,
- Site height,
- Site index (Bruce's, Reference age 50 yr).

The data manipulations done were:

- (1) Breast-height ages were converted to total ages using the age correction values contained in the PSP file. This was done to aid the interpretation of root rot spread and behaviour, because it is perceived to be simpler to comprehend on a volume--total age *versus* volume--breast height age basis.

- (2) Species compositions were classified into four laminated root rot susceptibility classes after Wallis (1976), Hadfield (1985) and Beale (1989a). Percent species compositions were recalculated and expressed as proportions for first and last measurements. Species Composition Classes used in this study were:

Susceptible = Douglas-fir, and grand fir;

Intermediate = western hemlock;

Resistant = lodgepole pine, western white pine and western red cedar;

Deciduous = arbutus bigleaf maple, red alder, birch and cherry.

- (3) Several new variables were calculated to describe the non-susceptible species classes (Intermediate and Resistant) at the First and Last measurements. The new variables (FTIR, LTIR and TIRD) aid evaluation of species shifts in relation to presence or absence of *Phellinus* root rot in PSP's. FTIR and LTIR are the sum of the Intermediate and Resistant species classes compositions, first and last measurements, respectively. TIRD is the difference between the first (FTIR) and last (LTIR) Intermediate and Resistant compositions.

Similarly, several new variables were calculated to describe the Susceptible species composition at the first and last measurements; FSUS and LSUS, respectively. SUSD is the difference between the first (FSUS) and last (LSUS) measurements of the Susceptible compositions. Deciduous compositions were not included due to little change over time and an unbalanced coverage across ecological units.

- (4) Stems/ha, basal area/ha, volume/ha and Curtis' relative density were back-estimated to reference age 10 yr using a Stand Projection model developed by Nick Smith for MacMillan Bloedel Limited, Woodlands Services, Nanaimo (Smith 1990). Given the variable conditions at PSP establishment, a reference age was required for comparison and sorting of similar PSP's for statistical analyses. Age 10 was selected to more closely approximate stand conditions at establishment. Age 10 seemed to provide realistic back-estimations, whereas at age zero (0) the results became much more variable and less realistic. Also, the author felt that back-estimation of about 20 to 40 yr was a reasonable regress in time.
- (5) Many PSP's were established as part of larger growth and yield installations. In a number of cases, two or more PSP's fitting the study criteria were sampled from within the same installation, often resulting in one common ecological description, and one root rot sample survey; thus two or more PSP's for one contiguous, homogenous ecosystem. In terms of data preparation and summarization, two options were available: (a) use all PSP's and replicate the ecological/root rot survey and stand history data to match the number of PSP's, or (b) use unique ecological/root rot survey/stand history data and average the appropriate PSP data. The latter option was chosen after consulting MacMillan Bloedel as to the suitability of averaging PSP data (Wilson 1989, and Bloomberg 1990). All stand measurement variables were averaged to obtain their arithmetic mean. Relative density was

recalculated for the ≥ 4.0 cm class as follows:

$$\text{Curtis' Relative Density} = \text{STAND-BA} / \text{DBHg}$$

Where: STAND_BA is the recalculated stand basal area (m²), and DBHg is the recalculated quadratic mean diameter. (see Appendix B)

6.6.5 Classification Of Root Rot Damage Intensity (%BAR)

Classification of continuous variables into categorical variables allows for a different view of the data and its relationships to other variables. Classification of a disease variable, such as BARS, into several meaningful damage intensity classes was done to discern ecological relationships. Where some independent ecological variables are highly variable, classification may improve the ability to search for relationships.

In order to determine meaningful damage intensity classes, the appropriate damage response estimate parameters had to be selected. Of the four %BAR estimators, only BARS provided a damage estimate for the larger diameter, susceptible species (of which the stands are primarily comprised). The other %BAR parameters included non-susceptible species and/or trees below the average stand age diameter that may mask the relationship in question (i.e., because of ingrowth). Operationally, BARS is most likely to provide the best estimate of what foresters are most often considering during stand management or pre-harvest silviculture assessments in the study area---that is, Douglas-fir

trees of average or better volume and value. Furthermore, in trying to visualize various damage levels and make conditional damage intensity classifications, the author could not easily communicate or visualize the subtleties of the other damage estimators; therefore, BARS was selected as the most useful damage estimator.

Three BARS-Damage Intensity Classes (BARS-DIC's) were determined on the basis of personal experience, consultation with other root disease workers (Bloomberg 1990(a), and Reynolds 1990), and graphical review of the data structure which included BARS frequency distributions and normal probability plots. The classification resulted in two class limits separating Severe, Medium and Low classes. The upper limit has a classic growth curve shape, perhaps best described by a nonlinear function, while the lower limit is well described by a linear function. Class limits and within-class conditions were also corroborated on the basis of recent root rot simulation summaries conducted on the TASS-ROTSIM model (Bloomberg 1990(a)). The class limit functions were used to code BARS data for statistical analysis. The functions describing the BARS class limits are as follows:

BARS UPPER CLASS LIMIT:

Two linear functions mimic the two important phases identifiable in the proposed nonlinear function:

- (i) the rapid root rot growth/center expansion phase (30 to 60 yr) followed by a
- (ii) slower root rot growth trend to a near asymptotic level phase (61 to 100 years).

$\begin{aligned} \text{BARS Rapid Growth Phase Limit} &= -3 + 0.300 X (\text{AGE87}) \\ \text{BARS Asymptotic Phase Limit} &= 10 + 0.083 X (\text{AGE87}) \end{aligned}$
--

Two linear functions were used instead of one non-linear function because it was easier to estimate, and subsequently classify BARS data in Systat.

BARS LOWER CLASS LIMIT:

$\text{BARS} = 3 + 0.033 X (\text{AGE87})$
--

The BARS-Damage Intensity Classes are superimposed on a BARS-total age scatterplot, illustrated in Figure 5. BARS variability across the BARS-DIC limits is illustrated by boxplot (Fig. 6). For an explanation of boxplots, and how to read them see Tukey (1977), McGill *et al.* (1987), Titus (1987) and Wilkinson (1988).

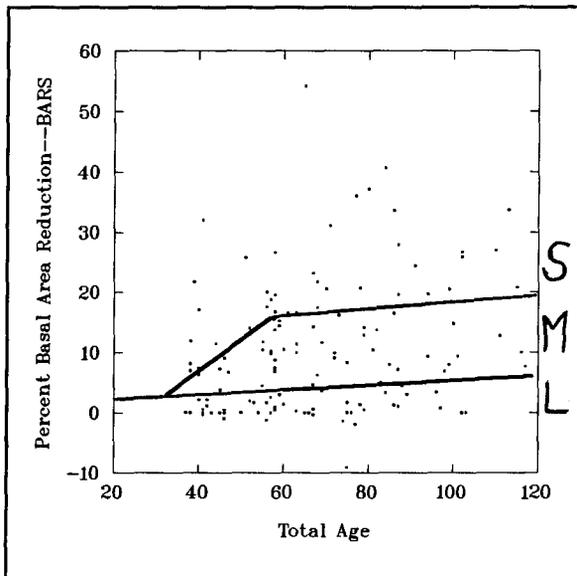


Figure 5 Percent Basal Area Reduction (BARS) - total age scatterplot classified by the BARS-Damage Intensity Classes; (L) Low, (M) Medium and (S) Severe.

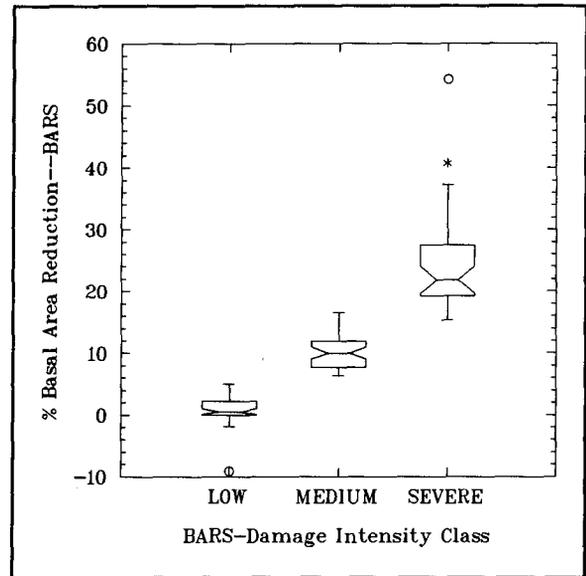


Figure 6 Boxplots of BARS classified by the BARS-Damage Intensity Classes (BARS-DIC's).

6.6.6 Ecological Classification

Ecological classification followed the methods for the system of biogeoclimatic ecosystem classification (BEC) outlined by Pojar *et al.* (1987). Three ecological concepts: (ecological equivalence, polyclimax condition and zonal ecosystem), are the basic principles of the BEC system that effect the resultant classification and interpretation of study plots. Ecological classification methods involve classification of climate, vegetation and site, with a final integrative stage to organize similar ecosystems at local or regional levels into a natural taxonomic hierarchy (BEC units). These methods, as used in this study, are described separately below.

6.6.6.1 Climate Classification

Permanent sample plot database designations for subzone variant were checked against the biogeoclimatic subzone map. Final adjustments to PSP subzone variant classifications were done following vegetation analysis and the formulation of plant associations and subassociations using diagnostic combinations of plant species. The resultant number of homogeneous sample units per subzone variant was 30, 60 and 49 for CDFmm, CWHxm1 and CWHxm2, respectively.

6.6.6.2 Vegetation Classification

Vegetation data (lifeform, species, plant layer, and species significance) were error checked and recoded from the 6-class cover scale to the 10-class Domin-Krajina scale required for quantitative procedures (Klinka *et al.* 1989).

Vegetation classification was based on analysis of species presence (frequency) and significance (percent cover) to formulate floristically similar units in a natural taxonomic hierarchy. Diagnostic combinations of species differentiate floristic communities into plant associations--the basic unit of vegetation classification (Pojar *et al.* 1987). The procedure is based on the Braun-Blanquet tabular method (Westhoff and van der Maarel 1980), a reciprocal averaging ordination technique (Gauch 1977), clarification of the floristic structure (exclusion of low <3% incidence species), application of professional judgement, principal components analysis, and formulation of diagnostic combinations

of species (DCS), according to Pojar *et al.* (1987). Plant associations, subassociation(s), alliance(s), and order(s) were named in accordance to the present classification hierarchy (Klinka 1990). The analytic procedure was based on a comprehensive vegetation and environmental data tabulation and summary computer program (Emmanuel 1989), lodged on the UBC computer. Principal components analyses were used on diagnostic species to detect relationships between environmental characteristics and vegetation units giving indication of units' relative moisture and nutrient condition. Spectral analysis also aided vegetation classification by relating plant species proportional distributions stratified by soil nutrient and soil moisture indicator values to conditionally named vegetation units (Klinka and Krajina 1986).

Naming of vegetation units for this study, followed the formulation of the Diagnostic Combination of Species (Table 6); this resulted in: two plant orders, three plant alliances, four plant associations and three plant subassociations, (after Pojar *et al.* (1987)), (Table 7).

A complete listing of plant species found in the study is in Appendix C. The vegetation summary table used in the formative stages of discerning floristic uniformity is in Appendix D.

TABLE 6 VEGETATION ENVIRONMENT ANALYSIS

Vegetation Unit		1 \$PA	2 \$PG	3 \$TM	4 \$PAT	5 \$PAA	6 \$PAP
Number of Plots	Diagnostic	25	47	27	38	8	8
Vegetation Units and Species	Value ¹	Presence class ² and mean species significance ³					
Pseudotsuga-Mahonia p.o. & p.all.							
<i>Holodiscus discolor</i>	(d)	IV 4	III 3	I +	I +		
<i>Rosa gymnocarpa</i>	(d,c)	V 3	V 3	II 1	II 2		II 1
1 \$Pseudotsuga-Arbutus p.a.							
<i>Arbutus menziesii</i>	(d)	III 3	I +				
2 \$Pseudotsuga-Gaultheria p.a.							
<i>Achlys triphylla</i>	(d)	II 1	IV 2	V 3	IV 4	V 4	IV 6
<i>Hylocomium splendens</i>	(d,cd)	II 4	V 5	V 5	V 5	IV 3	V 6
<i>Linnaea borealis</i>	(d)	I +	III 3	IV 4	IV 4	II 1	III 3
<i>Tsuga heterophylla</i>	(d)	II 2	IV 3	V 5	V 5	V 4	V 5
3 Tsuga-Mahonia p.o. & p.all., \$Tsuga-Mahonia p.a.							
[]							
Thuja-Tiarella p.o., Thuja-Achlys p.all., Pseudotsuga-Achlys p.a.							
<i>Plagiomnium insigne</i>	(d)				II +	II +	IV 3
<i>Polystichum munitum</i>	(dd,cd)	III 1	III 3	IV 3	V 5	V 7	V 6
<i>Tiarella trifoliata</i>	(d)	I +		I +	III 2	V 2	V 3
4 \$Pseudotsuga-Achlys-Typic p.sa.							
[]							
5 \$Pseudotsuga-Achlys-Alnus p.sa.							
<i>Alnus rubra</i>	(d,cd)	II 1	II 2	II 1	II 3	V 5	I 1
<i>Bromus vulgaris</i>	(d)	II 1	III 1	II +	II 1	IV 2	II 1
<i>Rubus spectabilis</i>	(d)		I +		I +	IV 3	I 2
6 \$Pseudotsuga-Achlys-Plagiomnium p.sa.							
<i>Plagiomnium insigne</i>	(d)				II +	II +	IV 3
<i>Rhizomnium glabrescens</i>	(d,c)	I +	I +		I +		V 4
<i>Trientalis latifolia</i>	(d)	II 1	II 1	II 2	II 1	II +	IV 2

¹ Species diagnostic values: d - differential, dd - dominant differential, cd - constant dominant, c - constant, ic - important companion (Pojar *et al.* 1987)

² Presence classes as percent of frequency: I = 1-20, II + 21-40, III = 41-60, IV = 61-80, V = 81-100.
If 5 plots or less, presence class is arabic value (1-5).

³ Species significance class midpoint percent cover and range: + = 0.2 (0.1 - 0.3), 1 = 0.7 (0.4 - 1.0), 2 = 1.6 (1.1 - 2.1), 3 = 3.6 (2.2 - 5.0), 4 = 7.5 (5.1 - 10.0), 5 = 15.0 (10.0 - 20.0), 6 = 26.5 (20.1 - 33.0), 7 = 41.5 (33.1 - 50.0), 8 = 60.0 (50.1 - 70.0), 9 = 85.0 (70.1 - 100).

TABLE 7		HIERARCHICAL SYNOPSIS OF VEGETATION UNITS DISTINGUISHED IN THE STUDY AREA	
VEGETATION UNIT Plant Order Plant Alliance Plant Association Plant Sub-association			
			<i>Pseudotsuga-Mahonia</i> <i>Pseudotsuga-Mahonia</i> <i>Pseudotsuga-Arbutus</i> <i>Pseudotsuga-Gaultheria</i> <i>Tsuga-Mahonia</i> <i>Tsuga-Mahonia</i> <i>Thuja-Tiarella</i> <i>Thuja-Achlys</i> <i>Pseudotsuga-Achlys</i> <i>Pseudotsuga-Achlys-Typic</i> <i>Pseudotsuga-Achlys-Alnus</i> <i>Pseudotsuga-Achlys-Plagiomnium</i>
Each vegetation unit is characterized by a typical diagnostic combination of species after Pojar			

The six lowest level vegetation classification units (plant associations and sub-associations), (Tables 6 and 7), are thought to be arranged mainly according to an increasing soil moisture gradient. This assumption was tested quantitatively via principal components analysis (PCA) of diagnostic species representative of the six units. The first two principal components accounted for 39.5% of total variance; 25% and 13.5% respectively for the first and second components. PCA component axis scores were then correlated to individual species (Table 8). To explain the correlations, 15 species with relatively strong positive and negative correlations were reviewed for relationships to environmental characteristics of each vegetation unit. Ordination of the PCA scores for the six vegetation units on the first two axes illustrates the units' discreteness represented

by the 95% confidence ellipses (Fig. 7). Although there is no separation of ellipses the trend along the moisture gradient illustrates the ecotonal relationship of these vegetation units. For the first component, high positive correlation coefficients for *Polystichum munitum* (.53), *Achlys triphylla* (.70), and *Tsuga heterophylla* (.60) (species indicative of slightly to fresh soil moisture conditions), and high negative correlations of *Holodiscus discolor* (-.54) and *Arbutus menziesii* (-.40) (species indicative of very dry to moderately dry soil moisture conditions), suggest that it adequately represents the soil moisture gradient. The second component is likely to represent the soil nutrient gradient as indicated by high positive correlations of *Linnaea borealis* (.41), *Rosa gymnocarpa* (.47), *Hylocomium splendens* (.65) (species indicative of soil nutrient poor to medium), and high negative correlation of *Polystichum munitum* (-.49) and, *Alnus rubra* (-.38) (species indicative of soil nutrient medium to rich). The assumption that the vegetation units are arranged along the soil moisture and nutrient gradients is further supported by spectral analysis (Klinka and Krajina 1986, pg.104) of plant species compared to the vegetation units, seen by increasing proportions of drier site indicator species on drier vegetation units and vice versa on fresher vegetation units (see Appendix E).

TABLE 8 DIAGNOSTIC SPECIES CORRELATIONS TO PCA AXIS SCORES			
Diagnostic Species		Correlation ¹	
		Axis 1	Axis 2
HOLODIS4	<i>Holodiscus discolor</i>	-.5379	.2695
ROSAGYM4	<i>Rosa gymnocarpa</i>	-.2533	.4721
ARBUMEN1	<i>Arbutus menziesii</i>	-.4028	.0025
ACHLTRI6	<i>Achlys triphylla</i>	.7001	.1716
HYLOSPL7	<i>Hylocomium splendens</i>	.5497	.6512
LINNBOR6	<i>Linnaea borealis</i>	.6127	.4130
TSUGHET1	<i>Tsuga heterophylla</i>	.6004	-.4685
POLYMUN6	<i>Polystichum munitum</i>	.5315	-.4919
TIARTRI6	<i>Tiarella trifoliata</i>	.5187	-.0758
ALNURUB1	<i>Alnus rubra</i>	.1440	-.3805
BROMVUL6	<i>Bromus vulgaris</i>	.1939	.0833
RUBUSPE4	<i>Rubus spectabilis</i>	.2052	-.3016
PLAGINS7	<i>Plagiomnium insigne</i>	.3175	-.0966
RHIZGLA7	<i>Rhizomnium glabrescens</i>	.2795	-.0041
TRIELAT6	<i>Trientalis latifolia</i>	.2899	.4081

¹ Correlations were significant at ($\alpha = .01$)

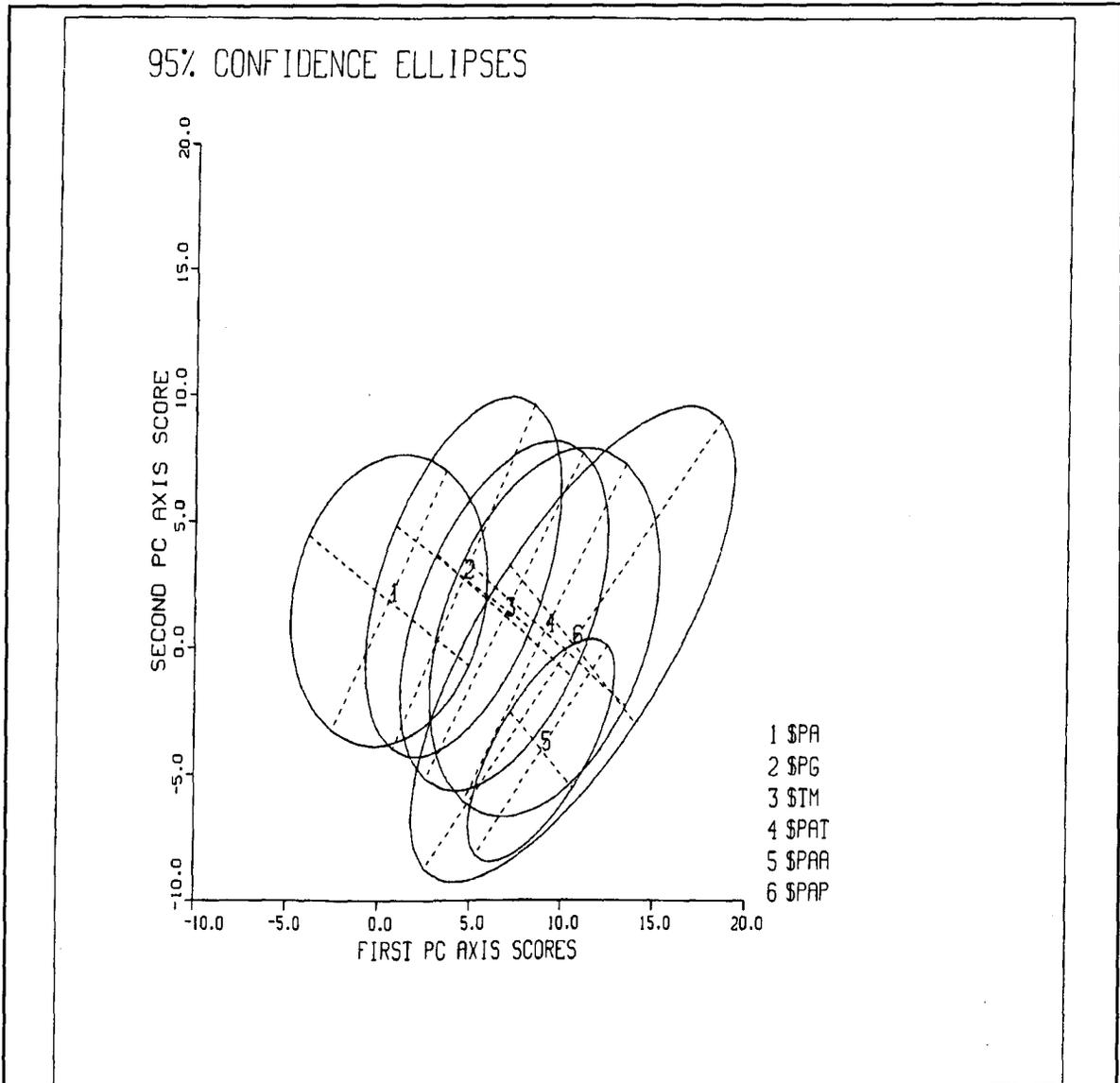


Figure 7 95% Confidence Ellipses of the PCA ordination scores of six vegetation units identified in the study; (1) *Pseudotsuga-Arbutus* p.a., (2) *Pseudotsuga-Gaultheria* p.a., (3) *Tsuga-Mahonia* p.a., (4) *Pseudotsuga-Achlys-Typic* p.sa., (5) *Pseudotsuga-Achlys-Alnus* p.sa., and (6) *Pseudotsuga-Achlys-Plagiomnium* p.sa.

6.6.6.3 Site Classification

The site classification procedures organize ecosystems into groups similar in site quality, site productivity and potential climax vegetation regardless of present vegetation (Pojar *et al.* 1987, Banner *et al.* 1990). Site associations, the basic unit of the classification, are characterized by certain climax vegetation (or late successional stages) predicted to occur on a certain range of soil moisture and soil nutrient regimes within a range of regional climates represented by biogeoclimatic subzones (Pojar *et al.* 1987). Climatically uniform groups at the biogeoclimatic subzone or variant level within a site association represent site series. Critical soil and/or topographic properties within an association or series can be used to group ecosystems to the site type level. Site type level differentiating criteria are presently not finalized and are dependent upon management or research objectives.

Using the site classification procedure, I identified nine site associations and 14 site series (Table 9), (after Banner *et al.* 1990). Classification to the site type level was envisaged but the heterogeneity of sites precluded the option, particularly when considering soil properties that may affect the incidence and severity of *Phellinus* root rot. This was especially true in trying to establish meaningful groups in the data considering the generally homogenous edaphic and topographic features of the study area as a whole. Environmental properties summaries were produced (Emmanuel 1989), to assist in classifying ecosystems to site association and series, but are not presented in this thesis. The relationships of most continuous ecological, site, soil and stand variables to

the site associations identified in this study are seen in Appendix F.

TABLE 9 HIERARCHICAL SYNOPSIS OF THE SITE UNITS DISTINGUISHED IN THIS STUDY	
SITE UNIT Site Association Site Series	SITE UNIT Site Association Site Series
FdPI - Arbutus CDFmm - FdPI - Arbutus	FdHw - Salal * CWHxm1 - FdHw - Salal CWHxm2 - FdHw - Salal
Fd - Salal * CDFmm - Fd - Salal	HwFd - Kindbergia * CWHxm1 - HwFd - Kindbergia CWHxm1 - HwFd - Kindbergia
FdBg - Oregon grape * CDFmm - FdBg - Oregon grape	Fd - Swordfern CWHxm2 - Fd - Swordfern
FdPI - Cladina CWHxm1 - FdPI - Cladina	Cw - Foamflower * CWHxm1 - Cw - Foamflower CWHxm2 - Cw - Foamflower
* Site Associations with $n \geq 6$ sample plots, and retained for further analyses.	

6.7 Statistical Analysis Methods

Statistical analyses were conducted using the SYSTAT and SYGRAPH PC computer package (Wilkinson 1988). The observational nature of this study required extensive exploratory data analysis (Tukey 1977), which included transformations and graphical review of the dependent (root rot) parameters on the independent variables (ecological/mensurational) prior to numerical analyses.

Subsequently, Pearson correlations and tests of significance (Bonferroni's adjusted

probabilities) were reviewed for linear correlations at the 20% significance level ($\alpha = 0.20$). This relatively large α value was used for two reasons: (i) very large ecological property variation and (ii) the presence of measurement errors.

Assumptions for linear regression were assessed with the following results:

- (a) Measurement of independent variables without error was impossible to confirm, but the work was done with skilled, well-trained field crews and laboratory analysts.
- (b) Homogeneity of variance (homoscedasticity) was evaluated via scatterplots, boxplots and examination of linear model residual plots; homoscedasticity was met for growth and yield data, but much less so for %BAR root rot parameters and ecological variables.
- (c) Linearity assumptions between dependent and independent variables were generally met, but many ecological and root rot variables/parameters patterns were extremely amorphous and ill-defined (many nonlinear intercorrelations were expected).
- (d) Normal distribution of variables was not met for root rot %BAR parameters (incidence and intensity) and second growth species composition survey-derived variables, but was met for the %BAR severity parameter, most ecological and growth and yield variables (checked with normal probability

plots).

The methods for evaluating linear model assumptions were taken from Weisburg (1985), Chatterjee and Price (1977), Miller (1986), Zar (1986), and Neter and Wasserman (1974). Root rot dependant variable distributions (%BAR variables) were positively skewed and leptokurtotic; this was due to few high root rot intensity estimates and many low to zero value estimates, resulting in non-normal distributions. Normal probability plots showed near normality for values greater than about 3% basal area reduction. Transformations to reduce heteroscedasticity and improve linearity such as arcsin square root of (%BAR/100) (Zar 1984), folded square root of the %BAR variables, (Tukey 1977), and Taylors power law transformation (Box and Cox 1964), provided no improvement. Some species dynamics variables appeared to have similar distributions, and as with %BAR variables were unresponsive to transformations. As a result, univariate analyses for ecological, stand history and species dynamics were conducted on untransformed variables.

Since two independent datasets were under study (%BAR sample survey estimates vs. PSP's), graphical and tabular presentations were done to assess similarities between the two datasets, to aid inference and descriptive model building.

Disease incidence relationships were evaluated through tabular analysis of categorical variables, aided by log-linear models. Disease intensity relationships and species dynamics were evaluated generally through construction of multiple linear

regression models--for descriptive purposes.

7.0 RESULTS AND DISCUSSION

7.1 Data Structure And General Relationships

Study-wide, 153 unique ecological units (244 unique PSP's) were classified and summarized for all variables. Due to later observed inconsistencies, missing data for key variables, and lack of replication, the total sample size was shrunk to 139 ecological units (215 PSP's). The volume of statistics relating to this dataset was enormous, and only the more "significant" findings are reported in this section.

7.1.1 Assessment Of The Percent Basal Area Reduction (%BAR) Variable And It's Components

Of the four %BAR root rot parameter estimates, only two were generally considered for analysis and inference; NSBAR (all-species ≥ 4.0 cm) and BARS (susceptible species ≥ 17.5 cm), respectively representing the smallest and largest root rot damage intensity estimates on average (Fig. 8), and Table 10.

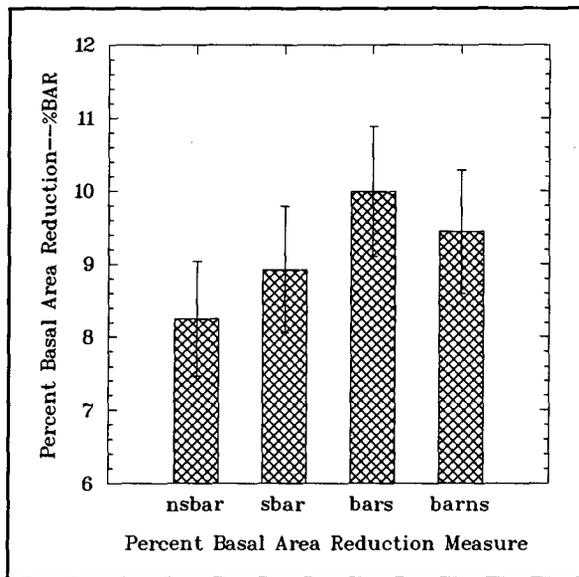


Figure 8 Histogram of the the four percent basal area reduction parameter estimates all-samples mean and (standard error).

Recall, that one of the %BAR sampling method assumptions was the expected relationships of the %BAR intensity parameters would rank out as per those tabled in Table 4, p.45. The rankings of intensity parameters in Figure 8 match the expected relationships exactly.

The principles of the Percent Basal Area Reduction sampling method are illustrated in part in the following descriptive statistics (Table 10). Table 10 is composed of the components of the %BAR equations for the NSBAR and BARS parameters. Most of the parameters are graphed later in this section, but note the variation of all parameters. Students t-tests were conducted on the incidence, severity subcomponents, resultant severity and %BAR intensity parameters shown in Table 10. The mean estimates of land-based (DSPT) and stand-based (DSWP) incidence were significantly different ($p = .000$). The mean estimates of the non-susceptible species (NSALH/NSALI) were significantly

different ($p = .000$), as were the susceptible species (SGRH/SGRI), ($p = .000$). The severity parameters (NSSEV/SEVS) and the %BAR intensity were also significantly different ($p = .005$) and $.0001$, respectively).

TABLE 10

**DESCRIPTIVE STATISTICS FOR STUDY-WIDE ESTIMATES OF
PHELLINUS ROOT ROT INCIDENCE, SEVERITY, SEVERITY SUB-COMPONENTS
AND INTENSITY**

	Incidence		Severity		Severity Subcomponents ¹				Intensity	
	Land-Area DSPT	Stand-Parameter DSWP	≥4.0 cm All Species NSSEV	≥17.5 cm Susceptible SEVS	≥4.0 cm All Spp. Healthy NSALH	≥4.0 cm All Spp. Infected NSALI	≥17.5 cm Suscept. Healthy SGRH	≥17.5 cm Suscept. Infected SGRI	≥4.0 cm All Species NSBAR	≥17.5 cm Susceptible BARS
No. of Cases	139	139	139	139	139	139	139	139	139	139
Minimum	0	0	-0.140	-0.490	5.64	1.000	1.250	0.000	-1.900	-9.100
Maximum	0.680	0.880	0.847	1.000	14.460	13.000	11.670	9.333	38.400	54.200
Range	0.680	0.880	0.987	1.490	8.820	12.000	10.420	9.333	40.300	63.300
Mean	0.168	0.263	0.290	0.318	8.958	6.380	7.181	4.882	8.248	9.994
Variance	0.027	0.049	0.037	0.053	2.853	4.045	3.154	3.038	85.570	110.759
Standard Dev.	0.164	0.221	0.192	0.231	1.689	2.011	1.776	1.743	9.250	10.524
Standard Error	0.014	0.019	0.016	0.020	0.143	0.171	0.151	0.148	0.785	0.893
Skewness (G1)	0.975	0.641	-0.124	-0.341	0.480	0.728	-0.142	0.278	1.312	1.237
Kurtosis (G2)	0.185	-0.566	-0.621	0.485	0.166	1.471	0.292	0.199	1.270	1.772
Coefficient of Variation	0.976	0.840	0.663	0.726	0.189	0.315	0.247	0.357	1.122	1.053

¹ The %BAR severity sub-components are raw "in" tree counts, yet to be factored by the prism' basal area factor (either 4, 6 or 8 m²).

The %BAR severity sub-components are used in the %BAR calculation; Severity = (healthy minus the infected) / (healthy).

Perhaps the most important principle of the %BAR sampling method is basal area reduction itself. How often it occurs is simply an estimate of incidence. Basal area reduction is illustrated by comparing mean tree counts of *healthy* sweeps (e.g., NSALH or SGRH) to *infected* sweeps (e.g., NSALI or SGRI) respectively (Fig. 9). (Also refer to Table 5, p. 46.) These are the Severity-subcomponents referred to in Table 10, above. Healthy tree counts were significantly greater than infected counts ($p = .0001$) by about 30% for both all-species and susceptible-only. Recall, that healthy and infected tree counts were used to estimate basal area reduction "severity", calculated in section 6.3.1. The coefficients of variation (CV) for healthy (NSALH) sweeps and infected (NSALI) sweeps were 18.9% and 31.5%, respectively, indicating a larger sampling-variability encountered in portions of stands infected with *Phellinus* root rot.

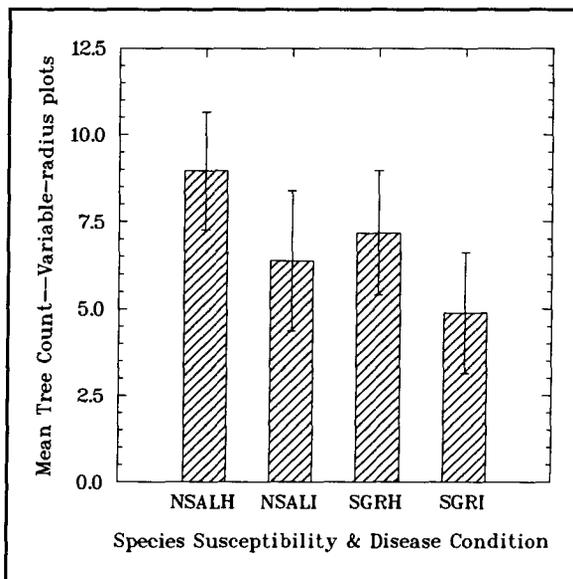


Figure 9 Histogram of the mean tree counts by species susceptible and disease condition; non-susceptible plus susceptible species, healthy and infected (NSALH and NSALI, respectively), and susceptible species only, healthy and infected (SGRH and SGRI, respectively).

7.1.2 Incidence-Severity, Severity-Intensity and Incidence-Intensity Relationships

The probability distributions of incidence, severity, and intensity were assessed for normality with cumulative probability plots and histograms. Land (DSPT) and stand (DSWP) based incidence variables both appear non-normally distributed with many healthy, uninfected sample plots, fewer lightly infected, and very few severely infected (Figs. 10 and 11). The severity variables (NSSEV and SEVS) have near normal distributions (Figs. 10 and 11). Root rot damage intensity parameters (NSBAR and BARS) also appear to be non-normal (Figs. 12, 13, 14 and 15), with high frequencies of zero to low intensities, and decreasing frequencies of higher intensities.

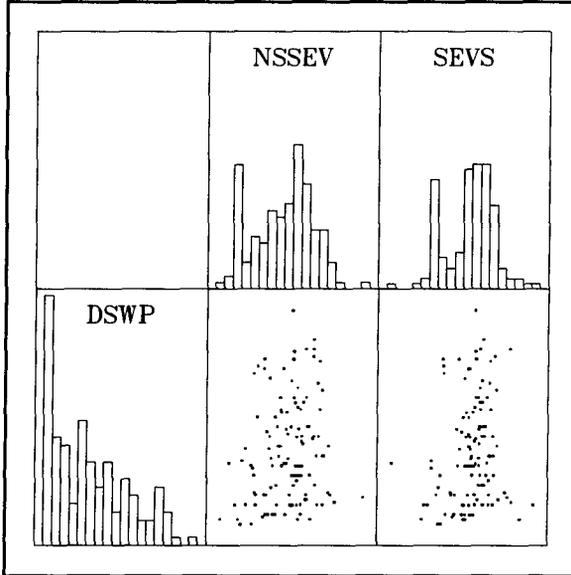


Figure 10 Incidence-Severity relationship of stand-based incidence (DSWP), on the y-axis, to damage severities (NSSEV) and (SEVS), on the x-axis. Note, the DSWP histogram has been rotated 90° clockwise.

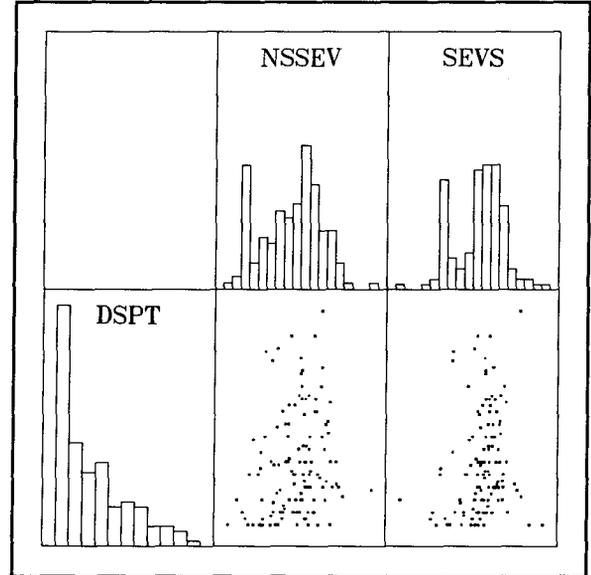


Figure 11 Incidence-Severity relationship of land-based incidence (DSPT), on the y-axis, to damage severities (NSSEV) and (SEVS), on the x-axis. Note, the DSPT histogram has been rotated 90° clockwise.

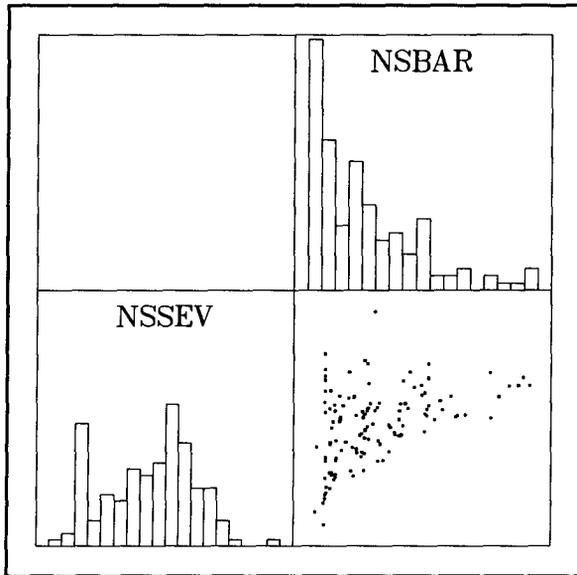


Figure 12 Severity-Intensity relationship of all-species damage severity (NSSEV), on the y-axis, to damage intensity (NSBAR), on the x-axis. Note, the NSSEV histogram has been rotated 90° clockwise.

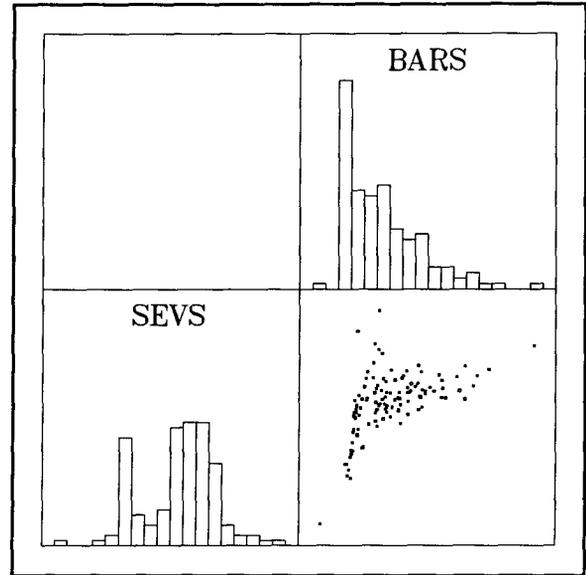


Figure 13 Severity-Intensity relationship of susceptible species ($\geq 12.0/17.5$ cm) damage severity (SEVS), on the y-axis, to damage intensity (BARS), on the x-axis. Note, the SEVS histogram has been rotated 90° clockwise.

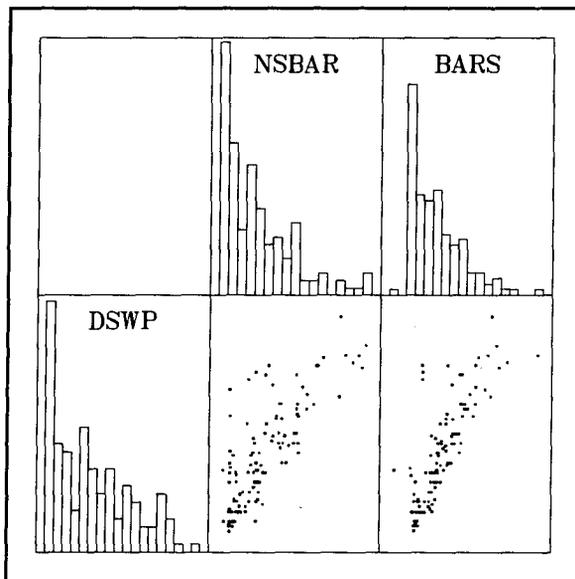


Figure 14 Incidence-Intensity relationship of stand-based incidence (DSWP), on the y-axis, to (NSBAR) and (BARS) damage intensities, on the x-axis. Note, the DSWP histogram has been rotated 90° clockwise.

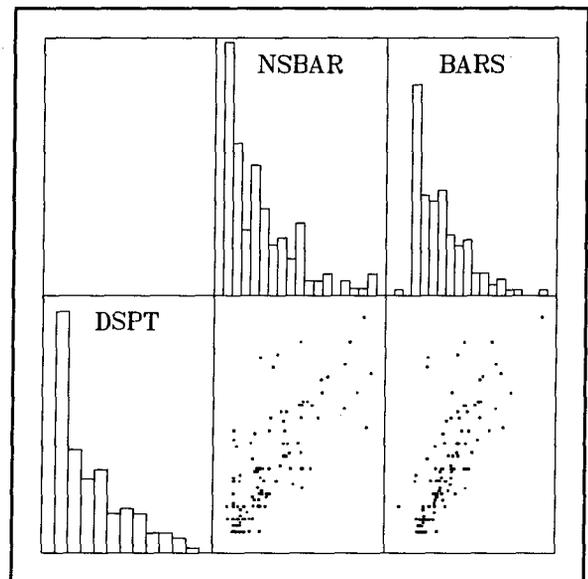


Figure 15 Incidence-Intensity relationship of land-based incidence (DSPT), on the y-axis, to (NSBAR) and (BARS) damage intensities, on the x-axis. Note, the DSPT histogram has been rotated 90° clockwise.

The incidence-severity variables shown in Figures 10 and 11, are significantly ($p=.0001$) and positively correlated with each other, but not strongly, with Pearsons r values ranging between .323 to .356 (Table 11).

TABLE 11		PEARSONS CORRELATION MATRIX OF <i>PHELLINUS</i> ROOT ROT SURVEY SAMPLING VARIABLES AND PARAMETERS						
	BARS	NSBAR	DSPT	DSWP	NSSEV	SEVS	AGE87	
BARS	1.00							
NSBAR	.874	1.00						
DSPT	.811	.792	1.00					
DSWP	.836	.817	.923	1.00				
NSSEV	.566	.510	.355	.356	1.00			
SEVS	.602	.456	.342	.323	.864	1.00		
AGE87	.264	.274	.312	.324	.185	.202	1.00	
AGE87 (p.'s) ¹	.035	.025	.004	.002	.617	.363		
¹ All Pearsons correlations are significant at the 99% level of significance; Note AGE87 p-values are indicated separately below AGE87 correlations.								

The severity-intensity relationships (NSSEV:NSBAR and SEVS:BARS) illustrated in Figures 12 and 13, show significant ($p=.0001$) and positive correlations between variable pairs; Pearsons r values were .510 and .602, respectively (Table 11). Severity displays a positive, quadratic, asymptotic behaviour when box plotted against the BARS-DIC's (Figs. 16 and 17). Although the variability is high, it appears that severity (the proportional difference between healthy and infected variable-radius plot tree counts) basal area stabilizes at about .50 or 50% basal area reduction in the Severe BARS-DIC.

Also, the Severe and Medium BARS-DIC's severity are not significantly different ($p = .289$), but are both significantly different from the Low BARS-DIC ($p = .0001$).

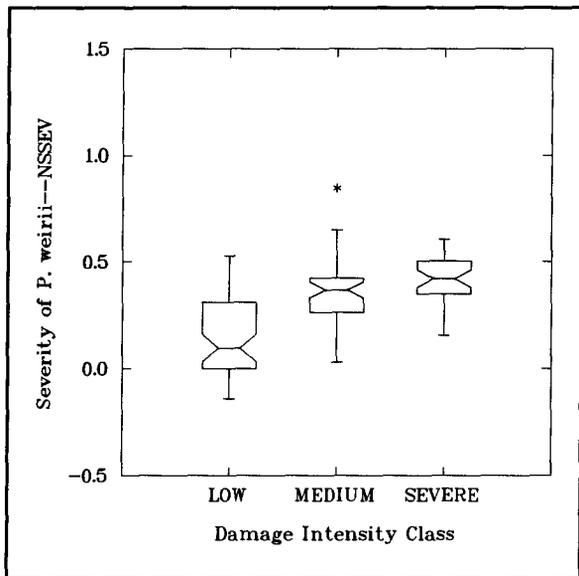


Figure 16 Boxplots of damage severity (NSSEV) classified by BARS-Damage Intensity Classes.

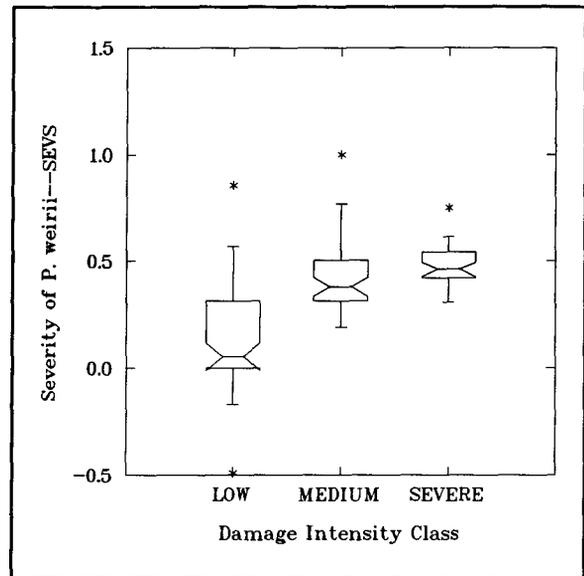


Figure 17 Boxplots of Damage severity (SEVS) classified by BARS-Damage Intensity Classes.

The incidence-intensity relationships (DSPT or DSWSP vs NSBAR or BARS) illustrated in Figures 16-19, show significant ($p = .0001$) and positive correlations between variables, with Pearson's r values ranging between .792 to .836 (Table 11). Incidence plotted against the BARS-DIC's shows a fairly strong linear relationship, with wide variation in all three classes, whether land-or stand-based incidence (Figs. 18 and 19). Simple linear regression incidence-intensity models indicate that between 63 and 70 percent of the BARS or NSBAR variability can be described by the disease incidence (Table 12). In both cases, stand-based incidence provides a better, slightly less variable estimate of disease

intensity compared to land-based incidence. This is not surprising, since the calculation for BARS/NSBAR intensity is partly based on the stand-based incidence.

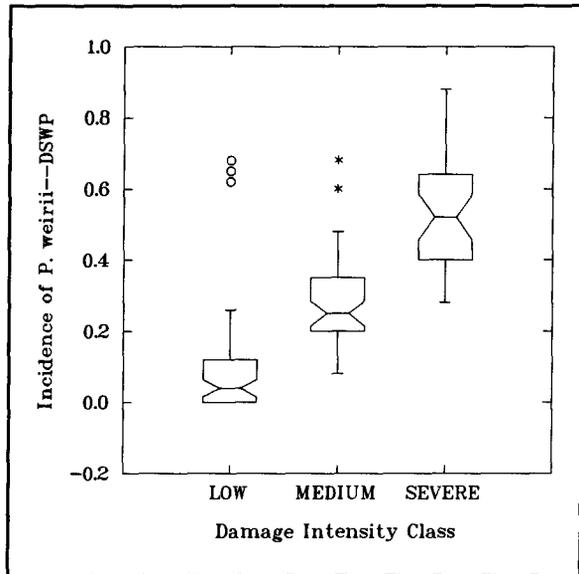


Figure 18 Boxplots of land-based disease incidence (DSPT) classified by BARS-Damage Intensity Classes.

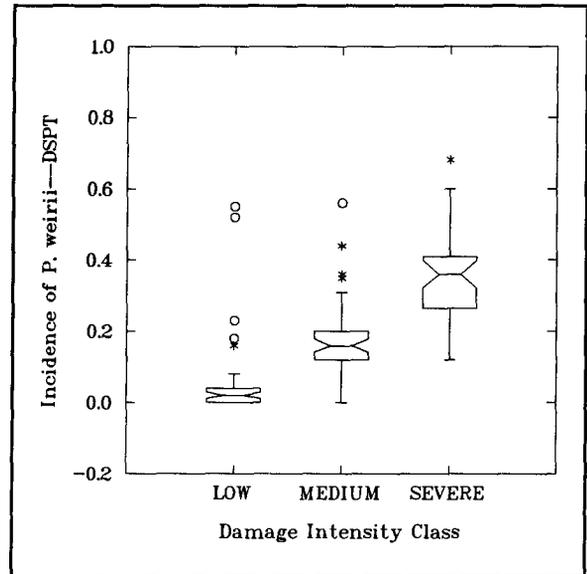


Figure 19 Boxplots of stand-based disease incidence (DSWP) classified by BARS-Damage Intensity Classes.

Comparison of land-based incidence to stand-based damage intensity estimates is of particular interest in coastal forests where most root disease sampling has been done using the Intersection Length Method (a land-based disease incidence estimation method). For example, consider solving for BARS damage intensities of 5%, 10% and 15% using land-based disease incidence (DSPT) (see Table 12). Disease incidence levels (DSPT) that respectively equate to 5%, 10% and 15% damage intensity BARS are 7.25%, 17.0% and 26.5%. This suggests that land-based incidence estimates, respectively translate into 45%, 70% and 76% overestimates of the stand-based root rot damage

intensity.

TABLE 12 INCIDENCE - INTENSITY RELATIONSHIPS (BARS/NSBAR) AS A FUNCTION OF STAND (DSWP) AND LAND (DSPT) BASED INCIDENCE				
Simple Linear Equation	R ²	SEE	5 and 15 %BAR Equivalencies of (DSWP) and (DSPT)	
			5 %BAR	15 %BAR
BARS = $-.491 + 39.861DSWP$	.70	5.79	14% DSWP	38.86% DSWP
BARS = $1.245 + 51.924DSPT$	.66	6.17	7.25% DSPT	26.50% DSPT
NSBAR = $-0.756 + 34.233DSWP$	.67	5.35	17% DSWP	46.03% DSWP
NSBAR = $0.737 + 44.578DSPT$	.63	5.66	9.5 DSPT	32.00% DSPT

7.1.3 Stand-Based:Land-Based and Land-Based:Stand-Based Incidence Relationships

The variance between the stand-parameter-diseased (DSWP) and land-area-diseased (DSPT) incidence expressions is quite large (Table 10), although the linear correlation between the parameters is very high at 0.923 (Table 11). The theory behind the fixed-radius and variable-radius sampling would only predict similar incidence estimates if "equivalent" areas were being sampled--this was not the case. The sampling efficiencies of the two expressions were evaluated in two ways: (1) by calculating a stand:land incidence ratio and plotting it over the land-based incidence; the assumption being that the land-based expression is the more accurate estimate and is therefore the baseline (Fig. 20); and (2) by calculating a land:stand incidence ratio and plotting it over the stand-based incidence, the assumption being that the stand-based expression is the more

accurate estimate and is therefore the baseline (Fig. 21). Note, a constant of .001 was added to both expressions of incidence prior to calculating the ratios, in order to avoid zero-values. The size of the constant will affect the scale of plots but should not affect the subsequent ratios.

In Figure 20 the stand:land-based incidence ratio has 10 non-plotted values ranging from 21 to 251 with land-based incidence equal to 0.001. The stand-based expression is clearly very sensitive to *Phellinus* root rot incidence at the lower land-based levels (<.35 or 35%), and stabilizing at higher incidence levels. The results are not surprising since the land-based expression is based on 0.005 ha (3.99 m fixed-radius plots), and the variable-radius plots, while not sampling land-area, are effectively sampling an average area of 0.027 ha. The variable-radius plot mean percent area sampled was determined as follows: the mean tree dbh marginal sphere was estimated to be about 0.0038 ha (3.5 m radius) multiplied by the mean tree count of 7.18 trees/sweep for a percent area of 0.027 ha.

The land:stand-based incidence ratio has no missing values (Fig. 21). The land-based expression does not seem to be as sensitive at the lower (<.35) end of the stand-based incidence, but does stabilize beyond about (>.35). The land-based incidence stabilization appears to be more variable than the stand-based stabilization baselined against stand-based incidence.

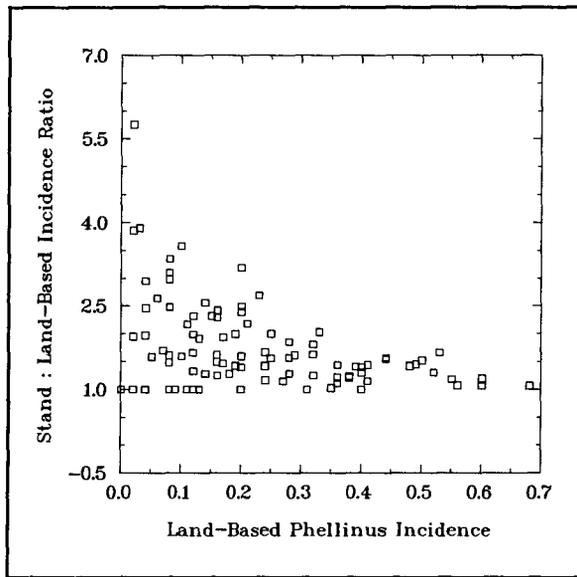


Figure 20 Stand:land-based incidence relationship. Note, there are 10 non-plotted observations equal to zero ranging between 21 and 251 on the stand:based incidence ratio axis.

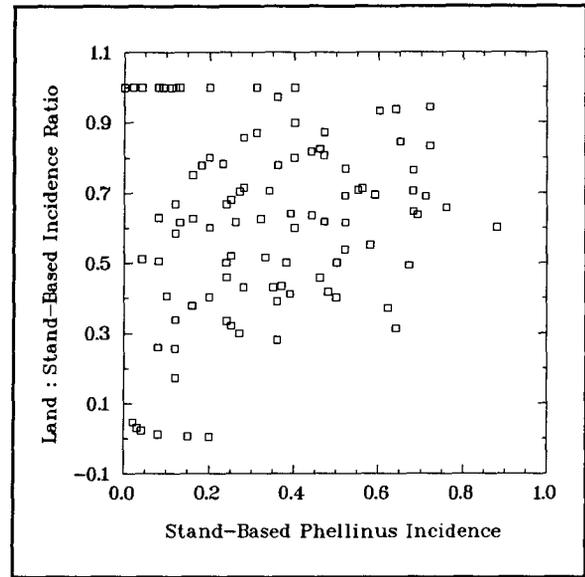


Figure 21 Land:stand based incidence relationship.

7.1.4 Comparison Of The %BAR Survey Data To The Permanent Sample Plot (PSP) Data

The two data sets were compared to determine if there is a relationship between PSP-based *Phellinus* root rot incidence and its associated 1 ha %BAR sample survey root rot estimators (incidence or intensity), since there was no common root rot estimator for both data sets. The sole estimator of *Phellinus* root rot in the PSP's was a land-based incidence variable (RRIN, respectively 0 or 1 or absence/presence), and similarly so for the 10m PSP buffer variable (RRBF). Root rot estimators for the 1 ha %BAR sample surveys were land-and stand-based disease incidence estimators (DSPT and DSWP, respectively), and %BAR intensity estimators (BARS and NSBAR). The two data sets

were compared graphically and tested with Students t-tests.

Infected permanent sample plots (RRIN=1) were found to occur in %BAR sample surveys which had significantly greater levels of BARS, NSBAR, DSWP and DSPT compared to healthy, uninfected PSP's (RRIN=0) (all p-values < .018) (Figs. 22-25). Five-percent BARS/NSBAR thresholds, and their stand- and land-based incidence equivalents (DSWP and DSPT) were estimated (see Table 12, p. 84) and plotted (Figs. 22-25). The 5% threshold corresponded approximately to the Low-Medium BARS-Damage Intensity Class boundary, and was consistently exceeded by the infected PSP's. In other words, 80% of the infected PSP's occurred in sample stands where *Phellinus* root rot exceeded 5% BARS/NSBAR, and had a corresponding BARS-Damage Intensity Classification of Medium to Severe.

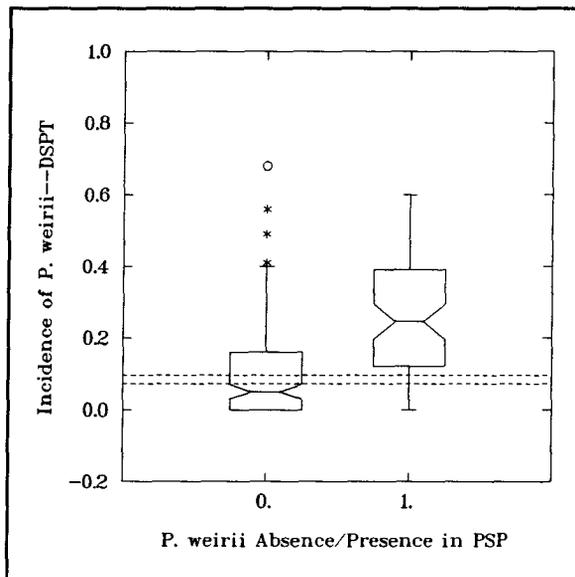


Figure 22 Boxplots of land-based disease incidence (DSPT) classed by absence (0) and presence (1) of disease incidence in PSP's. The upper and lower y-axis limits (---) refer to the 5% BARS and NSBAR damage intensity threshold.

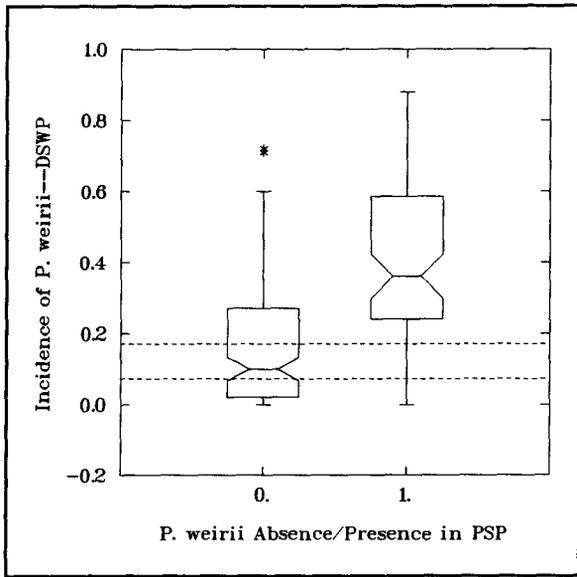


Figure 23 Boxplots of stand-based disease incidence (DSWP) classed by absence (0) and presence (1) of disease incidence in PSP's. The upper and lower y-axis limits (---) refer to the 5% BARS and NSBAR damage intensity threshold.

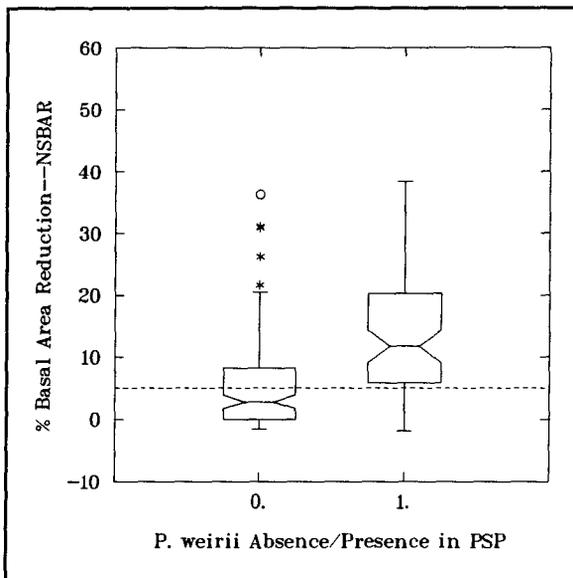


Figure 24 Boxplots of damage intensity (NSBAR) classed by absence (0) and presence (1) of disease incidence in PSP's. The y-axis limits (---) refer to the 5% damage intensity threshold. Note, that 80% of the infected PSP's occur in stands with greater than 5% damage intensity.

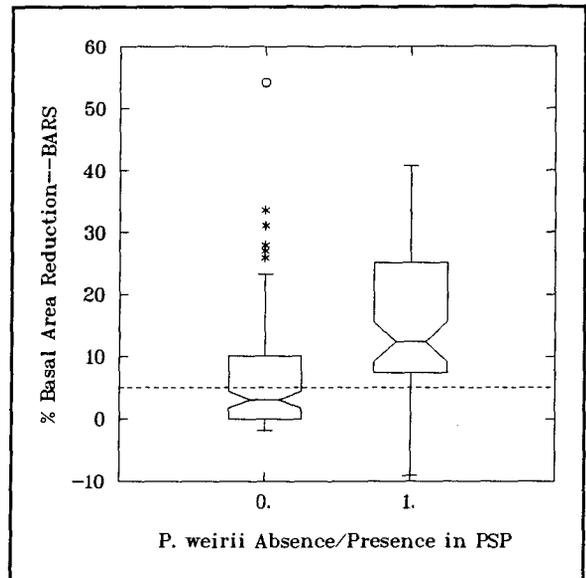


Figure 25 Boxplots of damage intensity (BARS) classed by absence (1) and presence (1) of disease incidence in PSP's. The y-axis limits (---) refer to the 5% damage intensity threshold. Note, that 80% of the infected PSP's occur in stands with greater than 5% damage intensity.

7.2 Ecological Relationships of *Phellinus weirii*

7.2.1 Describing *Phellinus* Root Rot Variability in Relation to Biogeoclimatic Units

Phellinus root rot variability within biogeoclimatic unit classifications was evaluated by comparison of root rot incidence, severity (in some cases), and intensity.

Disease incidence (or presence) in plots was assessed from several different sampling unit populations:

- a) *Phellinus* root rot sample surveys (1 ha), n=139,
- b) the Permanent Sample Plots (0.04 ha), n=215 and n=204,
- c) fixed-radius plots (0.005 ha), a land-area-diseased estimates (variable=DSPT), n=3 475 in 139 sample surveys, and
- d) variable-radius plots (area-less but approximates 0.0263 ha), stand-parameter-diseased estimates (variable= DSWP), n=3 475 in 139 sample surveys.

Damage severity was only evaluated in the site associations (n=139). Damage intensity was assessed graphically via boxplots, followed up by Tukey's Honestly Significant Difference multiple comparison tests of the means across biogeoclimatic units. Intensity was also assessed by comparing BARS-DIC and tested with log-linear models (Wilkinson 1988).

7.2.1.1 Zonal (Climatic) Classification And Disease Variability

7.2.1.1.1 Disease Incidence Variability: Zonal Classification

Disease incidence based on the presence/absence of *P. weirii* in 1ha sample survey plots did not vary much between subzones or variants (Table 13), but had a very high incidence at 86%-plus. Disease incidence in the PSP's, (n=215 or 204), indicated substantially more PSP's infected in the CWHxm unit(s) compared to the CDFmm.

Incidence estimates show that the CWHxm subzone had a 50%-plus greater incidence of root rot compared to the CDFmm; land-based significant at $p=.051$ and stand-based at $p=.020$, respectively. Note, the stand-based incidence estimates are 50 to 60% greater than land-based incidence estimates. Incidence estimates for the variants have a similar pattern, with no significant differences between the CWHxm1 and xm2 variants ($p=.968$). The land-based incidence indicated weak differences between the CDFmm and CWHxm1 ($p=.199$) and CDFmm and CWHxm2 ($p=.154$) variants, whereas the stand-based estimate indicated a strongly significant difference between the CDFmm and CWHxm1 variants ($p=.047$), and only a weak difference between CDFmm and CWHxm2 ($p=.154$).

BEC Unit	Sample Survey Basis (1 ha) n=139		PSP Basis (.04 ha) n=215		PSP Basis (.04 ha) n=204		Land Based-Fixed Radius (.005 ha)		Stand Based-Variable Radius	
	N	Incidence	N	Incidence	N	Incidence	N	Incidence (Std.Err.)	N	Incidence (Std.Err.)
<u>Subzone</u>										
CDFmm	30	.90	55	.25	55	.25	750	.117 (.024)	750	.180 (.030)
CWHxm	109	.86	160	.39	149	.41	2725	.183 (.016)	2725	.286 (.022)
<u>Variant</u>										
CDFmm	30	.90	55	.25	55	.25	750	.117 (.024)	750	.180 (.030)
CWHxm1	60	.87	96	.38	95	.39	1500	.179 (.021)	1500	.296 (.030)
CWHxm2	49	.86	64	.39	54	.44	1225	.187 (.026)	1225	.274 (.032)
Total/Mean	139	.87	215	.354	204	.368	3475	.168	3475	.263

7.2.1.1.2 Disease Intensity Variability: Zonal Classification

Sample survey plot frequencies by BARS-DIC's, varied significantly between the CDFmm and CWHxm subzones ($p=.016$), as tested by log-linear models. The CDFmm had a substantially lower frequency of Severe damage as compared to the CWHxm subzone (Table 14).

Similarly, sample survey plot frequency by BARS-DIC varied significantly between the CDFmm, CWHxm1 and CWHxm2 subzone variants ($p=.011$). The significant difference was due to nearly double the frequency of Severely classed plots in the CWHxm1 as

compared to CWHxm2, and four to seven times the frequency in the CDFmm variant (Table 14).

TABLE 14 DISTRIBUTION OF <i>PELLINUS</i> ROOT ROT IN SUBZONES AND VARIANTS AS ESTIMATED VIA THE BARS DAMAGE INTENSITY CLASSIFICATION							
BARS-Damage Intensity	Frequency of %BAR Sample Surveys with <i>Phellinus</i> Root Rot						
	Subzone			Subzone Variant			
	CDFmm	CWHxm	Total	CDFmm	CWHxm	CWHxm	Total
Low	18	40	58	18	20	20	58
Medium	10	36	46	10	17	19	46
Severe	2	33	35	2	23	10	35
TOTAL	30	109	139	30	60	49	139

Mean, disease intensity estimates (BARS), were compared by t-test and found to vary significantly ($p=0.017$) between subzones; the means are 5.94% and 11.11%, respectively for the CDFmm and CWHxm subzones (Fig. 26).

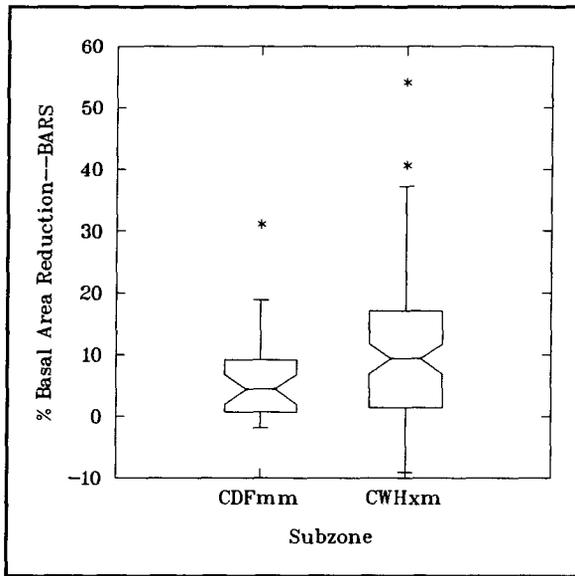


Figure 26

Boxplots of % Basal Area Reduction-BARS by subzone. Mean BARS damage intensity for the CDFmm and CWHxm subzones are respectively, 5.94% and 11.11%.

Similarly, mean disease intensity estimates (BARS) for subzone variants were compared using Tukey's HSD method. The CDFmm variant was significantly different from CWHxm1 ($p=0.007$), and from the CWHxm2 ($p=.110$); the variant means are respectively, 5.94%, 12.88% and 8.93%. No significant difference in mean BARS was seen between the CWHxm1 and CWHxm2 variants ($p=.419$) (Fig. 27).

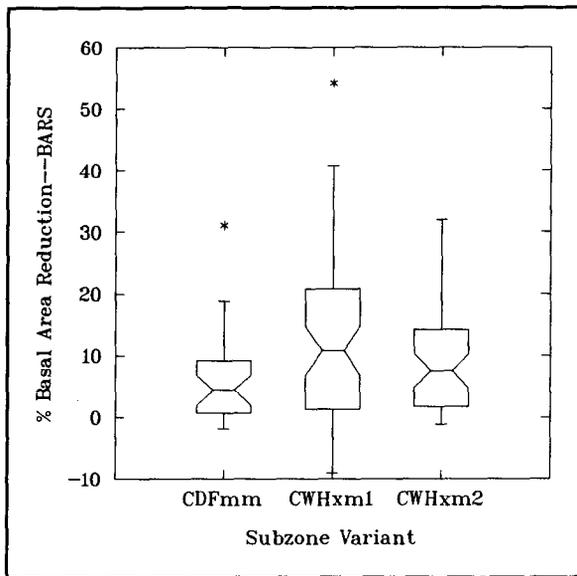


Figure 27

Boxplots of the % Basal Area Reduction-BARS by subzone variant. Mean BARS damage intensity for the CDFmm, CWHxm1 and CWHxm2 variants are respectively, 5.94%, 12.88% and 8.93%.

7.2.1.2 Vegetation Classification And Disease Variability

7.2.1.2.1 Disease Incidence Variability: Vegetation Classification

Disease incidence based on sample survey plots (1 ha), did not vary much between plant alliances (p.all.'s) or plant associations (p.a.'s) (Table 15). Incidence differences between the *Pseudotsuga-Mahonia* and *Tsuga-Mahonia* p.all., and the *Pseudotsuga-Mahonia* and *Thuja-Achlys* p.all. were nonexistent ($p=.307$) to moderately significant ($p=.096$) for the land-based estimates, and similarly for the stand-based estimates ($p=.149$ to $p=.107$) (Table 15). There is no evidence of differences between the *Pseudotsuga-Mahonia* and the *Thuja-Achlys* p.all. ($p=.975$). Incidence differences between the *Pseudotsuga-Arbutus* and *Tsuga-Mahonia*, and *Pseudotsuga-Arbutus* and *Thuja-Foamflower* p.a.'s are non-significant ($p=.192$) to moderately significant ($p=.067$)

for the land-based estimates, and for the stand-based estimates very weakly ($p = .113$) to moderately significant ($p = .090$) (Table 15).

BEC Unit	Sample Survey Basis (1 ha) n=139		Land-Based Fixed Radius (.01 ha)	Stand-Based Variable Radius
	N	Incidence	Incidence (Std. Error)	Incidence (Std. Error)
<u>Plant Alliances</u>				
<i>Pseudotsuga-Mahonia</i>	66	.86	.136 (.058)	.217 (.068)
<i>Tsuga-Mahonia</i>	25	.96	.192 (.029)	.312 (.040)
<i>Thuja-Achlys</i>	48	.83	.200 (.027)	.301 (.036)
<u>Plant Associations</u>				
<i>Pseudotsuga-Arbutus</i>	23	.96	.099 (.022)	.172 (.029)
<i>Pseudotsuga-Gaultheria</i>	43	.81	.156 (.025)	.241 (.034)
<i>Tsuga-Mahonia</i>	25	.96	.192 (.029)	.312 (.040)
<i>Pseudotsuga-Achlys</i>	48	.83	.200 (.027)	.301 (.036)

7.2.1.2.2 Disease Intensity Variability: Vegetation Classification

Sample survey plot frequency by BARS-DIC did not vary significantly between the three plant alliances ($p = .304$), or the four plant associations ($p = .183$) occurring in the study area. Interestingly, the driest plant association, *Pseudotsuga-Mahonia*, showed a similar pattern to the frequency in the CDFmm subzone (variant); they were in fact highly correlated. The *Tsuga-Mahonia* plant association paralleled the frequency pattern of the CWHxm1 variant, with a higher frequency in the Severe BARS-DIC than predicted by the log-linear model, though not as strongly. Overall, the sample survey plot frequency by

damage intensity class was inversely related to damage intensity (Table 16).

TABLE 16 DISTRIBUTION OF <i>Phellinus</i> ROOT ROT IN PLANT ALLIANCES AND PLANT ASSOCIATIONS ESTIMATED VIA THE BARS DAMAGE INTENSITY CLASSIFICATION									
BARS-Damage Intensity Class	Frequency of %BAR Sample Surveys with <i>Phellinus</i> Root Rot								
	Plant Alliance				Plant Association				
	PALL1	PALL2	PALL3	Total	PASS1	PASS2	PASS3	PASS4	Total
Low	32	7	19	58	12	20	7	19	58
Medium	20	8	18	46	9	11	8	18	46
Severe	14	10	11	35	2	12	10	11	35
TOTAL	66	25	48	139	23	43	25	48	139

Where: PALL1 = *Pseudotsuga-Mahonia*, PALL2 = *Tsuga-Mahonia* and PALL3 = *Thuja-Achlys*.
 Where: PASS1 = *Pseudotsuga-Arbutus*, PASS2 = *Pseudotsuga-Gaultheria*, PASS3 = *Tsuga-Mahonia* and PASS4 = *Pseudotsuga-Achlys*.

Mean BARS estimates for plant alliances were compared using Tukey's HSD method with no significant differences (all p-values > .319); the means are 8.84%, 12.40% and 10.33%, for *Pseudotsuga-Mahonia*, *Tsuga-Mahonia* and *Thuja-Achlys* p.all.'s, respectively (Fig. 28).

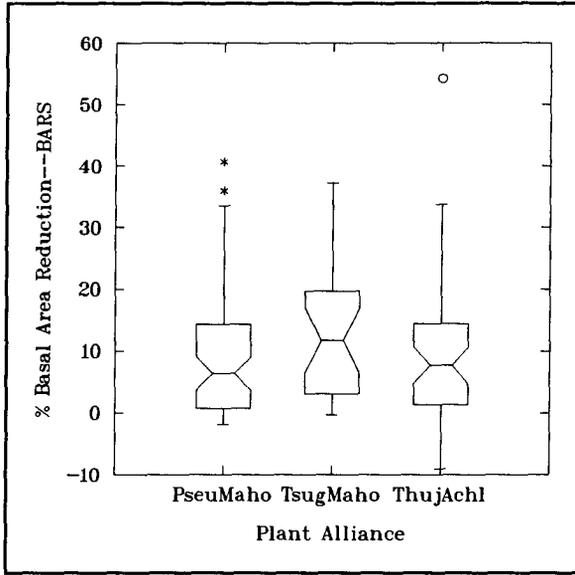


Figure 28

Boxplots of % Basal Area Reduction-BARS by plant alliances. Note the trend of elevated %BARS in the *Tsuga-Mahonia* mesic p.all. and tailing-off into the drier and fresher p.all's. Mean BARS intensities for the (1) *Pseudotsuga-Mahonia*, (2) *Tsuga-Mahonia*, and (3) *Thuja-Achlys*, p.all.'s, are respectively 8.84%, 12.40% and 10.33%.

Likewise, mean BARS estimates for plant associations did not vary significantly (all p-values > .206); the means are 6.48%, 10.09%, 12.4% and 10.33% for *Pseudotsuga-Arbutus*, *Pseudotsuga-Gaultheria*, *Tsuga-Mahonia* and *Pseudotsuga-Achlys*, respectively (Fig. 29).

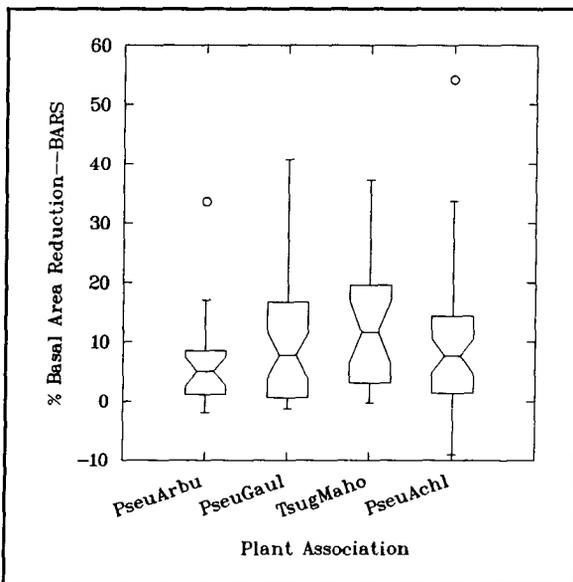


Figure 29

Boxplots of % Basal Area Reduction-BARS by plant association. Mean BAR intensities for the (1) *Pseudotsuga-Arbutus*, (2) *Pseudotsuga-Gaultheria*, (3) *Tsuga-Mahonia* and (4) *Pseudotsuga-Achlys*, p.a.'s, are respectively, 6.48%, 10.09%, 12.40% and 10.33%.

7.2.1.3 Site Classification And Disease Variability

7.2.1.3.1 Disease Incidence Variability: Site Classification

Disease incidence, based on sample survey plots (1 ha), did not vary much between site associations, although the *Cw-Foamflower* s.a. was much lower than other s.a.'s (Table 17). Disease incidence, based on either n=215 or n=204 PSP datasets, showed no differences between s.a.'s with the exception of the zonal site associations *Fd-Salal* and *HwFd-Kindbergia* which were weakly different ($p = .118$) (Table 17). Land- and stand-based incidence indicate the general similarity of incidence across s.a.'s, with the exception of weak to moderate differences between *Fd-Salal* and *FdHw-Salal*, (land-based, $p = .181$ and stand-based, $p = .058$), and the *Fd-Salal* and *HwFd-Kindbergia* (land-based, $p = .102$ and stand-based, $p = .075$) (Table 17).

BEC Unit	Sample Survey Basis (1 ha) n=139		PSP Basis (.04 ha) n=215		PSP Basis (.04 ha) n=204		Land Based Fixed Radius (.01 ha)	Stand Based Variable Radius (~.027 ha)
	Site Association	N	Incidence (Std. Error)	N	Incidence (Std. Error)	N	Incidence (Std. Error)	Incidence (Std. Error)
<i>Fd-Salal</i>	24	.88 (.0663)	40	.25 (.0685)	40	.25 (.0685)	.095 (.021)	.160 (.026)
<i>FdBg-Oregon grape</i>	6	1.00 (0)	13	.23 (.1167)	13	.23 (.1167)	.202 (.081)	.262 (.113)
<i>FdHw-Salal</i>	36	.92 (.0452)	49	.36 (.0686)	49	.36 (.0686)	.189 (.026)	.312 (.037)
<i>HwFd-Kindbergia</i>	54	.89 (.0426)	75	.45 (.0574)	73	.46 (.0635)	.193 (.023)	.297 (.031)
<i>Cw-Foamflower</i>	19	.68 (.1070)	34	.26 (.0752)	25	.32 (.0933)	.141 (.045)	.205 (.053)
TOTAL/MEAN	139	.87		.34		.36	.168	.263

7.2.1.3.2 Disease Intensity Variability: Site Classification

Sample survey plot frequency by BARS-DIC varied significantly between site associations ($p = .057$), using a log-linear model. Site associations (s.a.'s) of interest are the *Fd-Salal*, with a very high frequency of Low severity, and a low frequency of Severe plots and the *FdHw-Salal* and *HwFd-Kindbergia* s.a.'s which had a greater than expected frequency of Medium and Severe class plots. In contrast the *Cw-Foamflower* s.a. had a lower frequency of Medium and Severe plots than expected (Table 18).

TABLE 18 DISTRIBUTION OF <i>PELLINUS</i> ROOT ROT BY SITE ASSOCIATIONS AS ESTIMATED VIA THE BARS DAMAGE INTENSITY CLASSIFICATION						
BARS-Damage Severity Class	Frequency of %BAR Sample Survey with <i>Phellinus</i> Root Rot Site Associations					
	SA 11	SA 13	SA 21	SA 22	SA 24	TOTAL
Low	15	3	12	18	10	58
Medium	8	2	10	20	6	46
Severe	1	1	14	16	3	35
TOTAL	24	6	36	54	19	139
Where: SA11 = CDFmm-Fd-Salal, SA13 = CDFmm-FdBg-Oregon grape, SA21 = CWHxm-FdHw-Salal, SA22 = CWHxm-HwFd-Kindbergia, SA24 = CWHxm-Cw-Foamflower						

Mean BARS estimates for site associations were compared using Tukey's HSD method. Only *Fd-Salal* differed significantly from *FdHw-Salal* ($p = .066$), and was weakly different from *HwFd-Kindbergia* s.a. ($p = .121$). Mean BARS are 5.12%, 9.25%, 12.29%, 11.17% and 8.68% respectively, for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-*

Kindbergia and *Cw-Foamflower* s.a.'s, (Fig. 30). Other BARS comparisons were clearly not different (all p-values > .796).

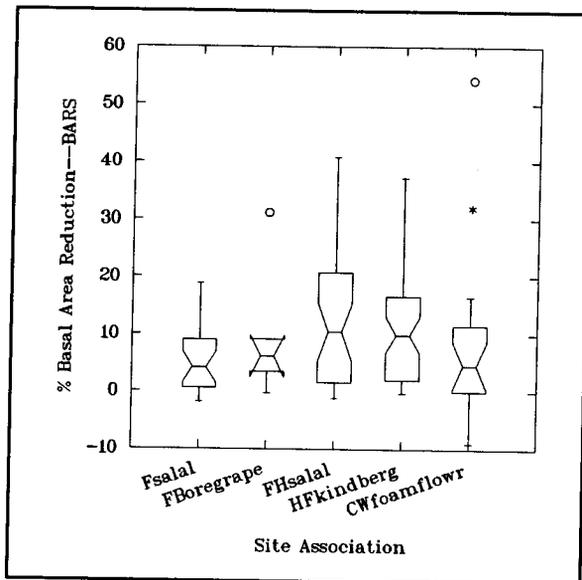


Figure 30 Boxplots of % Basal Area Reduction-BARS by site association. Mean BARS intensities for; *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia*, *Cw-Foamflower*, s.a.'s, are respectively, 5.12%, 9.25%, 12.29%, 11.17% and 8.68%.

7.2.2 Correlation Of Ecological Parameters And *Phellinus* Root Disease

Efforts to find functional relationships between ecological parameters, BEC units, continuous and categorical root rot variables were fraught with extreme difficulty because of data heterogeneity (lack of pattern). Ecological parameter--*Phellinus* root rot relationships were examined using Pearsons correlation, scatterplots and boxplots.

A Pearsons correlation matrix illustrates the non-existent to very weak correlations of BARS to most ecological variables (Table 19). Only SPHFH had a significant correlation at ($p < .20$) with BARS. Coarse fragment content (CF20) and mineral soil bulk

density (MSBDT) were negatively correlated and porosity (PORF) was positively correlated with BARS. Strong outliers appeared to strengthen the Pearson's correlation for several mineral soils and properties, (e.g., mineralizable nitrogen (MSMN), and MeqMg, MeqCa and MeqK). These weak correlations were disregarded due to a known large sampling variance that could not be corrected with the insufficient sample sizes used in this study (Green 1989, pg. 51-59).

Scatterplots for several weakly correlated, and thought-to-be-important, soil physical and chemical variables (CF20, MSBDT, MSBDF, PORF, SLOPE, ROOTDEPTH, MSPH, MSC, MSN, MSMN and MEQCA), illustrate very weak trends with BARS (see Appendix J).

Correlations significant at the 20% level of significance and/or variables of interest, eight ecological variables were boxplotted against subzone variant. Moving from the CDFmm through to CWHxm1 and CWHxm2, slightly-decreasing trends for CF20, MSBDT, MSBDF, MSPH and MEQCA were seen, and slightly-increasing trends were seen for PORF, SLOPE and ROOTDP (see Appendix F for ecological variables plotted against s.a. and Appendix G).

Interestingly, some site ecology variables have distributions strikingly similar to BARS plotted by site association. (Refer to Figure 30, and Figures 31-36, also see Appendix F). Of course many of the variables are integrated (thus correlated) to some degree in

TABLE 19

PEARSON CORRELATION MATRICES

I	BARS	AGE87	CF20	MSBDT	MSBDF	PORF	ROOTDP	SLOPE	MSPH	MSC	MSN	MSMN	MEQCA	MEQMG	MEQK
BARS	1.000														
AGE87	0.274*	1.000													
CF20	-0.133*	-0.065	1.000												
MSBDT	0.000	0.208	0.513	1.000											
MSBDF	0.001	0.115	0.022	0.605	1.000										
PORF	-0.001	-0.115	-0.022	-0.605	-1.000	1.000									
ROOTDP	-0.037	-0.102	-0.018	-0.024	-0.119	0.119	1.000								
SLOPE	0.178*	-0.127	0.094	0.083	-0.105	0.105	0.071	1.000							
MSPH	-0.100	-0.009	-0.023	0.230	0.098	-0.098	0.114	0.102	1.000						
MSC	-0.010	0.012	0.094	0.068	-0.064	0.064	-0.096	-0.053	-0.087	1.000					
MSN	0.034	-0.036	-0.179	0.040	0.076	-0.076	-0.060	-0.164	-0.111	0.314	1.000				
MSMN	-0.125*	0.039	-0.080	-0.122	-0.104	0.104	-0.190	-0.118	-0.045	0.087	0.087	1.000			
MEQCA	0.095*	-0.035	0.029	0.004	0.053	-0.053	-0.145	0.261	0.068	0.300	0.057	0.194	1.000		
MEQMG	0.172*	-0.047	0.039	-0.117	-0.036	0.036	-0.131	0.290	-0.144	0.182	0.103	0.193	0.879	1.000	
MEQK	0.188*	0.015	-0.005	-0.104	-0.065	0.065	0.067	0.053	-0.144	0.027	0.105	0.090	0.408	0.408	1.000

II	BARS	FSUS	FINT	FRES	FDEC	AGE87	ST410	BA410	VL410	CRD410	SPHFH	SPHCW	COMPFH	COMPCW
BARS	1.000													
FSUS	-0.002	1.000												
FINT	0.093	-0.690	1.000											
FRES	-0.079	-0.455	0.056	1.000										
FDEC	-0.040	-0.509	-0.004	-0.158	1.000									
AGE87	0.264*	-0.147	0.011	0.192	0.039	1.000								
ST410	-0.087	0.002	-0.090	0.230	-0.089	-0.317	1.000							
BA410	0.028	0.014	-0.011	0.114	-0.095	-0.197	0.695	1.000						
VL410	0.044	0.014	0.033	-0.035	-0.023	-0.265	0.339	0.889	1.000					
CRD410	-0.001	-0.005	-0.040	0.180	-0.089	-0.250	0.866	0.945	0.758	1.000				
SPHFH	-0.344	-0.140	0.152	0.117	-0.026	-0.448	0.283	0.252	0.215	0.272	1.000			
SPHCW	0.036	-0.021	-0.002	0.173	-0.111	-0.236	0.309	0.300	0.214	0.347	0.274	1.000		
COMPFH	-0.175*	-0.160	0.168	0.029	0.058	-0.029	-0.059	0.006	0.049	-0.034	0.333	-0.361	1.000	
COMPCW	0.265*	0.098	-0.088	0.081	-0.141	-0.059	0.189	0.181	0.108	0.215	-0.081	0.699	-0.547	1.000

SELECTED VARIABLES:

(I) Ecological and soils, (II) Ecological and stand variables.

NOTE: **Emboldend** correlations are significant at ($p \leq 0.20$), Bonferronis, adjusted probability.(*) indicates correlations of interest but not significant ($p > 0.20$)

the site classification procedure (Pojar *et al.* 1987 and Banner *et al.* 1990), for example elevation and percent slope (Figs. 32 and 33). Note, the substantially lower elevation and percent slope conditions for the CDFmm compared to the CWHxm s.a. Values for percent coarse fragments, mineral soil bulk density and mineral soil pH, are greater in the CDFmm s.a.'s compared to the CWHxm s.a.'s (Figs. 31, 34 and 36, respectively), and soil porosity is lower in the CDFmm compared to the CWHxm s.a.'s, (Fig. 35). The soil physical attributes appear to be related to the actual soil moisture and nutrient regimes shown in Table 20. The coarser soils have moderately dry soil moisture regimes. Soil coarse fragment content in particular is used to estimate site soil moisture.

TABLE 20 ACTUAL SOIL MOISTURE AND NUTRIENT REGIMES FOR SITE ASSOCIATIONS IN THE STUDY AREA					
	<i>Fd-Salal</i>	<i>FdBg-Oregon grape</i>	<i>FdHw-Salal</i>	<i>HwFd-Kind-bergia</i>	<i>Cw-Foam-flower</i>
Actual Soil Moisture Regime (SMR)	MD	MD	MD	SD/F	SD/F
Actual Soil Nutrient Regime (SNR)	VP/M	M/R	VP/M	VP/M	M/R
Where:	MD is moderately dry, SD is slightly dry, F is fresh; and VP is nutrient very poor, M is nutrient medium, and R is nutrient rich, from (Banner <i>et al.</i> 1990)				

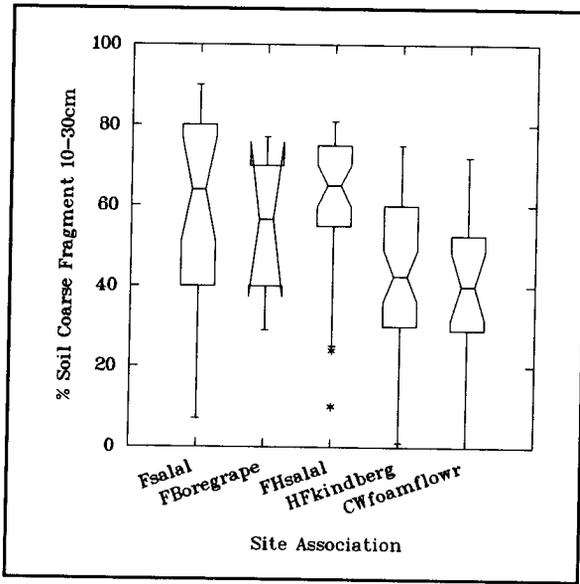


Figure 31 Percent (%) coarse fragment content (by volume) by site association. Means L to R are 60, 55, 62, 43 and 40. Note higher CF20's are associated with moderately dry, actual soil moisture regimes (refer to Table 20).

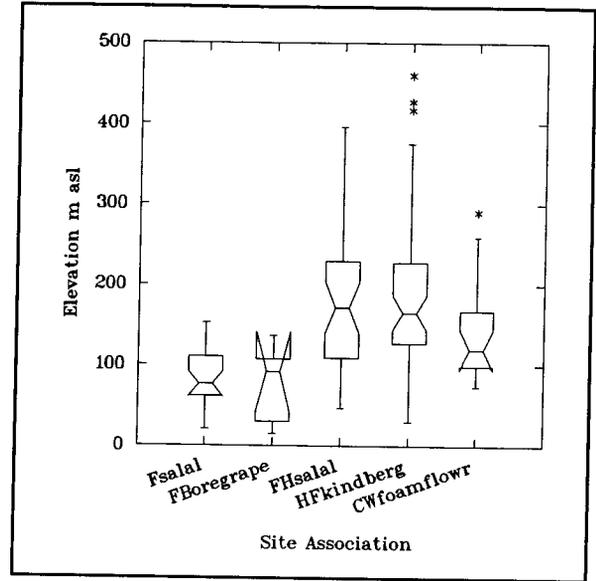


Figure 32 Elevation (m) asl by site association. Means are L to R, 85, 79, 191, 194 and 143 m. Elevation corresponds well with subzones. The CW-Foamflower unit is likely lower due to lower slope positions.

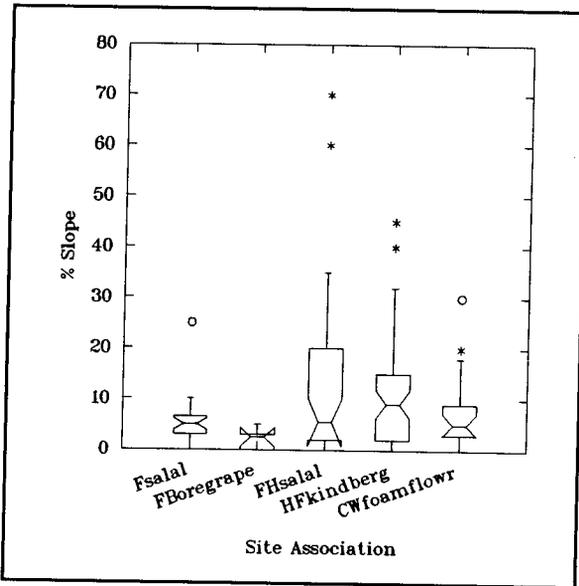


Figure 33 Slope (%) by site association. Means are L to R, 5.5, 2.2, 12.4, 10.9 and 7.6%. The CDF units correspond to the gentle coastal plain and CWHxm units to upland mid to lower slope conditions.

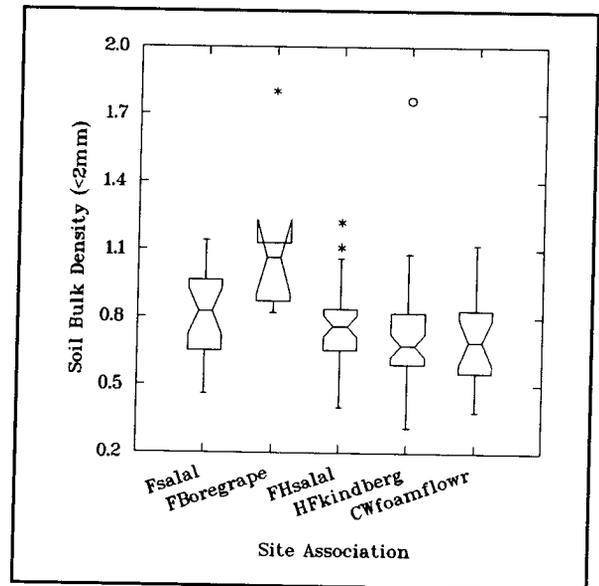


Figure 34 Fine fraction (<2 mm) mineral soil bulk density (g/cm^3) by site association. Means L to R; .828, 1.125, .766, 7.16 and .695.

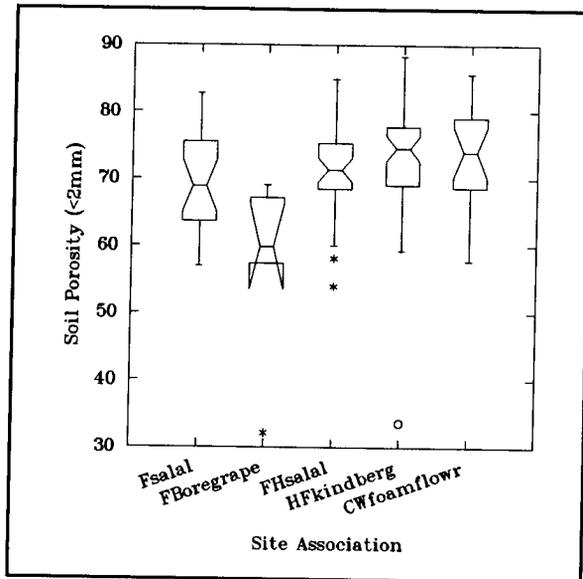


Figure 35 Mineral soil percent porosity by site association. Means L to R; 69, 58, 72, 73 and 74%. Note, porosity is inversely related to MSBDF, high bulk density equals low porosity.

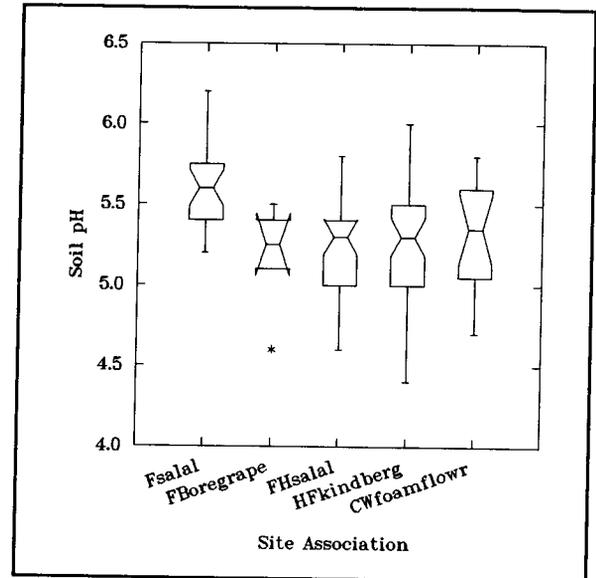


Figure 36 Mineral soil pH by site association. Means L to R are; 5.62, 5.18, 5.23, 5.26, and 5.3.

7.3 Stand History And Tree Species Dynamics

Stand history and second growth tree species dynamics were estimated from the %BAR root rot survey, old growth stand history (stump) survey and the PSP data sets.

7.3.1 Old Growth Stand Conditions and *Phellinus* Variability

Childs (1970) said that the potential for disease carry-over and intensification into subsequent rotations is largely dependent upon the number, size and spatial distribution of inoculum sources. Childs further stated many small well-distributed inoculum sources

lead to greater damage than a few large aggregated inoculum sources, because the expanding peripheral (and highly infective) area is greater with the former. Tkacz and Hansen (1982) found current stand infection in second growth Douglas-fir to be related to the spatial distribution of the preceding stand's diseased stumps. Because neither the stump inoculum size, spatial distribution, nor inoculum (stumps) infectivity were sampled in this study, and the fact that the stump survey data and disease incidence estimates are sample survey means, this could not be checked in this study. Instead, a picture of the old growth forest condition is presented, with a view to interpreting the possible cause and/or effect of susceptible and non-susceptible host species composition and stand density of previous stand conditions on the incidence and intensity of *Phellinus* root rot in today's second growth stands.

A tabulation of old growth stand conditions related to *Phellinus* root rot damage intensity (BARS) and various classifications of BARS-Damage Intensity, stand history/origins and biogeoclimatic units is presented in Table 21.

TABLE 21 DESCRIPTIVE STATISTICS FOR OLD GROWTH STEMS/HA AND SPECIES COMPOSITION BY VARIOUS CLASSIFICATIONS					
Damage Intensity, Stand Origin, and Ecological Classification	%BAR	Stems/Ha		Species Composition	
	BARS	SPHFH	SPHCW	COMPFH	COMP CW
	Mean	Mean, (Standard Deviation), & [Mean] ¹			
Damage Intensity					
Low	0.98	142(96)	21(31)	.82 (.26) [.871]	.11 (.14) [.129]
Medium	10.18	111(70)	15(24)	.86 (.24) [.881]	.10 (.16) [.119]
Severe	24.68	87(64)	29(48)	.77 (.23) [.750]	.21 (.24) [.250]
Stand Origin					
Wildfire	15.45	63(57)	12(26)	.77 (.34) [.840]	.10 (.17) [.16]
Logged	10.54	127(104)	10(16)	.93 (.13) [.927]	.07 (.13) [.073]
Logged & Burned	8.22	134(80)	26(37)	.82 (.24) [.838]	.15 (.19) [.162]
Logged (Logged + Logged & Burned)	8.49	133(82)	24(35)	.83 (.23) [.847]	.14 (.18) [.153]
Subzone					
CDFmm	5.94	76(75)	11(19)	.75 (.35) [.864]	.12 (.19) [.136]
CWHxm	11.11	129(82)	24(37)	.84 (.23) [.843]	.13 (.18) [.157]
Subzone Variant					
CDFmm	5.94	76(75)	11(19)	.75 (.35) [.864]	.12 (.19) [.136]
CWHxm1	12.88	125(84)	34(45)	.78 (.25) [.786]	.19 (.21) [.214]
CWHxm2	8.93	134(79)	12(18)	.91 (.17) [.918]	.07 (.10) [.082]
Plant Alliance					
<i>Pseudotsuga-Mahonia</i>	8.83	104(89)	18(30)	.80 (.28) [.852]	.12 (.17) [.148]
<i>Tsuga-Mahonia</i>	12.40	133(88)	25(43)	.81 (.29) [.842]	.16 (.24) [.158]
<i>Thuja-Achlys</i>	10.33	130(70)	24(35)	.85 (.20) [.844]	.13 (.16) [.156]
Plant Association					
<i>Pseudotsuga-Arbutus</i>	6.48	118(95)	18(39)	.85 (.25) [.867]	.11 (.16) [.183]
<i>Pseudotsuga-Gaultheria</i>	10.09	96(85)	18(23)	.77 (.30) [.842]	.13 (.18) [.158]
<i>Tsuga-Mahonia</i>	12.40	133(88)	25(43)	.81 (.29) [.842]	.16 (.24) [.158]
<i>Pseudotsuga-Achlys</i>	10.33	130(70)	24(35)	.85 (.20) [.844]	.13 (.16) [.156]
Site Association					
<i>Fd-Salal</i>	5.12	86(81)	8(18)	.81 (.34) [.915]	.06 (.14) [.085]
<i>FdBg-Oregon grape</i>	9.25	37(23)	24(19)	.51 (.28) [.607]	.32 (.20) [.393]
<i>FdHw-Salal</i>	12.29	127(85)	25(40)	.81 (.25) [.835]	.14 (.16) [.165]
<i>HwFd-Kindbergia</i>	11.17	128(83)	26(39)	.82 (.24) [.831]	.16 (.21) [.169]
<i>Cw-Foamflower</i>	8.68	138(75)	13(18)	.94 (.07) [.914]	.06 (.07) [.086]

[Mean]¹ represents mean species composition of the mean stems/ha of old growth stand density.

7.3.1.1 Old Growth Stand Conditions and *Phellinus* Root Rot Variability Between BARS-Damage Intensity Classes (DIC's)

Stems (or stumps) per hectare of Douglas-fir and western hemlock (SPHFH) are inversely related to the BARS-DIC's (Table 21, Fig. 37). Tukey's HSD tests, showed that the SPHFH in the Low DIC was very weakly different from the Medium ($p = .127$), and significantly different from the Severe DIC ($p = .004$). No mean differences were detectable between Medium and Severe BARS-DIC's ($p = .378$). The relationship of stems\ha of western red cedar (SPHCW) to DIC's was not as clear, with no substantial differences between DIC's (all p -values $> .163$) (Table 21, Fig. 38). Interestingly, the SPHCW were greatest in the Low and Severe DIC's, perhaps as a result of a possible host-pathogen dynamic equilibrium.

The contribution of Douglas-fir and western hemlock to the species composition (COMPFH), did not vary significantly between BARS-DIC's (all p -values $> .275$), though a slightly lower COMPFH was apparent in the Severe DIC. This likely indicated the mortality effects of root rot (Table 21, Fig. 39). On the other hand, the contribution of western red cedar to the species composition (COMPCW) varied significantly between Low and Severe, and Medium and Severe DIC's ($p = .016$) and ($p = .018$), respectively, but not between Low and Medium DIC's ($p = .402$) (Table 21, Fig. 40). The sharp increase in western red cedar composition in the Severe BARS-DIC appears to indicate a shift to more resistant tree species in the presence of increasing levels of *Phellinus* root rot.

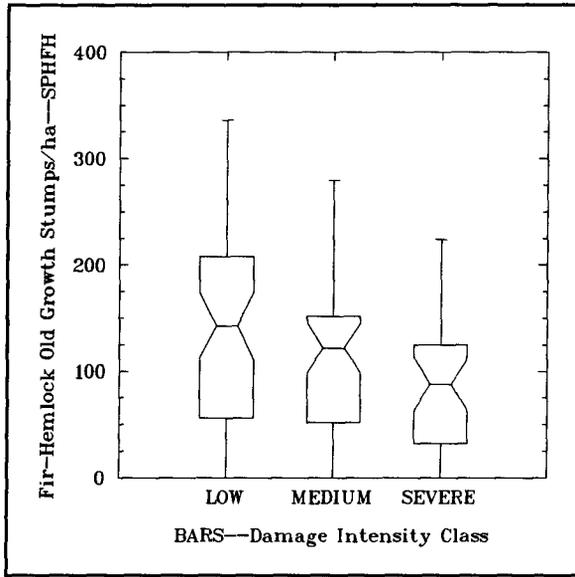


Figure 37 Boxplots of old growth Douglas-fir and western hemlock stems/ha (SPHFH) classified by BARS-Damage Intensity Classes.

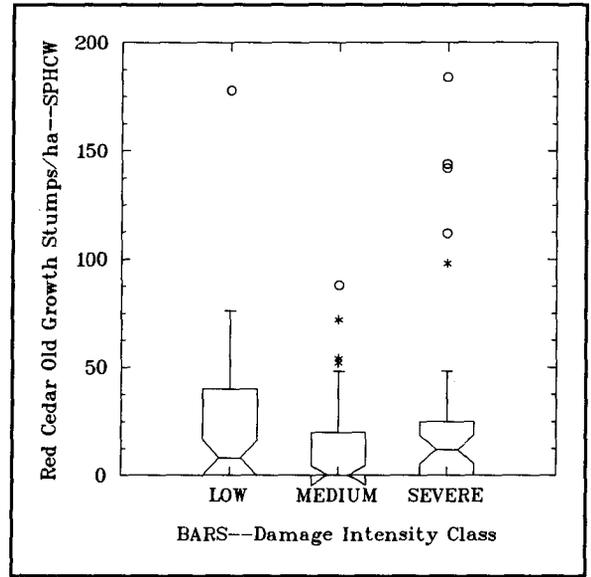


Figure 38 Boxplots of old growth western red cedar stems/ha (SPHCW) classified by BARS-Damage Intensity Classes.

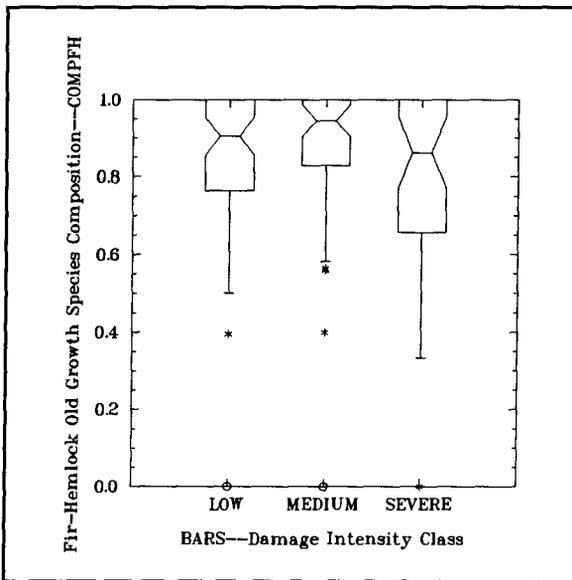


Figure 39 Boxplots of old growth Douglas-fir and western hemlock species composition (COMPFH) classified by BARS-Damage Intensity Classes.

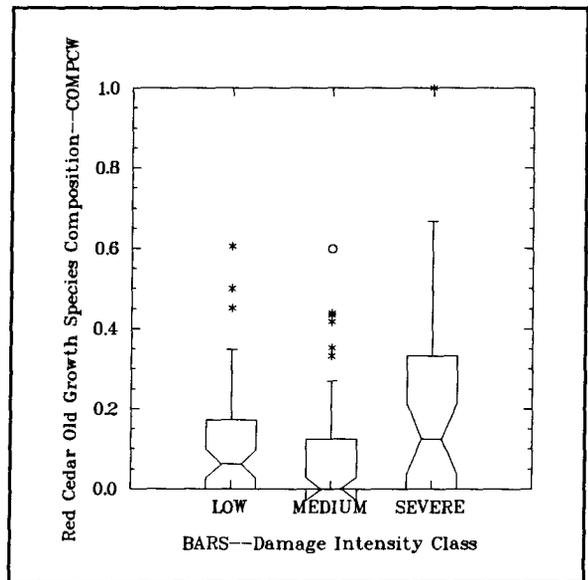


Figure 40 Boxplots of old growth western red cedar composition (COMPCW) classified by BARS-Damage Intensity Classes.

7.3.1.2 Old Growth Stand Conditions and *Phellinus* Root Rot Variability Between Subzones

The total old growth stems/ha of Douglas-fir and western hemlock (SPHFH) plus western red cedar (SPHCW) were significantly lower ($p=.017$) in the CDFmm as compared to the CWHxm, 87 vs 153 stems/ha, respectively (Table 21). This translates into the CDFmm having only 57% the old growth stand density of the CWHxm. The higher stand density in the CWHxm is likely attributable to the cooler, moister climate. Similarly, the stand density of SPHFH-only in the CDFmm is 58.9% that of the CWHxm. Interestingly, the mean species old growth species composition of Douglas-fir and western hemlock, (i.e., the susceptible and potential *Phellinus weirii* inoculum sources), for the CDFmm and CWHxm subzones were virtually identical at 86% and 84%, respectively (Table 21).

Old growth stand conditions at the subzone variant level were more varied within the CWHxm, and remained unchanged for the CDFmm (Table 21). Total stems/ha were slightly higher in the CWHxm1 compared to the CWHxm2. This was attributable to nearly three times the number of western red cedar stems, while stems/ha of Douglas-fir and western hemlock were slightly lower. This also dramatically affected the species compositions, with Douglas-fir/western hemlock (COMPFH) significantly lower ($p=.018$) and western red cedar significantly higher ($p=.001$) in the CWHxm1 compared to the CWHxm2. Notably, *Phellinus* root rot intensity (BARS) was greatest in the CWHxm1 compared to the CWHxm2.

7.3.1.3 Old Growth Stand Conditions and *Phellinus* Variability Between Plant Alliances and Plant Associations

Old growth stand density and species compositions did not vary significantly between p.all.'s (all p-values > .226) or p.a.'s (all p-values > .215). The only noticeable trend was a slightly lower stand density for both Douglas-fir/western hemlock and western red cedar in the drier *Pseudotsuga-Mahonia* p.all., and in the *Pseudotsuga-Arbutus* and *Pseudotsuga-Gaultheria* p.a.'s.

7.3.1.4 Old Growth Stand Conditions and *Phellinus* Root Rot Variability Between Site Associations

Old growth stand conditions varied considerably between site associations, very closely following the pattern of subzone and variants with the exception of the *FdBg-Oregon grape* s.a. Ecologically, it was surprising to see fewer stems/ha and lower composition of western red cedar in the *Cw-Foamflower* s.a., where cedar is indicated to be a climax species (Fig. 42). Rather, the greatest stems/ha and species compositions of western red cedar were in s.a.'s with the highest BARS damage intensities, (i.e., *FdBg-Oregon grape*, *FdHw-Salal* and *HwFd-Kindbergia*) (Figs. 41-44).

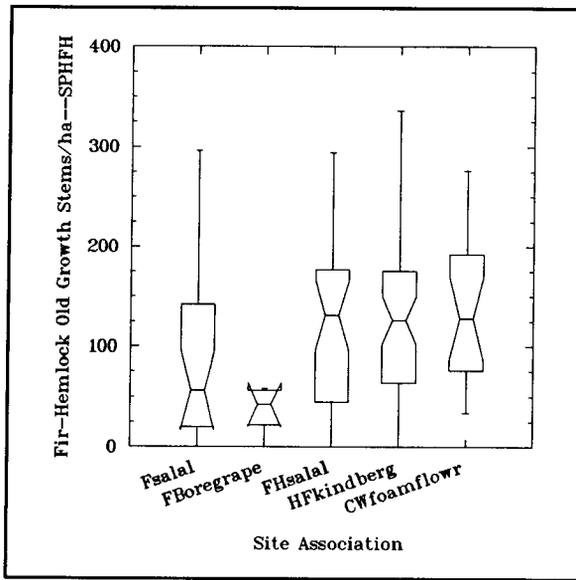


Figure 41 Old growth Douglas-fir and western hemlock stems (stumps)/ha by site association. Means L to R are; 86, 37, 127, 128 and 138.

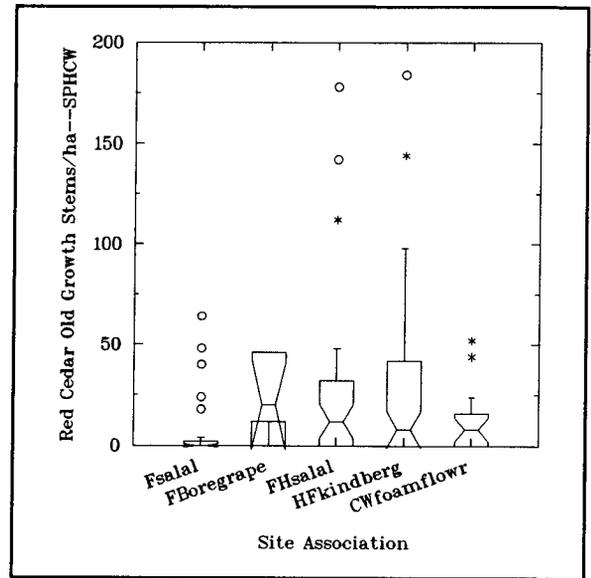


Figure 42 Old growth western red cedar stems (stumps)/ha by site association. Means L to R are; 8, 24, 25, 26 and 13.

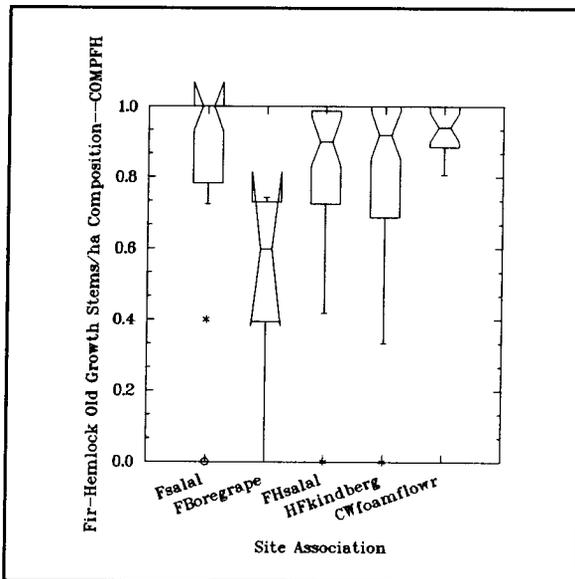


Figure 43 Old growth Douglas-fir and western hemlock species compositions by site association. Means L to R are; .916, .607, .835, .831 and .914.

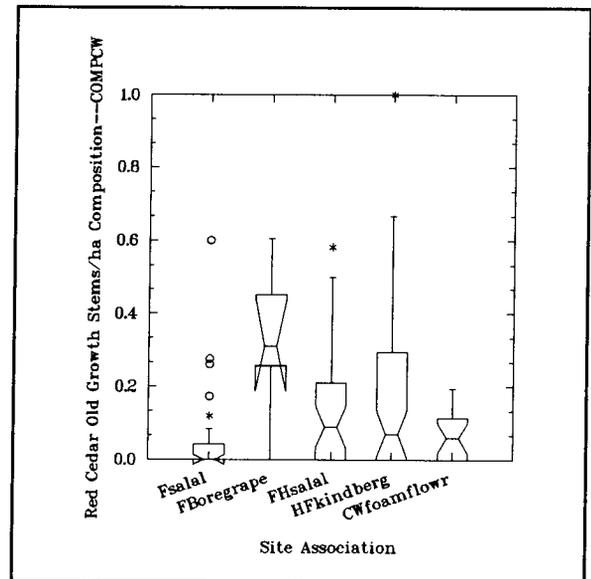


Figure 44 Old growth western red cedar species compositions by site association. Means L to R are; .063, .085, .393, .165, .169 and .086.

7.3.1.5 Old Growth Stand Density and Species Composition and Second Growth *Phellinus* Damage Intensity

The relationship between *Phellinus* root rot damage intensity and old growth stand density and species composition was also evaluated through contour plots and three-dimensional plots. *Phellinus* damage intensity (BARS) isobars were calculated using a negative exponentially weighted smoothing technique (McLain 1974) and plotted with SYGRAPH (Wilkinson 1988) (Figs. 45 and 46). These figures illustrate the *Phellinus* root rot relationship between old growth stems/ha Douglas-fir/western hemlock (SPHFH) and stems/ha western red cedar (SPHCW) for the full range of data.

Figures 45 and 46 illustrate three conditions which may have led to (conductive), or reacted to increasing levels of root rot in the old growth stand conditions: (i) decreasing susceptible species density (SPHFH) and increasing density of non-susceptible species (SPHCW), see lower left and lower right contour lobes, (ii) increasing susceptible and non-susceptible density, with emphasis on the latter, see upper right contour lobe, and (iii) increasing non-susceptible density (SPHCW) with stable susceptible density (SPHFH), see the -10% BARS contour which indicates a 10% gain in basal area due to severe *Phellinus* root rot activity. Two general observations are relevant. First is that second growth *Phellinus* root rot intensity appears related to decreasing SPHFH and increasing SPHCW. The high root rot intensities are generally related to high SPHFH (>200 sph) and moderate SPHCW (>120 sph); or low SPHFH (<200 sph) and moderate to high SPHCW (>100 sph). Secondly, the most striking feature of all the contour plots is a contour trough between two peaks of high root rot intensity. Arguably the contour trough

might be construed as an equilibrium zone.

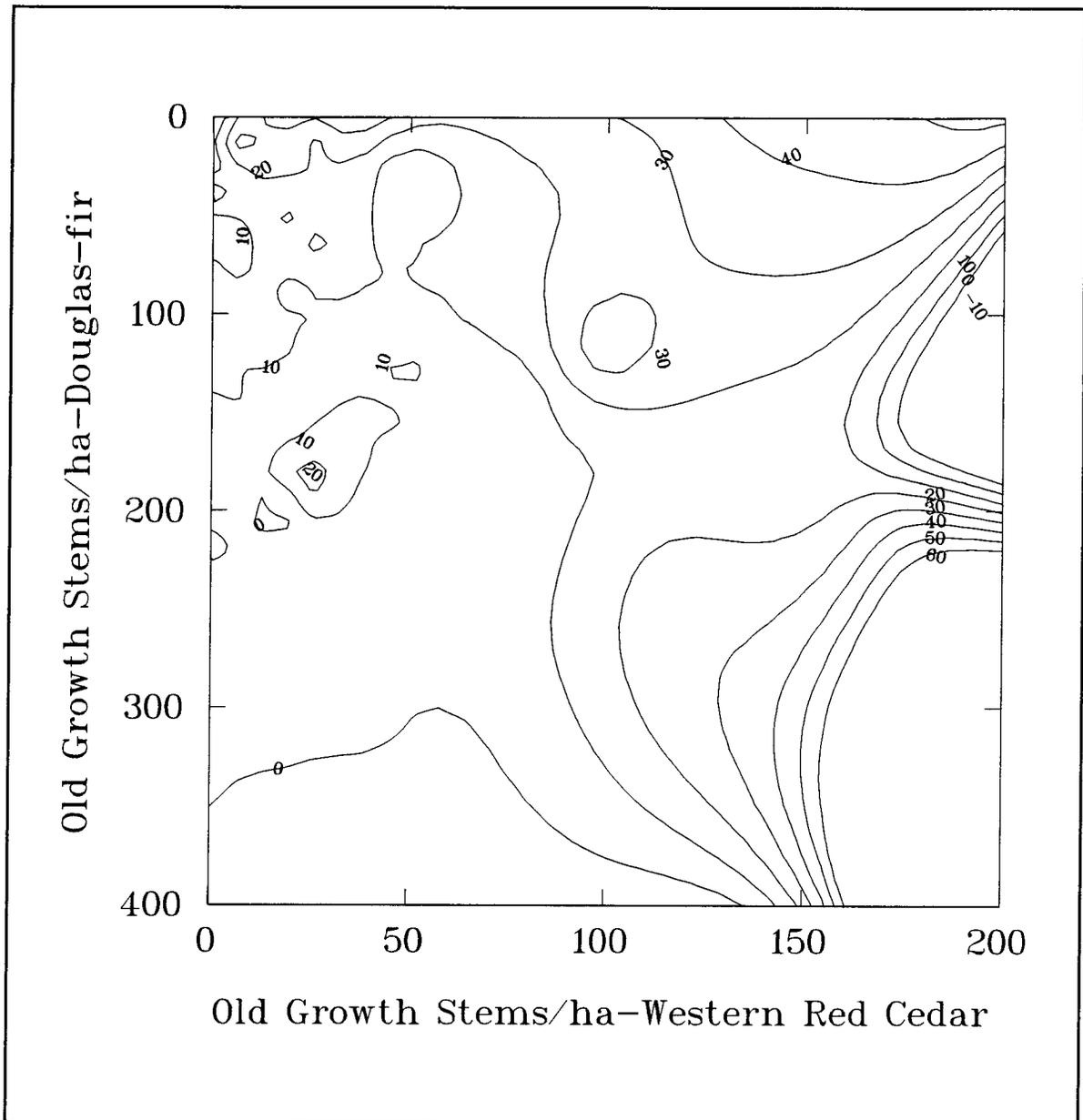


Figure 45

A two-dimensional contour plot illustrating the relationship between damage intensity (BARS) and old growth stand density (stems/ha) of Douglas-fir and western hemlock (SPHFH) and western red cedar (SPHCW).

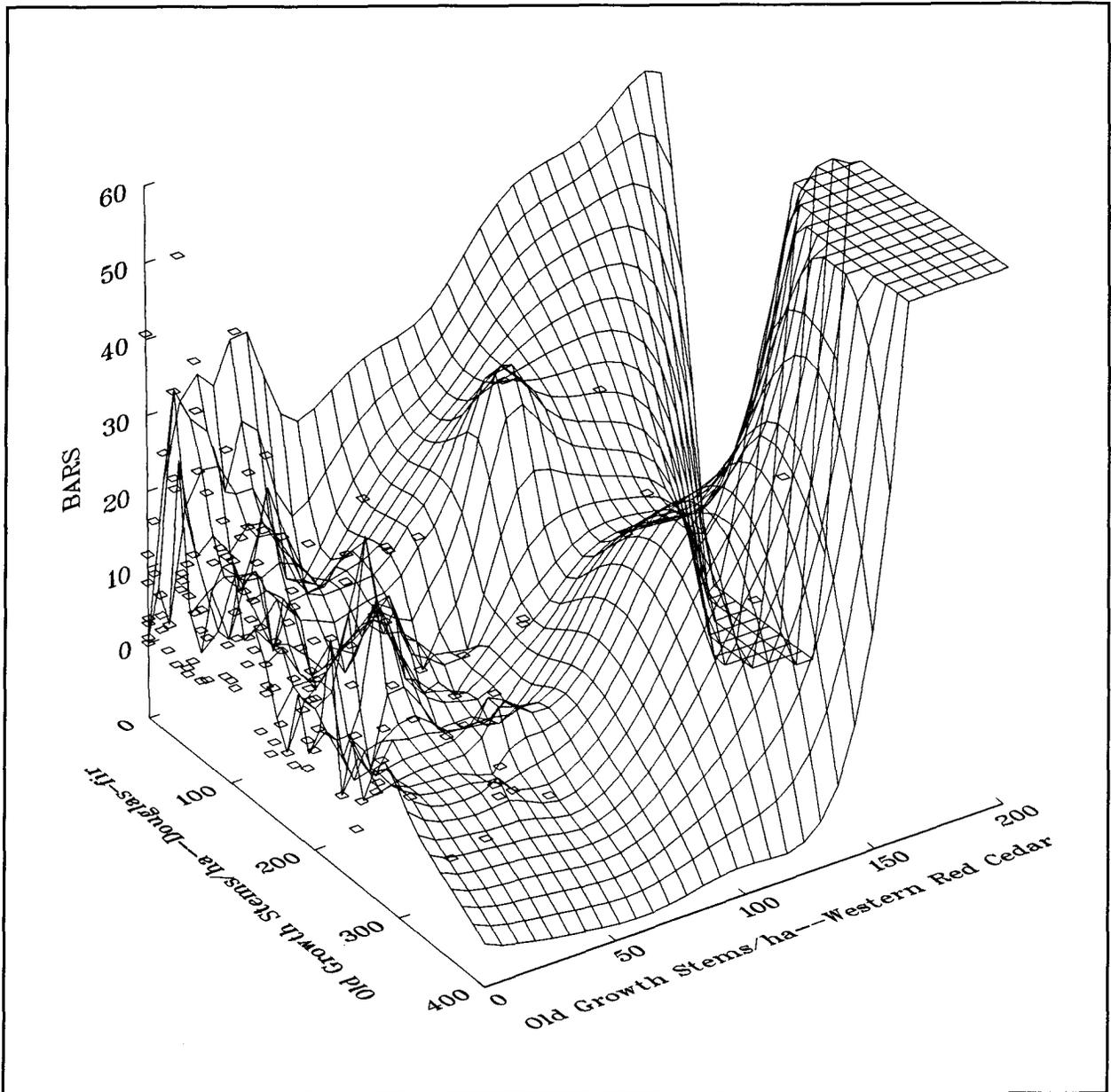


Figure 46

A three-dimensional plot illustrating the relationship between damage intensity (BARS) and old growth stand density (stems/ha) of Douglas-fir and western hemlock (SPHFH) and western red cedar (SPHCW). Data points are represented by (□) squares.

7.3.2 Second Growth - *Phellinus* Variability Relationships

The relationship of second growth stand conditions to the *Phellinus* root rot BARS intensities, BARS-DIC's and to biogeoclimatic units was evaluated using PSP-establishment (≥ 4.0 cm) stand attribute data. The stand parameters evaluated were six species composition classes based on susceptibility to *Phellinus* root rot, (FSUS (Fd, Bg), FINT (Hw), FRES (Pw, Pl, Cw) FDEC (Deciduous), FSUSINT (FSUS + FINT) and FRESDEC (FRES + FDEC)), and three stand density parameters, (stems/ha (ST410), basal area (m^2/ha) (BA410) and Curtis' Relative Density (CRD410)). A summary of parameter sample size, means and standard deviations is given in Table 22; volume/ha (Vol410) is included for comparison only.

TABLE 22

DESCRIPTIVE STATISTICS FOR SECOND GROWTH SPECIES COMPOSITION AND STAND DENSITIES
AND VOLUME ESTIMATES BY VARIOUS CLASSIFICATIONS

Damage Intensity, Stand Origin, and Ecological Classification	n	%BAR Mean	Measured Species Composition at PSP Establishments (> 4.0 cm by volume)						Estimated Stand Densities and Volume at 10 yr (>4.0 cm)				
			BARS	FSUS	FINT	FRES	FDEC	FSUSINT	FRESDEC	ST410	BA410	CRD410	VL410
			Mean and (Standard Deviation),										
Damage Intensity													
Low	58	0.98	.906(.110)	.026(.054)	.039(.072)	.027(.066)	.932(.098)	.067(.095)	2 218(1 659)	7.96(2.97)	2.94(1.33)	23.93(8.98)	
Medium	46	10.18	.868(.120)	.062(.079)	.017(.047)	.053(.083)	.930(.086)	.070(.086)	2 074(1 324)	7.85(2.74)	2.92(1.10)	23.67(8.41)	
Severe	35	24.68	.894(.137)	.055(.110)	.027(.048)	.021(.054)	.949(.072)	.048(.064)	2 033(953)	8.14(2.38)	3.00(0.93)	24.43(8.19)	
Stand Origin													
Wildfire	30	15.45	.871(.136)	.051(.079)	.047(.072)	.029(.069)	.922(.091)	.076(.085)	1 812(969)	7.98(3.13)	2.84(1.14)	22.73(10.47)	
Logged	13	10.54	.881(.164)	.073(.151)	.022(.043)	.017(.050)	.954(.082)	.038(.060)	1 823(870)	8.02(2.19)	2.80(.81)	24.46(8.08)	
Logged & Burned	96	8.22	.898(.110)	.039(.067)	.024(.057)	.038(.073)	.937(.088)	.062(.087)	2 262(1 540)	7.96(2.70)	3.00(1.20)	24.28(8.12)	
Logged + (Logged & Burned)	109	8.49	.896(.177)	.043(.081)	.024(.055)	.036(.071)	.939(.087)	.060(.085)	2 210(1 480)	7.96(2.01)	2.98(1.16)	24.30(8.08)	
Subzone													
CDFmm	30	5.94	.910(.119)	.004(.024)	.037(.081)	.046(.078)	.915(.106)	.083(.102)	1 777(879)	7.29(2.67)	2.64(.92)	20.78(7.76)	
CWHxm	109	11.11	.885(.121)	.056(.087)	.026(.052)	.031(.068)	.941(.081)	.058(.079)	2 219(1 492)	8.16(2.74)	3.03(1.20)	24.85(8.58)	
Subzone Variant													
CDFmm	30	5.94	.910(.119)	.004(.024)	.037(.081)	.046(.078)	.915(.106)	.083(.102)	1 777(879)	7.29(2.67)	2.64(.92)	20.78(2.76)	
CWHxm1	60	12.88	.898(.112)	.031(.062)	.038(.064)	.032(.075)	.929(.093)	.070(.090)	2 629(1 757)	8.50(3.33)	3.30(1.45)	24.70(9.52)	
CWHxm2	49	8.93	.869(.131)	.088(.102)	.012(.029)	.030(.059)	.957(.062)	.042(.061)	1 718(864)	7.62(1.66)	2.70(.68)	25.04(7.29)	
Plant Alliance													
<i>Pseudotsuga-Mahonia</i>	66	8.83	.930(.087)	.013(.037)	.025(.055)	.031(.066)	.943(.078)	.057(.078)	2 562(1 722)	8.24(3.10)	3.16(1.35)	22.92(8.55)	
<i>Tsuga-Mahonia</i>	25	12.40	.892(.141)	.071(.122)	.021(.043)	.016(.046)	.963(.057)	.037(.057)	2 128(854)	8.20(1.97)	3.06(.84)	25.11(5.91)	
<i>Thuja-Achlys</i>	48	10.33	.834(.130)	.076(.082)	.037(.072)	.048(.084)	.910(.107)	.085(.101)	1 520(759)	7.48(2.53)	2.59(.92)	24.83(9.63)	
Plant Association													
<i>Pseudotsuga-Arbutus</i>	23	6.48	.908(.089)	.001(.006)	.042(.078)	.049(.073)	.910(.088)	.090(.088)	2 890(2 212)	9.33(4.18)	3.61(1.82)	25.76(11.09)	
<i>Pseudotsuga-Gaultheria</i>	43	10.09	.942(.085)	.019(.044)	.017(.036)	.022(.060)	.961(.065)	.039(.065)	2 386(1 391)	7.66(2.16)	2.93(.96)	21.40(6.48)	
<i>Tsuga-Mahonia</i>	25	12.40	.892(.141)	.071(.122)	.021(.043)	.016(.046)	.963(.057)	.037(.057)	2 128(854)	8.20(1.97)	3.06(.84)	25.11(5.91)	
<i>Pseudotsuga-Achlys</i>	48	10.33	.834(.130)	.076(.082)	.037(.072)	.048(.084)	.910(.107)	.085(.101)	1 520(758)	7.48(2.53)	2.59(.92)	24.83(9.63)	
Site Association													
<i>Fd-Salal</i>	24	5.12	.922(.090)	.000(.000)	.035(.072)	.043(.067)	.922(.090)	.078(.090)	1 853(950)	7.46(2.82)	2.71(.98)	20.81(8.12)	
<i>FdBg-Oregon grape</i>	6	9.25	.863(.205)	.022(.053)	.048(.118)	.057(.120)	.885(.164)	.105(.148)	1 472(429)	6.60(2.00)	2.38(.65)	20.65(6.77)	
<i>FdHw-Salal</i>	36	12.29	.926(.102)	.032(.065)	.028(.050)	.014(.047)	.958(.064)	.042(.064)	2 801(1 925)	8.35(3.40)	3.25(1.55)	22.29(9.25)	
<i>HwFd-Kindbergia</i>	54	11.17	.875(.120)	.070(.097)	.027(.056)	.025(.051)	.945(.074)	.052(.068)	2 173(1 197)	8.16(2.51)	3.05(1.05)	25.41(7.93)	
<i>Cw-Foamflower</i>	19	8.68	.834(.139)	.064(.086)	.019(.048)	.083(.111)	.897(.115)	.103(.115)	1 252(509)	7.77(1.94)	2.56(.66)	28.14(8.06)	

Where: FSUS is Douglas-fir and grand fir; FINT is western hemlock; FRES is lodgepole pine, western white and western red cedar; FDEC is deciduous spp.; FSUSINT = FSUS + FINT and FRESDEC = FRES + FDEC.
Stand attributes are back-estimated to age 10 yr (>4.0 cm) are: stems/ha (ST410), basal area (m²/ha) (BA410), Curtis' relative density (CRD410) and volume (m³/ha) (VL410).

7.3.2.1 Second Growth Stand Conditions and *Phellinus* Variability in the BARS Damage Intensity Classes

Virtually no variation of susceptible (FSUSINT) or non-susceptible (FRESDEC) species compositions were seen between the BARS-DIC's.

7.3.2.2 Second Growth Stand Conditions and *Phellinus* Variability in the Subzones at PSP Establishment

No substantial difference in species compositions were detectable between the CDFmm and the CWHxm subzones. The FSUSINT compositions are within 3.6% of each other, and the FRESDEC compositions are within 2.5% of each other (Figs. 47 and 48, respectively). Note, that the susceptible species composition is slightly greater in the CWHxm subzone compared to the CDFmm, with the opposite conditions for the non-susceptible species composition.

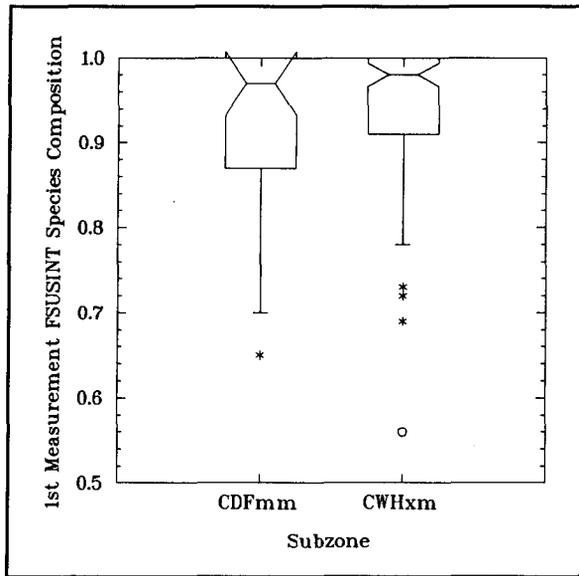


Figure 47 First PSP measure Fd, Bg and Hw (susceptible and intermediate) species composition by subzone. Means L to R are: .915 and .949, respectively for the CDFmm and CWHxm subzones.

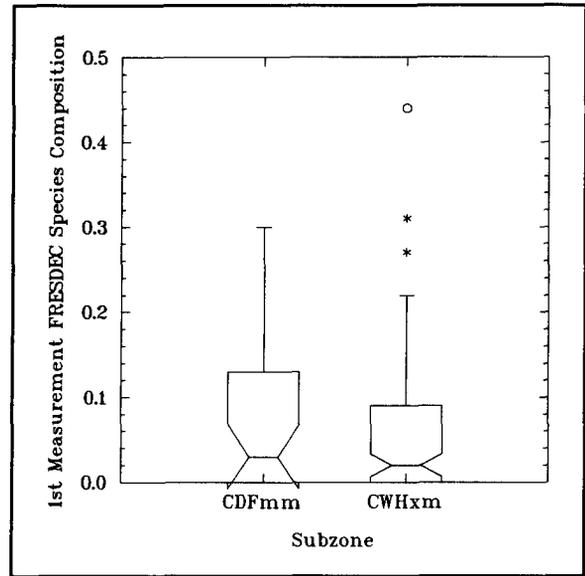


Figure 48 First PSP measure Pl, Pw, Cw and Deciduous (resistant) species composition by subzone. Means L to R are: .083 and .058, respectively for CDFmm and CWHxm subzones.

All three measures of stand density (stems/ha, basal area/ha and Curtis' relative density) back-estimated to reference age 10 yr indicated a greater density condition in the CWHxm subzone compared to the CDFmm subzone, though none are significantly greater (p-values are respectively .123, .124 and .104) and (Figs. 49, 50 and 51, respectively). *Phellinus* root rot intensity appears to have the same pattern as stand density across the subzones (see Fig. 26, pg. 93).

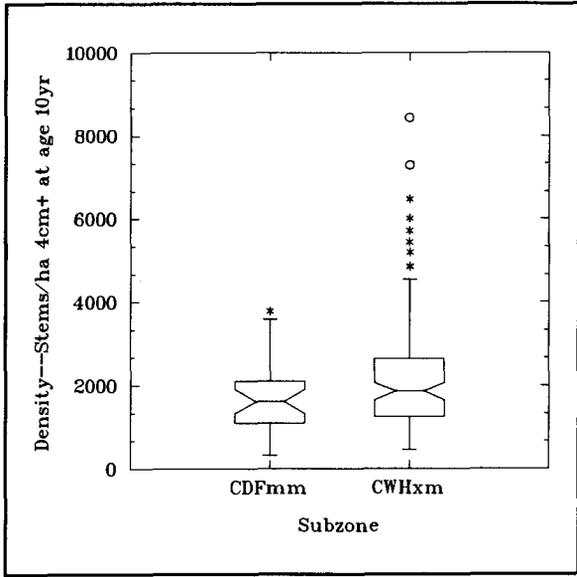


Figure 49 Back-estimated stems/ha, ≥4.0 cm at reference age 10 yr by subzone. Means L to R are: 1 777 and 2 219, respectively for the CDFmm and CWHxm subzones.

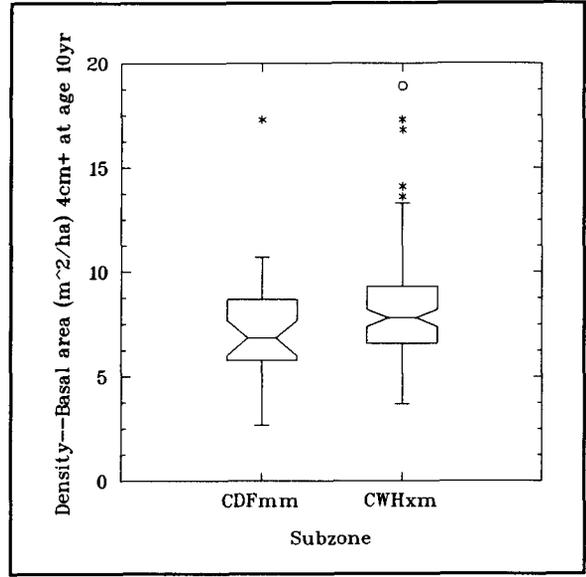


Figure 50 Back-estimated basal area (m²/ha), ≥4.0 cm at reference age 10 yr by subzone. Means L to R are: 7.29 and 8.26, respectively for the CDFmm and CWHxm subzones.

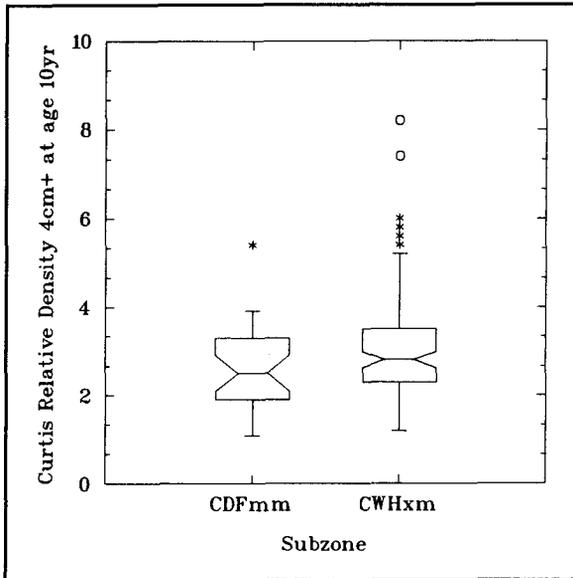


Figure 51 Back-estimated Curtis' relative density, ≥4.0 cm at reference age 10 yr by subzone. Means L to R are: 2.64 and 3.03, respectively for the CDFmm and CWHxm subzones.

7.3.2.3

Second Growth Stand Conditions and *Phellinus* Variability in the Subzone Variants at PSP Establishment

Susceptible species compositions (FSUSINT) increased slightly from the CDFmm through the CWHxm1 and CWHxm2 subzone variants. The mean compositions are 91.5%, 92.9% and 95.7% respectively (Fig. 52 and Table 22). The relatively high level in the CWHxm2 is due to a substantially greater composition of western hemlock compared to the other subzone variants. Concomitant and opposite compositions are seen for the non-susceptible species (Fig. 53 and Table 22).

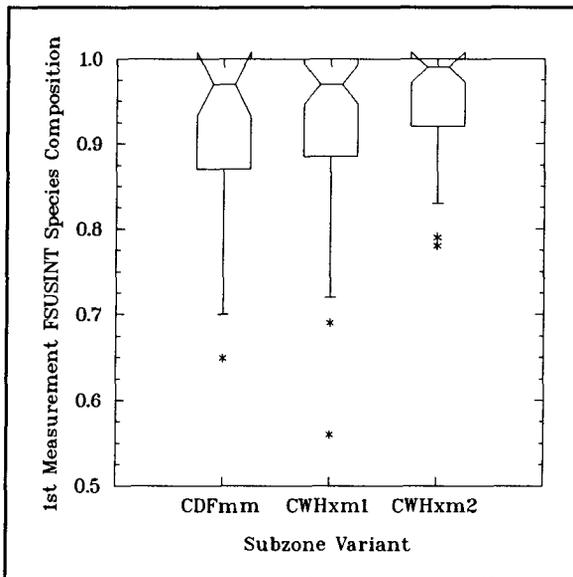


Figure 52 First PSP measure of Fd, Bg and Hw (susceptible and intermediate) species composition by subzone variant. Means L to R are: .915, .929 and .957, respectively for the CDFmm, CWHxm1 and CWHxm2 subzone variants.

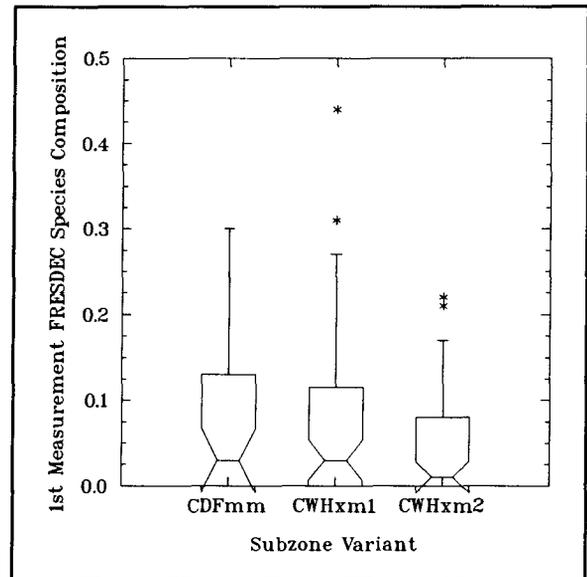


Figure 53 First PSP measure of PI, Pw, Cw and Deciduous (resistant) species composition by the subzone variant. Means L to R are: .083, .070 and .042, respectively for the CDFmm, CWHxm1 and CWHxm2 subzone variants.

Measures of stand density back-estimated to age reference 10 yr do not display the same patterns across the variants as the species compositions. In fact, mean stand density measures are all lowest in the CDFmm variant, peak in the CWHxm1 and then fall to levels slightly above the CDFmm in the CWHxm2 variant (Figs. 54, 55 and 56 and Table 22). *Phellinus* root rot intensity appears to have the same pattern as stand density across the subzone variants (Fig. 27, pg. 94). The CWHxm1 back-estimated stems/ha was significantly different from the CDFmm and CWHxm2 variants ($p=.012$) and ($p=.001$).

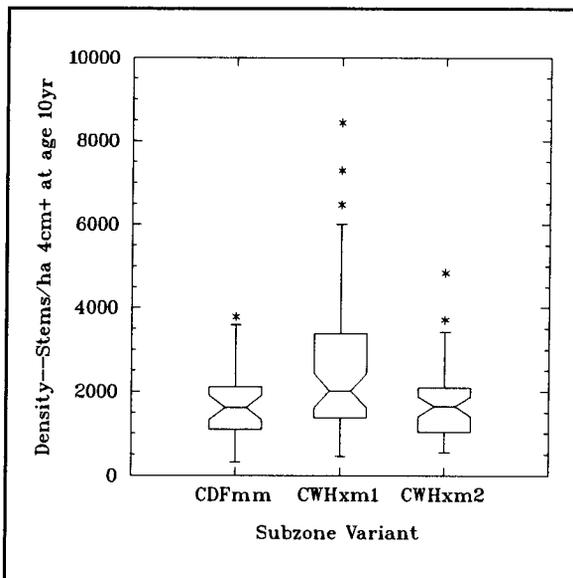


Figure 54 Back-estimated stems/ha, ≥ 4.0 cm at reference age 10 yr by subzone variant. Mean L to R are: 1 777, 2 629 and 1 718, respectively for the CDFmm, CWHxm1 and CWHxm2 subzone variants.

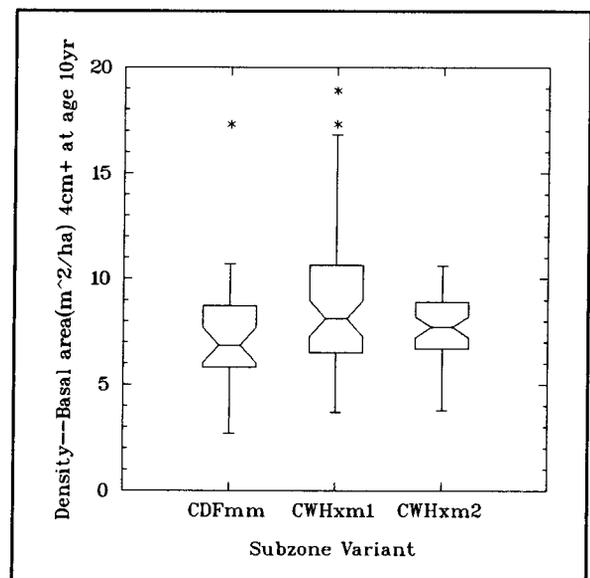


Figure 55 Back-estimated basal area (m^2/ha), ≥ 4.0 cm at reference age 10 yr by subzone variant. Means L to R are: 7.29, 8.60 and 7.62, respectively for the CDFmm, CWHxm1 and CWHxm2 subzone variants.

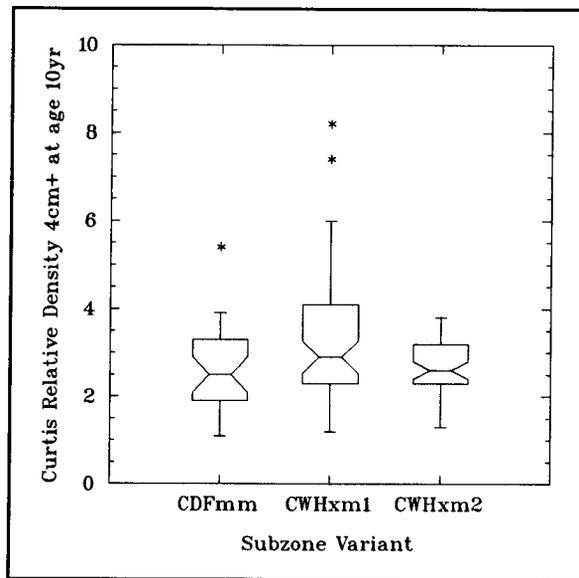


Figure 56

Back-estimated Curtis' relative density, ≥ 4.0 cm at reference age 10 yr by subzone variant. Means L to R are; 2.64, 3.30, and 2.70, respectively for the CDFmm, CWHxm1 and CWHxm2 subzone variants.

The CWHxm1 back-estimated basal area/ha was moderately different from the CDFmm ($p = .076$) and CWHxm2 ($p = .144$). Similar to the stems/ha, back-estimated Curtis' relative density for the CWHxm1 was significantly different from the CDFmm ($p = .023$) and CWHxm2 ($p = .014$) variants.

7.3.2.4 Second Growth Stand Conditions and *Phellinus* Variability in the Plant Alliances

Susceptible species compositions (FSUSINT) rose from the *Pseudotsuga-Mahonia* p.all. (94.3%), peaked in the *Tsuga-Mahonia* p.all. (96.3%), and fell to (91.0%) in the *Thuja-Achlys* p.all. The pattern somewhat mimics the *Phellinus* intensity levels observed (Table 22). Non-susceptible species compositions (FRESDEC) were opposite to the conditions described for the susceptible compositions (Table 22). Figures for the plant alliance relationships are not shown.

Measures of stand density were consistent across all parameters and were greatest in the *Pseudotsuga-Mahonia* p.all. and fell dramatically in the *Thuja-Achlys* p.all. (Table 22). No apparent trend between p.all.'s and *Phellinus* root rot intensity patterns was observed.

7.3.2.5 Second Growth Stand Condition and *Phellinus* Variability in the Plant Associations

Susceptible species compositions (FSUSINT) were lowest in the *Pseudotsuga-Arbutus* and *Pseudotsuga-Achlys* p.a., (both 91.0%) (Table 22), and were greatest in the *Pseudotsuga-Gaultheria* and *Tsuga-Mahonia* (96.1% and 96.3%, respectively) (Table 22). The *Pseudotsuga-Arbutus* p.a. comprised the majority of the *CDFmm-Fd-Salal* s.a.'s samples, and also the majority of the CDFmm subzone/variant samples. No apparent trend between susceptible species composition and *Phellinus* root rot intensity was observed. Figures for the plant association relationships are not shown.

Measures of stand density are less consistent across the p.a.'s than across the p.all.'s (Table 22). Stems per hectare are greatest in the *Pseudotsuga-Arbutus* p.a. (2 890 sph) dropping consistently with increasing soil moisture condition to the *Pseudotsuga-Achlys* p.ass. (1 520 sph) (Table 22). There was clearly no trend with the observed *Phellinus* root rot intensities and stems per hectare across the plant associations. Basal area and Curtis' relative density measures vary across the plant associations, with no apparent relationships between density and *Phellinus* root rot intensities. However, if the driest plant association (*Pseudostuga-Arbutus*) is not considered, it appears that basal

area has a similar pattern to *Phellinus* root rot intensity (Table 22). Note that the *Phellinus* intensity peaked in the *Tsuga-Mahonia* p.a. as did the basal area, dropping to near-equal values in the *Pseudotsuga-Gaultheria* and *Pseudotsuga-Achlys* p.ass's. Curtis' relative density had almost the same pattern as the basal area measures, but was slightly more difficult to interpret.

7.3.2.6 Second Growth Stand Conditions and *Phellinus* Variability in the Site Associations

The pattern of susceptible species compositions (FSUSINT) was not very consistent with the *Phellinus* root rot intensity when viewed within site associations (Fig. 57 and Table 22). However, when FSUSINT was viewed within a subzone (i.e., at the site series level), the susceptible species composition was positively correlated with *Phellinus* root rot intensity in the CDFmm units, and even more so within the CWHxm units. The extreme variability of FSUSINT in the *FdBg-Oregon grape* s.a. and the very small sample size (n=6) confounds the interpretation in this unit. The opposite relationships are true for the non-susceptible species composition (Fig. 58 and Table 22).

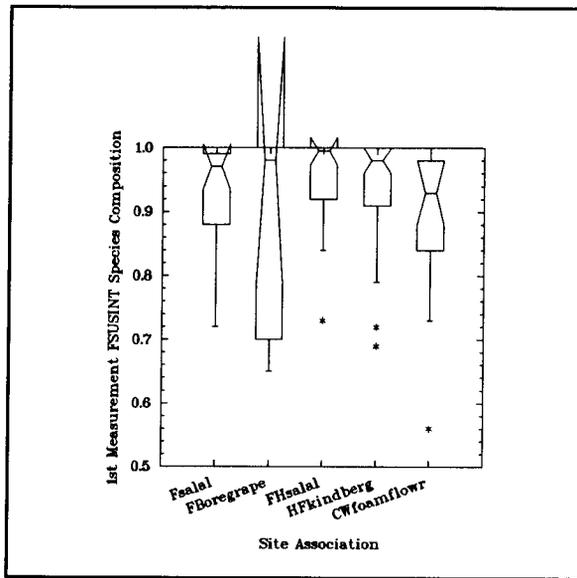


Figure 57 First PSP measure of Fd, Bg and Hw (susceptible and intermediate) species composition by site association. Means L to R are: .922, .885, .958, .945 and .897, respectively for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

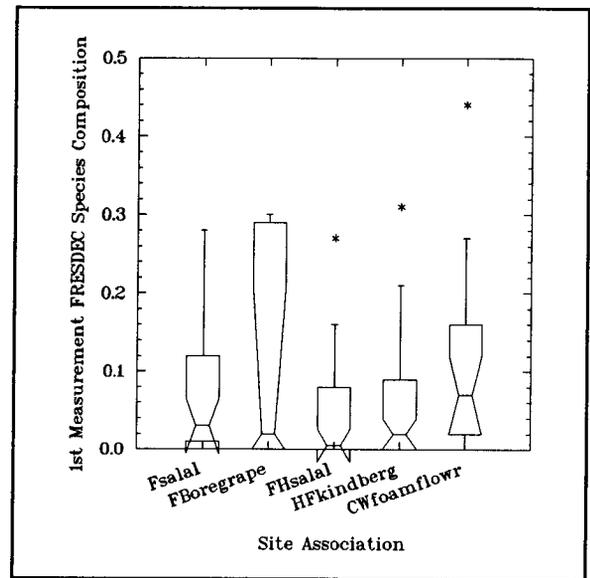


Figure 58 First PSP measure of PI, Pw, Cw and Deciduous (resistant) species composition by site association. Means L to R are: .078, .105, .042, .052 and .103, respectively for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

As above, stand density measures viewed at the s.a. level were difficult to interpret, but viewed within the subzone, (at the site series) the relationships to *Phellinus* root rot intensity became clearer. Consistently the *FdBg-Oregon grape* s.a. was difficult to interpret for the reasons stated above.

Generally, stems/ha, basal area/ha and Curtis' relative density all appeared to be positively related to *Phellinus* root rot intensity across all s.a.'s, (refer to Fig. 30, pg. 98). This was particularly obvious in the CWHxm s.a.'s (Figs. 59, 60 and 61 and Table 22). Figures 62, 63 and 64 illustrate the stand density measures at PSP establishment, and

provide a comparison to the back-estimated measures to reference age 10 yr. Also, note the generally similar pattern of the PSP establishment stand conditions to the reference age 10 yr conditions.

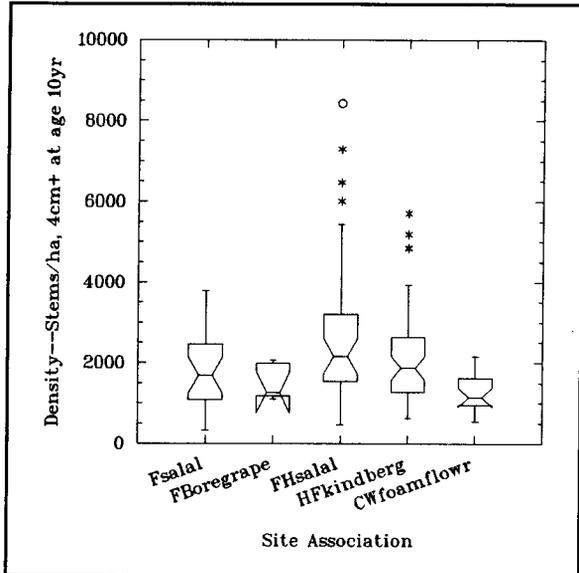


Figure 59 Back-estimated stems/ha, ≥ 4.0 cm at reference age 10 yr by site association. Mean L to R are: 1 853, 1 472, 2 801, 2 173 and 1 252 for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

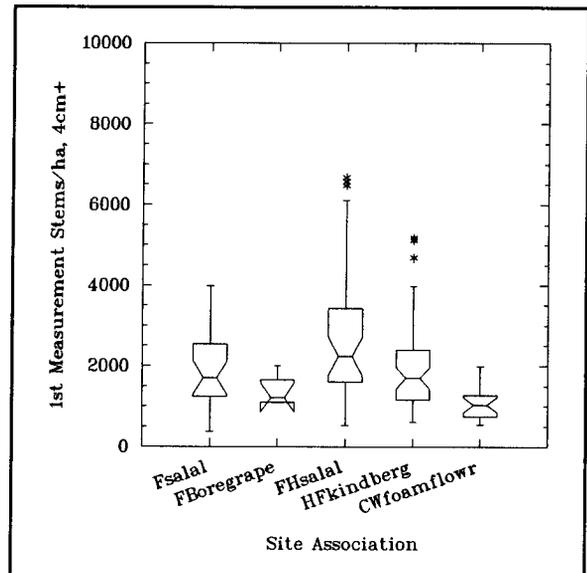


Figure 60 First PSP measure of stems/ha, ≥ 4.0 cm at reference age 10 yr by site association. Mean L to R are: 1 875, 1 379, 2 798, 2 001 and 1 072 for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

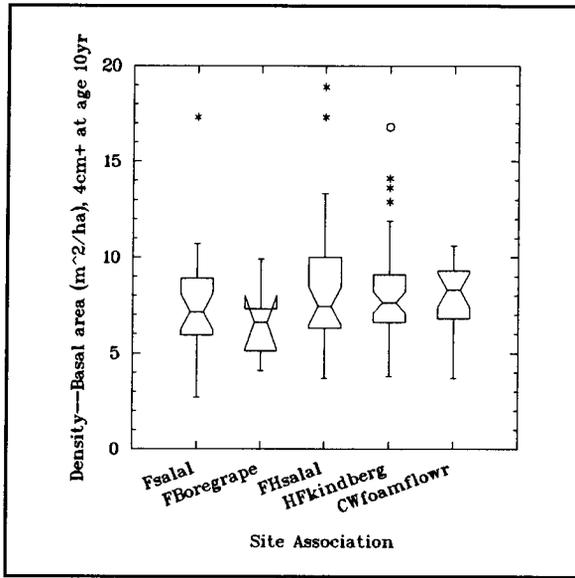


Figure 61 Back-estimated basal area (m^2/ha), ≥ 4.0 cm at reference age 10 yr by site association. Means L to R are: 7.46, 6.60, 8.35, 8.16 and 7.77 for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

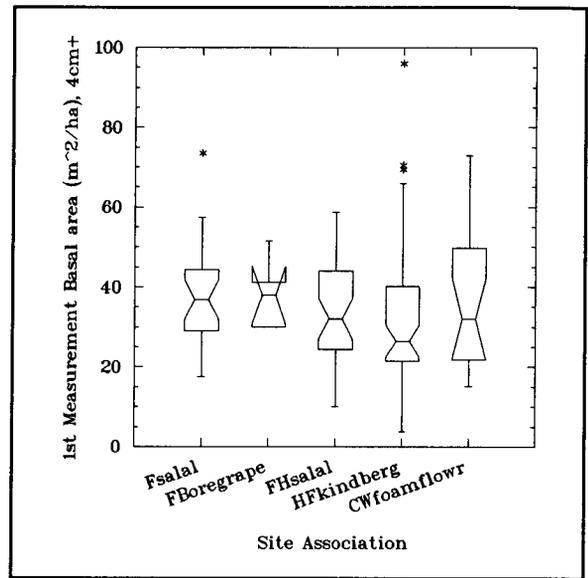


Figure 62 First PSP measure of basal area (m^2/ha), ≥ 4.0 cm at reference age 10 yr by site association. Means L to R are: 38.2, 38.1, 33.3, 32.7 and 36.9 for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

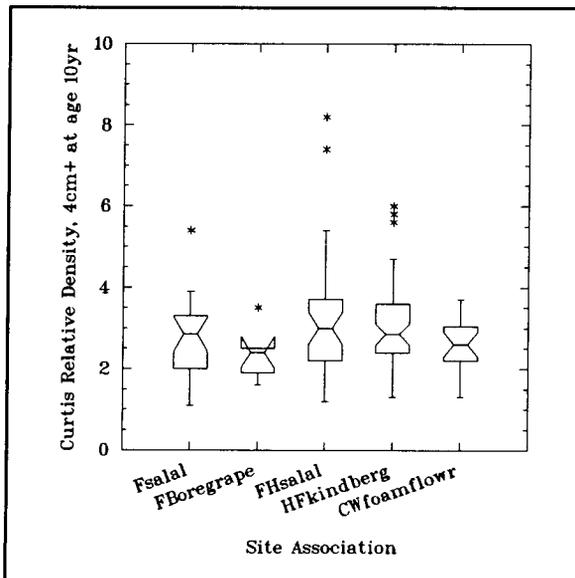


Figure 63 Back-estimated Curtis' relative density, ≥ 4.0 cm at reference age 10 yr by site association. Means L to R are: 2.71, 2.38, 3.25, 3.05 and 2.56 for the *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

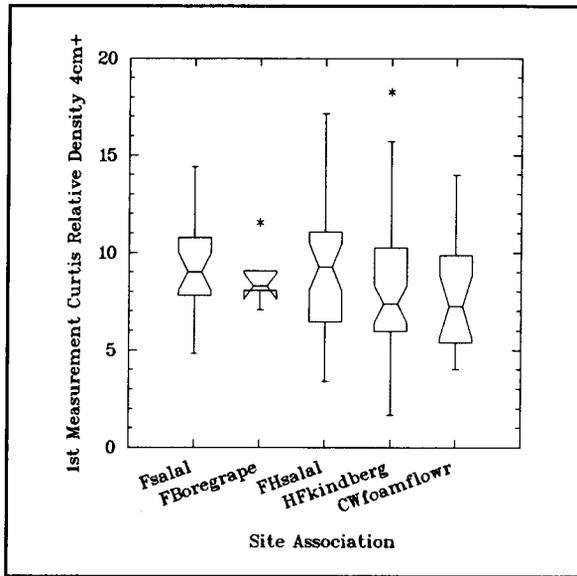


Figure 64

First PSP measure of Curtis' relative density, ≥ 4.0 cm at reference age 10 yr by site association. Means L to R are: 9.1, 8.7, 9.0, 8.2 and 7.8 for the *Fd-Salal*, *FdBg-Oregon-grape*, *FdHw-Salal*, *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s.

7.3.3 Second Growth Species Dynamics

The basis for investigating species composition shifts is that susceptible species commonly appear to be replaced with less-susceptible species as the former dies out due to *Phellinus* root rot activity. Variable-radius plot sample data were used to estimate second growth species dynamics (shifts) between healthy and infected disease conditions by evaluating: (i) species compositions, (ii) species composition ratios, and (iii) non-susceptible species composition stratified by diameter "age" class. Species compositions were based on the mean tree counts from the %BAR sample surveys. The results are also compared against species composition shifts observed in the PSP's. The three estimates were very comparable. Overall, a net gain of non-susceptible species composition (with a corresponding drop in susceptible species composition) in *Phellinus* infected stand conditions compared to healthy stand conditions.

7.3.3.1 Second Growth Species Dynamics Estimates from Variable-Radius Plot Sample (%BAR Survey) Data

7.3.3.1.1 Comparison of Species Compositions by Disease Condition

Species compositions were stratified by species susceptibility class and infection condition. Comparison of percent species compositions stratified by disease condition indicated a drop in susceptible species composition and an increase in non-susceptible species in infected portions of stands, (Table 23). In healthy stand conditions, the mean susceptible and non-susceptible species compositions were 91.52%, and 8.48%, respectively, (Fig. 65), whereas, in infected conditions, mean susceptible and non-susceptible species compositions are 87.06%, and 12.94%, respectively, (Fig. 66). The difference in susceptible species composition between disease conditions (-4.46%), while significantly different by t-test ($p=.000$), only represents a 4.87% drop from its healthy level. This is in sharp contrast to the non-significant t-test differences ($p=.274$) for the non-susceptible composition (-4.46%), which actually represents a 52.6% relative gain in non-susceptible species composition from the healthy condition.

The high variability of non-susceptible species composition shifts in infected conditions is likely due to; (i) a low and scattered composition, and (ii) ingrowth rates are slow and highly light dependent, which is in turn dependent on the size of and length of time since canopy gaps were created (in this case due to *Phellinus* root rot). In contrast, the lower variability of susceptible species composition shifts is mainly due to mortality or premature windthrow that almost always follows the infection of trees by *Phellinus* root rot.

TABLE 23 DESCRIPTIVE STATISTICS FOR SPECIES COMPOSITION BY DISEASE CONDITION				
Statistic	Non-Susceptible Species		Susceptible Species	
	Healthy (NALH)	Infected (NALI)	Healthy (SALH)	Infected (SALI)
Mean Tree Count	0.759a	0.839a	8.187b	5.646c
Standard Deviation	0.782	1.158	1.669	2.037
Standard Error	0.066	0.098	0.142	0.173
Spp. Composition	8.48	12.94	91.52	87.06
Absolute	+ 4.46		- 4.46	

NALH is Non-susceptible spp., ≥4.0 cm, Healthy
 SALH is Susceptible spp., ≥4.0 cm, Healthy
 NALI is Non-susceptible spp., ≥4.0 cm, Infected
 SALI is Susceptible spp., ≥4.0 cm, Infected

Mean tree-counts followed by dissimilar letters are significantly different at ($\alpha < .05$).

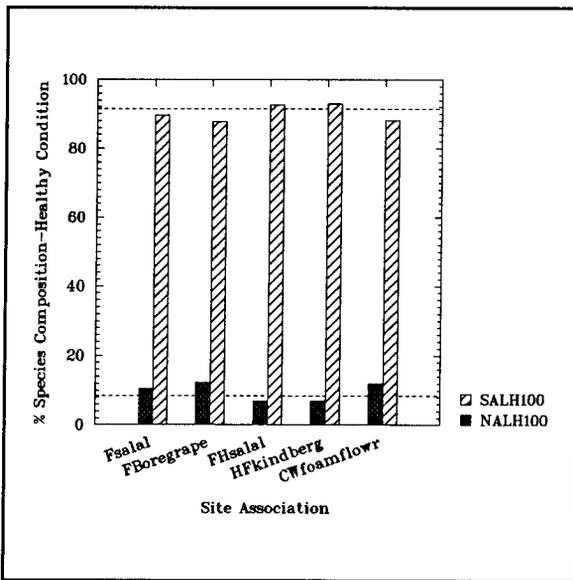


Figure 65 Second growth species composition for healthy stand conditions. Non-susceptible species (NALH), (pines, western red cedar and deciduous spp.), susceptible species (SALH), (grand fir, Douglas-fir and western hemlock) have mean compositions of 8.48% and 91.52%, respectively (y-axis limits).

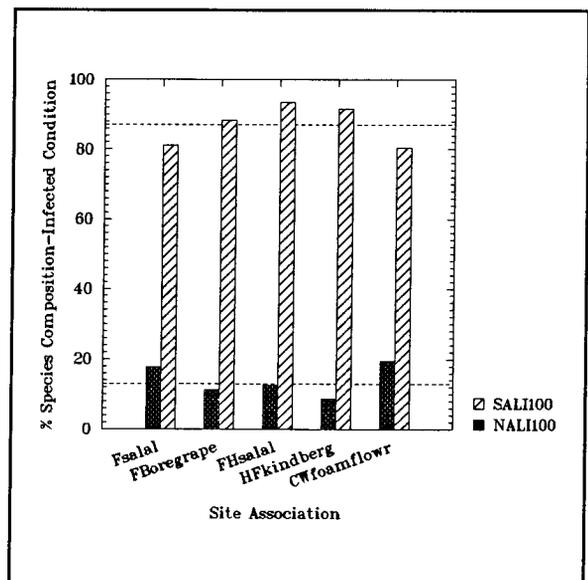


Figure 66 Second growth species composition for infected stand conditions. Non-susceptible species (NALH), (pines, western red cedar and deciduous spp.), susceptible species (SALH), (grand fir, Douglas-fir and western hemlock) have mean compositions of 12.95% and 87.06%, respectively (y-axis limits).

7.3.3.1.2 Species Composition Shifts Stratified By Disease Condition And Diameter Limit Classes

Ratios of non-susceptible-only, and susceptible-only to the combined total species composition, within a disease condition, and nested within diameter "age" limit classes, were compared. Two diameter limit classes were used as analogs of "age classes", assuming a close relationship between age and diameter. The larger diameter limit class ($\geq 12.0/17.5$ cm) may be analogous to an "older age" class comprised of mainly dominant and codominant crown class trees. The lower diameter limit class (≥ 4.0 cm) may be analogous to a "younger age" class, which includes all ages ("younger and older"). The ≥ 4.0 cm class was comprised of dominants/codominants but also a greater amount of suppressed and intermediate crown class trees, some of which were assumed to be younger as a result of ingrowth in response to *Phellinus* root rot activity. Unfortunately a sharp distinction between classes was not possible using this analysis. Diameter limit tree tallies, basal area and species composition derivations are shown in Section 6.3.4.2 and Table 5, p. 46, and species composition ratio derivations are shown in Table 24, pg. 134.

Bar graphs of the mean species compositions, grouped on a subzone basis, showed a consistent trend of higher proportions of non-susceptible species in infected conditions (N4, N2), compared to healthy conditions (N3, N1) (Fig. 67). Note the greater proportions of non-susceptible species composition in the ≥ 4.0 cm diameter limit class (N2), compared to the $\geq 12.0/17.5$ cm diameter limit class (N4) (Fig. 67). Virtually the opposite relationships existed for susceptible species compositions; they were reduced

in infected conditions (S4, S2) compared to healthy conditions (S3, S1) (Fig. 68). Again, the susceptible composition was greater in the $\geq 12.0/17.5$ cm diameter limit class (S4) compared to the ≥ 4.0 cm diameter class (S1) (Fig. 68).

Net changes in species compositions (infected minus healthy) shown in Table 24, and illustrated in Figure 68, indicated a study-wide net increase in non-susceptible species composition of 4.4% with a corresponding net decrease of -2.6% in susceptible species composition. Variation due to diameter limit "time/age" is minor, while increases/decreases were larger in the CDFmm subzone compared to the CWHxm subzone.

TABLE 24 SPECIES COMPOSITION RATIO VARIABLE DEFINITIONS	
Diameter Limits	
$(\geq 4.0$ cm) "Younger, All-Age"	$(\geq 12.0/17.5$ cm) "Older Age"
Non-susceptible species: (Pines, Cedar and Deciduous)	
N1 = NALH / NSALH (Healthy) N2 = NALI / NSALI (Infected) DNBA = N2 - N1	N3 = NGRH / NSGRH (Healthy) N4 = NGRI / NSGRI (Infected) DBAN = N4 - N3
Susceptible species: (Douglas-fir, grand fir and hemlock)	
S1 = SALH / NSALH (Healthy) S2 = SALI / NSALI (Infected) DSBA = S2 - S1	S3 = SGRH / NSGRH (Healthy) S4 = SGRI / NSGRI (Infected) DBAS = S4 - S3

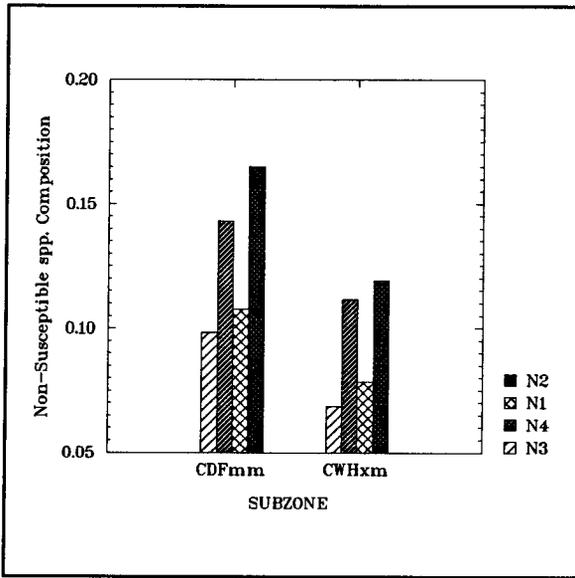


Figure 67 Non-susceptible species composition by diameter limit disease condition and subzone (see also Table 24). Note, the greater composition in the lower (≥ 4.0 cm) diameter limit and in the infected compared to the healthy conditions. Also, note the difference between consecutive pairs are shown in Fig. 69.

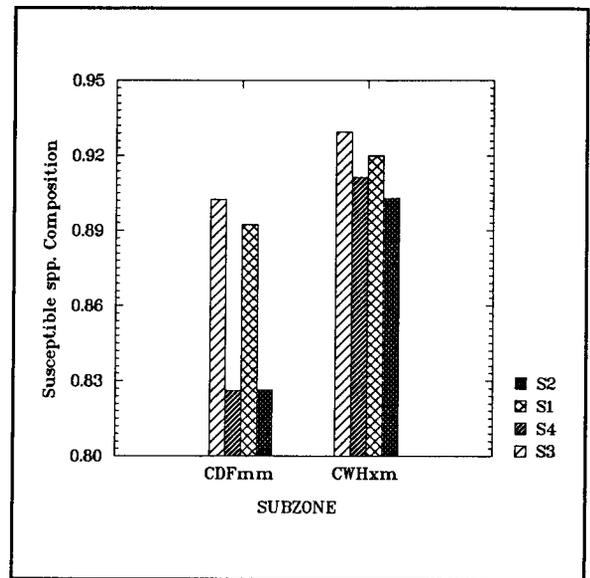


Figure 68 Susceptible species composition by diameter limit disease condition and subzone (see also Table 24). Note, the greater composition in the larger ($\geq 12.0/17.5$ cm) diameter limit and in the healthy compared to the infected conditions. Also, note the differences between consecutive pairs are shown in Fig. 57(c).

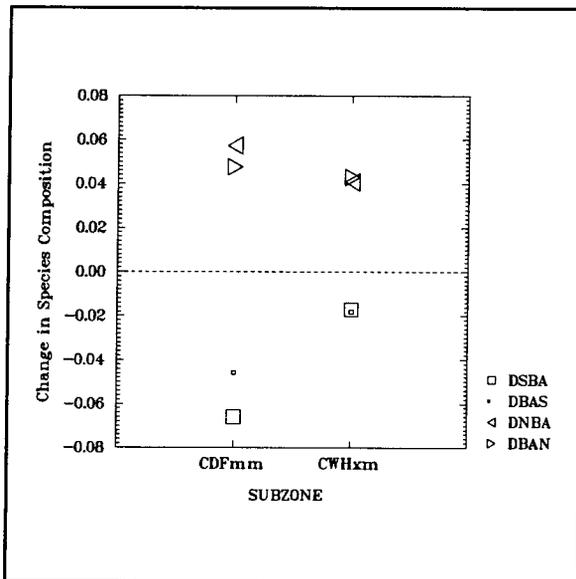


Figure 69 Changes in non-susceptible and susceptible species composition, as derived and defined in Table 22. Overall, the non-susceptible species change (DBAN/DNBA) was +4.4%, while susceptible species net change (DBAS/DSBA) was -2.6%.

7.3.3.1.3 Comparison of Non-susceptible Species Compositions Between Diameter Classes and Disease Condition

The basis for investigating non-susceptible species composition shifts between diameter classes was that susceptible species composition was thought to decrease non-susceptible species composition increase in response to *P. weirii* activity relative to healthy conditions (and shown in sections 7.3.2.1.1 and 7.3.2.1.2). Continuing with this notion, the non-susceptible composition should be greater in a truly smaller "younger age" diameter class ($\geq 4.0 \leq 12.0/17.5$ cm) relative to a larger "older age" diameter class ($\geq 12.0/17.5$ cm) in the presence of root rot.

Comparison of non-susceptible species composition between diameter classes showed no significant differences between the larger ($\geq 12.0/17.5$ cm) and smaller ($\geq 4.0 < 12.0/17.5$ cm) diameter classes, stratified by disease condition using paired t-tests, ($n = 139$, $\alpha < 0.10$). The population distributions were not normal, but Wilcoxon rank sign tests indicated similar results.

A further stratification by *Phellinus* root rot intensity (BARS $< 20\%$ vs. BARS $\geq 20\%$; $n = 116$ and 23 , respectively) was tested, which implied older, more damaged stand conditions for BARS $\geq 20\%$, and thus more time to allow for diameter-measured shifts towards increased non-susceptible species composition, if in fact it occurs (Table 25).

TABLE 25 COMPARISON OF NON-SUSCEPTIBLE SPECIES COMPOSITION (NSSppC)				
Diameter Class & Disease Condition	Mean NSSppC Tree Count By Root Rot		BARS \geq 20%	
	BARS <20%	BARS \geq 20%	Mean Diff.	P.
NGRH vs. NGRI	.588 vs .577 aa	.616 vs .475 cc	0.141	p=.533
NLSH vs. NLSI	.177 vs .152 bb	.114 vs .163 de	-0.050	p=.095
NALH vs. NALI	.765 vs .837 xx	.730 vs .847 yy	-0.117	p=.119
NGRH is Non-susceptible, \geq 12.0/17.5 cm Diameter limit, Healthy, NGRI is Non-susceptible, \geq 12.0/17.5 cm Diameter limit, Infected, NALH is Non-susceptible, \geq 4.0 cm Diameter limit, Healthy, NALI is Non-susceptible, \geq 4.0 cm Diameter limit, Infected, NLSH is Non-susceptible, \geq 4.0 cm <12.0/17.5 cm Diameter limit, Healthy, NLSI is Non-susceptible, \geq 4.0 cm <12.0/17.5 cm Diameter limit, Infected.				
Probability of differences were determined using paired t-tests on the mean differences between the first and latter variables in each pair. Pairs followed by the same letter are not significantly different at $\alpha < 0.10$.				

The paired t-tests indicated no significant differences between non-susceptible species composition diameter-disease conditions for the <20% BARS stratification (all p-values > .401). Although no significant differences were detectable, it is notable that the mean infected non-susceptible species composition (NALI) was in fact greater than the mean healthy non-susceptible species composition (NALH), thus emphasizing a consistent pattern of non-susceptible species composition increases due to *Phellinus* root rot incidence. However, in the \geq 20% BARS class, the smaller 'younger' diameter class had significantly greater non-susceptible species composition (p=0.095), in the infected condition (NLSI), compared to the healthy condition (NLSH). The larger 'older' diameter-infection condition classes (NGRH vs NGRI) were not significantly different (p=0.553). The results are consistent with the hypothesis. Since the sample stands are virtually pure

Douglas-fir, there was no expectation of unequal levels of non-susceptible species composition in the larger predominant tree cover ($\geq 12.0/17.5$ cm). Consistent with disease dependent diameter class shifts, infected non-susceptible species composition was much lower in the larger diameter class than the healthy; and in the smaller diameter class, the infected non-susceptible species composition was much larger than in the healthy condition.

7.3.3.2 Second Growth Species Dynamics From the PSP's Measurement Record

Species composition shifts in the PSP data (≥ 4.0 cm) were analysed in order to determine if some time dependent corroboration of the survey data existed. The PSP's have been measured on average for 30 to 35 yrs. The non-susceptible species composition was based on the sum of Tolerant (hemlock), Intermediate (pines) and Resistant (cedar) species (variable name is TIR), calculated for the first and last PSP measurements available, respectively FTIR and LTIR. The change in TIR species was calculated, $(LTIR-FTIR=\text{variable TIRD})$, and compared between PSP disease condition (RRIN=0 or 1, healthy or infected) and BEC units using t-test (Figs. 70 and 71 and Table 26). Similarly, the susceptible species compositions, (FSUS and LSUS) and changes (SUSD), were calculated and tested. The inclusion of western hemlock in the non-susceptible species class makes this test not directly comparable to the %BAR sample survey species classification previously discussed in section 7.3.3.1. The author has observed that a great deal of western hemlock regenerates in infection centre openings and that hemlock regeneration is uncommonly infected by *Phellinus* root rot. SUSD was

tested with and without western hemlock and found similar results as presented, but of a slightly lower and more variable magnitude.

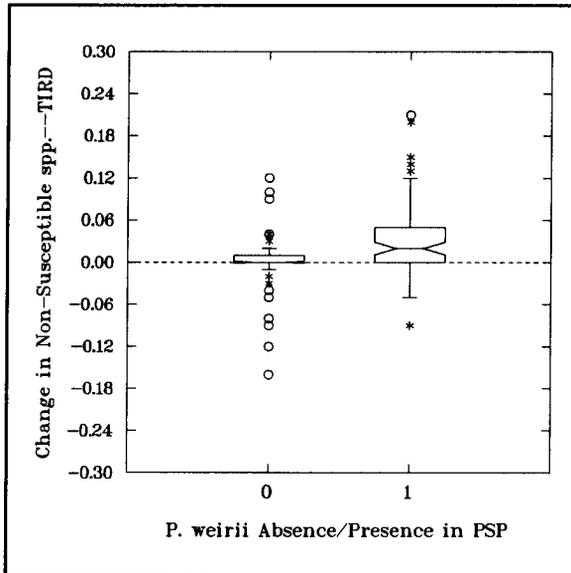


Figure 70 Net changes in non-susceptible second growth species composition over 30 to 35 yr in healthy and infected PSP's. Non-susceptible species are; western hemlock, western white and lodgepole pines and western red cedar.

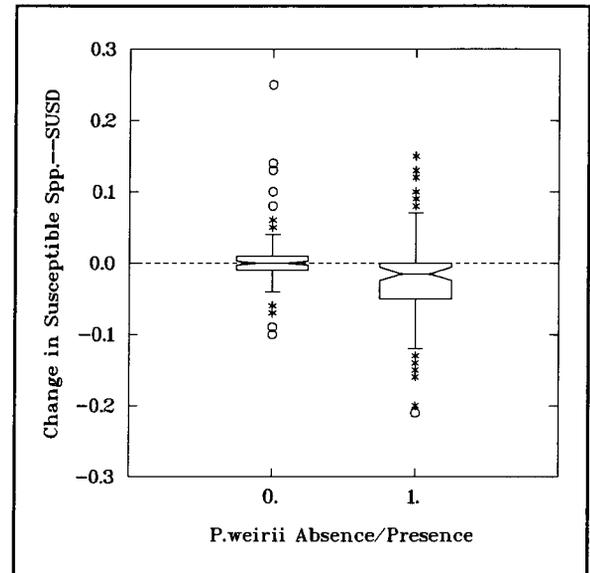


Figure 71 Net changes in susceptible second growth species composition over 30 to 35 yr in healthy and infected PSP's. Susceptible species are; grand fir and Douglas-fir.

Overall, the mean increase in TIRD species composition in PSP's infected with *P.weirii* is 3.7%, netted to 3.5% after subtraction of the 0.2% TIRD gain indicated in healthy PSP's (Table 26). The difference is highly significant ($p=.000$), whether from separate or pooled variance t-tests of the means. The mean change in susceptible species (SUSD) is opposite to non-susceptible species; in healthy PSP's, SUSD increased by 0.6%, and in infected PSP's, SUSD decreased by 2.1% for a net decrease of 1.5%.

The susceptible species composition changes are also highly significant ($p=0.006$).

Proportional increases in TIR species composition were largest in the zonal site associations, and in the CDFmm and CWHxm2 subzone variants as indicated by the change factor $((TIRD_{RRIN=1} - TIRD_{RRIN=0}) \times 100)$, (Table 26).

TABLE 26 MEAN DIFFERENCES IN TOLERANT, INTERMEDIATE AND RESISTANT (TIRD) SPECIES COMPOSITION PROPORTION IN PSP's BETWEEN FIRST AND LAST MEASUREMENTS						
Site Association	N	RRIN	TIRD	STD	SEM	Change Factor
<i>Fd - Salal</i> *	30	0	0	.034	.006	620.0
<i>Fd - Salal</i>	10	1	.062	.074	.023	
<i>FdBg - Oregon grape</i>	10	0	.008	.013	.004	3.75
<i>FdBg - Oregon grape</i>	3	1	.030	.010	.006	
<i>FdHw - Salal</i>	31	0	.005	.013	.002	6.80
<i>FdHw - Salal</i>	18	1	.034	.052	.012	
<i>HwFd - Kindbergia</i> *	41	0	0	.039	.006	410.0
<i>HwFd - Kindbergia</i>	34	1	.041	.063	.011	
<i>Cw - Foamflower</i>	25	0	.004	.013	.003	2.00
<i>Cw - Foamflower</i>	9	1	.004	.042	.014	
<i>All Associations</i>	139	0	.002	.029	.002	18.50
<i>All Associations</i>	76	1	.037	.059	.007	
Subzone Variant						
<i>CDFmm</i>	41	0	.002	.030	.005	26.00
<i>CDFmm</i>	14	1	.052	.064	.017	
<i>CWHxm1</i>	59	0	.005	.022	.003	5.00
<i>CWHxm1</i>	37	1	.025	.052	.008	
<i>CWHxm2</i>	39	0	.004	.036	.006	11.25
<i>CWHxm2</i>	25	1	.045	.065	.013	
<p>Where: RRIN=0, is Healthy and RRIN=1, is Infected. The largest changes in TIRD species composition appear to be in the zonal site associations *, and in the CDFmm and CWHxm2 subzone variants.</p> <p>The change Factor is $[TIRD_{(RRIN=1)} - TIRD_{(RRIN=0)}] \times (100)$, where default TIRD values of .001 are used for real zero values.</p>						

7.3.4 Stand History: Fire And Logging

The frequency of occurrence of stand origins shows that 69% of the 139 PSP's originated after logging- and-burning, 21.6% after wildfire, and 9.4% after logging. The

results are not surprising given that vast areas of eastern Vancouver Island were railway logged (Gold 1985), with many fires originating from the logging and railway operations. Fire intensity is presumed to have been high due to heavy slash loads from logging old growth (Leavitt 1913, 1915), and evidenced in thin and developing second growth mor/moder forest floors, commonly occurring burned-out old growth stumps (authors observations), and the photographic record (Gold 1985).

Tukey's HSD multiple comparisons of mean *Phellinus* root rot intensities (BARS), show wildfire origin PSP's (15.45%) to be significantly more infected than the logged-and-burned (8.22%) origin PSP's, ($p=.002$), but not significantly more infected than the logged-only (10.54%) origin, ($p=.314$), (Fig. 72). A t-test of wildfire *versus* logged (logged, plus logged-and-burned) origins shows a significant difference between groups (15.45% vs. 8.49%), ($p=.001$), (Fig. 73).

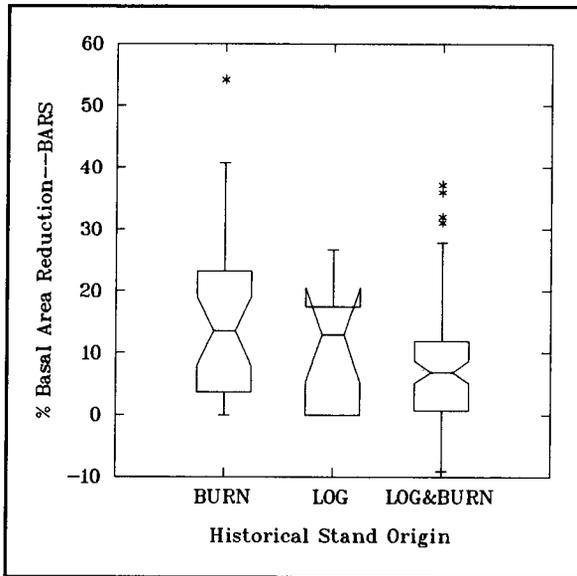


Figure 72 Boxplots of % Basal Area Reduction-BARS classified by three stand origins; wildfire (BURN), logged-only (LOG) and logged and slashburning (LOG & BURN).

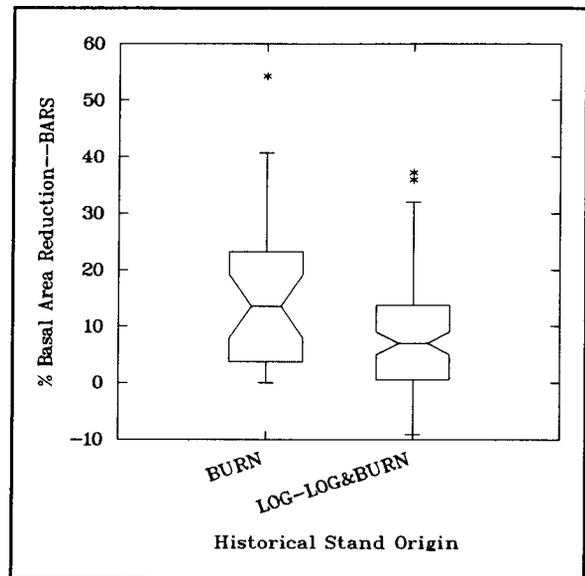


Figure 73 Boxplots of % Basal Area Reduction-BARS classified by three stand origins; wildfire (BURN), and logged and slashburned (LOG & BURN).

Interestingly, mean stand ages are significantly different between stand origins ($p < .088$) (Figs. 74 and 75). These age differences are likely the greatest factor in explaining variation of %BAR damage intensity between different stand origins, although other stand origin effects cannot be discounted.

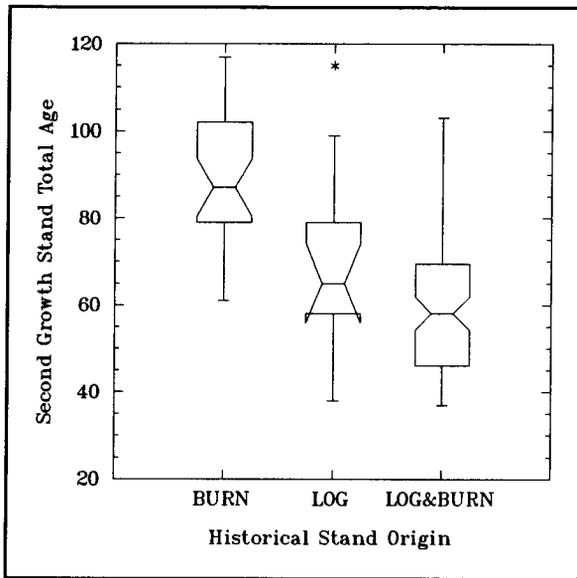


Figure 74 Boxplots of total age classified by three stand origins. Mean total ages for wildfire, logged-only and logged-and-burned are 90, 70 and 60 years old, respectively.

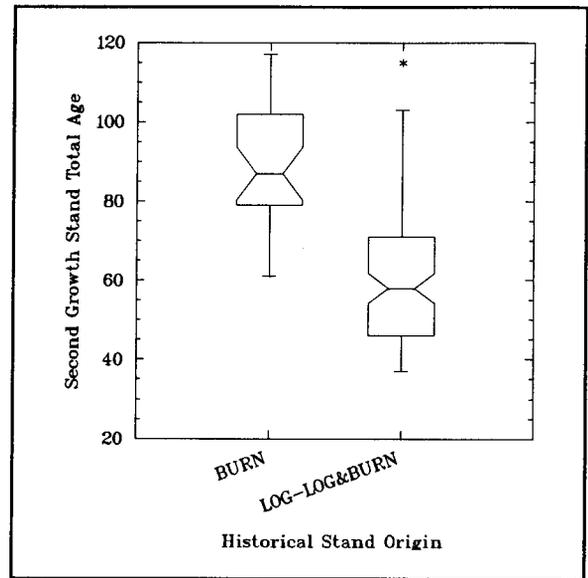


Figure 75 Boxplots of total age classified by two stand origins. Mean total ages for wildfire and logged-only plus logged-and-burned are 90 and 63 years old, respectively.

No other ecological variables, except old growth stand density and species compositions, had any apparent relationship to stand history (origin) (Table 21, p. 107).

Old growth stems/ha of Douglas-fir and western hemlock (SPHFH) for stands of wildfire origin are less than half (63 stems/ha) that of the logged-only (127 stems/ha) and logged-and-burned (133 stems/ha) origins (Table 21). Mean stems/ha (SPHFH) are significantly different between wildfire and logged ($p = .036$), and wildfire and logged-and-burned stand origins ($p = .0001$). Mean stems/ha of old growth western red cedar (SPHCW) were substantially greater in the logged-and-burned stands compared to wildfire origin stands, 25 vs 10 stems/ha ($p = .113$).

Similarly the wildfire *versus* logged origin stems/ha means were 63 vs. 133 stems/ha ($p=.000$) for SPHFH, and 12 vs. 24 stems/ha ($p=.082$) for SPHCW.

7.4 *Phellinus* Root Rot - Ecological and Stand History Models

Following on the exploratory data analyses discussed in 7.2.1 and 7.2.2, and multiple linear regression models were constructed to aid inference of the disease's behaviour, and to develop a disease hazard classification for subzone, variant, plant alliance, plant association, and site association units. All models included total stand age (AGE87) as a model term while several other models included terms for old growth stand history (stems/ha of Douglas-fir--(SPHFH), stems/ha of western red cedar (SPHCW), species composition of western red cedar (COMPCW), percent slope (SLOPE), mineral soil coarse fragment content, (CF20), and mineral soil total bulk density (MSBDT) variables.

Multiple Linear Regression Models:

Multiple linear regression models were constructed for two reasons; (a) heterogeneity of slopes for subzone and site association, and (b) to develop a comparative basis for an all-biogeoclimatic units hazard rating classification. All models, with the exception of the plant alliance and association models, were highly significant ($p=0.000$) and independent variables were all significant (all p -values <0.050). Ecosystem

classification unit-by-stand age (AGE87) interaction term models, with a constant, consistently accounted for low amounts of the variation in BARS, ($R^2 = .153$ to $.179$). (see models 1, 2, 4, 5 and 3 in Table 27). Regression through the origin (removal of the constant, or non-intercept models) produced near equivalent models that are no-less biologically correct than the intercept-models (see models A, B, C, D and E in Table 27 and respectively Figs. 76-80). These non-intercept models were used in the construction of the ecosystem hazard rating classification (Figs. 47-51). The addition of stand history variables, SPHFH and SPHCW, on the non-intercept model boosted explained variation to 27.1% and reduced the standard error (see model 9 in Table 27). Non-significant additions to model fit were made by including slope, soil porosity, bulk density and coarse fragment content (not shown in Table 27).

A stand history model, while only accounting for only 17.5% of the total variation, did indicate the tendency of lower old growth stand densities of Douglas-fir and western hemlock (SPHFH) being associated with higher levels of *P. weirii*, and increasing levels of western red cedar composition (COMPCW) associated with higher levels of *P. weirii* (Table 27). A second stand history model accounted for 13.6% total variation with old growth stems/ha of Douglas-fir/western hemlock, and western red cedar (Table 27). The model responses corroborate the earlier Pearson's correlation values for stand history in relation to BARS.

The model describing the relationship between BARS and several "thought-to-be-important" soil variables (CF20, MSBDT and SLOPE), indicated a very low explanation of

variability ($R^2 = .083$), with independent variables highly significant at ($p < 0.001$) (Table 27).

Although none of the ecological or stand history variables contributed much in themselves to the explanation of root rot variability, the models describe disease behaviour reasonably for the domain of coastal Douglas-fir ecosystems studied, especially considering the wide ecological and root rot variability within the area and, the fact that the PSP data base was assumed to be biased towards healthier stand conditions than was found. Furthermore, the findings clearly match root rot intensity relationships found with subzone variants (Beale, 1987), and s.a.'s (Beale 1989b, unpubl. data) that were determined from extensive, designed root rot surveys using the intersection length sampling method.

TABLE 27

**MULTIPLE REGRESSION PREDICTION MODELS FOR PERCENT BASAL AREA REDUCTION
(BARS) - SUSCEPTIBLE SPECIES, GREATER THAN THE SAMPLE DIAMETER LIMIT**

		R ²	SEE
Subzone Models			
(A)	Predicted BARS = 0.075SUBZ2*AGE87 + 0.173SUBZ2*AGE87	.153	9.722
(1)	Predicted BARS = -0.624 + 0.083SUBZ1*AGE87 + 0.182SUBZ2*AGE87	.142	9.757
Variant Models			
(B)	Predicted BARS = 0.075VARI1*AGE87 + 0.184VARI2*AGE87 + 0.154VARI3*AGE87	.159	9.719
(2)	Predicted BARS = 0.527 + 0.068VARI1*AGE87 + 0.177VARI2*AGE87 + 0.145VARI3*AGE87	.160	9.754
Plant Alliance Models			
(C)	Predicted BARS = 0.130PALL1*AGE87 + 0.202PALL2*AGE87 + 0.150PALL3*AGE87	.096	10.078
Plant Association Models			
(D)	Predicted BARS = 0.094PASS1*AGE87 + 0.147PASS2*AGE87 + 0.202PASS3*AGE87 + 0.150PASS4*AGE87	.110	10.039
Site Association Models			
(E)	Predicted BARS = 0.065SASS1*AGE87 + 0.117SASS2*AGE87 + 0.179SASS3*AGE87 + 0.190SASS4*AGE87 + 0.119SASS5*AGE87	.179	9.678
(3)	Predicted BARS = -0.831 + 0.0075SASS1*AGE87 + 0.127SASS2*AGE87 + 0.190SASS3*AGE87 + 0.202SASS4*AGE87 + 0.131SASS5*AGE87	.179	9.712
(9)	Predicted BARS = 0.086SASS1*AGE87 + 0.115SASS2*AGE87 + 0.195SASS3*AGE87 + 0.209SASS4*AGE87 + 0.158SASS5*AGE87 + -0.032SPHFH + 0.046SPHCW	.251	9.314
Stand History Model			
(14)	Predicted BARS = 13.004 - 0.041SPHFH + 14.074COMPCW	.175	9.631
(15)	Predicted BARS = 14.781 - 0.048SPHFH + 0.044SPHCW	.136	9.852

Where: AGE87=Total Stand Age; SUBZ1=CDFmm, SUBZ2=CWHxm; VARI1=CDFmm, VARI2=CWHxm1, VARI3=CWHxm2; PALL1=Pseudotsuga-Mahonia, PALL2=Tsuga-Mahonia, PALL3=Thuja-Achlys; PASS1=Pseudotsuga-Arbutus, PASS2=Pseudotsuga-Mahonia, PASS3=Tsuga-Mahonia, PASS4=Thuja-Foamflower; SASS1=CDFmm-Fd-Salal, SASS2=CDFmm-FdBg-Oregon grape, SASS3=CWHxm-FdHw-Salal, SASS4=CWHxm-HwFd-Kindbergia, SASS5=CWHxm-Cw-Foamflower; SPHFH=Stems/ha Fd & Hw; COMPCW=Species composition for old growth Cw; CF20=%Coarse fragment content by volume; MSBDT=Total bulk density (g/cm³); and SLOPE=%Slope.

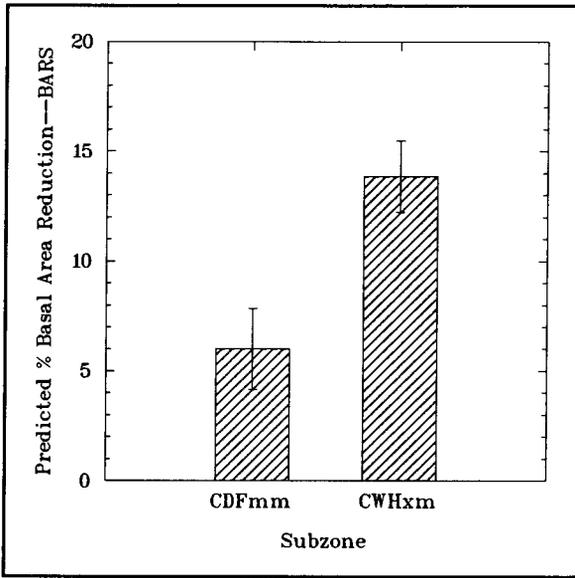


Figure 76 Predicted % Basal Area Reduction - BARS, at total age 80 yr by subzone. Note the variability indicated by the single standard error bars.

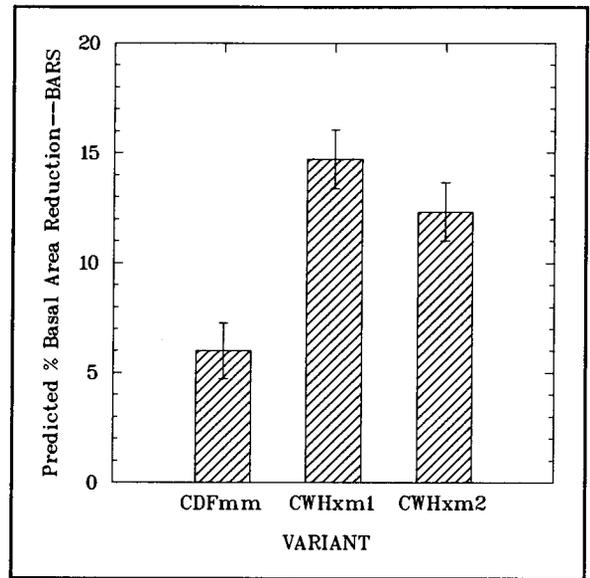


Figure 77 Predicted % Basal Area Reduction - BARS at total age 80 yr by subzone variant.

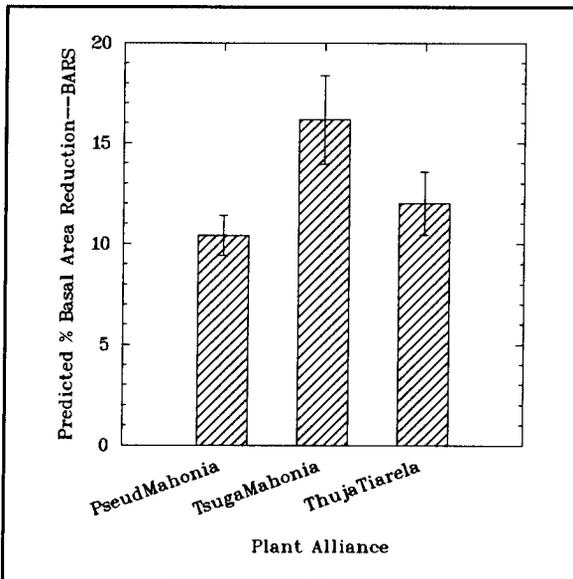


Figure 78 Predicted % Basal Area Reduction - BARS at total age 80 yr by plant alliances; *Pseudotsuga-Mahonia*, *Tsuga-Mahonia*, and *Thuja-Tiarella* p.all.'s, respectively.

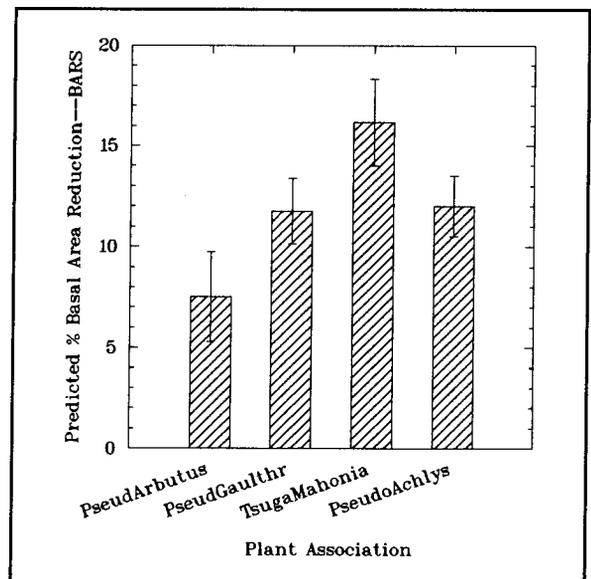


Figure 79 Predicted % Basal Area Reduction - BARS at total age 80 yr by plant association; *Pseudotsuga-Arbutus*, *Pseudotsuga-Gaultheria*, *Tsuga-Mahonia* and *Pseudotsuga-Achlys* p.a.'s.

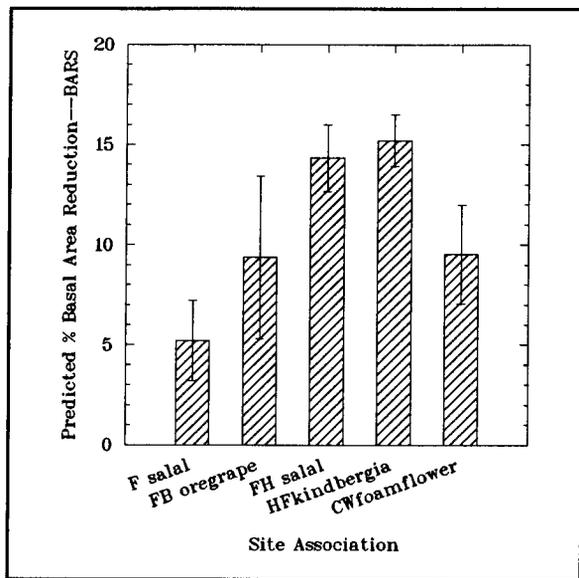


Figure 80

Predicted % Basal Area Reduction-BARS at total age 80 yr by site association; *Fd-Salal*, *FdBg-Oregon grape*, *FdHw-Salal*, *HwFd-Kindbergia*, *Cw-Foamflower* s.a.'s, respectively.

7.5 *Phellinus* Root Rot Growth And Yield Reduction Relationships

7.5.1 Damage Appraisal of *Phellinus* Root Rot on Growth and Yield of Second Growth Douglas-fir Ecosystems

The growth and yield response to *Phellinus* root rot was compared in healthy and infected PSP's. The results were evaluated in several ways: (1) one-on-one comparisons of healthy and infected PSP's within unique growth and yield installations (i.e., very similar site and stand conditions), (2) group comparison of healthy and infected PSP's dissimilar stands growing on similar sites, and (3) group comparison of healthy and infected PSP's within stands of similar initial density, and broadly similar site/ecological conditions. Growth and yield responses were expressed as volume, or basal area, by age, and by site height. Site height removes the effect of site and age in cases where the PSP's

would not otherwise be comparable (Mitchell and Cameron 1985). In some comparisons total age was better than breast-height age for evaluating the timing of stand responses to root rot.

In comparison method (1), the effect of stand density has been removed from within-installations evaluation, by grouping PSP's according to their estimated initial stand density (stems/ha at age 10 yr) (see section 7.5.1.1). Comparison method (2), used the Chapman-Richards volume over total age model (see section 7.5.1.2) and, a quadratic volume over site-height model (see section 7.5.1.3). Comparison method (3), a quadratic volume over site-height model was used (see section 7.5.1.4).

7.5.1.1 Growth and Yield Comparisons Within Selected Installations

Yield comparisons within selected PSP installations (near-identical stand and site conditions) illustrated some of the most dramatic and conclusive yield reductions due to *Phellinus* infection of PSP's, (Figs. 81-87). Volume and basal area are plotted against site height, with the exception of Figures 81 and 83 which are plotted against breast-height age for comparison. Graphs based on height or age show similar trends. Infected PSP's in comparison to healthy PSP's show departures in periodic volume and basal area increment (Table 28) resulting in lower gross volume and basal areas after 30 to 35 years of measurement. Infected PSP's relative to healthy generally have, (i) higher mortality (up to 4.2 times), and (ii) retain only 40% to 80% of the basal area increment, and (iii) 69% to 83% of the volume growth due to *Phellinus* damage which was most evident in the

Severely infected PSP's (219 vs. 218; and 2007 vs. 2008 & 2009). The growth rates in 'light to moderately' infected PSP's appear to be growing at rates equal to or better than the healthy PSP's.

TABLE 28 PERCENT CHANGE OF STAND VARIABLES BETWEEN FIRST & LAST MEASUREMENTS SPANNING 30 to 35 yr.					
PSP	Disease Condition	Percent (%) Change			Site Association
		Stems/ha	Basal Area (m ² /ha)	Volume (m ³ /ha)	
219	Healthy	- 6.37	25.61	38.76	<i>HwFd-Kindbergia</i>
218	Severely Infected "Infected, % of Healthy"*	-26.81 [420%]	10.27 [40%]	27.50 [71%]	
2007	Healthy	-33.37	31.05	45.69	<i>Cw-Foamflower</i>
2008	Severely Infected	-55.84	11.39	32.56	
2009	Severely Infected "Infected, % of Healthy"	-52.11 [162%]	14.80 [42%]	35.07 [74%]	
160	Healthy	-50.61	35.74	61.95	<i>HwFd-Kindbergia</i>
161	Healthy	-33.69	28.96	58.17	
162	Moderately Infected "Infected, % of Healthy"	-24.74 [59%]	22.44 [69%]	41.50 [69%]	
158	Healthy	-53.85	39.78	64.00	<i>HwFd-Kindbergia</i>
159	Lightly Infected "Infected, % of Healthy"	-26.42 [49%]	29.45 [74%]	52.99 [83%]	
349	Healthy	-33.31	24.36	36.22	<i>Fd-Salal</i>
348	Lightly Infected "Infected, % of Healthy"	-28.81 [86%]	19.55 [80%]	30.15 [83%]	

Negative values indicate a net loss while positive values indicate a net gain over the measurement period of 30 to 35 yr.

* "Infected, % of Healthy", indicates the percent retained by the Infected (PSP(s) as compared to the baseline
"Healthy" uninfected condition represented by "Healthy" PSP's within the same installation.

Note: Percent (%) change values have been determined from the measured values. Those values are not presented.

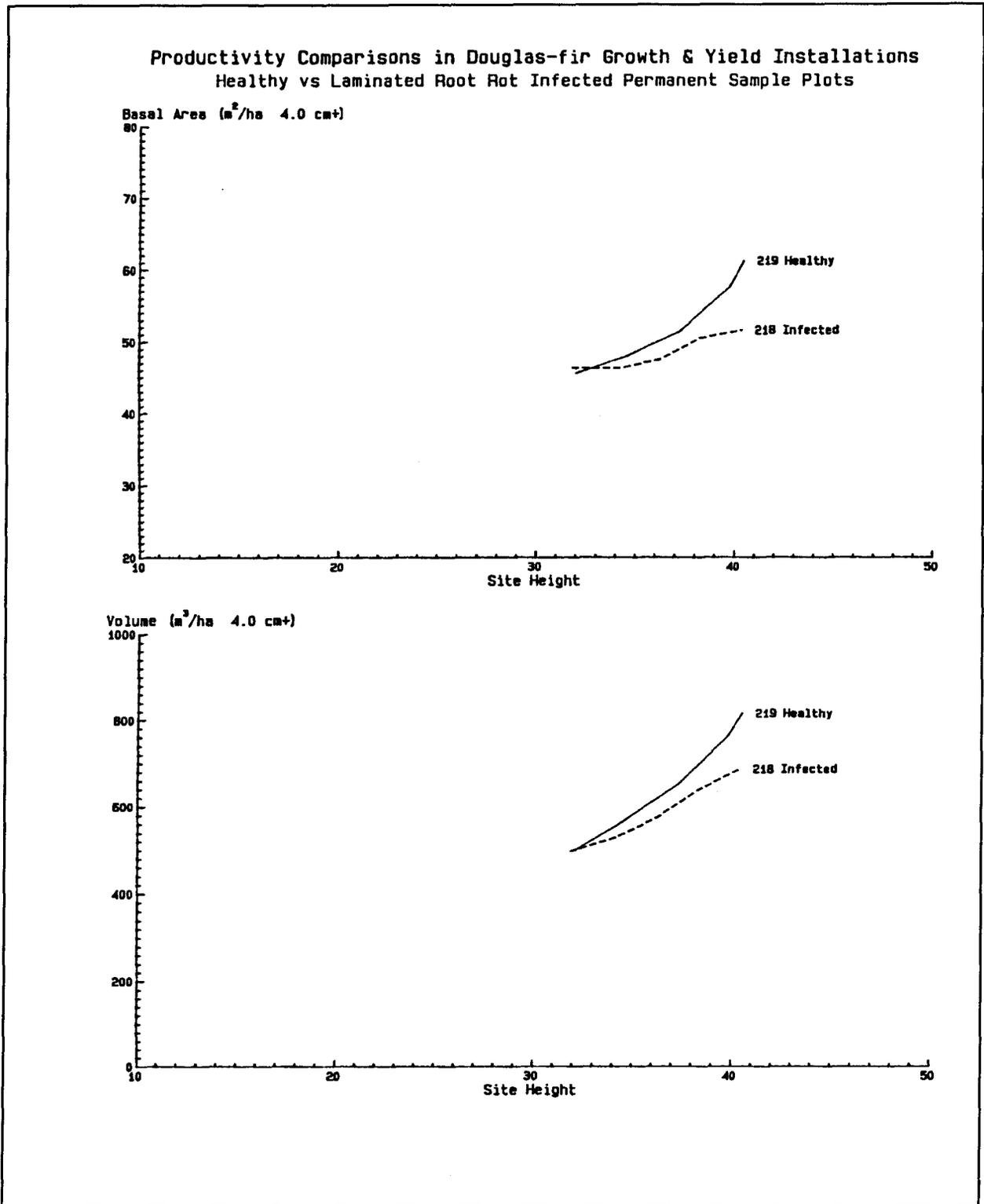


Figure 81 Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 218 and 219). All species ≥ 4.0 cm, "Severely" infected with *Phellinus* root rot.

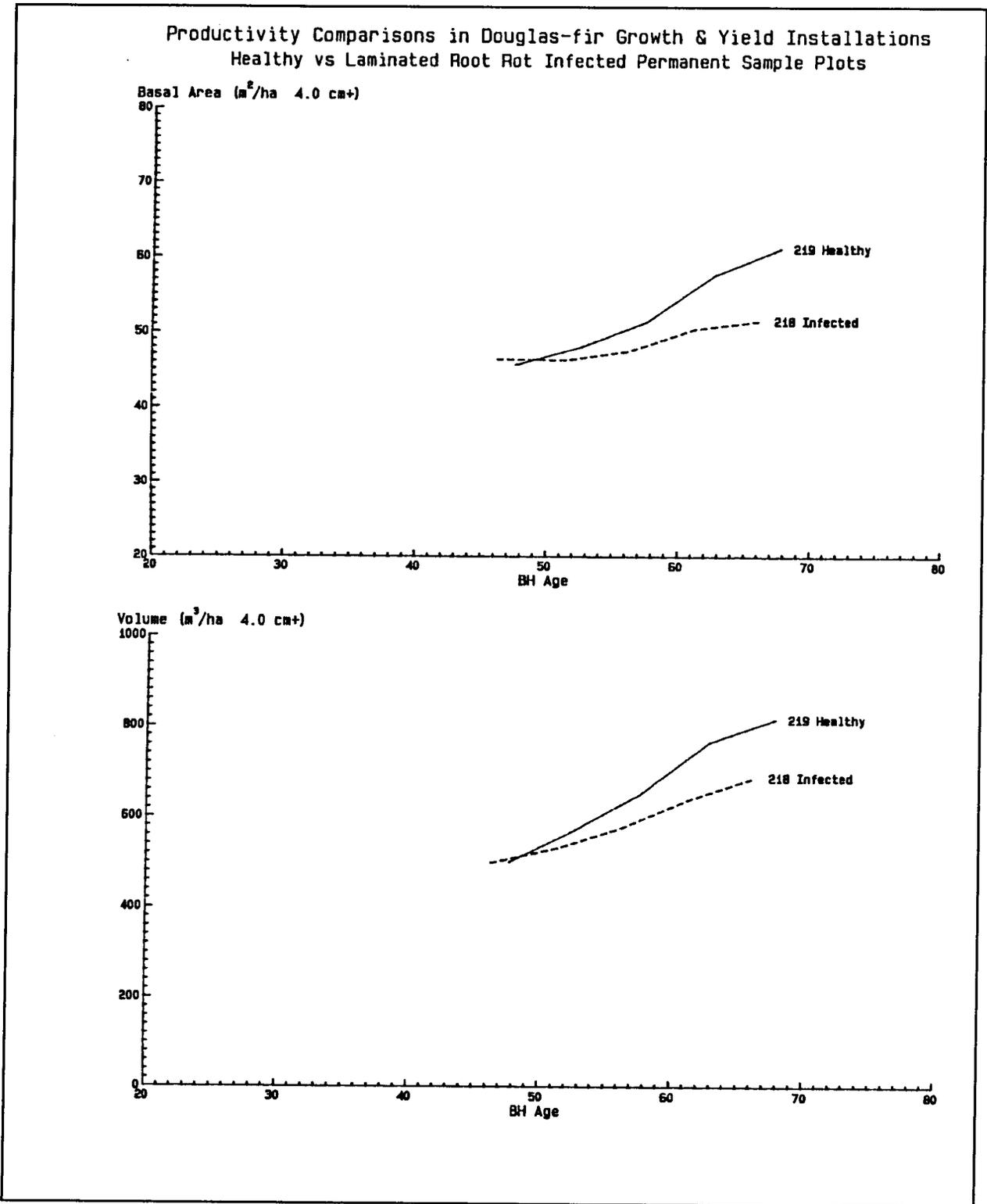


Figure 82

Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 218 and 219). All species ≥ 4.0 cm, "Severely" infected with *Phellinus* root rot.

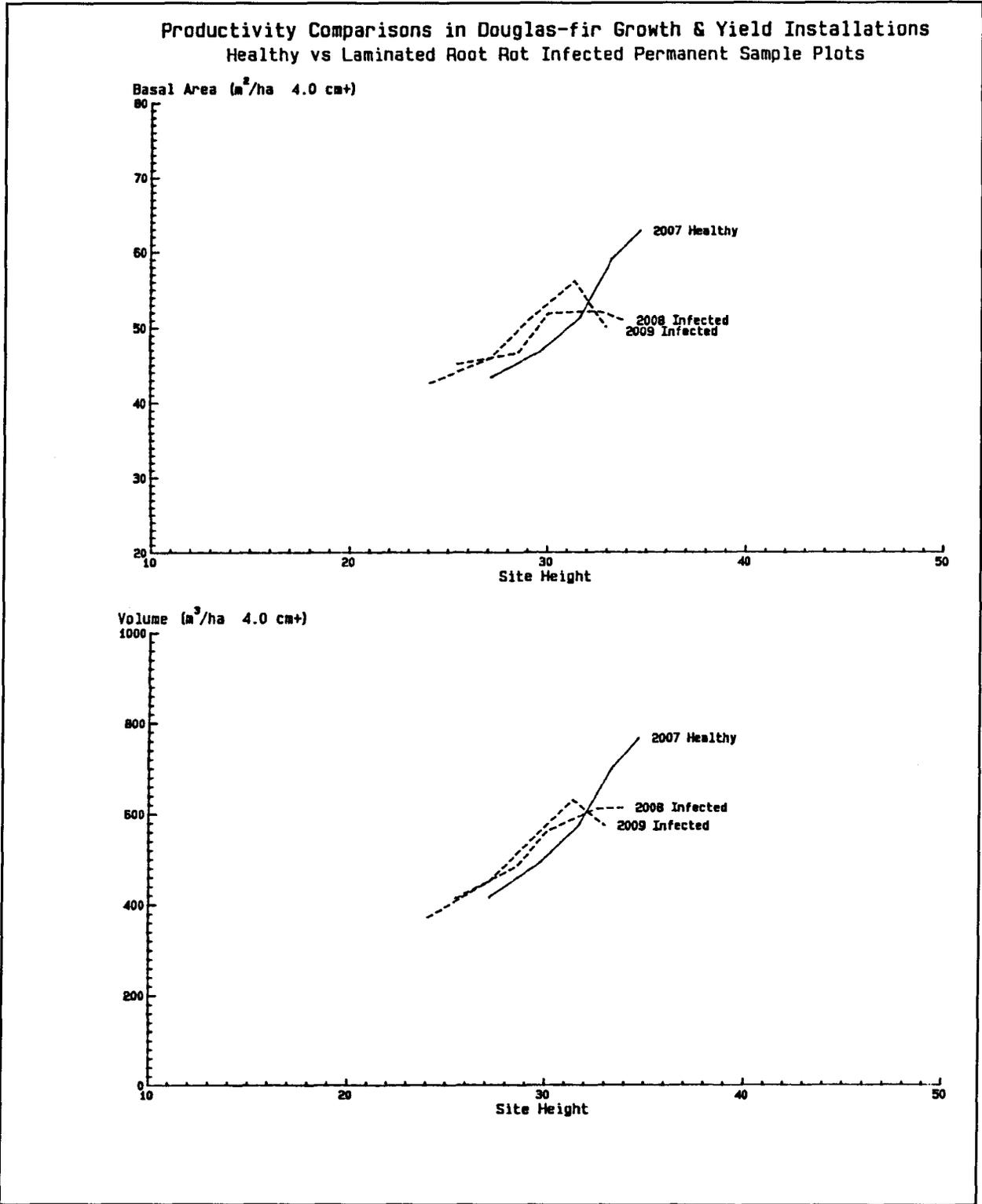


Figure 83

Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 2007, 2008, and 2009). All species ≥ 4.0 cm, "Severely" infected with *Phellinus* root rot.

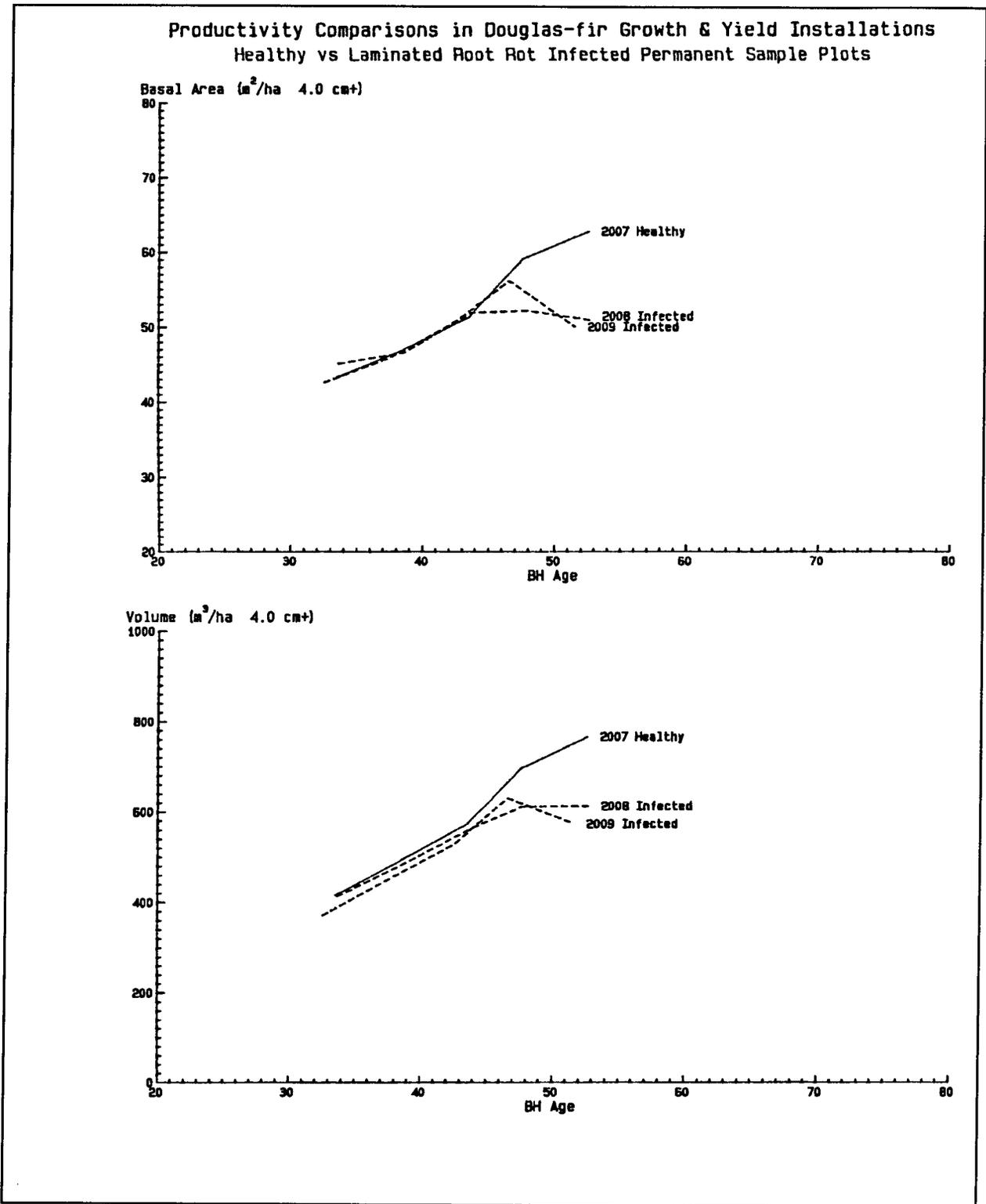


Figure 84

Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 2007, 2008, and 2009). All species ≥ 4.0 cm, "Severely" infected with *Phellinus* root rot.

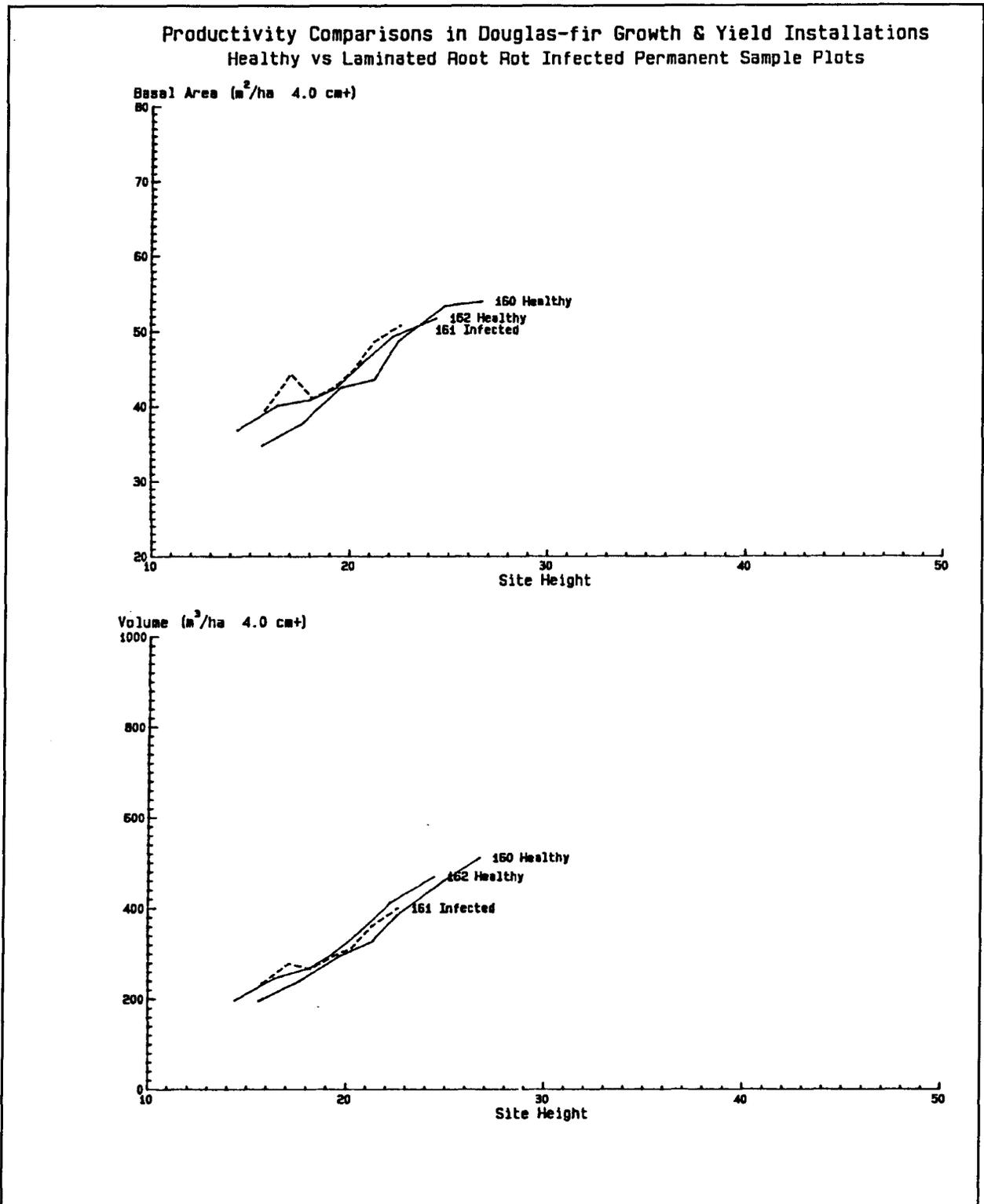


Figure 85

Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 160, 161, and 162). All species ≥ 4.0 cm, "Moderately" infected with *Phellinus* root rot.

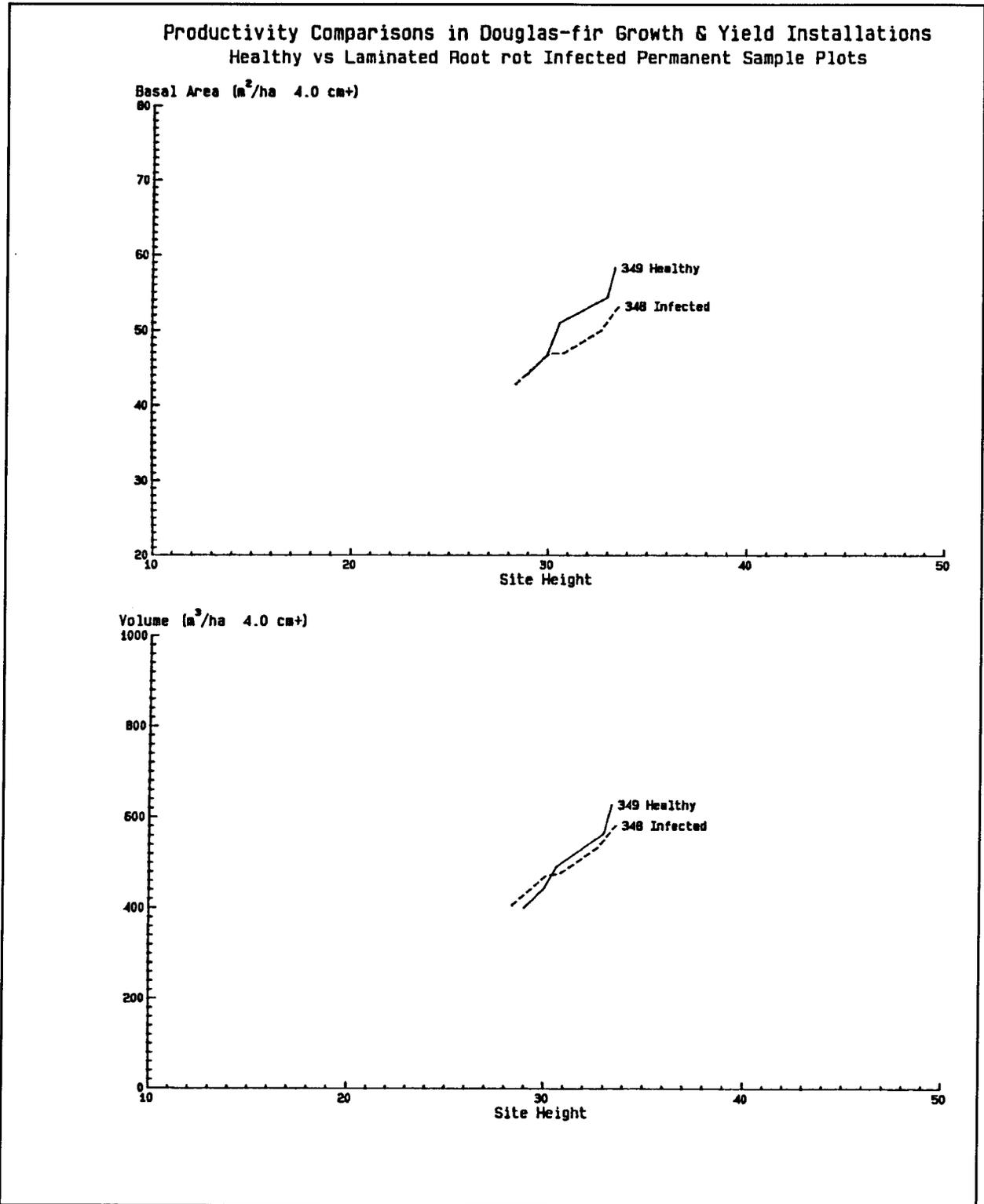


Figure 86

Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 348 and 349). All species ≥ 4.0 cm, "Light to Moderately" infected with *Phellinus* root rot.

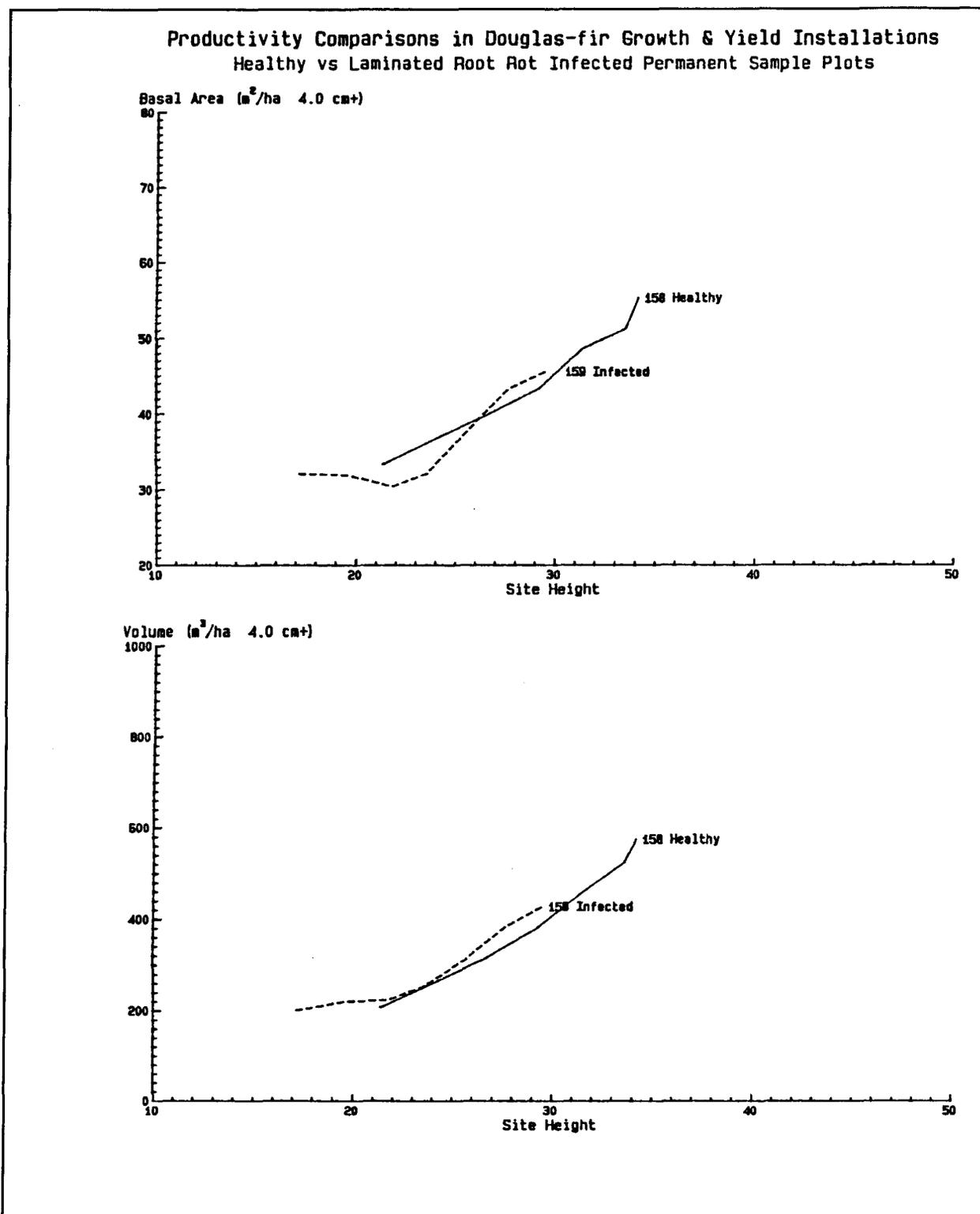


Figure 87

Productivity Comparisons in Douglas-fir Growth and Yield Installations (PSP 158 and 159). All species ≥ 4.0 cm, "Moderately" infected with *Phellinus* root rot.

7.5.1.2 Yield Comparisons Using the Chapman-Richards Non-Linear Growth (VAC) Model

The Chapman-Richards volume-age model curves could only be calculated for the combined *FdHw-Salal* and *HwFd-Kindbergia* s.a.'s (nearly all of the CWHxm subzone PSP's!). Gross volume (≥ 4.0 cm) was related to total age. Site index was not considered because it was virtually identical in healthy and infected strata (Table 29). The model estimates for healthy and infected plots fit the data very well (Table 30 and Fig. 88). The magnitude of yield reduction and the shape of the *Phellinus* infected curve (i.e., yield reduction increased gradually, virtually from regeneration) conforms well to observations from field survey work (Fig. 88), and simulations using the TASS-ROTSIM model (author's unpublished observations). The healthy and infected PSP's are estimated to have 732.9 and 668 m³/ha, respectively at age 80 yr for a reduction in yield of 8.86%. These reductions are probably conservative because the infected PSP strata is 7.5 yr older and has a mean site index of 1.2 m greater than the healthy strata, indicating that the infected strata in the absence of *Phellinus* root rot should have greater yields than the healthy strata.

TABLE 29 DESCRIPTIVE STAND STATISTICS FOR COMBINED SITE ASSOCIATIONS; <i>FdHw-Salal</i> and <i>HwFd-Kindbergia</i> MEAN AND (STANDARD DEVIATION)						
Disease Condition	Site Index	AGE87 ¹	ST410 ²	BA410 ³	VL410 ⁴	N
Healthy	27.22 (5.61)	61.38 (20.59)	2927 (1709)	8.77 (2.82)	24.74 (7.93)	70
Infected	28.45 (5.17)	68.88 (22.61)	2417 (1657)	8.16 (3.48)	23.75 (3.48)	53
Combined	27.75 (5.44)	64.62 (21.72)	2708 (1699)	8.51 (3.12)	24.32 (9.00)	123
1 Stand age 1987 2 Stems/ha ≥ 4.0 cm at 10 yr 3 Basal area/ha (m^2/ha) ≥ 4.0 cm at 10 yr 4 Volume/ha (m^3/ha) at 10 yr ≥ 4.0 cm						

TABLE 30 CHAPMAN-RICHARDS VOLUME - TOTAL AGE GROWTH MODEL STATISTICS (≥ 4.0 cm Gross Volume)					
Ecological Units	Disease Condition	Sums of Squares	Regression Coefficients		
			B1	B2	B3
<i>FdHw-Salal</i> and <i>HwFd-Kindbergia</i>	Healthy	864650.0	1143.236	.01232	1.437
	Infected	934093.5	975.308	.02181	1.971
	All PSP's	1819265.0	1132.611	.01746	1.713
NB: File=BGROMB.SYS. The Chapman-Richards Growth Model Equation, see below: <div style="border: 1px solid black; padding: 5px; display: inline-block; margin-top: 5px;"> $\text{Predicted VOL4} = b1(1 - \text{EXP}(-b2 \text{ AGE}))^{b3}$ </div>					

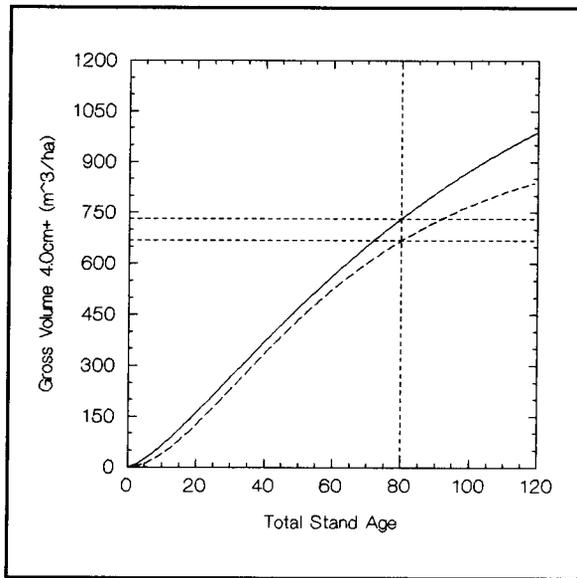


Figure 88

Chapman-Richards volume-age curves (≥ 4.0 cm) comparing healthy (—) and *Phellinus* root rot infected (---) stand conditions for the combined *FdHw-Salal* and *HwFd-Kindbergia* s.a.'s in the CWHxm subzone. The healthy yield at 80yr is $732.9 \text{ m}^3/\text{ha}$ compared to $668.0 \text{ m}^3/\text{ha}$ for infected yield, resulting in a 8.86% yield reduction.

7.5.1.3 Growth and Yield--Site Height Models for the Whole PSP Dataset

Growth and yield models were fit to PSP's after dropping several outlier PSP's with initial site heights over 40 m and several other PSP's with unexplainable measurement inconsistencies. Furthermore, growth and yield models for the *FdHw-Salal*, and *HwFd-Salal* s.a.'s were found to be virtually identical (graphically) to models produced for the all-PSP's model, therefore only the all-PSP's models are presented.

7.5.1.3.1 Growth Models

A linear growth difference model was fit for annual volume increment as a function of a constant, an annual site height increment term and a site height increment - PSP disease condition interaction term. (Note, the PSP disease condition was a dummy

variable; healthy or infected). The growth model provided a reasonably good fit for the data (Table 31). The site height increment - disease condition interaction term was highly significant ($p = .000$), indicating that disease condition is important in explaining the variation in volume increment rates. Healthy and infected increment data with their respective growth model functions are shown in Figures 89 and 90. Healthy PSP's have substantially greater homogeneity compared to the infected PSP's. More negative growth points in the infected PSP group. This was also reflected in the regression model intercept and larger standard error of the estimate. The plot of both growth model functions without the data points illustrates noticeably lower growth rates of the infected PSP's compared to the healthy PSP's, (Fig. 91). Infected PSP's grow more slowly by 4.4% to 11.7% over the range of 0.1 to 0.9 m annual site height increment. Assuming that site height measurement is independent of root rot effects in PSP's, the pattern of volume growth reduction indicates that site quality (site height) has a positive effect on volume growth reduction. Note, that this assumption is built into the model by using the constant. Furthermore, evidence of a positive site height effect on *Phellinus* intensity was not shown in the correlation testing nor in the relationships of *Phellinus* and the site associations. An alternative and more likely assumption, is that site height measurement is partially dependent on the effects of root rot (i.e., root rot has had negative, or depressive, effects on site height measurements). This assumption was tested by stratifying the data by disease condition, and by not including constants in separate models estimated for each disease condition.

TABLE 31 All-PSP's Growth Model "Independent" of Root Rot Effects on Site Height Measurements

DEP VAR: DVOL4		N: 952	MULTIPLE R: .568	SQUARED MULTIPLE R: .322		
ADJUSTED SQUARED MULTIPLE R: .321		STANDARD ERROR OF ESTIMATE: 5.223				
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	4.811	0.406	0.000	.	11.850	0.000
DSTHGHT1	20.562	0.985	0.598	0.870	20.867	0.000
DSTHGHT1*						
RRIN	-3.019	0.787	-0.110	0.870	-3.835	0.000
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	12307.381	2	6153.690	225.591	0.000	
RESIDUAL	25886.922	949	27.278			

Where: Predicted DVOL4 is the annual volume increment, ≥ 4.0 cm ($m^3/ha/yr$), DSTHGHT1 is the annual site height increment (m/yr) and RRIN is the incidence of root rot in PSP's (absence/presence 0/1).

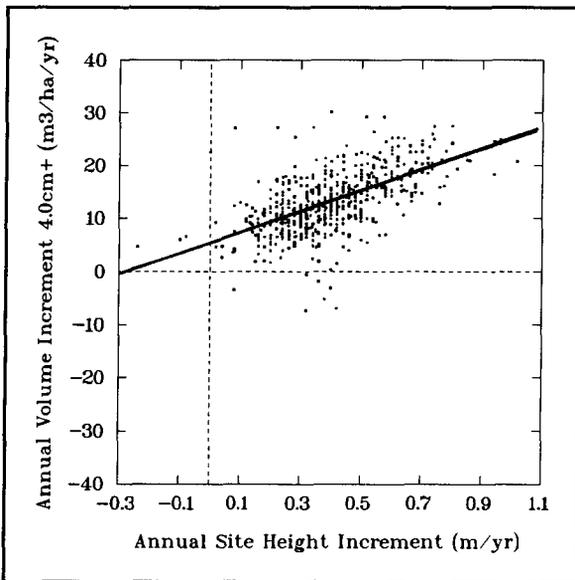


Figure 89 All-PSP's growth model; healthy PSP scatterplot and growth function, (Predicted $DVOL4 = 4.811 + 20.562 DSTHGHT1$). The model assumes that site height measurements are independent of root rot height depression effects.

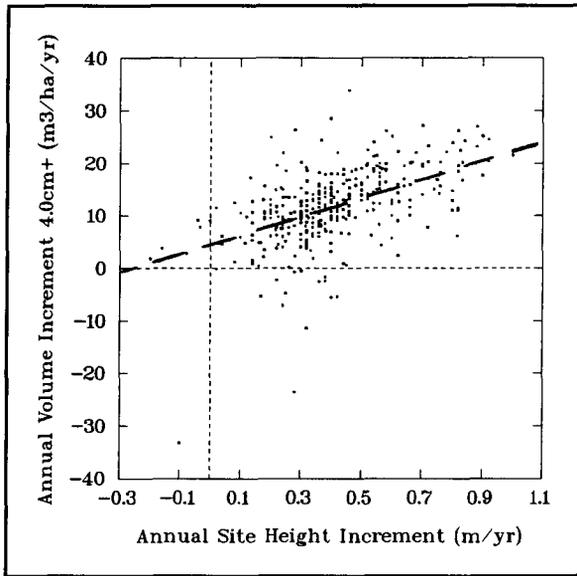


Figure 90 All-PSP's growth model; infected PSP scatterplot and growth function (Predicted DVOL4=4.811 + 17.543 DSTHGHT1). The model assumes that site height measurements are independent of root rot height depression effects.

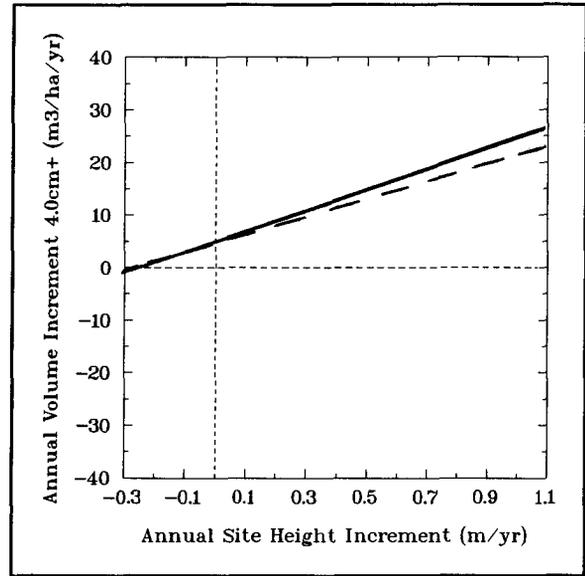


Figure 91 All-PSP's growth model; comparative growth function plots healthy (—) and infected PSP's (---).

To examine this alternative hypothesis, two more models were estimated for the healthy and infected PSP strata. The healthy PSP growth model (Table 32) has a higher constant and greater volume increment rate than the infected PSP growth model (Table 33). Figures 92 and 93 illustrate the healthy and infected model functions respectively plotted over the data. The effect of *Phellinus* root rot on site height increment is seen in that most of the negative and lower volume increments are at the lower end of the site height increments. In these cases it is hypothesized that the site height measurement trees are infected for many years before symptoms are readily expressed. There is a high probability that some trees measured for site heights in PSP's would be affected by root rot height depression before being

dropped for reference height measurements. If site height measurements are in fact somewhat dependent on the effects of *Phellinus* root rot, the volume growth reductions are then inversely related to site height increment, with growth reductions ranging between 17.33% to 7.48% for annual site height increments of 0.1 to 0.9 m (Figure 94, combined lines, no data, 2 constants). Intuitively, the site height measurement dependent models are sensible because the volume increments for infected PSP's must not be equal at low site height increments, unless ingrowth is so dramatic to make up for growth reduction and tree mortality - a generally inconceivable condition.

TABLE 32 All-PSP's Growth Model - Healthy Condition "Dependent" of Root Rot Effects on Site Height Measurements

DEP VAR:	DVOL4	N: 593	MULTIPLE R: .592	SQUARED MULTIPLE R: .350		
ADJUSTED SQUARED MULTIPLE R:	.349	STANDARD ERROR OF ESTIMATE:	4.643			
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	5.322	0.476	0.000	.	11.182	0.000
DSTHGHT1	19.488	1.092	0.592	1.000	17.843	0.000
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	6862.594	1	6862.594	318.362	0.000	
RESIDUAL	12739.552	591	21.556			

Where: Predicted DVOL4 is the annual volume increment, ≥ 4.0 cm ($m^3/ha/yr$),
DSTHGHT1 is the annual site height increment (m/yr).

TABLE 33 All-PSP's Growth Model - Infected Condition "Dependent" of Root Rot Effects on Site Height Measurements

DEP VAR: DVOL4		N: 359	MULTIPLE R: .529	SQUARED MULTIPLE R: .280		
ADJUSTED SQUARED MULTIPLE		R: .278	STANDARD ERROR OF ESTIMATE: 6.055			
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
CONSTANT	4.120	0.722	0.000	.	5.707	0.000
DSTHGHT1	18.920	1.605	0.529	1.000	11.789	0.000
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	5095.609	1	5095.609	138.982	0.000	
RESIDUAL	13088.985	357	36.664			

Where: Predicted DVOL4 is the annual volume increment, ≥ 4.0 cm ($m^3/ha/yr$), DSTHGHT1 is the annual site height increment (m/yr).

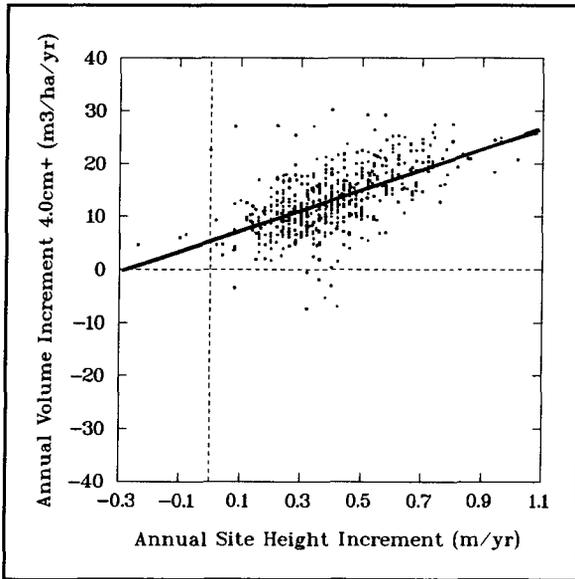


Figure 92 All-PSP's growth model; healthy PSP scatterplot and growth function (Predicted $DVOL4 = 5.322 + 19.488 DSTHGHT1$). The model assumes that site height measurements are dependent on root rot height depression effects.

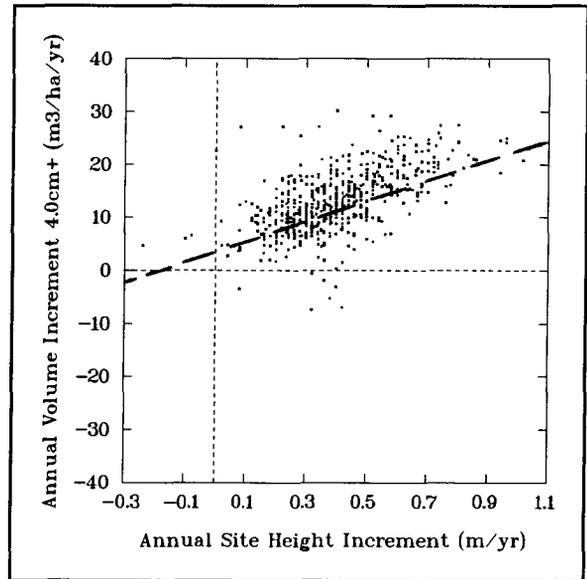


Figure 93 All-PSP's growth model; infected PSP scatterplot and growth function (Predicted $DVOL4 = 4.120 + 18.920 DSTHGHT1$). The model assumes that site height measurements are dependent on root rot height depression effects.

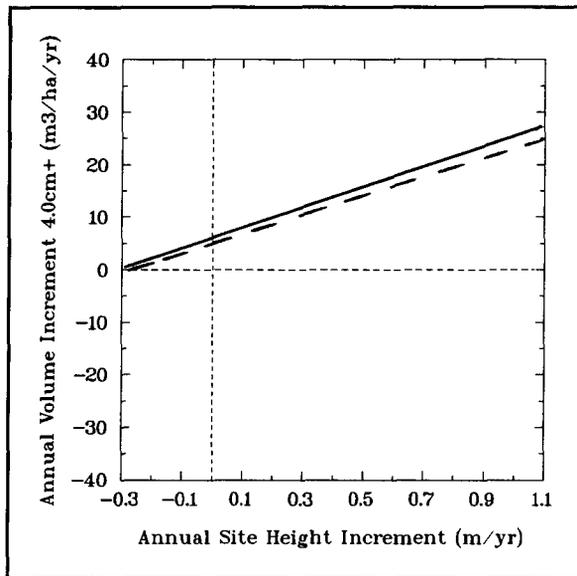


Figure 94

All-PSP's growth model; comparative growth function plots (—) healthy, and (---) infected. The model assumes that site height measurements are dependent on root rot height depression effects.

7.5.1.3.2 Yield Models

A quadratic volume yield-site height model (≥ 4.0 cm), predicted an increasing yield loss in *Phellinus* infected PSP's as compared to healthy PSP's. The model included a volume yield-PSP disease condition (healthy or infected dummy variable) interaction term which is highly significant ($p = .000$) (Table 34). All model terms were significant ($p = .000$). The volume increment-disease condition interaction term indicated the importance of root rot conditions in explaining volume variation. The healthy model functions indicate that healthy PSP's have a slightly higher yield than the infected PSP's, with the infected group having 5.5% less volume at 35 m site height (or approximately 80 years of age). Healthy and infected PSP data and their respective yield model functions again illustrate the greater homogeneity of the healthy PSP's compared to the infected PSP's (Figs. 95 and 96), respectively. In Figure 97, the infected PSP curve visibly departs from the healthy

curve at 10 m site height, but in fact is departing right from the origin. This is accurate biologically, and compares well with the Chapman-Richards volume-age function shown in an earlier section. The volume yield reductions are lower in the volume-site height models compared to the Chapman-Richards. Site quality (index) was not considered in the C-R volume-age functions. The yield models suggest that the yield increment rates are not yet showing significant effects of mortality in the infected PSP's although the growth rates are slowing, as shown in the previous section.

TABLE 34 All-PSP's Yield Model

MODEL CONTAINS NO CONSTANT.						
DEP VAR: VOL4		N: 952	MULTIPLE R: .977		SQUARED MULTIPLE R: .955	
ADJUSTED SQUARED MULTIPLE R: .955			STANDARD ERROR OF ESTIMATE: 91.948			
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
STHGHT	2.958	0.561	0.179	0.041	5.272	0.000
STHGHT2	0.458	0.019	0.821	0.039	23.653	0.000
STHGHT2*						
RRIN	-0.030	0.008	-0.033	0.613	-3.817	0.000
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	.171879E+09	3	.572932E+08	6776.702	0.000	
RESIDUAL	8023254.390	949	8454.430			

Where: Predicted VOL4 is the volume yield ≥ 4.0 cm (m^3/ha), STHGHT is the site height, STHGHT2 is the site height squared and RRIN is the incidence of root rot in PSP's (absence/presence 0/1).

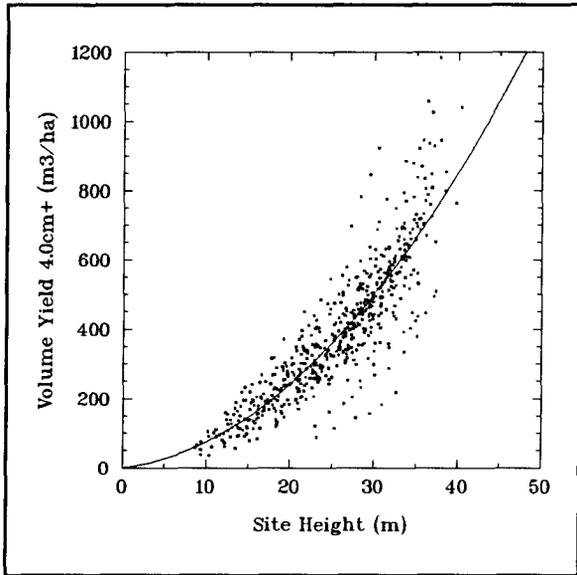


Figure 95 All-PSP's yield model; healthy PSP scatterplot and yield function (Predicted $VOL4 = 2.958 \text{ STHGHT} + 0.458 \text{ STHGHT}^2$).

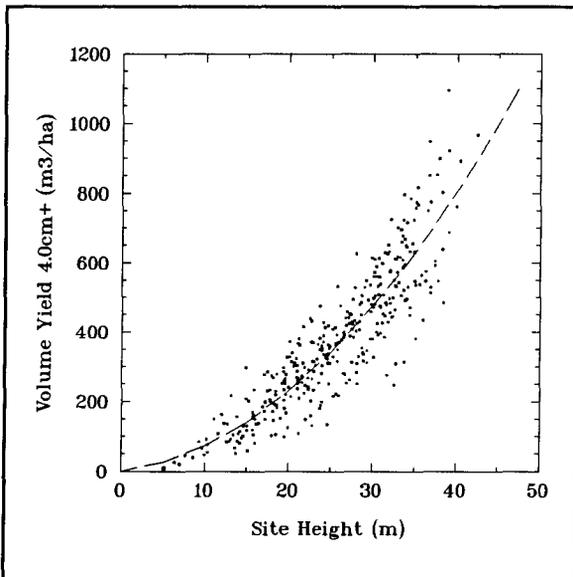


Figure 96 All-PSP's yield model; infected PSP scatterplot and yield function (Predicted $VOL4 = 2.958 \text{ STHGHT} + 0.428 \text{ STHGHT}^2$).

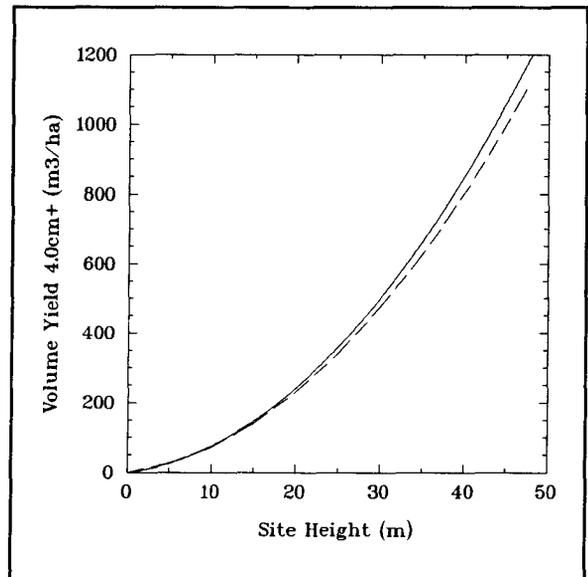


Figure 97 All-PSP's yield model; comparative yield function plots healthy (—) infected (---) PSP's.

7.5.1.4 Growth and Yield: All Data, Stratified by Stand Density Classes (stems/ha at age 10 yr)

Several of these models were estimated to evaluate the effects of initial stand density (back-estimated to reference age 10 yr) on the volume and *Phellinus* root rot related damage impacts. Although a logical argument was presented previously to rationalize the differences observed between %BAR and PSP-based damage estimates, I felt that stand densities were confounding the picture. In the absence of PSP-based *Phellinus* damage intensity information, it was impossible to determine if the PSP's were really portraying the same damage as the %BAR surveys.

Quadratic volume-site height yield models were fit for each of the young (1 to 20 yr old) stand density classes (< 1 000, 1 000 - 1 999 and 2 000 - 4 999 stems/ha, (Forest Productivity Councils of B.C., Sept. 1990).

7.5.1.4.1 Stand Density (Less than 1 000 stems/ha):

7.5.1.4.1.1 Yield Model

A quadratic yield model (Table 35) estimates yield reduction to be 8.25% for infected PSP's at a site height of 35 m (or approx. 80 yr), (Fig. 98).

Table 35 Stand Density Class (< 1 000 stems/ha) Yield Model

DEP VAR: VOL4		N: 169	MULTIPLE R: .975		SQUARED MULTIPLE R: .950	
ADJUSTED SQUARED MULTIPLE R: .949		STANDARD ERROR OF ESTIMATE: 95.699				
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
STHGHT	-2.275	1.760	-0.157	0.021	-1.292	0.198
STHGHT2	0.547	0.058	1.160	0.020	9.374	0.000
STHGHT2*						
RRIN	-0.039	0.017	-0.051	0.618	-2.293	0.023
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	.288112E+08	3	9603739.352	1048.645	0.000	
RESIDUAL	1520267.965	166	9158.241			

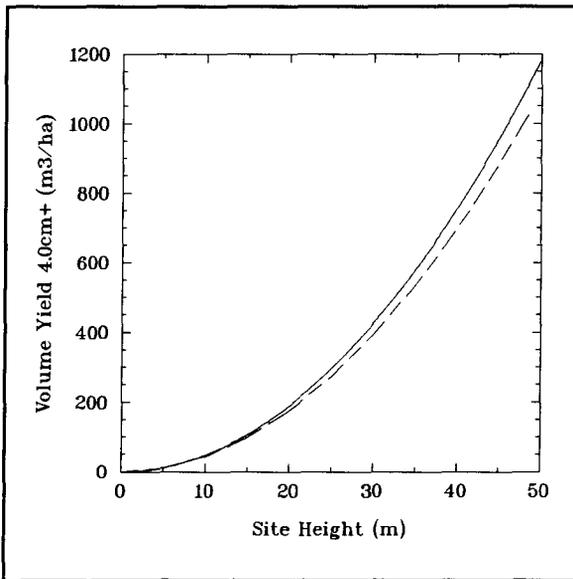


Figure 98

Yield models for stand density < 1 000 stems/ha at age 10 yr for healthy (—) and infected (---) PSP conditions.

7.5.1.4.2 Stand Density (1 000 - 1 999 stems/ha):

7.5.1.4.2.1 Yield Model

A yield model (Table 36) estimated yield reduction to be 8.63% for infected PSP's at a site height of 35 m (or approx. 80 yr), (Fig. 99).

Table 36 Stand Density Class (1 000 - 1 999 stems/ha) Yield Model

DEP VAR: VOL4		N: 412	MULTIPLE R: .986		SQUARED MULTIPLE R: .973	
ADJUSTED SQUARED MULTIPLE R: .972		STANDARD ERROR OF ESTIMATE:76.755				
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
STHGHT	0.313	0.767	0.019	0.031	0.408	0.684
STHGHT2	0.546	0.025	0.998	0.031	21.470	0.000
STHGHT2*						
RRIN	-0.048	0.009	-0.052	0.642	-5.115	0.000
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	.854946E+08	3	.284982E+08	4837.270	0.000	
RESIDUAL	2409575.929	409	5891.384			

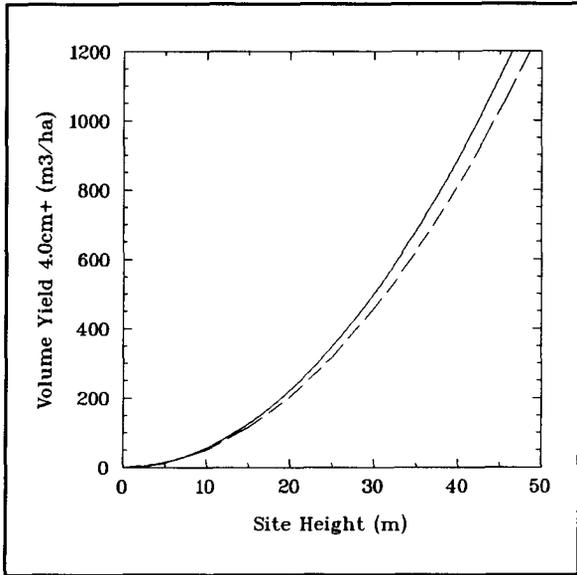


Figure 99

Yield models for stand density 1 000 - 1 999 stems/ha at age 10 yr for healthy (—) and infected (---) PSP conditions.

7.5.1.4.3 Stand Density (2 000 - 4 999 stems/ha):

7.5.1.4.3.1 Yield Model

A yield model (Table 37) estimated yield reduction to be 4.97% for infected PSP's at a site height of 35 m (or approx. 80 yr), (Fig. 100).

Table 37 Stand Density Class (2 000 - 4 999 stems/ha) Yield Model

DEP VAR: VOL4		N: 330	MULTIPLE R: .985		SQUARED MULTIPLE R: .969	
ADJUSTED SQUARED MULTIPLE R: .969		STANDARD ERROR OF ESTIMATE: 75.079				
VARIABLE	COEFFICIENT	STD ERROR	STD COEF	TOLERANCE	T	P(2 TAIL)
STHGHT	2.284	0.725	0.129	0.056	3.149	0.002
STHGHT2	0.561	0.028	0.877	0.051	20.347	0.000
STHGHT2*						
RRIN	-0.026	0.013	-0.027	0.536	-2.069	0.039
ANALYSIS OF VARIANCE						
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P	
REGRESSION	.580895E+08	3	.193632E+08	3435.127	0.000	
RESIDUAL	1843237.797	327	5636.813			

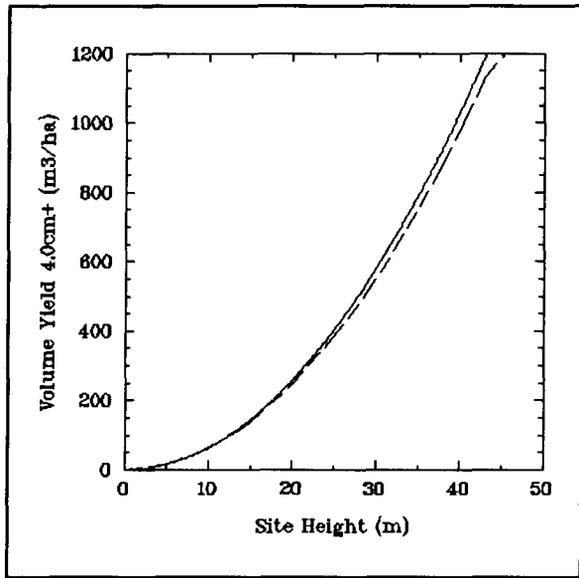


Figure 100

Yield models for stand density 2 000 - 4 999 stems/ha at age 10 yr for healthy (—) and infected (---) PSP conditions.

8.0 DISCUSSION

Variable-radius plot sampling was successfully used to estimate *Phellinus* root rot damage intensity using a Percent Basal Area Reduction (%BAR) parameter estimate technique. Damage intensity estimates were a function of damage severity and incidence estimates. Damage severity, or the proportional difference between the mean basal areas of healthy and infected point samples within a sample survey, ranged between 0 and 1 with a mean of 0.30. Stand-based damage incidence, or the proportion of variable-radius plots in a sample survey expressing *Phellinus* root rot symptoms (presence/absence), had a mean incidence of 0.263. Land-based disease incidence, had a mean incidence of 0.168. Mean %BAR estimates ranged from 8.25% to 9.99%, depending on the species susceptibility and diameter classes used for the parameter estimate. Means and (standard deviations) were as follows for the four parameter estimates: NSBAR 8.25% (9.25%); SBAR 8.92% (10.22%); BARNS 9.44% (9.99%) and BARS 9.99% (10.52%). These parameter estimates appear very reasonable in light of my experience and other workers estimates of damage incidence, severity and intensity.

Mean %BARS estimates showed that the first assumption regarding the sampling methodology and the expected %BAR's relationships was correct. The healthy-only, susceptible species composition was 91.5%, with statistically non-significant variation across s.a.'s. This ensured an equal probability for detection and measurement of *Phellinus* root rot. Infected stand areas compared to healthy areas, sustained about a 30% reduction in stand density. Damage severity or relative basal area reduction, was

statistically significant and provided conclusive evidence for the effects of *Phellinus* root rot and the sensitivity of the %BAR parameter estimate technique. The coefficients of variation for severity were respectively, 31.5% and 18.9% for the infected and healthy areas. The greater basal area variation of infected areas should be taken into consideration in the future designs of forest health and forest inventories.

8.1 Damage Incidence - Severity - Intensity Relationships

Incidence-Severity Relationship: Land- and stand-based incidence of *Phellinus* root rot increased with increasing damage severity. This was reasonable considering that both parameters are time-since-infection or stand age interdependent functions. That is, the frequency of stems expressing root rot symptoms contributes to increasing damage severity, which is related to increasing frequency of disease incidence as infection centers expand to affect more of the land or stand area.

Severity-Intensity Relationship: Damage severity increased with damage intensity and then stabilized at about 0.50 (or 50% basal area reduction) even in the most severe damage intensity conditions. The asymptotic behaviour of severity appears to indicate a resiliency of forest productivity in the presence of *Phellinus* root rot, in that basal area reduction equilibrated with basal area replacement (the latter likely due in part to ingrowth of less-susceptible, shade tolerant species such as western red cedar, western white pine and western hemlock), and enhanced growth of residual trees due to reduced competition. The severity-intensity relationship provided some indication of the

mechanisms of the proposed host-pathogen dynamic equilibrium.

Incidence-Intensity Relationship: Damage intensity increased with increasing damage incidence. Estimates of land- or stand-based incidence were highly correlated to damage intensity ($r=.811$ and $r=.836$, respectively). Linear prediction models for %BARS as a function of land-based incidence and stand-based incidence estimated incidence levels to be 0.5 to 2.6 times larger than observed intensity levels. This indicated that incidence estimates alone are inappropriate estimators of damage effects on stand productivity because they significantly overestimate over the %BARS range of 5 to 15%. In order to accurately appraise damage to stand productivity, sampling should include a measure of incidence and severity.

The data suggests that stand-based *versus* land-based sampling methods should be emphasized in forest productivity-disease impact studies in order to provide more accurate and meaningful estimates of damage to stand and forest productivity. Knowledge of land-based incidence and stand-based intensity relationships should provide direction to future root disease surveys that have forest productivity, damage appraisal objectives.

Incidence-intensity relationships may be particularly useful for increasing sampling efficiencies, in that if the relationship is well known (perhaps from previous sampling), then further disease sampling can be reduced to simply land-based incidence (binomial response) sampling, with stand-based damage intensity then estimated from the

appropriate incidence-intensity relationship model. Binomial incidence sampling methods are generally cheaper to conduct and more easily reproduce consistent results.

Incidence-Incidence Relationship: Both stand:land-based and land:stand-based incidence ratios were plotted over land and stand-based incidence, respectively (Figs. 20 and 21). The stand-based incidence apparently over-estimated the land-based estimates, particularly at low land incidences. The corollary, is that the land-based estimate underestimated the stand-based incidence at low stand incidence. Both incidence estimates appeared to level out and predict more closely to a 1:1 ratio as incidence approached .35 to .40 or 35 to 40%. Although the linear correlation coefficient estimate for land-stand incidence is .923, the greatest variation was at low levels of incidence (which is a critical area for management decision making). This variance might easily be corrected if the "effective" sampling areas were more closely defined, rather than the land-based fixed-radius plots set at 3.99 m or .005 ha, and the stand-based variable-radius mean tree critical distance radius at about .027 ha, (i.e., adjust BAF selection). Considering that the bases of the two incidence estimates are completely different, the estimates are remarkably similar, with the greater incidence captured by the stand-based method compared to the land-based method. A recommendation for further land-based incidence sampling is to increase the sample plot size to 0.010 ha, and select BAF's to more nearly approximate land-incidence areas sampled.

8.2 The Relationship Between PSP's And The %BAR Sample Survey Data

Eighty percent (80%) of the infected PSP's are in stands where *Phellinus* root rot exceeded 5% BARS or NSBAR, or that have a BARS-Damage Intensity Class of Medium-Severe. This was an important finding because it meant that the PSP's could be considered fairly representative of the stands sampled in and around the PSP, and vice versa, thus simplifying interpretations between ecological and growth and yield impact data in the %BAR survey and the PSP data sets.

8.3 *Phellinus* Root Rot Variability in Relation to Ecological Site Factors and BEC Units

8.3.1 Disease Incidence

Disease incidence ranged widely between 10 and 100% depending on the sampling unit population, but generally did not vary widely within the biogeoclimatic units. Disease incidence appeared to be positively correlated with the sampling unit size, and seen across all biogeoclimatic units. For example, the mean disease incidence in site associations increased from: 16.8% using 0.005 ha fixed-radius plots, to 26.3% using variable-radius plots, to 36.8% using 0.04 ha PSP's, to 87.0% using 1 ha %BAR sample survey plots.

The mean incidence observed using fixed-radius plots (mean was 12.5%) was, about

the same as that obtained in the large-scale root disease survey using the intersection length method (Beale 1987). These two land-area-diseased expressions appear to estimate similarly, although the study areas are not directly comparable. Incidence estimates using fixed- and variable-radius plots showed similar estimates, with the latter always greater (or more sensitive, particularly at lower land-based incidence levels) due to its "apparently larger" sampling unit area, thereby increasing the probability of sampling a *Phellinus* root rot incident. Incidence estimates based on the 1 ha sample surveys (mean was 87%) also provided identical estimates to 20 ha sample surveys conducted in the large-scale root disease survey (mean was 87%) in 1982-83 (Beale 1987). This finding suggests that future root disease sampling designs can be based on smaller sampling units and thereby maintain estimate fidelity, and gain additional ecological and stand condition homogeneity.

8.3.2 Disease Intensity

Disease intensity ranged from -10% to 55% basal area reduction (BARS estimates). Generally, the magnitude of percent basal area reduction (%BAR) estimates was dependent upon the combination of tree selection parameters. Thus, increasing the minimum tree sampling diameter limit from ≥ 4.0 cm to $\geq 12.0/17.5$ cm and/or dropping non-susceptible species trees from the tree count increased the %BAR damage intensity estimates. In mid-seral stands, selection of larger diameter susceptible species increases the probability of sampling *Phellinus* root rot infected trees and hence the percent basal area reduction estimate rises. Note, that negative percent basal area reduction (e.g., -10%

BARS) reflected a possible, although not a commonly occurring damage condition, in which the effect of root rot on stand yield (basal area) is actually positive. These situations occurred where very early *Phellinus* mortality removed susceptible species followed by very quick ingrowth of non-susceptible species (usually western red cedar or deciduous).

8.3.3 Site Ecological Factors

The relationship of site ecological variables to *Phellinus* root rot damage intensity was weak and tenuous at best. Although no ecological variables were significantly correlated to *Phellinus* damage intensity, several variables showed interesting patterns with *Phellinus* BARS-Damage Intensity Classes (BARS-DIC's). Mineral soil pH and coarse fragment content were negatively related to BARS-DIC's, and slope was positively related to BARS-DIC's. Similarly, coarse fragment content, mineral soil bulk density, porosity, pH, elevation and slope showed weak but interesting correlations to subzone, variant and site associations, which indicated the integrative nature of the site classification (Pojar *et al.* 1987 and Banner *et al.* 1990). Actual soil moisture was strongly related to mineral soil percent coarse fragment content (by volume), with the moderately-dry soils associated with the coarser soils in the *Fd-Salal*, *FdBg-Oregon grape* and *FdHw-Salal* s.a.'s, and slightly-dry soils associated with the *HwFd-Kindbergia* and *Cw-Foamflower* s.a.'s (Fig. 31 and Table 20). Interpreting the effect of any one of these variables to *Phellinus* root rot incidence, or intensity, outside of the integrative BEC system and the dominant stand

historical conditions provided little insight into the behaviour of *Phellinus* root rot. It appears that true differences in *Phellinus* behaviour may only be detected and interpreted in the framework of the system of biogeoclimatic ecosystem classification.

There was an apparent relationship of *Phellinus* root rot with the zonal or regional climate indicated by the subzone and variant models, and to a lesser degree, the soil moisture-nutrient gradient indicated by the site association model. Plant alliance and association models, though not significant, further suggested an apparent soil moisture relationship, within the resolution expected from lower precision plant-based classification units. The apparent moisture relationship with *Phellinus* root rot intensity is more quadratic, in that *Phellinus* root rot increased with actual moisture condition (class), and/or with the moisture-by-nutrient class to a maximum, then decreased (Table 20 and Figs. 76-80). The point at which root rot decreased was evident in: (a) the variant model at the CWHxm2 variant (Fig. 77); (b) the plant alliance model at the *Thuja-Achlys* p.all. (Fig. 78); (c) the plant association model at the *Thuja-Foamflower* p.a. (Fig. 79); and (d) the site association model at the *Cw-Foamflower* s.a. (Fig. 80). Curiously, western red cedar was associated with lower root rot levels; perhaps indicative of conducive or reactive stand conditions? Root rot levels in the CDFmm (driest) subzone and variant, and the *Fd-Salal* s.a., are about half that of the comparable units; the CWHxm subzone, CWHxm1 variant, or the *Fd-Hw-Salal* s.a., respectively, (Figs. 76, 77 and 80). These observations consistently hinted at actual moisture (Klinka 1984), as being a significant factor in root rot behaviour, since most sample plots were nutrient poor-to-medium in site

quality. However, that condition did not hold so firmly for the site association model, especially when other site and stand attributes were considered.

At the subzone level, five site ecological variables may have some bearing on *Phellinus* root rot incidence and intensity. Elevation, was significantly lower in the CDFmm, corresponding to its units' classification (Fig. 32), and has a significantly drier climate than the CWHxm (see Table 1, page 27). Percent slope was also significantly lower in the CDFmm which corresponds to the gently sloping, Nanaimo lowland coastal plain (Fig. 33). Percent slope has been shown to positively effect host tree root contact probabilities and subsequent spread rates of *Phellinus* root rot (Bloomberg and Reynolds, 1982 and Reynolds and Bloomberg, 1982). Thus lower mean percent slope conditions in the CDFmm may be contributing to lower levels of root rot, and conversely in the CWHxm subzone. Mineral soil bulk density (fine fraction <2 mm), and its inverse parameter, soil porosity, were respectively, higher and lower, in the CDFmm compared to the CWHxm subzone (Fig. 34 and 35). It is possible that the denser, less porous soils of the CDFmm might impede root egress and stand density, and thereby reduce root contact probabilities and consequent infection spread rates. The lower soil porosity in the CDFmm may also negatively affect respiration of *P. weirii*, thereby reducing its ability to colonize hosts. Soil pH was also shown to be significantly greater in the CDFmm compared to the CWHxm (Fig. 36). The 0.3 to 0.4 pH difference may be attributable to a higher proportion of marine and sedimentary base-rich parent materials, and/or slightly higher deciduous tree species compositions in the CDFmm. Experiments on the effects

of soil pH have shown elevated and reduced pH to adversely effect the growth of *P. weirii* (Angwin 1985). Other workers have observed similar effects with *P. weirii* (Williams and Marsden 1978, Hobbs and Partridge 1978), with *Armillaria mellea* Singh (1980), and with *I. tomentosus* (Van Groenewoud 1956, and Van Groenewoud and Whitney 1969). In summary, certain site characteristics (elevation, percent slope, mineral soil bulk density, porosity and pH) appear sufficiently different between subzones to lend some logical explanation as to their possible effects on *Phellinus* root rot incidence and intensity behaviour.

8.4 *Phellinus* Root Rot Variability in Relation to Old and Second Growth Conditions and BEC Units

A number of old and second growth stand density and species composition attributes also appeared to lend some logical explanation to the patterns and behaviour of *Phellinus* root rot. Integral to the explanation of patterns is the concept of a natural, host-pathogen dynamic equilibrium, which enables time to be considered into the behavioural patterns and not just simply snap shot conditions measured in this study.

A significant case for a dynamic host-pathogen equilibrium has been established by relating present day *Phellinus* root rot damage in second growth forests with old growth and second growth species compositions, stand densities, stand dynamics, stand origins, and via incidence-severity relationships.

A dynamic host-pathogen equilibrium for *Phellinus weirii* in coastal Douglas-fir ecosystems is expected to function as follows. The naturally occurring *Phellinus weirii* is a functionally significant and important organism in coastal ecosystems where Douglas-fir is a predominant tree species. *Phellinus* root rot behaves as a gap forming agent particularly in the early to mid-seral successional conditions (generally on the most *Phellinus*-susceptible species; grand fir and Douglas-fir, and to a lesser degree western hemlock enabling the more shade tolerant (and coincidentally less-susceptible or disease tolerant) often polyclimax tree species to occupy the site. As the susceptible host species increase in composition and density (i.e., root rot conduciveness increases) so does the ability of the pathogen to open up the stand (i.e., forming gaps). In most site associations, the chronosequence successional trend towards less-susceptible, polyclimax host species consequently acts to slow the disease' advance, hence there is an equilibrium between host and pathogen. The pathogen apparently does not have the ability to kill-off all species nor persist for periods longer than 50 years, while other less-susceptible to tolerant species have the ability to ingress into infected site conditions. Other site, climatic, fire and biotic factors may eventually return the site back to pioneer to early-seral conditions suitable for the pathogens role in gap forming dynamics and to reactive the cycle from remnant *Phellinus* inocula sources. Logging activity in these ecosystems could also play a role in reducing or increasing *Phellinus* intensity, depending on the equilibrium phase that the old growth forest was in at the time of logging, and in doing so, return the stand to pioneer early-seral conditions.

The following subsections expand on the development of the dynamic host-pathogen equilibrium postulate through discussion of the old and second growth stand conditions as they related to the incidence, severity and intensity estimates of *Phellinus* root rot measured in second growth stands. The inter-relationships between these three factors are fundamental to the mechanisms of the dynamic host-pathogen equilibrium.

8.4.1 *Phellinus* Root Rot Variability in Relation to Old Growth Stand Densities and Species Compositions Across BEC Units

The dynamic host-pathogen equilibrium was postulated in part on the basis of the following old growth stand condition observations: (a) an inverse relationship between old growth stand density (stems/ha) of Douglas-fir and *Phellinus* damage intensity (or BARS-DIC's), (b) old growth stand density (stems/ha) of western red cedar was greatest in the Low and Severe BARS-DIC's, and (c) old growth species compositions of Douglas-fir and western red cedar were, respectively, the lowest and greatest in the Severe BARS-DIC.

Old growth species compositions of Douglas-fir and western red cedar were lower and higher in the CWHxm1 compared to the CDFmm and the CWHxm2 subzone variants, respectively. Interestingly, the CWHxm1 variant had substantially higher *Phellinus* root rot damage intensity (12.88%) compared to 5.94% and 8.93%, for the CDFmm and CWHxm1 variants, respectively. The phenomena of lower susceptible host composition (Douglas-fir) countered by a higher non-susceptible host composition (western red cedar) at the variant level provided an indication of the dynamic host-pathogen equilibrium. This

phenomena at the high level of ecological classification tends to corroborate the observed trends of species dynamics in portions of stands infected with *Phellinus* root rot.

The potential old growth inoculum source composition (Douglas-fir/western hemlock species compositions--COMPFH) were shown to be virtually equal between the CDFmm and CWHxm subzones (86.4% and 84.3%, respectively). Because of this fact, the role of Douglas-fir/western hemlock stand density (stems/ha, SPHFH) was thought to be very important in a comparison of *Phellinus* root rot intensity. Stand density of SPHFH was shown to parallel the mean *Phellinus* root rot intensity in second growth stands in the CDFmm and CWHxm subzones and their respective site associations. Old growth stand densities in the CDFmm (76 stems/ha) were 59% that of the CWHxm (129 stems/ha), which corresponded remarkably well with the mean BARS *Phellinus* root rot intensity in the CDFmm (5.94%), which was 53% that of the CWHxm (11.11%). Since the old growth species compositions were virtually identical at the subzone level, it appeared that old growth stand density may be a critical factor in the transmission and intensification of *Phellinus* root rot in present second growth stands. Note, a causal relationship could not be established. In apparent contradiction to the subzone relationship, old growth stand density of Douglas-fir was negatively and significantly correlated ($p=.081$) to *Phellinus* damage intensity, while there was no significant correlation to stand density of western red cedar. If the dynamic host-pathogen equilibrium were true, then the negative correlation for old growth Douglas-fir may be explained if we assume the old growth forests were in a reactive phase of the equilibrium, that is, due to *Phellinus*-related

mortality and reduction of stand density. Similarly, old growth species composition of Douglas-fir was negatively correlated (non-significant, $p=.265$) to *Phellinus* damage intensity, and western red cedar was positively correlated (insignificant, $p=.346$).

Old growth stand density-*Phellinus* intensity relationships at the site association level were not as clear. Only a slight increase in stand density (stems/ha) of Douglas-fir from the drier to fresher site associations was observed. Stand density and species composition of western red cedar was notably higher in the site associations with the highest *Phellinus* root rot intensities; *FdBg-Oregon grape*, *FdHw-Salal* and *HwFd-Kindbergia* s.a.'s (Figs. 42 and 44). In the same site associations, the old growth species composition of Douglas-fir was notably lower. Ecologically, it was surprising to see relatively fewer stems/ha and lower composition of western red cedar in the *Cw-Foamflower* s.a., a site association in which cedar is indicated to be a climax species (Fig. 42). It appeared that western red cedar may have responded, or reacted, to the presence of *Phellinus* root rot earlier in the old growth stand life, and become a significant equilibration component of the stand. The high root rot intensity in the *FdBg-Oregon grape* s.a. is counter-intuitive given the low Douglas-fir stand density and species composition observed in that s.a. (Figs. 41 and 43). This may be explained, in part, by the fact that grand fir (*Bg*), (a very highly susceptible species, and an indicated component of the climax forest), decomposes very quickly, and was therefore absent in stump sampling.

Phellinus intensity contour plots (Figs. 45 and 46 in Section 7.3.1.5) illustrate the *Phellinus* root rot relationship with old growth stand density (stems/ha Douglas-fir (SPHFH) and stems/ha western red cedar (SPHCW)). The contour plots indicated a trough between two peaks of moderate to severe *Phellinus* root rot damage intensity. The peaks indicated high numbers of Douglas-fir and western red cedar and low numbers of Douglas-fir and western red cedar, possibly, relating to conducive and reactive stand conditions for *Phellinus* root rot behaviour, respectively. The upper peak approximately corresponds to high SPHFH (>200/ha) and moderate SPHCW (>120/ha), while the lower peak approximately corresponds to low SPHFH (<200/ha) and moderate to high SPHCW (>100/ha). The existence of the peaks and a trough in these figures further suggested the concept of a natural, dynamic host-pathogen equilibrium. Both peaks might be viewed as a conditions conducive for transmitting *P.weirii* to second growth forests; the upper peak is perhaps due to greater stand density of susceptible Douglas-fir, while the lower peak may be more the old growth reaction to *P.weirii* - related mortality. However, between the two peaks lay stand conditions where coastal Douglas-fir ecosystems appeared to approach equilibrium (very low damage intensity), over long periods of time.

In summary, the old growth stand conditions suggested that *Phellinus* root rot is likely responsive to increasing stand density of Douglas-fir/western hemlock (SPFH). That was most apparent between subzone variants. The host-pathogen equilibrium is also suggested by increasing stand density and species composition of non-susceptible

western red cedar, which generally corresponded to reduced density of susceptible species. *Phellinus* root rot appears to have contributed to a shift to western red cedar in the old growth, but not to the point of eliminating the disease. Without better knowledge of the duration of infection and inoculum distribution at the time of the second growth stand origin, it was impossible to confirm whether the old growth conditions are causal (conductive) or reactive to *Phellinus* root rot activity in the old growth. However, it is most likely that the old growth stand conditions were at least partially a result, or an effect, of some root rot induced succession of forest successional trends strongly related to *P. weirii* activity (i.e., an effect of the dynamic host-pathogen equilibrium) as well as climate, fire and ecologically induced succession.

8.4.2 Second Growth Stand Conditions

Second growth stand density and susceptible species composition factors that appear related to *Phellinus* damage intensity were; (a) first PSP measurement stand density (stems/ha ≥ 4.0 cm), (b) back-estimated stand density (stems/ha, ≥ 4.0 cm at 10 yr), (c) back-estimated Curtis' Relative Density (≥ 4.0 cm at 10 yr), and (d) first PSP measurement of *Phellinus* susceptible species composition Douglas-fir, grand fir and western hemlock ≥ 4.0 cm, FSUSINT).

Second growth stand conditions (species compositions, stems/ha, basal area (m^2/ha), and relative density) were seen to vary between site associations, and although

not significant at the 20% level, the patterns were so surprisingly similar to that of *Phellinus* root rot intensity that they could not be ignored. (See Section 7.3.2.6, p. 125). For example, the susceptible species compositions (FSUS, FINT or FSUSINT) measured at PSP establishment were highly correlated to the observed root rot levels within the CWHxm s.a.'s, (Pearson r-values were respectively: .96, -.63 and .96, but not tabled). The same does not hold true for the CDFmm s.a.'s (Table 21, p. 105). Generally, the greater the susceptible species composition, the greater the probability of *Phellinus* root rot, with the exception of the *FdBg-Oregon grape* s.a. (possibly due to the small sample size). Similarly, total stems/ha, (using either first measurement ≥ 4.0 cm, or the back-estimated to age 10 yr, ≥ 4.0 cm estimates), had virtually identical distribution patterns to *Phellinus* root rot BARS estimates (Figs. 59 and 60, p. 127). It appeared that stand density (stems/ha), was playing a real and significant role in *Phellinus* behaviour similar to that reported by Bloomberg (1990). Interestingly, the basal area estimates did not show similar relationships, (Figs. 61 and 62, p. 128), although basal areas were slightly greater in the CWHxm s.a.'s compared to the CDFmm s.a.'s. Curtis' relative stand density measures (reference age 10) did show patterns similar to *Phellinus* root rot (Figs. 63 and 64, p. 129). Evidently Childs' (1970) comment of "that beyond stand history" (i.e., of disease presence/absence), "stand density would likely be the most important factor in disease spread" appears to be true. Stand density of both the old and second growth was closely related to *Phellinus* root rot intensity at least the subzones and site associations.

8.4.2.1 Second Growth Species Dynamics: Variable-Radius Plot Sample Surveys

The dynamics of the postulated host-pathogen equilibrium were shown to be an active phenomena in the second growth by examining changes in species composition stratified by species susceptibility, diameter and disease condition classifications. Two sources of data were examined; (a) variable-radius plot sample survey data, and (b) 30-35 years of PSP records. Variable-radius plot %BAR sample survey data were examined in three ways.

The results of all three analytical approaches indicated similar trends in the relationships: (a) non-susceptible species compositions, and tree counts (hence basal areas) were greater in *Phellinus* infected conditions by about 30% compared to healthy conditions, (b) there was a greater net increase in non-susceptible species composition in *Phellinus* infected conditions (gained about 4.4%) compared to the susceptible species composition (lost about 2.6-4.4%), and (c) there appeared to be an inverse relationship between the amount of non-susceptible species composition and tree diameter size classes and *Phellinus* damage intensity (i.e., the non-susceptible species composition was greater in the small diameter classes vs. large, that is dependent on *Phellinus* intensity). In (c) above, the non-susceptible species composition shift strengthened above 20% basal area reduction (BARS) confirming that the differences in non-susceptible species composition levels were in part, time dependent, as root rot development is also highly time dependent. That is to say, the reduction of susceptible species was

countered by mensurational ingrowth (or a shift in species composition) of non-susceptible species in infected areas, which is more noticeable above the 20% BARS threshold. This was because *Phellinus* susceptible species composition drops relatively quickly, often episodically, while the subsequent ingrowth of non-susceptible species was slower, and was in response to the increased light, heat and moisture conditions enabling saplings to enter the ≥ 4.0 cm diameter limit class.

The successful attempt to estimate species succession using diameter limits "age class", and/or root rot intensity conditions to stratify tree tallies made at one measurement period, while not perfect, did allow for some interpretation of species dynamics.

8.4.2.2 Second Growth Species Dynamics: Permanent Sample Plot Records

Changes in non-susceptible and susceptible species compositions were examined using permanent sample plot (PSP) records (≥ 4.0 cm) stratified by disease condition (incidence: absence/presence) and the first and last measurement (spanning 30 to 35 yr).

Non-susceptible species compositions increased by 3.7% in *Phellinus* infected PSP's and 0.2% in healthy PSP's, for a net increase of 3.5%, while the susceptible species compositions decreased by 2.1% in *Phellinus* infected PSP's and 0.6% in healthy PSP's,

for a net decrease of 1.5%. Comparison of the PSP-based species composition shifts showed striking similarities to variable-radius %BAR sample survey data. PSP-based TIR (tolerant, intermediate and resistant) species increased by 3.7% over about 30 yrs, compared to the 4.4% to 4.46% increases in non-susceptible species composition from the %BAR sample survey data. Similarly, the PSP-based change in susceptible species of -2.1% was remarkably close to the -2.6% to -4.46% decreases seen in the variable-radius plot survey data (see Section 12.3.3.1). The similarities between the PSP and survey data lends strength to the PSP's being representative of the broader forest condition (that was sampled),-- perhaps having forest sampling implications beyond that required for evaluating root rot and species dynamics.

Changes in non-susceptible species composition over 30 to 35 yr measurements was large. The greatest increases occurred in the two zonal site associations (*Fd-Salal* and *HwFd-Kindbergia*), by over two orders of magnitude compared to the other site associations. The increases appeared somewhat related to *Phellinus* intensities. The reasons are unclear, but the following explanations are forwarded. The significant increase in *Phellinus*-tolerant, intermediate and resistant (TIR) species in the *HwFd-Kindbergia* zonal s.a. may be explained by the climatic, ecological, successional, and perhaps pathological factors that are integrated to form the basis of site association taxon names. The site association taxon would indicate that Douglas-fir is a predominant early seral species on *HwFd-Kindbergia* s.a.'s, with successional trends towards a stable climax vegetation comprised of western hemlock and Douglas-fir. Furthermore, Douglas-fir,

although dominant in the climax condition, becomes secondary to western hemlock (the latter substantial component of TIR species). Given the differential *Phellinus* susceptibilities to infection of Douglas-fir and western hemlock (Wallis 1976, Childs 1963, 1970, Filip and Schmidt 1979), and the fact that the *HwFd-Kindbergia* s.a. had the greatest incidence and intensity of *Phellinus* root rot, it is suggested that root rot is playing a major biogenic successional role in reducing the early seral component of Douglas-fir to a lower secondary level, as suggested by the site association taxon. A less effective case can be built for the *Fd-Salal* s.a., but the fact remains that stand density does drop by some means (suggested to be *Phellinus* root rot), and that there is an increase in species diversity, or a drop in Douglas-fir composition, although the site association remains essentially pure (>80%) with other minor species mixes (often deciduous).

It is possible that the more moderate environmental site conditions (e.g., light, heat or moisture) typical of zonal site associations may be contributing to the larger increases in non-susceptible species. The CDFmm and *Fd-Salal* units are warmer and have lower stand densities on average than the CWHxm2 and *HwFd-Kindbergia* units, although the latter two units are significantly moister. Considering that root rot incidence and intensity estimates in the CDFmm unit are about half that of the CWHxm2, it follows that light and heat likely contribute more to the release and mensurational ingrowth of TIR species than moisture.

8.4.2.3 Summary of the Natural, Host-Pathogen Dynamic Equilibrium Model

A model to explain the dynamics of species compositions can be postulated from the ecosystems sampled. In healthy, root rot free conditions, the proportion of non-susceptible to susceptible species remained fairly static, with a tendency to slight increases in non-susceptible species typical of the chronosequences. In *Phellinus* root rot infected conditions, there was a substantial reduction of susceptible species with a low proportion (replacement rate) of small diameter class ingrowth. This was countered with higher a proportion of non-susceptible species entering the lower diameter class as compared to healthy conditions. In other words, healthy stands over time, shift towards a higher composition of non-susceptible species as the ecological model would indicate, but at a less dramatic rate than in infected stands. *Phellinus* root rot acts as a biogenic successional agent removing *Phellinus* susceptible species (generally pioneer to early shade intolerant seral species) and favouring their replacement with *Phellinus* tolerant, intermediate and resistant (often shade tolerate, late-seral to poly-climax species). Assuming that this ecological process is consistent over time, shifts to increasing proportions of non-susceptible species would also have occurred in the old growth forests barring major climatic change. Although the old growth stump survey data was not dramatic in illustrating the root rot related successional pattern (i.e., increasing red cedar composition), the trend nevertheless appears strong enough to support the hypothesis of species dynamics as related to damage intensity, with strong implications of a dynamic host-pathogen equilibrium.

The similarity in forest successional trends in old and second growth coastal Douglas-fir ecosystems suggests a natural, dynamic host-pathogen equilibrium is at play. A host-pathogen equilibrium of this order and time-scale would go a long way towards explaining why *Phellinus* root rot has not covered the whole Douglas-fir forest ecosystem and brought it to a non-productive condition. Furthermore, the suggestion of a dynamic host-pathogen equilibrium provides forest managers and silviculturists with direct evidence that management prescriptions using less-to-non-susceptible tree species, will aid in reducing long term damage to *Phellinus* root rot, although not necessarily maximizing stand or forest timber (volume) productivity.

The existence of a dynamic host-pathogen equilibrium and very high level of *Phellinus* root rot incidence in coastal Douglas-fir ecosystems (87% of 1ha sample surveys, 35% of 0.04 ha PSP's and 26% of variable-radius plots), suggests that *Phellinus* root rot is a common and significant biological factor in the ecological functioning of these ecosystems. As such, the significance of *Phellinus* root rot and the host-pathogen equilibrium in the coastal Douglas-fir ecosystems should be *strongly considered* in all aspects of forest resources management (be it stand-specific or forest level management prescriptions) for timber, wildlife, recreation, or site productivity-potential assessments for land-use resource allocations.

It is clear from this study that the role of "pathogens" in forested ecosystems needs to be more clearly evaluated so that our management of these ecosystems does not

create an imbalance in the natural, dynamic host(s)-pathogen(s) equilibrium(s). Management actions favouring disequilibrium, will cause either reduced stand/forest productivity of the pathogens' preferred hosts, or require great efforts to eradicate the pathogen inoculum from the site. Allowing the dynamic equilibrium to occur naturally will reduce stand and forest productivity over time under volume maximization management objectives, but in doing so will provide a more tree species (bio-) diverse ecosystem. A balanced "production-forest" management approach should strive to use the principles of shade-tolerant species succession ingrowth into *Phellinus* infected sites (as seen in the dynamic host-pathogen equilibrium). This should be achieved by shifting to alternate less-susceptible species for regeneration and stand tending prescriptions, thus reducing the amplitude of the host-pathogen equilibrium. Since stand density also appears strongly related to enhancing *Phellinus* root rot intensity, regeneration and stand tending prescriptions should consider managing to lower densities, that are in principle less conducive to *Phellinus*, and thereby reducing crop risk. And, as unlikely as it is that fire will be used as a post-harvest *Phellinus* control treatment, fire appears to have had some effect in controlling *Phellinus* root rot, as seen in the next section.

8.5 The Effects Of Stand History (Logging And Burning) On The Behaviour Of *Phellinus* Root Rot

Present stand age was shown to be significantly different (all p-values < .088) between stand origins (Figs. 74 and 75), with root rot intensities paralleling mean stand age. In this study, stand age was not considered to be significantly correlated to damage

intensity (BARS), but this correlation is highly suspicious, since in most other root disease studies, stand age is highly and positively correlated, and important for prediction of damage intensity. There seems little doubt that the effect of stand age on *Phellinus* root rot intensity in this study is a positive one, albeit not strong, and therefore explains a substantial amount of the variation in damage intensity. Beyond the substantial role stand age plays, I have sought to establish if any ecological factors play a role in the variation of *Phellinus* root rot intensity between stand origins.

Several questions arose that after some deliberation lead to some explanation of the *Phellinus* root rot trend seen in these stand histories. What elements of *P. weirii* control are suggested by the logging-only origin as compared to stands of wildfire origin? What might the effect of slashburning be compared to wildfire? Are interactions between logging and slashburning suggested by the data? How do past and present stand densities and species compositions relate to present infection levels? The next several subsections will address these questions.

8.5.1 Evaluating The Effects Of Logging On *Phellinus weirii* Survival

The fundamental difference between *Phellinus* infected stands that are logged *versus* not logged (or wildfire killed) is that of cut stump surfaces. How does *P. weirii* survive to reinfect the planted or naturally regenerating crop, and what is its natural *P. weirii* decay curve?

Phellinus weirii is not considered to be an aggressive competitor, and is not able to colonize wood previously decomposed or inhabited by other microorganisms (Hansen 1979). When a *Phellinus* colonized tree dies (or is logged), the fungus can remain viable ectotrophically for 40 to 50 yr on old growth Douglas-fir (Hansen 1979), or over 100 yr when it is enclosed by bands of resin-soaked wood (Buckland *et al.* 1954, Wallis 1976), or for shorter periods when it establishes zone lines around colonized areas, thereby excluding antagonistic microorganisms (Nelson 1964, 1967, 1973, 1975). Zone lines are darkly pigmented sheets of swollen hyphal tissue (Nelson 1967). Li (1983) showed the pigment in *P. weirii* zone lines to be tryptophan-melanin in nature, and confirmed that it is important for the prolonged survival of *P. weirii* in infested stumps and roots. Li (1983) also observed the zone line pigment to inhibit two microorganisms antagonistic to *P. weirii* (*Bacillus* spp. (Hutchins 1980), and *Streptomyces griseoalbus* (Rose *et al.* 1980)) but, he did not find it inhibitory to *Trichoderma viride* Pers., an antagonistic fungus common in soil and wood. The antagonism of various *Trichoderma* spp. to *P. weirii* has been demonstrated by Nelson (1964, 1973, 1975) and by Goldfarb (1985, 1986) and (Goldfarb *et al.* 1989). Nelson and Thies (1985, 1986) demonstrated the ability of *Trichoderma viride* to colonize stump tops and with increasing success in stumps with advanced decay. Goldfarb (1985, 1986) has shown *Trichoderma* spp. to be slow, but well adapted invaders of *P. weirii* infected stumps and root systems, in nature. These workers suggest that *Trichoderma* spp. are likely effective biocontrol candidates. Nelson is continuing biocontrol research of *P. weirii* primarily with *Trichoderma* spp. using various types of stump top-or-side delivery systems (Nelson and Thies 1985, 1986, and Nelson

1990). Observations from the literature consistently point to the antagonistic effect of *T. viride* and its biocontrol potential. This suggested that the lower levels of *P. weirii* observed in logged versus wildfire originated stands may, in part, be due to a slow displacement of *P. weirii* by stump top invading antagonistic *Trichoderma spp.*

8.5.2 Evaluating The Effects Of Slashburning (& Logging) On *Phellinus weirii* Survival

Survival of infective *P. weirii* has been shown to decrease to near zero over 50 years (Hansen 1979), but with only a weak positive correlation to stump size and decay column condition (% hollowness) in stands logged 50 years previously. Notably, there is no indication of fire history in Hansen's (1979) study. Tkacz and Hansen (1982) have shown the dependence of second growth root disease distribution on the previous rotation, and interestingly their (1982) study sites were burned after harvest.

From personal observations, and discussion with colleagues (Reynolds 1990, and Bloomberg 1990a), it is very common to find old growth stumps completely burned out to a root bark shell in stands of logged-and-burned origin. The intensity and uncontrolled duration of much of the past railway logging slashburns likely provided some level of *P. weirii* control, with increasing effectiveness in stumps with sizeable *P. weirii* decay columns. The assumption made in the logging-and-burning scenario is that fire entered the stump/root system via the cut stump surface and burned out the root's woody tissues, likely baking ectotrophic *P. weirii* to temperatures beyond its tolerance, thus

sharply reducing its surface area and infective viability. The upper limit to thermal tolerance for *P. weirii* is in the range of 39°C plus (Nelson and Fay 1974, Angwin 1985), which burning root systems would generally exceed by an estimated 50 to 100°C (Parminter 1991). In support of this postulation, Wright and Tarrant (1958) found the occurrence of ectotrophic mycorrhizae decreased on logged and burned Douglas-fir sites, with ectotrophic mycorrhizal recovery depths increasing with burn severity.

Prescribed fire occurrence is also known to affect populations of antagonistic microorganisms in soil (Parmeter 1977). Actinomycete populations have been shown to increase sharply on severely burned Douglas-fir sites (Wright and Tarrant 1957). The actinomycete, *S.griseoloalbus*, has been shown to be antagonistic to *P.weirii* (Rose *et al.* 1980). Reaves (1985), showed that prescribed fire increased the soil cation concentration from forest ash leachate, which has been shown to have a negative effect on the *in vitro* growth of *Armillaria ostoyae* (Reaves *et al.* 1984). Furthermore, fire ash leachates are known to positively effect *Trichoderma spp.* which in turn reduce the growth and rhizomorph formation of *A. ostoyae* (Reaves *et al.* 1990). Since several *Trichoderma spp.* antagonistic to *P. weirii* are known to occur in coastal Douglas-fir forests soils (Nelson 1964, 1969), extensive work is underway to investigate biological control methods using antagonistic *Trichoderma spp.* in the U.S. Pacific Northwestern states, (Nelson 1981, Goldfarb 1985, 1986, 1989a, 1989b and Nelson and Thies 1985, 1986 and Nelson 1990).

It is possible that soil cation concentrations were raised following fires in the old growth logging slash. In that scenario, *P. weirii* survival and infectivity would be reduced directly by decay column burning, and possibly through enhanced soil cation effects on antagonistic fungi, thus lending explanation to why *Phellinus* root rot levels (BARS) are lowest in stands of logged-and-burned origin. As for wildfire origin stands, it was unlikely they had similar fire intensities as compared to the logged-and-burned origin since total stand densities of stems/ha Douglas-fir and western hemlock (SPHFH), and western red cedar (SPHCW) were half that of the logged-and-burned stands, and ground fuels were most certainly less. Thus the impact of fire on *Phellinus* was likely less in wildfire origin stands than in logged-and-burned stand origins, hence, the highest root rot intensities were in stands of wildfire origin.

Although the mean *Phellinus* (BARS) intensities between logged-only and logged-and-burned was not much different, 10.54% and 8.49% respectively, the trend should not be ignored. Note that beyond age, fire is the only factor that is different. Although an interaction of slashburning and logging was likely, fire following old growth logging appears to have had a significant effect in controlling *P. weirii*.

8.5.3 Evaluating The Effects Of Wildfire On *Phellinus weirii* Survival

In wildfire origin stands there were of course no man-made stumps; thus, regardless of the *P. weirii* infection condition in the old growth, wildfire might only reduce inoculum

loads in the odd natural stump, and possibly through changed soil chemistry and its effects on fungi antagonistic to *P. weirii* (as postulated above). Studies on the fire and *P. weirii* ecology of mountain hemlock forests of Oregon suggest that *P. weirii* infestations may enhance the probability of wildfire because of increased fuel loadings and ladder fuels (Dickman and Cook 1989). In this study, wildfire origin stands had less than half the old growth stems/ha of Douglas-fir and western hemlock (SPHFH), more stems/ha of western red cedar (SPHCW), and more than double the species composition of western red cedar (COMPCW) than stands of other origins (Table 21, pg. 105). These facts, combined with the observed negative correlation between BARS damage intensities and SPHFH, and a positive correlation with COMPCW observed in this study, lends support to probable high *P. weirii* infection levels in the old growth forests preceeding the wildfires. Dickman and Cook (1989) also suggest that, "if larger roots harbor mycelia for a longer time, then older stands that are destroyed by fire are more likely to leave inoculum capable of generating subsequent reinfestation than are younger stands". Stand density is known to have dramatic effects on stem sizes (McArdle *et al.* 1961), and hence stump and root systems. Since total old growth stems/ha in wildfire origin stands were less than half that of other origins, it is not only likely that the trees were larger in the wildfire origin old growth forests, but if infected with *P. weirii* would pose a greater inoculum potential.

Based on the observations of Childs (1970), Tkacz and Hansen (1982) and this study data, one can postulate that the distribution and infectivity of *P. weirii* inoculum sources

might be higher in wildfire origin stands as compared to the other origins, thus effecting the higher levels of infection observed in today's second growth forests for the following reasons: (1) a lower likelihood of wildfire directly affecting ectotrophic or endotrophic inocula on standing trees during a wildfire, (2) the increased probability of wildfire in areas of *P. weirii* infestation due to disease effects on stand structure/fuel loadings, (3) the likelihood of larger stem and root systems due to lower stand density (wildfire SPHFH 63 stems/ha vs. logged, logged-and-burned 130 stems/ha), therefore potentially larger and longer-living inoculum sources, and (4) a lower likelihood of wildfire producing as much ash and cation enhanced leachate (compared to post old growth harvest slash burns), which may negatively affect *P. weirii* by its beneficial effects of ash on fungi antagonistic to *P. weirii*.

In summary, the most likely explanation for the variability of *Phellinus* damage intensities (wildfire (15.45%), logged-only (10.54%), and logged-and-burned (8.22%)), are: (1) the significant and positive differences in present stand ages; (2) the effect of the very intense slashburning that followed much of the old growth (railway) logging, and its lethal effects on *Phellinus* decay columns via the cut stump surface and to a lesser extent on below-ground stump and root surface ectotrophic *P. weirii*; (3) the absence of cut stump surfaces in stands of wildfire origin; (4) the likelihood of lower intensity fire at or close to the ground level; (5) the stems/ha of Douglas-fir old growth stumps in wildfire origin stands were half (63) that of the logged-origin stands (133), combined with the western red cedar was less than half (12) that of the logged-origin stands (24), theoretically

indicating a more severe *Phellinus* damage intensity condition.

The frequency of occurrence of stand origins for the 139 sample survey locations showed that 69% originated after logging-and-burning, 21.6% after wildfire, and 9.4% after logging-only. The origin frequencies, while not providing any particular explanation in themselves, provided an interesting perspective to the Douglas-fir ecosystems on southeastern Vancouver Island.

8.6 Predicting Biogeoclimatic Unit *Phellinus* Root Rot Hazard And Risk

8.6.1 *Phellinus* Root Rot and the Site Association Taxon Model

The search for direct link correlations of site ecological variables to *Phellinus* root rot behaviour appears very uncertain. With the variability of ecological variables and parameters so high, an interpretation of *Phellinus* relationships at the site association level was attempted using a combination of past and present stand characteristics, *Phellinus*-host susceptibilities, predicted vegetation succession patterns (chronosequences) that are connoted in the site association taxon (names), and the concept of the natural, dynamic host-pathogen equilibrium. The relevancy of this approach is based on the fact that vegetation is a good measure of an ecosystems' productive potential as seen in the use of indicator plant species for identification of ecosystems (Klinka *et al.* 1989), and the corresponding major role of vegetation (plant) classification in the BEC system (Pojar *et*

al. 1987). Site association taxon (names) define potential climax vegetation (i.e., predominant tree(s) and ground cover) for a site that is characterized by a uniform climate (Banner *et al.* 1990). For example, the *Fd-Salal* s.a. connotes a major forest cover of Douglas-fir with a salal ground cover as the potential climax vegetation. The successional phases a s.a. goes through to reach this predicted climax condition are known as chronosequences (they are not clearly documented at this time).

Consider the coastal Douglas-fir ecosystem as a whole. It is a complex of tree species compositions of varying *Phellinus*-susceptibilities, in a variety of site and stand conditions, shaped by a variety of fire and harvest histories, and is in various successional phases and pest conditions. The success of measuring these factors, their interactions and their relationships to *Phellinus* root rot incidence, severity and intensity levels has not yet borne conclusive answers, as this study shows. Site classification, and the site association taxon model in particular, provided the most integrative tool for comprehending most of the sources of zonal (climate), plant and site variation, with the possible exception of *Phellinus* root rot.

An attempt to predict the relative *Phellinus* root rot incidence and intensity (risk) using the site association taxon model, is further predicated on the long term predictability of a s.a.'s chronosequence to propagate and maintain *Phellinus* inoculum, which is itself based on knowledge of the relative susceptibilities to *P. weirii* of the s.a. taxons' climax tree species vegetation. Other factors such as fire and harvest history, and past and

present stand conditions (species composition and stand density), could serve to adjust the scale of the relative incidence or intensity (risk) in order to compensate for stand conditions believed to be conducive-to or reactive-to *Phellinus* root rot, within the context of the dynamic host-pathogen equilibrium. Critical to determination of risk is the host-pathogen equilibrium phase of the preceding stand at the time of origin of the second growth forests, (i.e., estimation of previous stand conditions as they relate to probabilities of *Phellinus* inoculum carry-over). These phases are: (1) conducive, or highly-susceptible species phase, (2) reactive, or less-susceptible species phase, or (3) *Phellinus* root rot equilibrium phase. Over or underating the *Phellinus* risk is highly probable if the rating is based on past conditions only; knowing the potential condition is the essence of risk rating on an ecological basis.

The site association taxon model for *Phellinus* root rot behaviour is as follows. Site associations with grand fir (Bg) or Douglas-fir (Fd) as a leading species are considered to be the most conducive and have the highest probability to propogate *Phellinus* root rot to the upper limits of an implied dynamic host-pathogen equilibrium. Climax species combinations of lower susceptibility to *Phellinus* (e.g., western hemlock (Hw), lodgepole pine (Pl), western white pine (Pw) or western red cedar (Cw)) serve to impede or reduce root rot levels. In this context, the site association model proves to be very accurate in predicting *Phellinus* root rot (see Fig. 30, pg. 98). Within a subzone variant (e.g., CDFmm), the *Fd-Salal* had lower root rot levels than the *FdBg-Oregon grape* with two susceptible species. In the CWHxm variant the transition from *FdHw-Salal* to *HwFd-*

Kindbergia s.a. reduces the highly susceptible component (Douglas-fir) from a primary-major species to a secondary-major species, thus reducing the probability of sustained high damage. The observed BARS sample estimates show this, but when adjusted for an age interaction, the *HwFd-Kindbergia* s.a. was predicted (regression model) to have marginally higher *Phellinus* intensity. This phenomena could be possible because a greater *Phellinus* intensity may be required to kill-out the Douglas-fir component in order to achieve the *HwFd* climax forest cover condition predicted by the site association taxon. The *Cw-Foamflower* s.a. will sustain even lower root rot levels due to low levels of susceptible species in a climax condition. Notably, the *Cw-Foamflower* s.a. had a relatively low stand density (stems/ha) of old growth western red cedar, which is contrary to the s.a. taxon. It is very likely that this s.a. had not yet achieved its potential climax forest conditions at the time of the old growth harvest as its condition appears to be in a very conducive, or highly susceptible species phase.

In summary, a method for estimating the hazard and risk of *Phellinus* root rot for site associations has been demonstrated through the integration of, (i) present-day disease incidence and intensity, (ii) principles of a host-pathogen behaviour, (iii) a postulated, natural, dynamic host-pathogen equilibrium (conductive, reactive and equilibria phases), and (iv) the predicted patterns of ecological succession (chronosequences) to the vegetation potential within the BEC system of site classification. The implications for estimating biogeoclimatic unit pest hazard and risk in this manner is enormous, since much of the knowledge exists today.

8.6.2 Multiple Regression Models

Empirically-based multiple regression models were estimated to provide primarily a descriptive, and secondarily a predictive behaviour of *Phellinus* root rot intensity within biogeoclimatic units in order to develop a disease hazard and risk classification (see Section 8.6.3.). Models for each biogeoclimatic unit included a stand age-biogeoclimatic unit interaction term. Stand age, although not significantly correlated to *Phellinus* root rot intensity in this study, does appear to have some relationship to *Phellinus*, and is generally considered to be a strong determinant in detection, assessment and prediction of *Phellinus* behaviour. None of the root rot behaviour models described enough of the damage intensity variation for reliable stand-level prediction, but all the models did describe the general relationships within and between the biogeoclimatic units reasonably well. Generally, all the models were similar. Interestingly, the relative damage intensities are nearly identical to those observed in large-scale root disease surveys done by the BC Forest Service in the same ecosystems in 1982-83 (Beale 1987). Furthermore, the models appear to describe the disease behaviour reasonably and support the interpretations of *Phellinus* root rot behaviour in the coastal Douglas-fir ecosystems *vis a vis* the postulated dynamic host-pathogen equilibrium, and more importantly the observations made by the author from field experience and other disease analyses (Beale 1989b).

All *Phellinus* intensity models for the biogeoclimatic units were compared at reference

age 80 yr (Figs. 76-80) and were used for development of an ecologically-based *Phellinus* root rot hazard and risk classification, see Section 8.6.3.

8.6.3 *Phellinus* Root Rot - Coastal Douglas-fir Ecosystem Hazard (Susceptibility) and Risk Classification for Southeastern Vancouver Island

After a sober review of all the available data, models postulations, a first approximation of *Phellinus* root rot hazard and risk for Douglas-fir ecosystems of southeastern Vancouver Island was made (Table 44). Recall that *hazard* is an assessment of tree, stand forest and environmental conditions which are conducive to pest infestation without reference to probability (i.e., hazard is a measure of susceptibility). *Risk* is the probability and predicted intensity of an infestation. Hazard is in part a function of risk. The classification presented is heavily based on professional judgement and a crude classification of stand-based disease incidence ($<.25$ is Low-Medium and $\geq.25$ is Medium-Severe), and damage intensity based on prediction of BARS at 80 yr is, ($\leq 6\%$ is Low, $>6\leq 10\%$ is Medium, and $>10\%$ is Severe). Individual ecological variables/characteristics and stand attributes could not be considered in the classification, although as discussed earlier, many if not all variables/attributes (biological, geological and climatological) appear to be well integrated into the biogeoclimatic units and therefore do not need to be uniquely identified and accounted for.

TABLE 38 <i>PHELLINUS</i> ROOT ROT HAZARD AND RISK ¹ CLASSIFICATION FOR DOUGLAS-FIR ECOSYSTEMS ON S.E. VANCOUVER ISLAND			
BEC UNITS	Low	Medium	Severe
PLANT ALLIANCE <i>Pseudotsuga-Mahonia</i> <i>Tsuga-Mahonia</i> <i>Thuja-Achlys</i>	X	X	X
PLANT ASSOCIATION <i>Pseudotsuga-Arbutus</i> <i>Pseudotsuga-Mahonia</i> <i>Tsuga-Mahonia</i> <i>Thuja-Foamflower</i>	X X	X	X
SUBZONE <i>CDFmm</i> <i>CWHxm</i>	X		X
SUBZONE VARIANT <i>CDFmm</i> <i>CWHxm1</i> <i>CWHxm2</i>	X	X	X
SITE ASSOCIATION <i>CDFmm-Fd-Salal</i> <i>CDFmm-FdBg-Oregon grape</i> <i>CWHxm-FdHw-Salal</i> <i>CWHxm-HwFd-Kindbergia</i> <i>CWHxm-Cw-Foamflower</i>	X	X X	X X
<p>¹ Predicted Incidence (stand-parameter-diseased basis) at 80 yr Low <.25 or 25% Medium <.25 or 25% / ≥.25 or 25% Severe ≥.25 or 25%</p> <p>Predicted Damage Intensity (stand-based %Basal Area Reduction BARS) at 80 yr Low ≤6% Medium >6 ≤10% Severe >10%</p>			

8.7 Damage Appraisal Of *Phellinus* Root Rot On Growth And Yield Of Second Growth Douglas-fir Ecosystems

8.7.1 Yield Comparisons Within Selected Installations

Comparison of growth and yield within selected PSP installations (chosen for near-identical site and stand conditions at PSP establishment) indicated some dramatic reductions in the yield of *Phellinus* infected PSP's. Compared to healthy PSP's *Phellinus* infected PSP's generally have mortality (up to 4.2 times greater), retain only 40% to 80% of the basal area increment and retain only 69% to 83% of the volume increment. Greater reductions to stems/ha and lesser increments of basal area and volume were attributable to greater *Phellinus* damage intensity in the PSP's. Interestingly, the growth rates in infected PSP's, except in the cases of the most severely infected PSP's, appeared to be equal to or better than the healthy PSP's. This response was likely attributable to two factors: (i) increased light and moisture conditions for the residual (remaining) trees, perhaps similar to the *Phellinus* root rot related natural thinning responses reported by Oren et al. (1985), and (ii) increased mensurational growth rates for the residual trees and ingrowth rates of shade tolerant, non-susceptible species (i.e., the latter being part of the 3.5% net response of *Phellinus* non-susceptible species ingrowth shown in *Phellinus* infected PSP's, ...a resultant of the dynamic host-pathogen equilibrium described in this study).

8.7.2 Yield Comparisons Using the Chapman-Richards VAC Model

Yield models using the Chapman-Richards VAC growth model were calculated for the combined site associations *FdHw-Salal* and *HwFd-Kindbergia* (nearly all of the CWHxm subzone PSP's). Model estimates for healthy and infected PSP conditions (≥ 4.0 cm), fitted yield expectations very well. The estimated yield reduction and the form of the *Phellinus* infected curve (increasing gradually, virtually from regeneration) conformed well to observations from field and survey work, and simulations using the TASS-ROTSIM model. The healthy PSP yield at 80 yr is estimated at 732.9 m³/ha, and the infected PSP yield at 668 m³/ha, for an 8.86% yield reduction.

The multiple linear regression *Phellinus* intensity model estimated percent basal area reduction for site associations (all species, ≥ 4.0 cm; NSBAR) at 80 yr to be 12.68%, which compared well with the 8.86% yield reduction from the Chapman-Richards VAC.

8.7.3 Growth and Yield Comparisons Over Site Height

8.7.3.1 All Data-No Stratification

A growth difference model predicted a positive linear relationship between annual volume increment (≥ 4.0 cm) and annual site height increment for healthy and *Phellinus* infected PSP's. Infected PSP's grew more slowly by 4.4% to 11.7% over the range of 0.1

to 0.9 m annual site height increment, respectively. Assuming that site height measurements are independent of root rot effects in PSP's, the pattern of growth reduction indicated that site quality has a positive effect on growth reduction. An alternative and more likely assumption is that, site height measurements were somewhat negatively affected by *Phellinus* root rot. If so, then growth reductions were inversely related to site height increment, with growth reductions ranging between 17.33% to 7.48% for annual site height increments of 0.1 to 0.9 m.

A recommendation for growth and yield programs would be to carefully and regularly assess site height tree health, and attempt to have alternate measurement trees in or near the PSP to ensure the integrity of site height measurements.

A quadratic volume-site height model (≥ 4.0 cm) predicted an increasing yield loss in *Phellinus* infected PSP's compared to healthy PSP's. Losses began immediately following regeneration, but rose noticeably from 4.0% at site height 10 m to 5.5% at 35 m site height (or approximately 80 yr). The 5.5% yield reduction seemed low compared to the ≥ 4.0 cm, all-species NSBAR basal area reduction survey estimate of 8.28%, but it was likely due to several factors: (i) the %BAR survey estimates excluded all living symptomatic trees (the mean %BAR severity parameter was .30 or 30% reduction), therefore the intensity of "basal area reduction damage" was greater than the actual volume loss as measured in the PSP's, (ii) the generally "damage-free" establishment conditions for growth and yield PSP's mean that *Phellinus* infection is in most cases

making slow moving (on average 0.3 m/yr) incursions into PSP's well after PSP establishment, (iii) *Phellinus* incidence appears to be sampling unit plot size dependent, and since the PSP's are smaller (.04 ha) than sample surveys (1 ha), the probability of incidence and hence intensity is lower in the PSP's compared to the %BAR surveys, and (iv) the %BAR surveys were all conducted during the summer of 1987, while only 20% or 1/5th of the PSP's would have been measured in 1987 (the growth and yield data used in this analysis is current to the 1989/90 dormant season); perhaps 66% of the PSP data adequately reflects the root rot growth and yield conditions observed in 1987 %BAR surveys. A second explanation of the difference between the two estimates is that the quadratic volume-site height model is constructed over a wide range of stand densities. Volumes across sites and ages are only considered equivalent for stands of similar initial densities (Mitchell and Cameron 1985). The condition mentioned in (i) above, is one of the most significant factors in the disparity between the PSP and %BAR estimates of yield reduction. With these factors considered, the %BAR damage intensity estimates might be reduced to more closely approximate the percent basal area reductions estimated from a yield curve analysis of the PSP data. The conclusion then, is that the %BAR sampling method very nearly estimated the actual volumetric (PSP-measured) losses that occurred in the coastal Douglas-fir ecosystems of southeastern Vancouver Island. This also suggests that the set of growth and yield PSP's examined as part of this study satisfactorily reflected the damage intensity found in the areas immediately surrounding the PSP's.

Given that one of the largest factors in explaining the differences between the %BAR and the PSP-based estimates is the experimental error introduced in the %BAR sampling design (i.e., the exclusion of visibly symptomatic trees in the tree tallies), the author suggests that all symptomatic trees be counted in %BAR tree tallies. That would allow the %BAR estimate to be made not only on standing healthy but also standing infected basal area and dead and downed infected, separately or combined. These changes should be incorporated into future percent basal area reduction %BAR type sampling methodologies. The use of site height in modelling suggested that yield models be constructed for the three stand origin density classes.

8.7.3.2 Growth and Yield: All Data, Stratified by Stand Density Classes (stems/ha at age 10 yr)

8.7.3.2.1 Less than 1 000 stems/ha

A quadratic yield model estimated yield reduction to be 8.25% for infected PSP's at a site height of 35 m (or approx. 80 yr), which compared very well with the linear regression model estimate of percent basal area reduction (NSBAR) of 8.88%.

8.7.3.2.2 1 000 - 1 999 stems/ha

A yield model estimated yield reduction to be 8.63% for infected PSP's at a site height of 35 m (or approx. 80 yr), which compared very well with the linear regression

model estimate of percent basal area reduction of 8.96%.

8.7.3.2.3 2 000 - 4 999 stems/ha

A yield model estimated yield reduction to be 4.97% for infected PSP's at a site height of 35 m (or approx. 80 yr), which does not compare well with the linear regression model estimate of percent basal area reduction of 11.28%. This variance is likely due to a smaller sample size and widely ranging initial densities and ages.

The relevance of stratification into stand density classes was clearly borne out in the results of the first two density classes. For establishment densities below 2 000 stems/ha the yield models were amazingly similar between stand density classes, and also provide near-identical estimates to the NSBAR percent basal area reduction estimates for these strata. Beyond 2 000 stems/ha (actually 2 300) the data were few and scattered, dramatically affecting the analysis. It is conceivable that the damage is not yet so great in the PSP's with high establishment densities, in part, because gap formation is beneficial to the residual trees and/or the shade tolerant less-susceptible species are achieving increasing mensurational ingrowth rates.

Overall, this study has conclusively demonstrated that modelling of growth and yield PSP's to produce growth and yield functions that reflect disease incidence (i.e., presence or absence of *Phellinus* root rot) and stand density strata is possible. Several analyses

have all demonstrated similar growth and yield reductions through simple PSP-to-PSP comparisons, the Chapman-Richards volume-age growth models, quadratic volume-site height models and growth difference models. In all analyses the within strata variability is so great that statistically significant growth and yield differences are impossible to detect at this point in time, although the trend towards continuing and worsening yield reductions appears set. Continued analyses of this sort should be conducted periodically, with the following considerations: (i) ensure the highest degree of ecological and stand condition-at-establishment fidelity as possible (it does not matter that the stand conditions today are different as long as they started from near-identical site quality, species composition and stand density conditions), (ii) *Phellinus* infected PSP's (or any other damage condition) should be stratified on the basis of within-PSP severity or intensity. Furthermore, if forest level damage impact assessments are attempted using this technique, then ensure the appropriate proportional composition of healthy to *Phellinus* infected PSP's is made in the determination of a yield function. The mix of PSP's should be proportional to the amount of damage severity or intensity observed in the forest, as determined from PSP sized samples (.04 ha, and as of 1990, .10 ha), as incidence and intensity are sample size dependent.

9.0 SUMMARY

Variable-radius plot sampling and the percent basal area reduction (%BAR) parameter estimate proved to be an effective estimator of *Phellinus* root disease damage. The technique of sampling for incidence and severity to estimate %BAR damage intensity showed that root disease incidence was a larger predictive factor of damage intensity than severity.

Sampling for disease incidence (land-area-diseased vs. stand-parameter-diseased) showed the stand-based method to be more sensitive to damage incidence at low levels of land-based incidence. The estimates were highly correlated ($r = .82$), but the estimates only stabilized when the incidence was above .35 (35%). Overall, the mean stand-based incidence was .263 (26.3%) as compared to the mean land-based incidence of .168 (16.8%).

Sampling for disease severity (using two separate diameter limit tallies in the variable-radius plot sampling), allowed diameter-dependent views of damage intensity and stand dynamics to be made. Damage intensity was always greater in the large diameter class ($\geq 12.0/17.5$ cm) compared to the ≥ 4.0 cm diameter class. Mean damage severity was .30 (30%) basal area reduction at points incident with *Phellinus* relative to healthy points, although severity was highly variable within 1 ha sample survey units. A severity - intensity relationship showed severity to increase with incidence, but on average it did not exceed .5 (50%) basal area reduction. This would appear to indicate stand productivity

resilience in the presence of *Phellinus* root rot. Through a method of subtraction, *Phellinus* host susceptibility classification, and disease incidence stratification, it was found that the less- to non-susceptible species compositions (particularly in the smaller diameter class) were greater at infected points than at healthy points. This also provided some evidence of *Phellinus*-induced succession and led to the postulation of a natural, dynamic host-pathogen equilibrium. Similarly, the less- to non-susceptible species composition in *Phellinus*-infected permanent sample plots (PSP's) was found to increase by a much larger relative amount compared to the susceptible species in healthy PSP's.

Disease incidence estimates increased with sampling unit "effective sampling area"; from .005 ha fixed-radius, to "area-less" variable-radius (approximately .027 ha) plots, 0.04 ha PSP's to the 1 ha %BAR sample survey units. The incidence in the 1 ha units was identical to that found in 20 ha sample units in a separate root disease study in the same area of Vancouver Island. It is likely that 1 ha samples are close to the minimum sampling size required to accurately estimate *Phellinus* root rot incidence at the forest level in coastal Douglas-fir ecosystems.

Incidence - intensity linear relationships were shown to be fairly strong, and are potentially a very effective way of estimating damage intensity from binomial (presence/absence) incidence estimates alone. However, both land- and stand-based incidence estimates overestimated the observed intensity by 0.5 to 2.6 times. This result strongly suggests that stand damage intensity sampling is best if a measure of incidence and severity are combined, such as in the %BAR parameter estimate technique.

Damage intensity varied between levels of the zonal (climatic), plant and site classifications of the system of Biogeoclimatic Ecosystem Classification (BEC). The most significant differences in mean damage intensities were between the CDFmm and CWHxm subzones, (BARS intensities were respectively, 5.94% and 11.11%). Other differences, while not always statistically significant at the 10% or better level, were important to the interpretation of *Phellinus* root rot behaviour, but not necessarily for forest management prescriptions.

Stand origins were found to have significantly different damage intensities of *Phellinus* root rot, but were strongly affected by stand age. Beyond the substantial age effect, it is postulated that the effects of logging, and logging followed by intense slashburning both had an increasingly negative effect on the survival of *Phellinus weirii* ectotrophic inoculum sources in relation to the wildfire conditions.

Some site ecological variables were found to vary significantly with the subzone and variant units (elevation m asl, percent slope and mineral soil pH), but not with root rot intensity. Similarly, several old and second growth stand attributes (species composition, and stand density (basal area and stems/ha)) were found to vary with several of the biogeoclimatic units. Notably, stems/ha of old growth Douglas-fir and western hemlock were significantly and negatively correlated with *Phellinus* root rot intensity, which followed the pattern of root rot variation between subzones as well. Old growth stems/ha and composition of western red cedar were generally greater in ecosystems with higher *Phellinus* root rot intensities. Distribution patterns for second growth stems/ha and

Curtis' relative density index strongly reflected the root rot distributions of the site associations. Patterns in the old growth and second growth stand density, species composition and the dynamic behaviour of species in and out of the presence of root rot led to the postulation of a natural, dynamic host-pathogen equilibrium.

A classification of *Phellinus* hazard and risk for all biogeoclimatic units investigated was made on the basis of the %BAR sample survey damage incidence and intensity data. The classification should aid in planning and operational management of coastal Douglas-fir ecosystems. The site association taxon (name) model was shown to accurately describe, in relative terms, the site association hazard (susceptibility) and risk (probability of and estimated damage intensity) of *Phellinus* root rot. The s.a. taxon model was viewed in the context of the host-pathogen dynamic equilibrium, host susceptibilities and natural successional chronosequences and their relationship to effect conducive, reactive or equilibrating stand conditions for the pathogen.

Estimates of yield reduction (≥ 4.0 cm) due to incidence of *Phellinus* root rot in growth and yield PSP's were quite variable, but depended upon infection severity. In a carefully selected set of comparable PSP's, infected compared to healthy PSP's suffered greater reductions of stems/ha (49-420%) and retained (40-80%) less of the accrued basal area and (71-83%) volume. Interestingly, the infected PSP growth rates have remained equal to or better than the healthy PSP's except in the most severely infected conditions. Yield reduction estimates for the *FdHw-Salal* and *HwFd-Kindbergia* combined s.a.'s using the Chapman-Richards growth model indicated an 8.86% reduction in volume

at 80 yr. In comparison, the yield reduction estimated for all PSP's using a quadratic model was 5.5% at site height 35 m (approx. 80 yr). Similarly, yield reductions for stand density classes < 1 000, 1 000-1 999 and 2 000-4 999 stems/ha at reference age 10 yr, were 8.25%, 8.63% and 4.97%. Growth models for all-PSP's were extremely variable and generally showed some growth reductions in infected PSP's ranging between 7-17% over the annual site height increments of 0.1 to 0.9 m/yr. There appeared to be a site height measurement dependence on *Phellinus* root rot incidence, meaning that site height tree height growth was impacted by the disease--a situation that requires closer evaluation and correction if it really exists. Certainly the growth and yield analytical techniques applied to a PSP database stratified simply on the basis of *Phellinus* incidence has shown conclusively and dramatically the effects of the disease on stand dynamics and productivity. A more careful evaluation is recommended following more accurate estimates of *Phellinus* root rot intensities in the PSP's. The PSP-based yield reductions (4.97% - 8.86%) compared well with the %BAR (NSBAR) estimate of 8.25%. Some adjustments to the %BAR survey procedure to account for the symptomatic tree contribution to productivity would reduce the %BAR estimate and bring yet closer agreement between the two productivity damage estimates. Furthermore, it is recognized that even with 35 to 37% of the PSP's infected, the proportion of infected PSP's does not fully reflect the 87% incidence of *Phellinus* root rot found in the 1 ha sample survey units. Nevertheless, the effectiveness of both methods in estimating damage is remarkably similar, suggesting both damage appraisal methods should be pursued further for *Phellinus* root rot and other damaging pest agents. The %BAR parameter estimation technique proved to be a sensitive, and flexible sampling method that enabled a wealth

of statistics and interpretations to be made for productivity and ecological questions alike.

10.0 RECOMMENDATIONS FOR MANAGEMENT

10.1 Damage Appraisal

The greater sampling variation found in *Phellinus* infected areas, combined with the pervasive incidence of infected areas should be taken into account in designing future forest and pest inventories.

One hectare sample survey units were found to estimate incidence equally well as 20 ha samples conducted in a separate study. A minimum sample size for estimating the incidence of *Phellinus* root rot at the forest level is suggested to be 1 ha.

Continued field testing of the Percent Basal Area Reduction parameter estimate sampling technique should be carried out in other forest types for other pests (particularly root rots) to estimate the efficiencies of the method. The greatest advantages of the %BAR parameter estimate technique are that (a) it is easy to conduct and calculate results, and (b) it simply provides stand-parameter-diseased estimates of stand damage, rather than conducting land-area-diseased estimates then converting land-based estimates to stand-based parameters. Further estimation of incidence-intensity relationships is encouraged in order to build on the efficiencies of incidence sampling, as compared with incidence-plus-severity sampling to estimate a stand-based damage intensity parameter.

Incidence-Intensity relationships appear to be an effective way to reduce sampling to only incidence, once the incidence-intensity relationships are well known for a stratum (e.g., biogeoclimatic unit, forest cover, age class, management regime). Incidence sampling is easier to conduct, cheaper and more easily produces repeatably consistent estimates.

On average, *Phellinus* root rot was shown to reduce volume yields from comparable healthy conditions by about 8.25% to 8.86%. Growth and yield in the permanent sample plots appeared to be partially compensated for by enhanced growth of residual trees and ingrowth of tolerant and resistant species. This condition was particularly noticeable in light to moderate damage intensities. The magnitude and trends of damage intensity observed from this set of permanent sample plots was surprisingly close to what I and other root disease workers have observed over the years. The negative effect on height growth of site height measurement trees in PSP's should be investigated and alternate measurement trees be selected where warranted.

A closer examination of permanent sample plots (both growth and yield and inventory types) should be made to evaluate the relative incidence and intensity levels. The pervasive effects/impacts of pests such as *Phellinus* root rot should be incorporated in the development of growth and yield models and forest level yield analysis determinations.

10.2 Stand and Forest Level Prescriptions

Hazard and risk of *Phellinus* root rot in the CDFmm and CWHxm biogeoclimatic units was estimated. The greatest risk was predicted to be in the CWHxm subzone, and notably in the *FdHw-Salal* and *HwFd-Kindbergia* s.a.'s.

The site association taxon model was shown to accurately predict the hazard and risk of *Phellinus* root rot when considered in the context of; (i) a natural, dynamic host-pathogen equilibrium, (ii) host susceptibilities to *Phellinus* root rot, and (iii) the natural succession chronosequences. The potential for estimating the hazard and risk for other damaging agents (e.g., pests) using this method is enormous, and should be pursued as much of the knowledge needed for this is already available.

Several other factors may be useful in estimating site risk: (i) *Phellinus* root rot was weakly, but positively correlated to percent slope; (ii) *Phellinus* root rot damage intensity appears to be greatest on mesic sites, although this was not a consistent observation, and (iii) the old growth and second growth stand density (stems/ha) appear to have had a positive effect on today's second growth *Phellinus* damage intensity.

Mortality of primarily Douglas-fir in *Phellinus* infected sites was counteracted by substantial species composition shifts to less-susceptible to resistant host trees (western hemlock, lodgepole and western white pine, western red cedar and deciduous).

The density and species composition shifts seen in the presence of *Phellinus* root rot strongly suggests that management prescriptions consider lower stand densities and more consideration of less-susceptible to resistant species as a means of reducing damage, hazard and risk to ecosystem health.

The natural, dynamic host-pathogen equilibrium suggests that stand productivity of highly susceptible species seres will only be reduced to an unknown maximum before tolerant and resistant species ingress the *Phellinus* infected sites. It further suggests that management prescriptions should minimize the risk of stand disequilibrium conditions by not creating *Phellinus*-conducive stand conditions. To do otherwise will increase loss of stand productivity of highly susceptible species, and in all likelihood require expensive programs to eradicate the pathogen from the site and thereby re-equilibrate the site.

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The following formulae were used to convert chemical concentration data to kg/ha for the 10-30 cm mineral soil horizon and, kg/ha for the forest floor. The formulae were previously described by Green (1989), based on Kabzems (1985), Roy (1984) and Lewis (1976).

CONVERSION FORMULAE FOR MINERAL SOILS (10-30cm HORIZON):

$$\text{MinN kg/ha} = 0.10 * \text{MinN ppm} * \text{MSBDfin} * 20 \text{ cm} * (1 - \text{CF})$$

$$\text{N kg/ha} = 1000 * \%N * \text{MSBDfin} * 20 \text{ cm} * (1 - \text{CF})$$

$$\text{C kg/ha} = 1000 * \%C * \text{MSBDfin} * 20 \text{ cm} * (1 - \text{CF})$$

$$\text{Ca kg/ha} = 20.04 * \text{Meq Ca} * \text{MSBDfin} * 20 \text{ cm} * (1 - \text{CF})$$

$$\text{Mg kg/ha} = 12.16 * \text{Meq Mg} * \text{MSBDfin} * 20 \text{ cm} * (1 - \text{CF})$$

$$\text{K kg/ha} = 39.096 * \text{Meq K} * \text{MSBDfin} * 20 \text{ cm} * (1 - \text{CF})$$

Where CF is the estimated proportion of mineral soil coarse-fragment content by volume.

CONVERSION FORMULAE FOR FOREST FLOORS:

$$\%C \text{ kg/ha} = 444444.444 * 20 \text{ cm} * \text{FFBD} * 0.01 * \%C$$

$$\%N \text{ kg/ha} = 444444.444 * 20 \text{ cm} * \text{FFBD} * 0.01 * \%N$$

$$\text{MinN kg/ha} = 444444.444 * 20 \text{ cm} * \text{FFBD} * (\text{MinN ppm} * 10^{-6})$$

Where the component 444444.444 is the forest floor sample size (225 cm²) plot expansion factor to 1 ha.

Appendix B

Curtis' Relative Stand Density Index

This appendix describes the procedure used to recalculate Curtis' Relative Stand Density Index for ecologically similar PSP's within a growth and yield installation. In most cases stand conditions were very similar within an installation though great variability occurred due to microtopography and/or pests.

Curtis' Relative Density ($\geq 4.0\text{cm}$) = Stand_BA / QDBH

FULL FORMULA:
$$\text{CRD}_{\geq 4.0\text{cm}} = \frac{\text{STAND_BA}}{(\text{SQRT}(\text{SQRT}((\text{STAND_BA}/\text{STAND_STEMS})/0.00007854)))}$$

STEPS TO ESTIMATE CURTIS' RELATIVE DENSITY:

1. Calculate the average STAND_BA/HA and average STAND_STEMS/HA for ecologically similar PSP's within a growth and yield installation, then;
2. Calculate MEAN BASAL AREA/TREE = (STAND_BA) - (STAND_STEMS);
3. MEAN DIAMETER/TREE = SQRT((MEAN BASAL AREA/TREE)/0.00007854);
4. QUADRATIC MEAN DIAMETER = SQRT(MEAN DIAMETER/TREE).

NOTE: The factor '0.00007854' is the metric constant used to estimate cross-sectional areas of 'circular' trees (g) Where $g = 0.00007854 \text{ dbh}^2$, (Husch *et al.* 1972).

Appendix C

Species List

Coniferous trees

1	ABIEGRA	<i>Abies grandis</i>	(Dougl. ex D. Don) Lindl
2	PICESIT	<i>Picea sitchensis</i>	(Bong.) Carr.
3	PINUCON	<i>Pinus contorta</i>	Dougl. ex Loud.
4	PINUMON	<i>Pinus monticola</i>	Dougl. ex D. Don in Lamb
5	PSEUMEN	<i>Pseudotsuga menziesii</i>	(Mirb.) Franco
6	THUJPLI	<i>Thuja plicata</i>	Donn ex D. Don in Lamb.
7	TSUGHET	<i>Tsuga heterophylla</i>	(Raf.) Sarg.

Broad-leaved trees

8	ACERMAC	<i>Acer macrophyllum</i>	Pursh
9	ALNURUB	<i>Alnus rubra</i>	Bong.
10	ARBUMEN	<i>Arbutus menziesii</i>	Pursh
11	BETUPAP	<i>Betula papyrifera</i>	Marsh.
12	CORNNU	<i>Cornus nuttallii</i>	Audub. ex Torr. Gray
13	MALUFUS	<i>Malus fusca</i>	(Raf.) Schneid
14	POPUTRI	<i>Populus trichocarpa</i>	Torr. Gray ex Hook.
15	QUERGAR	<i>Quercus garyana</i>	Dougl. ex Hook.

Evergreen shrubs

16	ARCTUVA	<i>Arctostaphylos uva-ursi</i>	(L.) Spreng.
17	CHIMMEN	<i>Chimaphila menziesii</i>	(R. Br. ex D. Don) Spreng
18	CHIMUMB	<i>Chimaphila umbellata</i>	(L.) Barton
19	GAULOVA	<i>Gaultheria ovatifolia</i>	Gray
20	GAULSHA	<i>Gaultheria shallon</i>	Pursh
21	HEDEHEL	<i>Hedera helix</i>	L.
22	ILEXAQU	<i>Ilex aquifolium</i>	L.
23	MAHOAQU	<i>Mahonia aquifolium</i>	(Pursh) Nutt.
24	MAHONER	<i>Mahonia nervosa</i>	(Pursh) Nutt.
25	PAXIMYR	<i>Paxistima myrsinites</i>	(Pursh) Raf.
26	VACCOVT	<i>Vaccinium ovatum</i>	Pursh

Deciduous shrubs

27	ACERGLA	<i>Acer glabrum</i>	Torr.
28	AMELALN	<i>Amelanchier alnifolia</i>	(Nutt.) Nutt.
29	CORNSE	<i>Cornus sericea</i>	L.
30	CORYCOR	<i>Corylus cornuta</i>	Marsh.
31	HOLODIS	<i>Holodiscus discolor</i>	(Pursh) Maxim.
32	LONICIL	<i>Lonicera ciliosa</i>	(Pursh) DC.
33	LONIHIS	<i>Lonicera hispidula</i>	(Lindl.) Dougl. ex Torr.
34	LONIINV	<i>Lonicera involucrata</i>	(Richards.) Banks ex Spr
35	MENZFER	<i>Menziesia ferruginea</i>	Sm.
36	OEMLCER	<i>Oemleria cerasiformis</i>	(Torr.) Gray ex Hook
37	PRUNEMA	<i>Prunus emarginata</i>	(Dougl. ex Hook.) Walp.
38	RHAMPUR	<i>Rhamnus purshiana</i>	DC.
39	RIBEDIV	<i>Ribes divaricatum</i>	Dougl.
40	RIBELAC	<i>Ribes lacustre</i>	(Pers.) Poir
41	ROSAGYM	<i>Rosa gymnocarpa</i>	Nutt. in Torr. Gray
42	RUBUIDA	<i>Rubus idaeus</i>	
43	RUBUPAR	<i>Rubus parviflorus</i>	Nutt.
44	RUBUSPE	<i>Rubus spectabilis</i>	Pursh
45	RUBUURS	<i>Rubus ursinus</i>	Cham. Schlecht.
46	SALISCO	<i>Salix scouleriana</i>	Barratt in Hook.
47	SALIX	<i>Salix sp.</i>	
48	SORBSIT	<i>Sorbus sitchensis</i>	M. J. Roem.
49	SYMPALB	<i>Symphoricarpos albus</i>	(L.) Blake
50	SYMPHES	<i>Symphoricarpos hesperius</i>	G.N. Jones
51	VACCOVL	<i>Vaccinium ovalifolium</i>	Sm. in Rees
52	VACCPAR	<i>Vaccinium parvifolium</i>	Sm. in Rees

Deciduous shrubs - Cont'd

53	ADIAPED	<i>Adiantum pedatum</i>	L.
54	ATHYFIL	<i>Athyrium filix-femina</i>	(L.) Roth
55	BLECSPI	<i>Blechnum spicant</i>	(L.) Roth
56	DRYOEXP	<i>Dryopteris expansa</i>	(Presl) Fraser-Jenkins
57	GYMNDRY	<i>Gymnocarpium dryopteris</i>	(L.) Newm.
58	POLYMUN	<i>Polystichum munitum</i>	(Kaulf.) Presl
59	PTERAQU	<i>Pteridium aquilinum</i>	(L.) Kuhn in Decken

Graminoids

60	BROMUS	<i>Bromus sp.</i>	
61	BROMVUL	<i>Bromus vulgaris</i>	(Hook.) Shear
62	CALACAN	<i>Calamagrostis canadensis</i>	(Michx.) Beauv.
63	CALARUB	<i>Calamagrostis rubescens</i>	Buckl.
64	CAREHEN	<i>Carex hendersonii</i>	Bailey
65	CAREX	<i>Carex sp.</i>	
66	DACTGLO	<i>Dactylis glomerata</i>	L.
67	FESTOCC	<i>Festuca occidentalis</i>	Hook.
68	FESTSUT	<i>Festuca subulata</i>	Trin. in Bong.
69	FESTUCA	<i>Festuca sp.</i>	
70	LUZULA	<i>Luzula sp.</i>	
71	LUZUMUL	<i>Luzula multiflora</i>	(Retz.) Lej.
72	LUZUPAR	<i>Luzula parviflora</i>	(Ehrh.) Desv.
73	MELISUB	<i>Melica subulata</i>	(Griseb.) Scribn.

Herbs

74	ACHIMIL	<i>Achillea millefolium</i>	L.
75	ACHLTRI	<i>Achlys triphylla</i>	(Sm.) DC.
76	ADENBIC	<i>Adenocaulon bicolor</i>	Hook.
77	ANAPMAR	<i>Anaphalis margaritacea</i>	(L.) Benth. in Benth.
78	CLAYSIB	<i>Claytonia sibirica</i>	L.
79	COPTASP	<i>Coptis asplenifolia</i>	Salisb.
80	CORNCAN	<i>Cornus canadensis</i>	L.
81	CORNUNA	<i>Cornus unalaschkensis</i>	Ledeb.
82	DISPHOO	<i>disporum hookeri</i>	(Torr.) Nicholson
83	FRAGVES	<i>Fragaria vesca</i>	L.
84	FRAGVIR	<i>Fragaria virginiana</i>	Duchesne
85	GALIBOR	<i>Galium boreale</i>	L.
86	GALITRI	<i>Galium triflorum</i>	Michx.
87	GOODOBL	<i>Goodyera oblongifolia</i>	Raf.
88	HIERALB	<i>Hieracium albiflorum</i>	Hook.
89	LATHNEV	<i>Lathyrus nevadensis</i>	Wats.
90	LILICOL	<i>Lilium columbianum</i>	Hanson ex Baker
91	LINNBOR	<i>Linnaea borealis</i>	L.
92	LISTCOR	<i>Listera cordata</i>	(L.) R. Br. in Ait.
93	LYSIAME	<i>Lysichitum americanum</i>	Hult. St. John
94	MENTARV	<i>Mentha arvensis</i>	L.
95	MOEHMAC	<i>Moehringia macrophylla</i>	(Hook.) Fenzl
96	MONEUNI	<i>Moneses uniflora</i>	(L.) Gray
97	MYCEMUR	<i>Mycelis muralis</i>	(L.) Dumort.
98	ORTHSEC	<i>Orthilia secunda</i>	(L.) House
99	OSMOCHI	<i>Osmorhiza chilensis</i>	Hook. Arn.
100	PYROASA	<i>Pyrola asarifolia</i>	Michx.
101	PYROPIC	<i>Pyrola picta</i>	Sm. in Rees
102	RUBUPED	<i>Rubus pedatus</i>	Sm.
103	SMILSTE	<i>Smilacina stellata</i>	(L.) Desf.
104	STACCOO	<i>Stachys cooleyae</i>	Heller
105	STREROS	<i>Streptopus roseus</i>	Michx.
106	TIARLAC	<i>Tiarella laciniata</i>	Hook.
107	TIARTRI	<i>Tiarella trifoliata</i>	L.

Herbs - Continued

108 TIARUNI	<i>Tiarella unifoliata</i>	Hook.
109 TOLMMEN	<i>Tolmiea menziesii</i>	(Pursh) Torr. Gray
110 TRIELAT	<i>Trientalis latifolia</i>	Hook.
111 TRILOVA	<i>Trillium ovatum</i>	Pursh
112 URTIDIO	<i>Urtica dioica</i>	L.
113 VIOLA	<i>Viola sp.</i>	
114 VIOLADU	<i>Viola adunca</i>	Sm. in Rees
115 VIOLGLA	<i>Viola glabella</i>	Nutt. in Torr. Gray
116 VIOLORB	<i>Viola orbiculata</i>	Geyer ex Hook.

Paras. & saphroph.

117 BOSCHOO	<i>Boschinakia hookeri</i>	Walp.
118 CORALLO	<i>Corallorhiza sp.</i>	
119 CORAMAC	<i>Corallorhiza maculata</i>	Raf.
120 CORAMER	<i>Corallorhiza mertensiana</i>	Bong.
121 HEMICON	<i>Hemitomes congestum</i>	Gray
122 HYPOLAN	<i>Hypopithys lanuginosa</i>	(Michx.) Nutt.
123 MONOUNI	<i>Monotropa uniflora</i>	L.
124 PTERAND	<i>Pterospora andromeda</i>	Nutt.

Mosses

125 DICRFUS	<i>Dicranum fuscescens</i>	Turn.
126 DICRSCO	<i>Dicranum scoparium</i>	Hedw.
127 HYLOSPL	<i>Hylocomium splendens</i>	(Hedw.) B.S.G.
128 ISOPELE	<i>Isopterygium elegans</i>	(Brid.) Lindb.
129 ISOTSTO	<i>Isoethecium stoloniferum</i>	Brid.
130 KINDORE	<i>Kindbergia oregana</i>	(Sull.) Ochyra
131 KINDPRA	<i>Kindbergia praelonga</i>	(Hedw.) Ochyra
132 LEUCMEN	<i>Leucolepis menziesii</i>	(Hook.) Steere ex L. Koc
133 PLAGINS	<i>Plagiomnium insigne</i>	(Mitt.) Kop.
134 PLAGUND	<i>Plagiothecium undulatum</i>	(Hedw.) B.S.G.
135 PLEUSCH	<i>Pleurozium schreberi</i>	(Brid.) Mitt.
136 POLYJUN	<i>Polytrichum juniperinum</i>	Hedw.
137 RHACCAN	<i>Rhacomitrium canescens</i>	(Hedw.) Brid.
138 RHIZGLA	<i>Rhizomnium glabrescens</i>	(Kindb.) Kop.
139 RHYTLOR	<i>Rhytidiadelphus loreus</i>	(Hedw.) Warnst.
140 RHYTROB	<i>Rhytidiopsis robusta</i>	(Hook.) Broth.
141 RHYTTRI	<i>Phytidiadelphus triquetrus</i>	(Hedw.) Warnst.

Liverworts

142 CALYMUE	<i>Calypogeja muelleriana</i>	(Schiffn.) K. Mull.
143 MARCPOL	<i>Marchantia polymorpha</i>	L.
144 SCAPBOL	<i>Scapania bolanderi</i>	Aust.

Lichens

145 CLADCHL	<i>Cladonia chlorophaea</i>	(Florke ex Somm.) Spreng
146 CLADFUR	<i>Cladonia furcata</i>	(Huds.) Schrad.
147 CLADRAN	<i>Cladina rangiferina</i>	(L.) Harm.
148 ICMAERI	<i>Icmadophila ericetorum</i>	(L.) Zahlbr.
149 PELTAPH	<i>Peltigera aphthosa</i>	(L.) Willd.
150 PELTCAN	<i>Peltigera canina</i>	(L.) Willd.
151 PELTIGE	<i>Peltigera sp.</i>	
152 PELTMEN	<i>Peltigera membranacea</i>	(Ach.) Nyl.

Appendix D		Vegetation Summary Table					
Vegetation Unit	1	2	3	4	5	6	
Number of Plots	25	47	27	38	8	8	
Species	Presence class and mean species significance						
<i>Abies grandis</i>	III 2.0	II 1.2	I 1.1	II 2.7	II 2.1	II 1.4	
<i>Acer glabrum</i>	I +.0	I +.0					
<i>Acer macrophyllum</i>	II 3.1	II 2.1	I 2.3	I 2.0	III 1.7	III 2.6	
<i>Achillea millefolium</i>	I +.0						
<i>Achlys triphylla</i>	II 1.0	IV 2.5	V 3.9	IV 4.5	V 4.1	IV 6.2	
<i>Adenocaulon bicolor</i>	I +.0	I 1.1	I 1.6	I 1.4	II +.3	I 1.9	
<i>Adiantum pedatum</i>					I +.0		
<i>Alnus rubra</i>	II 1.4	II 2.9	II 1.1	II 3.0	V 5.1	I 1.9	
<i>Amelanchier alnifolia</i>	II 2.1	II +.8	I +.2	I +.0			
<i>Anaphalis margaritacea</i>		I +.0					
<i>Arbutus menziesii</i>	III 3.1	I +.0					
<i>Arctostaphylos uva-ursi</i>		I +.2					
<i>Athyrium filix-femina</i>		I +.0		I +.0	II +.3		
<i>Betula papyrifera</i>		I +.0		I +.0			
<i>Blechnum spicant</i>				I +.0	I +.0	II 3.5	
<i>Boschniakia hookeri</i>	I +.0	I +.0					
<i>Bromus sp.</i>			I +.0				
<i>Bromus vulgaris</i>	II 1.1	III 1.6	II +.9	II 1.8	IV 2.4	II 1.4	
<i>Calamagrostis canadensis</i>			I +.0				
<i>Calamagrostis rubescens</i>		I +.3	I +.1	I +.0			
<i>Calypogeja muelleriana</i>				I +.0		II 1.3	
<i>Carex hendersonii</i>					I +.5	I +.0	
<i>Carex sp.</i>				I +.0	II +.3	I +.0	
<i>Chimaphila menziesii</i>	I +.0	I +.0					
<i>Chimaphila umbellata</i>	I +.0	II 1.5	II 1.6	I +.0		II +.3	
<i>Cladonia chlorophaea</i>	I +.0						
<i>Cladonia furcata</i>			I +.0				
<i>Cladina rangiferina</i>	I +.2						
<i>Claytonia sibirica</i>				I +.0			
<i>Coptis asplenifolia</i>						II +.8	
<i>Corallorhiza sp.</i>						I +.0	
<i>Corallorhiza maculata</i>	II 1.0	II +.3	I +.0	I +.0			
<i>Corallorhiza mertensiana</i>		I +.0					
<i>Cornus canadensis</i>				I +.0			
<i>Cornus nuttallii</i>	II 1.5	I 1.2		I 1.0			
<i>Cornus sericea</i>	I +.2		I +.0	I +.0			
<i>Cornus unalaschkensis</i>	I +.0						
<i>corylus cornuta</i>	I +.0	I +.0					
<i>Dactylis glomerata</i>		I +.0					
<i>Dicranum fuscescens</i>		I +.0					

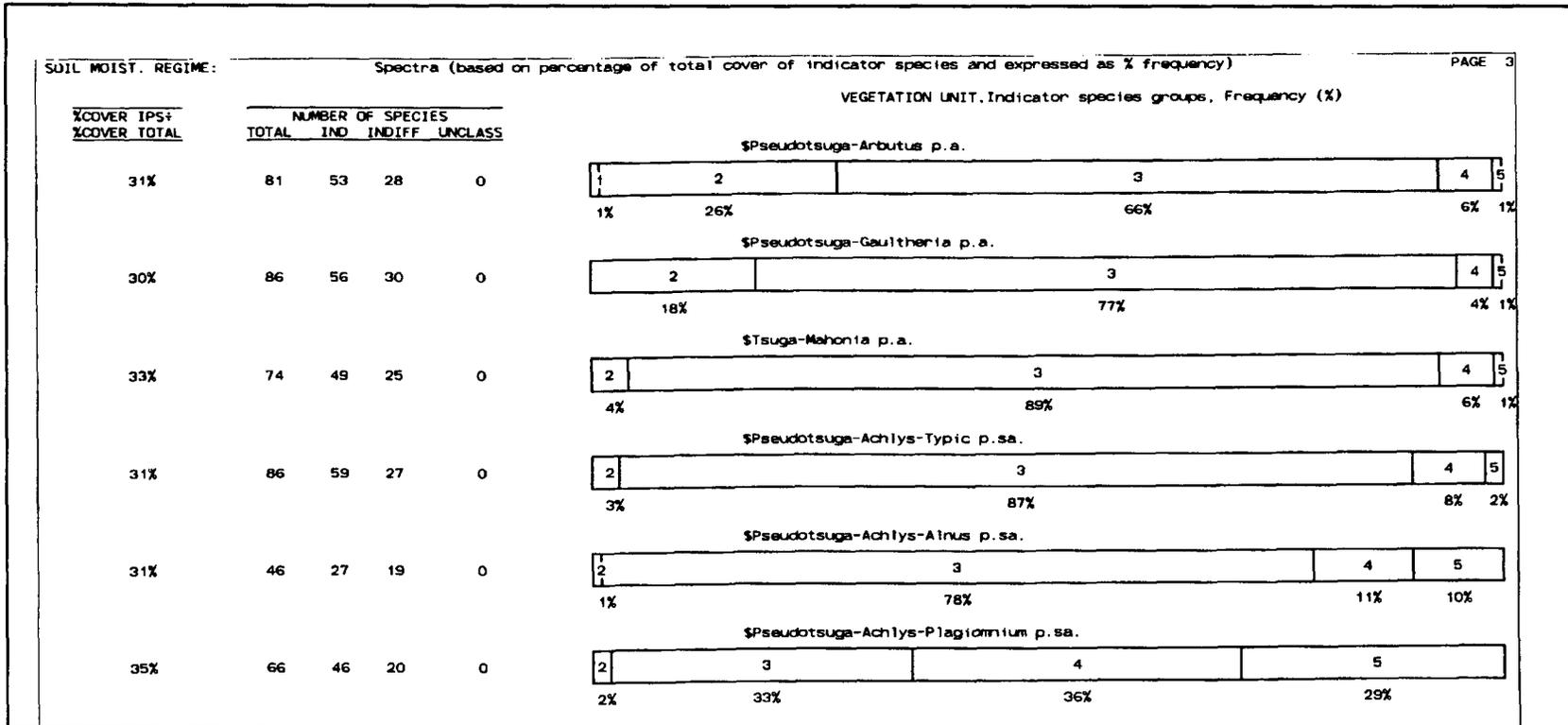
<i>Dicranum scoparium</i>	I 1.4	I +.0	I +.0	I +.0		
<i>Disporum hookeri</i>		I +.0				
<i>Dryopteris expansa</i>				I +.0	II +.3	
<i>Festuca occidentalis</i>	I 1.0	I +.0	I +.0	I +.0		
<i>Festuca subulata</i>		I +.0	I +.1			II 3.1
<i>Festuca sp.</i>	I +.0	I +.4	I +.0	II 1.4	II +.3	I +.0
<i>Fragaria vesca</i>	I +.0					
<i>Fragaria virginiana</i>		I +.0				
<i>Galium boreale</i>	I +.0	II +.6	II +.8	II 1.1	IV 2.1	IV 4.6
<i>Galium triflorum</i>			I +.0	I +.8	II 1.3	
<i>Gaultheria ovatifolia</i>		I +.0	I +.0			
<i>Gaultheria shallon</i>	V 7.6	V 7.7	V 7.3	V 6.7	III 3.8	IV 4.8
<i>Goodyera oblongifolia</i>	II 1.0	II 1.0	II +.5	II +.2	I +.0	I +.0
<i>Gymnocarpium dryopteris</i>						II +.3
<i>Hedera helix</i>	I +.0					
<i>Hemitomes congestum</i>		I +.0	I +.0			
<i>Hieracium albiflorum</i>		I +.0	I +.0			
<i>Holodiscus discolor</i>	IV 4.5	III 3.9	I +.0	I +.0		
<i>Hylocomium splendens</i>	II 4.0	V 5.6	V 5.1	V 5.4	IV 3.4	V 6.0
<i>Hypopithys Lanuginosa</i>		I +.0	I +.0			
<i>Icmadophila ericetorum</i>			I +.0			
<i>Ilex aquifolium</i>	I +.2	I +.0			II +.3	
<i>Isopterygium elegans</i>				I +.0		
<i>Isothecium stoloniferum</i>				I +.0		II +.3
<i>Kindbergia oregana</i>	V 6.2	V 6.6	V 7.5	V 6.9	V 7.1	IV 5.3
<i>Kindbergia praelonga</i>						II 5.0
<i>Lathyrus nevadensis</i>	I +.0	I 1.1	I +.1			
<i>Leucolepis menziesii</i>		I +.0		I 1.3		II +.8
<i>Lilium columbianum</i>	I +.0					
<i>Linnaea borealis</i>	I +.6	III 3.0	IV 4.4	IV 4.5	II 1.4	III 3.2
<i>Listera cordata</i>			I +.0	I +.0		
<i>Lonicera ciliosa</i>	II 1.1	I +.0	I +.0	I +.0		
<i>Lonicera hispidula</i>			I +.1	I +.0		I 1.2
<i>Lonicera involucrata</i>	I +.0	I +.2		I +.5		
<i>Luzula sp.</i>					II +.8	
<i>Luzula multiflora</i>		I +.0				I +.0
<i>Luzula parviflora</i>				I +.0		
<i>Lysichitum americanum</i>						I +.0
<i>Mahonia aquifolium</i>	I +.3	I +.0				
<i>Mahonia nervosa</i>	V 4.5	V 5.2	V 4.8	V 5.6	V 4.4	IV 4.8
<i>Malus fusca</i>	I +.2					
<i>Marchantia polymorpha</i>						I 1.2
<i>Melica subulata</i>	I +.5		I +.1	I +.0		I 1.2
<i>Mentha arvensis</i>				I +.0		
<i>Menziesia ferruginea</i>		I +.0	I +.0			I 1.2

<i>Moehringia macrophylla</i>	I +.0		I +.0			I 1.2
<i>Moneses uniflora</i>	I +.0	I +.0		I +.0		
<i>Monotropa uniflora</i>		I +.0	I +.0	I +.0		
<i>Mycelis muralis</i>	I +.2	I +.0	I 1.6	I +.1	II 1.4	I 2.7
<i>Oemleria cerasiformis</i>	I +.0	I +.0				
<i>Orthilia secunda</i>		I +.0	I +.0	I +.2		I +.0
<i>Osmorhiza chilensis</i>	I +.0	I +.6		I +.0		I +.5
<i>Paxistima myrsinites</i>	I +.0	I 1.1				
<i>Peltigera aphthosa</i>	I +.0	I 1.1	I +.0			
<i>Peltigera canina</i>	I +.0	I +.0	I +.0	I 1.1		II +.3
<i>Peltigera sp.</i>				I +.0		
<i>Peltigera membranacea</i>	I +.0	I +.0	I +.0	I +.0		
<i>Picea sitchensis</i>				I +.0		I +.5
<i>Pinus contorta</i>	I 1.4	I +.5		I +.0		
<i>Pinus monticola</i>	I +.0	I +.5	I +.0	I +.0		I 1.2
<i>Plagiomnium insigne</i>				II +.7	II +.3	IV 3.4
<i>Plagiothecium undulatum</i>		I +.0	II 1.2	III 2.2	II 1.3	IV 3.2
<i>Pleurozium schreberi</i>						II +.3
<i>Polytrichum juniperinum</i>	I +.0	I +.0				
<i>Polystichum munitum</i>	III 1.9	III 3.4	IV 3.4	V 5.1	V 7.4	V 6.5
<i>Populus trichocarpa</i>				I +.0		I 1.9
<i>Prunus emarginata</i>	I 1.6		I +.2			
<i>Pseudotsuga menziesii</i>	V 8.2	V 8.1	V 8.0	V 8.0	V 7.7	V 7.6
<i>Pterospora andromeda</i>	I +.0					
<i>Pteridium aquilinum</i>	V 3.4	V 4.1	V 4.6	V 4.4	IV 2.8	IV 4.6
<i>Pyrola asarifolia</i>		I +.0		I +.0		
<i>Pyrola picta</i>	I +.0	I +.0				
<i>Quercus garryana</i>	I +.0					
<i>Rhacomitrium canescens</i>	I 1.4					
<i>Rhamnus purshianus</i>	I +.0	I +.2	I +.0	I +.1	I +.0	I +.0
<i>Rhizomnium glabrescens</i>	I +.0	I +.0		I +.0		V 4.0
<i>Rhytidiadelphus loreus</i>	I +.0	II 1.6	II 1.8	III 2.0	I +.0	III 2.0
<i>Rhytidiopsis robusta</i>	I +.3	II 1.6	II +.5	I +.2		I +.0
<i>Rhytidiadelphus triquetrus</i>	II 2.7	III 3.0	I 1.4	I +.0	II 1.5	I +.0
<i>Ribes divaricatum</i>				I +.0		
<i>Ribes lacustre</i>			I +.1			
<i>Rosa gymnocarpa</i>	V 3.3	V 3.5	II 1.1	II 2.3		II 1.8
<i>Rubus idaeus</i>			I +.0	I +.2		
<i>Rubus parviflorus</i>	I +.0	I +.0	I +.1			
<i>Rubus pedatus</i>			I +.0			I +.0
<i>Rubus spectabilis</i>		I +.0		I +.0	IV 3.7	I 2.7
<i>Rubus ursinus</i>	V 3.3	V 3.3	IV 2.8	IV 3.3	V 3.1	IV 2.8
<i>Salix scouleriana</i>	I +.3					
<i>Salix sp.</i>	II 1.5	I 1.3	I +.0			
<i>Scapania bolanderi</i>						I +.0

<i>Smilacina stellata</i>		I +.0				
<i>Sorbus sitchensis</i>			I +.0	I +.0	I +.0	
<i>Stachys cooleyae</i>					I +.0	
<i>Streptopus roseus</i>						I +.0
<i>Symphoricarpos albus</i>	II 2.9	II 2.1	II 2.8	II 1.6	I 1.2	
<i>Symphoricarpos hesperius</i>	I 1.6	II 2.3	I 1.6	I +.1	I 1.2	
<i>Thuja plicata</i>	V 4.3	V 4.6	IV 4.1	IV 4.9	III 2.8	V 5.7
<i>Tiarella laciniata</i>				I +.0		I +.0
<i>Tiarella trifoliata</i>	I +.0		I +.0	III 2.2	V 2.0	V 3.2
<i>Tiarella unifoliata</i>	I +.0			I +.0		
<i>Tolmiea menziesii</i>					I +.0	
<i>Trientalis latifolia</i>	II 1.0	II 1.5	II 2.3	II 1.4	II +.3	IV 2.4
<i>Trillium ovatum</i>	I +.0	I +.0	I 1.4	I +.1		II +.3
<i>Tsuga heterophylla</i>	II 2.1	IV 3.7	V 5.0	V 5.8	V 4.6	V 5.3
<i>Urtica dioica</i>					I 2.7	
<i>Vaccinium ovalifolium</i>						II 5.0
<i>Vaccinium ovatum</i>				I 2.4		
<i>Vaccinium parvifolium</i>	IV 3.1	IV 3.7	V 4.0	V 4.5	V 2.7	IV 4.3
<i>Viola sp.</i>	I +.0	I +.0	I +.1	I +.0	I +.0	
<i>Viola adunca</i>			I +.0	I +.0		
<i>Viola glabella</i>				I +.0		I +.0
<i>Viola orbiculata</i>			I +.0	I +.0		

Appendix E

Spectral Analysis: Soil Moisture Regime



SOIL MOISTURE REGIME:	
1	Excess to very dry
2	Very to moderately dry
3	Moderately dry to fresh
4	Fresh to very moist
5	Very moist to wet
6	Wet to very wet

Appendix E - Continued

Spectral Analysis: Soil Nutrient Regime

SOIL NUTRI. REGIME:		Spectra (based on percentage of total cover of indicator species and expressed as % frequency)				VEGETATION UNIT, Indicator species groups, Frequency (%)			PAGE 4
%COVER IPS+	%COVER TOTAL	NUMBER OF SPECIES							
		TOTAL	IND	INDIFF	UNCLASS	1	2	3	
49%	81	65	16	0	\$Pseudotsuga-Arbutus p.a.				
					1	2	3		
					60%	30%	10%		
52%	86	71	15	0	\$Pseudotsuga-Gaultheria p.a.				
					1	2	3		
					63%	26%	11%		
41%	74	60	14	0	\$Tsuga-Mahonia p.a.				
					1	2	3		
					66%	17%	17%		
46%	86	70	16	0	\$Pseudotsuga-Achlys-Typic p.sa.				
					1	2	3		
					53%	21%	26%		
49%	46	35	11	0	\$Pseudotsuga-Achlys-Alnus p.sa.				
					1	2	3		
					12%	14%	74%		
62%	66	55	11	0	\$Pseudotsuga-Achlys-Plagiomnium p.sa.				
					1	2	3		
					35%	17%	48%		

Soil Nutrient Regime:	
1	N - Poor
2	N - Medium
3	N - Rich

Appendix F

Relationship Of Site And Stand Ecological Variables To The Site Associations Identified In The Study Area

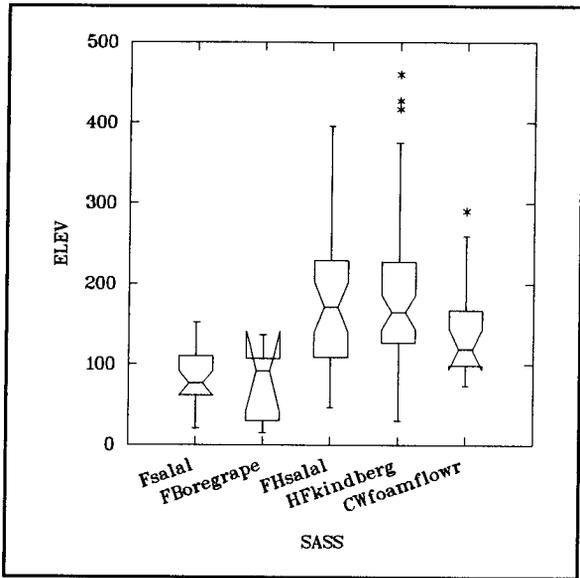


Figure 1 Elevation (m asl). Means are L to R, 85, 79, 191, 194 and 143 m, corresponds well with subzones. The last unit is likely lower due to lower slope positions.

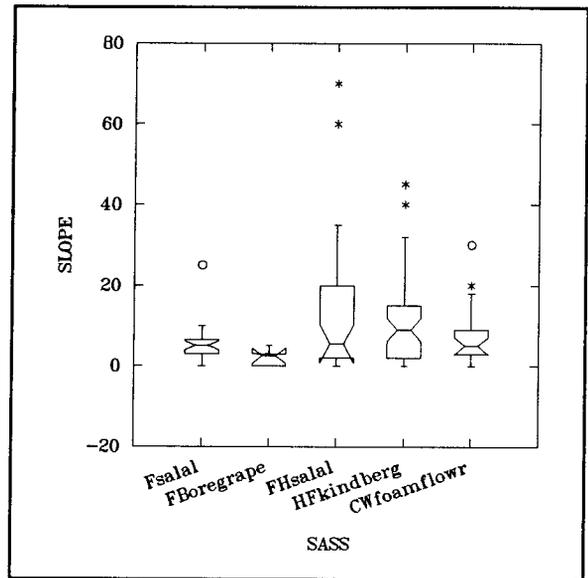


Figure 2 Slope (%). Means are L to R, 5.5%, 2.2%, 12.4%, 10.9% and 7.6%. The CDF units corresponding to gentle coastal plain and CWHxm to upland mid to lower slope conditions.

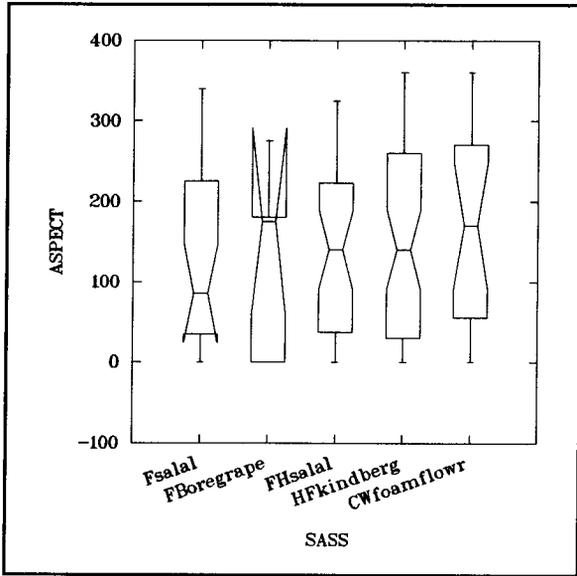


Figure 3 Aspect (azimuth degrees). Means are L to R, 128, 134, 133, 148 and 161°.

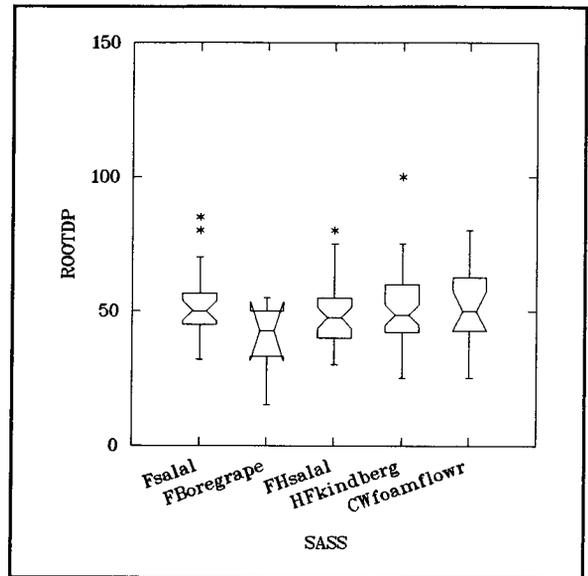


Figure 4 Major rooting zone depth (cm). Means are L to R, 52, 40, 49, 52 and 57 cm.

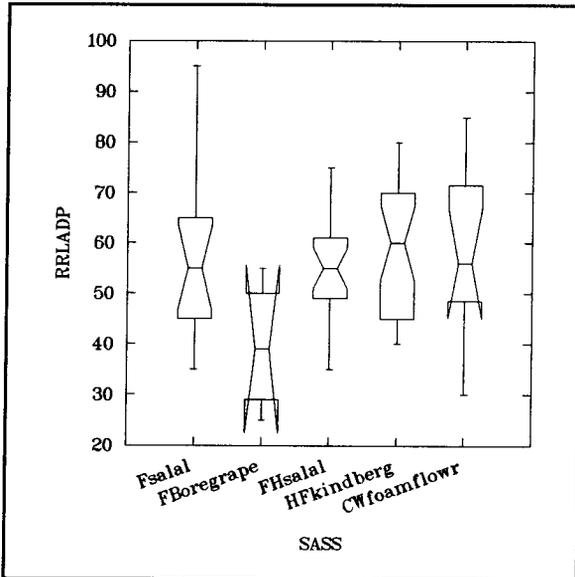


Figure 5 Root restricting layer depth (cm). Means L to R, 57, 40, 54, 58 and 59 cm. No substantial differences across site units, except in the *FdBg*-Oregon grape unit.

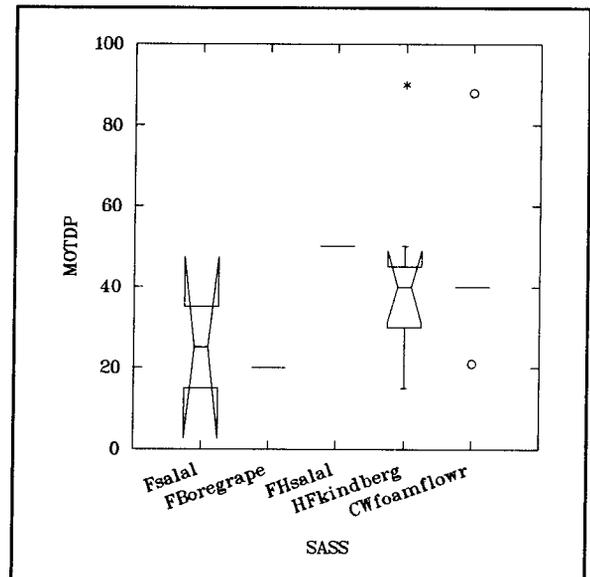


Figure 6 Depth to mottling (cm). Means L to R, 25, 20, 50, 42 and 45 cm.

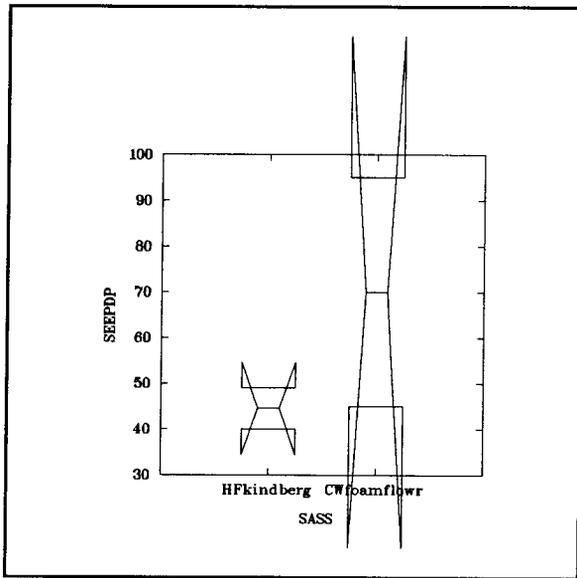


Figure 7 Depth to seepage water (cm), was well associated with slightly dry soil moisture conditions.

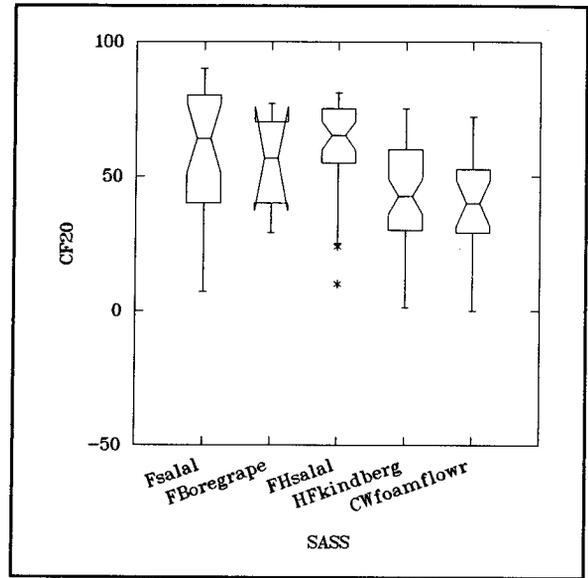


Figure 8 Percent (%) coarse fragment content by volume. Means L to R are; 60, 55, 62, 43 and 40. Note higher CF20's are associated with moderately dry actual soil moisture regimes.

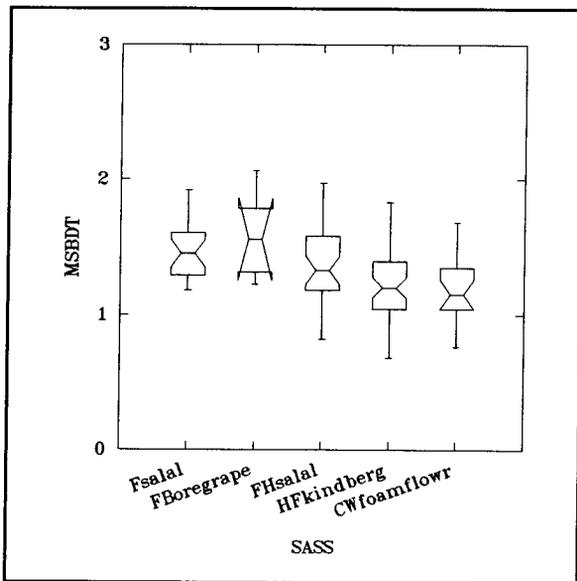


Figure 9 Gross total mineral soil bulk density (g/m³). Means L to R are; 1.46, 1.58, 1.38, 1.25 and 1.19. Note the higher MSBDT in the CDFmm site units. The trend corresponds to CF20.

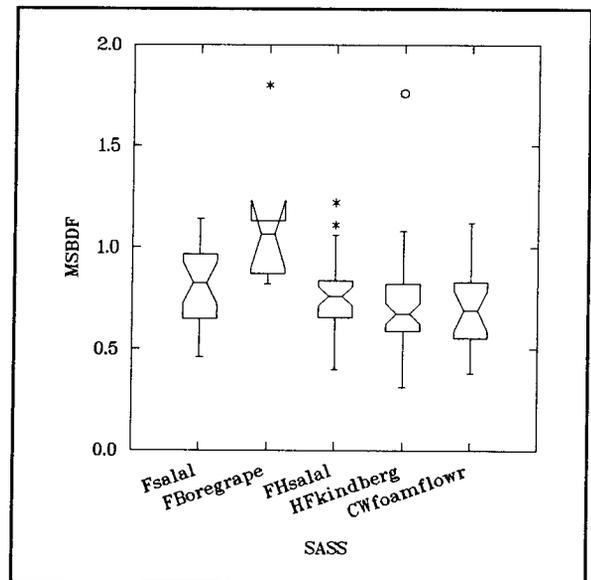


Figure 10 Fine fraction (<2 mm) mineral soil bulk density (g/m³). Means L to R are; .828, 1.125, .766, .716 and .695. Note the similar trend to MSBDT.

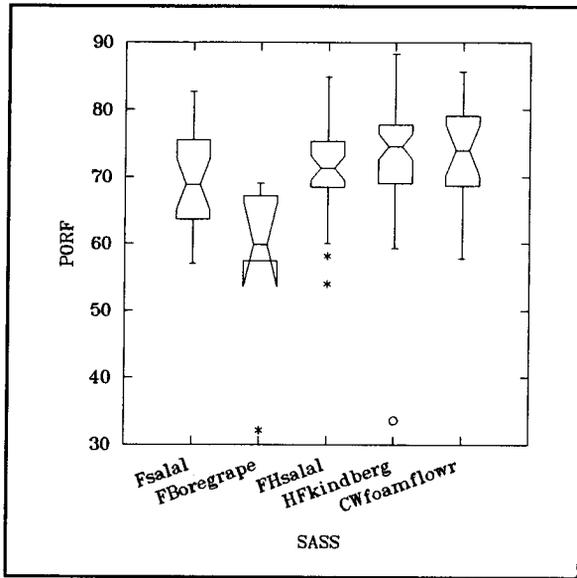


Figure 11 Mineral soil percent porosity, Means are L to R; 69%, 58%, 71%, 73% and 74%. Note, porosity is inversely related to MSBDF; high bulk density equals low porosity.

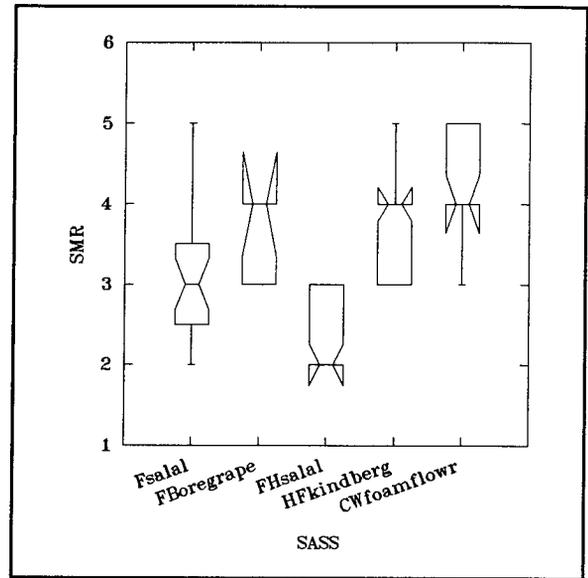


Figure 12 Relative soil moisture regime. Means are L to R; 3, 3.7, 2.4, 3.8 and 4.3. The moderately dry site units are predominated by high coarse fragment contents and bulk densities.

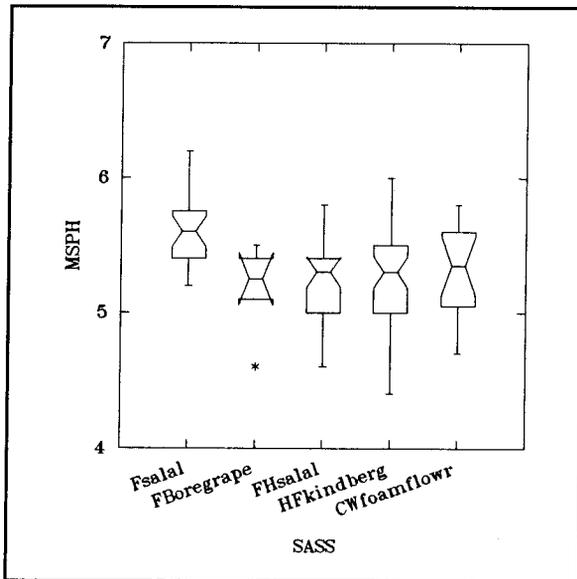


Figure 13 Mineral soil pH. Means L to R are; 5.62, 5.18, 5.26 and 5.3. *Fd-Salal* is significantly different ($\alpha = .05$) from all other pH distributions.

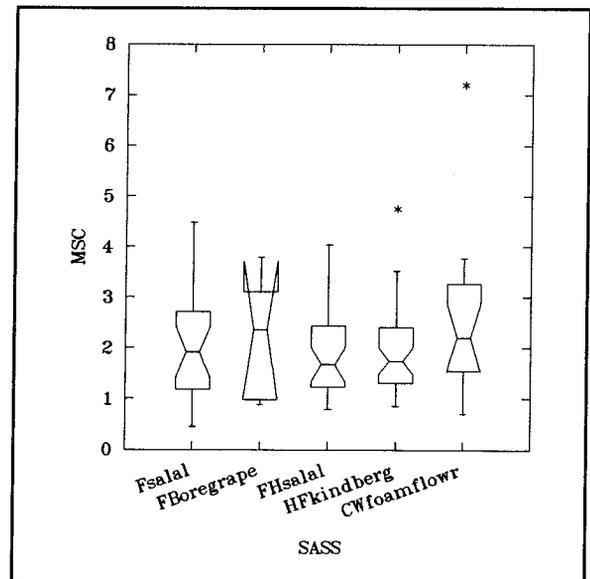


Figure 14 Mineral soil total (%) carbon content. Means are L to R; 2.04, 2.24, 1.84, 1.91 and 2.50, ($\alpha = .10$).

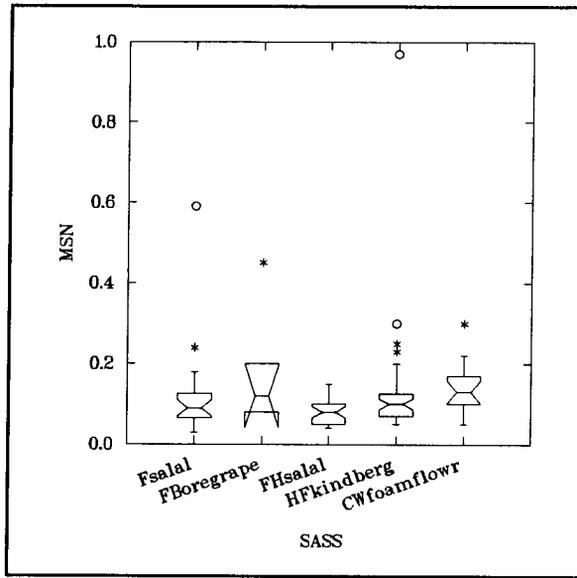


Figure 15 Mineral soil total (%) nitrogen content. Means are L to R; .12, .18, .08, .13 and .14, with no significant differences detected at ($\alpha < .10$).

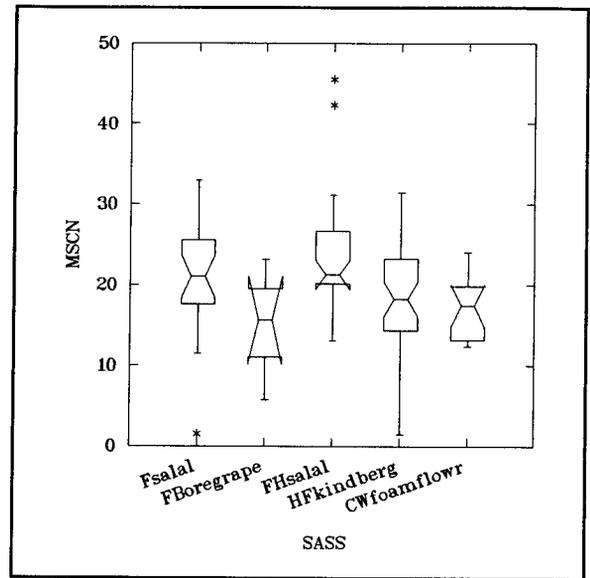


Figure 16 Mineral soil carbon: nitrogen ratio. Means L to R are; 21.14, 15.08, 23.42, 18.82 and 16.96.

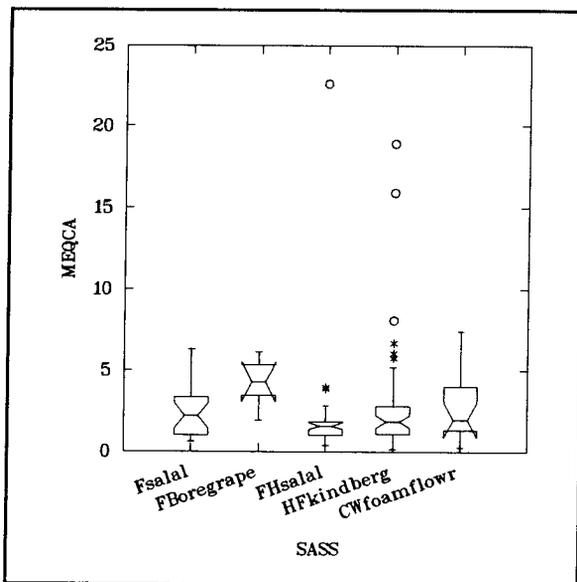


Figure 17 Mineral soil calcium concentration (meg). Means are L to R; 2.41, 4.24, 2.33, 2.94 and 2.64, with no significant differences detected at ($\alpha < .10$).

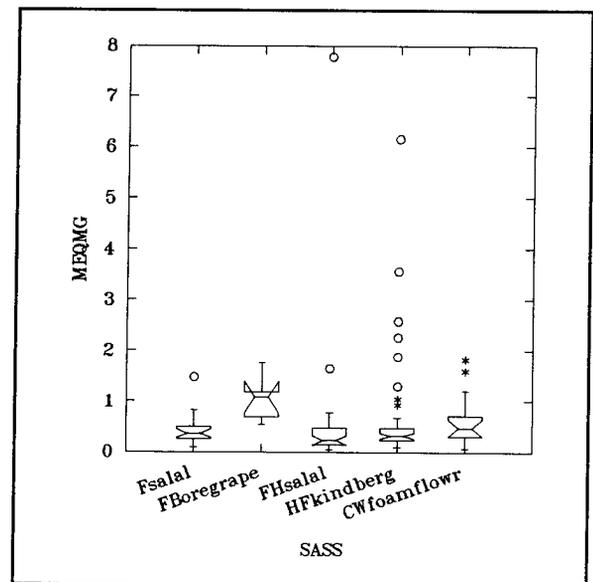


Figure 18 Mineral soil magnesium concentration (meg). Means L to R are; .42, 1.06, .56, .70 and .63, with no significant differences were detected at ($\alpha < .10$).

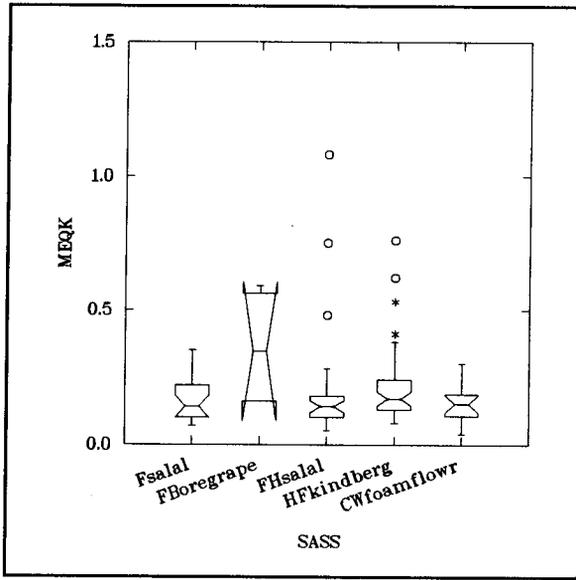


Figure 19 Mineral soil potassium concentration (meg). Means L to R are; .16, .36, .20, .22 and .15.

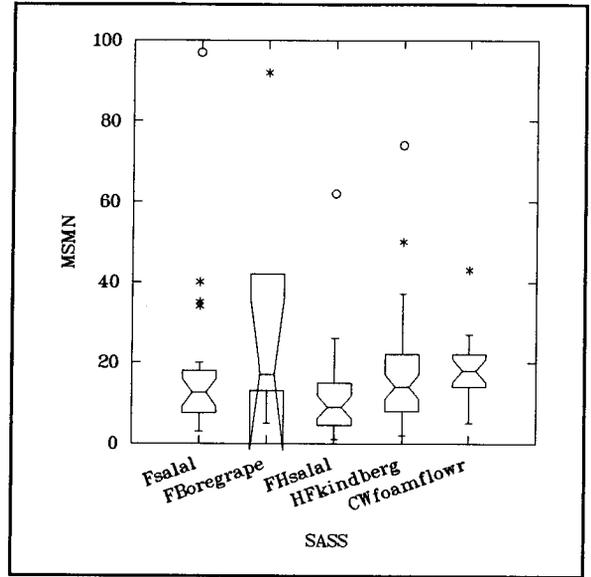


Figure 20 Mineral soil mineralizable nitrogen (ppm). Means L to R are: 17.5, 31.0, 11.6, 16.6 and 19.3. Note the substantial increase of MSMN across s.a.'s within CDFmm and CWHxm subzones.

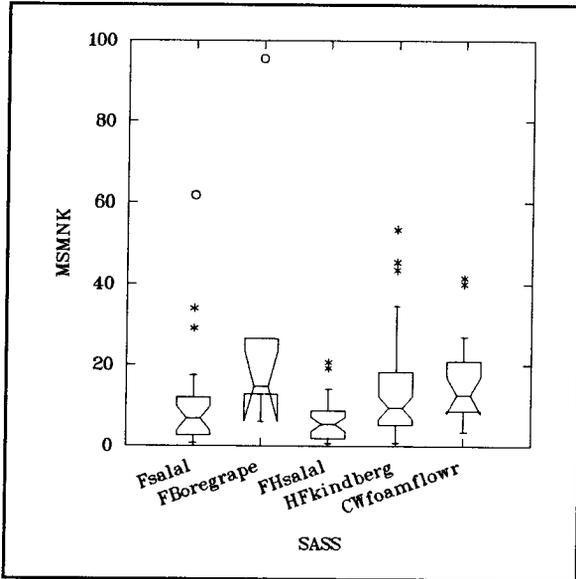


Figure 21 Mineral soil mineralizable nitrogen (Kg/ha). Means L to R are; 10.6, 28.4, 6.2, 13.1 and 15.7. Note the substantial increase of MSMNK across s.a.'s within the CDFmm and CWHxm subzones.

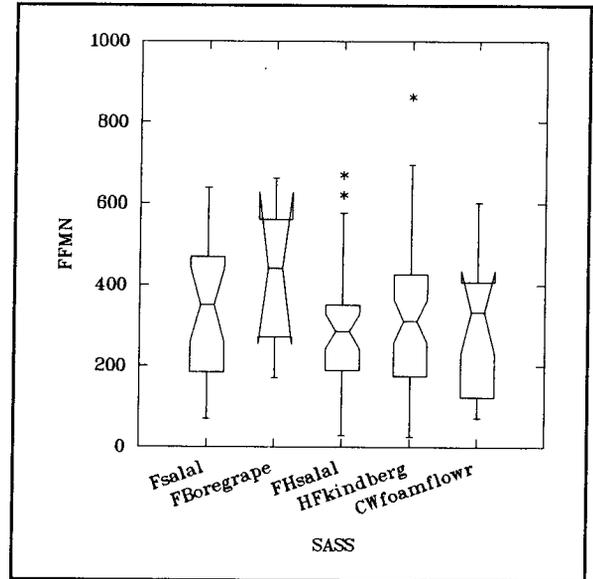


Figure 22 Forest floor mineralizable nitrogen (ppm). Means L to R are; 335, 424, 292, 316 and 306.

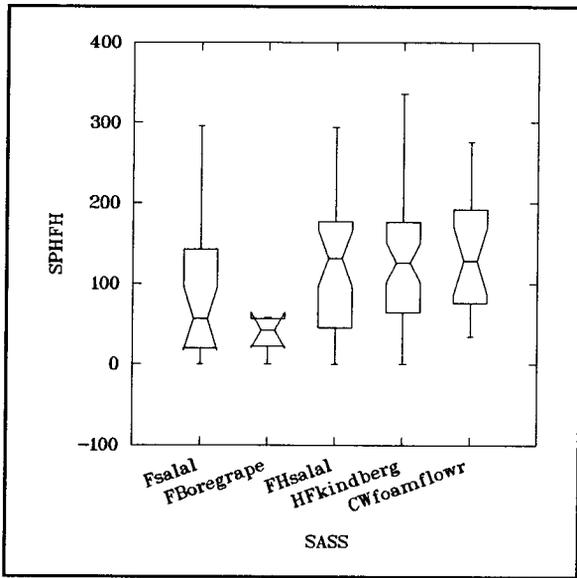


Figure 23 Old growth Douglas/fir and western hemlock stems (stumps)/ha. Means L to R are; 86, 37, 127, 128 and 138.

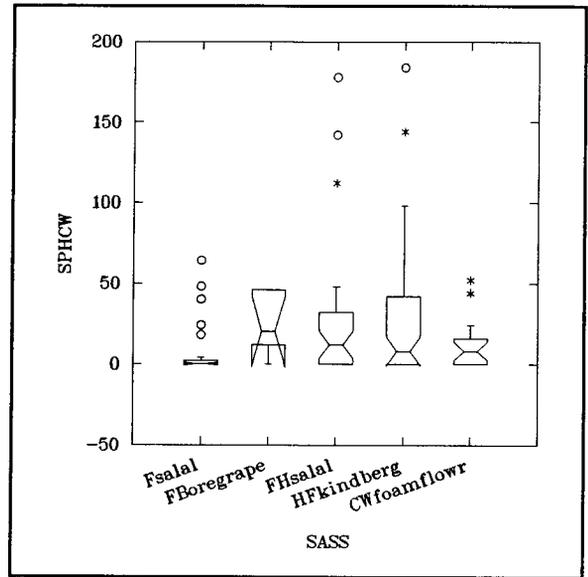


Figure 24 Old growth western red cedar stems (stumps)/ha. Means L to R are; 8, 24, 25, 26 and 13, with no significant differences detected at ($\alpha < .10$).

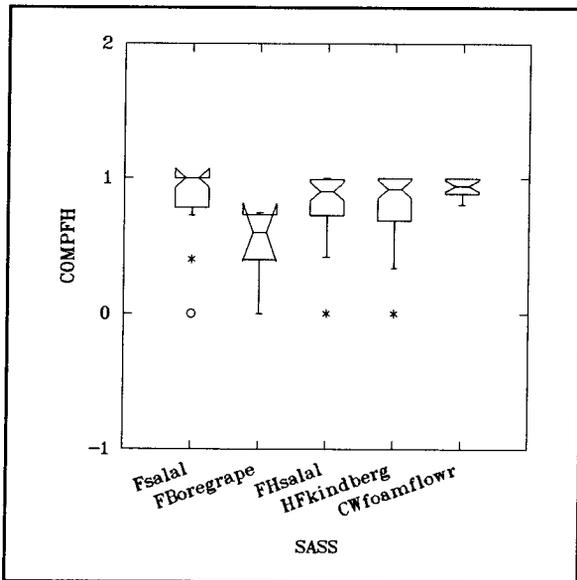


Figure 25 Old growth Douglas-fir and western hemlock species compositions. Means L to R are; .812, .511, .807, .824 and .937. *FdBg-Oregon grape* is significantly different from all s.a.'s at ($\alpha < .10$).

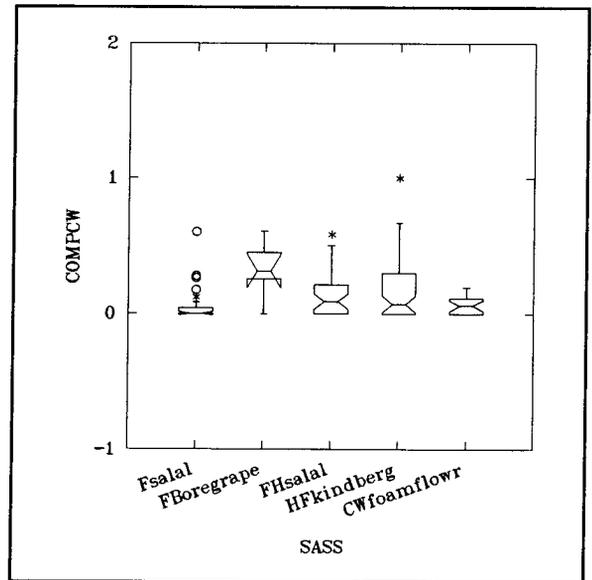


Figure 26 Old growth western red cedar species compositions. Means L to R are; .063, .323, .137, .158 and .063. *FdBg-Oregon grape* is significantly different from *Fd-Salal* and *Cw-Foamflower* at ($\alpha < .10$).

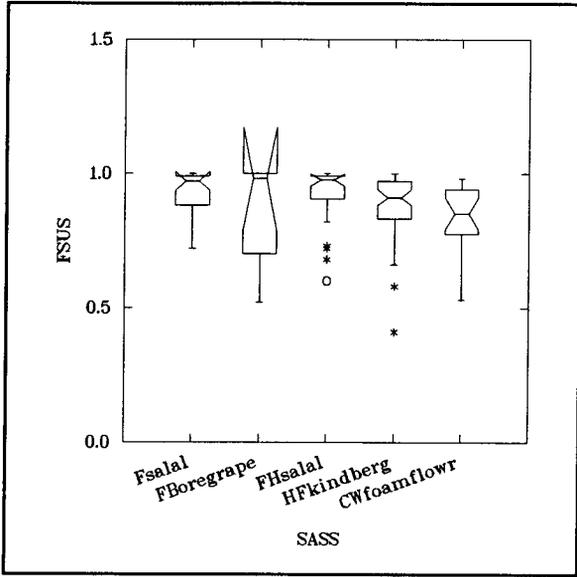


Figure 27 First PSP measure of Fd & Bg (susceptible) species composition. Means L to R are; .922, .863, .926, .875 and .834. Note the decreasing trend to FSUS with increasing soil moisture and nutrient regime.

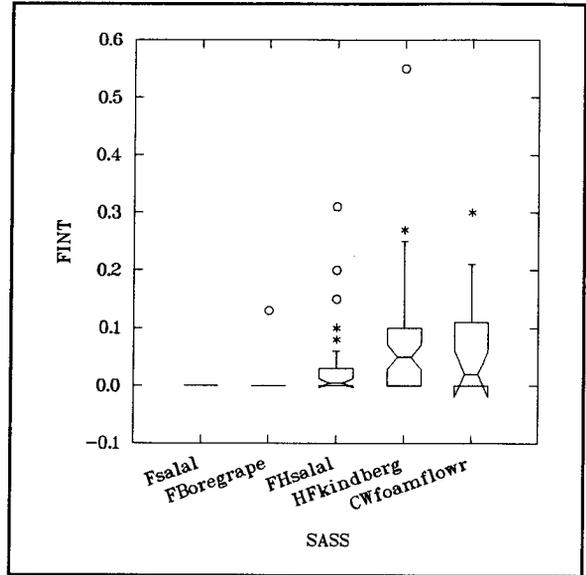


Figure 28 First PSP measure of Hw (intermediate) species composition. Means L to R are; 0, .022, .032, .07 and .064. Note the increasing trend with increasing soil moisture and nutrient regime.

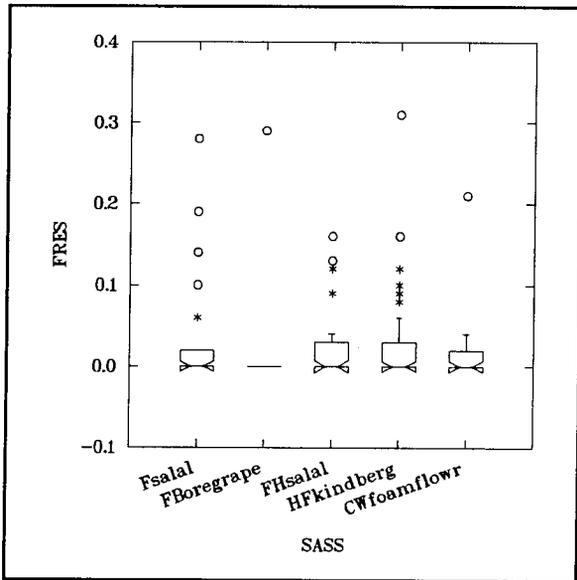


Figure 29 First PSP measure of PI, Pw and Cw (resistant) species composition. Means L to R are; .035, .048, .028, .027 and .019, with no significant differences detectable at ($\alpha < .10$).

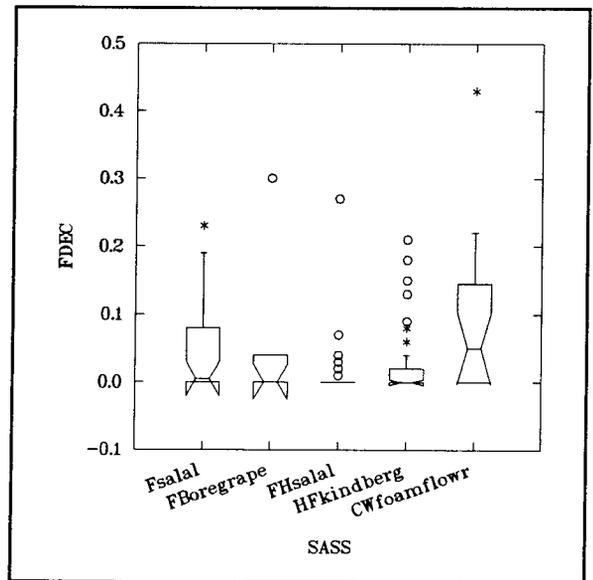


Figure 30 First PSP measure of Deciduous (resistant) species composition. Means L to R are; .043, .057, .014, .025 and .083. Note the significantly lower FDEC in the *FdHw-Salal* and *HwFd-Kindbergia* compared to the *Cw-Foamflower* ($\alpha < .10$).

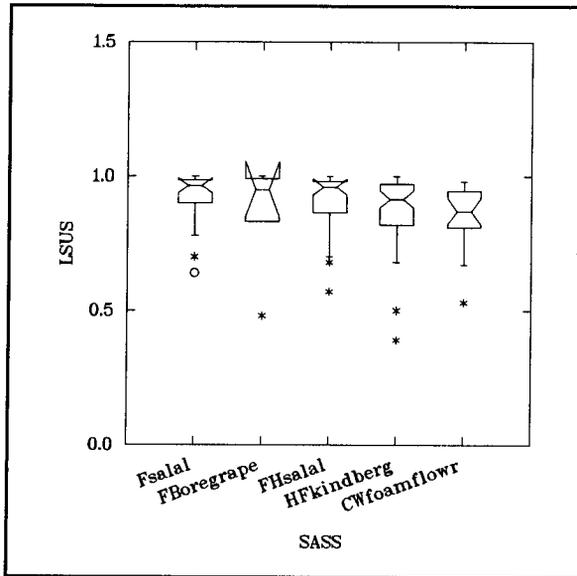


Figure 31 Last PSP measurement of Fd & Bg (susceptible) species composition. Means L to R are; .928, .867, .909, .870 and .857, with no significant differences

detected at ($\alpha < .10$). Note the similarity with FSUS.

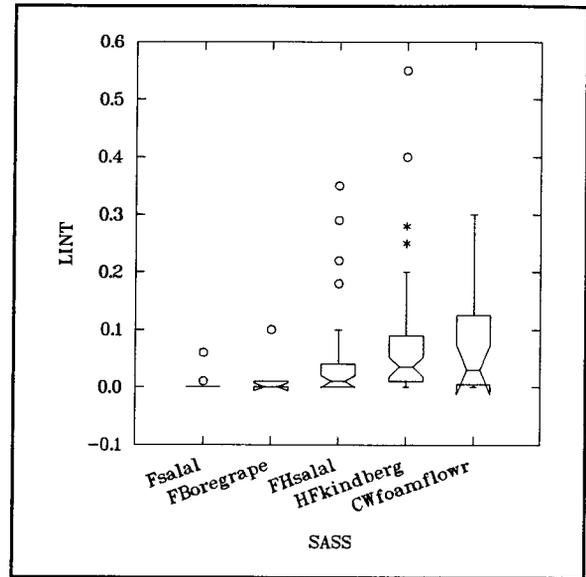


Figure 32 Last PSP measurement of Hw (intermediate) species compositions. Means L to R are; .003, .018, .043, .076 and .076. Fd-Salal is significantly different from HwFd-Kindbergia and Cw-Foamflower at ($\alpha < .05$). Note the similarity with FINT.

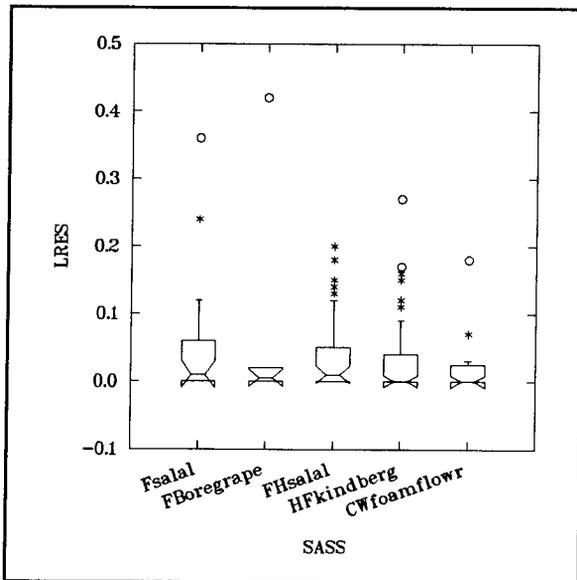


Figure 33 Last PSP measurement of PI, Pw & Cw (resistant) species composition. Means L to R are; .048, .075, .038, .035 and .020, with not significant differences

detected at ($\alpha < .10$). Note the similarity with FRES.

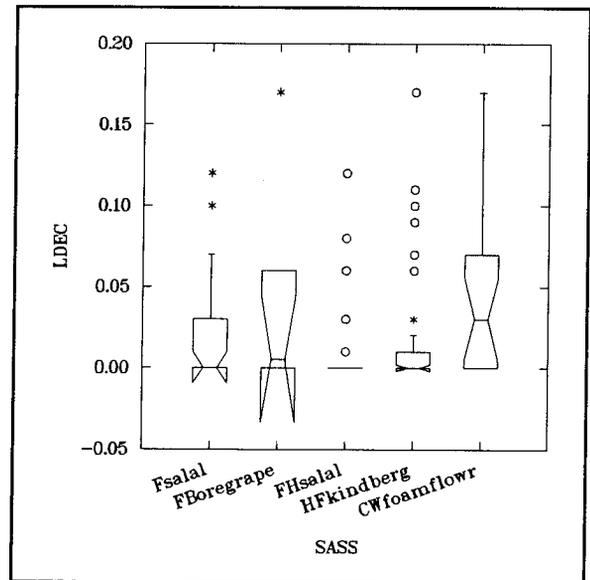


Figure 34 Last PSP measurement of deciduous species composition. Means L to R are; .021, .040, .009, .016 and .046. Note the similarity with FDEC.

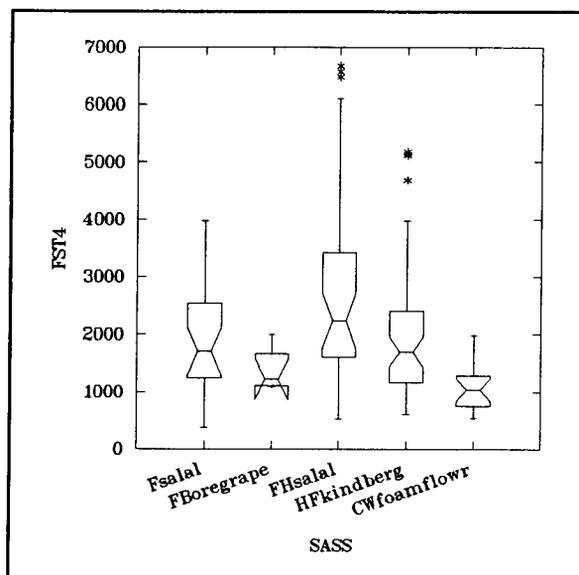


Figure 35 First PSP measurement of density (stems/ha) ≥ 4.0 cm. Means L to R are; 1 875, 1 379, 2 798, 2 001 and 1 072. *FdHw-Salal* is significantly different from *Fd-Salal* at ($\alpha < .05$), *FdBg-Kindbergia* and *Cw-Foamflower* at ($\alpha < .05$). The latter two site units were also significantly different at ($\alpha < .05$).

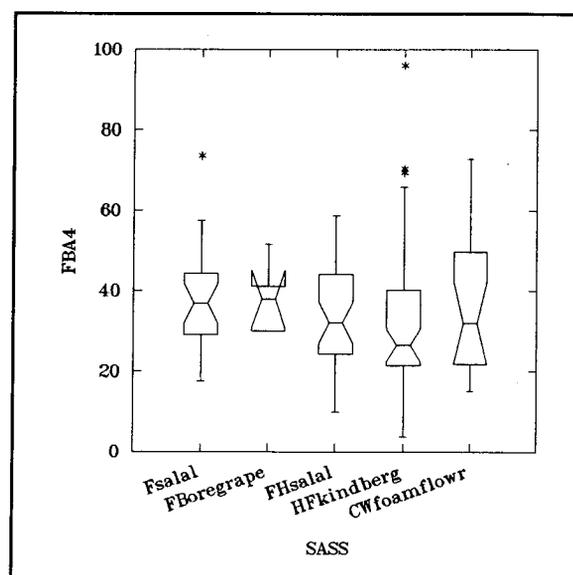


Figure 36 First PSP measurement of basal area (m^2/ha) ≥ 4.0 cm. means are L to R; 38.2, 38.1, 33.3, 32.7 and 36.9, with no significant differences detected at ($\alpha < .10$).

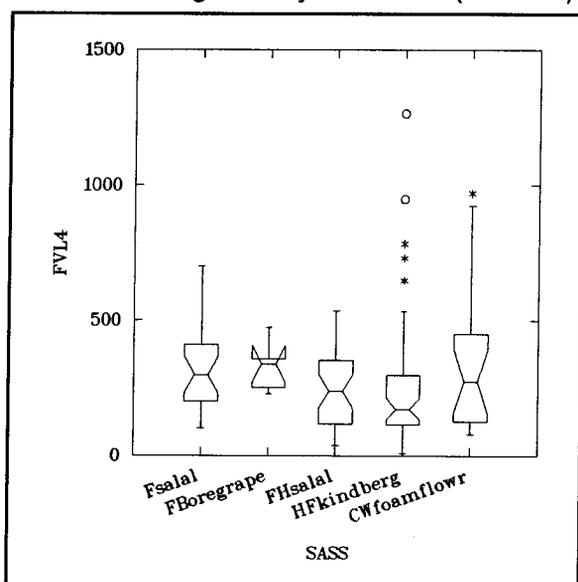


Figure 37 First PSP measurement of volume (m^3/ha) ≥ 4.0 cm. means L to R are; 319, 332, 246, 264 and 346, with no significant differences detected at ($\alpha < .10$).

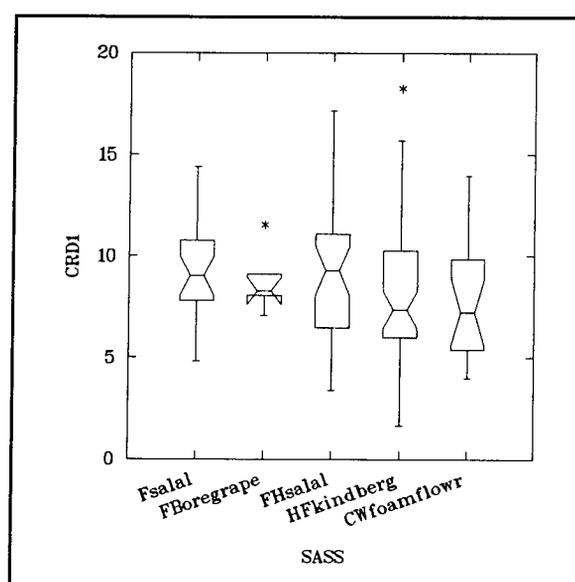


Figure 38 First PSP measurement of Curtis' relative density ≥ 4.0 cm. means L to R are; 9.1, 8.7, 9.0, 8.2 and 7.8, with no significant differences detected at ($\alpha < .10$).

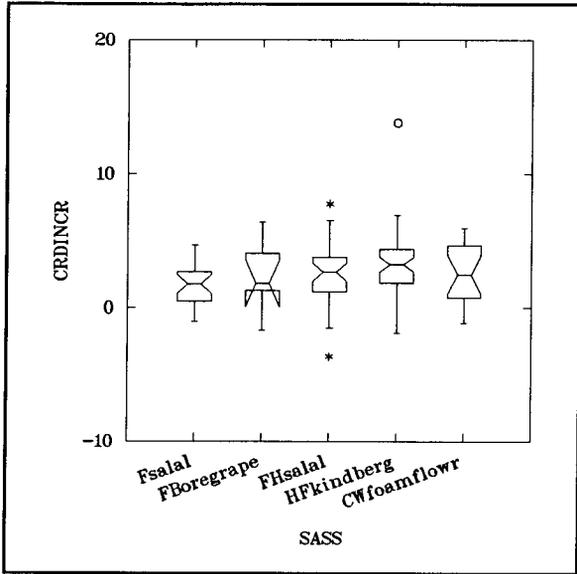


Figure 39 Curtis' relative density increment first-last PSP measurement ≥ 4.0 cm. means L to R are; 1.6, 2.3, 2.5, 3.3 and 2.7, with *Fd-Salal* significantly lower than *HwFd-Kindbergia* at ($\alpha < .05$).

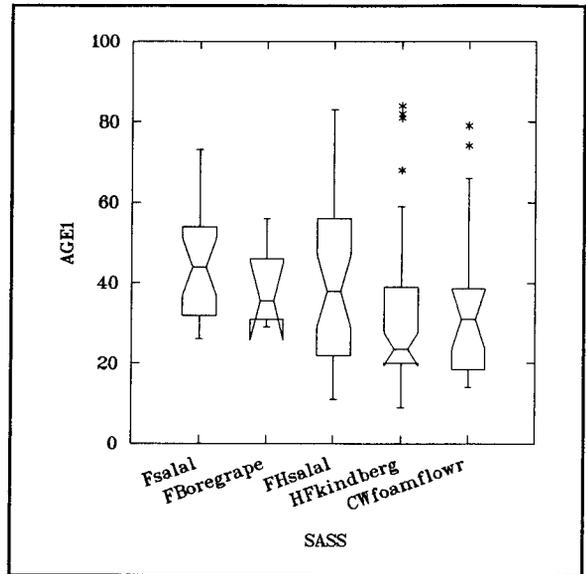


Figure 40 First PSP measurement of total age (yr). means L to R are; 45, 39, 39, 31 and 34, with *Fd-Salal* significantly greater in age than *HwFd-Kindbergia* at ($\alpha < .05$).

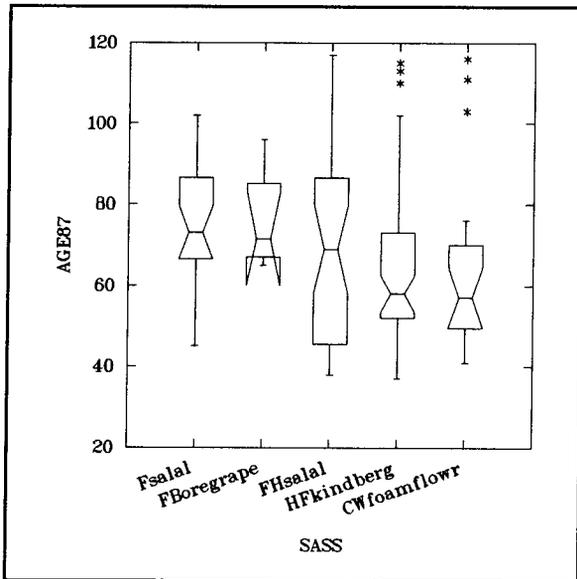


Figure 41 Last PSP measurement (approx. 1987) of total age (yr). means L to R are; 76, 76, 69, 62 and 64, with *Fd-Salal* significantly greater in age than *HwFd-Kindbergia* at ($\alpha < .05$).

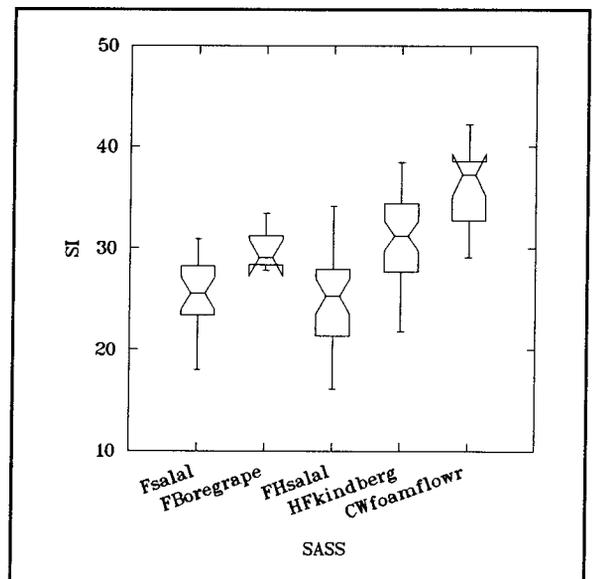


Figure 42 Site index, Bruces Douglas-fir ref. age 50 at breast-height. means L to R are; 25.4, 29.8, 24.9, 31.2 and 36.1, the only site units not differing significantly at ($\alpha < .05$) are *Fd-Salal*, *FdHw-Salal*, *FdBd-Oregon grape* and *HwFd-Kindbergia*.

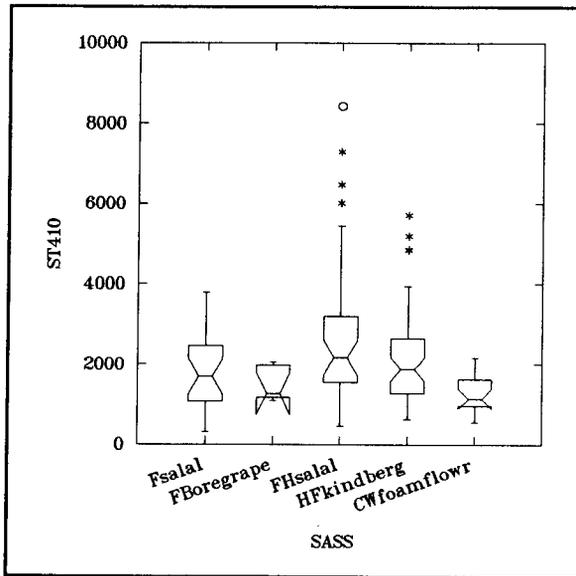


Figure 43 Estimated density (stems/ha), ≥ 4.0 cm at reference age 10 yr. Means L to R are; 1 853, 1 472, 2 801, 2 173 and 1 252, with *FdHw-Salal* significantly greater stems/ha than *Fd-Salal* ($\alpha < .05$) and *Cw-Foamflower* ($\alpha < .05$), and *HwFd-Kindbergia* is significantly greater than *Cw-Foamflower* at ($\alpha < .05$).

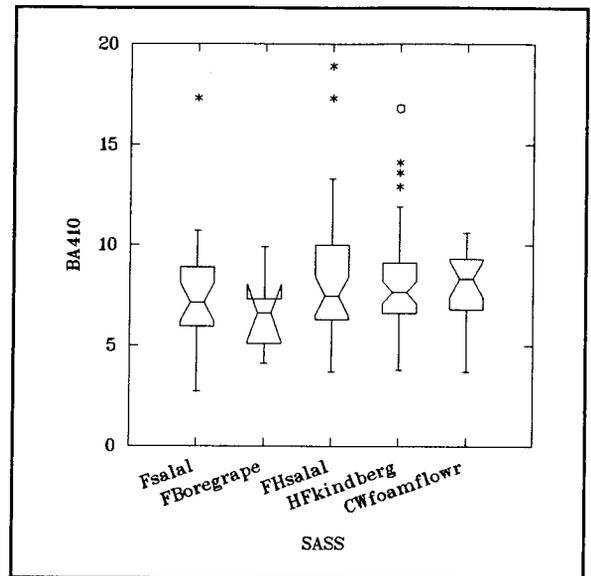


Figure 44 Estimated basal area (m^2/ha), ≥ 4.0 cm at reference age 10 yr. Means L to R are; 74, 6.6, 8.4, 8.2 and 7.8, with no significant differences detected at ($\alpha < .10$).

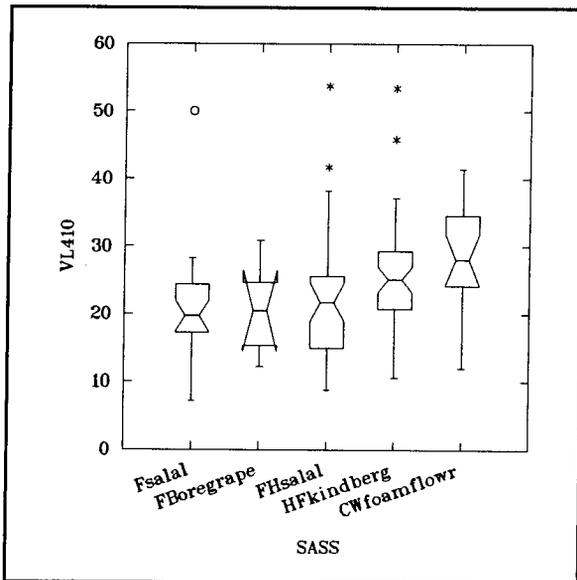


Figure 45 Estimated volume (m^3/ha), ≥ 4.0 cm at reference age 10 yr. Means L to R are; 21, 21, 22, 25 and 28, with *Cw-Foamflower* significantly different from *Fd-Salal*, ($\alpha < .05$) and *FdHw-Salal* at ($\alpha < .10$).

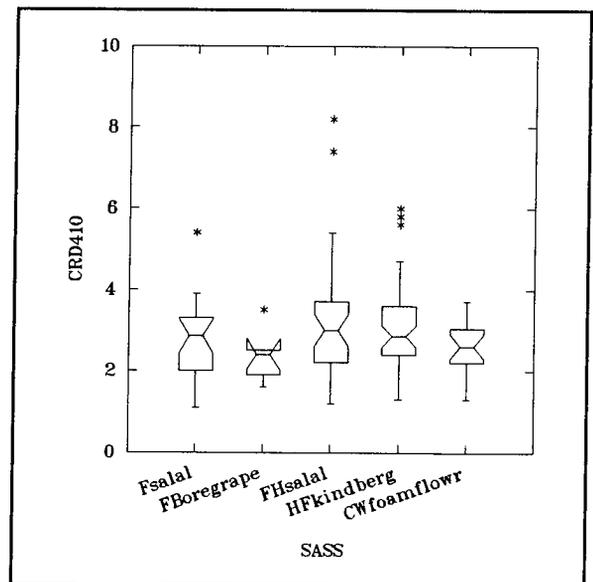


Figure 46 Estimated Curtis' relative density, ≥ 4.0 cm at reference age 10 yr. Means L to R are; 2.7, 2.4, 3.2, 3.0 and 2.6, with no significant differences detected at ($\alpha < .10$).

Appendix G

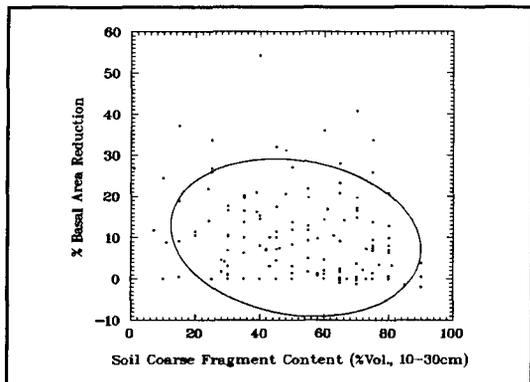
Illustration Of Selected Variables From
Pearsons Correlation

Figure 1(a)

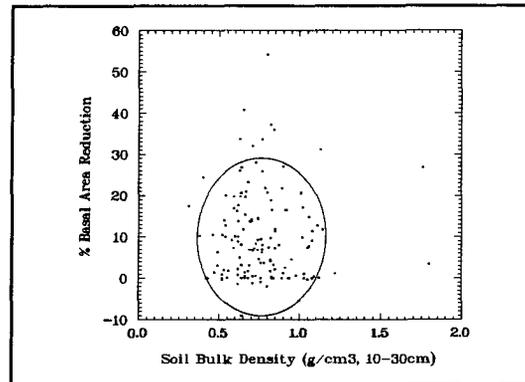


Figure 1(b)

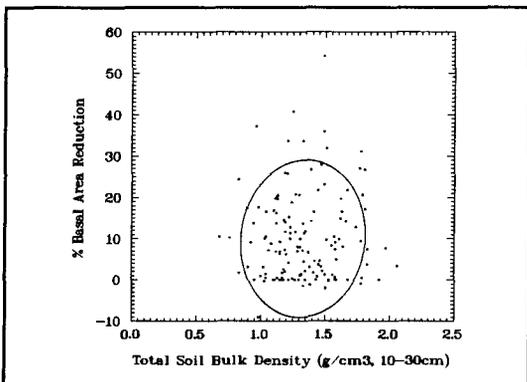


Figure 1(c)

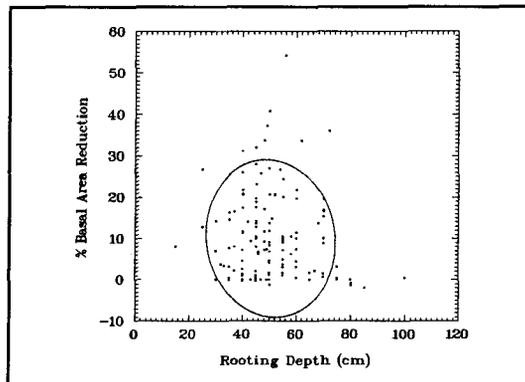


Figure 1(d)

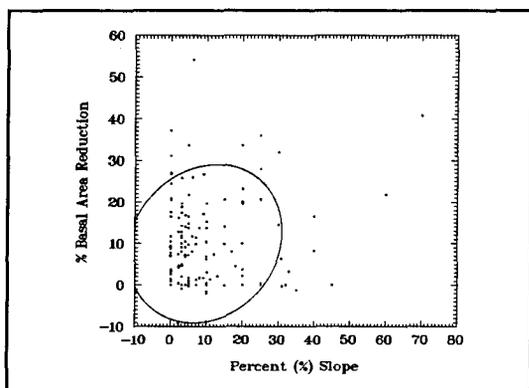


Figure 1(e)

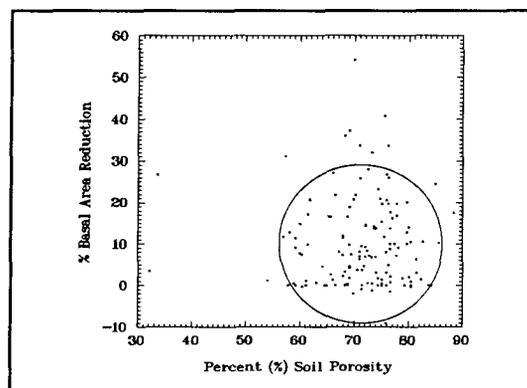


Figure 1(f)

Figure 1(a-f) Scatterplots of several thought-to-be important soil physical variables against % Basal Area Reduction-BARS. Figs. 1(a) CF20, (b) MSBDF, (c) MSBDT, (d) ROOTDP, (e) SLOPE, and (f) PORF. Gaussian 80% confidence ellipses are for interpretive aid only. Note the lack of correlation for all variables with the possible exception of % coarse fragment content.

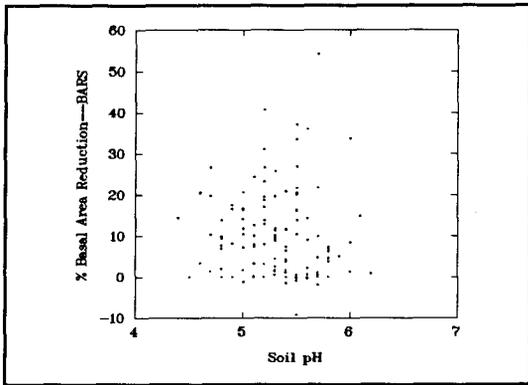


Figure 2(a)

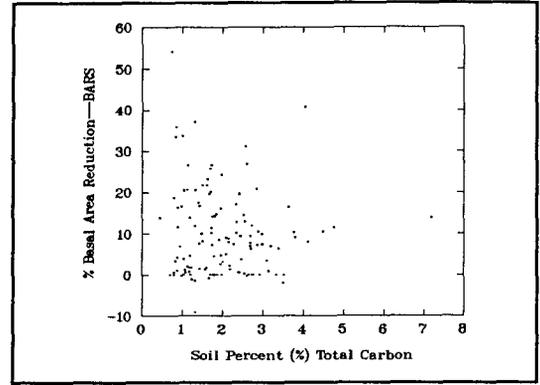


Figure 2(b)

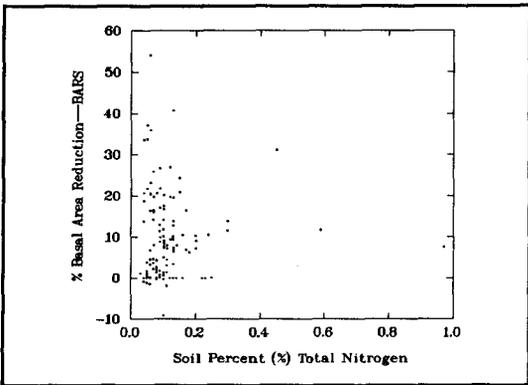


Figure 2(c)

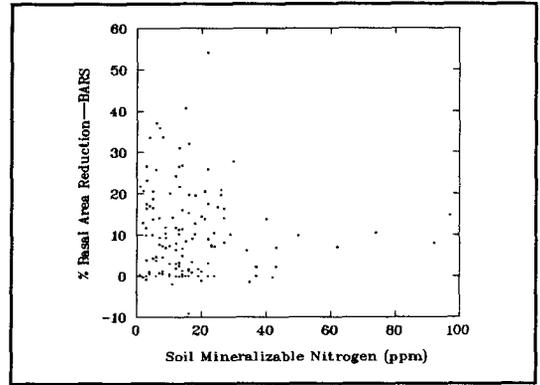


Figure 2(d)

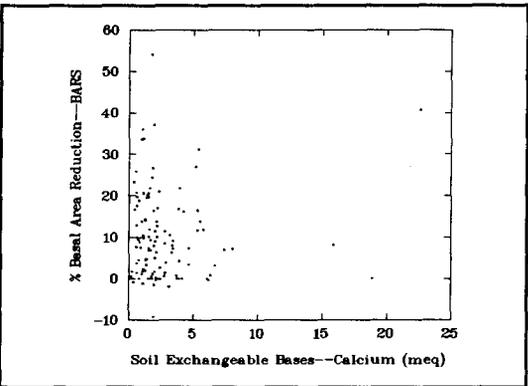


Figure 2(e)

Figure 2(a-e) Scatterplots of several thought-to-be important soil chemistry variables against % Basal Area Reduction-BARS; (a) MSPH, (b) MSC, (c) MSN, (d) MSMN and (e) MEQCA. Note the lack of correlation or trend, and outliers for virtually all variables.