

AN EVALUATION OF
THREE ROOT DISEASE SURVEY METHODS
FOR INTERIOR DOUGLAS-FIR STANDS

by

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Foreword

This Pest Control project was funded under the Intensive Forest Management program of the Canada - British Columbia Forest Resources Development Agreement (FRDA), 1985-1990, by the Province of British Columbia.

Results of the root disease surveys will be used to develop surveys for southern interior forests. However, opinions and recommendations of the report are those of the contractor, and are not necessarily those of the two governments nor FRDA management committee.

Anyone interested in more details should contact Protection Branch.

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Summary

In this study, three root disease survey methods were compared in terms of their relative efficiencies and were evaluated in terms of their suitability for the requirements of the Ministry of Forests and Lands. The three survey methods were: a line intercept method, a strip transect method and a fixed radius plot sampling method.

Two stem maps were constructed by recording the positions, disease conditions and other characteristics of trees on two selected Interior Douglas-fir stands. Simulated surveys on the two stem maps revealed that the plot sampling method was more precise than the other two methods. In timed field trials, the plot method was also faster to conduct, especially in conditions of intense root disease damage. Overall, the plot method was the most efficient for any desired level of precision.

These methods could be used to stratify stands in the Interior Douglas-fir biogeoclimatic zone by intensity of root disease damage. However, a point sampling method may be more efficient for this purpose.

From a planning perspective, particularly for the development of managed stand yield (volume) tables, re-evaluations of the Ministry's temporary and permanent inventory sample plots are implicated. The root disease surveys studied in this project do not appear to have application for this Ministry purpose, other than to stratify stands, as mentioned above.

From an operational perspective, these survey methods would need to be modified in order to add mapping capability.

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The author, however, assumes full responsibility for the contents of this report.

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I. INTRODUCTION

This report describes a F.R.D.A.¹ project which basically had two purposes. The first purpose was to compare three root disease survey methods in terms of their relative efficiencies. The second purpose was to determine the applicability of these surveys for the requirements of the Ministry of Forests and Lands.

More specifically, this project was designed to examine three ground-based survey methods that may be used to determine the intensity of root disease damage in mature Douglas-fir stands in the Interior Douglas-fir biogeoclimatic zone located in the southern Interior of British Columbia.

Root diseases, primarily *Phellinus weirii* (Murr.) Gilb. and *Armillaria obscura* (Pers.) Herink, are considered to be one of the most damaging groups of pests of Douglas-fir forests (Childs and Shea 1967; Wallis 1976; Nelson et al 1981; Thies 1984) and, therefore, have important implications for the Ministry's management of these forests.

From a planning perspective, root diseases, if not treated, will have a large but as yet unknown impact on the volumes that can be expected from regenerated Douglas-fir stands in this zone. If treated, the mitigated impact of root diseases may represent a significant source of enhanced wood volume from these forests. In turn, the expected volumes from these forests will influence the current and future rates of harvest in the southern Interior of B.C. Accurate estimates of root disease impacts in currently mature stands are needed in order to estimate the enhanced yields in treated regenerated stands, by means of projections.

From an operational perspective, the main opportunity for the treatment of root diseases occurs at the time of site preparation for reforestation. Again, accurate and cost effective surveys are needed in mature stands just prior to harvest in order to determine which sites and which portions of sites are to be treated for root diseases in preparation for the new crop of trees.

1. Canada-British Columbia Forest Resource Development Agreement.

In the development of a root disease survey method, the manifestation of root disease damage in stands (ie. infection "centers") presents two statistical problems. Firstly, root disease centers are highly variable in their spatial distribution among stands; they can be "random or clumped" (Bloomberg *et al.* 1980a). This limits the choice of possible survey methods. Secondly, "the deterioration and disappearance of root rot-killed trees over time" (Bloomberg *et al.* 1980a), indicates that standing trees are an unreliable parameter for sampling root disease damage.

Various root disease survey methods have been examined in the past. Foster and Johnson (1963) determined that sampling with 20-tree quadrats resulted in large coefficients of variation that, therefore, would have required very intense sampling in order to increase the precision. In a study of several possible methods, Waters (1978) concluded that it was impossible to construct decision boundaries for a sequential sampling graph without an understanding of the mathematical distribution of root diseases in affected stands. A previous decision boundary graph for infected coastal stands (Blair *et al.* 1976) was discovered by Waters (1978) to have been constructed "without any consideration of the population distribution." In effect, the aggregated, but variable, distribution of root disease centers in stands precludes the use of sequential sampling techniques by statistical invalidation. Although non-randomly spaced (ie. clumped) parameters can be sampled with sequential sampling techniques, the *particular* degree of non-randomness must not change (Green 1979). This requirement cannot be assumed for the distribution of root diseases among different stands, as Waters (1978) inferred and as implied by Bloomberg *et al.* (1980a) in their observation that "the distribution of infection centers in a stand may be random or clumped." Attempts to use prism plots to estimate root disease impacts in second growth Douglas-fir stands (Blair *et al.* 1976) were determined by Waters (1978) to be biased due to the non-random placement of the first plots. Waters (1978) also concluded that prism plot sampling gave unacceptably large sampling errors. This method is also potentially biased due to its

inability to directly measure the major component of root disease damage (ie. trees that have deteriorated and disappeared). In a comparison of prism plots and strip transects, Waters (1978) concluded that the percent of basal area infected was significantly lower than the percent of transect area infected (at 70% level of confidence). In addition, none of these three methods was capable of providing a map of the distribution of disease centers in a stand for operational purposes.

The line intercept method of surveying for root diseases was developed by the Canadian Forestry Service (Bloomberg *et al.* 1980a and 1980b) for use in coastal stands and with the intention of overcoming some of these sampling problems. The method has been streamlined for use in the B.C. Forest Service (Beale and Wood 1985) and has been extensively used in the Vancouver Forest Region (J. Beale, pers. comm.). However, the applicability of this survey method for Interior conditions has been questioned, as root diseases are known to manifest their impacts differently in Interior stands as compared to coastal stands (H. Merler, D. Morrison, J. Muir, pers. comm.).

Another root disease survey method, involving the sketch mapping of disease centers and 100% coverage of the surveyed site, is used for operational purposes on the coast but has been considered to be too imprecise for Ministry planning purposes (J. Beale, pers. comm.).

This project has examined in detail three root disease survey methods in terms of efficiency and effectiveness for meeting the Ministry's planning and operational purposes.

The line intercept method was chosen for this study partly to test its applicability for use in Interior stand conditions and also partly as a basis for comparison for the other two possible survey methods.

The strip survey method was also chosen, as this method is widely used in the B.C. Forest Service for a number of forest pests that are also known to have clumped distributions. Notably, mountain pine beetle (*Dendroctonus ponderosae*), spruce beetle

(*Dendroctonus rufipennis*) and spruce weevil (*Pissodes strobi*) are surveyed with this method (Carlson *et al.* 1984; B.C.F.S. 1985). The strip method has been used by Waters (1978) to estimate the proportion of stand area infected in coastal stands. It also has been proposed as a method specifically for surveying for root diseases in Interior stands (Curran and Shulting 1986).

In strip surveys for insect damage, the proportion of affected trees relative to healthy trees is determined within a (usually) 10 metre wide strip. However, in the application of this method to surveying for root disease damage, as tested in this project, the proportion of area in root disease "centers" is determined within the 10 metre strip width.

Fixed radius plot sampling was also chosen as a possible method. Fixed radius plot samples are widely used in silvicultural surveys in the B.C. Forest Service. Regeneration surveys, survival surveys, regeneration performance assessments and several stand tending surveys, for example, use fixed radius plots (R. Knotts, pers. comm.). For this project, the proportion of the plot area that was in a root disease "center" was recorded.

II. METHODS

The three survey methods were compared by running simulated surveys on stem maps produced from field data collected in two Douglas-fir stands in the Interior Douglas-fir Zone (IDF) in the Kamloops Forest Region, as described below.

A. Stem maps

Two Douglas-fir stands in the IDF were selected for stem mapping on the basis of the following criteria:

- a) The species component must be predominantly Douglas-fir, as this is the key species in the IDF and is more susceptible to the two primary root diseases than most of its sympatric species.

b) The stand must be in a mature age class, as mature stands will be the main target of Ministry root disease surveys for planning and operational purposes.

c) The stand must be approximately five hectares in size, or larger, in order to allow room for a reasonably large stem map to be produced.

d) The stand must contain at least a "typical" proportion of root disease damaged area. (This criterion was confirmed by forest pathologists from the Ministry's Protection Branch and/or Kamloops Forest Region.)

e) The stands must have minimal, or no, disturbance from previous selective logging. Since root diseases and selective logging both can create disturbances within a stand, the survey methods should preferably be tested only on their ability to estimate disturbances created by root diseases, as this is their intended purpose.

f) Preferably the stands should be easily accessible.

Two stands were stem mapped. One stand is located near Allison Lake, south of Merritt, B.C., in the transition between the "Dry Sub-montane Interior Douglas-fir" (IDFc) subzone and the "Dry Western Montane Interior Douglas-fir" (IDFd) subzone. The other is located in Turtle Valley, southeast of Chase, B.C., in the "Shuswap Highlands Moist Interior Douglas-fir" (IDFj) subzone.

The stem maps were produced by running parallel transects, spaced at 10 metre intervals, over the chosen stands. Each conifer that was 17.5 cm d.b.h. or larger and within 5 metres on either side of the transect line, was mapped by using two coordinates: the measured distance along the transect and a visual estimate of distance (0 to 5 metres) from the transect line at a right angle. For each tree mapped, the following attributes were recorded and are represented on the stem maps in coded form:

a) Tree species.

b) D.B.H. class: small (17.5 - 30 cm), medium (31 - 50 cm) or large (greater than 50 cm).

c) Condition: healthy; visually symptomatic of root disease infection; dead standing; or dead and recently down (bark firm and intact). Large old stumps that had obviously been colonized by root diseases were also recorded as indications of stand history, but were not used to define current root disease centers.

d) Species of root disease in affected trees.

Root disease "centers" were identified on the stem maps and in the field trials by roughly using the definition of root disease centers as employed in coastal stands. This definition is: "straight lines joining the inner faces of healthy-appearing, margin trees" (Bloomberg *et al.* 1980b). As discussed later in this report, this definition has limited applicability for Interior Douglas-fir stands due to the diffuse and indiscrete distribution of root disease damage in these stands. Consequently, some of the "center" boundaries on the stem maps were chosen almost arbitrarily.

B. Survey methods

The three survey methods chosen for this study are described as follows:

1. Line intercept method

This method was developed by the Canadian Forestry Service (Bloomberg *et al.* 1980a and 1980b) and has five increasingly complex variations. The "Intersection Length Method - Mapping Option" was one of them. It was chosen by the B.C. Forest Service as the simplest and fastest to use for Ministry purposes and was streamlined for Forest Service use (Beale and Wood 1985). It was also chosen for examination in this study. In this method several transects are run through the stand to be surveyed. Each transect has no width. The portions of each transect that are intercepted by root disease centers are recorded. In this manner, each transect is one sample of the stand and gives an estimate of the proportion of the area of the stand that is included in root disease centers. The transects are usually grouped into systematic "grids" in

which case each "grid" becomes a sample of the stand. The first transect for each survey has a random starting position along a baseline, with each subsequent transect being systematically spaced at roughly 50 to 70 m intervals, depending on the size of the stand (Beale and Wood 1985).

2. Strip method

The strip method used in this study consisted of 10 metre wide transects. Several transects are run through the stand and each transect represents one sample of the stand. In the application of this method to root disease sampling, the area of each strip that is contained in root disease centers is recorded. In this manner the survey estimates the total proportion of the area in the stand that is contained in root disease centers. In this survey method a random starting position between 0 and 50 metres is chosen for the first transect. Subsequent transects are spaced at 50 metre fixed intervals.

3. Fixed radius plot samples

In this study, 5 metre fixed radius plot samples were chosen. This radius produces the same width as the 10 metre wide strips described above, thereby minimizing the source of variation between the methods studied. Plots are spaced along transects. The starting position for the first transect is randomly chosen, as in the strip survey, with subsequent transects being spaced at fixed intervals (50 m). The position of the first plot on the first transect is randomly spaced between 5 and 45 metres along the transect line with subsequent plots placed at 50 metre fixed intervals from the first plot.

C. Simulations

Ten surveys of each of the three survey methods were simulated on each of the two stem maps, for a total of sixty complete surveys.

For the line intercept method, the simulated surveys used transects spaced at 50 m intervals. The first transect for the first survey started at 5 m from the stand edge. Each subsequent survey started 5 m further from the stand edge, with final of the ten surveys starting at 50 m from the stand edge. In this manner, the statistical requirement for a random start to each survey was approximated. With a limited number of simulations, this process intentionally spread each group of 10 starts among the 50 possible starting positions for the purpose of reducing unnecessary variation. This procedure effectively examines one out of every five possible random starts. The Turtle Valley stand was 200 x 250 m (5.0 ha) in size. Five transects of 200 m each were run through the width of the stand on each survey. The Allison Lake stand was 150 x 300m (4.5 ha) in size. Six transects of 150 m each were run through the width of the stand on each survey.

For the strip method, the strips were spaced at 50 m intervals, as in the line intercept method. The first strip for each survey was positioned the same manner as for the line intercept method. On the Turtle Valley stem map, five strips of 10 x 200 m each were run in each of the ten surveys. On the Allison Lake stem map six strips of 10 x 150 m each were run in each survey.

For the plot sampling method, lines were run at 50 m intervals as in the previous two surveys. Along each line, 5 m fixed radius plots were placed at 50 m intervals. The starting point for the first line of each survey was positioned in the same manner as for the previous two survey methods. The first plot in the first line of the first survey on each stem map was placed 5 m from the stand edge, with each subsequent first plot for each survey being 5 m further along the first line. On the Turtle Valley stem map, there were 5 lines with 4 plots each for a total of

20 plots in each of the ten surveys. On the Allison Lake stem map there were 6 lines of 3 plots each for a total of 18 plots in each of the ten surveys.

As can be seen from the above descriptions of the simulated surveys, the choice of a standard 50 m interval between transects, strips and lines of plots optimized the comparison of these survey methods by minimizing a source of variation among them.

D. Timed field surveys

All three survey methods were timed in field trials. The surveys were timed in three stands with different intensities of root disease damage but otherwise similar terrain. One stand had no visible root disease damage; the second had approximately 10% of the area in root disease centers; the third had 53% of the area in root disease centers. For each of the nine surveys (three survey methods in each of three stands), the time taken to conduct 2000 metres of survey was recorded.

E. Data analysis

The accuracy of the simulated surveys was evaluated by two methods. Firstly, the averages of the six groups (three survey methods by two stands) of ten surveys each were compared among themselves (Student's t-test). Secondly, the true populations (percentage of area in root disease centers) for the two stands were determined by using a planimeter. The averages for the six groups of ten surveys were then compared to the true populations (Student's t-test). With these two approaches, the three survey methods were evaluated for accuracy and, therefore, evaluated for possible bias.

The precision of the surveys was also evaluated by two methods. Firstly, the standard deviations and the 95% confidence limits of the three methods were

compared. In this comparison, the line intercept method was evaluated by using each transect as a sample of the stand and also by grouping the transects into grids, as recommended by Bloomberg, *et al.* (1980b). Secondly, for each of the methods and for each of the two stands, the required sample sizes for desired precisions were determined at the 95% confidence level. These were calculated from the following formula for simple random sampling:

$$n = \frac{t^2_{(n-1)} S^2}{D^2}$$

where: t = Student's t -value with $n-1$ degrees of freedom

S^2 = the average variance for the area and sampling method

D = desired precision (eg. 5%)

The relative field times that would be required to achieve the desired levels of precision were determined by calculating from Table 6 the time that would be required to place the number of samples for each desired level of precision (from Table 5). The results are presented in Table 7.

III. RESULTS

A. Accuracy

By comparing the averages of the six groups of ten surveys each (Table 3), no significant differences were determined ($p = 0.05$). By comparing each of the averages of the six groups of ten surveys to the true populations (Table 4), no significant differences were determined ($p = 0.05$). From these analyses, it can be concluded that none of the three survey methods is biased and, therefore, all will accurately estimate the true population.

B. Precision

By comparing the standard deviations of the means of the six groups of ten surveys each and the standard deviations of their 95% confidence limits (Tables 1 and 2) it can be seen that the plot method has greater precision than the other two methods. The strip method, in turn, revealed greater precision than the line intercept method. Within the line intercept method, the calculation of means by using only lines was more precise than when the data was grouped into grids, mostly due to the reduced degrees of freedom, as is discussed in section IV. The precisions of the three methods are presented in Table 5 as the sample sizes that would be required to achieve precisions of 5%, 10%, 15% and 20% on each of the two stands tested.

C. Efficiency

Timed field trials of the three survey methods indicated that when no root disease was visibly present in the stands, all three survey methods were conducted at essentially the same rate (time per 1000 m of line, see Table 6). For the lightly infected stand (approximately 10%), the plot method was conducted at essentially the same rate as in the disease-free stand. The line intercept method was perhaps slightly slower, and the strip method was slower again. In the heavily attacked stand (53%), all three methods took more time to conduct. The strip method, however, took nearly twice as much time per 1000 m as did the plot method. The line intercept method took longer than the plot method but somewhat less time than the strip method.

TABLE 1
95% Confidence Limits - Turtle Valley Stand

Survey No.	Plot Method	Strip Method	<u>Intersect Method</u>	
			Lines	Grids
Observations	20	5	4	2
t - value	2.09	2.78	3.18	12.71
1	66.00 ± 19.73	70.95 ± 24.16	72.31 ± 32.85	72.31 ± 30.38
2	67.00 ± 20.80	71.13 ± 35.53	73.44 ± 38.35	73.44 ± 111.21
3	70.50 ± 20.80	64.43 ± 35.19	72.50 ± 29.42	72.50 ± 60.63
4	60.50 ± 22.01	63.18 ± 35.67	57.00 ± 36.63	57.00 ± 307.96
5	62.00 ± 20.50	60.40 ± 37.45	63.19 ± 32.31	63.19 ± 228.02
6	68.00 ± 17.79	71.73 ± 29.47	69.38 ± 50.88	69.38 ± 402.14
7	64.50 ± 19.21	67.90 ± 34.97	68.69 ± 52.85	68.69 ± 275.17
8	67.50 ± 19.06	63.00 ± 35.81	69.19 ± 56.13	69.19 ± 230.31
9	66.00 ± 19.69	62.55 ± 38.75	65.88 ± 47.22	65.88 ± 271.87
10	72.50 ± 16.05	64.85 ± 23.82	56.13 ± 54.03	56.13 ± 413.46
Mean	66.45 ± 19.49	66.01 ± 33.08	66.77 ± 43.06	66.77 ± 233.12
Stand. dev.	3.59 1.65	4.10 5.35	6.21 10.20	6.21 131.54

Actual population mean = 66.44%

TABLE 2

95% Confidence Limits - Allison Lake Stand

Survey No.	Plot Method	Strip Method	<u>Intersect Method</u>	
			Lines	Grids
Observations	18	6	6	3
t - value	2.11	2.57	2.57	4.30
1	56.11 ± 21.40	48.53 ± 22.54	45.50 ± 18.84	45.50 ± 38.70
2	56.11 ± 21.67	62.94 ± 20.25	66.22 ± 23.82	66.22 ± 77.27
3	61.67 ± 21.27	59.64 ± 20.35	52.67 ± 19.79	52.67 ± 33.08
4	61.11 ± 19.90	50.72 ± 25.34	46.37 ± 31.20	46.37 ± 34.10
5	59.44 ± 20.93	44.58 ± 28.91	44.72 ± 26.65	44.72 ± 56.63
6	53.33 ± 19.98	55.53 ± 19.81	43.50 ± 28.19	43.50 ± 50.22
7	50.56 ± 21.08	63.97 ± 22.23	46.39 ± 22.69	46.39 ± 36.38
8	46.11 ± 19.39	55.42 ± 18.99	65.67 ± 20.71	65.67 ± 60.20
9	65.56 ± 18.95	46.19 ± 29.81	60.50 ± 20.53	60.50 ± 57.45
10	54.44 ± 22.79	45.31 ± 26.63	49.72 ± 26.52	49.72 ± 51.56
Mean	57.44 ± 20.74	53.28 ± 23.49	53.02 ± 23.89	53.02 ± 49.56
Stand. dev.	5.47 1.17	7.27 3.93	8.50 4.10	8.50 14.14

Actual population mean = 53.15%

TABLE 3

Comparison of Averages
(t-tests)

	<u>Turtle Valley</u> (t-values)*			<u>Allison Lake</u> (t-values)*		
	<u>Plot</u>	<u>Strip</u>	<u>Line</u>	<u>Plot</u>	<u>Strip</u>	<u>Line</u>
Plot	-	-	-	-	-	-
Strip	0.26	-	-	1.45	-	-
Line	0.14	0.32	-	1.38	0.07	-

* Critical t-value with $p = 0.05$ and 18 degrees of freedom = 2.10

TABLE 4

Comparison of Averages with Population Average
(t - tests)

<u>Sampling Method</u>	<u>Turtle Valley</u>			<u>Allison Lake</u>		
	<u>Calculated t-value</u>	<u>Critical t-value</u>	<u>Remark</u>	<u>Calculated t-value</u>	<u>Critical t-value</u>	<u>Remark</u>
Plots	0.001	2.09	ns	0.436	2.11	ns
Strips	-0.036	2.78	ns	0.014	2.57	ns
Lines	0.024	3.18	ns	-0.013	2.57	ns

Population averages: Turtle Valley = 66.44%; Allison Lake = 53.15%

ns = estimation mean is not significantly different from the population mean

TABLE 5

Required Sample Sizes for Desired Precisions
(at 95% level of confidence)

<u>Precision</u>	<u>Turtle Valley</u>			<u>Allison Lake</u>		
	<u>Plots</u>	<u>Strips</u>	<u>Lines</u>	<u>Plots</u>	<u>Strips</u>	<u>Lines</u>
5%	280	111	120	279	82	85
10%	70	29	31	70	22	23
15%	31	15	16	31	11	12
20%	19	9	10	19	8	8

TABLE 6

Times for Survey Field Trials
(hours per 1000m of transect)

	<u>Plot Method</u>	<u>Strip Method</u>	<u>Intercept Method</u>
Stand 1 (0% infection)	0.82	0.80	0.78
Stand 2 (10% infection)	0.83	1.08	0.92
Stand 3 (53% infection)	1.25	2.47	1.95

TABLE 7
Efficiencies of Surveys*
 (hours for required sample sizes)

<u>Precision</u>	<u>Plots</u>	<u>Strips</u>	<u>Lines</u>
5%	17.44	30.38	24.86
10%	4.75	8.15	6.73
15%	1.94	4.08	3.51
20%	1.19	2.96	2.34

* This example is calculated for the Allison Lake stand (4.5 ha @ 53% infection)

By calculating the time required to achieve a desired level of precision (Table 7) from the data in Tables 5 and 6, it can be concluded that the plot method is superior to the other two methods, due to the combination of its greater precision and its greater speed in field use.

IV. DISCUSSION

A. Efficiency of the three survey methods

1. Accuracy

None of the averages of the simulated surveys was significantly different from the other averages, nor from the actual proportions of infected areas on the stem maps, indicating that none of the three methods is biased.

Nevertheless, the average for the plot surveys in the Allison Lake stand is noticeably different from the other two averages for that stand, and from the actual proportion of infected area (see Table 2), even though it is not a

significant difference at a 95% level of confidence. It is presumed that the slight difference is an aberration of the method used to simulate the surveys. The intentional spread of the simulations over the range of possible random starting positions tended to concentrate plot samples in portions of the stem maps. A separate trial of ten surveys on the Allison Lake stem map, using the plot method but with completely random starts, gave an average of 51% of the area infected (actual area infected by planimeter reading was 53.15%) and had a similar standard deviation. This implies that the original average of 57.44% for the plot samples on this stem map was perhaps a slight aberration.

2. Precision

In this analysis of simulated surveys, variation due to human error was not examined. The simulations only examined the variations among the survey methods themselves. This is an important issue for two reasons.

Firstly, in the timed field trials for these survey methods it was noticed that considerably more judgment was required for the strip method as the area of infection had to be "sketch mapped" within the 10 metre wide strip. In the attempt to sketch in the area of infection, the boundaries of the disease centers were subject to considerable variation between individual surveyors. Less judgment was required in the plot and line intercept methods. In field use, therefore, the strip method likely would be the least precise of the three methods.

Secondly, the definition of a root disease "center" as defined by Bloomberg *et al.* (1980b) for coastal stands and as used in surveys of coastal stands (J. Beale, pers. comm.), was not well suited to the disease conditions experienced in the surveyed and stem mapped stands in this project. By extension, it is presumed that this definition may not be suitable for any Interior Douglas-fir stands. The interpretation of the boundaries of root disease "centers" would

undoubtedly be a significant source of error for the practical use of any of the three survey methods examined in this study. This problem is discussed further (below) regarding "effectiveness" of these survey methods.

Although the trends in relative precision are probably true among these survey methods in a general sense, the specific sample sizes presented in Table 5 are applicable only for the same plot, strip or transect sizes used in this study. The length of transect line or the area of a strip or plot affects the variance, which in turn affects the required number of samples for a given level of precision. It should also be noted that if strips or transects of unequal length were used in a survey, then the samples would be of unequal sizes. In this case, the proportion of infected area and the standard error of the mean should be calculated by using special formulas (see Appendix B).

It is interesting to note that the use of "grids" in the line intercept method produced highly inconsistent confidence limits as compared to using transect lines alone. Effectively, the grouping of transects into grids appears only to decrease the degrees of freedom and thereby increases the width of the confidence limits. Consequently, the theoretical justification for the use of "grids" is not apparent.

The conclusions concerning the relative precisions of these three survey methods in this study are, of course, based on ten simulated surveys of each type of survey on each of two stem maps. Although each group of ten surveys was intentionally spread out over the possible choice of random positions in order to reduce unnecessary variation, better indications of precision could be determined by using a much larger number of simulated surveys. The Ministry may want to consider the computer simulation of future survey designs by digitizing the stem map information developed in this project and programming simulated runs on this database.

3. Efficiency

Overall, the plot method was the most efficient of the three survey methods, as illustrated in Table 7. The plot method was more precise in the simulations and faster in field use. Two additional factors also favor the plot method in terms of efficiency. As discussed above, the strip method required more judgment in field use which would likely decrease the level of precision for this method; the plot method was not as subject to this problem. The plot method also required the least time for computation after the survey. The values for the plots could quickly be tallied and divided by the total number of plots for an average estimate of area infected. The intercept method required more computation. The strip method required the most time for computation as the affected area on each strip had to be measured.

B. Effectiveness of the three survey methods

1. Effectiveness in Interior Douglas-fir stands

The structure of Interior Douglas-fir stands and the pattern of root disease damage in them suggests that a new definition of the term "root disease center" is required before the three survey methods studied in this project can be effective.

In the process of selecting stands for stem mapping in this study it was observed that most mature, leading Douglas-fir stands (ie. inventory polygons) in the IDF zone appear to have non-contiguous species cover and/or non-uniform age class distribution. In effect, these inventory polygons appear to be composed of several smaller polygons of dissimilar timber types. This apparently is typical of Douglas-fir stands in this zone (A. Vyse, pers. comm.).

It was also observed that the root disease damage in these stands was not distributed in discrete "centers", as defined for coastal stands. This is also

typical of Douglas-fir stands in this zone (H. Merler, pers. comm.). In mature Douglas-fir stands, "pockets" of young fir or pine, interspersed with older Douglas-fir stumps infected with root disease, can frequently be observed. This observation indicates a history of stand disturbance due to root disease within the length of the rotation.

These stand characteristics can be seen in the two stem maps that accompany this report.

It appears, therefore, that the root disease itself is a site disturbance that continues to move throughout the stand in an insidious manner over the length of the rotation. This produces a mosaic of age classes within the inventory polygon. It also appears to create conditions for the more tolerant tree species (eg. the pines) to fill in where Douglas-fir once grew.

Together, these factors indicate that the concept of root disease "centers", as defined for coastal forest conditions, is not an appropriate working model for the distribution of root diseases in IDF stands. In the two typical IDF stands examined in this study, it appears that nearly the whole area in each of these stands had been affected by root disease over the length of one rotation, whereas only a smaller portion of each stand exhibited currently active root disease symptoms, including recently dead and down, dead standing and visually symptomatic trees.

The concept of coastal root disease "centers", when applied to IDF conditions, is most misleading when considering the portion of the stand outside the active centers. The "center" concept leads one to expect a uniform and contiguous distribution of trees, in terms of both species and age class, outside the "centers." For the IDF stands examined, this assumption is false; the areas outside the pockets have also been affected by root disease within the length of the rotation. This timeframe is critically important. Within this time, the age

class and species profiles can both be changed by the root disease. In effect, the net impact from the root disease over the length of a rotation is far greater than the impact exhibited by current "centers." Any survey method that is designed to estimate the proportion of area occupied by current "centers", therefore, is underestimating the impact of the diseases on the productivity of the site. Similarly, any survey method that estimates current volume on the site, or attempts to infer impact by extrapolating the standing volume per unit area from the "healthy" [*sic*] portion of the stand to the "centers", will also underestimate net impact.

If the concept of root disease "centers" is inappropriate for IDF stands, then what description would be more appropriate? Perhaps this question is best explored in the context of the purposes and uses of root disease survey information, which is discussed in the next section.

2. Effectiveness for Ministry purposes

The B.C. Forest Service can be considered as performing two basic functions, "Planning" and "Operations" (Sutton *et al.* 1985). These serve as convenient divisions for discussion in this report.

a) Planning:

Timber Supply Area (T.S.A.) plans are the major focus in the Ministry's planning framework. In the preparation of T.S.A. plans, the Ministry performs periodic T.S.A. yield analyses in order to help determine the annual allowable cut (A.A.C.) in each T.S.A. and selects program options which will optimally support the chosen A.A.C. (Sutton *et al.* 1985). These program options are presented in the T.S.A. plan.

In T.S.A. yield analyses, root disease impact information is needed in order to determine the projected growth rates for untreated host stands; determine the projected growth rates for treated stands; and determine the rate of increased yield that can be expected from various program options that include site treatments aimed at the reduction of root disease damage. The specific entry points for root disease information in the Ministry's T.S.A. planning framework requires some exploration, as discussed below.

(i) Inventory:

As T.S.A. yield analyses draw on inventory databases for their basic supply of information, it would seem reasonable that root disease impacts should be included in the inventory databases.

In the "inventory update" phase of a T.S.A. yield analysis, the inventory databases for the T.S.A. are updated for depletions due to disturbances that have occurred since the previous update. The Ministry's Inventory Manual defines a "disturbance" as "the result of an event that causes tree mortality or tree removal." The degree of disturbance is measured as the "proportion of the volume or area disturbed". Disturbances can be recorded in the inventory databases as either a percentage of area or volume depleted in any one inventory polygon, or as a change in the polygon's stand composition as reflected in the type label.

The survey methods studied in this project estimate disturbances due to root disease. However, the use of root disease surveys to update the Ministry's inventory databases for disturbance depletions is inappropriate for four reasons (L. Dellert, R. Quenet, J. Viszlai, pers. comm.).

Firstly, it would be entirely impractical for the Forest Service to attempt to survey every individual susceptible polygon and thereby update the databases on a polygon by polygon basis.

Secondly, an attempt to sample susceptible polygons for disturbance depletions due to root diseases and to apply the results to the Forest Cover Attribute List of each susceptible polygon would conflict with the Ministry's forest cover database. This database, which is mostly based on photo classification of stands and a number of ground truths, includes depletions due to root diseases. This is reflected in the species composition, age class and stocking class attributes of the polygon's one or more stand layers.

Thirdly, to apply the sampling results to the Ministry's volume determination curves would be in conflict with the Ministry's extensive system of temporary and permanent sample plots. These plots have already determined the stand structure and volume of these susceptible stands including depletions due to root diseases.

Finally, to apply the sampling results to the History Attribute Lists of susceptible polygons would also conflict with the Ministry's inventory databases. Depletions on the History Attribute Lists can be applied against the volumes in the respective polygons when an inventory update is compiled for a T.S.A. yield analysis. Yet the volumes calculated for these polygons already include root disease losses, as per the inventory temporary and permanent sample plots.

In effect, the Ministry's inventory systems assume that root disease impacts are already adequately reflected in the forest cover attributes for each polygon and in the current volume for each polygon. They also assume that volume projections for natural stands have adequately

accommodated root disease impacts. The gradual mortality of timber in a stand affected by root disease, therefore, does not qualify as a disturbance; it is already included.

In effect, therefore, there are no opportunities to apply root disease survey information to the Ministry's inventory databases unless the assumptions concerning the Ministry's methods for forest cover classification and volume determinations in natural stands are questioned.

Perhaps these assumptions do need to be questioned. Of particular concern is the observation in this report that Douglas-fir stands (polygons) in the IDF typically are composed of mosaics of smaller and dissimilar timber types that are not adequately reflected in the type labels. However, the Ministry's volume curves assume, in effect, that the polygon has a uniform distribution of the attributes described in the type label. This assumption is related to the way in which inventory plots are used to calculate yield curves. The volume determination in these IDF stands, therefore, may be biased.

The additional observation that the non-contiguous stand structure in these Interior Douglas-fir stands may be at least partly due to root diseases also suggests that the net damage due to root diseases may be underestimated in the inventory databases.

(ii) T.S.A. yield analyses:

In addition to inventory databases, T.S.A. yield analyses can make use of other data to aid in the projection of timber supply profiles. In particular, managed stand yield tables can be used to determine the expected yield from stands that undergo silvicultural treatment

regimes, including treatment for root diseases. A T.S.A. yield analysis, therefore, can project the net effect of root disease treatments in a T.S.A. by comparing the yield from a specified hectare of managed (ie. treated) stands to the yield from this same area if it were left as natural (ie. untreated) stands. Although this is the ultimate objective for including root disease information in T.S.A. yield analyses, it is not apparent how root disease surveys of the type studied in this project can help to construct appropriate managed stand yield tables. Instead, re-evaluations of the Ministry's temporary and permanent sample plot databases are implicated for this purpose.

b) Operations

Root disease surveys are needed in Forest Service operations in order to determine which stands and which portions of stands are to be treated for root diseases. In this regard, candidate survey methods must satisfy two essential criteria. Firstly, an estimate of the proportion of the stand that is affected is needed in order to rank stands for treatment and, secondly, the survey must provide a map that illustrates which portions of the stand are infected.

This study has emphasized the efficiency of the three chosen survey methods for fulfilling the first criterion. For the second criterion, involving the mapping of diseased areas in a surveyed stand, none of the three methods fulfills this requirement in a satisfactory manner.

The strip method covers the largest area, but would only provide a partial map. It is also the slowest (and therefore the most expensive) of the three methods, for a given level of precision.

The line intercept method, as originally developed by Bloomberg *et al.* (1980b), can infer the size and location of root disease centers and can map them by using a program called RRSAMP. More complex procedures associated with this method can roughly measure the size and location of each root disease center that is encountered along the transect. Yet the results of this study indicate that the line intercept method is relatively inefficient, even without the more complex procedures. In addition, experience in coastal stands has demonstrated that maps generated by RRSAMP are unsatisfactory for operational purposes (J. Beale, pers. comm.).

The plot method, although efficient for estimating the proportion of area affected, is not well suited for mapping purposes.

It appears that an alternative survey design is needed for operational surveys.

Regardless of the method that is chosen, the Ministry's History Record System (ie. "History of Crop Establishment and Tending") appears to be the most suitable location for the storage of operational root disease survey information, as these surveys would normally support and influence the Pre-Harvest Silviculture Prescription for each stand.

C. Possible Alternatives

1. Planning

In order to estimate future productivity increases from IDF stands treated for root diseases, managed stand yield tables will need to be developed. In this regard, there are at least three possible approaches.

Firstly, a selected number of the Ministry's temporary sample plots can be re-visited in order to separate healthy plots from plots that were affected by

root disease. (It is presumed that the presence of root diseases was not sufficiently well recognized in the past measurements of inventory plots.) If a sufficient number of plots can be located, managed stand yield tables can be constructed on the basis of the healthy plot data. The assumption in this method would be that future stands treated for root disease would grow at the same rate as the healthy portions of current natural stands. As mentioned previously, this may be a difficult procedure due to the stand structure and distribution of root disease damage in IDF stands. It is also suspected that the Ministry's temporary sample plot data may not be representative of IDF sites that will be managed in the future and that the permanent sample plot data may be more reliable (D. Gilbert, K. Mitchell, pers. comm.).

Secondly, the Ministry's permanent sample plot data for these IDF stands can be evaluated. A re-visitation of selected permanent sample plots can determine which plots have been affected by root disease. By using data from healthy plots only, it may be possible to construct managed stand yield tables. This method carries the same assumption as the previous method. However, this approach may be insensitive to correlations between site characteristics and the incidence and intensity of root disease damage and, therefore, may produce biased managed stand yield tables (K. Mitchell, pers. comm.).

Thirdly, a combination prism plot sample and area based point sampling system can estimate the net impact in current stands. This approach is currently being explored for coastal stands (J. Beale, pers. comm.). In this approach, the basal areas from random prism plots are separated into healthy and diseased subsets and the proportion of affected area is estimated from point samples. The difference in yield between healthy and diseased plots is applied to the area affected in order to estimate the theoretical yield from entirely healthy stands. This method carries the same assumption as the previous two

methods and has the same potential problems for application to Interior stands. This method would also require extensive sampling in the IDF.

A refinement on any of the above three methods would be to stratify Douglas-fir stands in the IDF on the basis of the intensity of root disease damage. In a T.S.A. yield analysis, managed stand yield table data is applied to a specified number of hectares (L. Dellert, pers. comm.). These hectares represent the area that can be treated. As not all Interior Douglas-fir stands are equally damaged by root diseases, only those stands with higher intensities of damage will need treatment. Only this proportion of the susceptible area would be modelled with managed stand yield tables in a T.S.A. yield analysis. A random survey of Douglas-fir stands in the IDF, using one of the survey methods studied in this project, could provide these estimates.

For this purpose, however, a point sampling survey method would likely provide more efficient estimates of the proportion of area infected in a stand than did the three methods studied in this project. Point samples placed every 10 metres along transects spaced at 50 metre intervals, for example, would give five times the number of samples as the plot sample method described in this study. In field use, this layout of point samples would likely take approximately the same time as the plot sample layout described in this report. Table 8, below, lists the number of point samples that would be required for the two stands studied in this project and for a stand of any size. By comparing Table 8 to Table 5, it can be seen that for an equivalent time spent in the field, the point sampling method would likely yield roughly twice the precision as would the plot sampling method.

As discussed above, the definition of root disease "centers" as used in coastal stands is inappropriate for Interior Douglas-fir stands. For the

TABLE 8
Required Sample Sizes for Point Sampling

<u>Precision</u>	<u>Turtle Valley</u>	<u>Allison Lake</u>	<u>Any Area</u>
5%	343	383	384
10%	86	96	97
15%	39	43	44
20%	22	24	25

Ministry's planning purposes, an expanded definition of root disease "center" is required for these stands. As the objective is to determine the net impact of root disease in natural stands over the length of a rotation, then the definition should include all manifestations of root disease damage in affected stands. In particular, the portions of mature stands that appear to have been affected within the rotation (as indicated by diseased stumps in younger timber, for example) need to be included along with the active centers.

2. Operations

Alternative survey designs for operational purposes must be able to produce a map of the diseased areas as well as an estimate of the proportion of the area infected. For these requirements, consideration should be given to the 100% sketch map system used for operational purposes in coastal stands. Point sampling could be conducted simultaneously in order to facilitate the simple and precise determination of the proportional area infected.

An expanded definition of root disease "center" for Interior Douglas-fir stands is also required for operational purposes. The definition should include portions of the stand that have evidence of previous disease damage even

though these portions may not be expressing symptoms of current disease activity. These areas of apparent "quiescence" should be considered for treatment and, therefore, should be included in operational surveys. Although this is essentially the same change in definition that is required for planning purposes, there is one important difference. Some "quiescent" areas may not need operational treatments, but these same areas would need to be included in impact assessments. For example, some older root disease centers in mature Douglas-fir stands may have filled in with young pine. These likely would not require root disease treatment, but they do have an influence on the assessment of root disease impact in the stand.

V. CONCLUSIONS

1. Among the three survey methods studied in this project, the method involving fixed radius plots was the most efficient due to the combination of its greater precision and its greater speed in field use.
2. In this study, it was concluded that the definition of root disease "centers," as defined for coastal stands, is not well suited to Douglas-fir stands in the IDF. Root disease damage in these Interior stands typically is more diffuse and indiscrete in distribution than in coastal stands.
3. It was also concluded in this study that most mature, leading Douglas-fir stands in the IDF appear to have non-contiguous species cover and/or non-uniform age class distributions. Some of this discontinuity may be due to root diseases.
4. The area-based survey methods studied in this project may have application for the stratification of susceptible timber types by intensity of root disease damage. For T.S.A. yield analyses this stratification may be important in order to determine the proportion of susceptible types in a T.S.A. that require root disease treatment.

5. In the Ministry's T.S.A. yield analyses, managed stand yield tables are required in order to determine the enhanced yield that can be expected from root disease-treated stands in the IDF. Re-evaluations of the Ministry's databases for temporary and permanent sample plots are implicated in efforts to develop these managed stand yield tables. The use of ground survey methods to estimate disturbance depletions due to root diseases has no apparent application for this purpose other than to stratify diseased stands, as mentioned above.
6. There appear to be no opportunities to apply root disease survey information to the Ministry's inventory databases unless the assumptions concerning the Ministry's methods for forest cover classification and volume determinations in natural stands are questioned.
8. For operational purposes, the three survey methods studied in this project can provide accurate and precise estimates (depending on the intensity of sampling and the definition of Interior root disease "centers") of the proportional area of stands affected by root disease. However, these methods are deficient in their abilities to provide the necessary maps of the infected portions of surveyed stands.
9. Alternative or modified survey designs are needed for operational purposes in Interior Douglas-fir stands in order to include mapping capability.
10. For planning and operational purposes, an expanded definition of the term "root disease center" is required and should include those portions of affected stands that contain evidence of previous damage within the length of the rotation but that also appear to be more quiescent at the time of the survey.

VI. RECOMMENDATIONS

1. For planning purposes, it is recommended that the Ministry investigate the feasibility of constructing managed stand yield tables for root disease-treated stands in the Interior Douglas-fir zone. Re-evaluations of the Ministry's temporary and/or permanent inventory plots are implicated for this purpose, as discussed in the report. The survey methods studied in this project are not recommended for this purpose, nor is it recommended that root disease survey information be stored in the Ministry's inventory databases.
2. For the purpose of stratifying Douglas-fir stands in the IDF on the basis of intensity of root disease damage, the plot method is recommended over the other two survey methods studied in this project. However, it is likely that a point sampling survey method would be more precise and efficient than any of these three methods. Consequently, for this purpose, it is also recommended that the Ministry test a point sampling survey method by simulation and field trials.
3. For operational purposes, the plot survey method is recommended over the other two survey methods studied in this project, although, again, a point sampling method would likely be more precise and efficient. It is also recommended that a method for mapping the distribution of disease damage in a stand, such as sketch mapping, be conducted simultaneously in operational surveys.
4. It is recommended that the Ministry re-define the term "root disease center" specifically for stands in the Interior Douglas-fir zone. Some suggestions for a re-definition are discussed in this report. Separate definitions may be required for planning purposes and for operational purposes.

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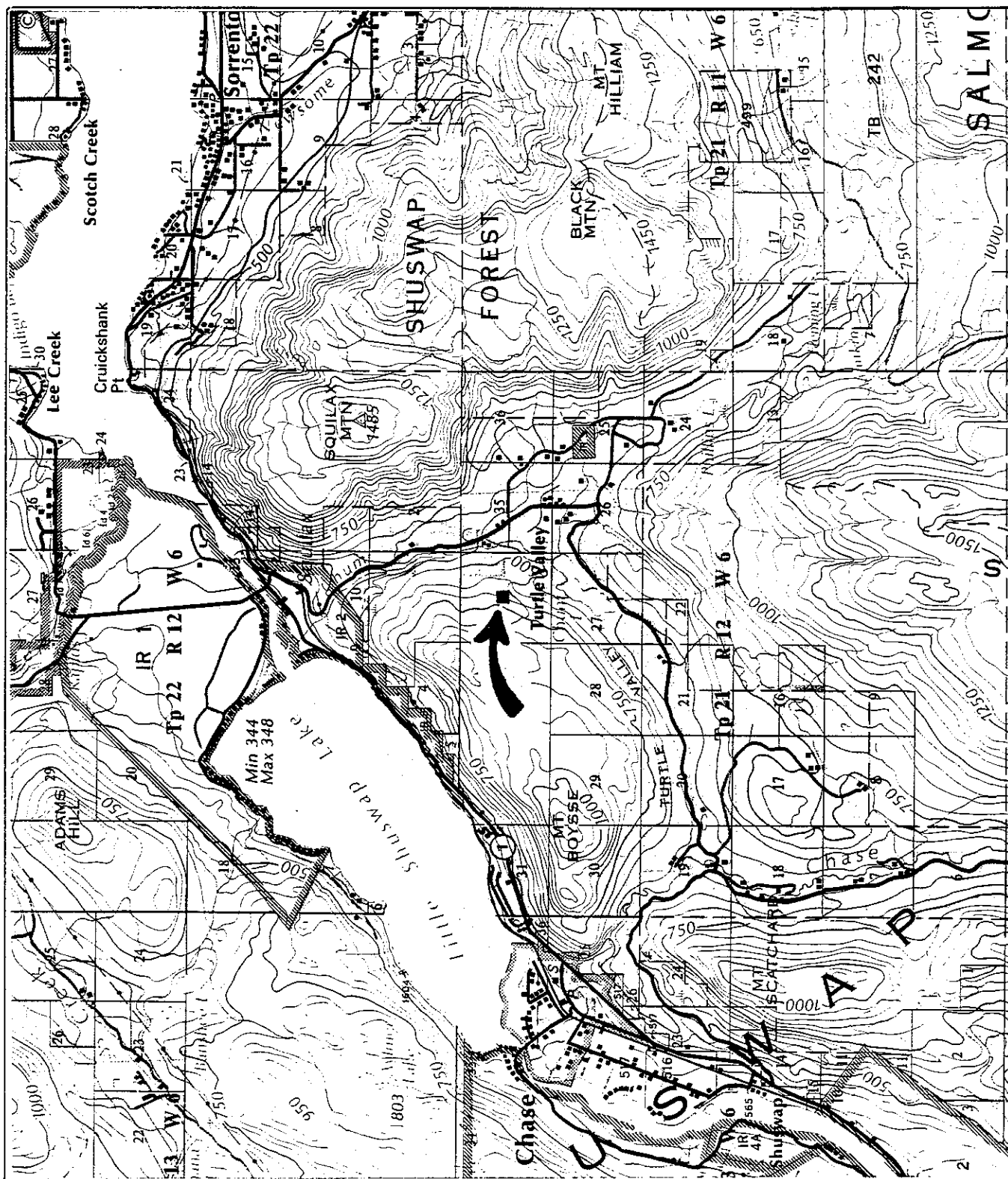
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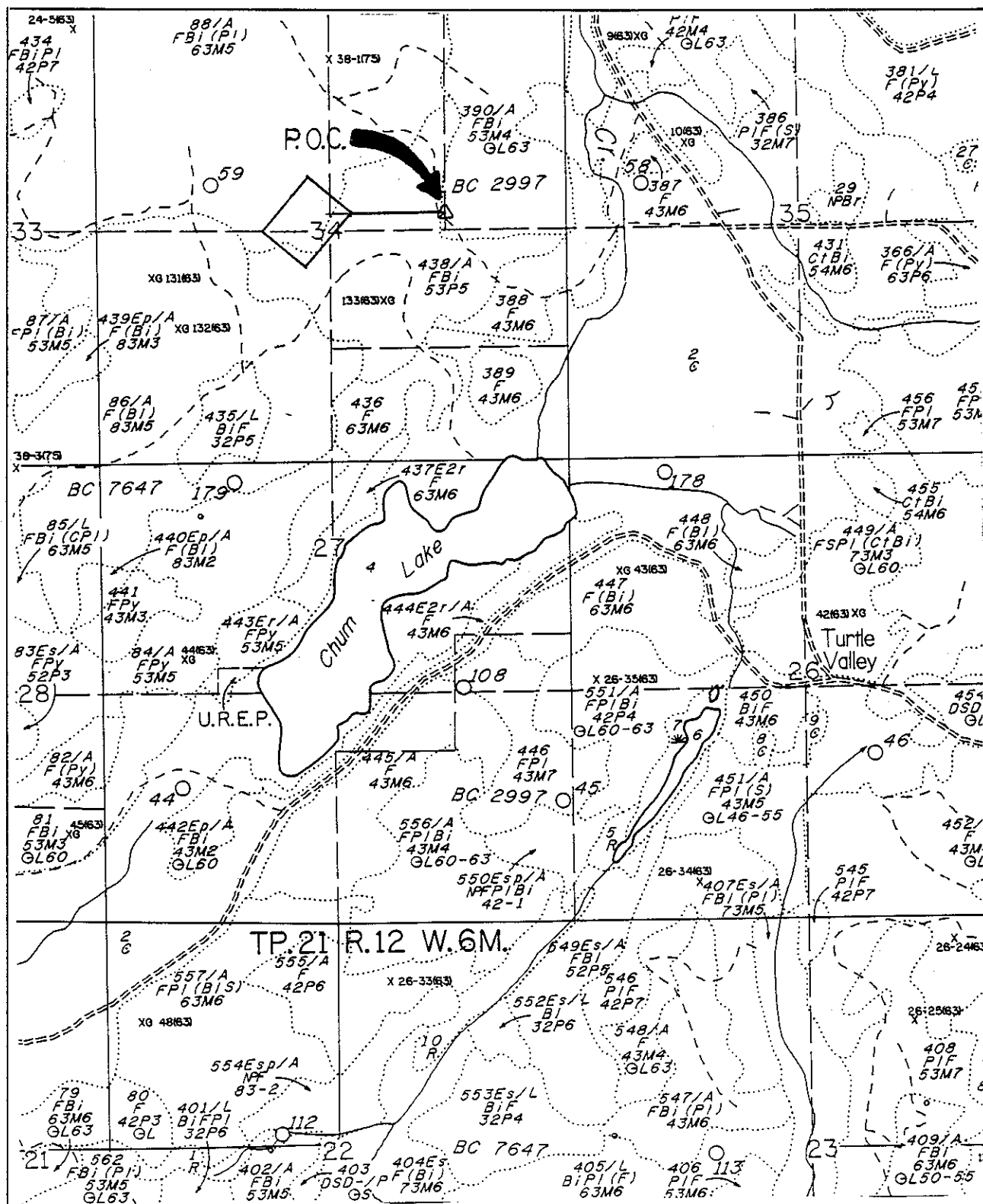
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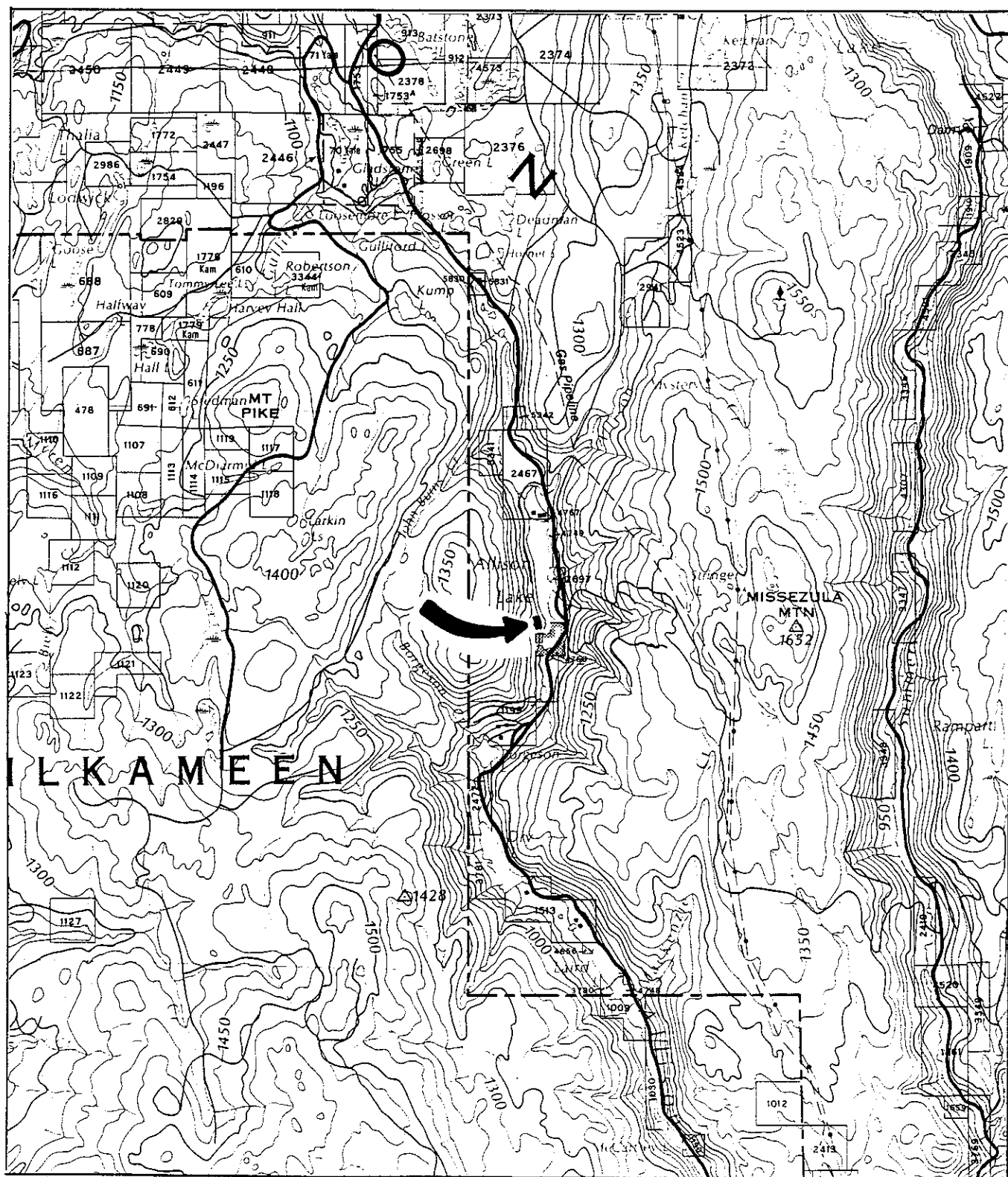
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3. Allison Lake Stand: 1:100 000



B. Calculations for Unequal Sample Sizes

When using strip or line samples of unequal length, the proportion of infected area can be calculated by using a ratio of means estimation, as follows:

$$\hat{R} = \frac{\bar{y}}{\bar{x}}$$

where: $\bar{y}$ = average of infected lengths or areas
 $\bar{x}$ = average length of the lines or area of the strips
 $\hat{R}$ = proportion of area infected

The standard error of the ratio can be calculated as:

$$S_{\hat{R}} = \sqrt{\frac{S_y^2 + \hat{R}^2 S_x^2 - 2\hat{R}S_{xy}}{n x^2} \left(1 - \frac{n}{N}\right)}$$

where: S_y^2 = estimated variance of y (infected lengths or areas).
 S_x^2 = estimated variance of x (length of lines or areas of strips).

S_{xy} = estimated covariance of x and y.

$1 - \frac{n}{N}$ = correction factor for finite population.

n = number of samples

N = total number of possible samples from the population.