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IV. Multiple-disease Recording and Stratification by Infection Intensity

W.J. Bloomberg, Pacific Forest Research Centre

Report BC-R-8

A GROUND-SURVEY METHOD FOR ESTIMATING LOSS CAUSED BY *PHELLINUS WEIRII* ROOT ROT

IV. MULTIPLE-DISEASE RECORDING AND STRATIFICATION BY INFECTION INTENSITY

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SUMMARY

Two modifications to the Pacific Forest Research Centre root disease ground-survey method are described. Multiple-disease recording allows up to nine disease types to be recorded during a single survey. Separate analyses and disease area estimates are produced for each disease and for combinations of diseases. Postsurvey stratification of stands by infection intensity allows the stand to be subdivided into compartments or blocks with differing intensities. Separate analyses and disease-area estimates are produced for each block. Data preparation for each modification is described and examples are given.

RESUME

L'auteur décrit deux modifications apportées à la méthode de l'inventaire au sol du Centre de Recherches Forestières du Pacifique sur les maladies des racines des arbres. L'enregistrement multiple des maladies permet d'enregistrer jusqu'à neuf types de maladie au cours d'un seul inventaire. Des analyses et des évaluations de l'étendue d'une maladie des racines des arbres sont produites pour chaque maladie et pour les combinaisons de maladies. La stratification de peuplements determinée par l'intensité de l'infection permet la subdivision du peuplement en compartiments ou en blocs portant des intensités differentes. Des analyses et des estimations de l'étendue de la maladie des racines des arbres sont produites indépendamment pour chaque bloc. La préparation des données pour l'utilisation de chaque modification est décrite et des exemples sont données.

INTRODUCTION

Since the root disease ground-survey method (developed at the Pacific Forest Research Centre) (Bloomberg *et al.* 1980) went into operational use in 1979, a need has emerged for methods of surveying multiple diseases within stands and of stratifying survey results according to disease intensity. Two or more distinct root diseases commonly occur within a stand, e.g., *Phellinus* root rot (caused by *Phellinus weirii* (Murr.) Gilbertson), *Armillaria* root disease (*Armillaria mellea* (Vahl ex Fr.) Kummer), black stain (*Verticicladiella wageneri* Kendrick), *annosus* root rot (*Fomes annosus* (Fr.) Karst.), and brown cubical butt rot (*Polyporus schweinitzii* Fr.) (Filip 1979; James and Stewart 1981, Johnson *et al.* 1972; D.J. Morrison, personal communication). The diseases differ in their effects on stands and in prescriptions for their management. *Armillaria* damage in coastal forests of British Columbia, for example, is generally considered to be limited to very young stands and to have little significant overall effect; whereas in interior forests, damage may continue throughout the rotation (Morrison 1981). *Phellinus* damage occurs throughout the rotation in coastal as well as interior forests (Wallis 1976). Black stain in coastal forests occurs throughout the rotation and causes similar damage to *Phellinus*, whereas in interior forests, it is more prevalent in mature lodgepole pine (Hunt and Morrison 1980). Individual diseases may also display variable symptomatologies, e.g., proportions of infected trees killed versus living infected and active versus static disease spread.

The assessment of current disease losses and the prediction of future disease development in stands infected with root diseases depend greatly on reliable estimates of incidence and distribution of each type of disease.

The Pacific Forest Research Centre survey method (PFRC method) was originally designed for estimating incidence of *Phellinus* root rot, but is applicable to all diseases in which symptoms are localized in infection centres (foci).

To accommodate the need for multiple recording of diseases, the PFRC method has been enhanced (version 3) to allow up to 9 disease types to be recorded during one survey. Disease types, as defined by users of the survey method, may consist of single or combined pathogens, e.g., *Phellinus*, *Armillaria*, and *Phellinus-Armillaria*. Symptom classes could also be combined with pathogens, e.g., *Phellinus*-active and *Phellinus*-static.

Not only are many root diseases in forest stands highly aggregated in infection centres but also the centres themselves are often concentrated in portions of stands, rather than distributed uniformly (Bloomberg, unpublished data). If prior knowledge of the uneven distribution of infection centres is available, the appropriate survey design is to compartmentalize (stratify) portions of the stand according to disease intensity. This procedure has the dual advantage of reducing sampling variation and serving as a basis for compartmental-disease management. In most cases, no prior knowledge of disease distribution exists and the additional expense of a pilot survey to obtain it would not be justified. Fortunately, postsurvey stratification of sampling data (Cochran 1963) can achieve much the same objective, provided that sufficient samples are well distributed throughout the stand.

The most practical way to delineate postsurvey disease-intensity strata is to superimpose block or compartment boundaries on a map of survey results in such a way as to segregate areas according to their numbers and sizes of infection centres. Additional stratification criteria include optimization of block size for management operations, segregation of different forest types, and allocation of samples (transects) proportionally to block size. Sample data are then redistributed to the appropriate blocks and estimates of disease incidence recalculated for each block. Since

this is a tedious operation to carry out manually (requiring the reallocation of centres to various strata), a computer program named RRSORT[1] has been developed. RRSORT uses specified coordinates and survey designs for each block to stratify the whole-stand data and create data subsets for individual analysis and estimate by block.

PROCEDURES

Multiple Disease Option

A few minor modifications must be made to the existing field recording and data analysis procedures in order to use the multiple-disease option.

1. Modifications to Field Recording Procedure

The only data entry additional to that required for the existing (version 2) field recording sheet (Bloomberg *et al.* 1980, Fig. 6) is "Disease Code" in column 6, formerly used for "Number of Tape Lengths." In version 3, only columns 7 and 8 are available for tape lengths. Disease code must be a digit from 1 to 9.

2. Modifications to Survey Specifications

The following modifications are necessary to the data analysis specifications for version 3 (Fig. 1), replacing those used for version 2 (Bloomberg *et al.* 1980, Fig. 12).

Card 1. Version must be 3, stratification index is 0.

Card 2. Stand areas are entered as for versions 2.

Card 3. Additional entries are required for number of disease types used in the survey and for codes for each type. The codes must be digits from 1 to 9, corresponding with those used in the field recording sheet. In addition, code 10 can be used for combining all disease types in one analysis. The codes need not be in sequential order.

Card 4. Disease-type names, each consisting of eight alphanumeric characters, are entered in the same order as corresponding type codes in card 3. The type name ALLTYPES is reserved for designating that all disease types be combined in one analysis. Succeeding cards are prepared as in version 2.

3. Modifications to Output

The form of the results of survey analyses for multiple diseases is essentially unchanged from that for version 2. Separate analyses are produced for each disease type. Additionally, by specifying the inclusion of all types, an analysis is performed on all data, regardless of type.

4. Modifications to the Analysis Program[2]

Changes have been made in most subroutines of the version 2 analysis program to accommodate data stratified by blocks.

Example of Multiple-Disease Survey Analysis

A 20-ha coastal Douglas-fir stand was surveyd for *Phellinus* root rot, black stain, and *Armillaria* root disease. Four disease types were defined—*Phellinus*, black stain, *Armillaria*, and a combination of *Phellinus* and black stain. They were assigned disease codes 1, 2, 3, 4 and type names P.WEIRII, BLCK. STN, A.MELLEA, P.W./V.W. (Fig. 1). The survey method was by intersection length (Bloomberg *et al.* 1980) and the estimate option was by centre size class (Bloomberg 1983).

Results are shown in Table 1 and Figure 2. The stand was moderately infected. About 50% of the infection area was attributable to *Phellinus*, 40% to *Armillaria*, 7% to combined *Phellinus* and black stain, and 3% to black stain alone; 88 to 100% of all centres fell into the smallest size class (less than 100 m^2). *Armillaria* and *Phellinus* accounted for 57 and 41% of the centres respectively. Distribution of centres was fairly uniform, with no obvious segregation by disease type.

If the total (all types) 10.4% infection incidence in the 35-year-old stand had been attributable wholly to

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[1] A program listing of RRSORT is available on request to the author.

[2] A listing of RRSAMP version 3 is available on request to the author.

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PHELLINUS ROOT ROT SURVEY: SURVEY SPECIFICATIONS
Versions 2 and 3

Location COWICHAN
Date 10/7/82
Crew A

SURVEY REFERENCE NO.	SURVEY MEASUREMENT UNITS	STAND MEASUREMENT UNITS	SURVEY/STAND UNITS CONVERSION FACTOR	MAP SCALE UNITS / INCH	TAPE LENGTH	VERSION	Stratification Index
BL2FR2G2	METERS	HECTARES	10000.0	60.0	50	3	0

STAND AREAS (IN SAME ORDER AS STANDS IN CARDS 5-13)

20.0									

NO. STANDS TO BE ANALYZED	INPUT MODE	SURVEY METHOD FOR STAND NO. (1 2 3 4 5 6 7 8 9 10)	NO. TYPES	TYPE CODE
1	06		5	1 2 3 4 5

TYPE NAME (VERSION 3 ONLY)

P.WEIRIBLCK.STNA.MELLEAP.W/V.W.ALLTYPES

INSTRUCTIONS

1. Right justify all numeric entries; center justify alphabetic entries
2. Observe preentered decimal point.
3. Cards 1-3 required for each analysis plus 1 of cards 5-13 for each stand. Card 4 required only for Version 3.
4. Enter "1" under each stand included in regression.
5. Input mode: 0 = cards, 1 = file, 2 = cards + file.
6. Survey method: 1 = areas measured, 2 = areas estimated, 3 = size classes assigned, 4 = intersection length measured, 5 = intersection length assigned, 6 = areas calculated from intersection length.
7. Estimate method: 1 = regression, 2 = intersection L., 3 = size classes, 4 = center numbers, 5 = size limits.
8. Outputs: 1 = descriptors + summary, 2 = regression stats, 3 = center listing, 4 = tables, 5 = map.
9. Map: 1 = intersection L., 2 = proj. + mid L., 3 = boundary pts.
10. Stratification index: 0 = nonstratified data, 1 = stratified data.

STAND NO.	STANDS FOR INCLUSION IN REGRESSION ENTER "1" (1 2 3 4 5 6 7 8 9 10)	GRID INTERVAL	STRIP WIDTH	ESTIMATE METHOD ENTER "1" (1 2 3 4 5)	OUTPUT OPTION ENTER "1" (1 2 3 4 5)	MAP	NO. SIZE CLASSES	UPPER LIMIT OF SIZE CLASSES (IN STAND MEASUREMENT UNITS) 1	2	3	4	5	TRANSECT BEARING	B/L ZERO END (L/R)	GRID START POINTS (IN SURVEY MEASUREMENT UNITS FROM START OF B/L) GRID NO. 1	2	3	4	5	6	BASELINE LENGTH	NO. GRIDS	NO. LINES/GRID
1	1	120	00	1111	1011		5	0.01	0.05	0.10	0.50	1.00	90	L	50	100					601	2	5
6																							
7																							
8																							
9																							
10																							
11																							
12																							
13																							
14																							

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Fig. 1. Analysis specifications for a root-disease survey for four disease types and total disease in a Douglas-fir stand. Specification cards are inserted at head of survey-data file.

Phellinus root rot and black stain, the total infected area at age 80, as predicted by simulation (Bloomberg 1983), would have approached 50% of the stand area. In fact, only 6.1% of the area was affected by these diseases, giving a predicted estimate of about 20% of stand area infected by age 80. Losses due to *Armillaria* in the 4.1% of stand area affected by this disease can be expected to decline as the stand grows older (Morrison 1981). Therefore at this stage, disease should not limit stand-tending operations. Had the stand been surveyed for infection without reference to different disease types, the results would have created reservations about the expenditure on such operations.

Stratification of Disease-Survey Results by Infection Intensity

The infection-intensity stratification option requires that data be recorded in version 3 format (see above). Data in version 2 format may be used for stratification, provided there are no entries in column 6; disease code 1 must be entered in this column as part of centre I.D. Stratification procedures involve the following. (1) Inserting stratification specifications at the head of survey field data; the specifications control the subdivision of a stand into blocks and the allocation of transect lines to blocks. (2) Running program RRSORT which executes the specifications and produces separate field-data sets for each block. The example used is a 66.2-ha coastal Douglas-fir stand surveyed for *Phellinus* root rot. The original (unstratified) survey specifications are not shown but are in the same format as Figure 1. Block boundaries were superimposed on the stand according to the stratification criteria. Each block must contain sufficient transects to allow a balanced survey design of grids and transects, i.e., at least two grids, each with equal numbers of transects (Fig. 3).

1. Stratification Procedure

Specifications for data stratification are prepared as follows (Fig. 4).

Card 1. The eight-character reference number must be different from that used for the original (unstratified) survey; the remaining entries are obtained from the data-analysis specifications of the original survey, i.e., survey units, stand measurement units, conversion factor, origin of baseline, tape length, transect bearing, strip width, codes for survey method, input mode, and estimate methods.

Card 2. If the original data were recorded in version 3 format (i.e., disease types were recorded), entries for number of disease types, disease-type codes, and names are the same. If, as in this example, data were recorded in format 2 (no disease types recorded), number of types and type codes are both entered as 1 and type name as ALLTYPES.

Card 3. Stand-number and survey-design variables are entered as for the original survey, i.e., number of grids and transects, grid interval and start points. In addition, the number of blocks into which the original survey is to be stratified must be specified.

Cards 4-6. Survey-design (number of grids and transects) and minimum and maximum coordinates are specified for each block. Coordinates are measured from the zero end of the baseline, i.e., from right to left if the origin is to the right of the stand and vice versa. Blocks must be numbered sequentially from bottom to top and from the baseline origin towards the end (Fig. 3). Blocks must be rectangular and coordinates of blocks must not overlap. One card is prepared for each block.

Cards containing the stratification specifications are inserted at the head of the unstratified field records (replacing the original survey analysis specification cards), and the resulting file, named RRSORT.IN, is submitted to program RRSORT for resorting into blocks. The output from this program is in a file named RRSORT.OUT, consisting of field records in which the original stand, grid, and transect numbers have been changed to correspond with the blocks in which they fall and with the survey design for each block. Centre numbers remain unchanged from the unstratified file to facilitate recognition in the stratified blocks. Other measurement data for each transect and centre are changed in accordance with the block coordinates.

Program RRSORT also prepares a file named BLOCK.PRM, containing block parameters and survey specifications for each block (Fig. 5).

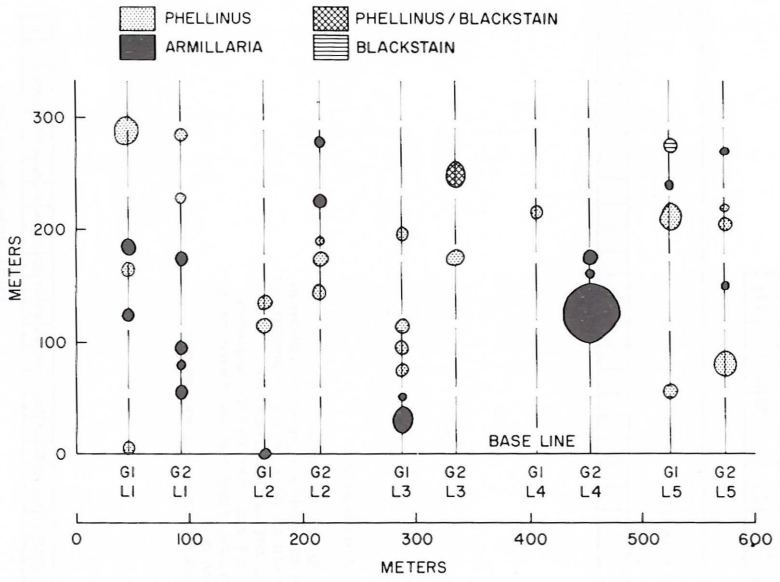

Fig. 2. Map of root-disease centres in a Douglas-fir stand recorded by type on survey transect lines according to their intersection lengths and left and right projections.

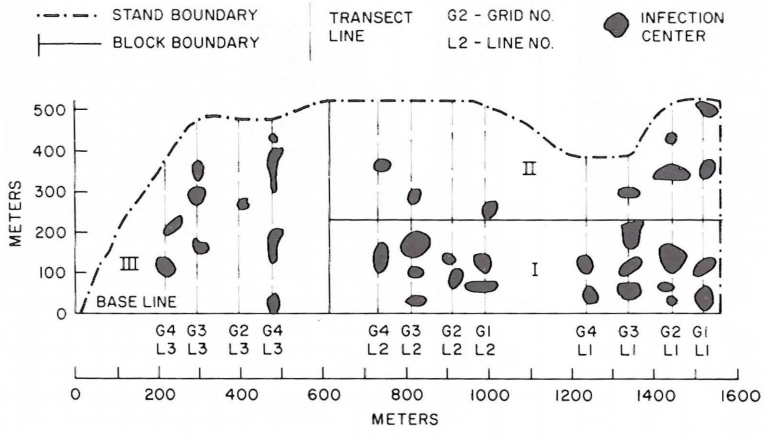

Fig. 3. Survey map of *Phellinus weirii* root rot infection centres recorded in a Douglas-fir stand with post-survey stratification block boundaries superimposed to segregate compartments according to disease intensity. Note that block boundaries have been positioned to allow balanced survey designs in each block. Baseline origin is to the right.

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ROOT DISEASE SURVEY: SPECIFICATIONS FOR POSTSURVEY STRATIFICATION

	SURVEY REFERENCE NO.	SURVEY MEASUREMENT UNITS	STAND MEASUREMENT UNITS	SURVEY/STAND CONVERSION FACTOR	B/L ZERO END (L/B)	TAPE LENGTH	TRANSECT BEARING	STRIP WIDTH	SURVEY METHOD CODE	INPUT MODE CODE	ESTIMATE METHOD (1 2 3 4 5)
1	SORT.MK3	METERS	HECTARES	10000.0	R	40	36	10	2	0	0 1 1 1 1

	NO. DISEASE TYPES	DISEASE-TYPE CODES	DISEASE-TYPE NAMES
2	1	1	ALLTYPES

	STAND NO.	NO. GRIDS	NO. TRANSECTS	NO. BLOCKS	GRID INTERVAL	GRID START POINTS 1	2	3	4	5	6
3	3	4	3	3	517	41	124	218	312		

	BLOCK NO.	NO. GRIDS	NO. TRANSECTS	BLOCK COORDINATES MIN. X	MIN. Y	MAX. X	MAX. Y
4	1	4	2	0	0	950	250
5	2	4	2	0	251	950	550
6	3	2	2	951	0	1550	550
7							
8							
9							
10							
11							
12							
13							

INSTRUCTIONS FOR STRATIFIED DATA

1. COPY FIELD DATA TO FILE RRSORT.IN.
2. INSERT STRATIFICATION INPUTS AT HEAD OF RRSORT.IN.
3. RUN RRSORT. STRATIFIED DATA IS IN FILE RRSORT.OUT. BLOCK PARAMETERS ARE IN FILE BLOCK.PRM.
4. EDIT FILE RRSORT.OUT AND COPY TO FILE RRSAMP.IN.
5. INSERT SURVEY SPECIFICATIONS FOR STRATIFIED DATA AT HEAD OF RRSAMP.IN.
6. RUN RRSAMP. RESULTS ARE IN FILE RRSAMP.OUT.

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Fig. 4. Stratification specifications for a *Phellinus weirii* root rot survey of a Douglas-fir stand to be stratified into three blocks. Data were originally recorded in version 2 format; therefore, number and code of disease types are entered at 1 and type name as ALLTYPES. Specifications are inserted at head of survey-data file.

Fig. 5. Block-parameter information produced by data-stratification program RRSORT. Information is used to prepare new survey-analysis specifications for analyzing stratified data.

SURVEY REFERENCE NO.:	SORT.MK3
NO. BLOCKS:	3
SURVEY MEASUREMENT UNITS:	HECTARES
STAND MEASUREMENT UNITS:	METRES
CONVERSION FACTOR:	10000.0
TAPE LENGTH:	40
TRANSECT BEARING:	36
STRIP WIDTH:	10
NO. OF DISEASE TYPES:	1
TYPE OF CODES:	1
DISEASE TYPE NAMES:	ALLTYPES
INPUT MODE:	0
SURVEY METHOD CODE:	2
ESTIMATE METHOD CODE:	0 1 1 1 1

BLOCK NUMBER 1

COMPUTED BLOCK SIZE:	23.8 HECTARES
COORDINATES MEASURED FROM R END OF BASELINE	
MIN. X: 0	MAX. X: 950
MIN. Y: 0	MAX. Y: 250
NUMBER OF GRIDS:	4
NUMBER OF TRANSECT LINES:	2
BASELINE LENGTH:	950
GRID INTERVAL:	475
GRID STARTING POINT 1:	41
GRID STARTING POINT 2:	124
GRID STARTING POINT 3:	218
GRID STARTING POINT 4:	312

BLOCK NUMBER 2

COMPUTED BLOCK SIZE:	28.4 HECTARES
COORDINATES MEASURED FROM R END OF BASELINE	
MIN. X: 0	MAX. X: 950
MIN. Y: 251	MAX. Y: 550
NUMBER OF GRIDS:	4
NUMBER OF TRANSECT LINES:	2
BASELINE LENGTH:	950
GRID INTERVAL:	475
GRID STARTING POINT 1:	41
GRID STARTING POINT 2:	124
GRID STARTING POINT 3:	218
GRID STARTING POINT 4:	312

Fig. 5 continued.

BLOCK NUMBER 3

COMPUTED BLOCK SIZE:		32.9 HECTARES
COORDINATES MEASURED FROM R END OF BASELINE		
MIN. X: 951	MAX. X:	1550
MIN. Y: 0	MAX. Y:	550
NUMBER OF GRIDS:		2
NUMBER OF TRANSECT LINES:		2
BASELINE LENGTH:		599
GRID INTERVAL:		299
GRID STARTING POINT 1:		124
GRID STARTING POINT 2:		207

2. Modifications to Survey Analysis Specifications

New survey-analysis specifications must be prepared as follows in order to analyze the stratified data (Fig. 6) and obtain disease estimates for each block.

Card 1. Survey reference number and all other variables, except for map scale, are copied from the block-parameter file. The map scale selected may differ from the original survey, since blocks are smaller than the stand. Version number must be 3 and the stratification indicator entered as 1.

Card 2. Stand (=block) areas are entered in sequence by block number. These areas may be obtained from the block-parameter file if the block boundaries are wholly contained within the stand; otherwise, recalculated block areas based on stand boundaries must be entered. In this example, computed area was used for block 1; areas of block 2 and 3 were measured.

Card 3. The number of stands to be analyzed must be equal to or less than the number of blocks into which the original stand was stratified. Input mode must be 0. The survey-method code, number of disease types and codes are obtained from the block-parameter file and entered under each block being analyzed.

Card 4. Type names are obtained from the block-parameter file.

Cards 5-14. One card is prepared for each block to be analyzed, in the same sequence as block numbering, i.e., 1 to 10. If the regression method of estimating centre area was used (Bloomberg *et al.* 1980), the code 1 should be entered under all block numbers included in the analysis. If the regression method was not used, this section is left blank. Grid interval, strip width, estimate method, transect bearing, origin of baseline, grid start points, baseline length, number of grids, and transects are obtained from the block-parameter file. Output options and number and limits of size classes can be specified individually for each block.

The revised survey specification cards are inserted at the head of the stratified field-data file RRSORT.OUT, replacing the stratification specification cards, and the resulting file RRSAMP.IN is submitted to program RRSAMP for analysis. The output from this program consists of separate survey analyses for each block.

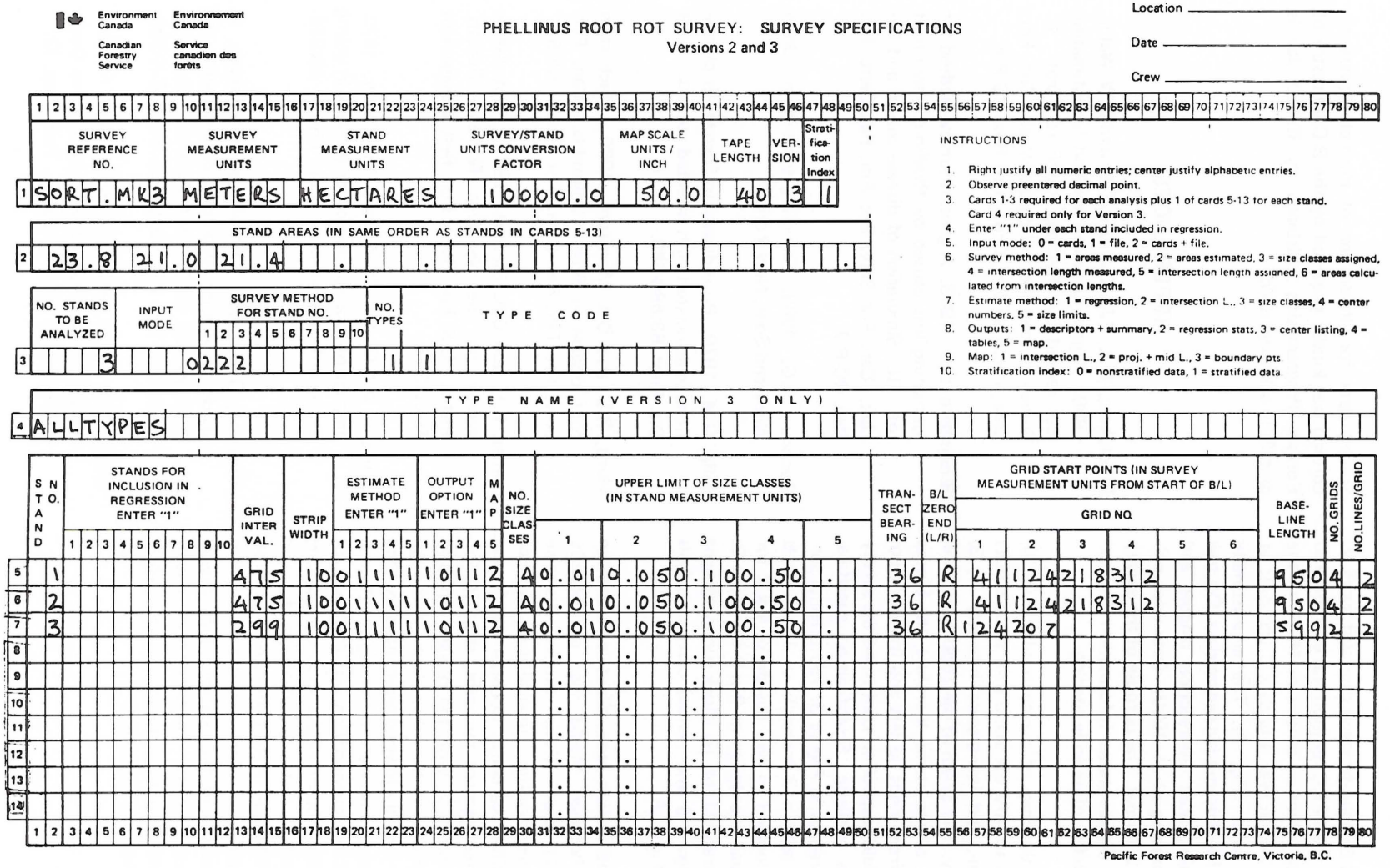

Fig. 6. Analysis specifications for a *Phellinus weirii* root rot survey poststratified into three blocks. Entries for variables are obtained from the block-parameter file.

Example of Disease Intensity Stratification

A 66.2-ha coastal Douglas-fir stand surveyed for *Phellinus* root rot by the PFRC method was estimated to contain 10.1 ha in infection centres or 16.1% of the area. The survey design was 4 grids x 3 transects or 12 transects in total (Fig. 3). The area-estimate option was used for determining centre sizes. Centres were mapped using their intersection lengths and projections (Bloomberg *et al.* 1980). Data were collected in version 2 format. The purpose of the survey was to provide disease-status information for decisions as to feasibility of juvenile spacing.

After examining the map of survey results (Fig. 3), it was decided to stratify the stand into three blocks of high-, medium-, and low-disease intensity—1, 3, and 2 respectively. The origin of the 1550-m baseline was on the right of the stand; therefore, the blocks were numbered from right to left and from bottom to top. A brief field inspection confirmed the survey stratification was realistic. Stratification specifications were prepared as in Figure 3. The original survey design of 4 grids x 3 transects or 12 transects in total was reallocated to two designs of 4 x 2 for blocks 1 and 2 and one design of 2 x 2 for block 3. Results of the stratification on block-survey designs are shown in Figure 5 and revised survey analysis specifications in Figure 6.

Statistically, stratification was effective. Variation (mean square) between blocks was significantly greater ($p = 0.01$) than within blocks. Relative efficiency of stratification (unstratified variance divided by stratified variance, Cochran 1963) was 5.4. For stand-management purposes, stratification was effective in block 2, with the disease intensity being much lower than in the other blocks. Although block 3 had only slightly lower disease intensity than block 1, it served as a convenient management unit. The management recommendation was that root rot would not seriously jeopardize the success of spacing operations in block 2, but would probably do so in blocks 1 and 3. Without stratification, recommendations for the stand as a whole would have been to reject spacing because of the relatively high overall estimate of disease intensity. The benefits of spacing would have thereby been denied to a relatively lightly diseased compartment of the stand.

ACKNOWLEDGEMENTS

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Table 1. Survey estimates of root-disease incidence in a 20-ha lodgepole pine stand containing three disease types

	Centre Size Class (ha)					
	0.00 to 0.01	0.01 to 0.05	0.05 to 0.10	0.10 to 0.50	Total	% of Stand
Phellinus						
Area	0.6	0.4	0	0	1.0	5.2
No.	126	17	0	0	143	
%	88.1	11.9	0	0		
Black stain						
Area	0.04	0	0	0	0.04	0.2
No.	8	0	0	0	8	
%	100	0	0	0		
Armillaria						
Area	0.4	0.3	0	0.2	0.9	4.3
No.	181	12	0	1	194	
%	93.3	6.2	0	0.5		
Phellinus and black stain						
Area	0	0	0.1	0	0.1	0.7
No.	0	0	2	0	2	
%	0	0	100	0		
All Types						
Area	1.1	0.7	0.1	0.2	2.1	10.4
No.	315	29	2	1	347	
%	90.8	8.2	0.6	0.3		

Table 2. Survey estimates of *Phellinus weirii* root rot incidence in a Douglas-fir stand stratified into three blocks and without stratification

		Area Infected		No. of Centres	
	Area (ha)	Per ha	%	Per ha	Total
Block 1	23.8	5.0	21.0	2.25	54
Block 2	21.0	1.3	6.2	1.52	32
Block 3	21.4	3.8	17.7	2.10	45
Stand[a]	66.2	10.1	15.2	1.99	132

[a] Surveyed without stratification.