

**SURVEY OF THE EFFICACY OF
ROOT REMOVAL OPERATIONS
SURVEY I**

by

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FOREWORD

This report is one of a series of internal reports distributed by Forest Protection Branch, B.C. Ministry of Forests, to record accomplishments and interim or provisional results for the information of staff, colleagues, and others.

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The guidelines for internal reports outlined in the Protection Manual were adhered to as closely as possible. All manuscripts were altered to comply with a common format, but entire reports were not rewritten to conform to a standardized outline.

Most Executive Summaries were the work of Graham Hawkins of MoF Inventory Branch (formerly with Pacific Coast Forest Biology). All word processing was accomplished by Catriona Kaufman of Top Kat Services. Will Gordon of R. White Woods inc. prepared all maps and figures.

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EXECUTIVE SUMMARY

Two separate surveys were conducted on the coast (January - March 1986: PM-PB-66) and in the interior and on the coast (November 1986 - January 1987: PM-PB-67) to determine the effectiveness of stump excavations for removing infected material. Both surveys employed the same methods. Suitable stumped areas, treated from less than one year to 15 years before the survey, were selected for sampling, and eight were surveyed. The amount of residual material and its infective potential were determined and analyzed with respect to site factors such as soil type and moisture, depth, percent coarse fraction and terrain. Strips and plots were established at regular intervals for uniform sampling at eight sites, while non-random sampling was employed at three sites due to access restrictions and the desire to intensively sample infection centres.

A small backhoe was employed to excavate roots and soil at each plot. Excavations were performed down to the C-horizon. Dimensions, species and notes on any infection were recorded for all excavated root pieces, and suspected infected roots were incubated for confirmation. Site and soil factors were determined and also recorded per plot. Data on residual root material were analyzed by the percent of roots infected, the volume of infected roots per total volume of soil and the volume of all roots per total volume of soil. Site and soil factors were correlated with these analyses.

Results from both surveys indicated that statistically meaningful relationships could not be made between either total or infected root volume and the method of root removal or site age. Trends indicated that root-raking operations are not significant in reducing the amount of infected material. More root material was left on sites with high soil cohesion (silt and clay types), but relatively little of this material was infected due to the poor survival of pathogens under the wet conditions generally existing in these soil types. More infected material occurred in soils with greater porosity (sand types), but more material was also removed from these soil types.

In general, stumping operations were certainly effective in removing much of the infected material from heavily infected sites. Data from this project indicated that there was no significant difference in removal efficacy between excavator and bulldozer equipment. However, another study conducted for Forestry Canada in 1987 clearly showed that a large excavator is capable of removing more material than either a bulldozer or small excavator. Relatively few and smaller pieces of infected root material remain after treatment with a large hydraulic excavator/bucket and thumb.

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1 INTRODUCTION

The causal agent of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) laminated root rot, *Phellinus weirii* (Murr.) Gilbertson, has been recognized as a chronic problem for some time (Childs 1963; Wallis & Reynolds 1962). The longevity of the pathogen poses a high potential threat for regeneration stands of susceptible tree species. Indeed, *P. weirii* is the most destructive disease of second growth Douglas-fir stands in the Pacific Northwest (Bloomberg & Reynolds 1982). While attempts have been made to monitor the disease by means of aerial reconnaissance, the need for more accurate ground surveys, involving extensive root excavations, has been widely recognized (James *et al.*, 1984). cursory surveys for detection of the disease will provide only conservative estimates of the problem after it has commenced.

If a survey method can be devised which considers all the necessary parameters in order to quantify the hazard, steps can be taken to either improve root removal operations in infected stands or at least predict the volume of wood that would be lost to the pathogen. Thus, with these considerations in mind, methods for accurately assessing the threat were investigated. Site factors such as soil type, moisture and depth, percent coarse fraction, and slope, were noted since the probability of root contact is dependent on these (Bloomberg & Reynolds 1982; unpublished). The volume of both infected and non-infected root material remaining in the soil was measured with respect to soil volume in order to determine the level of danger posed.

2 MATERIALS AND METHODS

Eight sites were sampled. Two stumped and root raked sites were examined, one at the Cowichan Lake, North Arm research site and the other at the Canadian Forestry Service Highway 18 demonstration area (designated C.F.S. 1). For comparison, sites at Lots 65, 68, 86, 141 and 429, which had been stumped and windrowed but not root-raked, and a site (designated C.F.S. 2), which had been stumped but neither root-raked nor windrowed, were surveyed. In addition, one control area was sampled at Skutz Falls in a non-stumped area in order to determine the initial root volume. Sampling here was exceptional in that it consisted of the random placement of plots around an average Douglas-fir stump. Plots were placed at specific distances, either two metres or one metre, but on random radii from the centres of the four stumps chosen (Figure 1a). The bearings, distances, diameters and species of all adjacent stumps were noted and only data on root volume and incubation samples were collected.

Procedures for uniform sampling were utilized at the Skutz Falls (Lot 65), Shawnigan Lake (Lot 141), Chemainus (Lot 429), and Canadian Forestry Service Highway 18 demonstration sites on southern Vancouver Island, B.C. The survey procedure at Lot 86, Shawnigan Lake, consisted of uniform sampling in infection areas only, and was therefore biased. A grid system consisting of a baseline, strips and plots was used. Strips were traversed at constant headings and at regular intervals, where possible, from an initially established baseline. Sample plots were also laid out at uniform distances along each strip where feasible. Sampling was performed at the Cowichan Lake, North Arm research site along the perimeter only, resulting in a non-uniform sampling procedure. Excavation down to the C-horizon was performed at each marked plot by a model 843 Bobcat with a backhoe attachment.

Six strips were traversed at the Skutz Falls stumped and windrowed area (Figures 1, 1a). The sixth strip was subsequently deleted since very little root material was found and an accurate map of the infection centres was lacking. Thus, five strips, with five plots each, were surveyed. Strips were placed at 25m intervals along the baseline and were traversed parallel to the tree rows in order to minimize any damage during the excavation procedure. Plots were positioned 20 metres apart unless the presence of slash windrows or swampy areas dictated that they be offset. Sampling of the Skutz Falls site differed from that of the other sites because three subplots, designated A, B and C, were employed to make up a single plot in order to reduce the local variation. One subplot was placed on the strip and the other two were positioned on each side. Subplots were not placed closer than one metre from one another and were not, in any case, further than five metres apart.

Eight strips were traversed at C.F.S. 1 and 49 single plots were laid out. Strips and plots were 10m apart where possible. The number of plots was subsequently reduced to 41 due to low-lying, swampy areas (Figures 2, 2a). Four strips were traversed at C.F.S. 2 (Figures 2, 2b). Strips and plots here were also 10m apart wherever feasible.

Forty single plots were traversed at C.F.S. 2. No subplots were employed for either C.F.S. 1 or C.F.S. 2, since very accurate maps of the infection centres were available.

A much larger area had to be sampled at Lot 86, Shawnigan Lake. Thus, strips and plots were traversed in infection areas only, since these had been mapped out by the MoF. Strips could not be placed at regular intervals along the baseline, but were positioned in such a way as to cover most of the infection areas, according to the available map (Figures 3, 3a, 3b). Two baselines with four or five strips each were employed for sampling. Sixty-two plots were laid out on strips 1 through 5 in order to effectively sample the most heavily infected region. Twenty-one plots were placed on strips 6 through 9 to cover the other extensively infected area. The bearing and distance of an adjacent removed stumps were recorded from any remaining stump holes. Further, if an adjacent non-removed Douglas-fir or western hemlock stump was found, it was also recorded.

Because the exact location of the infection centres was not known for the Lot 141 site, the area was sampled systematically. The baseline approximated the boundary between the treated and untreated portions of the site and extended to the stream. The east side of the stream was inaccessible. The eight strips were located at intervals of 25m. Plots were also 25m apart unless they were offset as a result of slash, wet soil conditions or inaccessibility (Figures 4, 4a). Eighty-eight plots were laid out and examined. This particular spacing of strips and plots allowed for adequate coverage of the large area surveyed.

Strips and plots were placed systematically at the Lot 429 site. A map of the infection areas was lacking for this site. Further, the area which could be effectively sampled was quite small due to wet areas, slash, and the presence of closely spaced trees on certain portions of the site. Thus, strips and plots were positioned 10m apart, where possible, in the area available (Figures 5, 5a). Thirty-four plots on five strips were laid out.

Due to the nature of the site, a different sampling procedure had to be employed at the Cowichan Lake, North Arm research area. Because the site maintains a 12-year-old Douglas-fir plantation, sampling was restricted to the plantation perimeter in order to minimize damage to the trees, and was thus not uniform in nature. The site consisted of two treatment areas, one having been stumped only and the others stumped and root-raked. Twenty-eight plots were established along three sides of the stumped area (Cow 1) and 32 plots were established along four sides of the stumped and root-raked area (Cow 2)(Figures 6, 6a, 6b). The fourth side of the stumped area was not sampled because it lies adjacent to another plantation and excavation would have resulted in some damage.

When examining plots or subplots, the following procedure was used with the exception of the Skutz Falls control area. A depth to the bottom of the B horizon was

considered to have been attained once solid clay was being removed from the pit or a depth of 1.3m was reached. Sampling for root material was conducted systematically down each strip and the necessary information recorded on specialized plot data cards for the computer. Data were recorded on print-outs and floppy disc by Wecom Data Centre Services Ltd. The plot or subplot was measured for depth, bottom length and width, and top length and width to the nearest 10cm in order to obtain the soil volume. A soil field analysis was then performed and the percent coarse fragments and soil fine fraction texture recorded. Soil pH, determined with litmus paper accurate to 1.0 pH units, along with soil moisture, depth and color, were also tabulated. Porosity and presence or absence of seepage were noted. Depth to bedrock was estimated and parent material, rock type and base status were assessed. Finally, the aspect and percent slope were determined from the plot centre. Any other pertinent remarks were noted on the back of the information card.

Sampling for root debris in the excavated soil or protruding into the sample pit was then commenced. Douglas-fir (and western hemlock) root debris was distinguished from that of other species in order to derive a volume for root material based on a potential source of inoculum. Thus, western redcedar roots, for example, were not included as root volume when discerned. Any Douglas-fir root material measuring one centimetre diameter or greater and at least five centimetres in length was recorded. All root pieces were measured to the nearest centimetre for length and diameter and the data tabulated. Thus, an accurate estimate of the root volume remaining in the soil was obtained. Twelve size categories were considered for incubation samples. When found, an example from each size category was kept for incubation from each plot provided that the root material was still reasonably intact. At least 25 samples from each size category were incubated when it was possible to obtain this quantity. Any suspected material was taken for incubation since evidence of *Phellinus weirii* infection was looked for in the field.

Sample roots were measured, noted as to whether or not they were suspect, and tagged for incubation. Samples were kept cold until preparation for incubation. Incubation samples were split, wrapped in wet newspaper, and left at room temperature (at least 20°C) for seven days in order for the mycelia of any *P. weirii* present to develop. The samples were then examined with a dissecting microscope. The presence of viable *P. weirii* mycelia could be determined readily since brown setaceous hyphae were easily discernible among the white mycelial mats. Any samples positive for the pathogen were noted for either the ectotrophic or endotrophic form of *P. weirii*, where possible, since the two trophic types may pose a different potential threat (Bloomberg & Reynolds 1982).

3 RESULTS

The amount of root material recovered varied considerably between sites in terms of the actual volume per unit of soil, the occurrence throughout a given area, and the percentage of root material with viable pathogen (Table 1; Figures 7 and 8). The highest incidence of *P. weirii* occurred at the stumped, windrowed and root-raked site (designated Cow 2) at the Cowichan Lake, North Arm research area. Six plots (18.8%) contained root material with viable *P. weirii* for a total volume of 0.058m³ of infected root material per 100m³ of soil and 25.9% of the total root volume (Table 1; Figures 7 and 8). The next highest incidence of the pathogen, in terms of the percentage of plots containing inoculum, occurred at the stumped, but not windrowed or root-raked, site (designated C.F.S. 2). Here, five plots (12.5%) contained viable pathogen for a total volume of 0.013m³ of infected root material per 100m³ of soil and 2.9% of the total root volume (Table 1; Figures 7 and 8). Greater volumes of infected roots were obtained at other sites, notably Lots 86 and 141 with 0.037 and 0.022m³ of infected root material per 100m³ of soil, making up 11.1% and 7.4% of the total root volume respectively (Table 1; Figures 7 and 8). However, the percentage of plots with viable inoculum at Lots 86 and 141 was lower than for the C.F.S. 2 or Cow 2 sites, with 8.4% and 5.7% respectively (Table 1; Figures 7 and 8). Lot 65 contained no viable pathogen despite the high volume of material recovered (0.681m³/100m³ of soil).

No meaningful relationships could be made between either total or infected root volume and the method of root removal or site age (Table 1; Figures 7 and 8). The difference in total root volume between C.F.S. 1 (root-raked) and C.F.S. 2 (stumped only) was insignificant, being 0.413 and 0.438m³/100m³ of soil respectively. Further, the non-root-raked site had a slightly lower percentage of *P. weirii* than did the root-raked site (0.013 as compared to 0.017m³/100m³ of soil respectively). Although a much higher percentage of total root material had been removed from the Cow 2 (root-raked) site (0.225m³/100m³ of soil remains), a very high proportion (25.9%) of the remaining root material was infected (Table 1). The less powerful D7E crawler may have been responsible for the high percentage of total roots left behind at Lot 65. Both crawler and excavator-type equipment left behind comparable volumes of both infected and non-infected roots. However, 5.59% of the stumps were left behind by the excavator at Lot 86. Three of these stumps contained viable *P. weirii*. This figure is based on the 40 stems per hectare found during the survey as compared to the pre-logged value of 715 stems per hectare. A decrease in both total and infected root volumes with increasing site age could not be determined. The 14-year-old Cow 1 and 2 sites had relatively high infected and total root volumes compared to those of Lot 86.

Total and infected root volumes could be correlated to soil type (Table 2; Figure 9). Generally, a greater total volume of root material, as expressed in cubic metres of material per 100m³ of soil, was found in those soils with high cohesion (Figure 9). Silty loam is the exception, but silty clay loam, clay, sandy clay loam and sandy clay

retained the highest total root volume with 0.271, 0.202, 0.196, and 0.170 respectively. However, these soil types contained little or no material with viable inoculum, sandy clay loam having only 0.030% and the others none. Silty loam retained both high total and infected root volumes at 0.187 and 0.157% respectively. The highest incidence of infected material occurred in sand, more material with viable inoculum being recovered than non-infected (0.095 as compared to 0.078%). Sand retained the lowest total volume of root material of any of the soil types. There was a fair amount of inoculum in sandy loam, loamy sand and loam, and none in silt (only two plots examined)(Figure 9). Very few roots were recovered from plots in which there was a high coarse fraction (greater than 70%)(personal observation).

4 DISCUSSION

Many variables are ultimately responsible for the volume of non-infected and infected root material remaining at a particular regeneration site after stumping operations have been completed. The number of stems per hectare and the degree of infection in the previous stand, the soil type, moisture, and nutrient regime, the microbiology of the soil and age of the site, as well as the excavation method and equipment used, affect the residual root volume. Further, the method of survey itself may influence the data obtained.

It would appear that the practice of root-raking has very little effect on reducing the threat from *P. weirii*. For instance, while the total volume of root material was much lower at the Cowichan Lake root-raked site, the potential hazard remaining was much higher than for the non-root-raked site. At the C.F.S. demonstration area, neither the total root volume nor the volume of infected material was significantly reduced by employing this practice. In the case of the Cow 2 site, the infected root material may have been situated in the deeper regions of the soil and thus remained unaffected by the 45cm teeth of the root rake. The loose, deep silty loam and sandy loam predominant at the Cow 2 site would allow relatively easy and deep root penetration. Since no significant decrease in the presence of *P. weirii* could be seen with increasing time since harvest, the probability of contact between the growing roots and deeply situated inoculum is probably quite high. While the occurrence of very large root pieces (11-15cm diameter and 51-100cm long) is low (about 4% of the total number of infected roots), long survivability of the pathogen in such sections can be expected. Viable pathogen was found in much smaller sections, regardless of site age. Root segments less than six centimetres diameter and 26cm long still contained inoculum after 14 years.

Certainly there is some doubt as to the statistical reliability of the data from the Cowichan Lake, North Arm research area since the survey was biased toward the perimeters only. Sampling would need to be performed in the same manner as for the other sites in order to be truly comparable. However, the occurrence along the perimeter, actual volume of infected material per unit soil, and percentage of root material with inoculum per total root volume all indicate a high threat at the Cow 2 site relative to those values of the same parameters obtained from any single strip of the uniform grid surveys. Thus, at least some comparison may be made between the different survey methods. The preceding three methods of measuring the presence of the pathogen have been deemed necessary in order to fully quantify the hazard. Obviously a high volume of infected root material contained in a single plot over a fairly large survey area does not pose the same threat to as many trees as does the same volume spread throughout the site. One can assume that the probability of root contact with the inoculum will increase in the latter case. Further, the percentage of wood carrying the viable pathogen relative to the total volume of residual root material may provide some measure of the effectiveness of extraction provided more thorough controls are

performed in the future. Sections of infected root material would be much more likely to break off, especially in the more cohesive soil types, than would healthy root sections with either crawler or excavator-type machinery. Some measure of this tendency is valuable in determining the actual efficiency of reducing the threat and not of merely removing healthy root material. While most powerful machinery may be more efficient at extracting healthy roots, the quantity of residual infected material may remain unchanged since the infected, laminated material would easily shear off under high force. The toe-equipped extractor was efficient at pulling out stumps. However, large sections appeared to be broken off and remained in the soil at Lot 86 (personal observation 1986). From the data, both crawler and excavator-type machinery seem to be similar in efficiency in terms of both residual infected and total root volume, but a large number of Douglas-fir and western hemlock stumps were left behind during the extractor operations, thus leaving behind a considerable threat. Perhaps this was due to lack of good visibility from the cab in combination with the low cut and unmarked stumps. The problem may have been further aggravated by the presence of high amounts of slash, and at times by snow on the site from December to January.

A further consideration is that of soil type. A relationship exists between high total residual root volume and increased cohesiveness of the soil. However, the threat posed by *P. weirii* appears to be much lower in the majority of the clay-type soils. This may be due to a combination of poor aeration, extreme moisture, and the presence or absence of organisms antagonistic to the pathogen. Thus, the difficulty of removing roots from these soil types might not imply an increase in the incidence of root disease after root removal operations. The pathogen poses a higher threat in silty loam and sand in particular, despite easier root removal from the latter soil type. *P. weirii* thrives in soil moisture regimes from fresh to moist (3 - 6) (Bloomberg & Beale 1985; unpublished). Perhaps adequate aeration under moist conditions is a prime factor here. Further, the soil microbiology could also be an important determinant. Fewer *Streptomyces* species antagonistic to *P. weirii* have been found in sand compared to other soil types (Hutchins & Rose 1984). Also, those antagonistic species that are present are at greatly reduced population levels. The presence or absence of such antagonistic *Streptomyces* species may, in part, determine the presence or absence of *P. weirii* (Hutchins & Rose 1984; Shea 1970).

No firm correlation between the quantity of infected root material and nutrient regime, pH, or coarse fraction could be determined. Nutrient regime may not be as important a factor as soil moisture (Bloomberg & Beale 1985). Soil pH, as measured in the field, is of little value since the pathogen survives well in the pH 5 - 6 range found throughout the survey. The accuracy of the pH field measurements was only to one pH unit. Lower root volumes were recovered from soils with a very high coarse fraction, but this may have been due to low volumes in these soils.

There seemed to be little difference in effectiveness of the survey techniques in terms of strip and plot spacing using the uniform grid method. Both infected and non-

infected root material was recovered from surveys using 10 x 10 and 25 x 25m spacing and with plots placed at five metre intervals, as at the Cowichan Lake, North Arm sites. Lot 65 was exceptional in that no infected root material was recovered, but this was probably due to insufficient information on the exact location of the infection areas rather than on the 25 x 25m spacing employed. The use of subplots at this site, in order to reduce local variability, did not appear to be of much use in handling the data. Subsequent use of single plots only was probably just as effective, since high variability was found between plots at a given site in any case. Thus, strip and plot spacing, using single plots, can be modified by the survey team to fit a given area under certain restrictions such as those imposed by terrain. Greater spacing, such as the 25 x 25m employed at Lot 141, can be used to cover a large area and obtain sufficient data. Conversely, tighter placement of strips and plots, such as the 10 x 10m spacing at Lot 429 or the C.F.S. 1 and 2 sites, can be employed to cover a smaller area intensively, if necessary. However, the resultant data might not be as accurate when gathered from a small area since the chosen area could be atypical of the site as a whole. For instance, very little root material was recovered from Lot 429, despite a prelogging stand density of 917 stems per hectare. The constraints on sampling imposed by terrain must be taken into account as they were at Lot 429. With the availability of highly accurate stem charts, as was the case for C.F.S. 1 and 2, limited area surveys using 10 x 10m spacing could be carried out with accurate results. Further, the need for more detailed maps showing infection areas would be of great help in order to stratify future sampling toward those regions suspected of containing the pathogen. Although the data were not conclusive, the close spacing of plots in infection areas at Lot 86 may have been responsible for the high percentage of infected root material per total root volume recovered.

The incubation technique employed in this survey is fast, simple and reliable, at least on a superficial level, but some doubt remains as to its accuracy. Some root specimens which exhibited obvious gross morphological manifestations of the pathogen did not show positive after incubation. An abundance of white mycelia could be observed, but the definitive brown setaceous hyphae were totally absent. Such questions as to viability could be eliminated with the application of accurate and fairly simple spore viability tests (Yu & Trione, 1984). The ATP content of either spores or hyphae, easily measured by the luciferin-luciferase system, gives a very reliable determination of the viability of the pathogen. Identification of strictly endotrophic forms was sometimes difficult because of the fragmented nature of much of the material. Differentiation between the endo- and ectotrophic forms is an important consideration since the latter form probably poses more of a threat.

The model 843 Bobcat performed well. It has adequate power for rapid excavation in all soil types. The presence of a very high coarse fraction did not significantly lower the speed of excavation. Further, moving slash out of its direction of travel proved to be a simple task. Traction was good on dry, level ground and on moderate slopes. Mobility was reduced on the steeper slopes and in very wet areas. Despite the balloon

tires on this particular machine, the high weight (nearly 3 000kg) required for digging proved to be disadvantageous at times. However, a tractor-mounted backhoe would be both heavier and too large. The Bobcat's small size meant that very few trees were damaged during excavation operations even in fairly dense stands.

5 RECOMMENDATIONS

The following recommendations are made:

1. More survey work should be performed on sites treated with excavator-type equipment. Only one such site was examined and thus comparisons between the crawler and excavator types are not conclusive.
2. At least one more root-raked site should be surveyed.
3. Extensive control surveys should be performed in order to truly quantify the data.
4. More attention should be given to infected sites with predominantly silty loam or sand-type soils.
5. Infection areas should be more thoroughly mapped out.
6. Stumps should be conspicuously marked or the practice of high stumping employed in areas to be treated by excavator-type equipment.

6 CONCLUSIONS

The more cohesive soil types retained more root material, but it would appear that the level of pathogen is generally lower in these. Silty loams and sands retained relatively high levels of *Phellinus weirii*. This is perhaps connected to the level of soil aeration or to the absence of species antagonistic to the pathogen. No decrease in the level of viable pathogen over time could be determined.

Root-raking was apparently of little value in reducing the threat. Both types of excavation equipment may have similar efficiency in removing root material, although the data are not conclusive. The uniform grid method employed to sample most sites was effective for gathering data. Wider spacing of strips and plots seems appropriate for a large survey area if no accurate map of the infected regions is available. Closer spacing of strips and plots works well if the small area chosen is within a known infection area. Further investigation into the efficacy of root removal operations is required.

7 REFERENCES

- Bloomberg, W.J. and Beale, J.D. Relationship of Ecosystem to *Phellinus weirii* Root Rot on Southern Vancouver Island, 1985, unpublished.
- Bloomberg, W.J. and Reynolds, G. Factors Affecting Transfer and Spread of *Phellinus weirii* Mycelium in Roots of Second Growth Douglas Fir. *Canadian Journal of Forest Research*, 12:424-427, 1982.
- Childs, T.W. *Poria weirii* Root Rot, *Phytopath*, 53:1123-1127, 1963.
- Hutchins, A.S. and Rose, S.L. The Variation in Antagonistic *Streptomyces* Populations in Soils from Different Vegetation Types in Western Oregon, *Northwest Science*, 58:249-254, 1984.
- James, R.L. *et al.* Estimating Root Disease Losses in Northern Rocky Mountain National Forests, *Canadian Journal of Forest Research*, 14:652-655, 1984.
- Shea, K.R. *Poria Root Rot: Problems and Progress in the Pacific Northwest in Root Disease and Soil-Borne Pathogens*, University of California Press, Berkeley: 1970. pp. 164-166.
- Wallis, G.W. and Reynolds, G. Inoculation of Douglas Fir Roots with *Poria weirii*, *Canadian Journal of Botany*, 40:637-645, 1962.
- Yu, S.Q., Trione, E.J. and Ching, T.M. Biochemical Determination of the Viability of Fungal Spores and Hyphae, *Mycologia*, 76:608-613, 1984.

TABLE 1 SUMMARY OF DATA FOR SITES VISITED

Site	Excavation Method and Date Stumped	Machine Used	Sampling Method Description	Sample Spacing Strips x Plots (Metres)	Number of Plots	Total Soil Volume Excavated (m ³)	Uninfected Root Volume Remaining (m ³)	Infected Root Volume Remaining (%)	% Infected Root Volume per Total Root Volume	Infected Root Volume per Total Root Volume %	Total Root Volume (m ³)	% Total Root Volume per Total Soil Volume	Number of plots Containing Viable Pathogen
Lot 65	1978 D, W	Caterpillar D7E with brush blade	• uniform grid • 3 subplots per plot	25 x 30	25 (75 subplots)	20.071000	0.13667124	0.0	0.0	0.0	0.13667124	0.68094	0.0
Lot 65 (control)	none	none	• biased • 4 subplots per plot • no grid	• random • no strips	4 (16 subplots)	6.884500	0.01035600	0.0	0.0	0.0	0.01035600	0.15042	0.0
C.F.S. 1	D, W, R	Caterpillar D8H with brush blade	• uniform grid	10 x 10	41	26.755750	0.10563656	0.00463375	0.01732	4.2	0.11052031	0.41307	1.0
C.F.S. 2	D	Caterpillar D8H with brush blade	• uniform grid	10 x 10	40	31.952000	0.13565808	0.00409643	0.01282	2.9	0.13995451	0.43801	5.0
Cow. 1	D, W	Caterpillar D8H with brush blade	• biased only • perimeter sampled	• no strip spacing 5	28	18.886500	0.54389188	0.00327899	0.01736	0.6	0.54717087	2.89715	2.0
Cow. 2	D, W, R	Caterpillar D8H with brush blade	• biased only • perimeter sampled	• no strip spacing 5	32	20.069500	0.03940301	0.01167533	0.05817	25.9	0.04507834	0.22461	6.0
Lot 86	1986 d, w	Excavator with toe	• biased only • infection areas sampled • uniform grid	• variable x 10 (a) or variable x 20 (b)	83	74.508500	0.22392497	0.02791386	0.03746	11.1	0.25183883	0.33800	7.0
Lot 141	1980 D, W	Caterpillar D8H with brush blade	• uniform grid	25 x 25	88	64.000250	0.17474058	0.01400026	0.02188	7.4	0.18874084	0.29491	5.0
Lot 429	1979 D, W	Caterpillar D8H with brush blade	• uniform grid	10 x 10	34	19.9675	0.02855032	0.00023883	0.00120	0.8	0.02878915	0.14418	1.0

Code: D, W, R = stumped, windrowed and root raked
D, W = stumped and windrowed
D = stumped only

TABLE 2 SUMMARY OF DATA BY SOIL TYPE

Soil Type	Total Soil Volume	Total Root Volume	Infected Rot Volume	Total Root Volume per Total Soil Volume	Infected Root Volume per Total Soil Volume
	(m ³)	(m ³ root/ m ³ soil)	(m ³ root/ m ³ soil)	(%)	(%)
S	23.0870	.018095	.021865	0.07838	0.09471
LS	36.7895	.040848	.0061533	0.11103	0.01673
SL	84.4025	.107408	.0291373	0.12726	0.03452
L	45.5330	.05335	.031105	0.11712	0.06828
Si	0.7150	0.0	0.0	0.0	0.0
SiL	11.0315	.020681	.0173057	.187472	0.15688
SiCL	14.0590	.038137	0.0	0.27216	0.0
SCL	13.0615	0.25614	.003960	0.19610	0.03032
SC	0.3810	.000646	0.0	0.16955	0.0
CL	37.0010	.04980	.0160801	0.13459	0.04346
C	3.6120	.007296	0.0	0.20200	0.0

FIGURE 1 LOT 65 OVERVIEW

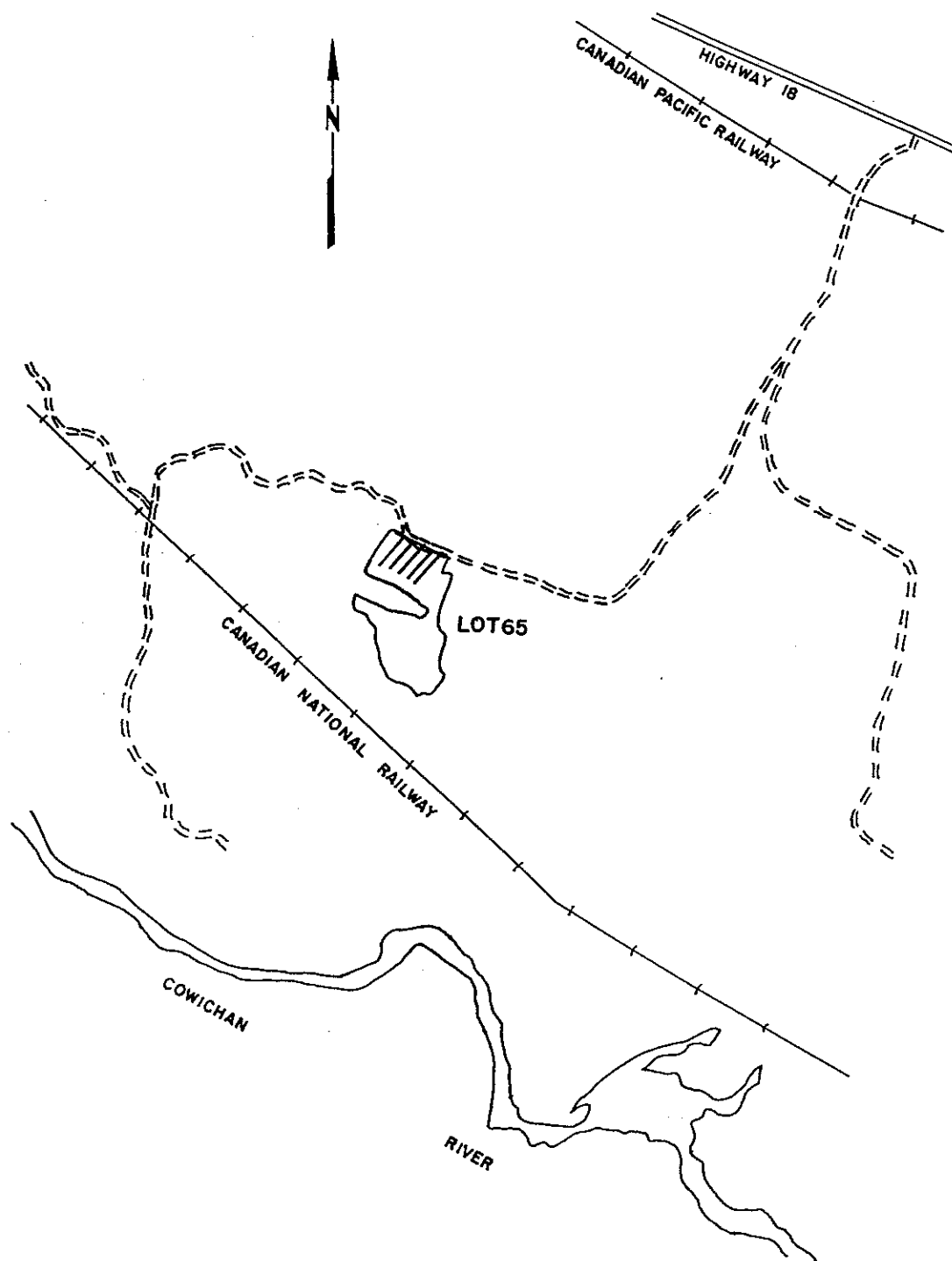


FIGURE 1a SKUTZ FALLS STRIP AND PLOT LAYOUT

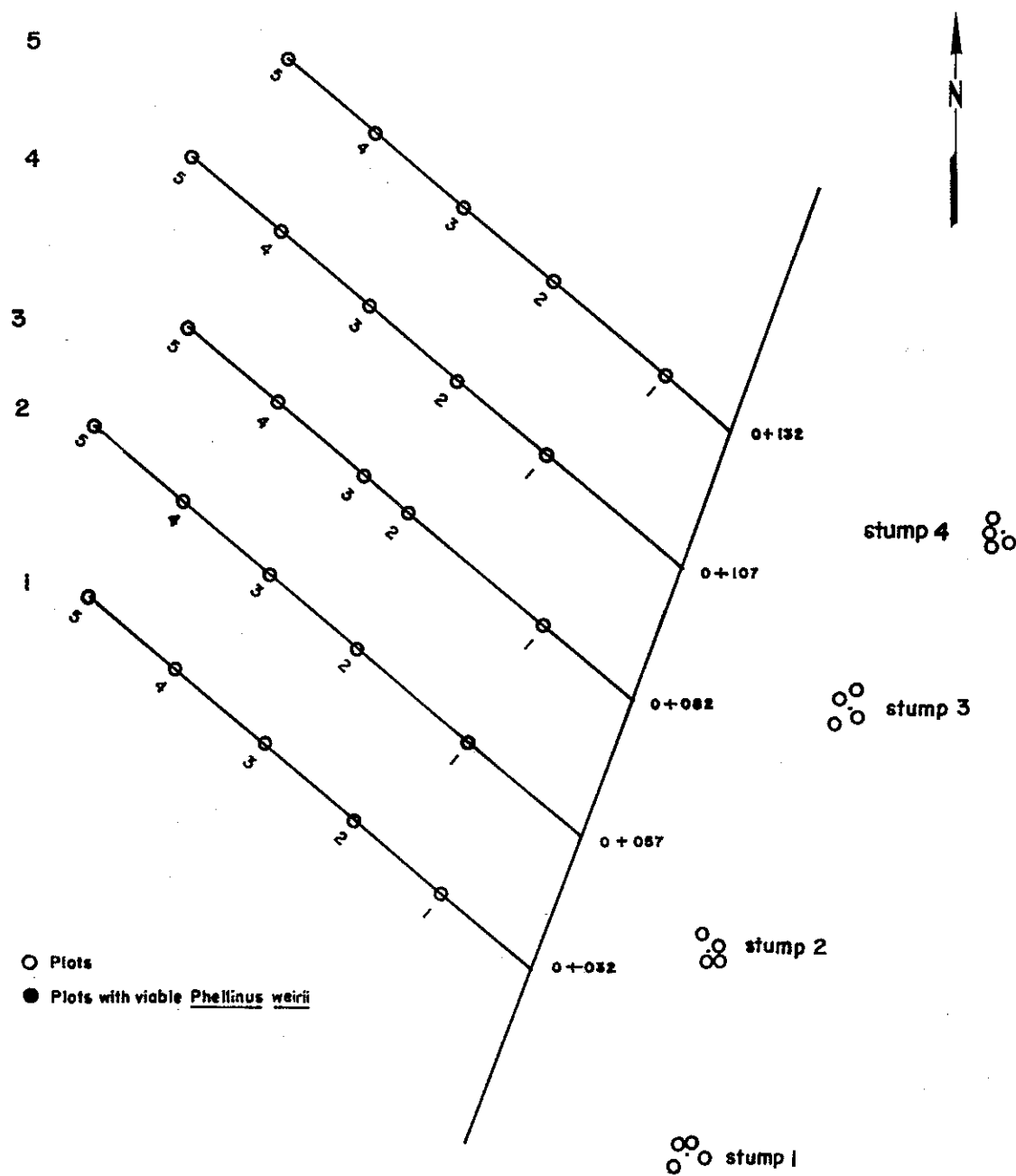


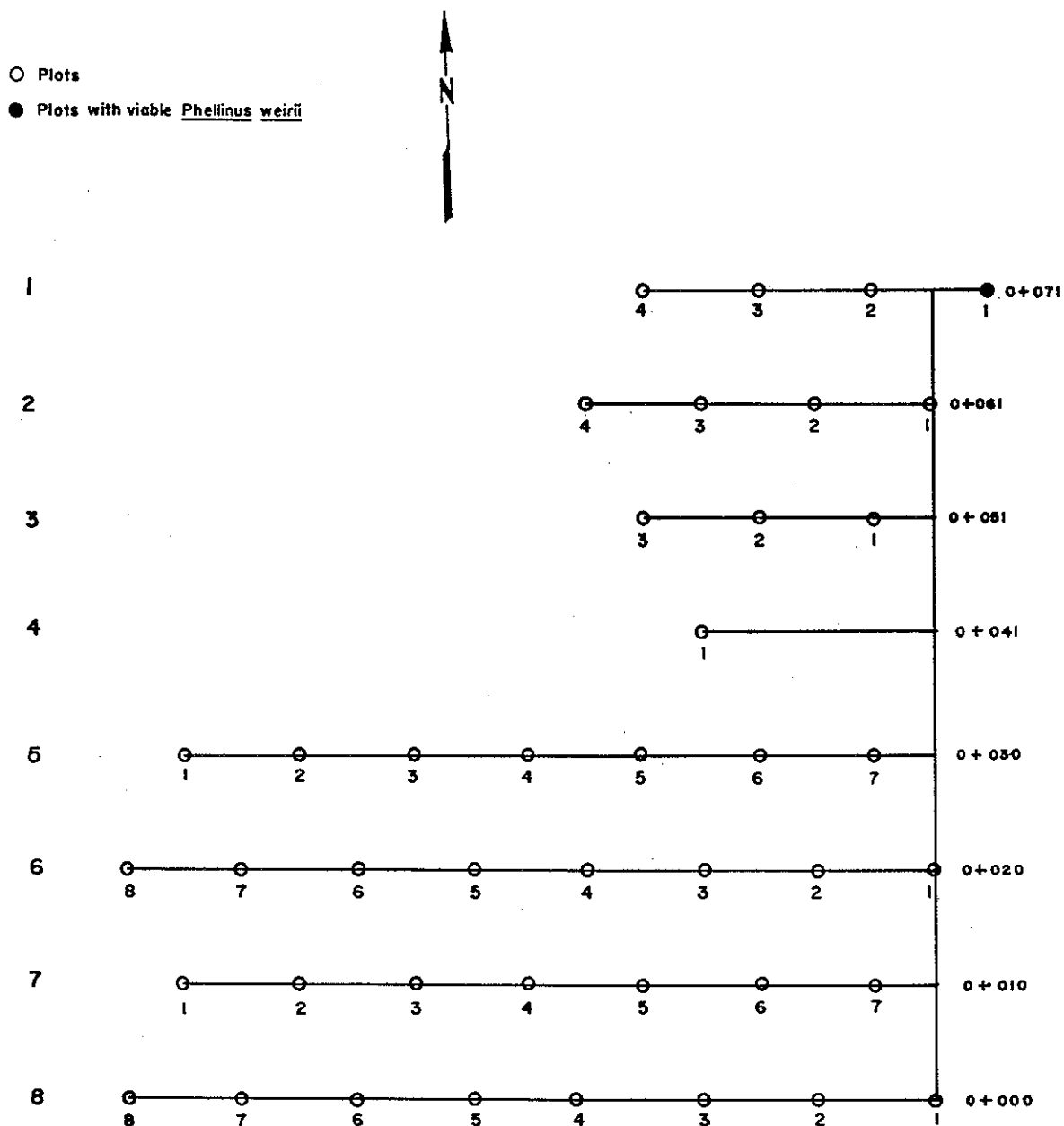
FIGURE 2a CFS 1 STRIP AND PLOT LAYOUT


FIGURE 2b CFS 2 STRIP AND PLOT LAYOUT

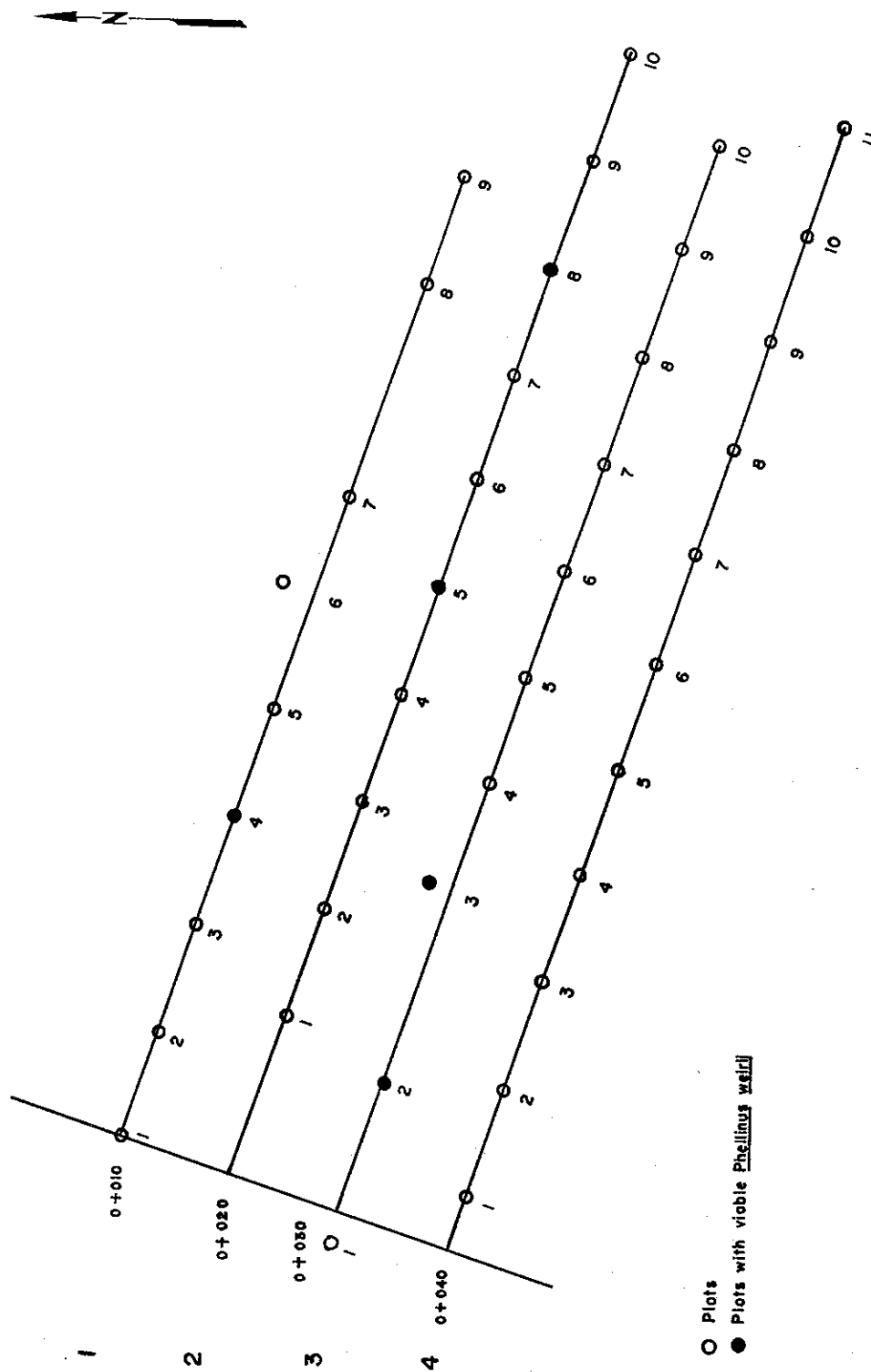


FIGURE 3 **LOT 86 OVERVIEW**

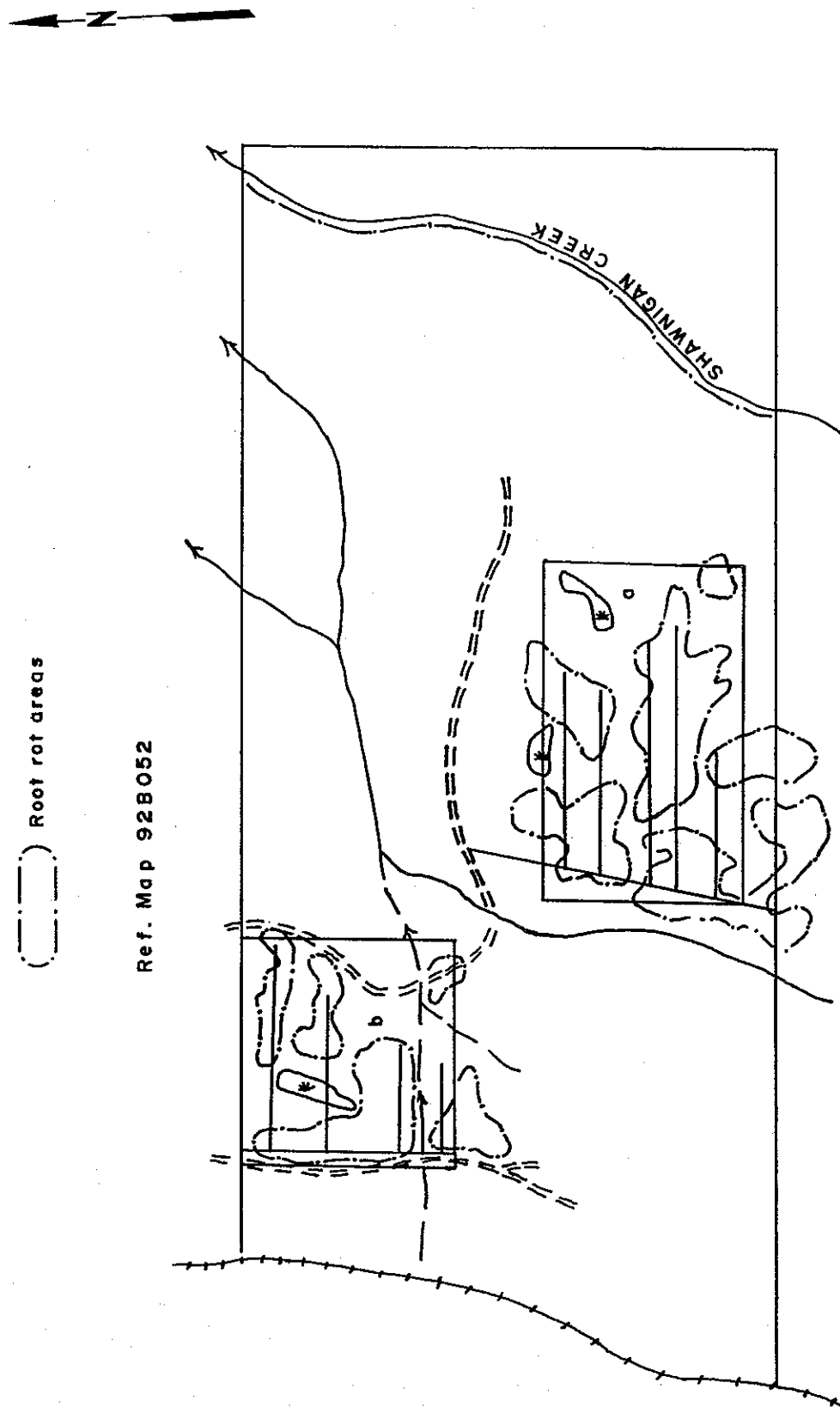


FIGURE 3a LOT 86, AREA a STRIP AND PLOT LAYOUT

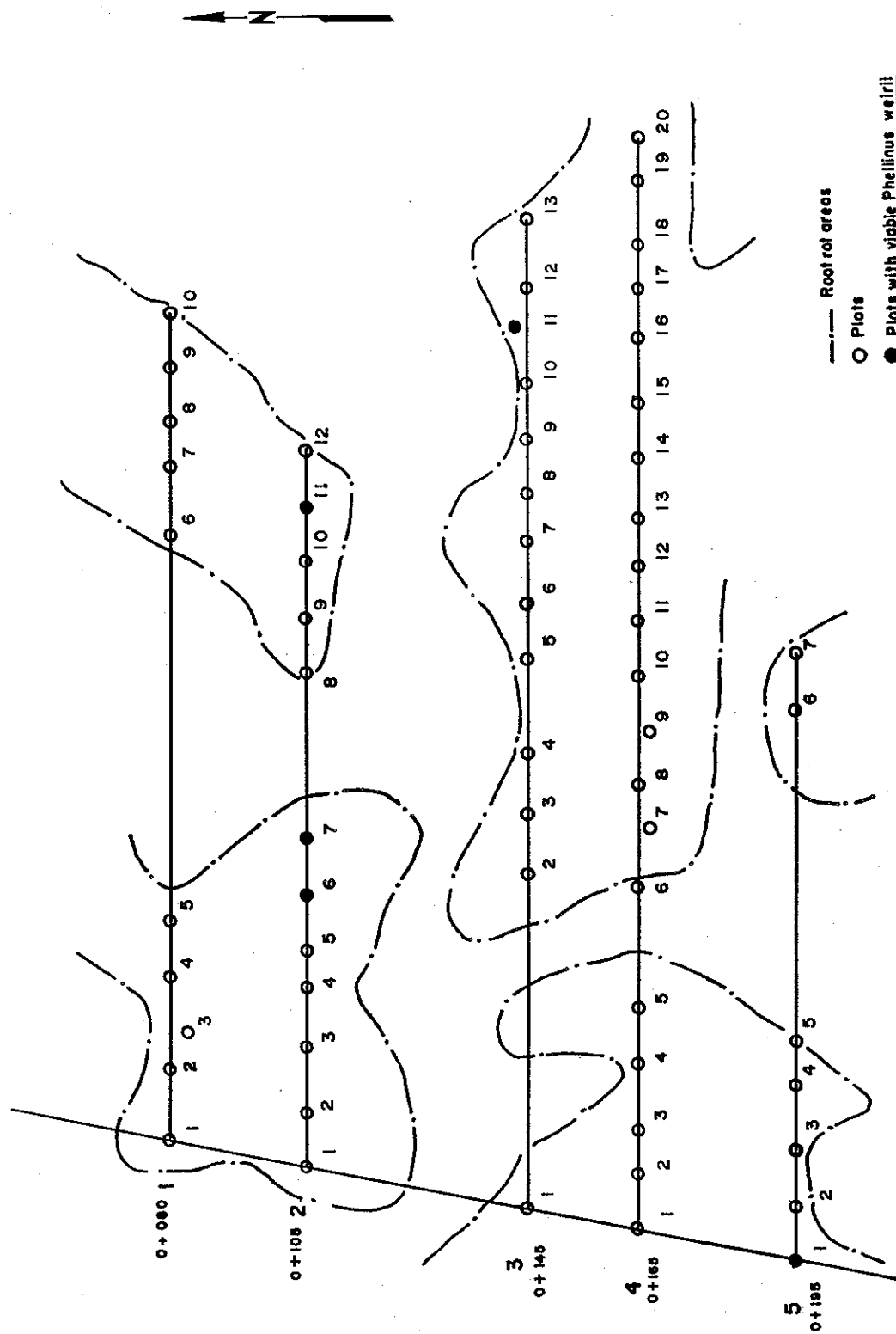


FIGURE 3b LOT 86, AREA b STRIP AND PLOT LAYOUT

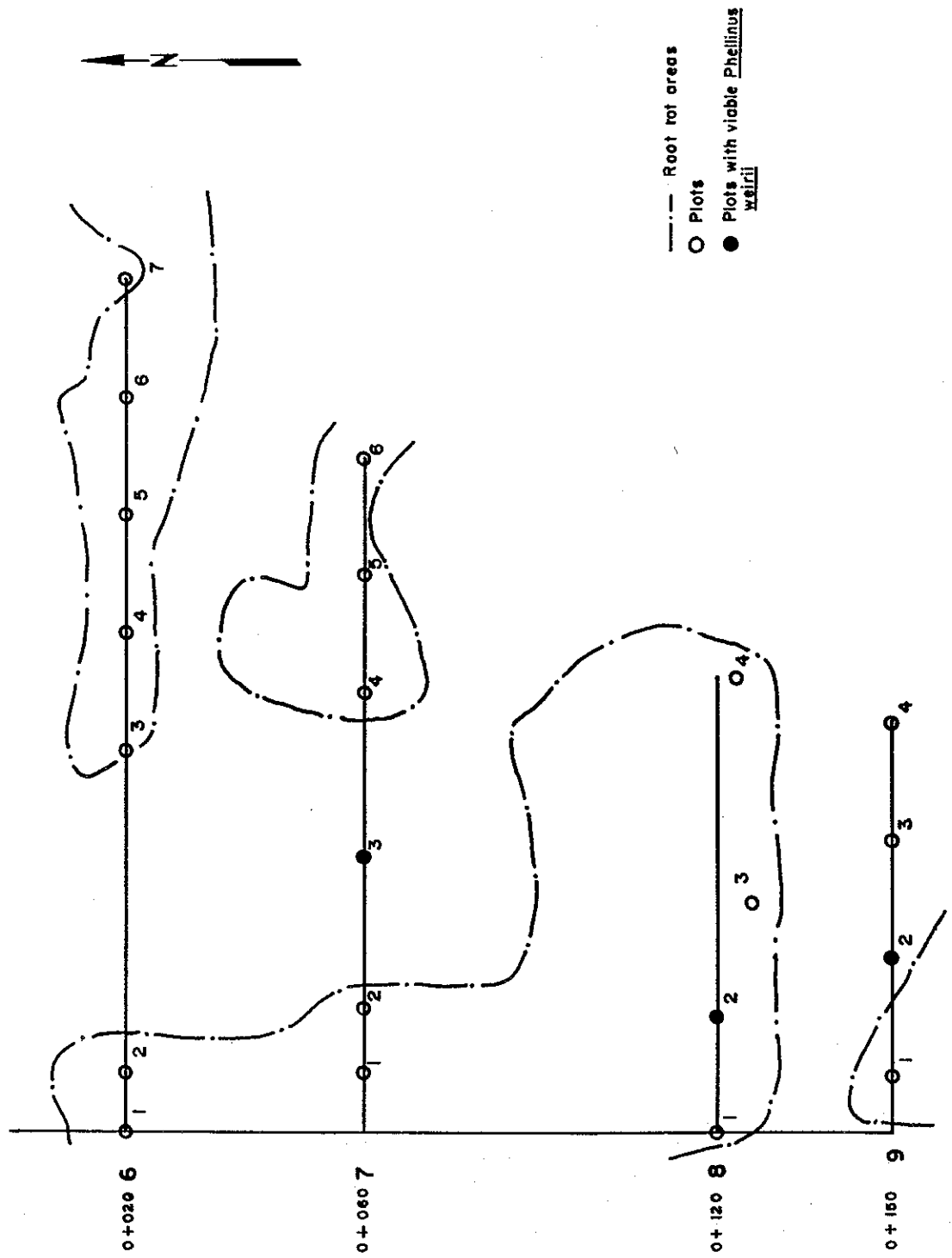
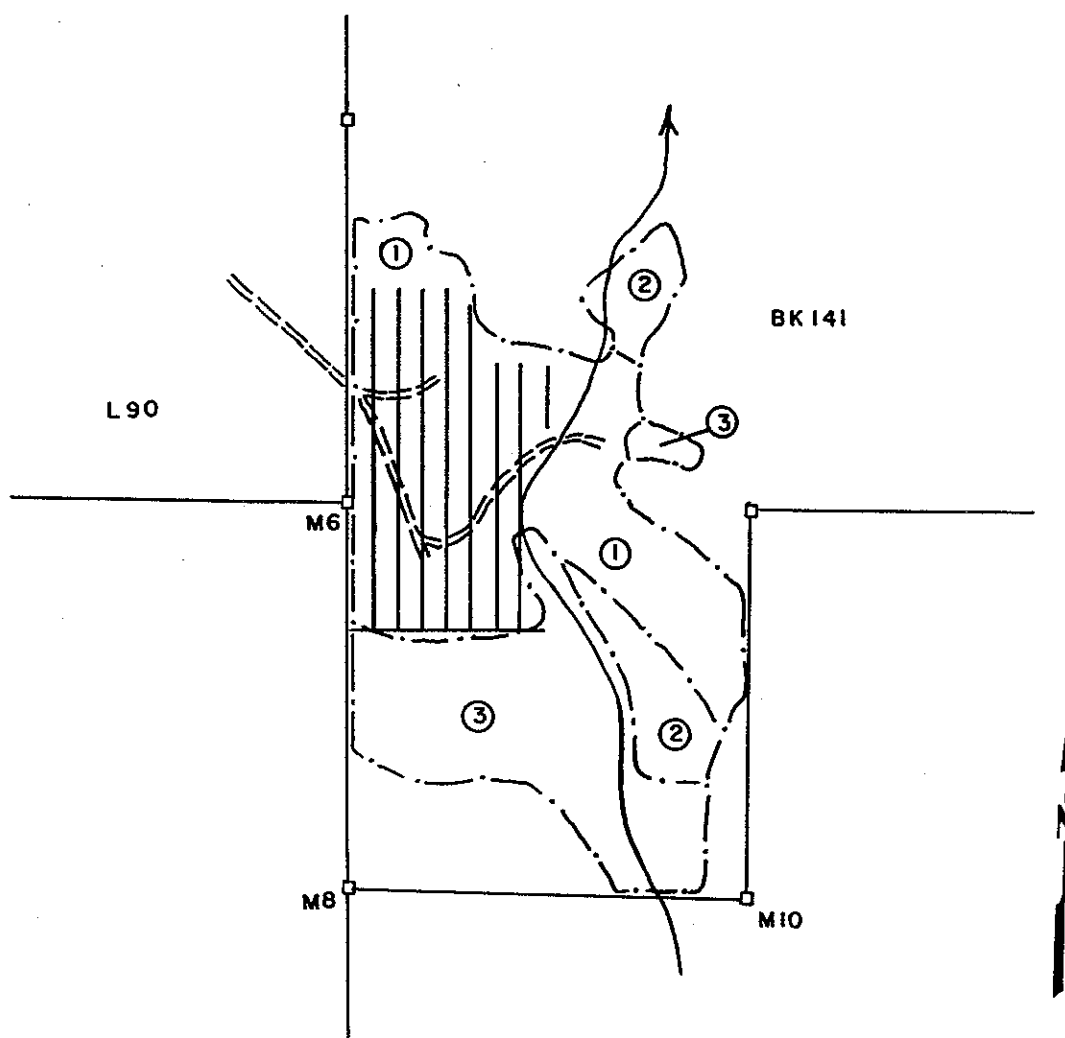
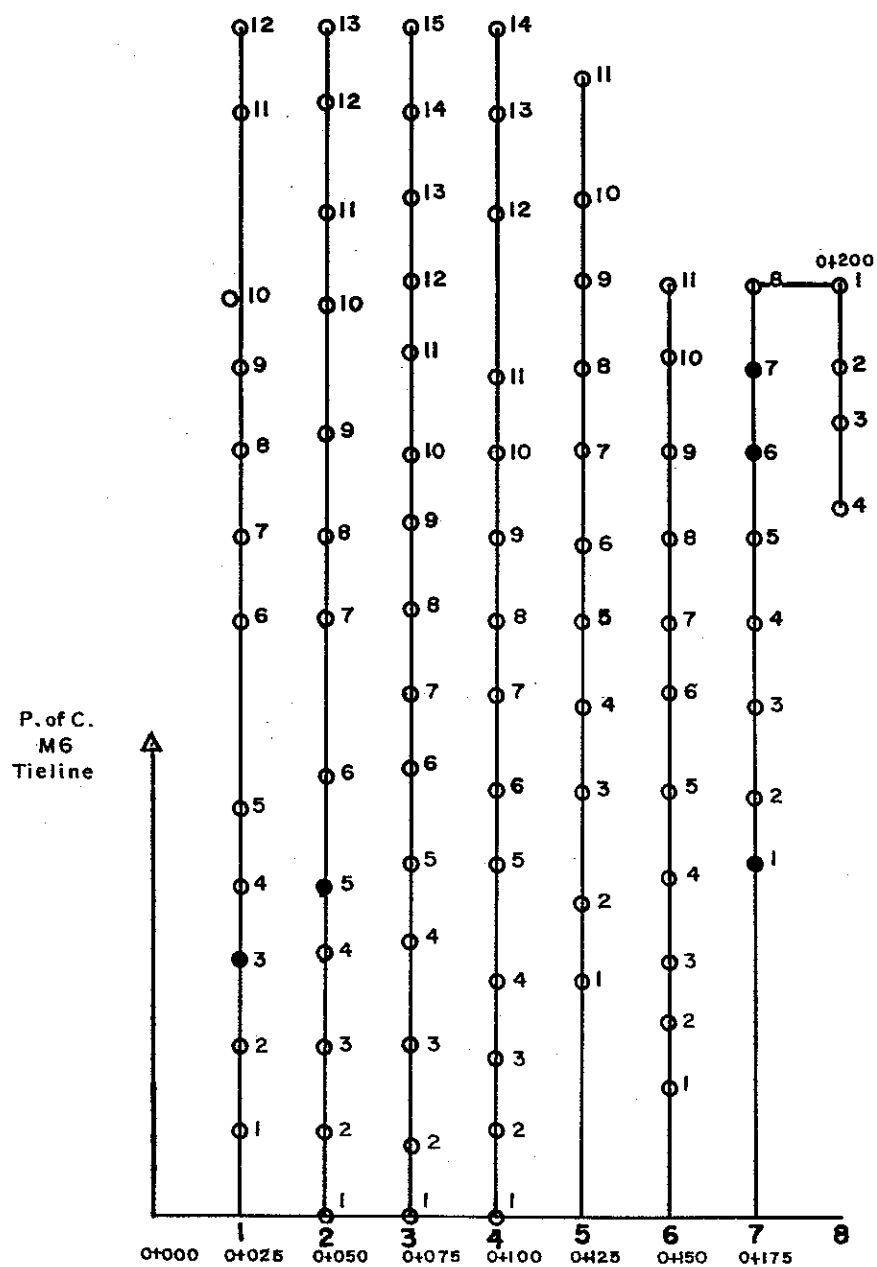


FIGURE 4 LOT 141 OVERVIEW

Legend

- ① Stumped and windrowed
- ② Untreated, infected
- ③ Untreated, not infected

Ref. Map 92 B/12a

FIGURE 4a LOT 141 STRIP AND PLOT LAYOUT


○ Plots

 ● Plots with viable *Phellinus welrii*

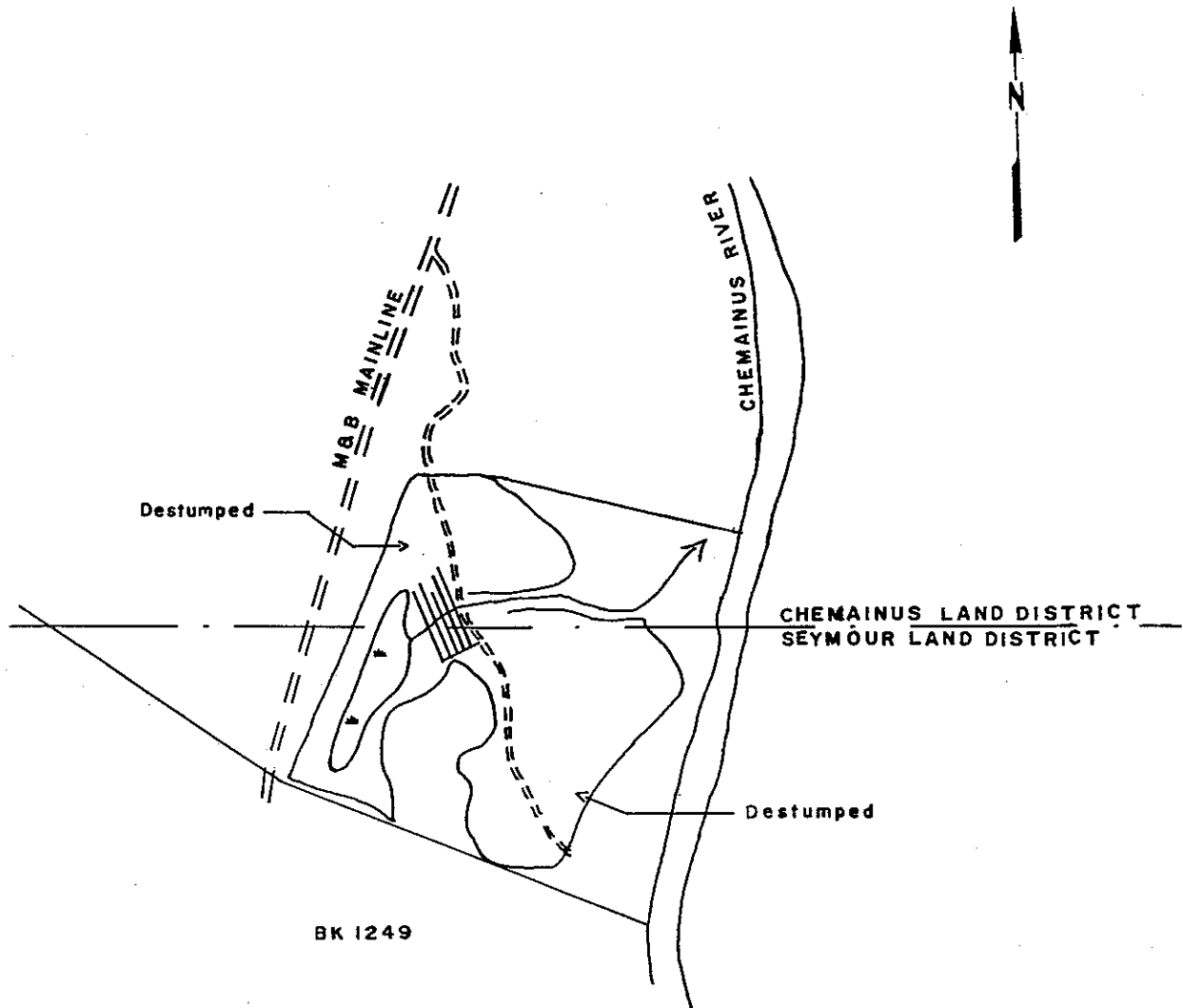
FIGURE 5 LOT 429 OVERVIEW

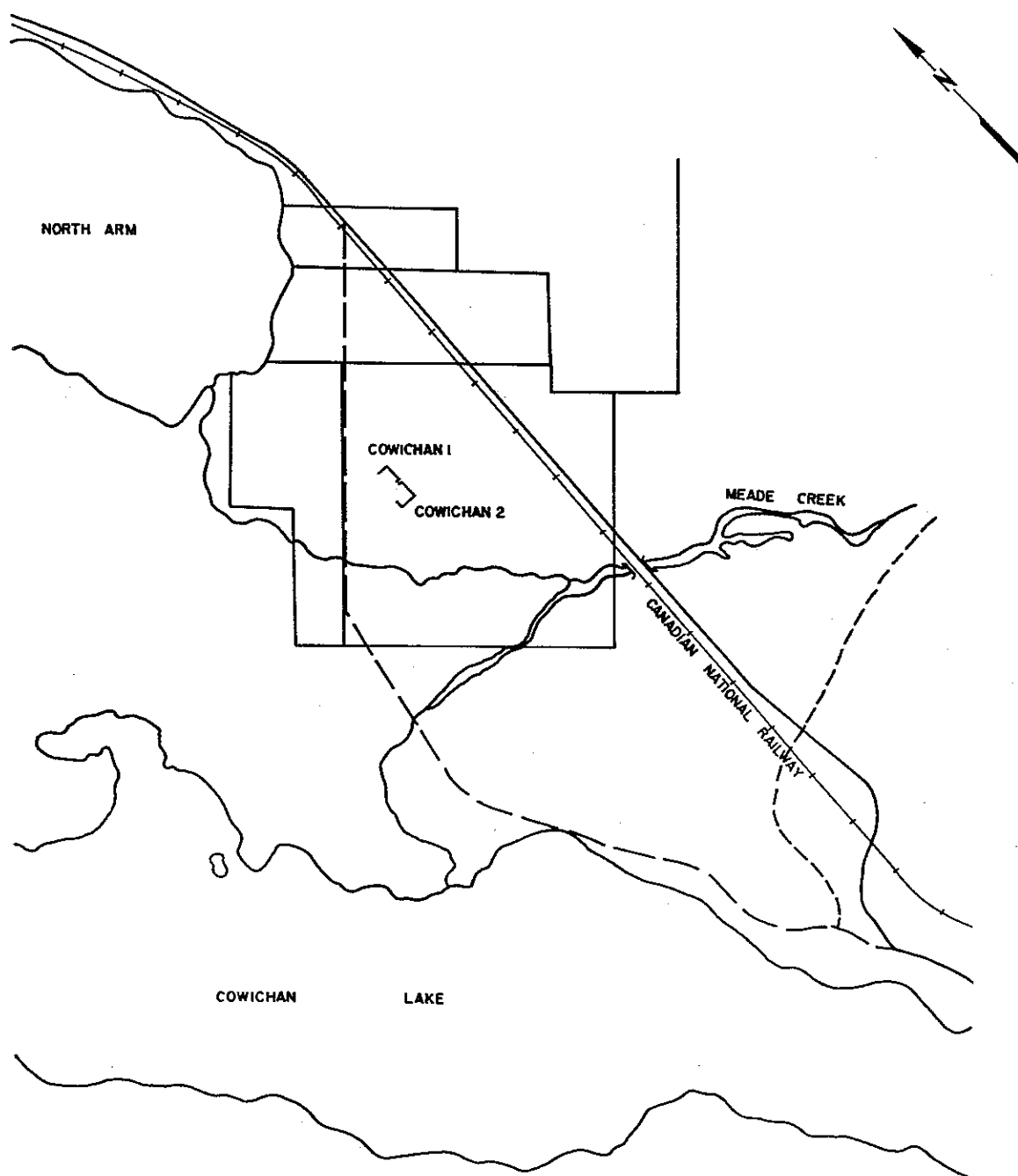
FIGURE 6 COWICHAN OVERVIEW

FIGURE 6a COWICHAN 1 STRIP AND PLOT LAYOUT

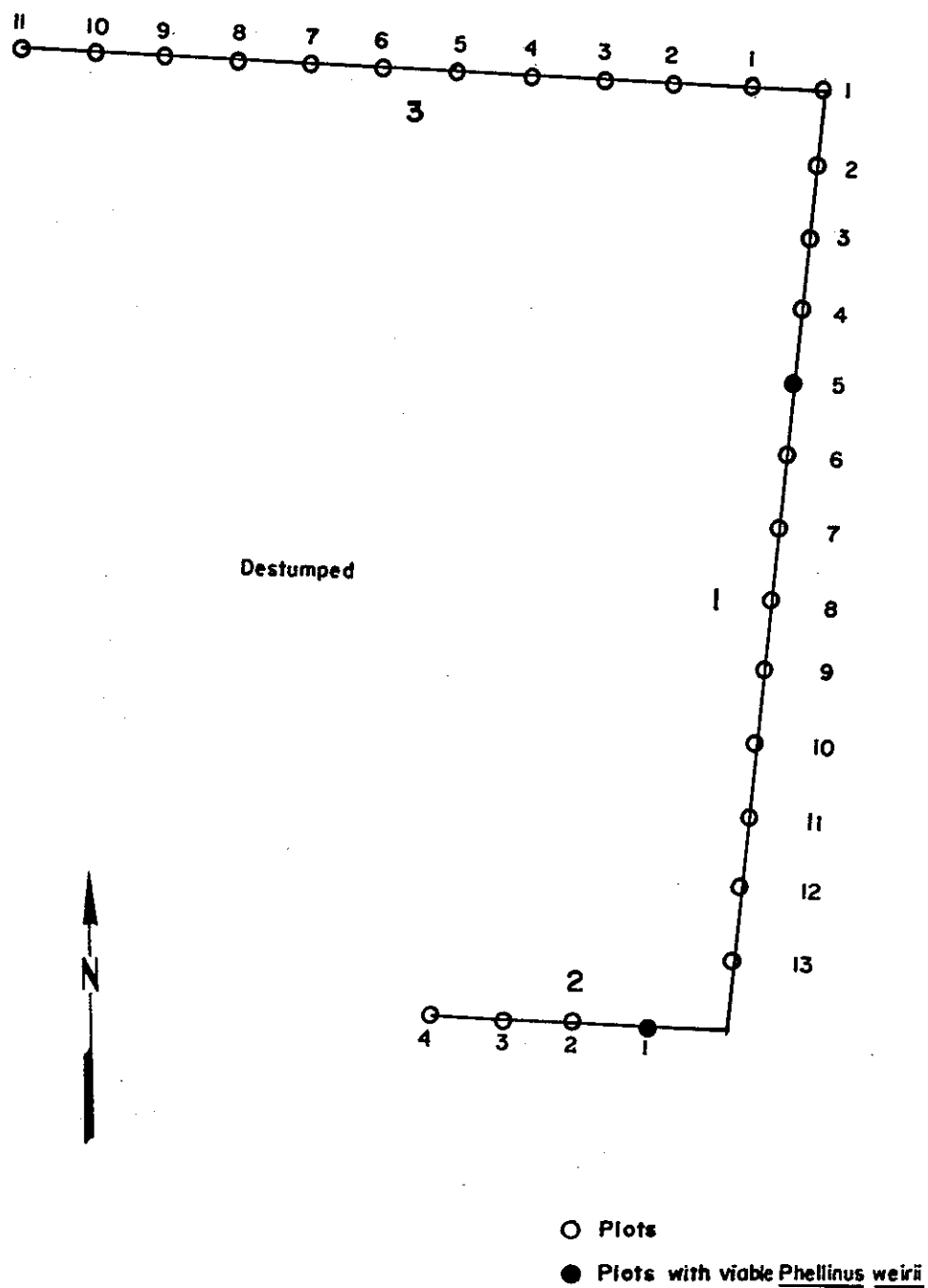


FIGURE 6b COWICHAN 2 STRIP AND PLOT LAYOUT

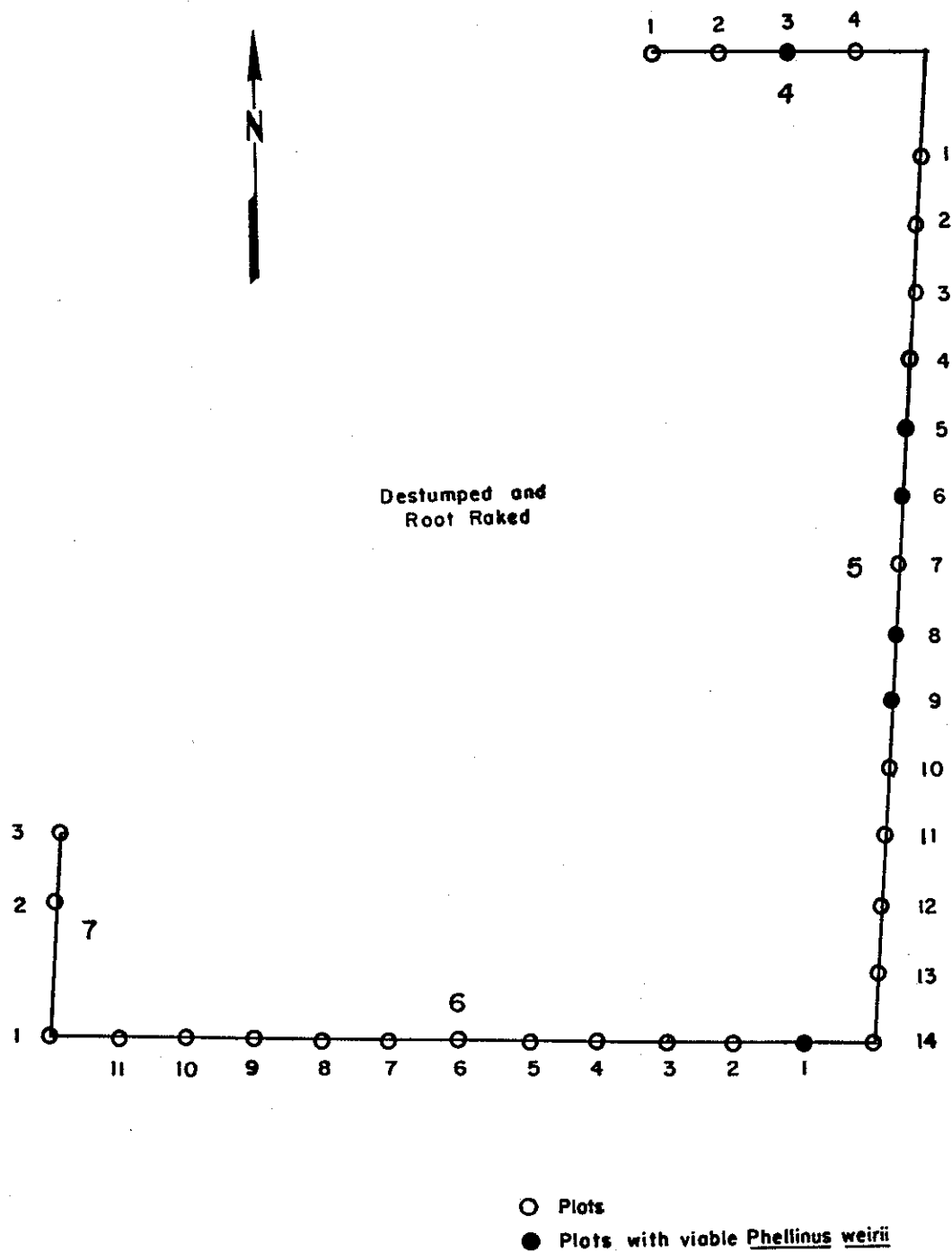


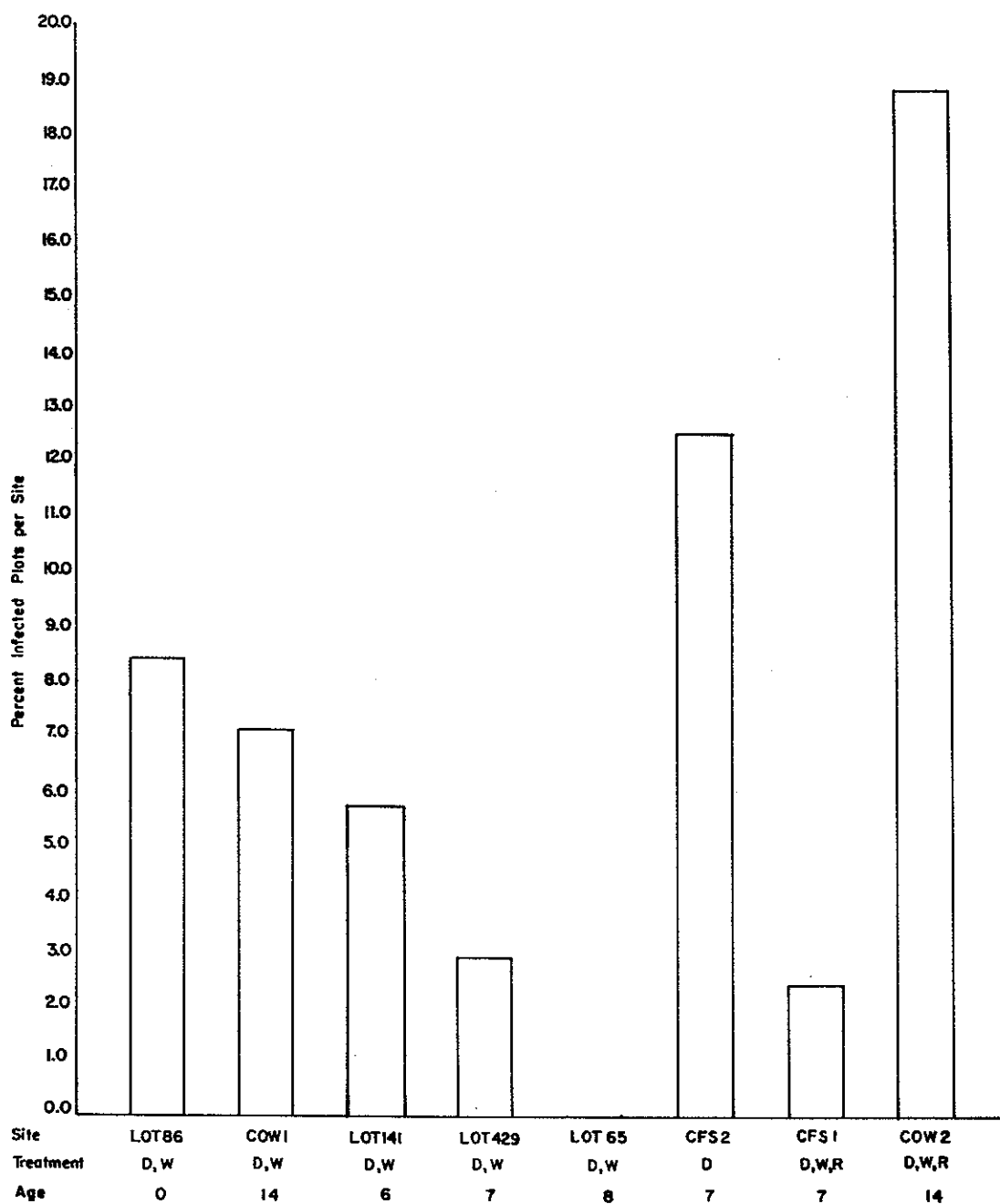
FIGURE 7 PERCENT INFECTED PLOTS PER SITE

FIGURE 8 **PERCENT TOTAL AND INFECTED ROOT VOLUME**
(m³/100m³ SOIL)

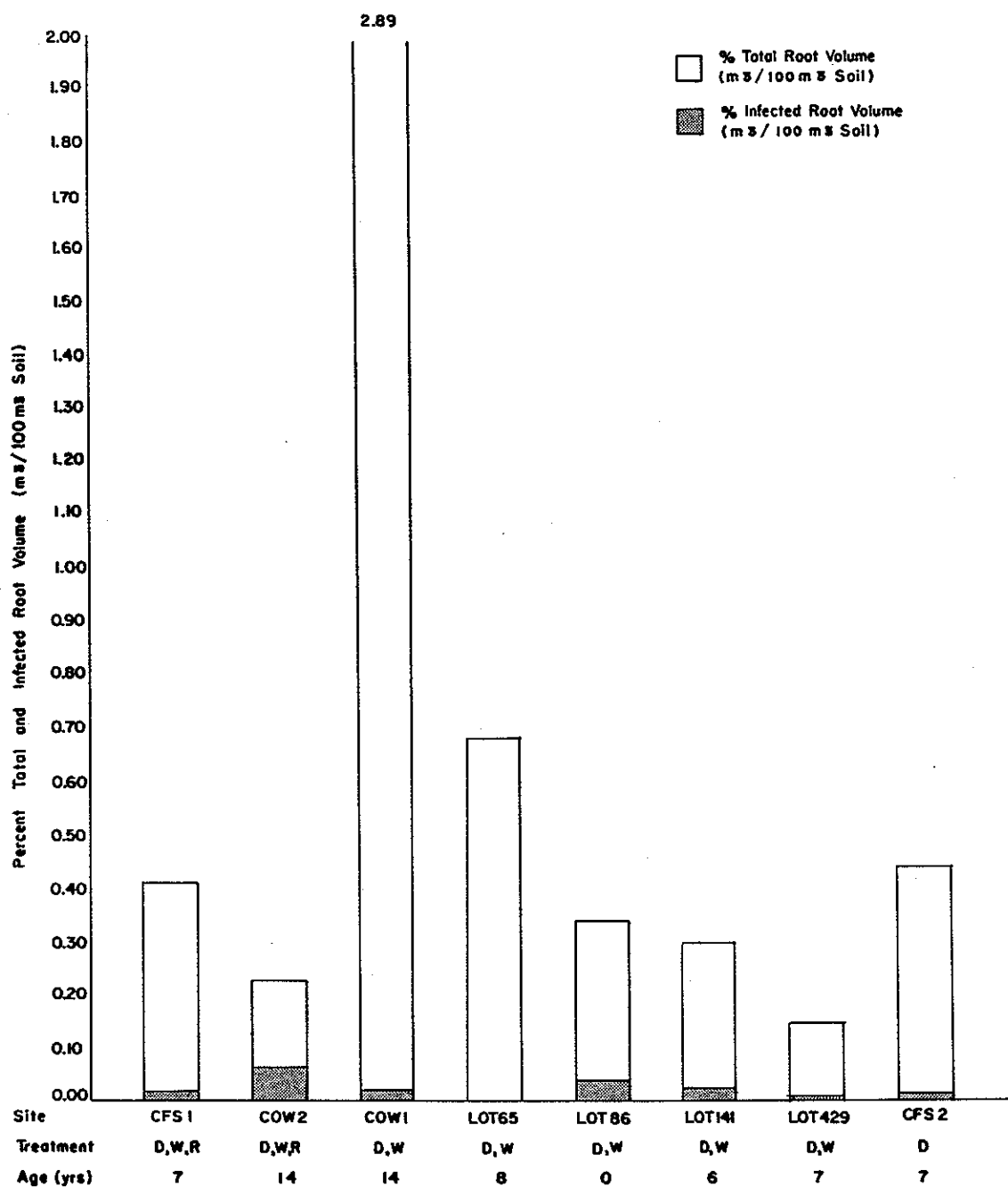


FIGURE 9 **TOTAL ROOT VOLUME AND INFECTED ROOT VOLUME
PER TOTAL SOIL VOLUME (%)**

