Forest Health Surveys in British Columbia: A Review of Sampling Methodology for Ground Surveys

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Forestry Health Surveys in
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ABSTRACT

The survey methods used by the Ministry of Forests of British Columbia and by Forestry Canada to monitor the health of forest stands throughout the province are reviewed. A number of potential weaknesses are identified and some general recommendations for improvement are made. Special emphasis is placed on an evaluation of the methods used in Pests of Young Stands (POYS) surveys, conducted by Forestry Canada as part of the Forest Insect and Disease Survey (FIDS) program.
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1 INTRODUCTION

Forest health surveys are used to gather data on the pests\(^1\) that threaten the productivity of our forests. This information is essential for effective forest management, including development of optimum harvesting strategies to minimize timber loss and help control the spread of disease, identification of areas that are at high risk of disease, prescription of treatments to prevent or eradicate disease, assessment of damage, and estimation of volume losses due to insects and disease.

According to the Forest Act, the Ministry of Forests is responsible for protecting the forests of British Columbia from damaging agents. There are, however, no specific provincial standards governing data collection for this purpose. Since enforcement of the act rests primarily with regional managers, survey guidelines have been developed by each of the six forest regions. These encompass a broad spectrum of methods, ranging from large-scale forest monitoring programs down to standard operating procedures for the identification and control of pests in individual stands. In addition to data acquired under regional programs, general forest health information is routinely recorded during silviculture surveys, (used to monitor forest regeneration, stocking, seedling survival, etc.), valuation cruises, (used to estimate timber volumes, etc.), inventory ground calls, and assessments of permanent and temporary growth-and-yield plots. Einfeldt and Beardsley (1986) reviewed some of these and various other sources of forest health data.

Another valuable source of forest health information is the Forest Insect and Disease Survey (FIDS) program of Forestry Canada. Under this program, which operates independently of the Forest Health Program of the Ministry of Forests, annual surveys are conducted to monitor pests throughout the province. These include aerial surveys to identify possible infestations, ground surveys of suspect areas, and Pests of Young Stands (POYS) surveys, used to assess the general state of health of stands established or treated under the Canada-British Columbia Forest Resource and Development Agreement (FRDA).

This report reviews the methods currently used by both the Ministry of Forests and Forestry Canada to gather forest health data. Attention is restricted to ground surveys, with emphasis on such statistical issues as sampling units, the number and placement of the sampling units, and estimation of prevalence and other parameters of interest. In reviewing the methods, five main points were considered: 1) the survey objectives, 2) the sampling design, 3) the data collected, 4) the data analysis, and 5) the summary of results. These are discussed in Section 2. Section 2 also defines the terminology used throughout the report (see Appendix 1 for a list of terms and abbreviations). Particular types of forest health surveys are discussed in Section 3, under the two broad headings of general, or "multi-pest", surveys (Section 3.1) and surveys for a specific insect or disease (Section 3.2). A summary and conclusions are given in Section 4. General recommendations for improvements are made in the case of the POYS survey (Section 4.2).

This review is based on information provided by the six forest regions, a review of the FIDS Manual (Forestry Canada 1990), silviculture and cruising manuals, and various other documents and internal reports supplied by Val Fletcher (Forest Health Program, Ministry of Forests), and on conversations with Allan Van Sickle and Nick Humphreys of Forestry Canada, Val Fletcher (Ministry of Forests), David Cavenly (Emst and Young), and Pat Humphreys (Ministry of Forests). There has been no attempt to conduct a systematic review of published literature pertaining to forest survey methodology in general. It should be noted that the opinions expressed here are those of the author and not necessarily those of the aforementioned people, or of the Ministry of Forests or Forestry Canada.

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\(^1\) in this report, "pest" means any damaging agent including insects, disease, mammals, adverse weather conditions (severe frost, drought, etc.), and pollutants.
2 FOREST HEALTH SURVEYS

A forest health survey has five main parts: 1) the survey objectives, 2) the sampling design, 3) the data collection, 4) the data analysis, and 5) interpretation and summary of results. Before discussing specific types of surveys, it will be helpful to describe what each component entails. This will also serve to define such terms as the “prevalence” and “severity” of a pest attack, and forest “stand,” terms central to any discussion of forest health survey methodology, but which tend to be a source of confusion. A list of definitions and abbreviations is given in Appendix 1. For a more detailed exposition of the design and analysis of sample surveys, the reader should refer to Cochran (1977).

2.1 Survey Objectives

A clear statement of the objectives is an important requirement for the successful execution of any survey. This usually involves delineation of a target population (e.g., a collection of trees) and identification of a characteristic of the population, or population parameter, about which inferences are to be made (e.g., the prevalence of a specific pest). These inferences are used to make planning or operational decisions (e.g., development of long-term harvesting strategies, operational decisions about when and how a stand should be treated). Alternatively, a survey may be conducted simply to collect data as part of an ongoing program to monitor and map areas of infection or infestation.

The surveys reviewed here are restricted to a single occasion and, as such, are not explicitly concerned with changes over time (except perhaps an informal assessment of trends — e.g., computation of green:red attack ratios for bark beetle infestations; see also the FIDS Manual for a description of trend assessment for bark beetles). This is a significant limitation, since knowledge of natural cycles, and the rates at which insect infestations and diseases spread throughout a stand, is obviously essential for effective and efficient pest management. Most surveys are limited further because they are not specifically designed to quantify what effect, if any, a pest has on timber volumes, although impact assessment is clearly of indirect interest in some or all surveys. For an example, see Standard Operating Procedures for Dwarf Mistletoe: Detection and Control (Nelson Forest Region 1986), which recommends the comparison of “vigour” ratios for trees with light, medium, and heavy dwarf mistletoe infestations. See also the discussion of severity in Section 2.1.2.

2.1.1 Target population

For most forest health surveys, the target population comprises all trees, and their associated pests, in one or more forested areas within well-defined boundaries. In some cases, the target population is limited to a particular subset of trees in an area of interest — e.g., the target population might be restricted to those trees that are susceptible to a particular disease or it might be restricted to spaced stands. In general, the size of the population — meaning both the total number of trees and the spatial extent of the population — depends on whether the survey is a forest-level or a stand-level survey.

A stand-level survey is defined here to be any survey for which the target population is a single stand — i.e., any forested area managed as a single unit, such as a forest cover polygon, an opening, or a plantation. A stand is usually confined to a relatively small area but may include one or more treatment units or cutblocks.

A forest-level survey will refer to any survey for which the target population comprises more than one stand. The stands that make up the target population may be contiguous (e.g., a mapsheet or Timber Supply Area [TSA]) or they may be widely dispersed over a large geographic area, spanning several biogeoclimatic zones or subzones (e.g., all young lodgepole pine stands in a forest region). In general, forest-level surveys are used for forest planning and large-scale monitoring programs, while stand-level surveys are used to make operational decisions about planting stock, site preparation, spacing, and the application of insecticides, on a stand-by-stand basis.
2.1.2 Population parameters

A population parameter is a constant that describes some characteristic of the target population (e.g., average height, average diameter, or proportion of healthy trees). In forest health surveys, there are two key quantities: 1) the prevalence of a particular insect, disease, or injury, and 2) the severity or amount of damage the agent causes. These have inconsistently been referred to as “incidence,” “prevalence,” “frequency of occurrence,” “severity,” or “intensity.” To avoid confusion, prevalence and severity will be used in this report and are defined as follows.

Prevalence

For a given population and time, the prevalence of a particular disease, insect, or other injury is the proportion (or frequency of occurrence) of entities (e.g., trees) with that condition. If \( M \) is the total number of affected entities at the specified time and \( N \) is the total number of entities in the population (e.g., all live and dead trees), then the prevalence \( p \) of the condition is the ratio

\[
p = \frac{M}{N}
\]

expressed as a number between 0 and 1, or as a percentage.

Interpretation of prevalence depends upon the definition of the pest and the definition of the entities that make up the population. For a stand-level survey, prevalence\(^2\) usually means the proportion of trees with a particular pest. However, in the case of a forest-level survey, prevalence could be either the proportion of stands in which a pest occurs in at least one tree (or in some threshold proportion of the trees) or the overall proportion of affected trees (i.e., proportion of trees pooled over all stands).

It should be noted that prevalence differs from incidence, as it is usually defined in epidemiology — i.e., incidence is the number of new cases occurring in a population during a specified period of time divided by the number of individuals at risk of developing the condition at the beginning of the period (see Lilienfeld and Lilienfeld 1980). Incidence is a measure of the rate at which new cases occur and prevalence is an instantaneous measurement of the proportion of affected entities.

Severity

Knowledge of the prevalence of a pest is often not enough to make a decision about what, if anything, should be done to control the problem. It is usually important to determine the overall severity of the attack as well. In general, severity is a number or code that measures, for each affected entity, the amount of damage caused by a specific insect, disease, or injury, or the current stage of the disease (also called the intensity of the attack). As such, severity is not a population parameter but is a random variable (i.e., it varies from one entity to the next). Various parameters might be used to describe the severity of the attack for the population as a whole. For example, in the case of injury caused by porcupines, the severity of the attack for an individual tree might be defined as the percent of the stem that is girdled, in which case average severity might be used to characterize overall severity for a stand. For some types of pests, the proportion of entities in one or more severity classes might be a more relevant parameter — for example, the percentage of trees with dwarf mistletoe infestations rated as Hawksworth’s classes 1–3. Although, severity (the random variable) and the parameters associated with severity (average severity, proportion in each severity class) are quite distinct, it is common practice to refer to both as severity.

Severity is not necessarily a good indicator of the actual or potential impact of a pest (i.e., timber loss). For example, a tree severely infested with aphids may suffer little or no decrease in growth, whereas the eventual impact of all bark beetle attacks is usually equally devastating, regardless of

\(^2\) Prevalence (commonly called “incidence”) has also been defined to be the percentage area infected or the volume per hectare infected (see discussion of intensity and other parameters). In this report, prevalence will refer exclusively to a proportion based on tree counts, stand counts, or any other type of frequency count.
the current severity or stage (i.e., green, red, grey) of the attack. Recognizing that it is impact and not severity that is important, the Kamloops Forest Region (see Pest Incidence Survey 1991) has developed a subjective scheme for converting severity ("pest intensity") codes for various insects, diseases, and other types of damage to a common five-point impact ("pest severity") rating: 1 = mortality, 2 = major volume loss, 3 = minor volume loss, 4 = insignificant volume loss, 5 = aesthetics only. The FIDS program has taken a similar approach for POYS by using a six-point "severity index" to rank damage caused by a range of pests as: 1 = no pests, 2 = minor damage, negligible impact, 3 = significant loss of current growth potential, 4 = net volume loss or loss of long-term growth potential, 5 = life threatening or severely deforming, and 6 = recently killed. The advantage of an impact rating is that it facilitates the comparison of different pests, which would, for example, be useful for deciding treatment priorities. However, until more data relating severity to actual timber loss are available, impact ratings are more or less subjective.

**Intensity and other parameters**

In addition to prevalence and severity parameters, various other parameters can be used to describe an infestation. For example, prevalence and average severity are sometimes multiplied to give an overall measure of the frequency of occurrence of a pest and the average severity of the attack (assuming average severity is meaningful). This has been called intensity, i.e., intensity = prevalence \times \text{average severity}. Notice that if severity is defined to be zero for unaffected entities, then intensity is simply the average severity for all (exposed and unexposed) entities. For a more complete discussion of prevalence (incidence), severity, and intensity, and the relationship among these parameters, the reader is referred to Seem (1984).

Other parameters of interest include the percentage area, volume, or basal area of timber attacked by a particular agent, and such parameters as stocking levels, average height, and average dbh (diameter at breast height), which describe general stand characteristics and which might be useful for risk assessment or for predicting the outcome of an attack.

### 2.2 Sampling Design

The target population in a forest health survey typically includes many thousands of trees distributed over a large area. Since it is obviously impossible to examine every tree, inferences about the target population must be based on a relatively small sample of trees (in a small sample of stands). The sampling design embodies all aspects of the sample selection, including definition of the population to be sampled (often much more restrictive than the target population), specification of the sampling units, and a method for selecting those units (i.e., a method for distributing the sampling units over space and time), and determination of an appropriate sampling rate or sample size.

Provincial guidelines for the design of forest health surveys have not been developed. However, because stand-level surveys are often conducted in conjunction with silviculture surveys or timber cruises, most aspects of their design have been influenced by the standards set for silviculture, valuation, and inventory surveys (see Section 4.1 of the Silviculture Manual and Section 2 of the Cruising Manual of the B.C. Ministry of Forests). For example, fixed circular plots (with a 3.99 m radius, as recommended in the Silviculture Manual) are commonly used for the collection of forest health data and the field forms are frequently silviculture survey or cruising forms. In addition, the scheduling of the surveys and selection of the stands to be surveyed are often tied to such surveys as Pre-Harvest Silviculture Prescription (PHSP) and Pre-Stand Tending (PST) surveys. In general, the suitability of these methods for forest health surveys has not been determined, although several studies to evaluate and compare survey methods for root disease (Wood 1987; Curran and Schulting 1991) have been completed, and Fletcher (1986) has compared several methods for leader-weevil assessment in a plantation.
Timing of survey

Since most surveys are limited to a single occasion, they provide only a snapshot of a population of trees. Therefore, for those pests that are transient, or have definite seasonal or annual cycles, the timing of a forest health survey can be important. For example, standard operating procedures for bark beetle ground surveys in the Nelson Forest Region suggest that late summer and early fall are optimum times for detection. In contrast, the timing of surveys for such chronic or "resident" pests as dwarf mistletoe and root disease may not be critical.

2.2.1 Sampled population

In most forest health surveys, it is not possible nor practical to sample the entire target population. In a forest-level survey, the target population might consist of all polygons on a mapsheet, but, because of the excessive cost of sampling remote sites, it may be necessary to restrict the sampling to those polygons that are readily accessible by land. Similarly, at the stand level, a stand may be so extensive that sampling may be restricted to only a small block. In such cases, it is important to distinguish between the target population and the sampled population because inferences based upon a sample apply only to the sampled population. Extrapolation to the target population is necessarily speculative and can be misleading.

2.2.2 Sampling units

A sampling unit is a convenient unit of measurement. Forest health surveys generally employ a hierarchy of sampling units. Fixed plots or strips are used almost exclusively as the primary sampling unit for stand-level surveys, except in the case of root disease and dwarf mistletoe, for which lines (transects) or pixels are also used (Figure 1). Within the plots or strips, the secondary sampling units are typically trees and, in some cases, trees are further subdivided into branches, roots, or other sub-units for the assessment of severity and other variables. For forest-level surveys, the primary sampling units are stands, with plots or strips serving as the secondary sampling units, and trees serving as the tertiary units, and so on. Prism plots (variable plots) are often used, in conjunction with fixed plots, strips, pixels, or lines, to collect inventory data, or to rate damage severity, and less frequently to estimate prevalence.\(^3\)

Fixed plots can be either circular (Fig. 1a) or rectangular plots. Strips (strip transects, probe lines) are a special type of rectangular plot, which as the name suggests, are laid out by measuring a fixed distance on either side of a transect (Fig. 1b). These are commonly used to map centres of infection for root disease and insect infestations. Strips may or may not run from one side of the stand to the other. They are sometimes broken down into contiguous strip plots of equal length (Fig. 1c).

The size of a fixed plot, or the width of a strip, is usually selected to give, for the stand, a specified average number of trees per plot. Therefore, plot or strip size is determined by the stocking level of the stand. The choice of plot shape appears to be mainly a matter of convenience or experience. Obviously, plot size will have an effect on the statistical properties of the measurements and the computed parameter estimates. For example, for a stand with a random (Poisson) distribution of trees, the coefficient of variation (CV) of the number of trees per plot is inversely proportional to the square root of the plot area. The effect of plot shape is unclear, but for clumpy distributions it seems reasonable to assume that both the size and shape of the plot are likely to be important. A number of studies have been conducted to investigate these issues (Freese 1961; O'Regan and Palley 1965; Kulow 1966; Zeide 1980; Wood 1987; Curran and Schulting 1991) but no general conclusions have emerged.

Methods for surveying diseases associated with areas of infection (e.g., root rot and dwarf mistletoe) tend to be different from those used to assess insect attacks. For the former, the parameter of interest is often the percentage area (volume, basal area) infected, rather than the proportion of infected trees. Two

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\(^3\) To estimate prevalence using prism plots, tree counts must be adjusted by a factor that depends on the diameter or basal area of the trees, unless it can be assumed that the prevalence is the same for all diameter classes, or that all trees in the population have the same diameter.
sampling units are commonly used to evaluate such diseases — pixels and lines (transects). Pixels are fixed (square or rectangular) plots, which are usually laid out (contiguously) on either side of a transect (Fig. 1d). For each pixel, the presence or absence of the disease is recorded, and, in some cases, the severity of the infection is also measured. A second method — the line intersection length method (or line intercept method) — uses a line as the primary sampling unit (Fig. 1e). For this method, the length and position of patches of disease that intersect each line are measured (see Beale and Wood 1985 for a description; see also De Vries 1986 and Section 4.42 of the Silviculture Manual, B.C. Ministry of Forests 1987–90).

FIGURE 1. Sampling units: (a) fixed plot, (b) strip, (c) strip divided into contiguous strip plots, (d) pixel, (e) line (intersection length method), and three common spatial arrangements of the sampling units: (f) equally spaced along a straight transect, (g) equally spaced along a zigzag transect (e.g., pseudo-random walk), and (h) equally spaced along parallel transects (or uniform grid).

2.2.3 Selection of sampling units

There are four main methods for selecting the sampling units: 1) random sampling, 2) stratified sampling, 3) one- or two-dimensional systematic sampling, and 4) pseudo-random sampling. (See Section 4.11 of the Silviculture Manual, B.C. Ministry of Forests 1987–90 and Section 2.2 of the Cruise-Compilation Program Documentation, B.C. Ministry of Forests 1982–91.)

Random sampling

Random sampling implies that all possible sampling units have a known and usually equal probability of selection. For example, a number of fixed plots might be randomly distributed over a stand by generating random coordinates to locate each plot centre (see Legg and Yeargon 1985). Random sampling is a fundamental principle of statistical inference. It not only ensures that the sample is representative of the population from which it is drawn, but is one of the basic assumptions of most parameter estimation methods and hypothesis testing procedures. True random sampling is generally not used in forest health surveys because it is thought to be too difficult to implement.

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4 One exception is prism plot sampling, in which trees are selected with probabilities proportional to their basal areas.
**Stratified sampling**

Stratified sampling is any sampling scheme in which the sampled population is divided into strata and a (random) sample is drawn from each stratum. Stratification serves several purposes. A forest may be stratified by district or geographic area strictly for administrative convenience or for logistic reasons. Sometimes it is desirable to stratify according to natural divisions of the population, such as by species. Finally, stratification of a heterogeneous forest or stand into relatively homogeneous strata can result in increased precision (a reduction in the variance) of the overall estimate of pest prevalence, average severity, or other relevant parameter.

In the case of forest health surveys, stratification is used primarily at the forest level for administrative reasons and to ensure adequate coverage of important subpopulations (e.g., forest polygons are often stratified by species, age, biogeoclimatic subzone, or site series). Stratification appears to be used less often at the stand level, although openings are sometimes divided into a small number of homogeneous strata on the basis of such factors as treatment or soil class (see Section 4.1121 of the Silviculture Manual for guidelines governing stratification of openings for silviculture surveys).

**Systematic sampling**

Systematic sampling is any sampling scheme that follows a regular pattern. Most forest health surveys have some element of systematic sampling. For example, it is common practice to lay out plots at equal intervals along one or more transects, even if the transects are randomly located. In general, three distinct types of systematic sampling are used in forest health surveys: 1) one-dimensional, in which sampling units are equally spaced along a single straight line transect (Fig. 1f), 2) “zigzag,” in which sampling units are equally spaced along a zigzag path (Fig. 1g); and 3) two-dimensional, in which sampling units are equally spaced along parallel transects, or located on a grid.

Systematic sampling is generally thought to be cheap and efficient, and to provide good coverage of the population, provided, of course, that two-dimensional sampling (or zigzag sampling with a sufficiently large number of sampling units or a sufficiently large interval) is used. In addition, systematic sampling imposes a certain amount of order on the sampling process, which is desirable in the field. The main disadvantage is that it can produce a biased estimate of prevalence if a pest exhibits some sort of spatial trend or other nonrandom pattern. One-dimensional systematic sampling has the further disadvantage that it is really a form of “pseudoreplication” (Hurlbert 1984), i.e., the sampling units do not sample the entire target population. Kulow (1966) argued against the use of systematic sampling and recommended random sampling.

**Pseudo-random sampling**

Pseudo-random sampling is any sampling scheme that attempts to select a “representative” or apparently “random” sample (of trees, transect locations, etc.) without the benefit of a random number table or other objective means of randomization. For example, the direction of each increment in a systematic zigzag sampling scheme (Fig. 1g) might be selected in a pseudo-random fashion (see description of “two tree bearing method of tree selection” in FIDS Manual, Forestry Canada 1990). A major disadvantage of pseudo-random sampling is the possibility of the unconscious introduction of bias, which is often difficult to detect and impossible to quantify. Furthermore, standard statistical procedures, which are based on the assumption of a random sample, cannot necessarily be applied with confidence. Despite these obvious drawbacks, pseudo-random sampling seems to be quite common in forest health surveys.
2.2.4 Sample sizes

Sample size selection is an integral part of the design of a survey. In the simplest case, determination of the sample size depends upon the required level of precision of the parameter estimate and the underlying variability or coefficient of variation (CV) of the measurements. When stratified random sampling is employed, an appropriate allocation of the total sample to individual strata must also be determined.

Sample sizes in forest health surveys are often expressed as a sampling rate or sampling intensity, such as one plot per 100 m, rather than total sample size. Guidelines for selecting a sampling rate or total sample size have not been developed for forest health surveys. In most cases, the sampling intensity seems to be dictated primarily by budget constraints or by habit.

2.3 Data Collection

Data are collected for all sampling units. Forest-level surveys record ecosystem information, site characteristics (e.g., slope and aspect), and silviculture information (e.g., number of well-spaced trees per ha) for each stand. At the stand level, each plot, pixel, or line is examined for signs of insects, disease, or other problems. For fixed plots, all trees are tallied by species and by pest, and a subjective assessment of the severity of any damage is made for each tree or for the plot as a whole. For strip plots, the location of each affected tree (or centre of infection) is recorded. Inventory data, such as dbh, height, and volume, are typically collected in conjunction with forest health data, but not necessarily for all trees in the sample.

Coding of forest health data has not been standardized. However, the three-letter silviculture system for coding insects, diseases, and abiotic agents (see Silviculture Survey Damage and Condition Codes, FS 747) is used for some regional surveys (e.g., Kamloops' Pest Incidence Survey and Nelson's Comprehensive Pest Inventory) and was recommended by the Pest Damage and Appraisal Advisory Committee for the assessment of permanent sample plots for growth-and-yield estimation. Certain damage severity ratings are more or less standard as well. For example, it is standard practice in regional surveys, and for FIDS, to use the six-point Hawksworth scale to rate dwarf mistletoe infestations, and bark beetle attacks are usually rated as green, red, or grey. A good coding system for pests, host species, and severity is necessary, not only to make the data collection as efficient and consistent as possible, but also to facilitate the data analysis.

Silviculture survey forms (e.g., FS 711 A and B, FS 657, FS 658, FS 659) are frequently used or adapted for the collection of forest health data. These have been supplemented by forms developed by the forest regions to meet specific needs, e.g., Root Disease Survey (FS 1061) — Vancouver, Pest Incidence Survey (multi-pest) — Kamloops, Regeneration Insect and Disease Survey Form (Douglas-fir dieback) — Cariboo, Multi-Pest Tally Sheet (FH 100) — Prince George. Forestry Canada has also developed a set of field sheets for the FIDS program.

2.4 Data Analysis and Summary of Results

Forest health data are routinely summarized either by preparing a sketch map showing areas of infection or by compiling tables of summary statistics — e.g., estimated prevalence and the proportion of trees in each severity class — by pest, host species, biogeoclimatic subzone or age classes. In most cases, simple (weighted or unweighted) averages are reported, often without standard errors or confidence intervals. This is probably because, for most types of forest health surveys, the underlying statistical theory is poorly understood or the computer programs necessary for more complicated analyses are lacking or in an early stage of development. One notable exception is the line intercept method for surveying root disease (in the Vancouver Forest Region), for which more advanced and fully automated methods of analysis are available (see Beale and Wood 1985).
3 TYPES OF SURVEYS

Forest health surveys can be grouped into two broad classes: 1) general (or multi-pest) surveys and 2) surveys for specific pests.

3.1 General Surveys

Four of the six forest regions — Kamloops (Pest Incidence Survey [PIS]), Nelson (Comprehensive Pest Inventory [CPI]), Prince George (Multi Pest Survey), and Prince Rupert (Multiple-Pest Survey) — have initiated some sort of ongoing forest-level survey program to monitor the general state of health of stands throughout these regions. Each program has a slightly different target population and objectives. The overall objective of the Kamloops PIS is to survey, over a period of years, all mapsheets in the region; Nelson's CPI is targeted at stands thought to be susceptible (i.e., have a "disease signature" according to ecosystem type) to such "resident" pests as dwarf mistletoe and root rot. The Prince George and Prince Rupert multi-pest surveys are primarily surveys of young stands — lodgepole pine in the Prince George Forest Region — which are sometimes (see Adamson 1991), carried out in conjunction with Pre-Stand Tending silviculture surveys. In addition to the regional surveys, Forestry Canada is currently conducting an annual POYS survey of stands established or treated under FRDA. Multi-pest surveys tend not to be carried out at the stand level, although general forest health data are usually collected during silviculture surveys or operational cruises.

Table 1 summarizes the design of the preceding multi-pest surveys. They are similar in that within stands all use fixed (circular, strip, or pixel) plots equally spaced (contiguous in the case of the Kamloops and Prince Rupert surveys) along one or more transects. The Kamloops, Nelson, and FIDS (POYS) surveys use only one transect per stand. This is located subjectively and may zigzag through the stand, either in a pseudo-random fashion or to avoid obstacles. The Prince George and Prince Rupert surveys use a series of systematically located transects. In all cases, the sample of stands to be surveyed is selected more or less subjectively, although in Kamloops the stands (polygons) are first stratified by inventory type group (ITG) and age. The type of data collected in all five surveys is similar, except for Nelson's CPI, which records pest presence or absence for each pixel, and not tree counts. The Prince George and Prince Rupert methodologies, respectively, are illustrated by the surveys described in Adamson (1991) and in Laing and McCulloch (1991).

3.2 Surveys for Specific Forest Health Problems

Surveys for specific forest health problems are conducted both at the stand level and at the forest level. Stand-level surveys include "walkthrough" assessments of dwarf mistletoe, bark beetle probes, and strip surveys to map centres of root disease infection. These are typically used to identify potential problems, to determine appropriate treatment strategies, and to evaluate operational treatment programs. In contrast, forest-level surveys provide information about the geographic distribution of insects and disease, and are used to evaluate the effects of such factors as host species, age, and site class on the prevalence and severity of disease and insect infestations. They are also used to identify possible risk factors, to develop regional control programs, and to assess timber losses. Some examples of forest-level surveys for specific health problems include, for root disease, Wood (1983), Beale (1987), Bloomberg and Hawkins (1991), and T.M. Thomson and Associates (1991a,b,c) for dwarf mistletoe, Muir (1982); and for spruce weevil, Taylor et al. (1990) and Ebata (1991).

Table 2 summarizes sampling methods currently used to conduct stand-level or forest-level surveys for specific diseases, insects, or other problems. Descriptions are very brief because, in many cases, documentation of the methods was incomplete. References for each method are given in parentheses (see Section 5.3); in all cases except "Other," the first two letters correspond to the silviculture code (e.g., "DR" stands for root disease). Details of methods used by FIDS are given in the FIDS Manual (Forestry Canada 1990).
<table>
<thead>
<tr>
<th>Survey</th>
<th>Sampled population</th>
<th>Sampling units</th>
<th>Selection of sampling units</th>
<th>Sample intensity (sample sizes)</th>
<th>Measurements</th>
</tr>
</thead>
</table>
| Pest Incidence Survey (Kamloops Forest Region) | selected mapsheet(s)                | 1. polygons                         | 1. polygons are stratified by ITG, species, and age (a maximum of 20-25 strata per mapsheet are selected); polygons are selected subjectively within strata | 1. the number of polygons per stratum is variable, since plots are distributed subjectively among polygons | 1. mapsheet reference, location, species, dbh, etc. 2. all trees in each plot are tallied by species, pest, and 3-class severity code ("pest incidence code") Species, height, dbh, etc. are measured for one healthy or "typical" dominant or co-dominant tree per plot  
Form: Pest Incidence Survey |
| Comprehensive Pest Inventory (Nelson Forest Region) | polygons with "disease signature"   | 1. polygons (strata)                | 1. a sample of polygons with "disease signature" is selected subjectively                     | 1. the total number of polygons is variable                                                   | 1. ecosystem habitat, site index capabilities, disease, insects, and other problems (pest code and percent incidence for "nastiest" and "second nastiest" pest are recorded for each polygon; average height and diameter are estimated for the polygon and the inventory label is recorded  
Form: Pest Management Ledger |
| Multi-Pest Survey (Prince George Forest Region) (carried out in conjunction with Pre-Stand Tending Surveys) | selected polygons (young lodgepole pine stands) | 1. polygons                         | 1. polygons are typically selected according to Pre-Stand Tending Survey criteria            | 1. the number of openings surveyed is variable  
2. plots are equally spaced (100 m apart) along parallel transects (100-m spacing to cover opening)  
If the survey is done in conjunction with a Pre-Stand Tending Survey, pest measurements are made on every third plot (or on a maximum of 5 plots per opening) | 1. opening identification, ecosystem sub-zone and association, stocking, etc. 2. dbh, status (dead/alive), and the presence of diseases (rusts, mammal damage (% gridled), and insects are recorded for each tree in plot; each damaged tree is classified as acceptable or unacceptable  
Form: Multi Pest Tally Sheet FS770 |
<table>
<thead>
<tr>
<th>Survey</th>
<th>Sampled population</th>
<th>Sampling units</th>
<th>Selection of sampling units</th>
<th>Sample intensity (sample sizes)</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-Pest Survey (Prince Rupert Forest Region)</td>
<td>selected polygons (young stands, 10-35 years old)</td>
<td>1. polygons</td>
<td>1. stands &quot;of interest&quot; are selected (these include stands that have undergone or will undergo extensive silviculture treatment, stands that have been free-to-grow for at least 10 years, and those with suspected pest or other problems)</td>
<td>1. the number of openings surveyed is variable</td>
<td>1. opening identification, ecosystem sub-zone and association, no. of well-spaced trees, and other silviculture information are recorded as required</td>
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<tr>
<td></td>
<td></td>
<td>2. 100-m (50-m) strip plots (3 m width can be increased if the trees are widely spaced)</td>
<td>2. parallel transects are at least 100 m apart (number unknown)</td>
<td></td>
<td>2. the species, status (live, dead, top-killed, other), location (on &quot;attack grid&quot;), pest, and location (on tree) of any damage are recorded for all attacked trees; total number of trees examined in each strip plot is recorded</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. circular plots (3.99 m radius) – optional, for collecting stocking data</td>
<td>3. circular plots – one plot per hectare</td>
<td></td>
<td>3. stocking, free-to-grow data are recorded for circular plots if required</td>
</tr>
<tr>
<td>Pests of Young Stands Survey (Forestry Canada)</td>
<td>polygons established or treated under FRDA (young stands, 2-25 years old)</td>
<td>1. polygons</td>
<td>1. stands are selected by district rangers</td>
<td>1. 15-25 stands are selected from each district with the number of stands of each species roughly proportional to the corresponding proportion for the district (250 stands sampled per survey)</td>
<td>1. opening identification, ecosystem sub-zone and association, age of stand, etc.</td>
</tr>
<tr>
<td></td>
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<td>2. circular plots – radius is selected to include (on average) at least 8 trees per plot</td>
<td>2. for each stand, plots are equally spaced (50-m interval) along a subjectively located zigzag transect</td>
<td>2. at least 10 stocked plots are sampled for each stand</td>
<td>2. the total number of trees of each species is recorded for each plot; pests are tallied by host species and the overall severity (&quot;intensity&quot;) of the attack is noted for each plot</td>
</tr>
</tbody>
</table>

Forms: Multiple-Pest Survey Field Card, FS657, FS658, FS659

Forms: Survey of Young Stands (FIDS #108) Pests of Young Stands Survey Summary (FIDS 89/1)
<table>
<thead>
<tr>
<th>Disease/Insect (other)</th>
<th>Cariboo</th>
<th>Kamloops</th>
<th>Nelson</th>
<th>Prince George</th>
<th>Prince Rupert</th>
<th>Vancouver</th>
<th>FIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root diseases</td>
<td>1. pixel method (DR1)</td>
<td>1. parallel strips used to map infection centres (Curran and Schulting 1991)</td>
<td>1. Rhizina/stocking survey—circular plots (3.99 m radius), equally spaced along parallel transects (DR3)</td>
<td>1. intersection length methods—parallel transects, with or without prism plots</td>
<td>1. sequential sampling scheme for disease: pseudo-random sampling of trees (i.e., along a zigzag path) until incidence can be estimated with the desired level of precision</td>
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<tr>
<td></td>
<td>2. parallel strips used to map infection centres (DR2)</td>
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<tr>
<td>Dwarf mistletoe</td>
<td>1. strips with circular &quot;check&quot; plots (3.99 m radius) every 100 m (DM1)</td>
<td>1. walkthrough</td>
<td>1. circular plots (3.99 m radius) on a zigzag or grid, in conjunction with silviculture surveys</td>
<td>1. prism plots: 10 equally spaced plots per stand (50-m intervals)</td>
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<td></td>
<td>2. permanent plots (DM1)</td>
<td>2. timber cruise</td>
<td>2. as above, plus residuals within 10 m of plot centre</td>
<td></td>
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<tr>
<td>Stem rusts</td>
<td>1. circular plots (3.99 m radius) equally spaced (50 m apart) along parallel transects (100-m intervals) (DS1)</td>
<td></td>
<td>1. all white pine plantations are currently registered as operational trials and monitored accordingly</td>
<td>1. prism (or fixed for young stands) plots: 10 equally spaced plots per stand (50-m intervals)</td>
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<td></td>
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<td></td>
<td>2. detection of rust-resistant strains—PHSP or drainage survey, operational timber cruise</td>
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<td></td>
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<td></td>
<td>3. plantation establishment surveys—same as surveys for well-spaced trees, regeneration and free-growing surveys (DS2)</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Disease/Insect (other)</td>
<td>Cariboo</td>
<td>Kamloops</td>
<td>Nelson</td>
<td>Prince George</td>
<td>Prince Rupert</td>
<td>Vancouver</td>
<td>FIDS</td>
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<tr>
<td>Leader and branch die-back</td>
<td>1. parallel 5-m strips (DL1)</td>
<td>1. walkthrough</td>
<td>1. walkthrough – parallel strips with bark samples every 20 m (IB6)</td>
<td>1. walkthrough probe</td>
<td>1. patch probe – parallel strips to map small infestations</td>
<td>1. prism plots – 50-m spacing</td>
<td></td>
</tr>
<tr>
<td>Bark beetles</td>
<td>1. general probe – parallel 5-m strips with a maximum spacing of 100 m; fixed or prism plots every 100–200 m for collecting inventory data (optional) (IB1)</td>
<td>2. prism (count) plots, equally spaced along a transect (IB4)</td>
<td>2. probe survey – one 5–7.5-m strip with bark samples taken from 10 trees every 2000 m (IB5)</td>
<td>2. intensive probe</td>
<td>2. star probe – map quadrants of a 100-m circle that encloses centre of infestation</td>
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<td></td>
</tr>
<tr>
<td>1. 10-m parallel strips – 100-m spacing (IB1)</td>
<td>3. trap assessment survey (IB2)</td>
<td>3. grid survey – parallel strips (100–200-m spacing) (IB5)</td>
<td>4. fall and burn layout probe</td>
<td>3. grid probe – parallel strips with prism plots every 100 m (IB8)</td>
<td>5. blowdown survey (IB7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. circular plots (3.99 m) – equally spaced (50 m apart) along parallel transects (IW2)</td>
<td>1. parallel strips (Taylor et al. 1990)</td>
<td>2. spruce weevil survey in conjunction with silviculture survey (all plots assessed) (IW3)</td>
<td>1. 5-m parallel strips (20 strips per plantation – strips are divided into 25 tree sections with a 3.99 m radius circular (regeneration) plot at the start of each strip plot (Ebata 1991)</td>
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<tr>
<td>Weevils</td>
<td>1. black army cutworm: moth sampling – specified number of traps per hectare</td>
<td>1. Eastern spruce budworm survey in conjunction with silviculture survey (every second plot assessed) (ID2)</td>
<td></td>
<td>1. sequential sampling scheme – every tenth tree sampled (minimum sample size is 25); see root disease above for a general description</td>
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<tr>
<td>Defoliators</td>
<td>larval sampling – one square every 50 m along parallel transects (50-m spacing) (ID1)</td>
<td></td>
<td></td>
<td></td>
<td>1. permanent sampling stations – annual assessments (tree-beatings)</td>
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<td></td>
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<tr>
<td>2. forest pest damage appraisal plots – annual assessments (tree-beatings, defoliation estimates, egg and pupal sampling)</td>
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<tr>
<td>Other</td>
<td>1. porcupine damage plots – circular plots (5.64 m) equally spaced (100 m apart) along 1.5–2 km transect (01)</td>
<td></td>
<td></td>
<td></td>
<td>2. hazard site inspection (02)</td>
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</tr>
</tbody>
</table>
3.2.1 Root disease

Parallel strip surveys and the line intersection length method appear to be the two most commonly used methods for surveying root disease. A strip survey is a two-dimensional extension of the line intersection length method, for which transects are replaced by strips and the area of any patches of infection that lie within the strip are measured instead of cross-sectional length. Unlike the line intersection method, strips can also be used to estimate prevalence and to map individual trees. In general, prism plots are used to collect inventory data when the line intersection method or a strip survey is employed, since neither is particularly well suited to that purpose. Other methods for estimating the prevalence of root disease, or the percentage area, volume, or basal area infected, include fixed plot surveys (Prince Rupert Forest Region), pixel surveys (Cariboo Forest Region), prism plot surveys (Bernardy 1991), and pseudo-random samplings of individual trees (the method recommended by FIDS for surveying diseases in general). Various comparative studies of these methods have been carried out (Wood 1987; Curran and Schulting 1991) but these are inconclusive because they are based on studies of a small number of sites. One advantage that the line intersection length method has over other methods is that data collection (using the FS 1061 form) and analysis have been more or less standardized (see Beale and Wood 1985).

3.2.2 Bark beetles

Beetle probes are a type of strip survey, commonly used to map the boundaries of an infestation or to estimate prevalence, severity of the attack, annual trends, etc. In general, data are collected using a compass and traverse sheet (FS 375 VAL 80/11). Probes may consist of a single strip through a known area of attack (e.g., as located by aerial survey) or may comprise several parallel probes through areas in which beetles have or have not been previously identified. Several variations on the basic beetle probe have been developed by the regions (e.g., those used by the Prince Rupert and Vancouver Forest Regions — see references IB7 and IB8 in Section 5.3.5). In addition to beetle probes, prism plot surveys have been used to estimate the prevalence of bark beetle attacks, as well as the volume and basal area affected (see FIDS Manual, Forestry Canada 1990, and reference IB4 in Section 5.3.5).

3.2.3 Other forest health problems

Surveys for other forest health problems encompass a wide range of methods (Table 2). Some surveys are incorporated into routine silviculture surveys (e.g., spruce weevil surveys in the Prince Rupert Forest Region) and therefore use standard silviculture survey methods. Others are similar to methods used for other pests — for example, weevil data are often collected using a strip survey approach similar to that used to assess bark beetles. Prism plots located at 50-m intervals is the method recommended by FIDS for dwarf mistletoe, stem rusts, and bark beetles. The method that FIDS suggests for surveying diseases, in general, differs from most other methods because it employs a sequential approach, in which sampling stops when prevalence can be estimated with the required level of precision. Furthermore, it uses pseudo-random sampling of individual trees rather than a sample of plots.
4 SUMMARY AND CONCLUSIONS

4.1 Summary of Forest Health Surveys

It is essential to have a clear statement of the objectives at the outset of any forest health survey. This usually involves delineation of a target population and identification of the population characteristics of interest. For stand-level surveys, the target population is a collection of trees. If the survey is conducted for operational purposes — e.g., to assess the health of a stand or to determine what, if any, treatment should be applied to a insect-infested stand — then prevalence is of primary interest. Severity is generally of secondary concern because identification of a pest provides some information about the severity of the damage it causes. For example, if a tree has been attacked by mountain pine beetle then the tree is likely to die.

The target population for a forest-level survey is a collection of stands. The relevant population parameters for this type of survey are generally less obvious than they are for stand-level surveys, mainly because the objectives are more diverse. For example, if a survey is conducted as part of a pest management program for a TSA, it may be important to determine the overall proportion of stands in which there is a "significant" pest problem (i.e., stands in which the prevalence of a particular pest or pests exceeds some threshold value). Alternatively, it may be more informative to estimate the overall prevalence of a particular pest for various type groups, ages, or biogeoclimatic subzones, thereby giving some indication of where problems are likely to occur. Of course, if one of the purposes of the survey is to assess impact, then it may also be important to estimate the expected timber volume loss per hectare as a function of the prevalence of a particular pest, the severity of the attack, and such other predictive factors as type group, age, or biogeoclimatic subzone.

Forest health surveys encompass a broad range of designs. The sampling units for sampling a stand can be prism plots, fixed plots of various sizes and shapes (circular plots, strips, pixels), or, in the case of root rot surveys, lines. The methods for selecting the sampling units (the spatial arrangement of the sampling units) include stratified (random) sampling, pseudo-random sampling, one- or two-dimensional systematic sampling, or a combination of methods. For forest-level surveys, the selection of a sample of stands — the primary sampling units — is usually based on some sort of stratified (random or pseudo-random) sampling scheme. In general, the choice of sampling units, the spatial arrangement of the units within a stand, and the sample size is either a subjective decision or is a matter of convenience or cost. For example, 3.99 m circular plots are widely used, simply because some forest health surveys are conducted with silviculture surveys (for which that type of plot is standard).

It is difficult to draw any conclusions about the precision and accuracy of estimates derived from forest health surveys (estimated prevalence, relative frequency of occurrence of various severity classes, percentage area affected, etc.), or the advantages and disadvantages of the different sampling methodologies, particularly in the case of multi-pest surveys. Previous studies of the effect of plot size, shape, and spatial arrangement are not generally applicable because they are based on data from a limited number of sites, are restricted to a particular insect or disease, or are concerned with the estimation of parameters other than frequency of occurrence. There are, however, several common deficiencies in the designs reviewed here. These are:

1. a failure to define the survey objectives in sufficiently precise terms to ensure that those objectives are met — e.g., what is the target population? what are the parameters of interest?
2. a failure to state explicitly how the sampled population differs from the target population and how, if at all, this limits any inferences that can be made about the target population — e.g., what are the implications of restricting a forest-level survey to accessible stands?
3. inadequate sampling (or "pseudoreplication") within stands — e.g., sampling along a single transect within a stand will generally not provide a reliable estimate of the variability over the entire stand;
4. widespread use of pseudo-random or subjective sampling instead of an objective method of sampling, such as true random sampling or systematic sampling;
5. a lack of standardization in the collection, coding, and reporting of pest data, and little or no 
   reference to quality control;
6. an apparent lack of adequate planning of the data analysis at the design stage; and
7. a failure to provide standard errors for parameter estimates, or some other indication of their 
   uncertainty (e.g., a range).

Some of these problems (e.g., 1, 2, 5, 6) could be remedied fairly easily. In other cases, such practical 
limitations as prohibitively high costs present a serious obstacle to improvement, and compromises must be 
made. It is essential that the consequences of those compromises be fully understood to avoid misinterpre-
tation of the survey results.

4.2 Recommendations for POYS Survey

The purpose of the POYS survey (and other inventory-type surveys such as the PIS of the Kamloops 
Forest Region) is to provide an overview of the insects and diseases that occur in stands. The required degree 
of precision is therefore less than might be necessary if the estimates were used to determine treatment 
priorities, to assess timber loss, or to make other types of decisions for which relatively accurate estimates 
are needed. Nevertheless, it is worth considering areas in which the survey might be improved. Some 
recommendations are given below.

4.2.1 Sampling design

Since POYS is a forest-level survey, there are two levels of sampling — a sampling of stands and a 
sampling of trees within stands. Currently, stands are sampled subjectively by district officers. This could 
be a source of bias as there might be a tendency to select stands that have, or are suspected of having, 
a pest problem. Implementation of a random sampling scheme would be an improvement. This could be 
either a simple random sample of all stands in all districts or, if it is desirable to ensure coverage of 
particular subpopulations, a stratified random sample. Selection of a random sample should be relatively 
easy since a computer file (history record file) containing a complete list of stands and their attributes is 
available. Random numbers can easily be generated with SAS or a table of random numbers. The sample 
size for each stratum should be proportional to the total number of stands in each stratum or, depending 
on the most important parameters, the total area of the stands, or the total number of trees in each stratum.

There is also room for improvement in the sampling within stands. The present design calls for a 
subjective placement of the sample plots at the time of sampling. This is another potential source of bias, 
since there is probably a natural inclination to over-sample areas with an obvious pest problem. Some 
effort to remove or minimize any such bias should be made if possible, for example by locating the plots 
randomly or systematically, or at least locating the plots on maps before sampling commences. A more 
objective method of sampling the stands would also help maintain consistency in the sampling from one 
stand to the next.

Another possible deficiency in the sampling methodology is a failure to ensure that the sample plots 
are distributed over the entire stand, either by random sampling or by sampling on a grid that covers the 
whole stand. This could produce a biased estimate of the variability within stands. For example, if the plots 
are located more or less along a straight line, then sampling 10 plots will not be much better than sampling 
a single strip, in which case the variability seen among the 10 plots is likely to be less than the variability 
seen among 10 randomly located plots.
4.2.2 Data collection

For ease of manipulation at the analysis stage, the simplest and most flexible way of collecting the data would be to record the measurements for each tree on a separate line (or lines), and enter for each live or dead tree (including stumps and fallen trees), the species and current state of health of the tree (e.g., H = healthy or apparently pest-free, D = dead, P = clear evidence of pest damage or other injury, and S = suspect). For those trees listed as damaged, enter the cause or causes (in decreasing order of severity and coded appropriately) and the severity of the damage associated with each, coded appropriately for each type of pest (e.g., Hawksworth six-point scale for dwarf mistletoe). If the additional cost of rating severity on an individual pest basis is not considered worthwhile, then the overall severity of damage attributable to all causes (the POYS severity index) could be recorded for each tree. At the end or beginning of each plot, the total number of trees might be tallied as a check.

Apart from computational convenience, recording the data for each tree has the added advantage of retaining information about pest associations (e.g., a tendency for two particular pests to occur together on a tree), which is lost in the present system. Since the number of trees per plot is relatively small (5–20), the benefits of recording the data for individual trees might justify any additional cost.

4.2.3 Data codes

The 1991 POYS survey did not use pest codes for the data collection. This made the analysis (and probably the data collection) unnecessarily time-consuming and cumbersome. Since then, a numerical coding system has been adopted, which will be tested in the field during the 1992 survey. This system, like the Survey Damage and Condition Codes (FS 747 SIL 90/6) of the B.C. Ministry of Forests Silviculture Branch, has several desirable features: 1) it is logical and easy to learn because it is a hierarchical system, 2) its simplicity facilitates data entry, and 3) it is easy to manipulate by computer.

In addition to the pests, all other data should be coded (if appropriate) and recorded in a consistent and systematic fashion. Before finalizing the design of the field sheet, it might be worthwhile examining other field sheets used to collect multi-pest data — such as the multi-pest tally sheet (FH 100) used by the Prince George Forest Region and the Pest Incidence Survey field sheet used by the Kamloops Forest Region. The former records data for individual trees while the latter records tree counts by species, pest type, and severity of damage in a manner similar to the present POYS field sheet. Of course, any changes to the current method of recording should be field-tested before they are accepted.

4.2.4 Quality control

Appropriate quality control measures should be implemented to ensure consistency between districts and field crews in the method used to locate and measure plots, and in the data collection — i.e., identification of pests and coding of damage severity.

4.2.5 Data analysis

The proposed method of analyzing or summarizing the data should be given careful consideration before the sampling design is finalized, since it could have an impact on the data collection. Summary of multi-pest data is quite challenging because of the relatively large number of pests and host species to report. There are many ways of summarizing such data — by host species, stand age, stand area, stocking levels, etc. — depending on which factors are considered most important. If standard errors are reported, care must be taken to use the correct formula (one that matches the sampling design); alternatively, it may be more appropriate and simpler to quote the range, as in previous years.

Finally, the definition and interpretation of a "pest-free" stand requires more thought, if the proportion of pest-free stands is to have any useful meaning. Classification of a stand as pest-free depends to some extent on the sampling effort exerted — e.g., the more trees or plots examined, the less likely a stand will be classified as pest-free. Therefore the definition of pest-free must, in some sense, adjust for the differences in sampling effort — e.g., by testing the hypothesis that the proportion of trees with a least one pest is less than some threshold value.
5 REFERENCES

5.1 General References


5.2 Multi-pest Surveys

1. Kamloops: Pest Incidence Survey

2. Nelson: Comprehensive Pest Inventory


3. Prince George: Multi-pest Survey

4. Prince Rupert: Multiple-pest Survey

5. Forestry Canada (FIDS): Pests of Young Stands
5.3 Surveys for Specific Forest Health Problems

5.3.1 Root disease


5.3.2 Dwarf mistletoe


5.3.3 Stem rusts


5.3.4 Leader and branch die-back

5.3.5 Bark beetles


5.3.6 Weevils


5.3.7 Defoliators


5.3.8 Other

O2. ________. Prince Rupert Forest Region tree hazard site inspection field procedures. Note.
APPENDIX 1. Glossary of terms and abbreviations used in this report

BAF
basal area factor for a prism plot; the fixed ratio of the basal area of any tree included in the plot to the area of a circular plot with radius R, where R is the maximum distance from the sample point that a tree with the same diameter can be and still be included in the plot

beetle probe
a form of strip sampling often used to map bark beetle infestations in stands; probes may consist of one or more strips

CPI
Comprehensive Pest Inventory, formerly known as Site Discrepancy Survey (Nelson Forest Region)

cutblock
a harvested area of forest; may comprise one or more treatment units; (see opening, treatment unit)

CV
coefficient of variation; ratio of the standard deviation to the mean of a random variable

dbh
diameter at breast height

FIDS
Forest Insect and Disease Survey (Forestry Canada)

fixed plot
a sampling unit with a fixed shape and area (circular, rectangular, or square)

forest-level survey
any relatively large-scale survey in which the target (or sampled) population comprises more than one stand; (see stand-level survey)

FRDA
Forest Resource and Development Agreement, between the governments of Canada and the Province of British Columbia

ITG
inventory type group; a classification of forest polygons based primarily on tree species composition

mapsheet
a map of a relatively large forested area, divided into forest cover polygons; mapsheets are identified by a unique inventory label

opening
an area of forest that has or will be harvested (sometimes called an obligation); an opening may include one or more cutblocks; (see stand)

parameter estimate
an estimate of a population parameter based upon a sample drawn from the population (e.g., the sample proportion of trees affected by a pest is an estimate of the prevalence of the pest)

PDAAC
Pest Damage and Appraisal Advisory Committee

pest
any insect, disease, mammal, or other biotic or abiotic agent that is potentially damaging

PIS
Pest Incidence Survey of the Kamloops Forest Region

pixel
a type of fixed plot used to estimate prevalence as the percentage area infected; often only the presence or absence of the pest is recorded for each pixel

plantation
a regenerated opening or cutblock, which has been planted or naturally regenerated; plantation often implies that the trees have a regular or uniform spatial distribution (e.g., rows)

polygon
forest cover polygon, a relatively homogeneous unit of forest, which is identified by a unique inventory label and is classified by species composition and ecosystem; (see stand, mapsheet)
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>population parameter</td>
<td>a single number that describes some characteristic of the target population (e.g., the average height of all trees in a stand)</td>
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<td>POYS</td>
<td>Pests of Young Stands survey (FIDS, Forestry Canada)</td>
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<tr>
<td>prevalence</td>
<td>the proportion of entities (in a given population of interest) affected by a particular insect, disease, or other potentially damaging agent</td>
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<td>prism plot</td>
<td>a circular plot with radius proportional to tree diameter; also called a variable plot or point sampling; (see BAF)</td>
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<td>pseudo-random sampling</td>
<td>any sampling method that involves a more or less subjective selection of an apparently “representative” or “random” sample; also called haphazard or subjective sampling</td>
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<td>pseudo-replication</td>
<td>failure to distribute the sampling units over the entire population of interest which often results in a biased estimate of the sampling variability; (see Hurlbert 1984)</td>
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<tr>
<td>random sampling</td>
<td>a sampling scheme by which all sampling units in the sampled population are selected with known (usually equal) probabilities</td>
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<td>random variable</td>
<td>a value associated with a sampling unit or population entity</td>
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<tr>
<td>sample</td>
<td>a collection of sampling units</td>
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<td>sampling unit</td>
<td>a unit on which measurements are made (e.g., stand, plot, or tree)</td>
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<tr>
<td>sampled population</td>
<td>the collection of entities or units from which a sample is drawn; often much more restrictive than the target population</td>
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<td>severity</td>
<td>a measure of the amount or stage of a disease for a given entity; a population parameter associated with severity</td>
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<td>stand</td>
<td>a general term used to refer to a forest polygon, opening, plantation, or any other well-defined, relatively small (10–100 ha), and homogeneous area of forest that is managed as a single unit</td>
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<tr>
<td>stand-level survey</td>
<td>a survey of a single stand; (see forest-level survey)</td>
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<td>stratified sampling</td>
<td>a sampling scheme by which the sampled population is divided into strata and a sample is drawn from each stratum</td>
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<td>strip</td>
<td>a sampling unit laid out by measuring an equal distance on either side of a transect; a special type of fixed plot; other names include strip transect, probe line and strip plot</td>
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<td>systematic sampling</td>
<td>a sampling scheme by which the sample is drawn according to a regular pattern (e.g., plots are located on a uniform grid)</td>
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<td>target population</td>
<td>the complete collection of entities about which inferences are to be made (e.g., all forest polygons on a mapsheet or all trees in a particular plantation)</td>
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<td>TSA</td>
<td>timber supply area</td>
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<tr>
<td>transect</td>
<td>a sampling line along which measurements are made or plots (strips, pixels) are laid out; often straight but can also have zigzag pattern</td>
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<td>treatment unit</td>
<td>an area that has received or will receive a particular site preparation, silviculture, or other treatment (e.g., broadcast burn, thinning, herbicide, or fertilizer)</td>
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