DECISION SUPPORT SYSTEM DESIGN DOCUMENT FOR PESTS OF YOUNG STANDS IN BRITISH COLUMBIA

Discussion Paper

Canada

BC

DECISION SUPPORT SYSTEM DESIGN DOCUMENT
FOR PESTS OF YOUNG STANDS
IN BRITISH COLUMBIA

Prepared for

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1.0 Introduction

This report is a detailed design document for a decision support system for the management of pests of regenerating stands in British Columbia. As such, it represents the findings of the project, Model Development to Forecast Effects and Impacts of Pests of Young Stands as a Basis for Management, for the British Columbia Forest Resources Development Agreement. This project, conducted over the past six months by ESSA Environmental and Social Systems Analysts Ltd., is intended to serve as the basis for the development, testing, and implementation of a full decision support system for pest management in regenerating stands.

1.1 Background to the Project

Historically, research and development on forest pests concentrated on mature and overmature stands and forests. This was understandable, as this part of the forest was in apparently plentiful supply. This gave rise to a series of pest decision support systems directed primarily towards the mature stand situation: western spruce budworm (CANUSA 1985, Thomson 1979); Douglas-fir tussock moth (Brookes, Stark and Campbell 1979); mountain pine beetle (Gillespie et al. 1990, Thomson 1991).

As the supply of mature forest has decreased, stand and forest regeneration has become a more important issue, receiving increasing funding from Forest Resource Development Agreements and becoming a more important focus of research effort. As of 1986, for example, approximately 17 million ha of land in British Columbia was less than 20 years of age, and 27 million ha of land was between 21 and 40 years of age; these represent about 4% and 6% of stocked, productive, nonreserved forest land in the province (Forestry Canada 1988). This is a direct result of recent intensive regeneration efforts made in British Columbia forests (Figure 1).

There is little practical experience for these stands. The growth and yield of these new stands, particularly those under intensive management regimes, is unknown. Concomitantly, the new forest provides a set of conditions for pests that have not occurred before. This regenerating forest will form much of the future wood supply of the province. In spite of the uncertainties and information deficiencies described above, timber supply analyses are being conducted and forest management plans developed. It is likely that these are being developed with little or no regard to the possible short and long term effects of pests on young stands that will form the future wood supply and forest resource of the province.
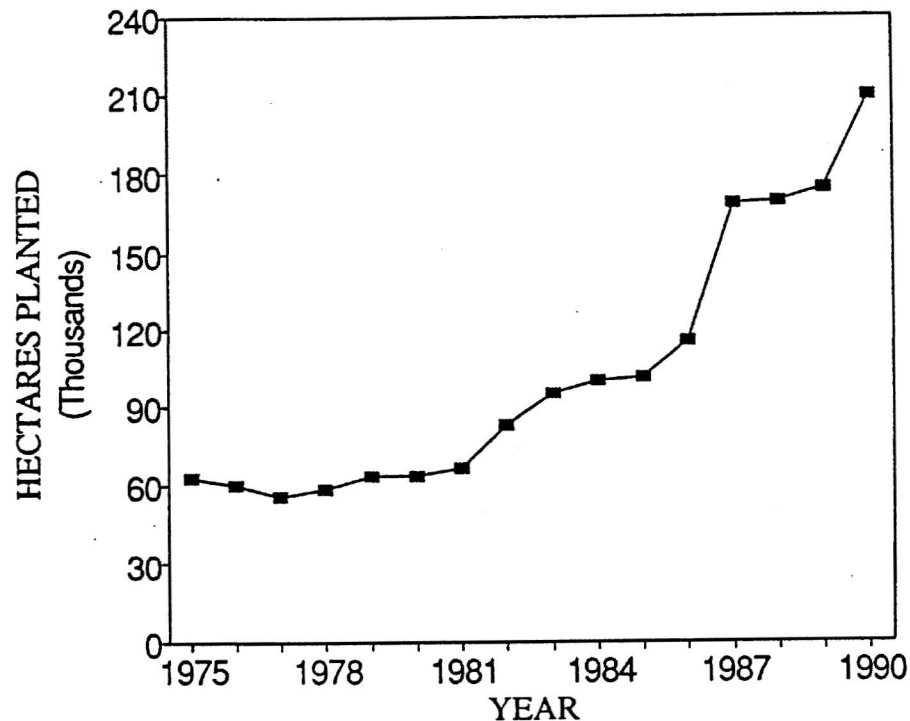
Figure 1: Recent regeneration statistics for British Columbia. (Source: Data compiled from Canadian Forestry Service 1986 and Forestry Canada 1992b)

In spite of this lack of understanding, there likely exists a substantial body of knowledge concerning pests of young stands, and this body of knowledge exists in a number of forms:

1.   the British Columbia and Yukon Region of Forest Insect and Disease Survey of Forestry Canada has initiated a survey of young stands to provide an empirical database to describe spatial and temporal dynamics of important pests of young stands (POYS) (Humphreys & Van sickle, 1992). POYS samples cover the six forest regions of British Columbia, and the major tree species in each region. The results to date of POYS are providing valuable information on the changing status of pests and their impact in the regenerating second forest (e.g., Wood and Van Sickle 1989, 1990, 1991);

2.   the province of British Columbia maintains descriptions of the host forest and the timber resource through comprehensive stand inventories;

3.   the province of British Columbia, forest companies, and Forestry Canada jointly plan, conduct, and document pest control programs;

4.   various institutions have conducted population and impact research on pests of young stands. Some of this information has been encoded in the form of models (e.g., Stage et al. 1990); and

5.   there exists a large body of undocumented, yet highly useful knowledge about pests in young forest stands in British Columbia in the experience of researchers, pest managers, and timber managers.

Taken together, these data form an extremely rich set of information from which a decision support system for pests in young stands may be developed. There are data and there is understanding which can be used to improve management decisions taken in young stands. The challenge is how best to provide this information to pest and forest managers. This project was to develop a proposed structure for such a system for British Columbia, review and evaluate existing information for its applicability and completeness for building such a system, and propose a workplan for building a full decision support system for pests of young stands in British Columbia.

1.2   Project Objectives

The specific objectives of this project were:

1.   systematically review and document the existing knowledge (literature and subject matter experts) on the spread and impact of important pests of young stands in British Columbia, and the effects of management practices on the dynamics of these systems;

2.   recommend a structure for a decision support system for pests of young stands in British Columbia;

3.   recommend a plan for developing this decision support system; and

4.   identify important information and knowledge gaps that, if resolved and filled, would improve the reliability and utility of the decision support system.

1.3   Outline of This Report

This report is divided into seven sections. Chapter 2 describes the current management situation with respect to regenerating stands in British Columbia as well as a description of the problems created by pests of young stands that can be addressed by a decision support system. Chapter 3 details the scope and the bounds of such a decision support system and lists the priority pests for inclusion into the decision support system. Chapter 4 is a detailed design for the system, and Chapter 5 describes a "proof of concept" prototype developed for the spruce leader weevil. Chapter 6 contains a summary of the data and information that can be used to build the decision support system for each of the priority pests that have been identified. Particular attention in Chapter 6 is paid to key data and information gaps for the priority pests. The report concludes with a presentation of a plan for the future development and maintenance of a complete decision support system for the identified priority for pests of young stands in British Columbia.

2.0 User Needs and Problem Profile

There are essentially two user groups for the POYS decision support system. First, FIDS staff within Forestry Canada have an intimate knowledge of pest and forest dynamics and are continually being asked for technical information and knowledge by forest managers during the conduct of the POYS surveys. In addition, district and regional silviculturalists, both within the BC Forest Service and within industry are continually having to make regeneration assessments and recommend action for regenerating stands in response to management objectives, management history, and current stand conditions.

There are two important features of these groups which must be borne in mind when developing and implementing this system. First, many of the users, particularly the silviculturalists, are not always aware that there may be a problem with stands they are managing and that they may need some tool to give them further information with which to make decisions. Second, users generally will have very little time to learn or to use a new system. Therefore, a system that is developed and implemented must be easily learned and easy to use. Detailed, complicated models are inappropriate. A system that contains simple rules of thumb, perhaps derived from existing simulation models or from the knowledge and experience of pest and forest management practitioners, will have a greater chance of success.

2.1 Problem Profile

We have developed a general conceptual model to guide discussions of the problem profile and system design (Figure 2).   This conceptual model is described below.
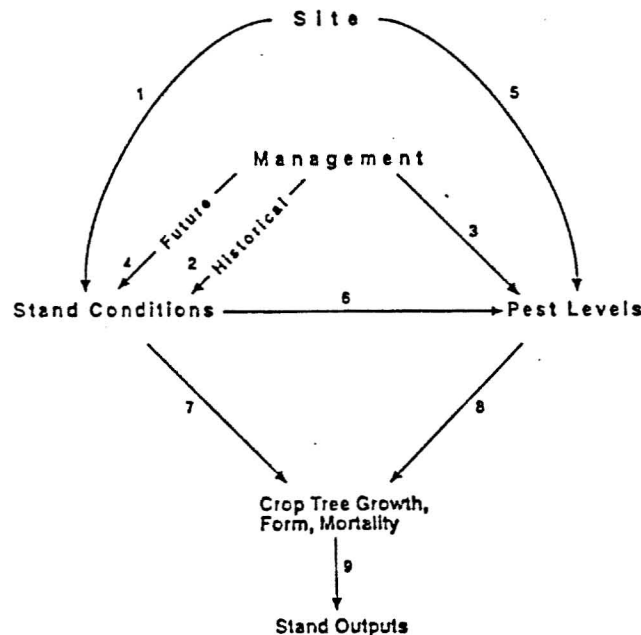

Figure 2:   General conceptual model for pests of young stands.

Pest levels in regenerating stands are affected by the following factors:

- stand conditions (Link 6) which are in turn determined by site conditions (Link 1), the management history of the previous and current stand (Link 2), and specific management actions which can potentially be taken (or not taken) to indirectly (Link 4) affect pest levels;

- direct effects of site conditions on pest levels (Link 5); and

- specific management actions which can potentially be taken (or not taken) to directly (Link 3) affect pest levels.

The temporal pattern of pest levels and stand conditions determine changes in crop tree growth, form, and mortality rates (Links 7 and 8). These in turn determine key stand performance outputs such as attainment of free to grow, merchantable volume, and possible economic measures (Link 9).

Site and management history of the previous and the current stand are the prime determinants of the future risk[1] of pest problems and of current pest levels (Links 1 and 2). Future management actions, either on the stand or directly against the pest (Links 3 and 4) provide the opportunity to alter pest levels.

There are essentially two major questions that users need to answer with regard to making management decisions on regenerating stands:

1. What is the risk and hazard[2] to a regenerating stand given site conditions, stand conditions and stand management history (the entire conceptual model of Figure 2 save for Links 3 and 4)? and

2. What is a feasible management alternative for this stand to reduce the future risk and hazard of pest infestations of this regenerating stand (the entire conceptual model of Figure 2)?

Very simply, users need to be able to assess future pest levels and consequent impacts on stands with and without management. In addition, with respect to regenerating stands, this is important both at the time of determining free to grow status and at the time(s) of future harvest.

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[1]   in this report, risk is defined as the probability or likelihood that pest levels will increase

[2]   in this report, hazard is defined as the likelihood of damage from increased pest levels

Present Problem Solving Environment

Silviculturalists currently have access to a number of important databases and manuals for making management decisions in regenerating stands, particularly:

- the guidelines for tree species selection and stocking standards for British Columbia (Silvicultural Interpretations Working Group 1993);

- the TIPSY stand growth simulator (Mitchell et al. 1992); and

- the POYS database system.

While information exists which would improve the management of regenerating stands with regards to pests, this information is not available to the users in a consistent, integrated format (as represented in Figure 2). That is, there is currently no method of providing the users the best available information on either the risk and hazard to a regenerating stand given site conditions, stand conditions and stand management history, or feasible management alternatives to reduce future risk and hazard of pest infestations of this regenerating stand. Some specific examples:

- the silvicultural guidelines present stocking, regeneration delay, and crop tree height targets to which regeneration management should be directed;

- the forest health charts in the silvicultural guidelines contain general risk factors for various pests according to site (as defined by biogeoclimatic zone/subzone) and primary crop tree species, but not by management history;

- there exists no simple method by which management recommendations can be made for regenerating stands to reduce the risk of future pest infestations or to reduce or remove existing pest problems;

- silviculturalists may or may not have had a POYS survey conducted for the stands about which they are concerned;

- the POYS survey provides the most complete survey of pest conditions in regenerating stands in British Columbia; and

- the TIPSY model is an increasingly well-accepted model for predicting changes in stand conditions and there are methods for simulating pest effects in TIPSY. But, the specific procedures by which to simulate pest effects within TIPSY have not been developed.

Despite the limitations described above on the knowledge that is being brought to bear on management decision making for regenerating stands, silviculturalists are making management decisions. Even a decision not to do any management, for whatever reason, is a management decision. A decision support system for pests of young stands must be capable of:

1. providing the best available information to managers of regenerating stands;

2. integrating information on all components (Figure 2); and

3. improving the consistency with which management decisions in regenerating stands are made.

3.0 Scope and Bounds of Decision Support System

3.1 Management Actions

The specific management actions which will need to be considered depend on the pest being considered (Chapter 6). But, there are essentially six classes of management actions which will need to be considered:

Stand Manipulation

- species selection
- stocking level
- timing of regeneration

Pest Manipulation

- application of direct mortality agents
- physical removal of the pest
- physical barriers to pest attack

3.2 System Outputs

The system will produce the following outputs: estimation of stocking levels at the free to grow evaluation periods (earliest and latest); and merchantable volume.

3.3 Spatial Extent and Resolution

The system will be used for one stand at a time. In addition, there will be no spatial resolution (explicit or implicit) within the stand, although the stocking levels of the main tree species will be maintained.

Initially, the system will be used for plantation-type stands, and will not be used for multi-age, multi-storey stands.

3.4 Temporal Extent and Resolution

Only stands that have passed the establishment stage but are not yet at the commercial thinning stage will be considered. The system will be used after a diagnosis of the pest has been made and an estimate made of current pest infestation and damage levels as are made in POYS.

The system will project consequences of no management at three points in the stand history: the free to grow stage; the commercial thinning stage; and rotation age.

3.5 Priority Pests and Stand Types

The priority pests are listed below, in order of decreasing priority. This list was built from the results of the initial POYS survey (Humphreys and van Sickle 1992), and from discussions held at the project scoping meeting.

• root diseases *(Armillaria, Phellinus,)*
• gall rusts
• stem rusts (hard and soft pines)
• root collar weevils
• leader weevils
• mammals
• abiotics
• mistletoe
• competing vegetation (very low priority)

3.6 Method of Projecting Stand Growth

The TIPSY system (Mitchell et al. 1992) should be the core of the tree and stand projection system. There will need to be a number of changes to the TIPSY system; these are highlighted in the review of existing data and information (Chapter 6) and are summarized in Chapter 7.

4.0 System Design

As silvicultural decisions (particularly those related to determining free to grow status) are many on a large number of stands each year, and not all have been surveyed for pests using the POYS procedures, we propose a system design in which it will be possible to use the system under three situations:

- there is POYS information indicating the presence of pest infestations in the stand;

- there is POYS information indicating the absence of pest infestations in the stand; or

- no POYS survey has been conducted for the stand.

The information provided to the user, however, if a POYS survey has been conducted will be richer and provide greater certainty on predictions and management recommendations than if no POYS survey has been conducted.

4.1   Proposed Problem Solving Strategy

As stated in Chapter 2, the essential problems related to management of pests in regenerating stands are:

1.   What is the risk and hazard to a regenerating stand given site conditions, stand conditions and stand management history? and

2.   What is a feasible management alternative for this stand to reduce the future risk and hazard of pest infestations of this regenerating stand?

We propose the following problem solving strategy which will form the core of the computerized system:

1.   assess the free to grow and merchantable volume consequences of current pest infestation levels;

2.   assess the free to grow and merchantable volume consequences of current and future projected pest infestation levels in the absence of management;

3.   develop a set of management prescriptions for the stand;

4.   assess the free to grow and merchantable volume consequences of current and future projected pest infestation levels with the implementation of the management prescriptions; and

5.   repeat steps 3 and 4 until a suitable (to the user) management prescription is developed.

The system should carry the user through these steps for each case being considered by the user.

4.2   Required Information and Method of Organization

Appropriate information is required to implement this problem solving strategy, and there are a number of options as to the type of information that is used and the manner in which it is organized for manipulation by the user. We examined a number of alternative approaches for the design of this type of decision support system. These include:

1.   **rule-based** - these are ideal in situations in which there is some general knowledge but perhaps less quantitative information about the pest;

2.   **detailed pest-specific models** - a large advantage over the other options since they have generally been tested and accepted, and people are more likely to believe the results. Although simple, pest-specific models may be less realistic than the more detailed models, they may be more appropriate for pests where we have limited understanding;

3.   **generic simple model** - uses the fact that all pests are the same in several respects: pests affect a tree by slowing growth, killing it, affecting the quality of the wood, or some combination. Pest intensity in the stand may vary with the age and composition of the stand, with previous pest levels, and with the pest's own growth rate. A simple model could be created using these facts. Users could then enter new pests by defining each of these characteristics for the new pest. The primary disadvantage with this approach is that the resulting model may be hard to defend; or

4.   **database** - would contain all the relevant information about stands, such as location, description, and management history, and would list possible stand outcomes based on varying pest levels, and different management alternatives. The database would also contain information about management procedures and guidelines. The advantages of this approach are that the database would be fast to use, and could be stored both in printed form and on a computer. Thus, a user could access the information while in a stand. However, in order to generate the numbers needed for the database, some type of model would be necessary. Consequently, the basic system would still be one of the other options listed above.

Since no decision support system is likely to work perfectly for all pests, the ideal system may combine several different methods, so that the approach would vary with the level of knowledge about the various pests.

After considering the various options, we decided to propose an approach similar to that used by the TIPSY model: a database accessed by the user according to information provided about the stand and the pest situation. This database would consist of a series of temporal regimes of important variables, stratified by a very small set of key stand, site, and management variables. The variables forming the stratification would be specific to the pest being considered. The temporal regimes could be defined either by abstractions of detailed simulation models or professional judgement (i.e., more of the expert system approach).

4.3   General Set of Information Required For a Pest Case

Essentially, in order to construct a decision support system with a structure like that provided in Chapter 2 and in Sections 4.1 and 4.2, above, there is a (relatively) small set of information required:

1.   a base temporal regime of pest infestation levels, such as the % trees attacked;

2.   an identification of the key variables that influence pest infestation levels. These fall into three classes (Figure 2): stand factors, site factors, and management activities directed at the pest;

3.   a family of these regimes that describe how the temporal pattern of pest infestation varies with each combination of the key variables;

4.   an identification of the important first order effects of pest infestation levels: diameter increment reduction, height reduction, mortality, or quality/form;

5.   functions relating pest levels (defined in items 1 and 3, above) to the first order effects; and

6.   appropriate methods of translating the first order effects to indicators that can be used to assess free to grow status and merchantable volume at stand maturity.

4.4   Hardware and Software Platform

There are several options that are possible, such as mainframe computers; microcomputers using DOS; OS/2; Windows; (or Visual Basic). Each alternative has advantages and disadvantages that are independent of the type of decision support system.

Mainframe computers are fast and powerful, but are expensive, not very portable, and may not be as flexible in designing user interfaces as some of the other choices. A second

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option is to use character-based DOS programs. Using this approach it is possible to design programs that are relatively user-friendly and do not have large memory requirements. A third alternative is to create a Microsoft Windows-based system running on IBM PC and compatible systems. The advantage of this approach is the programs can be made extremely user-friendly, with users clicking on buttons and changing values in designated areas. The two principal problems with this approach are that users must have Windows installed on their computers and the memory requirements are higher than non-Windows-based systems.

The system design below is predicated on the use of Windows and Visual Basic for two reasons:

1.   the general availability of powerful PC hardware, and

2.   the power and flexibility of the user interface.

4.5   Detailed Description of Decision Support System

The system will consist of a main menu which will allow users to access a series of separate windows/dialogue boxes. Figure 3 shows the basic sequence of activities that would be carried out when using the system. Although ideally the user would move through the screens in the order shown, the user would be able to move between categories easily. At any time, the user would be able to change initial conditions, define management activities, and write reports. Each of the major components of the system is described in more detail below.
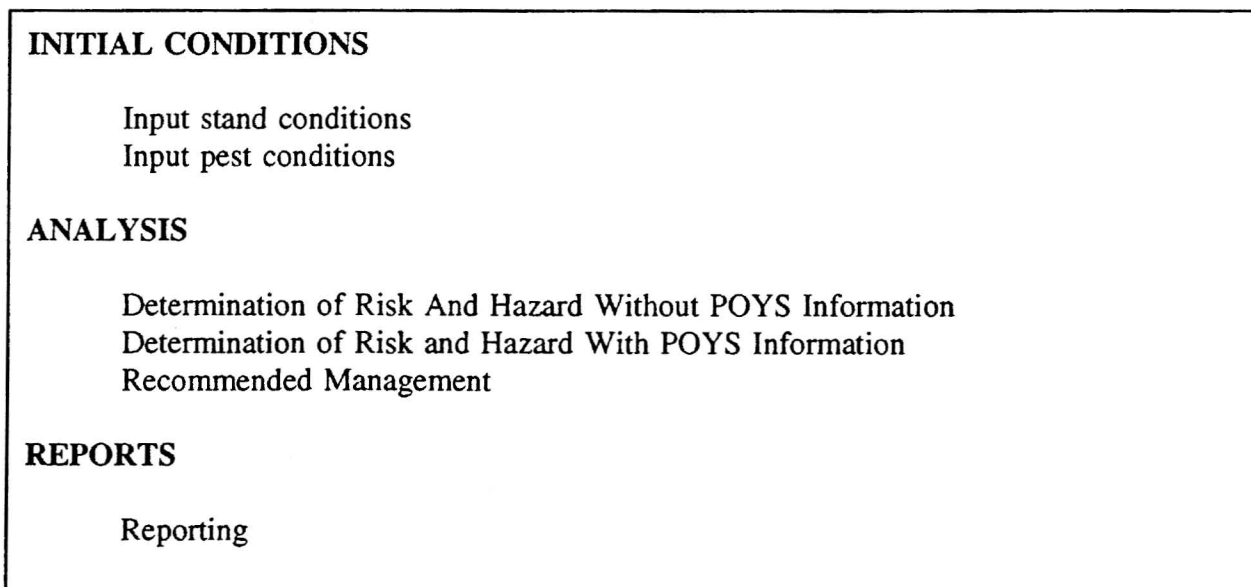

INITIAL CONDITIONS

    Input stand conditions
    Input pest conditions

ANALYSIS

    Determination of Risk And Hazard Without POYS Information
    Determination of Risk and Hazard With POYS Information
    Recommended Management

REPORTS

    Reporting

Figure 3:   Basic sequence of system activities

4.5.1 Main Menu

A Main Menu bar containing the following options would always be accessible:

- File - to load or save information
- Initial Conditions - to return to initial condition screens at any time
- Analysis - to go to the analysis screen
- Reports - to write a report
- Quit - to end the session

Each of these options would be available from any window. Many of the screens would also have their own menus that would include "Help" and other functions.

4.5.2 Initial Conditions

When the program is first loaded, the windows in which the user inputs the stand conditions would be visible (Figure 4). The information could either be entered by hand or be loaded from an existing file, and the system state could be saved after each of the following steps. Initial conditions could be changed at any time by choosing "Initial Conditions" from the main menu and entering the new information.

Input stand information

The basic characteristics of the stand would be entered (Figure 4). This information would serve two purposes: to allow silviculturalists to identify the stand from the stand identification number, region, and district, and to enter biophysical information important for the determination of pest risk and the analysis of management alternatives. This information would include region, stand opening number, slope, aspect, elevation, site index, site, series, age, date surveyed, etc.

Figure 4:   Stand Information Screen

Input pest conditions

If POYS information is available, the user will be able to enter the synthesized results of the POYS survey (Figure 5). The user will choose the pest type of interest from a list of pests which the system can potentially support. If the system were configured so that the user could enter new pests, one of the pest choices would be "new". In all cases, the user would then enter, by tree species, the number of trees per hectare infested at each severity level. The severity codes are those indicated by the POYS survey (Appendix 3, Humphreys and Van Sickle, 1992). The "Summary" button on the Pest Information Screen will give the user some idea about how much of the stand is infected by the current pest. The user could also enter qualitative estimates of pest levels if no POYS data were available.

Figure 5: Pest Information Screen

4.5.3 Analysis

After all the data had been entered and/or reviewed, the user would then have the opportunity to view alternate futures under varying management regimes (including no pest management) for the stand and pest conditions.

Determination of Risk And Hazard Without POYS Information

If only stand information were entered, the user would be able to use the system, but the results would be tempered by a statement of the risk associated with such future outcomes. That is, if no POYS information were available, the user would be advised that the analysis of future patterns of pest and stand dynamics would have a certain probability of occurring (i.e., None, Low, Medium, and High).

The description of the likelihood of particular outcomes would initially begin with the preliminary forest health charts in the Guidelines for Tree Species Selection and Stocking Standards. Additional professional judgement could be brought to bear, such as risk rating systems (if they are developed). The screen would contain qualitative risk measures (None, Low, Moderate, High) for each of the major potential pests of these young stands (Figure 6). The measures would be colour-coded to enable easy identification of the potential pests.

Figure 6:   Example output from the system if there were no POYS information available.

Determination of Risk And Hazard With POYS Information

The user will be asked to choose which of the pests for which information had been entered should be analyzed. All losses are reported at the earliest and latest Free-to-Grow assessment year, and the user will be asked to choose two other years for which information is desired (Figure 7).

Figure 7: Screen for choosing pests and for entering years to report results.

The more detailed information that would be provided here would be a projection of potential future impacts based on current infestation levels, assuming the absence of future management activities. Information would come either from summaries of simulations of models (if models exist), or from syntheses of expert knowledge.

The information presented would be critical information required by users in order to make management decisions. This information includes potential volume losses and the predicted Free-to-Grow eligible stems per hectare of the host tree species. For easy comparison, the Free-To-Grow target and minimum stocking standards will be listed on the screen (Figure 8).

Figure 8:   Analysis screen showing volume loss and stems/hectare if no pest management occurs.

At any time the user will be able to select another pest to simulate, or the user will be able to re-choose the same pest and choose different reporting years. Also, if the user is interested in the effects of error in pest measurement, the user can return to the Pest Information Screen and enter different values for pest infestation levels.

Recommended Management

Some management alternatives will be suggested by the system. The consequences of the management that will be shown will contain the same information as with no management, i.e., volume loss and stems/hectare at four different ages. This will allow for easy comparison of the potential benefits (whether or not there are any) of doing some sort of management.

Other management possibilities can be created by the user. A created alternative will always replace the worst of the two recommended alternatives, even if the created strategy was worse than one of the recommended ones. The management recommendations will likely relate either directly to pest management strategies (such as clipping for leader weevil; Link 3 of Figure 2) or stocking levels (such as spacing or thinning; Link 4 of Figure 2) (Figure 9).

Figure 9:   Management recommendations screen

4.5.4 Reporting

The user would be able to print or save the following various reports to a file, at any time, by choosing "Reports" from the Main Menu:

- summary results (those seen on the Analysis screen, with and without management recommendations); and
- input data used for the stand and pest (essentially the assumptions).

These reports could be used in many ways, including for reference away from the computer terminal, for communication of the results to a non-user (for example, showing a non-user the consequences of doing nothing), or for comparison of large numbers of pest or options.

5.0   Leader Weevil Case Study

This chapter presents a case study application of the decision support system design described in Chapter 4. We emphasize that this is simply a "proof of concept", conducted to demonstrate that the proposed system design is feasible. We have used spruce weevil as an example pest. Data used in this case study come primarily from Vancouver Island and the Prince Rupert Region, and may not be strictly comparable. The application will need further modification before being able to be used with reliability.

5.1   Information Base

As described in Section 4.3, there is a (relatively) small set of information required to develop an application of the decision support system for any pest:

1.   a base temporal regime of pest infestation levels, such as the % trees attacked;

2.   an identification of the key variables that influence pest infestation levels. These fall into three classes: stand factors; site factors; and management activities directed at the pest;

3.   a family of these regimes that describe how the temporal pattern of pest infestation varies with each combination of the key variables;

4.   an identification of the important first order effects of pest infestation levels: diameter increment reduction, height reduction, mortality, or quality/form;

5.   functions relating pest levels (defined in items 1 and 3, above) to the first order effects; and

6.   appropriate methods of translating the first order effects to indicators that can be used to assess free to grow status and merchantable volume at stand maturity.

These are presented below for the leader weevil case study.

5.1.1   Key Variables

Existing literature suggests that the key variables with respect to leader weevil dynamics and impact are: proportion of host in the stand; stocking level; and leader clipping regimes (the only current viable option for direct pest control). These form the stratification variables defining the temporal regime of pest infestation levels in the stand.

5.1.2 Important First Order Effects

Leader weevil has two major effects on stands: height reduction and consequent reduction in volume; and reduction in quality and form, which also causes a reduction in volume. With respect to determination of free to grow status, weevil-infested trees are assumed to exhibit sufficiently poor height and volume growth. It is assumed that these trees do not contribute to the "free growing" part of the growing stock (Carlson et al. 1984).

5.1.3 Temporal Regimes of Pest Infestation Levels

Stocking

Data from three weevil infested stands with different stocking levels were used (Alfaro and Omule, 1990). These data catalogued the percentage of trees attacked per year in the stand from the time of first infestation to near the end of the weevil outbreak. Alfaro and Omule (1990) indicate that there are three phases in a leader weevil infestation: establishment, plateau and decline. The data were regressed within each of these periods (Figure 10).
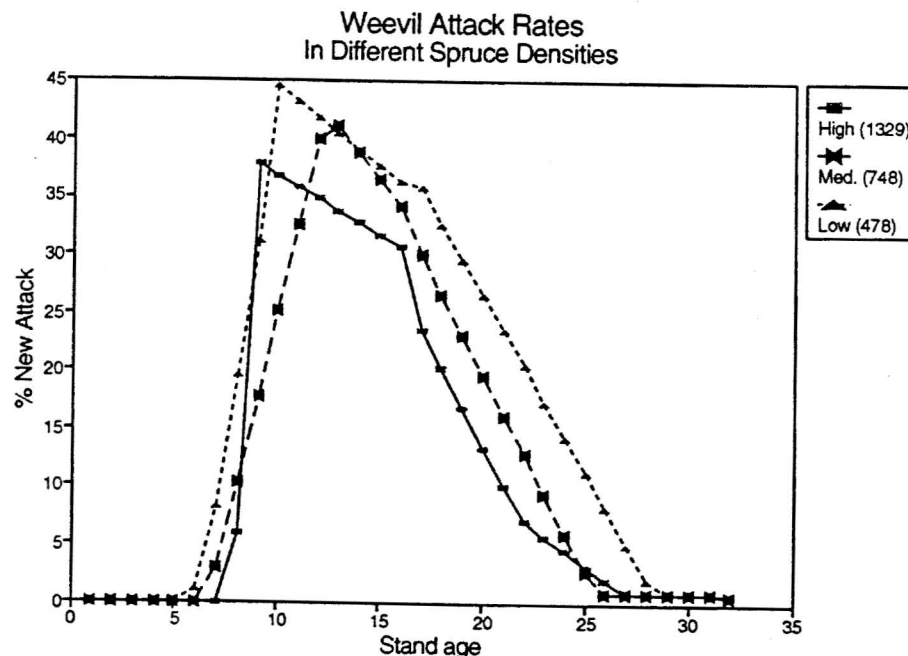
Figure 10: Weevil attack rates in pure Sitka Spruce stands with different densities. Actual data have been regressed in each of the three infestation phases to get smoother curves.

The program takes the proportion of infestation and the age of the stand and determines which infestation curve to follow. It is likely that the actual infestation level provided in POYS will not exactly match any of the curves so the model will follow the curve that is closest to the observed infestation level.

Clipping

There is some information on the potential impact of clipping on weevil infestation levels. McMullen et al. (1987) published a model in which various control strategies, including leader clipping, are simulated. The effect of clipping is taken from these results:

1. when clipping is done, the infestation level decreases to near zero (95% of the infestation level at the time of the first clipping) during the years of clipping;

2. since clipping is not totally efficient, the population is able to increase to the level at which it would have been had there been no clipping after cessation of the management activity; and

3. in years with clipping, there is no resulting volume loss.

5.1.4 Relating Infestation Levels to First Order Effects

Information on merchantable volume loss due to weevil attacks was calculated from output of the SWAT model (Alfaro 1992). A synthesis of extensive model simulations, provided in Alfaro (1992), relates percentage volume loss at different infestation intensities for varying numbers of years. These syntheses were used to determine what the volume loss would be for one year of infestation (calculated as 20% of the predicted volume loss for a five year infestation level) (Figure 11).
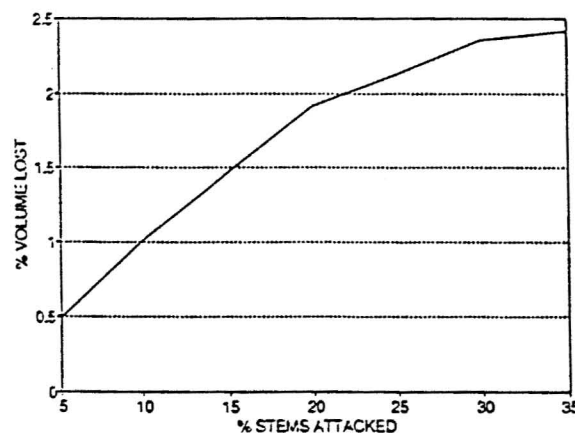
Figure 11:   Percent volume loss per year at different infestation intensities. Data derived from extensive simulations of the SWAT model (Alfaro 1992).

Volume loss is calculated each year as a proportion of remaining volume, and the total volume loss is accumulated through the infestation. Volume loss across the stand is also weighted on the relative frequency of host in the stand. So, in a pure spruce stand, the reported volume loss is the same as the calculated loss, while if the stand was mixed with some non-spruce, the reported volume loss would be proportionally less than the calculated loss.

5.1.5 Translation of First Order Effects

Free to Grow Status

In the case study example, any attacked trees are removed from the tree density that can potentially contribute to free growing stock. Since cumulative weevil attack intensities may add to more than 100% of the available host, it is evident that trees sustain multiple attacks. It is assumed that once trees have been attacked they are not attacked again for two years (Alfaro 1992).

Merchantable Volume at Maturity

The volume loss function (Figure 11) is calculated and presented as a % volume loss to the user. Ideally, the volume loss function would be used to build a specific "operational adjustment factor" time stream for direct input into the TIPSY model, which would then be able to provide actual predicted volumes.

5.2 Example Session With the Case Study Pest

The user will first enter information about the stand in the stand information screen. Some of the relevant information for the leader weevil is:

1. region = Prince George;

2. age = 7; and

3. density = 2220, a pure spruce stand.

Next, if POYS data are available for this stand, the user will enter the POYS survey results in the pest information screen. For this example assume:

1. leader weevil is the only pest; and

2. there are 230 trees per hectare attacked (10%).

Now, the user can ask the system to simulate the effects of leader weevil, giving additional output at the Free-To-Grow assessment periods as well as at ages 50 and 100.

Figure 12 gives the initial results. The stocking guidelines and Free-to-Grow assessment ages are given in the top left corner and are based on the region given in the stand information. In the top right corner are the unattacked stems per hectare at the different ages. The user will immediately notice that stocking at the first assessment period is below target stocking although it is still well within the guidelines. However, by the end of the assessment period, stocking is below minimum standards. Also, by age 100, there is 35% volume loss from the weevil. This is a minimum volume loss which assumes weevil-attacked trees will still be harvested.

Figure 12.   Initial analysis with no management occurring. The stocking guidelines and Free-to-Grow assessment ages are shown in the top, left corner. The stand is currently at age 7.

The user may then be interested in seeing what would happen if some pest management was done. The system initially assumes that optimum management would be to start clipping immediately, thus it gives the results, clipping either every year or every two years, starting at age 8, the year after the survey occurred (Figure 13, bottom half of screen). Looking again at stocking (stems/ha), it is clear that clipping has an effect; stocking at the initial assessment age (9) is now above the target. However, in both scenarios, stocking at the later assessment time is below the minimum allowable.

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Figure 13: System generated example recommendations for managing leader weevil.

The user may be worried about this result, but may also realize that only a limited amount of money is available to do any clipping. Therefore, the user decides to create another scenario which clips for five years, the same number of years as in Recommendation 1 (Figure 13) but which starts one year later, when the stand is 9 years old. This output replaces the worst of the two previous recommendations, so the results are shown as #2 (Figure 14). This management strategy lowers the stocking at age 9, the first Free-To-Grow assessment age but raises it at the end of the assessment period. This occurs because of the pattern of weevil outbreak. Figure 10 shows that starting clipping at age 9 rather than at age 8, reduces the population during the worst of the outbreak, thus weevils affect fewer trees.

POYS Analysis

Stocking Guidlines
Stems/ha
  Target [1200]
  Min.   [700]

Assement: (year)
  Earliest [9]
  Latest   [15]

Results with no management

	Volume Lost [%]	Stems /ha
Free to Grow	5.43	1124.27
	18.43	46.44
@ 50yrs	34.98	2.16
@ 100yrs	34.98	2.16

[New Post]   [Recalculate]   [Recommendations]

Example Recommendations

1. Do leader clipping starting at age 8 every year for 5 years.

2. Do leader clipping starting at age 9 every year for 5 years.

	Volume Lost [%]		Stems /ha	
	#1	#2	#1	#2
Free to Grow	.83	3.11	2032.07	1631.75
	7.87	7.75	459.93	620.2
@ 50yrs	26.57	26.47	21.44	28.92
@ 100yrs	26.57	26.47	21.44	28.92

[Create]   [Run]

[References]   [Done]

Figure 14: A user-created recommendation has replaced Recommendation #2.

At the end of the Free-To-Grow assessment stage, there are still too few trees (Figure 14). There is now a choice of strategies: either to try starting to clip one year later still (i.e., at age 10), or to somehow find the money to clip for one more year. Either or both choices should be simulated. Figure 15 shows the results of clipping for one extra year, starting immediately at age 8. Now the stocking at the latest assessment period is within the guidelines, although initially it is high. There is also close to 30% more volume present in the stand at age 100 than if no clipping were done.

Figure 15: Two user-created recommendations.

Thus, from this simulation the user may make the following decisions:

1. pest management of some form is necessary;

2. if no or little management is done, the Free-to-Grow assessment should be made early, while the stocking will meet the guidelines; or

3. if clipping is done, it must be efficient, and it may be more worthwhile to wait for one or two years before starting to clip to ensure that clipping is done during the worst of the outbreak. Also, the Free-to-Grow assessment should be made closer to the later assessment year (so that the manager is not tempted to thin the stand in order to meet the requirements).

6.0   Summary of Available Data and Information

Figure 2 and the proposed system design (Chapter 4), provide a basis by which to evaluate the existing data and information on the currently important pests of young stands as revealed in the POYS survey. As described in Chapters 3 and 4, there is a (relatively) small set of information required to build an application for the decision support system. These information needs provided the basis by which the review of existing information was conducted.

The summary results of the review are presented in the following tables, organized according to each type of information required.

Table 1: Important site and stand factors to be used as stratification for pest infestation regimes.

Pest	Key Site and Stand Variables
root diseases	mature stands • stand structure. Spread and impact in a two or more storey stand is higher than in a single storey stand • tree species vulnerability (i.e., time to death given infection) regenerating and immature stands (as well as variables for mature stands): • level, species, and quality of inoculum remaining from the previous stand. The greater the remaining inoculum, the faster the spread of root disease and the greater the mortality caused by root disease. This has implications for the POYS survey • stocking. The higher the stocking in the regenerating stand, the faster the spread of root disease and the greater the mortality caused by root disease. *Stage et al. (1990)*
gall and stem rusts	• tree height. Measure of tree size which determines available surface (foliage, branch, stem) for rust infection and the resistance of the tree to attack. The taller the tree the greater the available surface for infection and the longer the time until mortality • tree DBH. Measure of tree size which determines available surface (foliage, branch, stem) for rust infection and the resistance of the tree to attack. The larger the tree the greater the available surface for infection and the longer the time until mortality • stocking. The higher the density of host the greater the availability of surface for rust infection and the greater the total potential mortality • genetic resistance • level of alternate hosts in the stand. This is minor and only generally true at very low levels of alternate host. *Bingham et al. (1973), McDonald et al. (1981), Kinloch (1982), Goddard et al. (1985), Hagle et al. (1989), Hunt (1983, 1988)*[1]
root collar weevils	• site conditions. Optimal conditions are moist sites with coarse textured soils and heavy duff layer • tree species. Lodgepole pine, Engelmann spruce and white spruce • tree size. Usually only trees over 1.5 m and > 2 cm diameter • adjacent stands. Significant damage may occur when a young stand is located adjacent to an older infested stand • stand density. Less abundant in overly dense, overstocked stands *Finck et al. (1989), Wilson and Millers (1983), Lavender et al. (1990), H.F. Cerezke (pers. comm.)*[2]*, Prof. J. McLean (pers. comm.)*[3]

[1] These come from the interior western United States experience. The Methods Application Group of the U.S. Forest Service, using the white pine blister rust model, has developed a simpler set of factors applicable to Washington, Oregon, and British Columbia. In addition, it must be recognized that there are differences in behavior and impact among the various gall and stem rust species.

[2] H.F. Cerezke, Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta

[3] Prof. J. McLean, Faculty of Forestry, U.B.C.

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Pest	Key Site and Stand Variables
leader weevils	• stocking. The lower the stocking of host in the regenerating stand, the greater the infestation • proportion of host. The higher the proportion of host, the greater the infestation *McMullen et al. (1987), Alfaro and Omule (1990)*
mammals	**Vole and field mice** • planted vs natural. Planted trees are attacked significantly more than natural regeneration • management history of previous stand. Susceptible plantations contain complex post harvest debris and limited vegetation cover • tree size. *Sullivan (1990), Sullivan and Martin (1991), Sullivan et al. (1990)* **Deer and Elk** • management history of previous stand. Broadcast burning and scarification, which improves access for deer • tree species. Preferred species are Douglas-fir, western red cedar, yellow-cedar and western hemlock. • site conditions. Particular combinations of site quality, aspect, slope, and elevation, may influence deer use • tree height. Under 2 meters *Gill (1992), Howard (1982), Sullivan (1990), Sullivan et al. (1990)* **Snowshoe Hare** • type of adjacent stands. Damage is most severe in the plantations near areas with sufficient cover of coniferous and deciduous species • DBH. Damage to seedlings and saplings (DBH < 6 cm). Trees with DBH > 6 cm are not susceptible • tree species. Preferred species are lodgepole pine, Douglas-fir *Sullivan et al. (1988), Sullivan (1990), Sullivan and Sullivan (1988), Sullivan et al. (1990)* **Red Squirrel** • tree size. Susceptible stands have an average dbh 6-20 cm • site conditions. High levels of brush provide cover for squirrels • stand age. 20 to 60 year age class generally sustains the greatest injury • snowshoe hare cycle *Sullivan (1990, 1992a, 1992b, 1992c), Sullivan and Moses (1986), Sullivan and Vyse (1987), Sullivan et al. (1990)* **Porcupine** • tree size. Coniferous saplings and major branches of larger trees are most susceptible. In general, prefer larger diameter stems *Sullivan (1992b), Sullivan (1990), Sullivan et al. (1990), Sullivan et al. (1986)*
abiotics	level of abiotic disturbance cannot be predicted

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Pest	Key Site and Stand Variables
mistletoe	• **level of infection in surrounding stands.** Infected trees in surrounding stands act as mistletoe seed sources for regeneration • **level of removal of infected overstory.** Similar to level of infection in surrounding stands, residual infected trees in the overstory act as mistletoe seed sources for regeneration • **stocking of host.** The greater the proportion of host in the stand, the greater the likelihood of mistletoe spread, and the lower the likelihood that non-host trees will act as blocks to dispersal • **size of host.** The taller the tree the greater the potential for mistletoe seed dispersal • **spatial distribution of trees.** Spread and intensification will be greater in more evenly spaced host than in clumped host.

Hawksworth and Johnson (1989), Robinson and Sutherland (1993), Van Sickle and Wegwitz (1978)

Table 2: Important first order effects of pest infestation levels. Only those most important first order effects are noted by provision of key references

	DBH	Height	Tree Mortality	Quality/Form
root diseases			Stage et al. (1990)	butt rot in older stands
gall and stem rusts			Hagle et al. (1989)	occurrence of multiple leaders
root collar weevils			Finck et al. (1989), H.F. Cerezke (pers. comm.)	
leader weevils		Alfaro (1992), Carlson et al. (1984), McMullen et al. (1987)		Alfaro (1992), Carlson et al. (1984), McMullen et al. (1987)
mammals			most important effect of most mammals (various authors)	second most important effect of most mammals (various authors)
abiotics	little empirical information, best assumption may be that regeneration damaged by abiotic factors are killed and removed from growing stock. Most important non-mortality effects are on height growth and quality/form.			
mistletoe	Hawksworth et al. (1992)	Hawksworth et al. (1992)	Hawksworth et al. (1992)	Hawksworth et al. (1992)

Table 3: Pest management alternatives for pests of young stands. These are management actions that have a direct effect on pest infestation levels (rather than those causing indirect effects via stand manipulation). Also noted, is whether management keys exist which can assist in developing specific applications of the decision support system. Management activities which are not yet operational are italicized. Stocking and species control are management alternatives for all pests.

	Direct Mortality	Physical Removal	Physical Barriers	Management Keys
root diseases	*various chemical methods (Hagle and Shaw 1991)*	stump removal (throughout the rotation) (Shaw and Roth 1980, Morrison et al. 1988)	planting less susceptible species	
gall and stem rusts		pruning branch cankers (Hunt 1982) removal of intermediate host (Hagle et al. 1989)	planting less susceptible species	Hagle et al. (1989)
root collar weevils		pruning lower part of stem and scraping away duff material. Extremely heavy infestations should be cut, leaving no residuals (H.F. Cerezke pers. comm.)	planting less susceptible species	
leader weevils	*pesticides (McMullen et al. 1987)* , *biocontrol strategies (Hulme 1992)*	removal of infected leaders	planting less susceptible species	
mammals	A wide range of management alternatives exist for the most important mammals, including shooting, hunting, trapping, increased predation, trapping alive and relocating, fencing, planting less susceptible species, vegetation control, and alternative foods (e.g., Sullivan 1987, 1990, 1992c, Sullivan et al. 1988, Sullivan and Sullivan 1986, 1988, Sullivan et al. 1990).			
abiotics	no management prescriptions are possible against abiotics			
mistletoe		sanitation cutting (Hawksworth and Johnson 1989, Van Sickle and Wegwitz 1978)	planting less susceptible species	Hawksworth and Johnson (1989), Van Sickle and Wegwitz (1978)

Table 4: Comments on POYS inventory procedures.

Pest	Comments on POYS Inventory
root diseases	There has been considerable work done to relate above-ground symptoms to root disease infection rates, largely in *Armillaria* and *Phellinus*. Each tree recorded in the inventory, in the United States, is classified according to crown symptoms. This is used by the stand model to assign a root disease infection level in those trees. In addition, it is assumed that all trees within 10 meters of a root disease infected tree, even if they exhibit no symptoms of root disease, are inside a root disease center. For the POYS survey, this may mean having to use similar assumptions, although the distance for young stands may be 3 meters. *(Stage et al. 1990)*
gall and stem rusts	Rust status data required for rust model is somewhat more detailed than what is currently gathered in POYS and has been developed by U.S. Forest Service, Methods Application Group. *(Hagle et al. 1989).*
root collar weevils	no comment.
leader weevils	no comment.
mammals	no comment.
abiotics	no comment.
mistletoe	While it is generally accepted that the level of mistletoe infection is not completely captured by the DMR rating system, and the DMR systems is generally not adequate for young trees and stands, this system remains the core on which most mistletoe inventories are conducted. In addition, practically all mistletoe models being used for mistletoe management, and for developing silvicultural prescriptions use the DMR system of rating mistletoe trees for predicting spread and intensification, and growth and mortality impacts. These relationships are generally well understood and well quantified. *(Hawksworth and Johnson 1989)*

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7.0 Recommendations For Future Development and Maintenance of Decision Support System

This project has achieved the following:

1. developed a design for a decision support system for pests of regenerating stands in British Columbia;

2. defined the information required for applying the design for a particular pest;

3. demonstrated the feasibility of this design using the spruce leader weevil as a case study application; and

4. assessed the status of existing data and information for each of the important pests of regenerating stands that have been identified in the POYS survey; and

5. identified modifications that need to be made in existing surveys, databases, and models to improve the utility of any fully developed and implemented decision support system.

This section of the report presents our recommendations for future work on the decision support system, should Forestry Canada and the British Columbia Ministry of Forests to continue with system development and implementation. We present our recommendations in the form of modules from which Forestry Canada and the British Columbia Ministry of Forests can select given priorities and available resources.

The pests identified as important pests of young stands can be divided into three groups: those for which detailed operational management models have been constructed: root disease; leader weevil; stem rust; and dwarf mistletoe; those for which detailed operational management models have not been constructed: gall rust; root collar weevil; and mammals; and those for which there is no requirement for a management model: abiotics. For the first group, those pests which have an operational model, we have estimated the level of effort required to adapt the model to the decision support system. For the second group, those pests for which an operational model does not exist, we have estimated the level of effort required to construct a simple model, likely using professional judgement as well as existing data.

7.1 Adapting Existing Management Models For Use in POYS Decision Support System

Pests: root diseases, leader weevil, stem rust, dwarf mistletoe

Existing operational models are too complicated for use within a POYS decision support system and will need to be simplified. The recommended approach is to develop a

database of scenarios, much like has been done for the TIPSY model, and to provide these scenarios in the POYS decision support system. Important information that would be obtained from this simulation would be the % initial stocking (to be used to evaluate Free-to-Grow status), and percent volume loss at particular stand ages, perhaps each decade interval. These would then be used to generate the appropriate operational adjustment factors for TIPSY.

The database of scenarios would be stratified according to the important variables determining model behaviour (Table 1). We estimate that approximately 8,000 scenarios would be developed and made available in this fashion for each of the available pest models[3].

7.1.1 Resources Required

Numbers in the table below are the estimated person days required for each pest application.

Task	Knowledge Engineer	Programmer	Subject Matter Experts
1. Detailed Design of Scenario Analysis	5.0	0.0	5.0
2. Scenario Generation	1.0	15.0	5.0
3. Packaging of Results into POYS DSS Format	3.0	5.0	0.0
4. Documentation	5.0	1.0	
Total	14.0	21.0	10.0

7.2   Developing Simple Management Models

Pests: gall rust, root collar weevil, mammals

These pests should be included in the decision support system to the same level of detail as those pests for which operational management models exist; that is, a database of approximately 8,000 scenarios, stratified according to the important variables determining model behaviour (Table 1). What is needed for these pests is to build this database with the subject matter experts, through detailed knowledge engineering. Subject matter experts, with the knowledge engineers, would essentially use existing data and information (published and unpublished) to build a family of temporal pest infestation regimes that describe how the temporal pattern of pest infestation varies with each combination of the key variables and damage functions relating pest levels to the key first order effects. Key outputs would remain

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[3]   It is worth noting that the British Columbia Forest Service is contemplating undertaking some of this work as a part of transferring the root disease model to silviculturalists in British Columbia (Mr. Jeff Beale, pers. comm.). It may be possible to develop synergy between the POYS decision support system effort and the B.C. Forest Service initiative.

percent initial stocking and percent volume loss at particular stand ages, to be used to define the appropriate operational adjustment factors for TIPSY.

7.2.1 Resources Required

Numbers in the table below are the estimated person days for each pest application.

Task	Knowledge Engineer	Programmer	Subject Matter Experts
1. Design Meeting with Subject Matter Experts	2.0	2.0	6.0
2. Detailed Knowledge Engineering	15.0	15.0	15.0
3. Review of Proposed System	2.0	2.0	6.0
4. Model Revisions	5.0	5.0	0.0
5. Packaging of Results Into POYS DSS Format	3.0	3.0	0.0
6. Documentation	5.0	1.0	0.0
Total	32.0	28.0	27.0

7.3 Abiotics

Abiotics are relatively more straightforward. As it is practically impossible to manage existing stands to reduce impacts from abiotics or to predict future damage from abiotic events, what is really required is to build appropriate damage functions relating levels of observed abiotic damage to operational adjustment factors for TIPSY.

7.3.1 Resources Required

Numbers in the table below are the estimated person days for including abiotics.

Task	Knowledge Engineer	Programmer	Subject Matter Experts
1. Knowledge Engineering	2.0	0.0	6.0
2. Programming	1.0	5.0	0.0
3. Packaging of Results Into POYS DSS Format	2.0	5.0	0.0
4. Documentation	3.0	1.0	0.0
Total	8.0	11.0	6.0

7.4 Additional Work

As well as developing the modules for the specific pests as described above, additional work is required to make the decision support system a complete tool for pest management in young stands. These activities are described below.

7.4.1 Modifications to TIPSY

We recommend that TIPSY be the core of the tree and stand projection system portion of the decision support system. But, there are two modifications to TIPSY that would make it an even more useful tool for pest management in young stands.

First, specification of the operational adjustment factors would have to be made more flexible. Ideally, for maximum utility, it should be possible to input year or decade specific operational adjustment factors into TIPSY to more accurately simulate the effect of pests on stands and the reduction in pest damage resulting from management.

Second, a key effect of some of the pests of young stands, such as leader weevil is reduction in height growth. In addition, a portion of the silvicultural guidelines pertain to the minimum height of the crop trees over other vegetation. The height versus age curves in TIPSY currently can not be modified; this makes it impossible to consider a major effect of pests in young stands.

7.4.2 Integrating TIPSY Into POYS Decision Support System

Users should not have to first simulate the POYS decision support system, then simulate the TIPSY system when evaluating pest management alternatives for young stands; both systems should be integrated. We suspect that this would be a relatively simple task and would consist largely of programming work.

7.4.3 Integrating Silvicultural Guidelines

The silvicultural guidelines provided in Silvicultural Interpretations Working Group (1993) would have to be entered into the POYS decision support system as a database.

7.4.4 Automated Input of Stand and Pest Information

Stand and POYS pest information is maintained in a series of federal and provincial databases. Rather than have the user of the system enter stand and pest information manually, it would be advantageous for the user to be able to recall the information automatically from these existing databases.

7.5 Total Resources Required

Figure 16 presents our estimate of the total level of effort required to develop and implement a decision support system for pests of young stands in British Columbia for the priority pests identified in this project.

Activity	Knowledge Engineer	Programmer	Users and Subject Matter Experts
1. Adapting Existing Management Models (root disease, leader weevil, stem rust, mistletoe)	70.0	100.0	50.0
2. Build Simple Models (gall rusts, mammals, root collar weevils)	100.0	85.0	80.0
3. Abiotics	8.0	10.0	6.0
4. Modifications to TIPSY	5.0	20.0	4.0
5. Integrating POYS DSS and TIPSY	2.0	20.0	4.0
6. Integrating Silvicultural Guidelines	0.0	20.0	6.0
7. Automated Input of Stand and Pest Information	0.0	10.0	2.0
8. User Interface	5.0	20.0	4.0
9. Training and System Implementation	30.0	30.0	60.0
Project Management	40.0	0.0	0.0
10. System Maintenance (per year)	10.0	60.0	0.0
Total (excluding System Maintenance)	260.0	315.0	216.0
Disbursements (travel, communications, etc.)	$30000		

Figure 16: Total resources required for full system development and implementation. Numbers are in person days.

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