SEPPIR© expert system
Expert system for red pine plantations
Version CFL 1.0

Robert A. Allard, Louis Archambault, Gilles Bonneau, Gaston Laflamme, and André Lavallée

Quebec Region • Information Report LAU-X-102E

Forestry Canada Forêts Canada

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ABSTRACT

This document presents the main steps in adapting the expert system PREDICT© (*Pinus resinosa* expert diagnostic consultation tool) to the specific conditions found in Quebec. The forest pest database for Quebec from FIDS and SPIM was extremely useful in developing historical frequency maps for red pine pests. The Level 5™ shell used in developing PREDICT© was also used to develop SEPPIR© (Système expert pour les plantations de pins rouges - Expert system for red pine plantations). To validate SEPPIR©, 106 plantations were considered in the hardwood and mixed forest ecological regions; in 69 of these plantations it was possible to handle the pest involved using the expert system. Twelve of the 21 pests included in SEPPIR© were validated on the basis of actual cases encountered in the field. A breakdown of results by pest is included.

RÉSUMÉ

Ce document présente les principales étapes d'adaptation du système expert PREDICT© (*Pinus resinosa* expert diagnostic consultation tool) aux conditions particulières du Québec. La base de données sur les ravageurs forestiers du Québec provenant du RIMA et du SPIM fut d'une grande utilité pour la création d'une carte synthèse de la fréquence historique des ravageurs du pin rouge. La «coquille» Level 5™ qui a servi au développement de PREDICT© fut aussi utilisée pour le developpement de SEPPIR©, acronyme de Système expert pour les plantations de pins rouges. Pour valider SEPPIR©, 106 plantations furent retenues dans les régions écologiques des forêts feuillue et mixte et dans 69 de ces plantations l'agent responsable a pu être traité par le système expert; douze des 21 ravageurs inclus dans SEPPIR© furent validés à partir de cas réels rencontrés sur le terrain. Une ventilation des résultats par ravageur est présentée.

INTRODUCTION

Expert systems are computer programs that simulate the reasoning used by experts to solve highly specific, complex problems. Fiegenbaum, an expert in artificial intelligence at Stanford University, defined an expert system as "*a computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution*" (Harmon and King 1985).

There are expert systems for several areas of activity, including MYCIN in medicine (Shortliffe 1976) and PROSPECTOR in prospecting (Campbell et al. 1982). Except for the work developed at the Petawawa National Forestry Institute to control forest fires (Kourtz 1987), there are currently very few forest pest diagnostic applications in Canada (Rauscher and Hacker 1989). However, interest in expert systems is on the rise (Kourtz 1990).

The objective of the present work is to adapt the PREDICT© expert system (*Pinus resinosa* expert diagnostic consultation tool) for the Quebec situation. Developed at the University of Wisconsin (Madison), it assists foresters with pest diagnostics and the evaluation of potential damage to red pine plantations (*Pinus resinosa* Ait.) (Schmoldt 1987).

COMPONENTS AND OPERATION OF AN EXPERT SYSTEM

All expert systems comprise a knowledge base, a fact base, and an inference engine (Figure 1). The knowledge base is derived from the literature, experience, and knowledge of experts; the fact base includes observed phenomena related to the problems to be solved using the expert system, while the inference engine builds the line of reasoning for solving a given problem using the knowledge base. To these main components may be added a knowledge acquisition module, a data base, and a user interface module. The user interface may be either graphic, digital, or a combination of the two.

The knowledge base is specific to the problem area. It contains all the knowledge an expert in the field would use: descriptions of objects and their relationships, descriptions of particular cases or exceptions, different viewpoints on a particular problem, and various problem-solving strategies and conditions for their application. Some of the knowledge is derived from basic undisputed principles; some is heuristic knowledge or the kind that translates the intuitions or convictions of the expert.

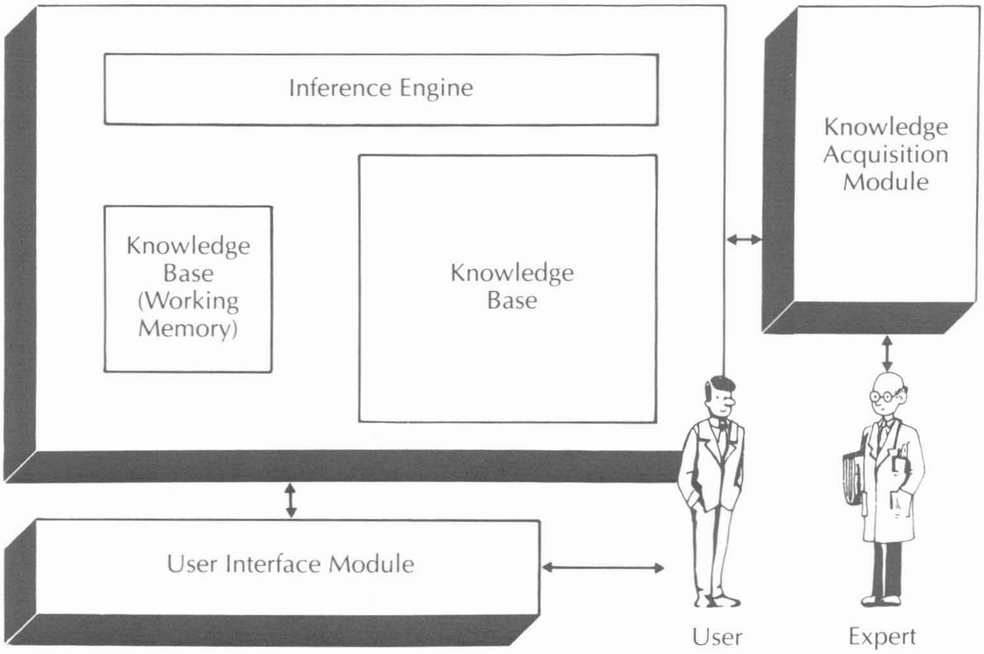

Figure 1. Main components of an expert system.

Whereas beginners need to work their way through instructions line by line, page by page, and might sometimes get sidetracked on details far removed from the problem at hand, experts zero in on useful knowledge, guided by information they retain in memory. Likewise, an expert system stores in its working memory or *fact base* a precise view of the current situation by which the inference engine can use the knowledge base in an effective and problem-specific manner.

The inference engine is the program that builds the line of reasoning using the knowledge base. In a given situation, it detects the knowledge of interest, which it uses and chains together, for which it then builds a resolution plan. Regardless of the problem area, it gathers the "reasoning" mechanisms needed to use the knowledge base.

The inference engine combined with the attendant interface programs forms what is called an *essential system*. For it to function in a particular field, it merely needs to be stocked with the relevant expertise. To this essential program are added the necessary interface modules designed to facilitate user-machine dialogue. Although they have no direct impact on the value of the expert system's reasoning process, they nevertheless play a vital role in making the system accessible to both specialists and non-specialists. The interfaces allow experts to easily access the knowledge base and make changes by eliminating useless or wrong information, or by adding details. Non-specialists can follow the system's line of reasoning in natural language. They can ask questions or request explanations without having to acquire an in-depth knowledge of expert systems or computers.

Expert systems are built in two distinct phases: first, an inference engine, is constructed, and then the knowledge base for the problem area is built and fine-tuned. An inference engine can be developed using PROLOG or LISP programming languages. Although these languages are very flexible, an enormous programming effort is still required. Another approach is to use an expert system development shell. These shells are complete development tools. A wide variety of shells with roughly the same features are commercially available at prices ranging from $100 to $9,500 (Cooney 1986).

LEVEL 5™ SHELL VERSION 1.3

The Level 5™ Shell Version 1.3 produced by Information Builders Inc., New York, was used for this adaptation.

The development shell consists of a text editor, a knowledge base compiler, an inference engine, and software to access a data base or provide real time control over all types of instruments (Figure 2). The knowledge representation scheme uses a production rule language (PRL) (Information Builders Inc. 1989) such as "IF a THEN b".

The inference engine for Level 5™ shell provides forward chaining (deductive reasoning) and backward chaining (regressive reasoning). Let us take the example of a forest pathologist trying to identify a fungus in a culture tube. The two reasoning modes discussed earlier correspond to the two approaches the pathologist could take. He could examine the specimen and, on the basis of his observations, determine its phylum, then its class, family, and finally species. This is forward chaining. He might also start with an assumption and then look for specific signs on the specimen. This is backward chaining.

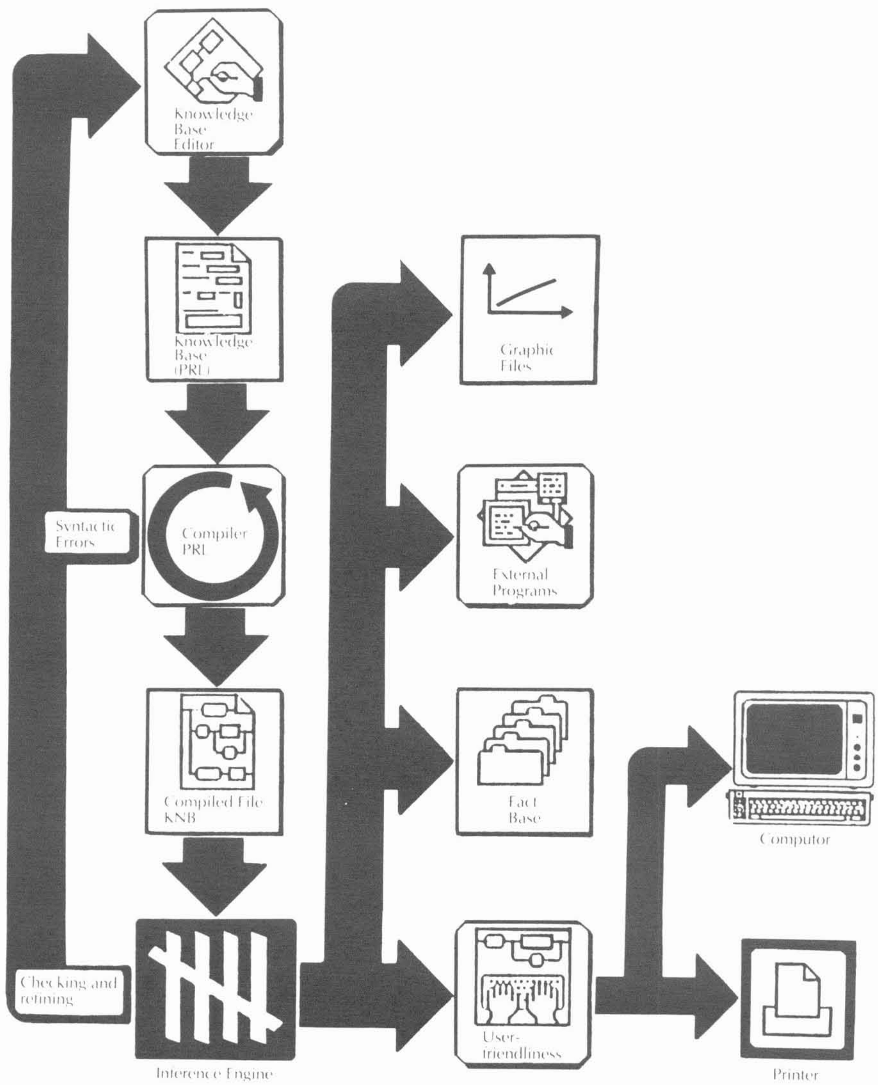

Figure 2. Elements required and supplied by the Level 5™ development shell (adapted from Information Builders Inc. 1989).

The shell will run on an IBM PC/AT/XT or compatible computer. The minimum RAM required to run all the basic shell functions is 256K; however, 640K is needed to fully benefit from the shell. The system can be used with two 360K floppy disks for mass storage, but a hard disk would provide better performance. DOS 2.0 or higher is required to operate the shell.

PREDICT© EXPERT SYSTEM IN WISCONSIN

The PREDICT© expert system was developed as part of a doctoral thesis at the University of Wisconsin (Madison) (Schmoldt 1987). The expert system consists of two components: one module to diagnose pests, and another to evaluate the damage that could be caused by pests. In the two modules, the software recognizes 28 pests on red pine in Wisconsin. Pest selection criteria included in the system are: a) economic cost of damage caused, b) potential confusion in identifying pests and c) visual impact of damage in plantations.

Schmoldt's team of experts consisted of a forest pathologist with 24 years' experience, two forest entomologists with 6 and 28 years' experience and two foresters with 5 and 10 years' experience.

Diagnostic module

To operate the diagnostic module, the user selects a series of signs, symptoms, or observations contained in the questionnaire (Schmoldt 1987). The system then diagnoses one or more forest pests on the basis of the initial data and the established rules. The rules in this module are strategy rules, diagnostic rules which are divided into three categories, and logic rules (Figure 3).

<u>Strategy rules</u> are used by the expert system to select one or more categories of pests for diagnostic purposes, in terms of either the general or specific damage observed.

Structure of PREDICT© Rules

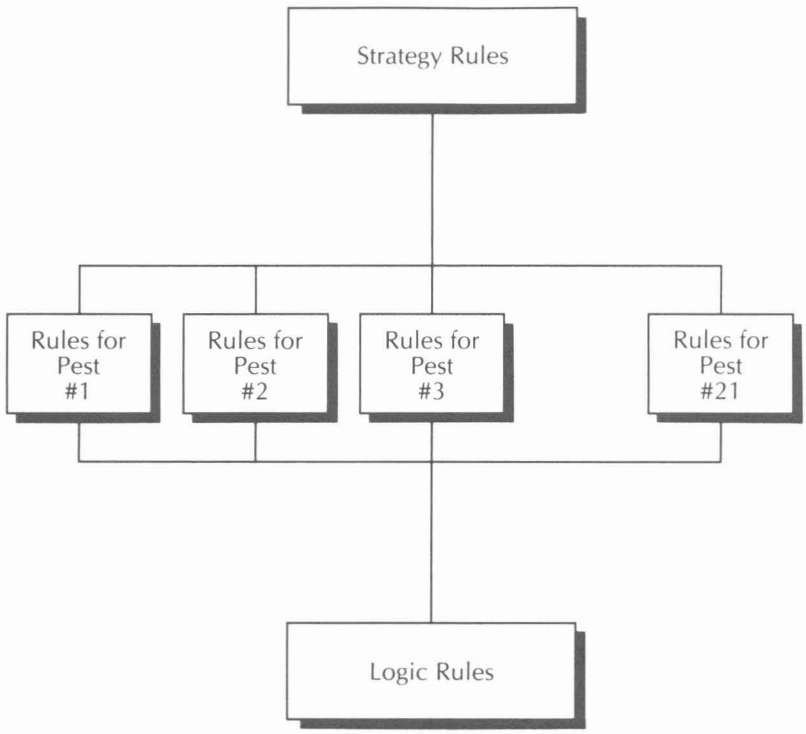

Figure 3. Structure of PREDICT© rules in Diagnostic module (adapted from Schmoldt 1987).

Diagnostic rules are used by the system to compare observations incorporated into the knowledge base and to draw conclusions to identify the pest involved. There are a fairly large number of rules for each forest pest. They are divided into three categories: evidence accumulation rules, elimination rules, and certainty rules. Each rule category is assigned a probability value indicating the level of confidence in the conclusions. Every time a rule assigns probability P to a conclusion, the new probability P_n is calculated using the following formula:

$$P_n=P_0+P(1-P_0)$$

where P_0 is the old probability assigned to the conclusion by a previous rule (Schmoldt 1989). It should be noted here that, according to Schmoldt, when a level of confidence less than 53%

is assigned, the pest involved is eliminated from the conclusion. This threshold was maintained in the present report.

Logic rules are used to deduce facts as the user inputs information into the expert system. Figure 4 illustrates this process. One diagnostic rule questions whether the seedling is discolored in order to establish evidence for pales weevil. Since the fact is not known, the rule is temporarily suspended. The system attempts to determine the fact by another rule which tries to establish seedling discoloration. It must, however, be proven that the size class of the stand is seedling and, once again, the system does not know this, and the rule is suspended. The system then invokes another rule that uses height to prove that the size class is seedling, but since the information is not available, the rule is also suspended and the system asks the user to supply the information. Once the height of the stand is known, the system can rerun the rules.

Hazard assessment module

The hazard assessment module is much more straightforward. This module reorganizes the information acquired for diagnostic purposes and uses historical pest frequency data for 72 Wisconsin counties to come up with a hazard assessment. The notion of hazard is defined as the probability of an increase in the population of a forest pest or the potential damage caused to plantations by abiotic factors. Historical frequency is divided into four classes: no pests present, some pests present, presence of pests at endemic level, and presence of pests at epidemic level. The risk of damage to plantations by pests is also expressed using four levels: zero, low, moderate, or high hazard.

The structure of the rules in the hazard assessment module is relatively straightforward. For each of the 28 forest pests, there are four or five rules that use a combination of facts, including historical frequency and such facts as sandy soil, presence of dead trees, local depressions, height, age, and the general condition of the stand. As opposed to the diagnostic module, the level of confidence for answers supplied by the user corresponds directly to the confidence value assigned to the conclusion of the rule.

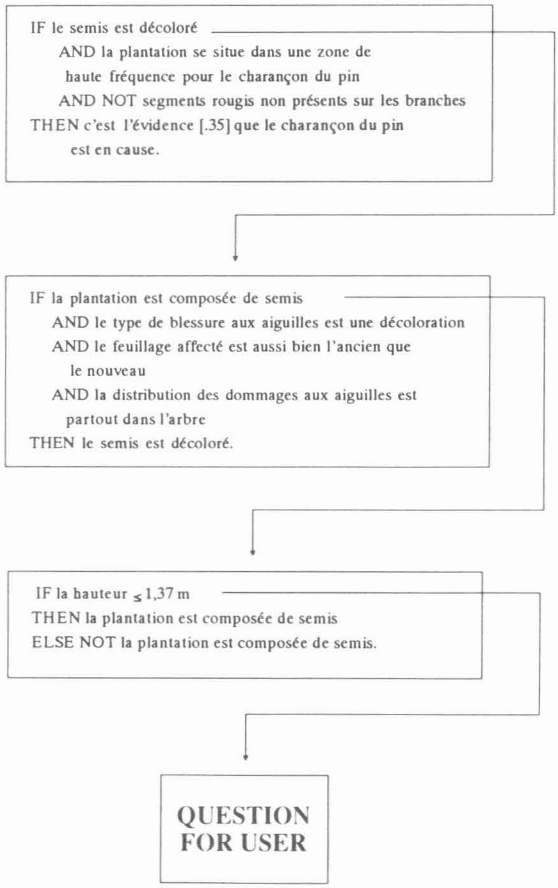

Figure 4. Partial example of operation of logic rules for inferring facts based on available information (adapted from Schmoldt 1987).

To validate PREDICT©, 20 certain cases were submitted to the expert system and to two expert teams in order to determine the system's level of refinement. Each of the two teams was made up of a pathologist, two entomologists, and two foresters.

Summarizing Schmoldt's (1988) results, in the first team, the pathologist and the two entomologists were in agreement with the actual diagnosis checked out in a laboratory in 16 of the 20 cases. The two foresters were in agreement on 9 and 12 of the 20 cases. PREDICT©

arrived at the actual diagnosis in 17 cases. The results for the second team resembled those of the first team except that there was agreement between the expert or the expert system and the actual diagnosis in an average of two cases less (i.e. 14/20 for the entomologists and pathologist, 13 and 8/20 for the foresters, and 15/20 for PREDICT©).

Based on these results, Schmoldt (1988) concluded that the performance of the expert system is comparable to those of human experts. The foresters' poor results may be due to a lack of experience and knowledge of pest diagnostics.

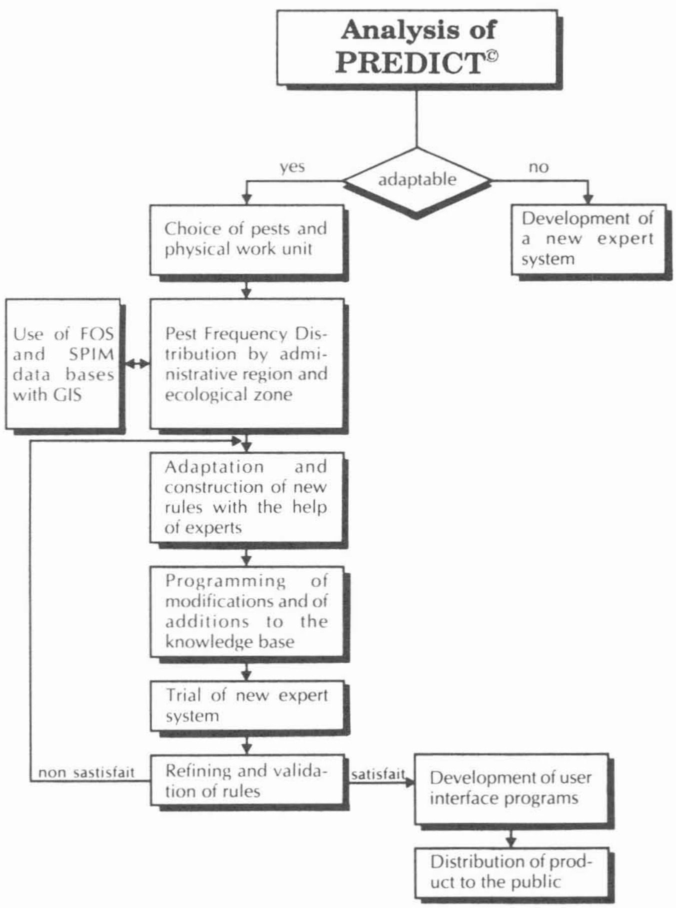

Figure 5. Steps required to adapt PREDICT© to Quebec conditions.

ADAPTATION OF PREDICT© TO QUEBEC

Adaptation of the PREDICT© expert system to Quebec was carried out in several stages (Figure 5) described below.

Formation of an expert group

The following criteria were used to select relevant experts:

- knowledge of insects and/or pathogenic agents specific to red pine plantations;
- in-depth knowledge of the ecology of red pine pests;
- general knowledge of problems related to red pine plantations.

Based on these criteria and to ensure progress, the expert groups were made up of two pathologists, one entomologist, and one ecologist-entomologist. A knowledge engineer also joined the team to convert the experts' knowledge into computer language and write the programs needed for the various components of the expert system.

Selection of forest pests

An analysis was first made of the Wisconsin list of pests and those specific to Wisconsin were eliminated. Only 15 pests were included in the new version of the expert system. The experts were then consulted to determine whether other pests might cause damage to red pine plantations in Quebec.

Using the Forestry Canada Forest Insect and Disease Survey (FIDS) and the Forestry Quebec Service de la Protection contre les Insectes et les Maladies (SPIM) data bases, we extracted all the pests found on red pines in plantations. The time period covered by the list was from 1953 to 1990. The FIDS data base covers the period 1953 to 1983, and the SPIM data base runs from 1984 to the present. An initial selection was done to eliminate non-relevant pests before the list was submitted to the experts. The results of this data base selection were then submitted to the experts who decided which pests to include in the expert system. Based on this selection (performed by the experts working independently), an intermediate list was compiled according to the following criteria:

forest pest selected unanimously	CODE 1;
forest pest selected by all experts except one	CODE 2;
forest pest selected by all experts except two	CODE 3.

All other forest pests were excluded.

The experts then selected from the intermediate list the forest pests to be included in the expert system. Selection of pests for the final list was made as follows: Code 1 forest pests also on the PREDICT© list were automatically included in the new list. Code 1 pests not part of the PREDICT© list had to meet the three selection criteria established for the PREDICT© expert system, i.e. economic value of damage, possible confusion in identification, and visible sign of damage caused. The selection process for codes 2 and 3 was the same as for Code 1. Table 1 gives the final list of forest pests included in the new SEPPIR© expert system.

Determination of basic geographic unit

There are several types of geographic units in Quebec, including management units, municipalities, regional county municipalities, and administrative regions or countries. Upon analysis and consultation of experts, and based on the data available, it was decided that the unit for establishing historical frequencies would be the administrative region. The ecological zones of Quebec were also considered so that the impact of ecological factors on the distribution and extent of forest pests could be included. Only the three major ecological zones of Quebec were used, i.e. boreal, mixed wood, and hardwood. The final basic geographic unit is thus the administrative region according to ecological zone.

Although theoretically 27 basic units are possible, there are in fact only 23, because the three ecological zones are not situated in each of the nine administrative regions (Figure 6). As was done in PREDICT©, the historical frequency of each forest pest in each of the 23 basic

Table 1. List of forest pests included in SEPPIR© for Quebec

Animals
Small rodents (*Microtus* spp.)
Porcupine (*Erithizon dorsatum* L.)

Insects
Pine bark beetle (*Ips pini* [Say])
Pales weevil (*Hylobius pales* [Hbst.])
June beetle (*Phyllophagus* spp.)
Pine rootcollar weevil (*Hylobius radicis* Buch.)
Redheaded pine sawfly (*Neodiprion lecontei* [Fitch])
Red pine needle midge (*Thecodiplosis piniresinosae* Kearby)
White pine weevil (*Pisodes strobi* [Peck])
European pine shoot moth (*Rhyacionia buoliana* [D.& S.])
Northern pine weevil (*Pissodes approximatus* Hopk.)
Pit borer (*Pityophthorus puberulus* Le Conte)
European pine needle midge (*Contarinia baeri* [Prell])

Diseases
Scleroderris canker (*Gremmeniella abietina* [Lagerb.] Morelet)
Pine needle rust (*Coleosporium* spp.)
Armillaria root rot (*Armillaria mellea* [Vahl ex Fr.] Kumm.)
Fomes root rot (*Heterobasidion annosum [Fr.] Bref*)

Abiotic factors
Snow and freezing rain
Herbicides
Winter drying
Planting techniques

units had to be established. To accomplish this, we used a geographic information system (GIS) and the FIDS and SPIM data bases.

Determining historical pest frequency

Figure 7 shows the procedure used to establish the historical frequency of each forest pest. This frequency is used for both modules of the SEPPIR© expert system. The main steps in establishing this historical frequency geographically are summarized in the pages that follow.

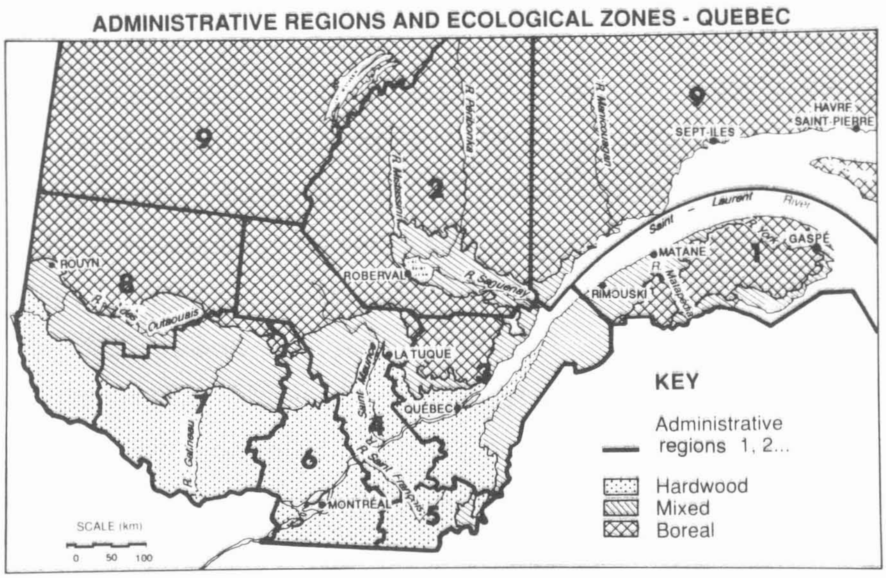

Figure 6. Distribution of administrative regions by ecological zones yielding 23 base units for determining historical pest frequency.

Use of FIDS, SPIM, and GIS data bases

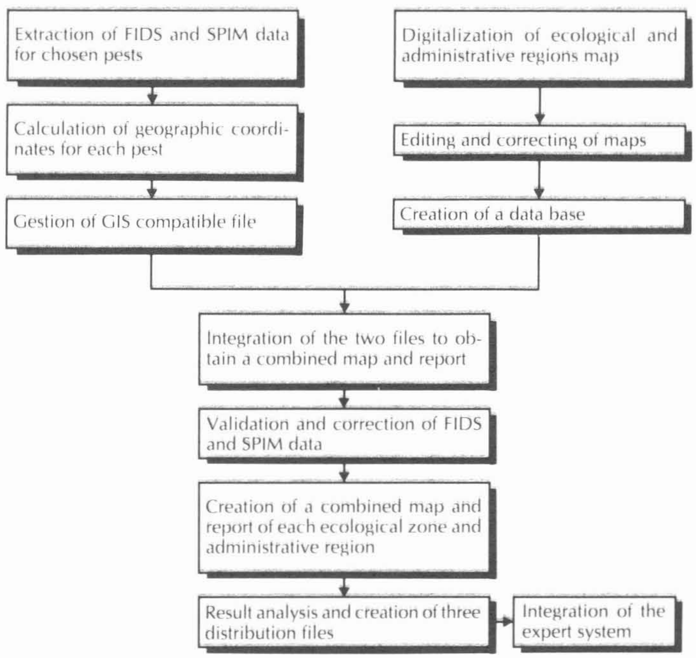

Figure 7. Use of FIDS and SPIM databases with GIS to create a historical frequency map for each problem found on red pine.

Production of map

The goal was to create a digital map that combines the administrative regions map and the ecological map produced by the Research Section of the ministère des Forêts du Québec. By linking this digital map to a data base containing information on the distribution of forest pests, we produced a digital map and an alphanumeric file of the historical frequency of each pest.

The first step in the creation of the digital map was to either digitize existing maps or purchase maps that had already been digitized. Since no relevant digital maps were available, we had to digitize them using the geographic information system (GIS) PC ARC/INFO®.

The next phase was integration of the two digital maps to produce one map that shows the administrative regions in terms of the ecological zones. This combined map was produced using the OVERLAY module of PC ARC/INFO®.

Extraction of FIDS and SPIM data and calculation of geographic coordinates

Data was extracted from the FIDS and SPIM data bases during the pest selection stage. All the information from the two data bases was stored as ASCII files so that they could subsequently be processed using computer programs.

The geographical positioning of surveys for each forest pest required a whole series of programs. One program was written to extract the geographic coordinates of each survey from the main file. A second program then creates an input file for the program to convert data from the UTM (Universal Transverse Mercator) projection grid to the LAMBERT system. A third program performs this conversion. An additional program was required for the SPIM output file. The MTM (Modified Transverse Mercator) coordinates had to be converted to GEOGRAPHIC coordinates before they could be produced as LAMBERT coordinates. This was due to the fact that the conversion program could not convert the MTM data directly to LAMBERT data. A final program was required to use the converted output files to create new files compatible with the PC ARC/INFO® input format. Throughout the conversion operation, the programs also checked all input and output files for major errors and in the process validated our information. The final structure of the files indicating the location of each survey is as follows:

	Identification number	Coordinates	
		X	Y
(Sample)	101	78244.677	26432.030
	5101	78400.444	25114.659

To differentiate the two sources of information, FIDS data were coded using a serial number starting with 101 and the SPIM data using a number starting with 5001.

Integration of FIDS and SPIM data with map

The observations from the FIDS and SPIM data bases were then integrated with the GIS to produce a digital map locating each observation. This map was then superimposed on the geographical summary map to determine the number of observations for each administrative region in terms of the ecological zones for each pest. Table 2 shows a sample output file for *Coleosporium* spp.

Creation of a historical frequency file and validation of distribution

These files were used to calculate four classes of historical frequency: zero, low, moderate, and high. These frequencies are used mainly to assess the risk of forest pest damage and are based on the number of surveys in the historical FIDS and SPIM data bases. If no survey is available for a given region and ecological zone, a zero frequency class is automatically assigned. The other classes are calculated by dividing the highest survey rate by three, thus establishing three classes. For example, if we divide by 3 the highest survey rate of 53 (Table 2), the result after rounding is 17 and the classes are broken down as follows: 0=zero, 1-17=low, 18-34=moderate, 35 and over=high.

This process is repeated for each selected forest pest for which historical data are available. Different historical frequency classes are thus obtained for each pest. Experts and

Table 2. Sample output file after integration with the two digital *Coleosporium* spp. pest files

Ecological zone	Administrative region	Number of observations on *Coleosporium* spp.
Hardwood	3	53
	4	46
	5	22
	6	27
	7	31
	8	8
H total		187
Mixed	1	12
	2	3
	3	27
	4	8
	5	4
	6	1
	7	3
	8	3
	9	2
M total		63
Boreal	1	2
	2	2
	8	3
	9	1
B total		8
Total		258

experienced forest technicians were consulted to establish territorial probable frequency (based on ecology) for the two forest pests for which no historical data were available (Fomes root rot and the pit borer). Once this exercise was complete, we had a file showing the historical frequency for each forest pest on the basis of administrative regions and ecological zones (Table 3). In this table, it will be noted that the frequency for *Phyllophagus* and "defective planting techniques" is zero; these are real problems in Quebec but are not regularly reported in insect and disease surveys.

Historical distribution maps for forest pests for the basic unit used (Figure 8) were produced using the GIS. These maps were examined by experts to determine the accuracy of the various distributions. Once this validation was complete, the historical frequency file could be used by the expert system.

Verifying data, correcting existing rules, and building new rules

This is a critical step in adapting the PREDICT© expert system to the SEPPIR© expert system. In this phase, each rule is carefully analyzed with the experts and knowledge engineer to ensure that the stated conditions are valid for Quebec. If any series of rules is not sufficient for Quebec, the experts adjust it. The knowledge engineer is responsible for encoding the knowledge and incorporating it into the appropriate series of rules. Since some different forest pests were included in the SEPPIR© expert system compared to PREDICT©, there is no rule for processing these new pests. The knowledge engineer must bring the experts together and get from them all the necessary information on the forest pest involved. For example, with Fomes root rot, the experts identified all supporting evidence for and against this disease. Supporting evidence for included: recent thinning of the stand (recently cut stumps), the presence of dead trees in groups (localized mortality), fungi at the base of dead or declining trees, fruiting period of fungi in September or October, and discoloration of all foliage. Evidence against includes the presence of rhizomorphs, thinning done more than four years ago, and stumps treated with borax during thinning. A definite diagnosis can be made for this forest pest if there is evidence of fruiting on root collars and roots below humus level, with fruiting structures 8 to 15 cm wide in a chocolate brown colour with a vanilla coloured border. The experts noted that Fomes root rot should be clearly distinguished from Armillaria root rot in constructing the rules. These elements of knowledge are analysed and translated by the knowledge engineer for inclusion in the expert system.

This set of new rules is added to the rules in the expert system. The new facts generated by these rules have to be considered, and the knowledge base modified accordingly. In formulating the diagnostic rules for the new forest pests, we must bear in mind that in the logic of the knowledge base the rules are established so that one or more forest pests are contrasted with other forest pests. For example, the Fomes root rot rules are established in

Table 3. Historical frequency of pests on the basis of administrative regions and ecological zones

Reg.+ Zone		Pests																				
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Mixed wood	3	1	1	4	2	2	1	2	2	4	3	2	4	1	1	2	2	2	2	1	1
1	Boreal	1	1	2	3	2	2	1	2	1	3	2	3	2	1	1	1	2	1	1	1	1
2	Mixed wood	2	1	1	2	2	2	1	1	1	3	2	2	2	1	1	1	2	1	1	1	1
2	Boreal	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	2	1	1	1
3	Hardwood	3	2	1	4	4	4	2	1	4	4	4	3	4	1	3	4	2	2	2	1	1
3	Mixed wood	3	1	1	4	3	3	1	1	1	3	2	2	4	1	1	2	2	1	1	1	1
3	Boreal	1	1	1	2	2	2	1	1	1	2	2	1	2	1	1	2	1	1	1	1	1
4	Hardwood	2	2	1	3	4	3	3	2	2	4	2	2	4	1	2	3	2	2	2	1	1
4	Mixed wood	1	1	1	2	2	2	1	1	1	2	2	1	2	1	2	2	1	1	2	1	1
4	Boreal	1	1	1	2	1	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1
5	Hardwood	3	2	2	3	3	2	2	2	2	4	2	2	2	1	4	3	2	3	2	1	1
5	Mixed wood	3	2	1	2	3	2	2	2	2	4	2	1	2	1	4	3	2	1	2	1	1
6	Hardwood	2	3	1	3	3	3	4	3	2	4	2	2	4	1	2	4	3	2	3	1	1
6	Mixed wood	1	1	1	2	2	2	1	1	1	2	2	2	2	1	1	2	2	1	1	1	1
6	Boreal	1	1	1	2	1	1	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
7	Hardwood	2	4	2	3	3	4	4	2	1	4	3	3	4	1	2	4	4	2	4	1	2
7	Mixed wood	1	1	1	2	2	3	2	1	1	3	2	1	2	1	1	4	2	1	1	1	1
7	Boreal	1	1	1	2	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1
8	Hardwood	1	1	1	2	2	2	1	1	1	2	2	2	2	1	1	1	1	1	2	1	1
8	Mixed wood	1	1	1	2	2	2	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1
8	Boreal	1	1	1	2	2	1	1	1	1	2	2	2	1	1	1	1	1	3	1	1	1
9	Mixed wood	1	1	1	2	2	2	1	1	1	3	2	1	2	1	1	1	1	1	1	1	1
9	Boreal	2	1	1	2	1	1	1	1	1	2	2	1	2	1	1	1	1	1	1	1	1

Where 1 indicates zero frequency; 2 indicates low frequency; 3 indicates moderate frequency; 4 indicates high frequency

A= *Microtus* spp.
B= *Ips pini*
C= *Hylobius pales*
D= Snow/freezing rain
E= *Coleosporium* spp.
F= *A. mellea*
G= *N. lecontei*
H= *Pissodes strobi*
I= *R. buoliana*
J= *G. abietina*
K= *E. dorsatum*
L= Herbicides
M= Winter drying
N= Planting techniques
O= *C. baeri*
P= *P. puberulus*
Q= *P. approximatus*
R= *H. radicis*
S= *T. piniresinosae*
T= *Phyllophagus*
U= *H. annosum*

(See Table 1 for complete names of pests)

contrast with the rules for Armillaria root rot, and vice-versa. A weight is provided for the knowledge or fact statement. The weight is determined by the experts and is used to increase or decrease the evidence for a forest pest. The mathematical formulation has

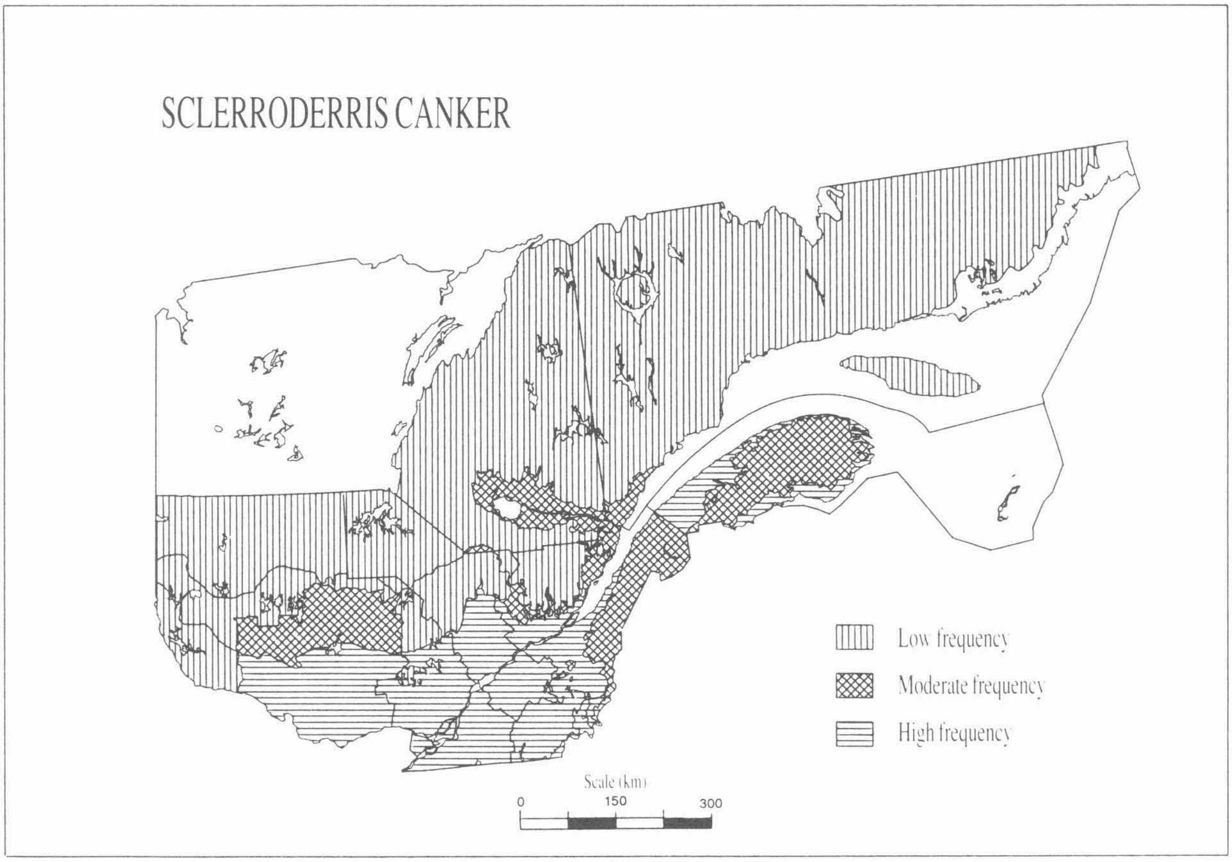

Figure 8. Historical frequency distribution map for scleroderris canker according to administrative region and ecological zone.

already been described. Once all this is complete, the actual validation is performed using authentic cases.

Validation of SEPPIR© expert system

This last step provides a concrete verification of whether the adaptation of the expert system is valid, the new rules are properly constructed and the system as a whole gives accurate results under authentic conditions.

Preparation of field data acquisition questionnaire

A questionnaire was developed to ensure the maximum amount of information is collected during plantation visits (Appendix 1). It is designed to collect information in roughly the same way as is done during a working session on the expert system. The advantage of the format selected is that information relevant to the expert system is collected, and other information that is not necessarily obvious during plantation visits can be deducted. A description of the questionnaire and the procedure for completing it, along with definitions of the various terms used, are presented in Allard et al. (1992).

Data acquisition

The plantations to be inspected were those which, in 1989 surveys of the FIDS and SPIM data bases, brought to light a problem with one or more of the forest pests included in the expert system. Other plantations were also inspected to increase the number of surveys used in the expert system validation process. In 1990, data was acquired in two stages. The first step involved a site inspection to determine whether the forest pest was still causing damage; if so, the questionnaire was completed. If the pest was not present, the stand was thoroughly inspected to determine whether other problems were present. The second step involved a collection of samples for laboratory analysis and identification. Where a forest pest was present, samples were taken of branches, foliage or other parts of the tree that would provide information on the forest pest. The samples were then submitted to experts for a formal identification of the problem.

Once all plantation inspections were completed, the data were run through the expert system for a diagnosis. The expert system diagnosis was then compared with that of the expert who examined the plantation samples. Such comparisons made it possible to refine the new rules introduced into the expert system and validate the expert system under authentic conditions.

RESULTS

Of the 190 plantations inspected, 84 were eliminated for the following reasons: the forest pest encountered was not one of the pests included in the expert system, the stand had been improperly coded (grey pine instead of red pine), the plantation was too old, the plantation had undergone silvicultural treatment, or the plantation had been completely harvested.

This left 106 plantations for validation of the expert system. Although these plantations were adequately distributed among hardwood and mixed wood ecological zones, only 12 of the 21 forest pests were represented in 69 of these plantations. The 69 real cases (Table 4) could be broken down as follows: 55 cases (79.7%) in which the expert and the expert system made an identical diagnosis and 14 cases (20.3%) where they differed.

For each of the nine other forest pests, about three hypothetical cases were tested using systems described in the literature and information provided by experts. The questionnaire was completed as for an authentic case and then entered in the expert system to obtain a diagnosis. The breakdown of these hypothetical cases (22 identical and 5 different) was similar to that for authentic cases (81.5% and 18.5%).

The proportion of problems usually encountered in the field is well represented in the table showing results by forest pest (Table 4). In descending order, the most commonly found were scleroderris canker, poor planting techniques, needle rust, white pine weevil, and red-headed pine sawfly. In its present form, two elements of SEPPIR© involving (a) determination of snowfall levels and (b) the definition of the term "red flag" post obstacles to diagnosis of scleroderris canker, snow and freezing rain, and winter drying. Further research will be carried out to find a solution to the problem of these two elements in order to improve the accuracy of the expert system.

Table 4. Number of cases where the results of the diagnostic part of SEPPIR© were identical to or different from that provided by experts (breakdown by forest pest)

Pest	Number of cases			
	Identical		Different	
	T[b]	H	T	H
Animals				
Microtus spp.	3		0	
Erithizon dorsatum	3		1	
Insects				
Ips pini	3		0	
Hylobius pales[a]		2		0
Phyllophagus spp.[a]		2		1
Hylobius radicis[a]		3		0
Neodiprion lecontei	4		0	
Thecodiplosis piniresinosea	2		0	
Pissodes strobi	6		2	
Rhycionia buoliana[a]		3		0
Pissodes approximatus	3		1	
Pityophthorus puberulus	2		0	
Contarinia baeri[a]		2		1
Diseases				
Gremmeniella abietina	9		5	
Coleosporium spp.	8		0	
Armillaria mellea[a]		3		2
Heterobasidion annosum[a]		3		0
Abiotic factors				
Snow and freezing[a]		2		1
Herbicides[a]		2		0
Winter drying	3		4	
Planting techniques	9		1	
TOTAL	55	22	14	5

[a] Hypothetical situations generated from literature descriptions since these pests were missing in the plantations examined.

[b] True (T) or hypothetical (H) situations are presented separately to better compare totals.

DISCUSSION

We may conclude from the results that the expert system meets our expectations, even if the expert system and the experts disagreed in 20% of cases. All these cases are related to the type of information provided on the questionnaire, and they may be divided into three categories. The main factor governing this difference is contradictory information provided on questionnaires. For example, the person may answer that the type of damage observed on trees in the plantation is both partial discoloration and total discoloration of foliage. The expert system thus cannot process subsequent information logically. Currently, there is no way for the expert system to detect this type of contradictory information.

Another factor occasionally encountered is an overabundance of symptoms, where minor problems are reported in a plantation that presents a much more serious problem. The individual carrying out the survey did not want to overlook any information or did not know exactly what to look for and thus noted as many symptoms as possible, for example dead, twisted, crooked, or lopsided buds, etc. The expert system then considers all forest pests indicated by such symptoms and will end up identifying several forest pests with a very low confidence level. These are rejected by the system, since it will be recalled that the elimination level for a pest is a confidence level of 53%. If a limited number of dominant symptoms were input for these same cases, the system would generate a valid response.

The last factor governing the rate of failure is lack of information on the part of the observer or the user, who may not be familiar with either pathology or entomology or the operation of an expert system. Although system users need not be experts, they do require some knowledge of forest pathology and entomology to better describe the observations made during site inspections and thus make the best use of the system. It should be noted that the field questionnaire contains far fewer questions than the expert system. It is therefore important to make as many notes as possible in the comments section of the questionnaire.

CONCLUSION

The expert system is a valid tool for diagnosing and evaluating forest pests and the damage they may cause in red pine plantations in Quebec. To prevent high damage levels, the system should be used promptly when a problem appears. Close continuous monitoring is thus essential if adequate control measures are to be taken in time.

With a view to improving the system, mechanisms to detect illogical elements introduced with field data could be included. In addition to the diagnosis of one or more forest pests, the system could indicate the type of damage to be expected and possible recommended treatments for plantations against this pest, such as thinning, fungicide application, etc. These control measures would be even more useful, however, if there was a module to assess the extent of the problem and recommend treatment once damage reaches a certain level. As well, graphics could be used to illustrate the different parts of the red pine tree, such as a branch segment, to enhance user understanding of the case during a working session, but this type of improvement would require a computer more powerful than a PC.

The expert system could also be an excellent educational tool, since it can be used to review the main symptoms of the various forest pests. Development of this expert system also assisted in identifying further studies required to improve diagnosis. For example, there should be a way to make a clearer distinction between the specific symptoms of scleroderris canker, winter drying and damage, as noted in the results. The present work also underscores the pressing need to develop other expert systems to draw on the knowledge of experts in other areas of forestry while we still have access to this knowledge and experience.

A detailed technical report is available on request from the Laurentian Forestry Centre (LFC) for readers interested in using the approach presented in this report to develop other expert systems.

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APPENDIX

FIELD DATA ACQUISITION FORM

REPORT OF DAMAGE TO RED PINE

GENERAL INFORMATION

Administrative region:____________________Regional county municipality:____________________

Municipality:_________Township:__________Range:_________Lot :____________________

Owner's name: ____________________Address: ____________________

Plantation name:____________________Observer's name:____________________

Date :______/______/______UTM Grid:__________Map number:____________________

Day Month Year 1/50 000

Ecological zone: Boreal ( ) Mixed ( ) Hardwood ( )

GENERAL OBSERVATIONS

Type of damage observed

( ) partial tree discoloration
( ) whole tree discoloration
( ) bark damage

( ) root or root collar damage
( ) needle defoliation
( ) shoot and bud damage

Examination of the bark

Yes ( ) No ( )

If yes:

( ) normal
( ) patches removed at the base of the tree
( ) loose on the stem in patches
( ) boring dust and/or holes in the bark's cracks
( ) small pits present within 0.5 cm of the ground

Examination of the roots

Yes ( ) No ( )

If yes:

( ) normal
( ) completely removed from dead trees
( ) small roots chewed off
( ) fine roots missing
( ) chew marks present on tap root

( ) tender bark eaten off in patches
( ) patches removed in upper crown
( ) green discoloration beneath bark
( ) none of these conditions

( ) surrounded by black shoe-string-like structures
( ) wound up in itself
( ) shaped like hockey sticks

Examination of root collars

Yes ( ) No ( )
If yes:
( ) normal
( ) girdled
( ) swollen
( ) blackened
( ) resin present on the bark
( ) surrounded by pitch-soaked soil
( ) white mycelium present under the bark
( ) presence beneath the humus of fructifications 8-15 cm in diameter with chocolate-brown coloring and a white edge

Examination of the soil

Yes ( ) No ( )
If yes:
( ) sandy soil

The trees examined are healthy

Yes ( ) No ( )
If no:
( ) dead
( ) dead over a large area
( ) dead in a circle
( ) dead by group
( ) deformed
( ) leaning or loose in the ground
( ) dispersed
( ) curled
( ) infected with a resinous canker on the base of branches that appeared during the month of July and subsequently
( ) wilting of branches less than 2 m above the ground

Flagging

Yes ( ) No ( )

If yes: month: _________

Needles affected

Yes ( ) No ( )

If yes:

( ) both old and new

( ) those from the current year

( ) only old needles

( ) only the past year's needles

( ) only the needles of the past two years

Distribution of needle damage

( ) no damage

( ) lower half

( ) lower than 2 m above the ground

( ) terminal leader

( ) under the snow line

( ) above the snow line

( ) dispersed in the crown

( ) higher than 4.5 m above the ground

( ) near the buds

( ) on dominant trees

( ) on a particular side

( ) mostly near the top

( ) on the lower branches of smaller trees

Abnormal needle coloring

Yes ( ) No ( )

If yes:

( ) yellow

( ) red

( ) brown

Needle injury

Yes ( ) No ( )

If yes:

( ) dead

( ) needle loss, shedding

( ) wilting month: ________

( ) discoloration after wilting

( ) discoloration on the base

( ) cream-colored blisters from May to July

( ) discoloration after bending and drooping

( ) curled

( ) needles bent sharply at the sheath while still green during August and September

( ) totally or partially defoliated month: ________

Describe any defoliation

____

____

____

Shoots affected

Yes ( ) No ( )

If yes:

( ) curved

( ) bent over

( ) dead

( ) discolored brown

( ) resinous coating

( ) curled

( ) mined hollow

( ) dead or bent over on smaller trees

( ) withering of lateral branches after June and when: _____________

( ) resinous cankers on shoots from the current year in July, and subsequently

Buds affected

Yes ( ) No ( )

If yes:

( ) growing at an angle

( ) coated with resin

( ) curved

( ) dead

( ) drop of resin present at the base

( ) dead less than 2 m above the ground

( ) curved growth

( ) curled

( ) flow of resin

month when injuries occurred: _________

INDICATIONS

Chip cocoons

Yes ( ) No ( )

If yes:

( ) on the ground, at the surface of stump wood or damaged trees

( ) in July, under the bark (on the surface of the terminal leader) from current or preceding year

( ) under the bark (on the surface of the wood) of the main stem

Larvae

Yes ( ) No ( )

( ) with reddish-brown heads

( ) with reddish-brown heads, yellow bodies with six segments of small black circles

( ) orange colored and feeding under pairs of needles from May to October

( ) numerous, whitish, like worms, and under the bark of the terminal leader from April to July

( ) numbering from 2 to 5, small, brown, and under a layer of resin at the base of buds from August to March

( ) from 2 to 5, brown, and present on the elongated shoots in May and June

( ) feeding under the bark of primary roots near the collar

Larval feeding patterns

( ) in colonies
( ) alone
( ) in groups of 6 or less

Galleries

Yes ( ) No ( )

If yes: presence
( ) eggs
( ) larvae

description
( ) present in the area of the collar with larvae
( ) present with larvae under the bark of the terminal leader or prior shoots
( ) present in the cambium of the shoots
( ) eggs laid out in a line

INFORMATION CONCERNING THE PLANTATION

Plantation characteristics

- basal area greater than 12 m²/ha	Yes ( ) No ( )
- site index <= 4 m at age 15	Yes ( ) No ( )
- recently treated with a herbicide (within 1 year)	Yes ( ) No ( )
- presence of competitive trees	Yes ( ) No ( )
- presence of competitive herbaceous vegetation	Yes ( ) No ( )
- maple stand nearby (0-300 m)	Yes ( ) No ( )
- presence of drought conditions	Yes ( ) No ( )
- plantation under stress	Yes ( ) No ( )

Age of plantation:______________________________

Average diameter of trees:________________________cm

Average height:__________________________m and cm

Minimum height of foliage above the ground:___________m and cm

Maximum height of snow cover the previous winter:________m and cm

- recent tree injuries (within 1 year)	Yes ( ) No ( )
- in the red pine distribution area	Yes ( ) No ( )
- recent thinning of the plantation	Yes ( ) No ( )
- presence of windthrows, wounds of more than 4 cm, or untreated red pine stumps	Yes ( ) No ( )
- presence of an overstory	Yes ( ) No ( )
- presence of dead trees in or near the plantation (white or red pine)	Yes ( ) No ( )
- type of plantation	Windbreak ( ) Christmas trees ( ) Other ( )
- thick grass or weed cover from the previous year	Yes ( ) No ( )
- presence of jack or scotch pines in or near the plantation	Yes ( ) No ( )
- presence of local depressions	Yes ( ) No ( )
- site exposed to the wind	Yes ( ) No ( )
- located on a site previously occupied by hardwoods (within 5 years)	Yes ( ) No ( )
- signs of rodents (fieldmice, mice, etc.)	Yes ( ) No ( )
- types of plants present	Aster ( ) Goldenrod ( ) Not observed ( )

COMMENTS:

___

___

___