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MANAGING SCLERODERRIS: THE PERSPECTIVE OF PEST SPECIALISTS AND ECONOMISTS

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THE SCLERODERRIS PROBLEM

Scleroderris canker, caused by the fungus *Gremmeniella abietina* (Lagerb.) Morelet, has been regarded as a major pest of pine for more than 30 years. Two distinct strains of the fungus, referred to as the North American and European races, cause damage to pines in North America. Either race may cause mortality to trees less than 1 m in height, and can result in cankering and a loss of merchan-table volume to trees less than 3.5 m in height (Dorworth 1976).

The North American race of scleroderris canker causes cankering and mortality to jack pine (*Pinus banksiana* Lamb.) and red pine (*Pinus resinosa* Ait.) seedlings, and has been associated with numerous plantation failures. However, this strain of the disease apparently does not cause mortality to trees over 2 m in height, although it affects lower branches. The European strain is considered more damaging to larger red pine (>2 m), and has caused mortality to several thousand hectares of immature red pine and scots pine (*Pinus sylvestris* L.) in New York State. More recently, it has caused extensive damage to red pine plantations in western Quebec.

The range of the European race has been restricted in Ontario through an annual detection program of the Canadian Forest Service (CFS), followed by control measures taken by the Ontario Ministry of Natural Resources (OMNR). The control efforts consist primarily of pruning lower branches and burning diseased material (Hopkin and McKenney 1995). Both monitoring and treatment are labor intensive and costly. However, the disease can cause important economic losses if not controlled. The question currently being posed by forest managers is under what circumstances are control or mitigation treatments both biologically effective and economically worthwhile.

Using a generic pest management framework developed by Fox et al.,[1] a threshold management model can be applied to the scleroderris problem in red pine plantations. The model permits comparison of net present values of alternative treatment and harvest regimes. Forest managers can use this model to assist in determining optimal harvest and treatment regimes (investment levels) for scleroderris control. Some general results are presented in this note.

THE ECONOMIC MODEL

A cost-benefit analysis of scleroderris infections over a single rotation was developed using the Mathcad[2] personal computer software package. The approach helps to identify threshold conditions for which control is worthwhile. Two threshold definitions exist: a) a fixed treatment threshold, and b) an optimal treatment threshold. The fixed treatment threshold considers control efforts to be fixed and pest incidence to vary. This approach helps to identify the level of pest incidence where benefits of control exceed or break even with control costs. This criterion was developed by pest specialists. The optimal treatment threshold treats pest incidence as fixed and varies the control treatments (i.e., costs). This later approach is more in line with the way

[1] Fox, G.; Beke, J.; Hopkin, A.A.; McKenney, D. A framework for the use of economic thresholds in forest pest management. For. Chron. (In review.)

[2] A single rotation analysis is not consistent with the Faustman multiple rotation model, the basis of much forest economics (*see* Samuelson 1976). This approach was deemed appropriate because the endemic pest population increases after each harvest, thus changing the starting conditions. Also, given all the inherent data uncertainties, overall results are not sensitive to this assumption.

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economists think about pest management, particularly those individuals involved in agricultural crop protection. Applying either of these concepts to forestry is complicated by the long production periods, but the essential principles are the same.

To apply the economic framework to scleroderris, five interrelated functions that capture the basic biological and economic elements of the problem were modeled.[3] These functions model the relationships among pest occurrence, damage, control measures, wood yields, and net present value of a forest stand. The following description provides further details.

Total Yield Function

Expected merchantable yields over time indicate potential gross returns from plantation investments. A merchantable volume (m^3/ha) function that incorporates height/age relationships for red pine on Site Class 1 was taken from Payendeh (1973). Because the height of infected trees is a critical element of the extent of the impact, it was explicitly included.

Pest Density Function

Pest density refers to the pest population growth function. A logistic growth function was adapted from Rawat et al. (1987). Pest density is a function of age, pest population at time zero, a pest growth rate, and the carrying capacity of the pest. Carrying capacity was assumed to equal the number of trees planted in the stand (assumed to be 1 500 trees/ha in this example).

Control Function

The control function describes the effect of a treatment on the pest population. Scleroderris was assumed to attack red pine aged 1 to 10 years, or until trees were >2 m in height. Treatment would be carried out sometime within this window. Scleroderris can survive and increase after the 10-year window, but after this age the increased pest population is not expected to have any further effect on the merchantable volume (Dorworth 1976).

Damage Function

The damage function describes the way in which the merchantable harvest varies with pest incidence. In this analysis, two damage functions, with and without treatment, are considered. These combine the results of the merchantable volume function, the pest population or density function, and the control function to calculate merchantable volumes.

Total Net Present Value Function

Net present value (discounted harvest revenue minus costs) is calculated with and without treatment. Net present value calculations require information on yields at different ages, the interest rate to discount future costs and benefits, the time and cost of treatment, and the value of harvested timber.

The objective of the fixed treatment threshold is to determine when a treatment is justified, using a fixed level of treatment. This is a total revenue and cost approach. For the optimal treatment threshold, the objective is to find the optimal level of treatment for a given pest density. This is a marginal revenue and cost approach. This rule can be stated as, "treat at a level that maximizes the long run returns". These two decisions require similar information; however, the results of the decisions are different. A fixed treatment threshold indicates a range of treatment and harvest times where the application of a fixed treatment is financially justified. Optimal treatment thresholds indicate the single best solution for a particular pest density, given all the other model assumptions.

MODEL CALIBRATION

As with most forest economics research, some of the input variables were determined through research; others were educated estimates. A rate of time preference (the interest rate) of 0.05 was estimated for Canada by Kula (1984). Current stumpage values for red pine in Ontario are approximately \$5–10/m^3. The \$10 value was used as the initial starting point. Treatment costs of \$200 per hectare were estimated after consultation with CFS and OMNR staff. Information from Laflamme (1991) and Dorworth (1976) implies that the damage windows for scleroderris canker occur primarily by the age of ten. Sensitivity analysis was applied to all of these variables.

One major point of uncertainty concerns the rate of spread (growth) of the European strain and the proportion of pest population remaining after control. O'Brien (1972) studied the growth rate of the North American strain in sample plots of 4- to 6-year-old trees in the United States, and found that scleroderris had initially infected 7 percent of the trees. Four years later, without any control, 16 percent of the plot had been infected with scleroderris. Thus, for the present study, it was assumed that the European strain spreads at the same rate as the North American strain. The initial pest density and efficiency growth rate of the pest were adjusted so that the logistic function reproduced O'Brien's (1972) results. This calibration resulted in an initial pest density of 45 infected trees, and an efficiency growth rate of 0.24. Sensitivity analysis was performed on these assumptions.

The available literature suggests that application of control (removing and burning infected trees or limbs) will not fully eliminate the pest (Dorworth 1976). It was assumed that 35 percent of the pest population prior to treatment would remain after treatment was conducted. Although this value is arbitrary, it maintains the previously mentioned biological assumption of residual pest populations.

[3] The mathematical formulation of the model, detailed in a report by the same authors, is on file with the Canadian Forest Service, Sault Ste. Marie, Ontario.

THE FIXED TREATMENT SCENARIO

Results of the fixed treatment base scenario are illustrated in Figure 1. The horizontal axes represent harvest age and treatment age in years. The vertical axis measures net present value ($/ha). The floor of the graph represents solutions, where the present value of treatment benefits are less than or equal to the costs of treatment. A fixed treatment threshold is reached when the treatment benefits surpass the treatment costs (in present value terms) as pest incidence varies. The surface plotted in Figure 1 represents the combinations of harvest ages and treatment ages for which treatment at least breaks even, given assumptions about pest incidence.

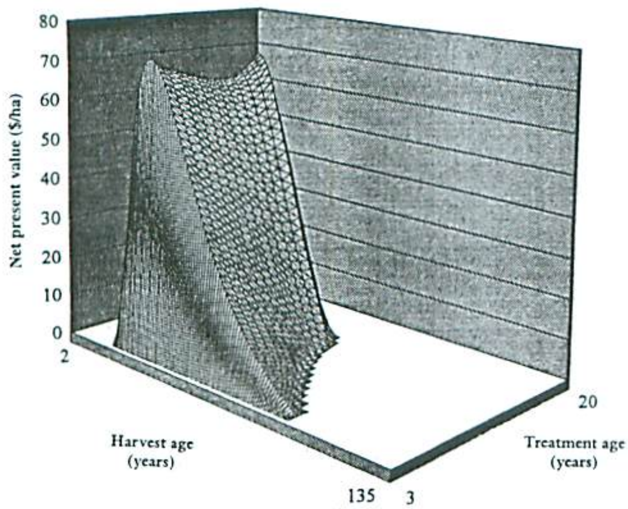

Figure 1. Base scenario fixed treatment thresholds.

The reader will note the two ridges in Figure 1, the highest at Treatment Age 3, and the other at Treatment Age 14. Initially, the cost of treatment is low because the growth of the pest is in its infancy; this explains the peak in net present value at Year 3. The choice to treat at the age of 14 maximizes the merchantable volume of the stand. Treatment at the age of three yields 90 m^3 by the age of 31; treatment at the age of 14 yields 105 m^3 at that age. However, because of the discount rate and the logistically increasing cost function, the net present value of treating at the earlier age is more beneficial. This could be counter intuitive as one would expect future discounted costs to be less than present costs, thus indicating a later treatment time. Because the growth rate of the logistic cost function exceeds the growth rate of the return on capital, future treatment times are generally less attractive.

Table 1 summarizes data used in the base scenario for the fixed treatment decision rule. The best net present value associated with treating the pest ($202/ha) exceeds the best present value without treatment ($130/ha). Merchantable volume, which was also determined in the model,

Table 1. Base scenario – fixed treatment threshold.

Input variables		
	Initial pest density (number of infected trees per ha)	45
	Interest rate (discount rate)	5%
	Stumpage price ($/m³)	10
	Efficiency variable for pest growth (part of the logistic pest growth function)	0.24
	Range of first damage window (years)	1 – 3
	Range of second damage window (years)	4 – 20
	Final stand age to consider	135
	Number of trees (per ha)	1 500
	Cost of treatment ($/ha)	200
	Proportion of pest remaining after control	35%
Fixed treatment results		
	Best net present value, with treatment ($/ha)	202
	Optimal treatment age	3
	Optimal harvest age	30
	Merchantable volume (m³/ha)	86
	Best present value, without treatment ($/ha)	130
Foresters' results		
	Age of harvest	90
	Age of treatment	3
	Net present value, with treatment ($/ha)	15
	Merchantable volume, with treatment (m³/ha)	194
	Present value, without treatment ($/ha)	13
	Merchantable volume, without treatment (m³/ha)	108

Range of possible treatment times: 3 to 17 years

Range of possible harvest times: 19 to 93 years equals 86 m³/ha in the base scenario. Optimal values for treatment and harvest age are 3 and 30 years, respectively.[4] The low treatment age may be a result of the low rate of infection. Early treatment would be justified because the low rate of spread of the pest will not permit it to make a significant comeback within the damage windows (Rawat et al. 1987). The difference between the best net present value solutions with treatment, and without treatment, is the total net present value of benefits of treatment (the fixed treatment threshold value).

An arbitrary harvest age of 90 was also chosen to represent a decision to harvest for products of larger dimension, like poles and sawlogs. This result provides a net present value of $15/ha. The difference ($187/ha) between the best net present value and the $202/ha reported earlier indicates the opportunity cost of harvesting at a later date. A higher stumpage value is required to justify harvesting at this age. Note that for the base scenario a harvest based on the mean annual increment result would occur at the age of 40. Rotation ages for red pine range from 35 to 100 years, depending on product objectives.

Given the inherent uncertainty of many of the values employed in the base scenario, sensitivity analyses were undertaken. Sensitivity analysis relates changes in the model parameters to consequent changes in the net present values, merchantable volume, and treatment and harvest ages. Table 2 summarizes the results of all sensitivity analyses.

According to Anderson (1991) the harvest age would be influenced primarily by changes in the interest rate. When the interest rate is decreased to 2.5 percent, the harvest age increases from 30 to 39 years. Conversely, when the interest rate increases to 7.5 percent, the harvest age decreases to 27 years. As the interest rate increases, consumption in the present is valued more than consumption in the future. Because the interest rate indicates the value of future investments, the best net present value rises from $202/ha to $488/ha when the interest rate falls to

Table 2. Summary of sensitivity analyses of the fixed treatment model.

Variable changed (from and to)	Best NPV* treated ($/ha	Sensitivity factor	Treatment age	Harvest age	Mechantable volume	Best NPV untreated ($/ha)
Base scenario	202		3	30	86	130
Interest rate (0.05→0.025)	488	2.86	14	39	138	277
Interest rate (0.05→0.075)	100	1.04	3	27	71	68
Pest growth efficiency (0.24→0.18)	301	2	3	31	132	220
Pest growth efficiency (0.24→0.30)	115	0.86	3	29	48	83
Stumpage price ($10m³→$5/m³)	97	1.04	3	30	86	65
Stumpage price ($10/m³→$15/m³)	324	1.2	14	31	105	194
Initial pest density (45 trees/ha→25 tree/ha)	258	0.28	3	31	112	171
Initial pest density (45 trees/ha→65 tree/ha)	169	0.36	14	31	96	108
Proportion of pest remaining (0.35→0.25)	232	0.51	3	31	103	129
Proportion of pest remaining (0.35→0.45)	181	0.34	3	30	77	30
Treatment costs ($200/ha→$250/ha)	200	0.04	3	30	86	130
Treatment costs ($200/ha→$150/ha)	212	0.2	14	31	105	130

*NPV = Net present value.

[4] An optimal harvest time occurs when the growth rate of capital equals the growth rate of the timber. The low rotation age is a reflection of the constant stumpage price per cubic meter regardless of age. In principle, the stumpage price could vary with age, but no data were available to complete this calculation.

2.5 percent. When the interest rate is increased to 7.5 percent, the best net present value falls from $202/ha to $100/ha. Generally, as the interest rate falls the optimal treatment time increases. Future revenues are valued more highly, thereby providing an incentive to undertake activities that increase total wood production.

Higher values of the pest growth rate signify an increase in the speed of infestation. The pest efficiency growth rate changes the harvest time by reducing the merchantable volume, and by affecting the rate of growth of the stand. By decreasing the pest growth rate to 0.18, the merchantable volume from the stand increases to 132 m^3/ha. This brings about a corresponding increase in the net present value from $202/ha to $301/ha. An increase in the pest growth rate to 0.30 causes the merchantable volume to fall to 48 m^3/ha, thereby decreasing the net present value from $202/ha to $115/ha. For both of these cases, the optimal treatment occurs at the age of three.

Decreasing the stumpage price reduces the net present value of the harvest revenue. A decline in the stumpage price to $5/$m^3$ causes the net present value to decrease from $202/ha to $97/ha. An increase in the stumpage price to $15/$m^3$ causes the net present value to increase to $324/ha. The increase in stumpage value causes the optimal treatment time to shift to the age of 14 so as to increase total wood production.

A reduction in the initial pest density, from 45 to 25, causes an increase in merchantable volume. Merchantable volume increases from 86 m^3/ha to 112 m^3/ha, and the best net present value increases to $258/ha. As expected, a loss in merchantable volume (86 m^3/ha to 46 m^3/ha) causes the net present value to decrease to $169/ha. The proportion of pests remaining was varied from an initial value of 35 percent to 45 percent, and then to 25 percent. The increase caused merchantable volume to decrease in the presence of treatment, with a corresponding decrease of the net present value. When the proportion of pests remaining is decreased, merchantable volume increases. In this case, because the proportion of pests remaining after treatment is larger, the pest recovers faster and there is a reduction of the merchantable volume in later years. Per hectare treatment costs were varied from $200/ha to $250/ha and $150/ha. In both cases, the treatment age remains at three and the harvest ages are only slightly affected. A decrease in interest rates had the greatest effect on all of the variables examined (i.e., net present value, treatment age, and merchantable volume at harvest age). This was followed by a decrease in the pest growth rate. The least sensitive factor increased costs to $250/ha.

The sensitivity factors are nonlinear because of the model's structure. Functions such as the pest density are nonlinear, so changes in pest density parameters result in a nonlinear response. However, use of a discounting mechanism also causes nonlinear relationships because the net present value function is nonlinear in the discount rate. Sensitivity analysis gives an indication of where better biological data are needed to improve the usefulness of economic analysis. Relationships or parameters that have the greatest impact on the net present value and suggested management activities need to be better understood.

THE OPTIMAL TREATMENT THRESHOLD

The second type of pest threshold model identifies the level of treatment effort that maximizes the net present value for a given level of pest infestation. It is possible that this optimal treatment level can be zero. Figure 2 illustrates the results of an optimal treatment threshold when the pest detection, and hence the time of treatment, occurs at the age of three. The figure has axes defined as harvest age in years, net present value ($), and application rate (per ha). The floor of the graph represents solutions where the benefits of treatment are less than or equal to the costs of treatment (in present value terms). The highest point of the surface of the graph represents the optimal control threshold for a given treatment time (and pest density).

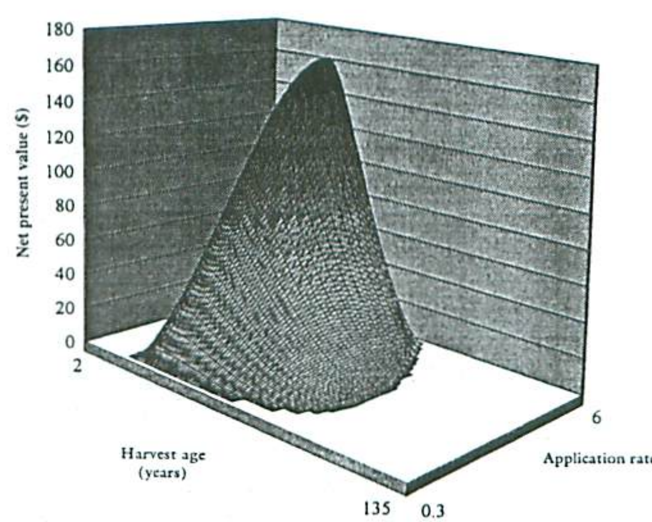

Figure 2. The optimal control thresold.

Table 3 summarizes the base scenario. The same input parameters as the base scenario of the fixed treatment threshold were used where appropriate. Generally, application rates, merchantable volume, and net present value decrease as the detection or treatment time increases. Treatment costs depend on the growth rate of the pest and the application rate. A later treatment time implies higher losses in merchantable volume (more trees are infected).

Sensitivity analysis was conducted by varying the interest rate, the pest growth rate, stumpage price, initial pest density, and costs of treatment. Detailed results are available in Fox et al.[5] An increase in the interest rate causes a decrease in the harvest age and corresponding decreases in

[5] Fox, G.; Beke, J.; Hopkin, A.A.; McKenney, D. A framework for the use of economic thresholds in forest pest management. For. Chron. (In review.)

Table 3. Base scenario – optimal treatment decision rule.*

Year treated	NPV** treated ($/ha)	Application rate (units/ha)	Harvest age, treated (years)	Merchantable volume, treated (m^3/ha)
3	291	5.7	31	147
4	282	5.4	31	144
5	273	5.1	31	141
6	264	4.8	31	137
7	255	4.8	31	138
8	247	4.5	31	135
9	239	4.2	31	132
10	232	3.9	31	129
11	227	3.9	31	125
12	221	3.3	31	123
13	216	3.0	31	120
14	208	2.4	31	111
15	195	1.8	31	101
16	180	1.5	30	89
17	168	0.9	30	81
18	152	0.6	30	73
19	137	0.3	30	65
20	120	0.3	30	59

* Untreated NPV is $129/ha and merchantable volume is 55m^3/ha in all cases.
**NPV = Net present value.

the application rate and the net present value, when compared to the base scenario. Because future revenues decrease, costs must be reduced to maximize net benefits. The only variable that can be altered is the application rate. Therefore, application rates decline from the base scenario to accommodate the decline in revenue.

As the pest growth rate increases, the merchantable volume (treated and untreated) that can be harvested decreases. This reduction in harvested merchantable volume causes a decrease in the net present value. The harvest age declines because the growth rate of the timber supply is adversely affected.

Increases in the stumpage price bring about an increase in the net present value (both treated and untreated) for all possible treatment times. This price increase also permits the justification of higher application rates at later treatment times, because future revenues have increased and costs can be justified.

When the initial pest density is increased, merchantable volumes and optimal application rates decrease. This occurs because of the increased losses resulting from the greater negative impact on the harvest volume caused by the increased pest population. Increases in the treatment costs reduce the net present value and optimal application rates.

Decreases in the pest growth rate had the largest impact in this model. A decrease in the stumpage price had the second greatest impact. Each sensitivity analysis showed a similar pattern, if considered in the three dimensional form of Figure 2; rising, falling, and then rising again. This is a nonlinear pattern caused by the combination of the nonlinear pest growth function and the effect of discounting future costs and benefits. As mentioned in the fixed treatment section, variables associated with large sensitivity factors require more accurate specification.

MANAGEMENT IMPLICATIONS

Each of the threshold decision rules has advantages and disadvantages. An optimal treatment decision rule is the ideal approach to maximize the value of the plantation investment. The fixed treatment threshold is useful when pest control is constrained through legislation or policy, or through biological limitations on control.

The fixed treatment threshold decision provides a range of harvest and treatment times, making it a simpler tool for gauging forest pest management strategies. Based on the assumptions used earlier, Table 4 provides some general rules of thumb for use by a plantation manager. It indicates the ranges of financially viable treatment and harvest times for the fixed treatment threshold decision. Both the fixed treatment and optimal treatment base scenarios suggest that treatment is generally more profitable than not treating. However, managers should carefully scrutinize the assumptions to ensure that they coincide with ground conditions (e.g., wood growth rates, treatment costs).

As for many pest problems, information regarding various components of the scleroderris model was limited. The results of the sensitivity analysis can be used as a guide for research on scleroderris, but with more knowledge of the disease comes a better understanding of both damage and control. For example, over large areas, logistic growth may

Table 4. Rules of thumb from the fixed treatment model.

Base scenario	
Range of treatment age:	3 – 17 years
Range of harvest age:	19 – 93 years
Increasing interest rates to 0.075	
Range of treatment age:	3 – 15 years
Range of harvest age:	19 – 75 years
Increasing the proportion of pest remaining after control to 0.45	
Range of treatment age:	3 – 15 years
Range of harvest age:	19 – 86 years
Increasing costs to $250/ha	
Range of treatment age:	3 – 15 years
Range of harvest age:	19 – 88 years
Increasing the efficiency variable for pest growth to 0.30	
Range of treatment age:	3 – 15 years
Range of harvest age:	19 – 75 years
Increasing the initial pest density to 65 trees/ha	
Range of treatment age:	3 – 15 years
Range of harvest age:	19 – 82 years
Increasing the stumpage price to $15/m^3	
Range of treatment age:	3 – 18 years
Range of harvest age:	19 – 102 years

approximate the spread of scleroderris. However, within plantations, scleroderris tends to spread erratically. In future, collection of data on spread patterns will permit a more accurate portrayal of the economic effects of scleroderris on red pine. In addition, the current model does not account for multiple stands or stands of mixed age or various objectives (e.g., recreation, wildlife, etc.). A number of possible extensions are available to increase confidence in this model; nevertheless, the basic principles will remain the same.

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