Final Report: Plantation Risk Assessment Workshop

An internal Natural Resources Canada, Canadian Forest Service report prepared for

Forest 2020 Plantation Demonstration and Assessment Initiative

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EXECUTIVE SUMMARY

Disturbance risks that would affect yields of plantations established in afforestation programs in Canada are described in this document. Experts in various disciplines from all CFS Centres across Canada were asked to provide best estimates of the probability of occurrence and impacts caused by these disturbances. These estimates are provided in spreadsheet format appended as part of this document. Significant sources of variation in risks were identified. These include the species and/or clone used in plantations, the ecozone in which plantations may be established, stand age, and the nature of impacts; whether growth reductions or tree mortality with the latter being more important. The major disturbances considered are: extreme weather events (mainly drought), stand replacing mortality due to fire, and insect and disease pests of the fast growing tree species used in plantation culture since 1990 in Canada. A database of the relevant pest population dynamics, tree susceptibility and impact parameters was prepared. A Monte Carlo simulation model that could handle multiple disturbance agents simultaneously was developed to explore the implications of these risks. Impacts from multiple disturbance scenarios explored suggest that one might expect a 27% mean reduction in yields from a hypothetical maximum yield for 30 year-old white spruce plantations affected by the spruce budworm. Similarly there was a 33% reduction in the mean yield from low drought tolerant hybrid poplar plantations at age 30 in semi-arid prairie environments. Management actions to control spruce budworm would boost yields by 18%. Drought tolerant hybrid poplar plantations would be expected to improve yields by 20% over those with drought sensitive clones**.** There are obvious applications of this approach to assessing economic opportunities and optimizing harvest strategies. Not the least of these is determining the optimum rotation age when marginal growth rates decline to a realistic discount rate. These explorations may also be used to assess the contribution research might make in improving yields. A preliminary estimate suggests that these opportunities amount to some 23% in yield improvement. The appendices include the EXCEL file containing the database, a description of the model and its EXCEL implementation, and a summary of future work required to make this information useful to practitioners.

INTRODUCTION AND BACKGROUND

Purpose and scope

The Forest 2020 Plantation Demonstration and Assessment (PDA)/Feasibility Assessment of Afforestation ~~t~~for~~o~~ Carbon Sequestration (FAACS) Dec. 2003 workshop identified risks to fast growing plantations as a key information piece needed to inform potential investors. In January, 2004, Dr. Ken Mallet, (Director, Forest Biology, Natural Resources Canada, Canadian Forest Service (CFS), Northern Forestry Centre), made a proposal to Terry Hatton (Project Leader, Forest 2020 PDA) to organize a workshop of CFS experts to examine the question of risks to fast growing plantations.

This report deals with the outcome of consultations with experts to determine risks that might affect forest plantation performance. It is a preliminary record of information related to these risks and is intended as background information for those contemplating establishing fast growing forest plantations in Canada. The report describes the nature of risks that threaten plantations and provides the best information available to assess losses that might be incurred by such ventures from weather related impacts (mainly drought), fire, and pests (including insects, diseases and vertebrates). It does not include problems associated with invasions of alien pests, because they pose a small but presently largely unknown risk to fast growing plantations.. Similarly, problems associated with weeds are not considered because they are normally addressed in plantation establishment and tending. Because many inimical agents may impinge on plantations through out their lives, some means of handling multiple risks is desirable. This is accomplished by formulating a model that projects plantation growth, using Monte Carlo simulation techniques.

A group of experts was identified who were experts in their respective fields and willing to give opinions regarding major threats to plantation success. The experts were given an understanding that their participation was sought even though scientifically sound information might not be available to quantify risks involved in many cases. This is particularly relevant in afforestation when plantations will be established under conditions not previously encountered. As such they were provided assurance that this was to be a snap shot in time, and not a definitive or exhaustive examination of each of the key risks. The group was chosen to represent various regions of the country, understand something of the ecology of key potential fast growing species, the key risks (disturbance - insects, disease, fire drought, etc.) that might threaten afforestation investments and be able to provide the best currently available information.

The Process & Experts Involved

A workshop was convened at the end of January, 2004 at which the experts were briefed by Dr. Mallett and charged with producing the information required. In this briefing, Mr. Chris Lee provided a general overview of the PDA program. Messrs Thomas White and Edwin Banfield provided an outline of the carbon model requirements for assessing carbon sequestration to assess Canada's afforestation potential in meeting Kyoto protocol commitments. Dr. Denys Yemshakov provided an overview of a comprehensive economic model that might be used to evaluate investment opportunities. The briefing was concluded with a presentation by Mr. Juha Metsaranta. This presentation detailed a model that would be used in evaluating multiple risks to the productivity in plantations. Mr. Metsaranta was charged to work with the experts in eliciting and standardising the information required to quantify these risks.

The disturbance experts who were asked to provide information on threats to plantations:

Dr. Rene Alfaro	PFC, Research Scientist, Forest Entomologist
Mr. Peter Bothwell	NoFC, Forestry Officer, Fire Specialist
Dr. Ted Hogg	NoFC, Research Scientist, Forest-Climate Interaction Specialist
Dr. Anthony Hopkin	GLFC, Research Scientist, Forest Pathology, Abiotic Damage
Mr. Edward Hurley	AFC, Forestry Officer, Forest Health Unit Leader
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Dr. Gary Warren	AFC, Forest Pathologist

Bounding the problem

Fast growing plantations are defined for purposes of this paper as tree stands established and tended to produce volumes of wood at rates at least double that expected from native stands growing under similar conditions. Plantations of this nature are useful in programs to off-set fibre deficits and may also provide a means for ameliorating the consequences of land alienation by land-use changes or policy initiatives that reduce the forested land base. More recently, these plantations provide a means of sequestering carbon to meet ‘Kyoto’ mandated targets through afforestation programs. Because of the accelerated growth, however, such installations tend to be vulnerable to climate, and pest-related risks. Because they may be established outside currently forested areas, culture and land use practices may have unforeseen impacts on plantation success. This is particularly true with respect to fire risks to plantations.

The outcome of the workshop January was to bound the problem and to define the nature of information to be furnished for the model. The exercise limited our consideration by specifying the geographical area and time horizons to be considered. Correlated with the spatial and temporal dimensions considered was a definition of the climatic regimes to be considered. It was agreed to assemble details for each disturbance type that might significantly affect plantation performance in afforestation programs thus bounded. Plantation management activities that might alter impacts of pests or other disturbances were also captured in this process. In addition, if control measures were available, their efficacy and costs were detailed. Finally, the experts insisted on ascribing some measure of reliability to the information provided on each disturbance. At the end of the workshop a template in the form of an EXCEL spreadsheet was prepared by Mr. Metsaranta and circulated to the experts. They provided the necessary information that was then compiled and discussed at a second workshop held in Toronto in early March. The purpose of this workshop was to examine the information provided by the group, rationalize any discrepancies, and resolve problems of interpretation.

The final form of the information is the basis of the present report. This report was complied on behalf of the experts and Mr. Metsaranta by Jan Volney.

The report consists of two items: this text file, and the EXCEL worksheets with details of the disturbance data, including ecozone/ecoregion maps and notes on items included in the data set.

Time horizons

Consideration was limited to fast growing plantation trees. It was also necessary to accommodate concerns for carbon accounting required to assess Canada's commitment to the Kyoto agreement. Thus, plantations established in 1990 and beyond, which might be included in these assessments in 2030, dictated that early development to at least 40 years of age be considered. Investors will require information beyond this age because harvests will certainly occur beyond that age to accommodate saw-log production and the vagaries of markets. Therefore plantation development to age 60 years was considered in this exercise because this was thought to be the extreme harvest age for such installations in Canada. All projections were thus limited by the 60 year time horizon.

Geographical regions

The geographical regions considered are areas that were not forested or have been settled in Canada before 1990 (a date pregnant with Kyoto consequence). This region includes terrestrial Ecozones along Canada's southern border and the zones adjacent to the Prairies of western Canada. As such, it includes the Boreal Shield (BS), Atlantic Maritime (AM), Mixed Wood Plains (MWP), Boreal Plains (BP), Montane Cordillera (MC), Pacific Maritime (PM) and the Prairies (P).

Climate

Climatic conditions are assumed to be the current climate in each of the ecozones. Climate alters the impact and incidence of disturbances and its effects are handled by the stratification offered by the ecozone designation. No consideration has been given to climate change in these assessments. It was felt that a separate process would be needed to incorporate these concerns, in any event the scenarios currently available from climate change scientists can be modeled with the information provided by an appropriate sensitivity analysis, and information on altered impacts is generally not available. Nevertheless we recognize that climate change is a significant long-term concern that will affect the vulnerability of plantations.

Tree species

The tree species considered were limited to those planted in afforestation trials since 1990. The list provided by Mr. Thomas White was adopted because it reflects land-owner preferences for planting on 'Kyoto qualified' land. It is thus based on current practice. The list was augmented with a few species that were considered possible choices either for bioenergy projects or specialty wood products. The species considered are listed in Table 1 along with the approximate geographical extent where they might be planted. The 'East' is considered to the Boreal Shield approximately east of the Ontario/Manitoba border, the Mixed Wood Plains, and the Atlantic Maritimes. The 'West' includes the remainder of the Boreal Shield ecozone, the Prairies and the Boreal Plains while 'BC' includes the Pacific Maritime and the British

Columbia portion of the Montane Cordillera. The 'Kyoto qualified' lands in the Alberta portion of the latter is negligibly small. The products expected are only general designations to indicate economic opportunities for plantations. In each case the most "valued product" is listed first, whereas "default products" derived from pest-damaged plantations are listed last.

Table 1. Fast growing tree species for afforestation on Canadian 'Kyoto qualified' lands.

Common name	Scientific name	Geographical Extent	Valued product	Default products
White spruce	*Picea glauca*	East & West	Saw logs	Pulp/ bioenergy
Red spruce	*Picea rubens*	East	Saw logs	Pulp/bioenergy
Norway spruce	*Picea abies*	East	Saw logs	Pulp/bioenergy
Sitka spruce	*Picea sitchensis*	BC	Saw logs	Pulp/bioenergy
Red pine	*Pinus resinosa*	East	Saw logs	Pulp/bioenergy
White pine	*Pinus strobus*	East	Sawlogs	Pulp/bioenergy
Scots pine	*Pinus sylvestris*	West	Saw logs	Pulp/bioenergy
Larches	*Larix* spp.	East & West?	Bioenergy	
Sugar maple	*Acer saccharum.*	East	Saw logs	bioenergy
Manitoba maple	*Acer negundo*	West	bioenergy	
Red alder	*Alnus rubra*	BC	Saw logs	bioenergy
Aspen	*Populus tremuloides*	West	OSB/Pulp	bioenergy
Hybrid poplar	*Populus* sp. X sp.	East & West	OSB/pulp	bioenergy
Balsam poplar	*Populus balsamifera*	West	OSB/pulp	bioenergy
Willows	*Salix* spp.	All	Bioenergy	

<u>Disturbances</u>

Both biological and abiotic disturbances are considered in this analysis. Decisions as to which disturbances to include are based on experience gained through 100 years of observations and literature accumulated through forest science work in Canada. A major contributor to this understanding has been the Canadian Forest Service and its predecessors through the work of its scientists, forestry officers, and biologists. Generally, these disturbances have caused growth loss and partial or stand replacing mortality in native stands of the species that they affect. They are thus thought to be able to frustrate attempts to develop plantations by delaying the time when the site might be expected to yield its maximum wood volume. Abiotic influences include weather events, whose frequencies and impacts are generally correlated with ecozone, and uncontrolled fire, whose occurrence is also correlated with ecozone but modified by vegetation management practices used in plantation development. Biotic factors include mammalian, fungal and insect pests. Whereas the abiotic disturbances will affect all tree species, pests tend to be more species specific. Even pests might be a general problem affecting several species, however. Thus there are pests, such as rodents, that affect all tree species; others that affect all coniferous tree species; and still others that pose a risk to all species within a genus such as pests of *Populus*. The response to any specific disturbance differs among tree species and thus must be accounted for in the assessment of risk. However, disturbances may be categorized as annual events; cyclical events that recur at least quasi-periodically; and chronic disturbances that, once established, affect the plantation for extended periods. In some cases the occurrence of certain diseases on a site from a previous forest crop may preclude planting its host tree species in the next rotation. An attempt was made to capture the characteristic temporal distribution of the disturbance, the statistical distribution of its occurrence in time and whether its effects would linger and affect plantation productivity after several years.

Disturbance Management

In general, the risks posed by abiotic disturbances are best managed by avoidance. Tree plantations are long-term investments whose success is critically dependent on their establishment where risks can be eliminated or minimized. Many of these concerns can be mitigated by attention to three major issues. First, there must be a genetics program to select, develop, and use appropriate material in establishing plantations. This program will address issues of pest resistance and climatic tolerances appropriate to the geographical location and specific site applications. This must be integrated with concerns about productivity and product streams to be derived from the material at harvest. Second, there must be a well-conceived silviculture program that will ensure maximum productivity with an appropriate schedule of stand tending, fertilization and vegetation management where required. Third, pest management will be an integral part of the plantation management system from its conception and including planning to the establishment and final harvest. In this analysis we assume that mistakes, such as using drought-susceptible stock to establish plantations in regions that experience chronic drought, will not be made. If such plantations are established, it will be assumed that a source of water, such as effluent from some industrial process, would be available. Vegetation control to reduce competition with crops will also pay dividends in the reduction of risk to un-intended fire occurrence by reducing fuels near to, and in the plantation. In several cases proper plantation management will avoid problems related to several disturbances simultaneously.

Specific management options are detailed for pests. Attempts have been made to indicate the general efficacy of such treatments, their costs, and the period over which such control options might be necessary and effective. Again, it is assumed that the control measure, when undertaken, is properly applied. The indications of efficacy given represent a distillation of what is known of operational control methodologies.

Data Quality

As a general observation, plantations developed in an afforestation program will establish novel environments for which we have little or no experience. Several of the organisms listed have not been studied in detailed, even in their native habitats. Usually we only have sporadic observations or general surveys on which to base assessments of risk. Thus the quantitative data provided here must be regarded as best guesses and where possible we have listed the sources that might be consulted on any particular disturbance agent. Nevertheless, what is known has been extended to the situations that are likely to occur in plantation development. These plantations themselves will be the source of much future information to better define disturbance risks in future. The data quality reported is categorized as coming from: 1) peer reviewed literature, 2) anecdotal or survey information or 3) extrapolation by an expert. No specific study on any one agent has been completed to give the information required to provide objective estimates of risk. Thus the whole package represents a synthesis of understanding by the experts involved. No undertaking is without risk; it was thought that the data quality rating itself could be used in determining risks associated with uncertainty and/or erroneous information.

OUTCOMES FROM EXPERT OPINIONS

An attempt was made to develop a standard framework on which to capture data on specific disturbance types. A spreadsheet approach was developed to capture the data needed to describe each disturbance type. For some disturbances, such as weather events and possibly fire, the number of combinations involving species and ecozones is prohibitively large. Thus only examples illustrating the spreadsheet entry of drought data for specific species-ecozone combinations are provided. A more detailed description of how these are handled is provided below. *Examples* are provided to illustrate how risks are handled in the proposed assessment procedure. The complete examples, incorporating several risk factors simultaneously, are detailed below as Scenarios 1 through 4. They illustrate the effect of going from an area of low risk of drought-induced damage (Scenario 1) to one of high risk of this damage (Scenario 2); the effects that pest management can have on altering risks (by contrasting results from Scenario 3 with those from Scenario 1); and how drought induced risks can be ameliorated by choosing a drought-tolerant clone (Scenario 2 vs. Scenario 4).

Weather-induced impacts on plantations

Forests and plantations may be adversely affected by a wide variety of extreme climate events (Hiratsuka and Zalasky 1993). For this exercise, the focus will be on the impact of drought, which is assumed to be the most important event causing regional-scale impacts on plantations established on non-forested land through afforestation. Other types of extreme events such as thaw-freeze events and ice storms will be considered implicitly.

Drought and other extreme events affect all tree species in all regions, and their impacts may vary according to stage of development, e.g. seedlings, established trees, and older trees. A simple model was developed to capture all aspects of weather-induced mortality and growth reductions on plantations. For this simple model, there are a very large number of combinations when considering four climate zones (according to drought risk), three categories of drought tolerance for tree species, two types of impact (growth reduction and mortality), and three stages of tree development listed above. (Thus there are up to 4 x 3 x 2 x 3 = 72 combinations that could be entered into the spreadsheet developed for this exercise.)

Geographic variation in risk

First, the spatial, regional-scale variation in the probable risks and impacts of drought-induced damage is captured by defining four broad vegetation zones (Table 2) for those areas of Canada where afforestation is likely to occur. A promising approach is to define these vegetation zones based (approximately) on values of the Climate Moisture Index (CMI) of Hogg (1994, 1999).

Examples from scenarios 1 and 2 using Table 2 would thus result in assigning ‘low risk’ of drought induced damage for spruce growing in the ‘boreal plains’ ecozone and ‘high risk’ for poplars growing in the ‘prairie’ ecozone. These risks are only the first part in considering the weather related risks to plantation success.

Table 2: Preliminary classification of ecoregions within ecozones, according to risk of drought-induced damage of plantations as defined by values of the CMI. Note that all areas of Ontario, Quebec and Atlantic Canada, as well as coastal British Columbia, are considered to be in the "Low risk" zone (CMI > 15).

CMI	Ecozone	Vegetation zone (Hogg)	Ecoregions
Low risk			
> +15	Taiga plains	"Moist boreal"	ALL except 64 (Hay River lowland)
	Boreal shield	"Moist boreal"	ALL except 90-91 in Manitoba
	Boreal plains	"Moist boreal"	136, 137, 139-145, 147, 148, 151-154
	[Montane cordillera	"Moist cordilleran"	Southern interior BC*, western AB*]
Medium risk			
zero to +15	Taiga plains	"Dry boreal"	64 (Hay River lowland)
	Boreal shield	"Dry boreal"	90-91 in Manitoba
	Boreal plains	"Dry boreal"	138, 146, 149, 150, 155
	[Montane cordillera	"Dry cordilleran"	Southern interior BC*]
High risk			
-15 to zero	Prairies	"Parkland"	156, 160, 161, 162, 163, 164
	[Montane cordillera	"Upper Montane"	Southern interior BC*]
Very high risk			
< -15	Prairies	"Grassland"	157, 158, 159
	[Montane cordillera	"Lower Montane"	Southern interior BC*]

*Not easily defined in terms of ecoregions due to mountainous terrain, could consider overall risk as the same as "Dry boreal"

Species variation in drought tolerance

The second step is to classify the candidate tree species according to their overall tolerance to drought damage and mortality. The three categories (high, medium and low) are a preliminary classification of tree species based on expert judgment (Table 3).

Examples: In applying this to our examples, Table 3 suggests that white spruce (featured in Scenarios 1 and 3) has a high tolerance for drought, whereas a hybrid poplar clone such as NM6 has a low tolerance (Scenario 2) in contrast to Brooks #6 which has a high tolerance for drought (Scenario 4).

Table 3. Species stratified on probable tolerance to drought.

Species		Drought tolerance* expert judgments DS	PB	USDA	DM**	Overall Rating (Hogg)
White spruce (east/west)		H	MH	H	MH	**H**
Eastern white pine (east)		L	H	?	M	**H**
Norway spruce (east)		H	ML	M	ML	**M**
Red pine (east/central)		M	MH	L	M	**M**
Scots pine (west)		H	H	M	M	**H**
Populus spp (east/west)						
native trembling aspen		MH	L	H	**H**	
Northwest, Brooks #6		H				**H*****
Walker, Assiniboine, Hill		M				**M*****
DN34, DN 182 (P. deltoides nigra)		ML				**L*****
NM6 (P. nigra X P. maximowizzi)		ML				**L*****
Red spruce (east/central)		H?	M	M	L	**M**
Sitka spruce (BC)		M?	L?	L	L	**L**
Alder (BC) [Red Alder]			M			**M**
Larix (east/west?)	General	M				
	Larix laricina	L	L	MH		**L**
	Larix sibirica		H			**H**
Acer (east/west)	Acer saccharum	M	M	M		**M**
	Acer negundo	H		H	MH	**H**
Salix (east/west)	General	H	L			**L**
	Salix nigra				L	

Note that for some genera such as Populus, Larix and Acer, drought tolerance varies according to species.
*H is high, MH is medium high, M is medium, ML is medium low, L is low
**Based on potential range on Canadian prairies from Dan McKenney's plant hardiness site, other experts' identities remain anonymous until we clear their suggestions with them.
***Note that hybrid poplar becomes more vulnerable to drought and other extreme events after age 20. (This is not yet included in the preliminary model).

Drought impacts and lags

The third step is to associate probabilities and impacts of drought and other extreme weather events on tree growth for each of four zones (regions). Here we assume that growth of all tree species is affected equally by extreme events. As noted below, "tolerance" will refer only to the ability of the tree to survive following extreme weather events.

In all vegetation zones and for all tree species (all tolerance classes), we assume that an extreme event leads to a cumulative growth loss equivalent to 35% of total growth over one year. At a given site, this impact may occur within a single year (e.g. spruce plantations) or 2-3 years (e.g. pine plantations and native aspen). However, when scaling up to the level of an ecozone (e.g. boreal plains) for aspen, analyses indicate that the impact lasts for up to 4 years following the extreme event. For simplicity, we will assume that the 35% impact is spread over the 2 years following the extreme event. In the following table, Year 0 represents the year when the extreme event occurs.

Table 4a. Growth reductions - estimated average at ecozone level (for plantations >3 years old)

Zone	Species	Year	% Growth reduction Relative to normal annual growth
All	all	Year 0	20%
All	all	Year 1	10%
All	all	Year 2	5%
		Total	35%

Annual probability of extreme climate events leading to growth reductions

Zone:

Moist forests	**4%**	**(Extrapolation)**
Dry boreal/cordilleran forests	**8%**	**(Estimate from CIPHA data)**
Parkland/montane	**12%**	**(Estimate from CIPHA data)**
Grassland/semi-arid	**20%**	**(Estimate from prairie plantations)**

Examples for growth reduction would thus indicate that for the species growing in the boreal forests (Scenarios 1 and 3) the annual probability for a drought event is 8% (Table 4a). This would cause a growth reduction of 20% in the year of the drought, followed by 10% and 5% growth reductions in the two subsequent years. For the trees growing in the prairies (Parkland/montane), the annual probability of such a growth reduction is 12%. Note: the growth reduction impacts are modeled with the same sequence of 20%, 10% and 5% in the year of the drought and the two successive years, respectively.

Differences in drought-tolerances among tree species are handled by assigning elevated mortality rates for species with low drought-tolerance in contrast to the lower rates assigned to the more tolerant species (Table 4b).

Table 4b: Estimated probabilities and impacts of severe climate events leading to significant regional-scale tree mortality (for plantations >3 years old).

		% Mortality by Drought tolerance class*		
Zone	Annual Probability of severe event	High	Medium	Low
Moist forests	1%	8%	10%	12%
Dry boreal / cordilleran forests	2%	8%	12%	15%
Parkland / montane	5%	10%	15%	20%
Grassland / semi-arid	10%	20%	30%	40%

*Values given are the estimated total % mortality caused by the extreme event, but the timing of mortality may be delayed for a few years following the event.

Total mortality is apportioned to years following the event as follows:

Total estimated % mortality	Year 0	Year 1	Year 2
8%	3%	3%	2%
10%	4%	4%	2%
12%	5%	5%	2%
15%	6%	6%	3%
20%	8%	8%	4%
30%	12%	12%	6%
40%	16%	16%	8%

Examples: For our white spruce example growing in the boreal plains (Dry boreal) the annual probability of a drought would be 2% (Table 4b). Because white spruce has a high tolerance to drought (Table 2), the mortality is modeled as 3% in the year of drought, 3% the following year and 2% in the 2^{nd} year after the drought for a total of 8% mortality (Table 4b). For the low drought-tolerant poplar growing in the prairies (Parkland) the annual probability of drought is 5% (Table 4b). The resulting mortality is modeled as 4%, 4% and 2% for the year of the drought and the two successive years, respectively for a total of 10%.

For trees up to 3 years old, the corresponding mortality rates (Table 4c) are double those in Table 4b. Note that the corresponding annual probability of drought occurrence remains the same as in Table 4b.

Table 4c. Estimated seedling mortality of plantations up to 3 years old, caused by the same extreme (growth-reducing) climate events listed in 4a above (assumed to occur within the year of the event).

Zone	Annual Probability of severe event	% Mortality by Drought tolerance class** High	Medium	Low
Moist forests	4%	16%	20%	24%
Dry boreal / cordilleran forests	8%	16%	24%	30%
Parkland / montane	12%	20%	30%	40%
Grassland / semi-arid	20%	40%	60%	80%

**These mortality rates are double the values given in Table 4b.

Summary of risks and impacts

Drought is modeled as an event with the annual probability of occurrence of a severe event varying by ecozone. Severity also depends on the tree stage being considered and whether growth reduction or tree mortality is being considered. Growth reduction ranges in occurrence from 4% in moist forests, to 20% in grasslands (Table 4a) resulting in loss of expected volume increments totalling 35% in three years. Whereas, for trees greater than 3 years of age the annual probability mortality-causing drought occurring ranges from 1% in moist forests to 10% in the semi-arid grasslands (Table 4b), the corresponding probabilities for seedlings (trees less than 3 years old) are 4% and 20% (table 4c). Mortality impacts of drought on stands depends on the species tolerance but ranges from 8% mortality for stands with high drought tolerance in moist forests to 40% for stands of low drought tolerance species grown in the semi-arid grassland. This mortality is apportioned over the year of the drought and two subsequent years (Table 4b). For seedlings the corresponding mortality rates are doubled; note they are not assessed a growth loss impact in this analysis.

Fire Risks and Impacts

Description and data analysis

The chance of any given area being burned in any given fire season is a very complex estimate to obtain. Fire cycle periods are calculated by dividing the total burnable area (TBA) by the average annual area burned (AAB). The reciprocal of this function provides the percent annual area burned (PAAB). At the national scale, and using area burned data over a long period of time, the PAAB can be considered a rough estimate of the probability of a random point being burned in a given year. It must be noted however, that this probability ignores many factors that are very important at smaller scales including weather, fuel, topography, and fire cause (human vs. lightning ignitions). Given the large variation associated with area burned from year to year, the numbers of years of data and the quality of these data collected have a substantial impact on the estimate of probability.

Calculation of PAAB was the method employed to assess the probability of fire occurrence in plantations for this exercise. Spatial boundaries for making the calculations were by province and ecozone combinations (i.e. the calculation was made for each ecozone in each province). Setting these spatial boundary characteristics was necessary because every provincial agency has a unique method of collecting fire data. Also, the number of years of data available varies by province.

The derived probabilities are generally appropriate at very large scales, but many caveats apply. In some cases, two adjacent ecozones can have drastically different PAAB. Of course this is not possible because two very large landscapes that are distinguished from one another by a line must share common values. In some cases this is appropriate where drastic ecological transitions occur, as is the case from Prairies to the Boreal Plains, or the Mixedwood Plains to the Boreal Shield.

Furthermore, the PAAB values reported in the spreadsheet probably overestimate the risk to plantations. Ultimately, many plantations established to meet Forest 2020 PDA objectives will be located in landscapes that may not have continuous forest vegetation; this would reduce the actual probability of a plantation burning relative to more continuous forested areas. Secondly, plantations that are established and maintained in areas of human settlement are much less likely to have larger fires than those established in areas with little human settlement. This is because rapid suppression of fires is feasible in settled areas. While fire occurrence is generally higher in settled areas, average fire sizes are usually smaller, and containment more rapid.

Other site-specific considerations are also important in influencing a plantation's probability of being burned in any given year. These considerations might include the fuel type immediately surrounding the plantation, location of busy travel corridors, distance to the closest suppression resources and vegetation management strategies. It is impossible to effectively assess such considerations in an analysis at this spatial scale.

Fires are considered to cause stand-replacing mortality in all ecozones for plantations with any of the tree species considered here. It is also clear that vegetation management that breaks up fuel continuity reduces the probability of fire. The estimated PAAB ranges from 0.001% in the Mixed Wood Plains (and the Prairies in Alberta) to 1.499% in the Boreal Shield of Saskatchewan. The low value in the Prairies of Alberta reflects the nature of the data used to generate these estimates. Historically no forest fires have been reported from this area. We repeat that these risk values cannot be used without risk of error. A means of dealing with this uncertainty is discussed below.

Examples: For Scenario 1, consulting Sheet 1 of the spreadsheet on risk agents, one finds that fires in the boreal plains affect all species, including white spruce, with stand replacing (100%) mortality that is modeled as an annual event. Sheet 2a of the spreadsheet indicates that the annual probability of fires is 0.079 for all species growing in the boreal plains. A similar process for the prairies example indicates that the annual probability of a stand replacing fire is 0.01%.

Summary of risks and impacts
Fire is modeled as an event that occurs with an annual probability of occurrence that has a uniform distribution and varies by jurisdiction and ecozone. Because of jurisdictional variations in fire control activity and fire reporting statistics it was deemed necessary to retain this attribute in the analysis. The risk associated with fire occurrence is based on the percentage annual area burned. This value ranged from 0.001% in the Mixedwood plains to 1.499% in the Boreal Shield in Saskatchewan. The impacts are assumed to result in 100% mortality.

Pest (Insect and Disease) Risks and Impacts
Background
In general pest risks are derived from experience with the behaviour of these organisms in native stands. This information may be gleaned from several compilations developed in Canada for pests (Ives and Wong 1988, Martineau 1984, etc.) and the relevant portions of American publications (Furniss and Carolin 1977, Drooz 1985) on insects. Information on diseases can be gleaned from several sources such as Hiratsuka (1987), Callan (1998) and Sinclair *et al.* (1987). As to control options, two sources are helpful: Martineau (1984) and the compilation by Armstrong and Ives (1995).

Table 5 is a listing of pests that were considered to be important in fast growing plantations. The agents are included in this tabulation if the experts agreed that they could significantly reduce yields in plantations of tree species that might be used in Canadian afforestation programs. These tables are organized by host species to simplify access to the information provided in the spreadsheet. In each table the ‘Host range’ lists the species that the risk agent is known to affect. The geographical range over which the risk agent is likely to occur is called ‘Risk agent range”. In these tables the risk agent impacts are just characterized as “growth loss”, “Mortality”, or “stand replacing (mortality)”. Similarly, their temporal occurrence is designated as “annual” “cyclical” or “chronic”. Details associated with impacts and temporal occurrences of these agents are to be found in the appended spreadsheet (Appendix 1). A subset of these pests affecting fast growing plantations, illustrative of the different impacts and temporal occurrence patterns and which are used in the scenarios modeled, are described in the examples below.

A general scheme was developed for handling disturbance agents. This scheme could accommodate fires and weather events such as drought. However, in dealing with biotic agents the variation in behaviour over the life of stands, ecozones and time specific risk rates present special challenges This information is captured in the spreadsheet that accompanies this report. (Appendix 1). In dealing with each pest, an attempt was made to obtain information on the epidemiology of the agent involved so that temporal aspects of its occurrence could be modeled. Where necessary, variations in the temporal patterns over geographic ranges were accounted for by creating separate epidemiological profiles for the each group of ecozones as appropriate. The temporal distribution of outbreaks of pests modeled with annual probabilities of occurrence was, for the most part, considered to be uniform. Their impacts, whether growth reduction or mortality, was apportioned over varying times, depending on the nature of the damage and the lifecycle of the agent. Agents with known cyclical dynamics were handled similarly except that the time of initiation and development of damage was linked to conditions of outbreak development current in the ecozone. The length of the outbreak period when trees are at risk, the period between damaging population densities when trees are not at risk, the beginning of the current cycle, and the probability of a stand becoming infested once the outbreak cycle begins are all parameters that must be specified for these pests. Also, the temporal pattern of damage development, whether growth reduction or mortality, was linked to the appropriate time in the outbreak period and used to calculate time specific impacts. Agents that are chronic problems in plantations were described with the probability of infestation and the pattern of damage development. By and large agents in the last category were disease-causing organisms, although an insect is used in the example below. For every agent, the host stand ages over which they presented a threat was specified. The impact factors, reported in percentages, were used against the standing volume at the beginning of the year being considered. Thus growth reduction impacts reduced the expected increments given a certain stand volume, and mortality impacts were assessed against the standing volume of the stand in the year considered. Because several agents will affect a stand over its life time, an attempt was made to model multiple impacts so only mean stand performance volumes can be compared under different disturbance occurrence scenarios. Thus the examples used were picked to illustrate the impacts of these agents against the expected volume curves (without disturbances).

Risk agent by host species

Table 5 is broken down into sections that deal with species having a similar host range. Thus Table 5a deals with agents that can affect all species or conifers or 'hardwoods' (broadleaved deciduous trees). Note that fire and weather events such as drought and have been included for purposes of completeness. Examples of their probabilities of occurrence and impacts have been dealt with above. Tables 5b to 5d deal with pests affecting 'hardwoods' that are grouped by host genus: *Alnus* (alder), *Populus* (poplars and aspens including hybrids) and *Salix* (willows) respectively. Similarly, Tables 5e to 5g list conifer pests of spruces (*Picea*), pines (*Pinus*), and larches (*Larix*). Care must be taken in interpreting the probability of an event occurring in a plantation. This probability assumes that stand conditions (such as age) are appropriate and that, where appropriate, there is an outbreak in progress. The probability reported is the maximum calculated or from the Spreadsheet. Similarly, the maximum impacts reported are the highest reported or the maximum that can be expected, given the annual mortality rates reported for chronic diseases, for instance. These impacts are only reported by way of example of what could affect stands; it is essential that the spreadsheet be consulted for details on any particular agent operating on stands of a given kind in a particular ecozone.

Table 5a. Risk agents affecting many hosts

Host range	Risk agent	Agent range	Impacts*	Temporal Pattern	Prob.**	Max. Impact
All species	Weather events	All	GL&M	Annual	***	***
All species	Fire	All	SR	Annual	***	***
Hardwoods	Ice storms	East	M	Annual	2.5	25.0
Conifers	Rodents	All	M	Cyclic	10.0	30.0
Hardwoods	Rodents	All	M	Cyclic	10.0	30.0
Conifer	Ungulates	Boreal	GR	Annual	10.0	6.0
Hardwood	Ungulates	All	GR	Annual	10.0	2.0

*GR=growth loss, M=Mortality, SR=Stand replacing mortality
** Probability of impact occurring (expressed as a percentage).
*** See discussion in appropriate section above.

Table 5b. Risk agents affecting red alder

Host range	Risk Agent	Agent range	Impact	Temporal pattern	Prob.*	Max. Impact
Alder	Alder sawflies (2 spp.)	BC	GR	Cyclic	0.1	10.0
Alder	Alder flea beetle	BC	GR	Cyclic	0.1	10.0
Alder**	Exotic ambrosia beetles	BC	M	Chronic	0.05	80.0

* Probability of impact occurring (expressed as a percentage).
**Introduced species

Table 5c. Risk agents affecting Poplars and their hybrids

Host range	Risk agent	Agent range	Impact	Temp. pattern	Prob. *	Max. Impact
Populus spp.	*Platypus mutates***	PM, AM, MWP	M	Chronic	0.01	40.0
Populus spp.	*Melampsora* rusts	All	GR	Annual	10.0	40.0
Populus spp.	*Marsonnina brunnea*	BS (Nfld.)	GR	Annual	10.0	40.0
Exotic poplars & hybrids	*Mycosphaerella/ Septoria* leaf spot & canker	All	M	Annual	7.0	85.0
Populus spp.	*Venturia/Pollacia* leaf & shoot blight	All	GR& M	Annual	10.0 5.0	50.0 85.0
Populus spp.	*Cytospora* canker	All	M	Chronic	60.0	100.0
Aspen	Forest tent caterpillar	P, BP, BS	GR& M	Cyclic	80.0 80.0	90.0 10.0
Aspen	Large aspen tortrix	Boreal Pl.	GR	Cyclic	40.0	60.0
Populus spp.	Cotton leaf beetle	All	M	Annual	1.0	40.0
Populus spp.	Poplar borer	All	M	Chronic	0.1	20.0
Populus spp.	Poplar-willow borer***	All	M	Annual	0.1	45.0

* Probability of impact occurring (expressed as a percentage).
**Potential pest of poplars and willow, not yet established in North America.
***Introduced from Europe

Table 5d. Risk agents affecting willows

Risk agent	Agent range	Impacts	Temporal Pattern	Prob.*	Max. impact
*Platypus mutates***	PM, AM, MWP	M	Chronic	0.01	40.0
Melampsora rusts	All	GR	Annual	10.0	85.0
Physalaspora/Botryosphaeria canker &dieback	BS(Nfld.)	GR	Annual	7.0	30.0
Venturia/Fasicladium scab blight*	All	M	Annual	3.0	80.0
Cytospora canker	All	M	Chronic	60.00	100.0
Poplar borer	All	M	Chronic	0.1	20.0
Poplar-willow borer***	All	M	Annual	0.1	45.0

* Probability of impact occurring (expressed as a percentage).
**Potential pest of poplars and willow, not yet established in North America.
***Introduced from Europe.

Table 5d. Risk agents affecting spruces

Host range	Risk agent	Agent range	Impacts	Temporal pattern	Prob.*	Max. impact
Sitka, white & Norway spruces	White pine weevil	All	GR	Chronic	90.0	40.0
All	*Armillaria* root disease	All	GR& M	Chronic	60.0 0.5	25.0 55.0
All except Sitka	Yellow-headed spruce sawfly	E&W	GR& M	Annual	10.0 10.0	20.0 10.0
All	*Tomentosus* root rot	All	GR & M	Chronic	1.0 1.0	15.0 60.0
White & red	Spruce budworm	E&W	GR & M	Cyclic	5.0 5.0	80.0 36.0

* Probability of impact occurring (expressed as a percentage).

Table 5e. Risk agents affecting Pines.

Host range	Risk agent	Agent range	Impac ts	Temporal pattern	Prob.*	Max. Impact
All on list	Diprionid sawflies	E&W	GR	Annual	10.0	20.0
E. white pine	White pine weevil	East	GR	Chronic	90.0	40.0
Red pine	*Annosus* root rot	East	GR& M	Chronic	100.0 100.0	15.0 95.0
Red pine	*Scleroderris* canker**	East	M	Chronic	0.1	100.0
E&W white pines	White pine blister rust	E&BC	M	Chronic	100.0	25.0

* Probability of impact occurring (expressed as a percentage).
**European race

Table 5 f. Risk agents affecting larches

Host Range	Risk Agent	Agent range	Impacts	Temporal pattern	Prob.*	Max. Impact
Exotic larches	European larch canker**	AM	GR& M	Chronic	0.1 0.1	50.0 10.0
East & exotic larches	Eastern larch beetle	E&W	M	Cyclic	1.0	90.0
All larches	Larch sawfly	E&W	GR & M	Cyclic	5.0 1.0	50.0 100.0

* Probability of impact occurring (expressed as a percentage).
**Introduced, regulated pest

A note on alien pests
Please note that we have not included any world-wide assessment of potential invaders. We give one example (*Platypus mutates* on poplars) because of its recent rise to prominence in

European poplar culture and to serve as a reminder that there is great risk from this source. However, there is a need to review listings of interceptions at ports and the collective Canadian experience of all potential introductions if foreign pests are to be assessed. Several introduced pests established in Canada have been included in the survey if they are known to threaten plantations.

Examples

<u>*A cyclic pest*</u>: The spruce budworm is an example of a cyclic insect pest that causes mortality and growth loss of white and red spruces stands right across Canada (Table 5d). Sheet 1 of the spreadsheet (Appendix 1) indicates that the insect affects stands 20 years or older. Mortality occurs in years 5 to 13 after outbreak initiation and amounts to 36% of the initial volume (4% for 9 years). There are 14 years of growth reduction on the surviving trees, peaking at 80% of the expected annual growth. In the 16^{th} year of the outbreak no further growth reductions are applied under the assumption that the trees have recovered. From Sheet 2b (for cyclic events) we see that 1) the interval between outbreaks (the time during which there is no risk of the agent) is 17 to 21 years, (2) the outbreak length (the time during which there is a risk of an outbreak occurring) is 14 – 18 years, (3) the annual probability of occurrence of an outbreak during the period of time where there is risk is 5%, (4) the year of last occurrence in the region (in order to initialize the agent on its cycle) is 1990.

<u>*A chronic pest:*</u> The poplar borer is a considered a chronic pest of all species in the genus *Populus* (Table 5c*).* Consulting the spreadsheet data indicates that it is causes tree mortality after stands reach an age of 15 years, and mortality begins 2 years after its occurrence in the stand. This mortality is 0.5% in infested stands and lasts for the life of the stand. Sheet 2c indicates that after age 15, the annual probability of a stand becoming infested is 0.1%.

<u>*An occasional pest*</u>: The cotton leaf beetle also affects poplars but is thought to occur sporadically so it is modeled with an annual probability of occurrence (Table 5c). Consulting the Sheet 1 of the spreadsheet indicates that the pest only impacts stands that are less than 15 years of age and that the mortality induced occurs in the year after infestation and amounts to 20% in each of the two following years for a total of 40% per event. Sheet 2a (for annual events) indicate that the probability of an outbreak of this pest occurring is 1% and this probability has a uniform distribution.

Summary of risks and impacts

Pests are usually not a problem in native forests, however in fast growing plantations they pose an unknown threat because conditions in these habitats are unlike those found in nature. This implies that plantation culture will have to accommodate pest management as a key component of the undertaking. For pests with cyclic population behaviour, the risks of incurring impacts are also cyclic. The tables above indicate that growth reductions from pests may reach 80% of expected growth with 80% chance of occurrence once an outbreak of tent caterpillars on aspen occurs (Table 5c). Although the risk of outbreaks in this case is cyclic, the recurring epizootics may damage stands substantially when tree mortality occurs: the spruce budworm can result in close to 40% losses in standing volumes of some stands (Table 5e) and the probability of this occurring is 5% once an outbreak starts. Chronic pests pose special problems because they whittle away at the stand. Although the annual mortality rate may appear low, when these forces operate over a long period (decades) the result is yields far below projected. Thus, *Cytospora* canker on susceptible poplar hybrids can result in complete destruction (100%) of the stand from a persistent infection that might have 60% chance of occurring in a stand. This level of risk will make plantation culture with hybrids of this sort economically unviable. This is an extreme case of extreme cases. Not all agents pose this sort of risk, however the potential to experience stand-replacing mortality is real and the probabilities finite. Nevertheless, this points to the need of having a sound genetic program as a basis for selecting planting stock, for having appropriate silviculture procedures in place and having pest management systems built into the planning and tending of these installations. After all, forest plantations are successfully managed to produce spectacular yields.

Putting it all together

The following scenarios are presented to illustrate the nature of outputs derived from the model (described in Appendix 2) using the data obtained through the expert process. The yields on the growth function appear unrealistically high so the results should be scaled appropriately. As a consequence, we will only report on percentages losses in dealing with impacts. This observation, begs the question, however, as to what the appropriate yield functions are for this type of exercise. To circumvent this problem, the decision was made to report all impacts in the tables that support this document in terms of percentages of the expected volume or increment. The scenarios are intended for illustrative purposes only, and so do not represent any real or contemplated scenario. In all of these scenarios, stands were replanted after failure, with no planting delay. Plantation failure was assumed to occur when the cumulative mortality in any year was greater than or equal to 100%. Annual increments were reduced when reductions to stocking occurred through mortality.

Scenario 1 – White Spruce in the Boreal Plains Ecozone. (Figure 1)

- Fire – 0.79% annual probability. All ages eligible.
- Assumed a high drought tolerance species in a medium drought risk zone
- Growth reducing drought – 8% annual probability, causing growth reduction (20%, 10%, 5%). Only affects stands greater than 3 years of age
- Mortality causing drought – 2% annual probability, causing 8% mortality (3%, 3%, 2%). Only affects stands greater than 3 years
- Chronic growth reducing drought – 8% annual probability, causing chronic growth reduction of 16% for rest of life of stand. Only affects stands less than 3 years of age.
- Spruce Budworm – Outbreak started in 1990, has a length of 14-18 years, during which time there is a 5 % annual probability of a disturbance, causing the following impact:
  - 4% mortality from year 5 to year 13 after the ‘event’
  - 14 years of growth reduction, peaking at 80% from year 4 to year 9
  - This is followed by an interval of 17-21 years when there is no risk. Only affects stands greater than 20 years of age.
- Yellowheaded Spruce Sawfly - 10% annual probability when less than 20 years of age. Causes two years of 5% mortality when it occurs.

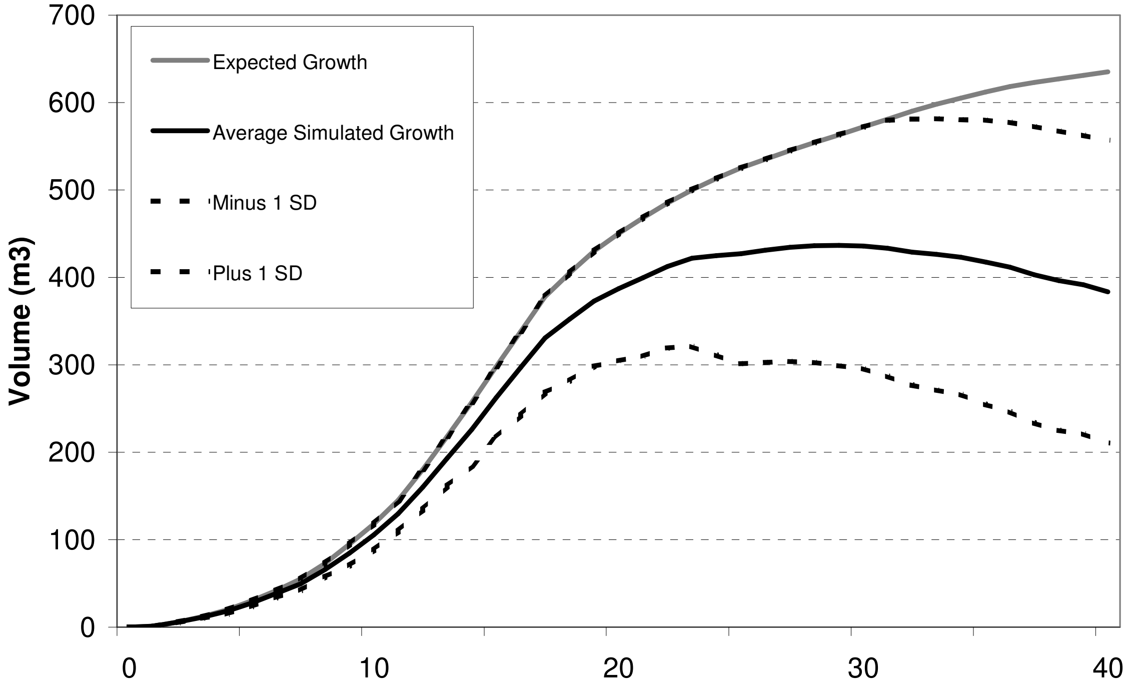

Figure 1 – Mean and standard deviation observed growth of a white spruce plantation in the boreal shield ecozone from 256 monte carlo simulations of risk agents defined for scenario 1. This assumes that no spruce budworm management will be conducted.

In this case, it appears that the potential plantation yield increases monotonically over the 40-year period modeled. However, the mean yield culminates at year 30 corresponding to the onset of spruce budworm mortality impacts. Note that some stands continue to track the expected yield curve but these represent stands in the upper percentiles. Stands in the lower percentiles perform much more poorly starting about year 15. The investor may choose to rogue these at some point if they could be recognized in surveys. The simulation suggests that the mean losses amount to 27.5% of the volume at age 30, and 37% by age 40. These losses are very similar to losses reported for spruce budworm in native stands. Note that at age 40, 16% of the stands (those in the lower performing percentiles) would yield less than 32% of the expected volume. The corresponding yield for the top 16% of stands would be above 82% of the expected volume.

Scenario 2 – Hybrid Poplar in the Prairies Ecozone (Figure 2)

- Fire – 0.01% annual probability. All stand ages are eligible
- Assumed a low drought tolerance, and a high drought risk zone
- Growth reducing drought - 12% annual probability of a (20%,10%,5%) growth reducing causing drought disturbance when greater than 3 years
- Mortality causing drought - 5% Annual probability of an (8%,8%,4%) mortality causing drought disturbance when greater than 3 years

- Chronic growth reducing drought - 12% probability of a chronic 40% growth reducing disturbance that lasts the life of the stand, which can occur when stand is less than 3 years of age
- Aspen defoliators (FTC, LAT) – The last outbreak started in 2002, and will have a length of 2-4 years, during which the annual probability of occurrence will be 5% on stands older than 20 years. This will cause 10% mortality in the year in which it occurs, and {70%,90%,90%,90%75%,15%) growth reduction over the next six years. This will be followed by an interval of 9-11 years during which there will be no risk.
- Cotton Leaf Beetle – 1 % annual probability of two years of 20% mortality when the stand is less than 15 years of age.
- Poplar Borer – After age 15, a 0.1% annual probability of a chronic mortality of 0.5% per year for the rest of the life of the stand.

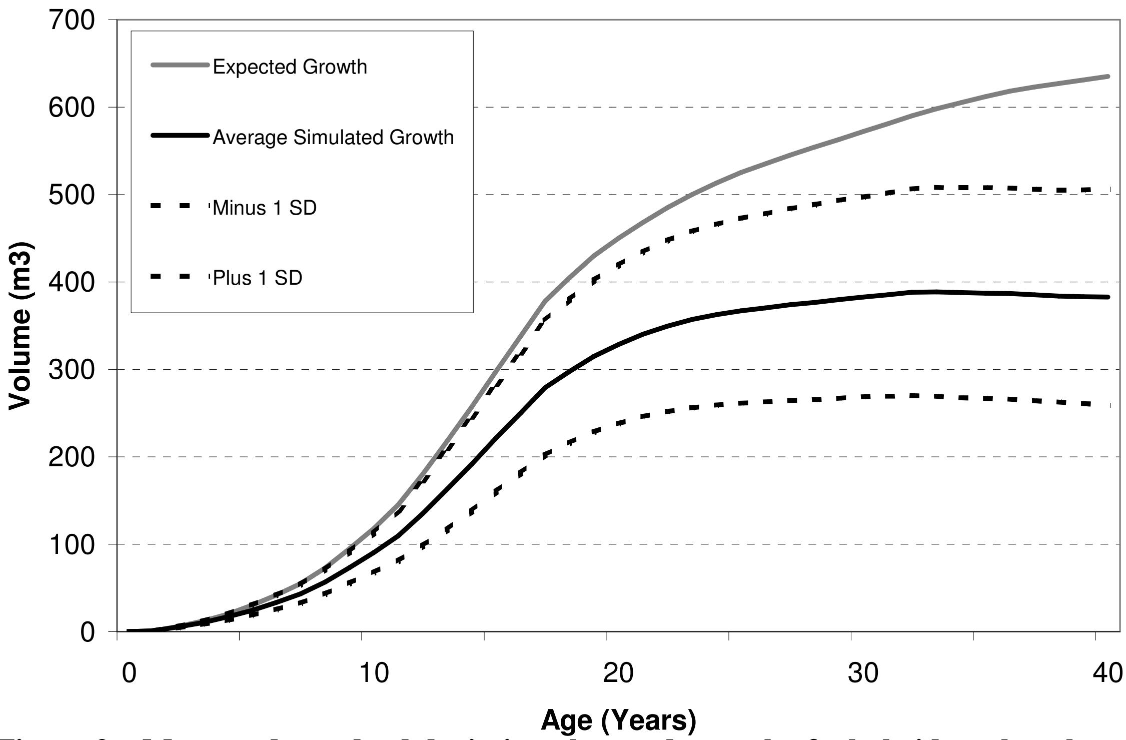

Figure 2 – Mean and standard deviation observed growth of a hybrid poplar plantation in the prairies ecozone from 256 Monte Carlo simulations of risk agents defined for scenario 2. This scenario assumes a low drought tolerance clone in a high drought susceptibility region

As in the example above, the expected growth continues to rise over the period modeled, but the mean volume levels out after about year 30. For stands that are 1 standard deviation below the mean this occurs at about age 20 and for those 1 standard deviation above the mean this happens at about year 35. At age 30, the mean yield is 33% below the expected value and this is 37% lower than the expected yield. At age 40, 16% of the stands have yields above 80% of the expected values and 16% have yields less than 43 % of the expected volume. These results indicate that most plantations should be harvested between ages 20 and 35 to maximize the yields. A well-designed monitoring program could indicate the harvest sequence of such stands and the model could be used to calculate the savings from such an optimized harvesting plan.

Scenario 3 – White Spruce Plantation in the boreal shield ecozone with SBW control (Figure 3)

All the same risk agents and probabilities, however, this time with SBW control. In the control scenario, SBW has the same probability of occurrence, but the impacts are much reduced. Causes only 4 years of 4% mortality, rather than 9 years. Also, growth reduction is capped at a maximum of 20%, though it still occurs for14 years.

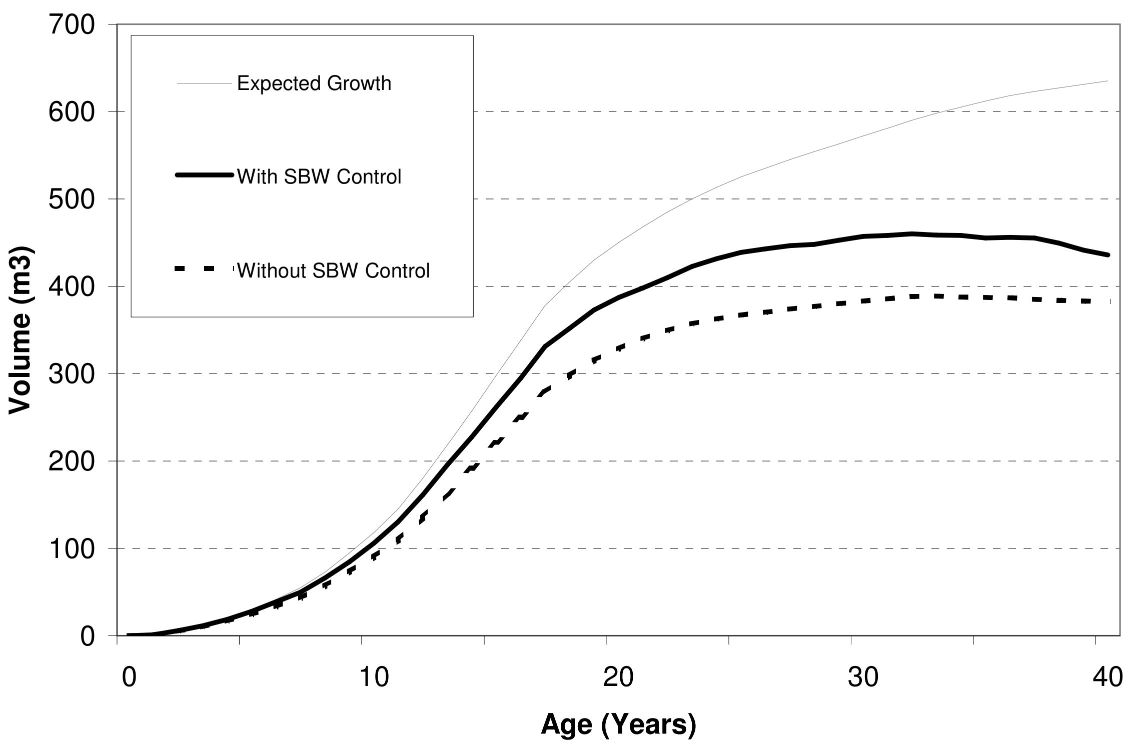

Figure 3 – Expected mean growth of a white spruce plantation in the boreal plains ecozone with and without spruce budworm control. (Scenario 3)

The result indicates that the mean yields are increased as a result of measures to control spruce budworm. However, the time of yield culmination is not changed by the control measures. Thus at age 30, the mean yield from the simulation runs with spruce budworm controls is 118% that of stands grown without treatments. Yield in the treated stands are still 19% below the expected yield compared to a 32% yield reduction in untreated stands in this simulation. This difference is attributed to the effects of weather, fire and yellowheaded spruce sawflies on stand development. The suggestion is that over half the depression in yield can be managed by pest mitigation treatments that are 80% effective.

Scenario 4 – Hybrid Poplar Plantation in the prairies ecozone with high drought tolerance clone (Figure 4)

All the same risk agents and probabilities, however, this time assuming a high drought tolerance clone. This changes the drought probabilities and impacts to the following:

- Growth reducing drought - 12% annual probability of a (20%, 10%,5%) growth reducing drought disturbance when greater than 3 years. This is unchanged.
- Mortality causing drought - 5% Annual probability of a (4%,4%,2%) mortality causing drought disturbance when greater than 3 years (reduced from an 8%, 8%, 4% mortality disturbance)
- Chronic growth reducing drought - 12% probability of a chronic 20% growth reducing disturbance (reduced from 40% for low tolerance clone) that lasts the life of the stand, which can occur when stand is less than 3 years of age

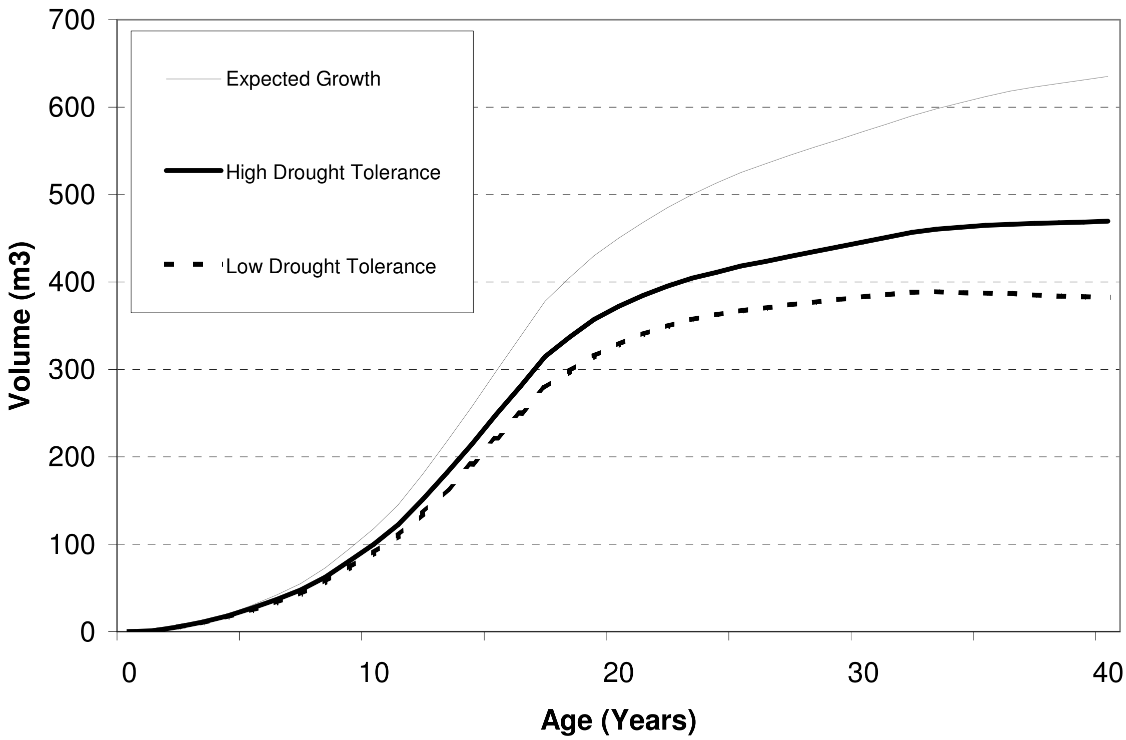

Figure 4 – Expected mean growth of a low vs high drought tolerance hybrid poplar clone in the prairies ecozone

In this scenario the effect of choosing the right genetic material for the conditions to be experienced by the growing stock elevates the yields 13% at age 30. However, the yields of the plantations with 'high drought tolerant' material culminate at age 35 and are 7% above what they are at age 30. The yield at this point is 20% greater than yields in plantations of 'low drought tolerant material'.

These scenarios give a general idea of what kinds of savings may be expected from different management interventions to protect plantations from pests or selecting the appropriate genetic material for the site and environmental conditions under which they are to be grown. When better information on yield curves is available other types of analyses could be performed. For example, the time marginal growth increments fall below the discount rate could be explored to optimize the harvest schedules. The return on investments from pest control or genetic selection work could be more objectively evaluated. Other inputs, such as weed control, site protection and silvicultural inputs could be built into scenarios to explore their impacts on yield, carbon sequestration and, ultimately, the viability of these projects. As importantly, the simulation approach gives the analyst some feel for the uncertainties around the mean projection and the exploration may be used to develop strategies around harvesting these stands. The model also shows how much gain may be achieved by research investments in this area provided that a theoretical upper limit to productivity could be developed. In the current simulator, the suggestion is that, with our best hybrid poplar selection for the prairies, yields are still 23% below what they could be when yields culminate at age 30.

CONCLUSIONS

The process undertaken to develop risk estimates for disturbances that might threaten plantations produced a listing of disturbance agents that might be of sufficient threat to tree species used in afforestation programs on ‘Kyoto qualifying lands’. These agents included abiotic agents, such as drought, ice storms and fire, and biotic agents: pests, including mammals, insects, and diseases. Both native and exotic pests that were thought to pose serious threats to plantations were included. Competition from weeds and intra-tree interactions were not included in this consideration because it was assumed that plantation silvicultural treatments would alleviate such problems in properly managed systems. Nevertheless, vegetation management has a direct effect on some agents such as fire, sawflies and some root diseases. The spatial and temporal occurrence characteristics of disturbance agents were documented down to the ecozone level in most cases. Where necessary, differences among ecoregions, within ecozones, were documented. No attempt was made to model interactions among disturbances. The impacts of agents were characterized as to whether they caused growth loss, partial, or stand-replacing tree mortality. If control options existed attempts were made to state their probable efficacy and costs of application. A *key message* is that the information presented would provide links to economic analyses that investors might wish to consider.

The range of impacts caused by individual agents depends on stand age, ecozone and the species of tree affected. Impacts might result in either growth reductions or tree mortality. Weather extremes are assigned probabilities of occurrence which range from 4% in moist forests to 20% in the semi-arid grass lands. Impacts depend on the species tolerance to drought, thus mortality may range from 16% in moist forests to 80% in grasslands for the least tolerant species. Fire occurrence is modeled as stand replacing fire (100% tree mortality) and the risk of fire is estimated as equal to the percentage annual area burned. This varies from 0.01% to 1.499. Pests are classified as representing chronic, cyclical or annual threats. Their impacts may range up to 80% growth reduction during outbreaks and 100% mortality from chronic disease infections. Despite these extreme impacts, a *key message* resulting from this analysis is that plantation culture is feasible provided a well-integrated management plan to select the appropriate planting stock, tend stands and manage pests can be implemented.

A model (Appendix 4) was prepared to assess effects of multiple risk agents on plantation performance. A Monte Carlo approach was taken to produce hypothetical yield curves for plantation volumes. By comparing yields with and without disturbances the impacts of various agents could be compared. Similar runs with and without control measures would provide the gains from a plantation protection program. Although climate change effects on altering the risk structure plantations might face were not considered, the model might be used to obtain approximate impacts where the risk of drought or fire are concerned. (This is achieved by comparing local scenarios to those from the altered environment.) A few scenarios are presented to illustrate the model application. A *key message* from this exploration is that reasonable impacts are obtained with the data base used but the model needs to be developed with realistic and theoretical maximum yield curves.

A *key message* is that future development of the information product is recommended to explore policy alternatives. This would be detailed review of the work and preparation of a report suitable for public use, ultimately for use on a website. Advantage could be taken of several opportunities provided by this work in addition to its original purpose. Attempts should be made to incorporate these considerations with economic and carbon accounting models that are already being developed. More immediately a decision support system for plantation management should be developed that incorporates disturbance effects. The information assembled here would represent the basic data on which such a system could be developed. What is most appealing about this is that these developments could be made available to the interested public electronically for immediate application. Such a system could be integrated with other elements to undertake investigations of national forest investment strategies. The investigation of the balance required by the TRIAD approach to forest-land management, for example, could be addressed with such systems.

Considerable uncertainties in the data used to estimate the probability of occurrence of disturbances were encountered in this exercise. The sensitivity of the model and its performance with respect to many of the assumptions made need to be explored. Many of the pest attributes are based on data from conditions in natural forests. These probabilities and impact rates may not apply to conditions found in plantation culture. A *key message* from this is that there is a need to thoroughly examine the literature for information and cases where pests have altered their behaviour in moving from native to plantation habitats.

Coupled with this is the need to examine existing plantations to determine what organisms have become important causes of yield reduction. This work should be integrated with the literature review, database development and an analysis of gains to be made through research on particular problems in plantation management. A means of making this information available through web products and demonstration plantations should be developed. A *key message* is that the PDA demonstration sites and other plantations should be used to assess and validate the information collected here. These sites should be further developed to provide longitudinal case studies and a validation of the conclusions to be drawn from forest plantation culture in Canada. This process is described in appendix 3 entitled ‘Next Steps’.

REFERENCES

Armstrong, J.A.; Ives, W.G.H. 1995. *Editors* Forest insect pests in Canada. Natural Resources Canada, Canadian Forest Service, Ottawa. ON.

Broberg, C.L.; Borden, J.H.; Mumble, L.M. 2002. Distribution and abundance of *Cryptorhynchus lapathi* on Salix spp. In British Columbia. Can. J. For. Res. 32:561-568.

Callan, B. 1998. Diseases of Populus in British Columbia. A diagnostic manual. Natural Resources Canada, Pacific Forestry Centre.

Cerezke, H.F.; Pendrel, B.A. 1995. Root collar weevils, *Hylobius* and *Steremnius* spp. Pages 253-263. *In* Armstrong, J.A.; Ives, W.G.H. 1995. *Editors* Forest insect pests in Canada. Natural Resources Canada, Canadian Forest Service, Ottawa. ON.

Drooz, A.T. 1985. Insects of eastern forests. U.S. Dept. Agric., For. Serv., Misc. Publ. 1426. Washington, DC.

F.A.O. 1979. Poplars and willows in wood production and land use. F.A.O. of the United Nations, FAO Forestry Series No. 10. 328 pp.

Furniss, R.L., Carolin, V.M. 1977. Western forest insects. U.S. Dept. Agric., For. Serv., Misc. Publ. 1339. Washington, DC.

Graham, S.A. 1956. The larch sawfly in the lake states. For. Sci. 2: 132-160.

Hiratsuka, Y. 1987. Forest tree diseases of the prairie provinces. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-286.

Hiratsuka, Y. and H. Zalasky. 1993. Frost and other climate-related damage of forest trees in the prairie provinces. Forestry Canada, Northern Forestry Centre Information Report NOR-X-331.

Hogg, E.H. 1994. Climate and the southern limit of the western Canadian boreal forest. Can. J. For. Res. 24: 1835-1845.

Hogg, E.H. 1999. Simulation of interannual responses of trembling aspen stands to climatic variation and insect defoliation in western Canada. Ecol. Model. 114: 175-193.

Hopkin, A.A. T. Williams, R. Sajan, J. Pedlar, and C. Nielsen. 2003. Ice storm damage to eastern Ontario forests –1998-2001. Forestry Chronicle Vol 79: 47-53

Ives, W.G.H.; Wong, H.R. 1988. Tree and shrub insects of the prairie provinces. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-292.

Ives, W.G.H.; Nairn, L.D. 1966. Effects of defoliation on young upland larch in Manitoba. For. Chron. 42: 137-142.

Jordon, Y., Filion, L., Cloutier, C. 1994. Long-term impact of insect defoliation on growth and mortality of eastern larch in boreal Quebec. Ecoscience 3: 231-238.

Laflamme, G. 1998. La rouille vésiculeuse du pin blanc: ça se contrôle!. p. 41-48 *in* Receuil des conférences du colloque tenu à Mont-Laurier les 3 et 4 juin 1998. 123pp.

Laflamme, G. 1999. Traitement réussi d'une plantation de pins rouges affectée par le *Gremmeniella abietina*, race européenne. Phytoprotection 80: 55-64.

Langor, D.W. and A.G. Raske. 1989. The eastern larch beetle, another threat to our forests (Coleoptera: Scolytidae). Forestry Chronicle 65:276-279.

Lavallée, A. 1992. The spread of white pine blister rust in young white pine plantations. Information Report LAU-X-101E Forestry Canada. Quebec Region 23pp.

Magasi, L.; Pond, S. 1982. European larch canker: a new disease in New Brunswick and a new North American host. Plant Disease. 66: 339.

Mattson, W.J.; Hart,E.A.; Volney, W.J.A. 2001. Insect pests of *Populus*: coping with the inevitable. *In* Poplar Culture in North America. Part A, Chapter 7. *Edited by* D.I. Dickman, J.E. Eckenwalder, and J. Richardson. NRC Research Press. National Research Council of Canada. Ottawa, ON K1A 0R6, Canada pp 219-248.

Martineau, R. 1984. Insects harmful to forest trees. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Morse, B.W.; Kulma, H.M. 1986. A method of hazard-rating white spruce plantations for yellowheaded spruce sawfly defoliation. Northern Journal of Applied Forestry 3: 104-105

Morrison, D. and Mallett, K.1996. Silvicultural management of Armillaria root disease in western Canadian forests. Can. J. Plant Pathology. 18: 194-199.

Nielsen, C., O. Van Dyke and J. Pedlar. 2003. Effects of past management on ice storm damage in hardwood stands in eastern Ontario. For Chron. 79: 70-74.

Ostaff, D. 1985. Age distribution of European larch canker in New Brunswick. Plant Disease. 69: 796-798.

Shaw, C.G. and Kile, G.A. (ed.) 1991. Armillaria Rot Disease. USDA, For. Service, Agric. Handbook No. 691. 233 pp.

Sinclair, W.A., Lyon, H.H. and Johnson, W.T. 1987. Diseases of trees and shrubs. Cornell Univ. Press, Ithaca New York. 574 pp.

Whitney, R.D. 1977. Polyporus Tomentosus Root Rot of Conifers. Fisheries & Envir. Canada, Can. For. Service, G.L.F.R.C. Forestry Tech Rep. No. 18. 12 pp.

Whitney, R.D. 1989. Root rot damage in naturally regenerated stands of spruce and balsam fir in Ontario. Can. J. For. Res. 19: 295-308.

Whitney, R.D. 1993. Damage of Tomentosus root rot in white spruce plantations in Ontario, and effects of thinning on the disease. For. Chron. 69: 445-449.

Whitney, R.D. 1989. Root rot damage in naturally regenerated stands of spruce and balsam fir in Ontario. Can. J. For. Res. 19: 295-308.

Wilson,L.F.; Wilkinson, R.C. Jr.; Averill,R.C. 1992. Redheaded pine sawfly: its ecology and management. U. S. Department of Agriculture Forest Service. Handbook 694. 53p.

APPENDIX 1

The content of this appendix is in an EXCEL file that should accompany this report.

APPENDIX 2

A MODEL

Some means of handling these multiple risks and evaluating their impacts on productivity is essential if the myriad of threats are to be integrated into the decision making process required to invest in plantations. There is a further problem that disturbances can only be categorized in terms of probabilities of occurrence and probabilities are derived from observing several outcomes. Thus it is impossible to provide an estimate of success (or failure) of an individual plantation when success is modeled in terms of a certain volume at harvest. One way of handling these problems is to structure a model that uses these risks and make assumptions about their combined effects to model outcomes. Monte Carlo simulations, involving several runs, provide a means to obtain estimates, distributions of such estimates, and variances of the estimates to be used in decision-making. This approach has the appeal that it provides a prediction as well as some estimate of uncertainty in the estimate. Although it may not provide a suitable prediction for a single investment, it does provide estimates of the expected gains from a portfolio of such undertakings.

Statistical Concepts

A simulation model was developed to undertake such analyses. The model was coded in Visual Basic, and implemented in a Microsoft Excel environment. It reads data from input data worksheets, and outputs data to output data worksheets. The model does Monte Carlo simulations. The occurrence probabilities are modeled using a uniform random number generator that draws numbers between 0 and 100. Any number drawn that is less than the annual probability percentage means that the event occurs. For example, if the annual probability for a given risk agent was 4.5%, a draw of 8 would result in the event not occurring, while a draw of 1.7 would result in the event occurring. At present, there are no correlations between risk agent types built in. Each acts independently of the others. In certain cases, this may not be a correct assumption. Future improvements to the statistical algorithm can be incorporated to deal with this when more information on conditional probabilities can be obtained about these systems. In its present configuration, the model can only generate uniform random variates, either as unit random variates (between 0 and 1), or by specifying other minimum and maximum values. In the future, improvements to the statistical algorithm can be implemented such that risk agents can be characterized using other statistical distributions (e.g. normal, log-normal, triangular, etc.)

Risk Agents

The model handles each risk agent differently depending on whether it is categorized as ‘annual’, ‘cyclic’, or ‘chronic’. Where the temporal occurrence of a disturbance agent was not well enough known its probability of occurrence was considered to be an annual event with a uniform probability of occurrence. This is perhaps the most data neutral method of handling this uncertainty. By providing different values for the temporal characteristics of a disturbance agent in different ecozones, some measure of spatial variation in their impacts can be accommodated by the model. This can only occur if the nature of this variation is known. As importantly, these parameters can be altered to reflect changes in climate on their effects, if they are climate driven. Climate change effects can thus be modeled using the information in this manner.

Annual

Annual risk agents have an annual probability of occurrence. The probability of an annual event in any given year is independent of its occurrence in any previous years. An annual event can have impacts that only occur in the year in which an event occurs, or it can have impacts that linger for a number of years after the event occurs. Fire is an example of an annual risk agent that has impacts only in the year in which the event occurs. Drought is an example of an annual risk agent that has impacts that linger for a number of years after an event occurs.

Cyclic

Many insects are cyclic risk agents. Cyclic risk agents have periods of time, called the outbreak interval, during which there is no risk of the agent occurring. They also have periods of time, called the outbreak length, during which there is a risk of the agent occurring. The sum of the outbreak interval and the outbreak length corresponds to the traditional peak to peak outbreak cycle in forest entomology.

During the outbreak length, cyclic risk agents behave in the same way as annual risk agents. That is, they have an annual probability of occurrence, with the probability of an event independent of its occurrence in previous years during the outbreak length. Cyclic risk agents can also cause impacts only in the year in which the event occurs, or impacts that linger for a number of years after the event.

Chronic

Some diseases are examples of chronic risk agents. Chronic risk agents have an annual probability of starting, and a length of time for which they occur. The maximum length of time is the rest of the life of the stand. Chronic risk agents have impacts that occur for this length of time.

<u>Impacts</u>

Once the disturbance has occurred, it is necessary to model its impact. Only growth reduction and mortality are modeled. Again, if impacts vary by ecozone, then this can be accommodated in the system. Similarly changes associated with changing climate can be accounted for by using the appropriate altered values in simulations.

Mortality

Mortality acts to reduce the standing volume. After a mortality event, the standing volume will be less than it was before the event. Mortality also reduces the stocking level of the stand. There are two options for dealing with this in the model. One option is to permanently reduce the stand growth increment for the rest of the life of the stand, since there are fewer trees present. This assumes that individual tree growth of survivors after a mortality event will be the same as before the disturbance. The second option is to not reduce the stand increment, even though there are fewer trees present in the stand. This assumes that there is perfect compensatory growth in the surviving, due to the thinning effect, and this is modeled as if there were no change in stand increment.

Growth Reduction

Growth reduction acts on the expected current annual increment. After a growth reduction impact, the standing volume will still grow, but the amount that it grows will be less than what you expected.

Examples

To demonstrate how mortality and growth reduction work, imagine a stand that currently has 100m^3 of wood, with a current annual growth increment of 10m^3. If a 10% mortality event occurs, the volume of wood the next year will either be 99 m^3 if you change the growth increment for the stocking reduction (i.e. 100 m^3 minus 10% plus the expected CAI of 10 m^3, also reduced by 10%), or 100 m^3 if you don't change the growth increment for the stocking reduction (i.e. 100 m^3 minus 10%, plus the expected CAI of 10m^3). If a 10% growth reduction event occurs, the volume of wood the next year will be 109 m^3 (i.e. 100m^3 plus the expected CAI of 10m^3 reduced by 10%).

Impact of Management

Management activities can do two things. The first is to reduce (or eliminate) the probability of an event occurring. The second is to reduce (or eliminate) the impacts that an event has when it occurs. These two things can happen individually, or in combination. However, the model doesn't deal with these at "run time". Rather, it deals with them at the input data stage. For example, you can specify a set of probabilities and impacts for an insect without control, and a set of probabilities and impacts for an insect with control. These would be two separate runs of the model, and you could infer the management impact from the difference between the two simulations.

Algorithm

Growth

The model allows you to input any growth curve as a set of volume and age pairs. It then converts these to expected annual volume increments. As the model grows the stand, it does so by adding the annual increment to the volume accumulated in the previous years.

Risk Agents
The model applies annual risk agents first, followed by cyclic agents, and then chronic agents. The impacts are considered additive. For example, if two agents causing 10% growth reduction occur in the same year, their additive impact will be a 20% growth reduction.

Simulation Options

Agents to apply The model allows the user to turn on or off different classes of risk agents. For example, the user can specify the model to apply only annual risk agents, only cyclic risk agents, etc. This allows the user to evaluate the relative importance of each to growth risk.

Adjust by Stocking This allows you to either permanently adjust growth increment when mortality events that reduce the stocking occur, or to not adjust the growth increment when mortality events occur.

Plantation Failure Presently, the model allows you to choose a few management options to apply at run time. These are whether or not to replant stands when plantation failure occurs, a planting delay between plantation failure and growth resumptions, and a plantation failure criterion. The replant option specifies whether or not stands will be replanted after plantation failure. The planting delay specifies the number of years after a plantation failure occurs before growth resumes again. The plantation failure criterion specifies the annual mortality level that must be reached before plantation failure is assumed to have occurred.

Other management options
The model doesn't explicitly simulate other management impacts when it is running. In order to evaluate the impact of management activities like spraying pesticides to control an insect, it is necessary to conduct two simulations. The first would include the probability and impact parameters without control. The second would include the probability and impact parameters with control. The difference between the two simulations would be interpreted as the impact of insecticide sprays on growth.

Potential Outputs

The model outputs the observed accumulated volume (m^3), the observed mortality (%), the observed growth reduction (%), the observed current increment (m^3), the observed stocking (%), and the observed density (stems ha^{-1}) for each annual time-step and each iteration. Therefore, it is possible to calculate statistics for any of these variables for any scenario that is conducted.

Note that the model was developed by Mr. Metsaranta and is attached to this report as the second EXCEL file

APPENDIX 3

NEXT STEPS

Nine steps are necessary to make this report useful to practitioners and investors. As a minimum, the first four steps listed here should be undertaken. The additional steps constitute an outline for a disturbance information development program that could be undertaken to further develop this knowledge product for use by CFS clients. As each is completed the information and tools could be added to the databases and reporting vehicles described in step four. Steps 5 and beyond could proceed simultaneously. Note that the tenth step is not necessary, but is included because it would make the exercise complete.

First, the **manuscript should be reviewed** in its entirety. This review should be undertaken by plantation experts. It is suggested that this step be undertaken with people actively involved in establishing plantations under the Forest 2020 PDA program for starters.

Second, a **database should be built** to collect and standardise the data pertaining to plantations. This project would capture and archive the myriad of pest related information available to workers but now only resident in the scientific literature. Many pests will be recognized as important disturbance agents as experience with these organisms accumulates. A relational database will permit the easy capture and reporting of this information.

Third, a thorough **literature review**, derived from a **comprehensive literature database** on Canadian plantation disturbances should be developed.

Fourth, the emended report, the plantation disturbance database, literature review and literature database, along with model should be maintained and made public on the intranet and translated to French for ultimate release as a **website on the NRCan, CFS internet**.

Fifth, the database should be used to **capture the experience of plantation specialists** and workers in the field. The scope of this step should assess experiences with disturbances of both private and government (federal, including **PFRA** etc., provincial and municipal) **horticultural programs**. It is important to include people working in **tree nurseries** and **genetic improvement installations** and **provenance trials**, nation-wide. This information should be captured because much occurs that is not now recorded and is an essential step in improving probability estimates of disturbance occurrence, effects and geographical distributions. It is also necessary to capture their experience with control and mitigation methodologies. The worksheets developed here and database suggested for development in the second step described above would be used to capture this information.

Sixth, a **systematic analysis of the national forest health database** should be undertaken to better quantify the estimates provided here. The information stored in this database varies by region. Where information in the database is limited, this could be augmented by adding data from FIDS records that are now archived in regional CFS Centres and not currently in the database.

Seventh, information provided in the current document should be subjected to an **analysis of several plausible plantation scenarios.** This will have to be done with experts familiar with plantation management.

Eighth, a **sensitivity analysis should be undertaken** to assess where future effort in improving probability estimates should be undertaken. This could become part of the Forest 2020 PDA project to direct future efforts in plantation protection research.

Ninth, an **analysis of the effects climate change will have** on disturbance characteristics, impacts, management and strategies for mitigation should be undertaken. Several scientific research networks already exists that could be approached with this opportunity.

A tenth step might be necessary if we wish to include threats from accidental introductions of alien pests. Witness the legislative requirements that require the Canadian Food Inspection Agency to liquidate susceptible hosts in quarantined zones. This is certainly a type of plantation failure whose risk is not considered in this report.

Most importantly a field program to validate any of these findings should be implemented to survey existing plantations and demonstration areas to improve the estimates currently in the database for some disturbances.