A framework for poplar plantation risk assessments

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A tool for evaluating risk, adapting management and optimizing benefits from plantations.

The native poplar (*Populus* spp.) resources of Canada are the largest of any country. Of the 80 million hectares occupied by poplars worldwide, 28.3 million hectares (35 percent) are in Canada (FAO, 2004). Until recently, this bounty and the high quality of wood derived from native poplar species precluded the economic development of poplar plantation culture in Canada, but the area of planted poplars is likely to grow with increasing remoteness of native stands from mills and markets, pressures to protect native forests and afforestation opportunities for carbon sequestration in meeting Canada's commitments under the Kyoto Protocol. At present, committed poplar plantations and amenity plantings cover only 14 300 ha, generating some 43 000 m^3 of forest products annually (van Oosten, 2004).

Because of the limited area planted with poplars in Canada, experience with this culture is limited, and uncertainty about risks to plantations could frustrate potential investors. A group of specialists therefore convened to develop a framework for identifying and addressing the uncertainties associated with disturbances and their impacts on fast-growing tree plantations of *Populus* or *Salix* cultivars, among other species, in Canada.

The framework was based on the best information available for assessing losses that plantation ventures might incur from weather-related impacts (mainly drought), fire and pests (including insects, tree diseases and vertebrates). The effects of multiple risk agents were then assessed using Monte Carlo simulation, which involves running a model many times over, each time using values for random variables selected from their probability distributions. No attempt was made to model interactions among disturbances.

CHARACTERISTICS OF THE FRAMEWORK

The framework was developed for unforested areas along Canada's southern border and the zones adjacent to the prairies of western Canada. The cultivars considered were aspen (*Populus*

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Clonal poplar nursery in Quebec: the model for assessing risk indicates that with appropriate planting stock, sound site-clone matching and proper management, plantation culture of poplars in Canada is feasible

tremuloides), hybrid *Populus* sp. × sp. and balsam poplar (*Populus balsamifera*), used in afforestation trials since 1990. All projections were limited by a maximum 60-year time horizon, because this was thought to be the extreme harvest age for plantations in Canada.

The framework takes into account both biological and abiotic disturbances that have caused growth loss and partial or stand-replacing mortality in native stands. 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, although some might affect several species.

The response to any specific disturbance differs among tree species and this must be accounted for in the assessment of risk. Disturbances may be categorized as annual events; cyclical events, which recur at least quasi-periodically; and chronic disturbances which, 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 for several years.

The analysis was based on the assumption that plantations will be properly managed.

Although climate change is another factor likely to affect plantation yields, the assessments did not take it into consideration because a separate process would have been required to incorporate this concern. However, comparisons can be made by using parameters for dryer or warmer ecozones.

Data quality

The data used in the model came from peer-reviewed literature, anecdotal or survey information or extrapolation by experts, and were not based on specific studies on any one agent. Thus the framework represents a synthesis of the understanding of the experts involved in its development. No undertaking is without risk, and a data quality rating could be used in determining risks associated with uncertainty and/or erroneous information.

DEVELOPMENT OF THE FRAMEWORK

Weather impacts

A simple model was developed to capture all aspects of weather-induced mortality and growth reductions on plantations. Drought is given as an example here as it was assumed to be the most important type of event causing regional-scale impacts on plantations established on non-forested land.

The model encompasses a large number of combinations in that it considers 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: seedlings, established trees and older trees.

First, the geographic variation in the probable risks and impacts of drought-induced damage was captured by defining four broad vegetation zones (Table 1) for those areas of Canada where afforestation is likely to occur, based approximately on the climate moisture index (CMI) of Hogg (1994, 1999).

The second step was to classify the candidate cultivars according to their overall tolerance to drought damage and mortality – high, medium or low – based on expert judgment. “Tolerance” refers only to the ability of the tree to survive following extreme weather events.

The third step was to estimate probabilities of drought and other extreme weather events and their impacts on tree growth for each of the four vegetation zones (Table 2). Growth reductions were expressed as a decrease in growth as a percentage of expected normal growth. It was assumed that extreme events affect growth of all tree species in all vegetation zones equally, leading to a cumulative growth loss equivalent to 35 percent of total growth, spread over two years following the event (20 percent growth loss in the year of occurrence, 10 percent in the first year thereafter and 5 percent in the following year).

For example, for species growing in the boreal forest the annual probability of a drought event leading to growth reduction

TABLE 1. Preliminary classification of ecozones and vegetation zones according to risk of damage to plantations by drought

CMI	Ecozone	Vegetation zone
Low risk (> +15)	Taiga plains	Moist boreal
	Boreal shield	Moist boreal
	Boreal plains	Moist boreal
	Montane cordillera[a]	Moist cordilleran
Medium risk (0 to +15)	Taiga plains	Dry boreal
	Boreal shield	Dry boreal
	Boreal plains	Dry boreal
	Montane cordillera[a]	Dry cordilleran
High risk (-15 to 0)	Prairies	Parkland
	Montane cordillera[a]	Upper montane
Very high risk (<-15)	Prairies	Grassland
	Montane cordillera[a]	Lower montane

[a] Not easily defined in terms of ecoregions because of mountainous terrain; overall risk can be considered the same as for “dry boreal”.

TABLE 2. Estimated annual probabilities and impacts of severe climate events leading to growth reductions and mortality (for plantations >3 years old)

Zone	Probability of severe events (%)	Annual probability of extreme events leading to growth reductions (%)	% Mortality by species drought tolerance class[a]		
			High	Medium	Low
Moist forests	1	4	8	10	12
Dry boreal/ cordilleran forests	2	8	8	12	15
Parkland/montane	5	12	10	15	20
Grassland/semi-arid	10	20	20	30	40

[a] 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.

was estimated as 8 percent. This would cause a growth reduction of 20 percent in the year of the drought, followed by 10 and 5 percent 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 percent.

Mortality rates were assigned based on the cultivar's drought tolerance; higher mortality rates were assigned for species with low drought tolerance and lower rates for more tolerant species.

Fire impacts

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), which was taken to represent the probability of fire occurrence in plantations. 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. The derived probabilities are generally appropriate at very large scales, but they ignore many factors that are important at smaller scales including weather, fuel, topography and cause of fire (human versus lightning ignitions). Given the large variations in area burned from year to year, the numbers of years of data, the quality of the data and the specific period over which data are collected can have a substantial impact on the estimate of the probability of fire occurrence.

The PAAB values used probably overestimate the fire risk to plantations because many plantations will be established in landscapes outside forested areas, meaning that fire is less likely to spread, and because plantation management generally includes better surveillance and emergency response than is likely in natural forest.

In the risk evaluation framework, fires are considered to cause stand-replacing mortality in all ecozones for all poplar plantations.

The estimated PAAB ranges from 0.001 percent in the mixed wood plains (and the prairies in Alberta) to 1.499 percent in the boreal shield of Saskatchewan. The low value in the prairies of Alberta illustrates the problem with the data used to generate these estimates. Historically no forest fires have been reported from this area.

Pest impacts

Pest risks were derived from experience with pest behaviour in native stands, although plantations of hybrid poplar clones may be more susceptible to insects and diseases than unimproved species. From the literature, the experts tabulated information on those pests that they agreed could significantly reduce yields in fast-growing tree plantations (Table 3). A detailed database is being developed so that it can be consulted for specifics on any particular agent operating on stands of a given kind in a particular ecozone.

In estimating impacts from biotic agents, the variation in behaviour over the life of stands, ecozones and time-specific risk rates present special challenges. For each pest, an attempt was made to obtain information on the epidemiology of the agent involved and to take account of variations by ecozone. 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, were apportioned over varying times, depending on the nature of the damage and the life cycle of the agent, in a process similar to that used for impacts of drought. The maximum impact was reported as percentage mortality of the standing volume at the beginning of the year being considered.

The cottonwood leaf beetle (*Chrysomela scripta*) is an occasional pest on poplars, so it is modelled with an annual probability of occurrence (Table 3). The pest only affects stands that are less than 15 years of age; mortality occurs in the year after infestation and amounts to 20 percent in each of the two following years for a total of 40 percent per event. The probability of an outbreak of this pest occurring is 1 percent.

Agents known to have 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. Parameters used in this framework were the length of the outbreak 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. The temporal pattern of damage, whether growth reduction or mortality, was linked to the appropriate time in the outbreak period and was used to calculate time-specific impacts. For example, the forest tent caterpillar (*Malacosoma disstria*) is an example of a cyclic insect pest that causes morta-

TABLE 3. Risk agents affecting poplars and their hybrids

Risk agent	Host range	Agent range	Impact	Temporal pattern	Probability of impact (%)	Maximum impact (growth loss or mortality) (%)
Disease						
Cytospora canker	*Populus* spp.	All	Mortality	Chronic	60.00	100
Marsonnina leaf spot	*Populus* spp.	Boreal Shield	Growth loss	Annual	10.00	40
Melampsora rusts	*Populus* spp.	All	Growth loss	Annual	10.00	40
Mycosphaerella/*Septoria* leaf spot and canker	Exotic poplars and hybrids	All	Mortality	Annual	7.00	85
Venturia/*Pollacia* leaf and shoot blight	*Populus* spp.	All	Growth loss Mortality	Annual	10.00 5.00	50 85
Insect pest						
Choristoneura conflictana	*Populus tremuloides*	Boreal Plains	Growth loss	Cyclic	40.00	60
Chrysomela scripta	*Populus* spp.	All	Mortality	Annual	1.00	40
Cryptorhynchus lapthi[a]	*Populus* spp.	All	Mortality	Annual	0.10	45
Malacosoma disstria	*Populus tremuloides*	Prairies, Boreal Plains, Boreal Shield	Growth loss Mortality	Cyclic	80.00 80.00	90 10
Platypus mutatus[b]	*Populus* spp.	Pacific Maritime, Atlantic Maritime, Mixed Wood Plains	Mortality	Chronic	0.01	40
Saperda calcarata	*Populus* spp.	All	Mortality	Chronic	0.10	20

[a] Introduced from Europe, established.
[b] Potential pest of poplars and willow, not yet established in North America.

lity and growth loss in trembling aspen stands in the prairies, boreal plains, and boreal shield ecozones of Canada. This insect affects stands that are 20 years or older. Mortality occurs in years 1 to 13 after outbreak initiation and amounts to 20 percent of the initial volume (10 percent for two years). Surviving trees have reduced growth for six years, with a maximum impact of 90 percent of the expected annual growth.

Agents known as chronic problems in plantations were described by the probability of infestation and the pattern of damage development. For example, the poplar borer (*Saperda calcarata*) causes tree mortality after stands reach the age of 15 years, and mortality begins two years after its occurrence in the stand. This mortality is 0.5 percent in infested stands and lasts for the life of the stand. After age 15, the annual probability of infestation is 0.1 percent throughout the life of the stand.

Because several agents will affect a stand over its lifetime, an attempt was made to model multiple impacts; consequently, only mean stand performance volumes can be compared under different disturbance scenarios.

A note on alien pests. The framework includes several introduced pests known to threaten plantations, but it does not include potential invaders from outside Canada except for one example, *Platypus mutatus*, which has recently risen to prominence in European poplar culture. Further research would be necessary, including a review of listings of interceptions at ports, if all potential introductions of foreign pests were to be assessed.

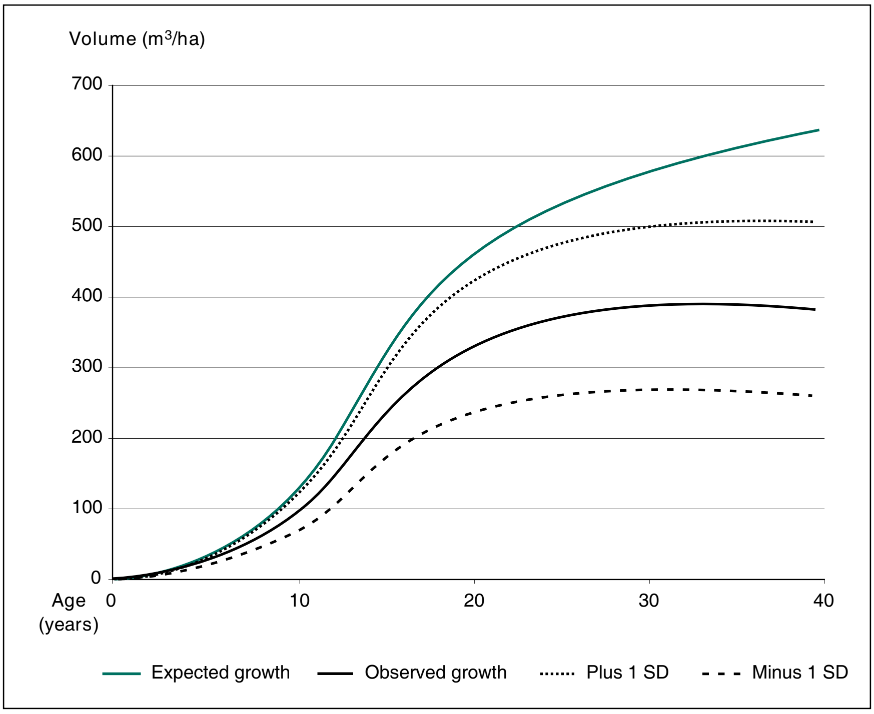
PUTTING IT ALL TOGETHER

The following hypothetical scenarios are presented to illustrate the nature of outputs derived from the model. In both scenarios, stands were replanted after failure, with no planting delay.

Scenario 1: hybrid poplar in the prairies ecozone, with low drought tolerance clone

This example (Figure 1) was derived from the model through 256 Monte Carlo simulation runs using the following inputs:

- Fire: 0.01 percent annual probability; all stand ages eligible;
- Low drought tolerance clone in a high drought risk zone;
- Growth-reducing drought: 12 percent annual probability of growth reducing drought for plantations greater than 3 years old; growth reductions for the year of the drought and two subsequent years are 20, 10 and 5 percent, respectively.
- Mortality-causing drought: 5 percent annual probability of mortality-causing drought for plantations more than three years old. Mortality pattern: 8 percent, 8 percent and 4 percent for year of the drought and two subsequent years;
- Chronic growth-reducing drought: 12 percent probability of a chronic 40 percent growth-reducing disturbance that lasts the life of the stand, which can occur when stand is less than three years of age;
- Aspen defoliators (forest tent caterpillar and large aspen tortrix, *Choristoneura conflictana*): outbreak started in 2002, lasting two to four



1
Growth of a plantation of a low drought tolerance hybrid poplar clone in the prairies ecozone of Canada (a drought-susceptible region), generated from 256 Monte Carlo simulations of risk agents

years during which the annual probability of occurrence is 5 percent on stands older than 20 years; this will cause 10 percent mortality in the year in which it occurs and substantial growth reduction over the next six years (70, 90, 90, 90, 75 and 15 percent), followed by 9 to 11 years of no risk;

- Cotton leaf beetle: 1 percent annual probability of two years of 20 percent mortality when the stand is less than 15 years of age;
- Poplar borer: After age 15, a 0.1 percent annual probability of a chronic mortality of 0.5 percent per year for the rest of the life of the stand.

The expected growth continues to rise over the period modelled, but the mean simulated volume levels out after about year 30 as the influence of the combined disturbances negates the expected increases in yield. Until age 5 the average simulated growth is about the same as the expected yield, but by age 10 there is a discernible difference. At age 15 even the top 16 percent of stands (those one standard deviation above the mean) start to deviate markedly from the expected yield curve. At age 30, the mean simulated yield is 37 percent lower than the expected yield.

The results indicate that most plantations should be harvested between ages 20 and 35 to maximize yields. Growth culminates at age 21 with a yield of 320 m^3.

Scenario 2: Hybrid poplar in the prairies ecozone, with high drought tolerance clone

In this example the risk agents and probabilities are the same as in the first example except that a clone with high drought tolerance is planted. This influences the drought probabilities and impacts as follows:

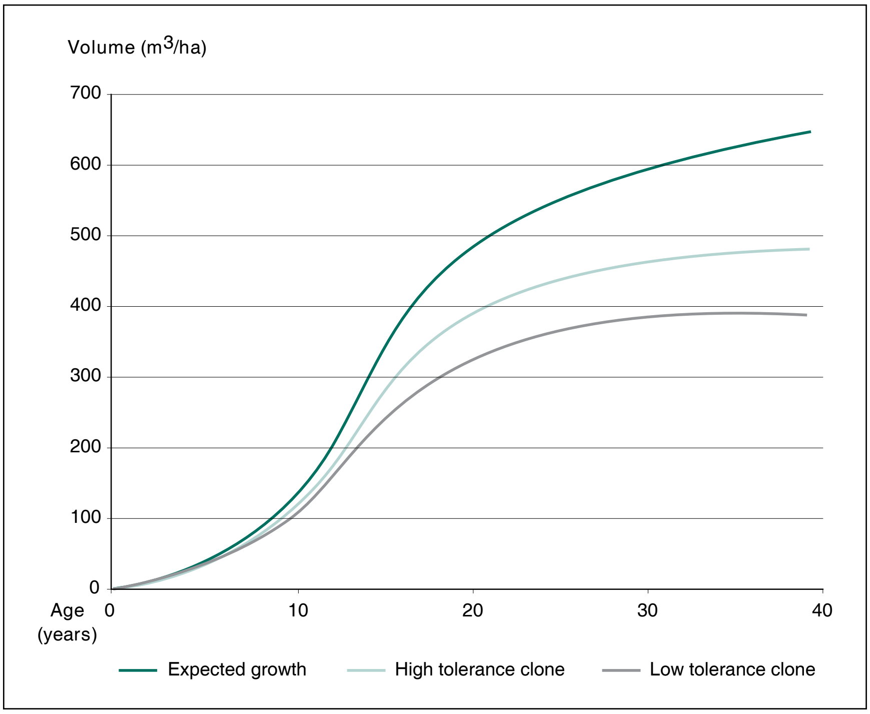
- Growth-reducing drought: unchanged;
- Mortality-causing drought: 5 percent annual probability of a drought causing 4, 4 and 2 percent mortality when the plantation is older than three years, i.e. mortality reduced from 8, 8 and 4 percent;
- Chronic growth-reducing drought: 12 percent probability of a chronic 20 percent growth-reducing disturbance (reduced from 40 percent for the low tolerance clone) that lasts the life of the stand, which can occur when the stand is less than three years of age.

In this scenario, the effect of choosing the right genetic material for the conditions raises the yields by 13 percent at age 30 (Figure 2). The simulated yield culminates at age 35, when it is 7 percent higher than at age 30. The yield at this point is 20 percent greater than for plantations of cultivars with low drought tolerance. The mean annual increment reaches a maximum at age 21 in both scenarios, but the yield in the second case is 18 percent greater at that age, at 380 m^3.

CONCLUSIONS

In summary, the model indicated that the probability of extreme weather events in poplar plantations in Canada ranges from 4 percent in moist forests to 20 percent in the semi-arid grasslands. The resulting mortality may range from 16 percent in moist forests to 80 percent in grasslands (for the least tolerant species). The risk of stand-replacing fire (100 percent tree mortality) varies from 0.01 to 1.499 percent. Pest impacts may reach 80 percent growth reduction during outbreaks and 100 percent mortality from chronic disease infections. Despite these extreme impacts, the analysis indicates that plantation culture is feasible, given a well-executed management plan including tending and pest management, sound site/species-clone matching and appropriate planting stock.

A tree plantation is a long-term investment whose success is critically dependent on an establishment strategy where risks can be eliminated or minimized through prediction, prevention and preparedness. Many of these concerns can be mitigated by including the following components in plantation establishment:



2
Expected mean growth of low versus high drought tolerance hybrid poplar clones in the prairies ecozone

- a genetics programme to select, develop and use appropriate planting material, addressing concerns such as pest resistance and climatic tolerances appropriate to the site, as well as productivity and end use;
- a silviculture programme that will ensure maximum productivity, with an appropriate schedule of stand tending, fertilization and vegetation management where required;
- pest management will be an integral part of the plantation management system from its conception through to final harvest.

The scenarios derived from Monte Carlo simulations suggest that the model may be used to explore the savings that might be expected from different management interventions and harvesting plans. Better information on yield curves would improve the model further. For example, the time at which marginal growth increments fall below the discount rate could be explored to optimize 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. In the current simulator, the suggestion is that, with the best hybrid poplar selection now available for the prairies, yields are still 23 percent below what they could be when yields culminate at age 30.

Constraints to be addressed in using the model include uncertainties in the data used to estimate the probability of occurrence of disturbances and uncertainties about the sensitivity of the model and its performance with respect to many of the assumptions. Many of the pest attributes were derived from data or experience with conditions in natural forests and may not apply to plantation conditions. A research programme on plantations is needed to acquire the understanding and information required to make more informed choices in plantation management.

The model, which was originally developed to deal with all tree species planted in Canada since 1990, may be applied wherever the disturbance regime of a region can be quantified. The data requirements may appear daunting at first, but experienced personnel can make conjectures about the epidemiology and impacts of the pests or about the probabilities and impacts of drought and fire. Management choices will ultimately depend on how risk averse or tolerant the user is. The framework provides a decision tool to help planners document their choices of parameter values explicitly so that outcomes can be evaluated objectively. More importantly, it codifies the understanding that goes into plantation development and provides a means for ranking alternatives. It should be better than rolling dice! ◆

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