Divided land bases, embedded Quotas and fire risk in the Alberta Pacific Forest Industries Inc. Forest Management Agreement Area.[1]

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1 Introduction

Cumming and Armstrong (1998) analysed by simulation the current tenure arrangements in the Alberta Pacific Forest Industries Inc. (APFI) FMA. Their results suggested that significant economic and ecological benefits could be achieved by moving from the present allocation of rights (Business as usual or BAU) to a more unified management system, whereby a single land manager was responsible for delivering specified periodic volumes of hardwood or softwood to all forest products companies dependent on the landbase. I will refer to the latter case as Global planning, or GP. The study relied on `TARDIS`, a township-resolution forest landscape simulator. I will assume that readers of this document are familiar with the original study.

Discussions with industry representatives identified some inadequacies in the way `TARDIS` allocated wood supply. Furthermore, the original model formulation had no representation of fire. Since the first study was completed in December 1998, I have developed a suite of statistical models of fire ignition, size and effect. These models have all been incorporated into `TARDIS`. The aims of the present study were to 1) re-evaluate the original conclusions using the new model, which more accurately reflects the behaviours of APFI and the various Quota and CTP holders (all referred to as Quotas henceforth); and 2) explore the effects on wood supply and delivered wood costs of adding fire into the system.

2 Model changes

This section documents substantive changes to the model structure, as per the agreement of December 9th 1999, and subsequent discussions with D. Cheyne and G. Grover.

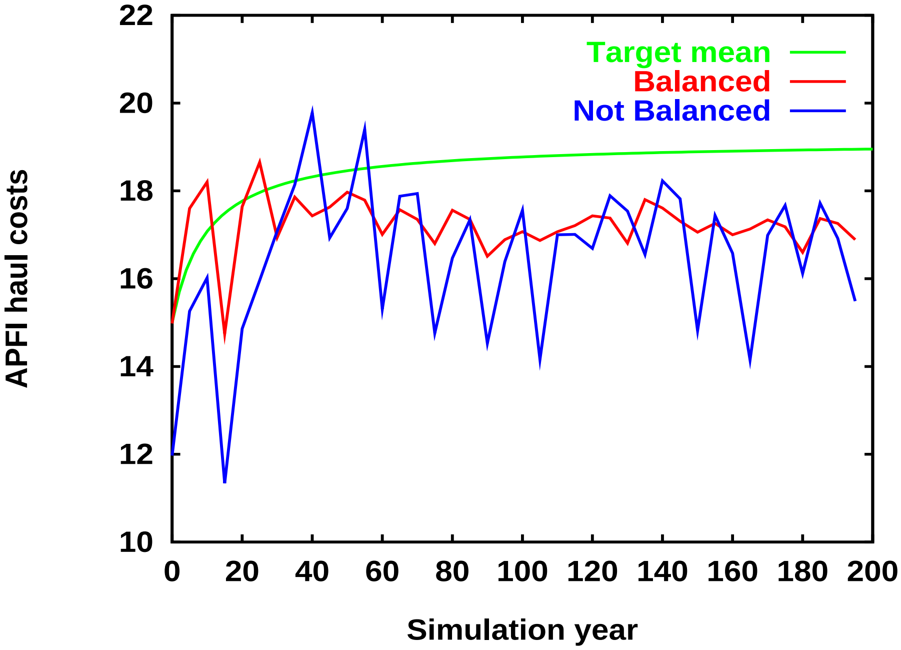
2.1 Load balancing

In the original version (Cumming and Armstrong, 1998), delivered wood costs to the APFI mill were quite variable over time. Much of this variability was due to haul costs, reflecting changing spatial patterns of harvest.

`TARDIS` is at heart a simple harvest scheduler, that uses so-called "greedy" optimisation. That is, at each of many steps within a simulation year, it determines the best (cheapest) action to take next, given the areas available for harvesting and the remaining demands for delivered wood volume. Unlike true optimising schedulers, it does not "look ahead" within or between years. It is difficult to achieve constant delivered wood costs in this way.

One factor in the scheduling decisions is the estimated haul cost from the operating compartment to a mill in $\$\ \mathrm{m}^{-3}$, which is a function of haul distance. As an approximate solution to the balancing problem, I replaced this cost with a desired average value, which changes smoothly over time t from an initial value of x_s to a final value x_e at rate c, according to equation 1. Thus all townships are weighted equally at every

Figure 1: Effect of load balancing on haul cost variability.



given stage of the simulation. This weighted value is used in scheduling. Delivered wood costs are computed using “real” haul costs.

$$x_t = x_s + \frac{t}{t+c} * (x_e - x_s) \tag{1}$$

For APFI in BAU scenarios, these variables are $x_s = 15.0$, $x_e = 19.15$ and $c = 10$. These values were estimated from preliminary simulation trials. No load-balancing is attempted for Quota holders, who operate within relatively small areas. Variable haul costs are not a major factor for Quota holders in these simulations.

Haul costs for APFI with and without load balancing are compared in Figure 1. The variability under load balancing is substantially reduced, with the standard deviation over $200\ \mathrm{yr}$ declining from $1.71\ \$\,\mathrm{m}^{-3}$ to $0.68\ \$\,\mathrm{m}^{-3}$. This comes at a cost, as mean haul costs rise from $16.48\ \$\,\mathrm{m}^{-3}$ to $17.20\ \$\,\mathrm{m}^{-3}$. In both cases, mean costs rise over the first 25 years, as the capital road network is completed. Costs drop sharply at year 15 with completion of the second pass on townships harvested in the first five years. In the balanced case, haul costs are nearly constant after year 20.

No load balancing is attempted under global planning. If this policy were to be implemented, constant delivered wood costs could presumably be negotiated, at a premium, between any contracting mill and the notional woodlands management agency.

2.2 Chip trade

There was no representation of the chip trade in the previous version of the model. This has been corrected. Quota holders having a chip trade arrangement with APFI are identified in the "Agents" file by the `chips` command, which specifies relevent aspects of the agreement. These are

> `destination` identifies where the chips gol
>
> `conversion` specifies what proportion of delivered wood volume is converted to saleable chips (I assume 0.4);
>
> `haul` distance in km between the source and destination mills. This is converted to $\$\,\mathrm{m}^{-3}$ assuming that haul cost per unit volume of chips is one half that for raw logs;
>
> `payment` by APFI per delivered tonne of chips (I assume $30.00). This is converted to payment per m^3 by dividing by 2.0.

All the four variables used in the model can be varied independently for each saw mill. The net value received from chip sales is thus `payment` less haul costs, which I assume are borne by the supplier. Quota holders and others having such an arrangement with APFI were identified by APFI staff. In `TARDIS`, the specified arrangements satisfy APFI's requirements for softwood furnish.

2.3 Incidental cut

The previous version of the model allowed too much incidental harvest to be lost (*e.g.*, to decay). This was partly because of price structures, and partly a combined artefact of the scheduler and the decay model. The new version of the model has substantially reduced the magnitude of simulated losses. This was done by modifying the scheduler, by simulating a finer temporal scale, and by changing the decay rates.

The original round-robin scheduler had the effect of having many townships scheduled by APFI after all Quotas and CTPs had been satisfied. Resulting incidental was all subject to a 20% loss. The scheduler has been modified so that APFI has $n = 10$ "kicks" (at the cat) at each turn: that is, it schedules n townships at a time. The resultant incidental conifer is then usually purchased.

`TARDIS` runs at a five year time step. However, a psuedo-year can be associated with each harvesting action by dividing the total harvested volume up to that point by the total required periodic volume. This year is associated with every parcel of incidental deciduous. When these parcels are aged at the end of a model time step, those older than 1 year are assumed to be lost to decay. The rest remain at the roadside, so to speak, and are available for purchase the next time step. Incidental conifer decays at 20% per year, as before.

In BAU mode, mean conifer losses are $3.6 \times 10^3\ \mathrm{m}^3\,\mathrm{yr}^{-1}$ and mean deciduous losses are $9.4 \times 10^4\ \mathrm{m}^3\ \mathrm{yr}^{-1}$. Conifer losses are negligeable, while deciduous losses are less than 4% of the AAC. For comparison, under BAU in the earlier version of the model, decidious losses were about the same, but conifer losses were 40 times higher. In global mode, conifer losses are $7.3 \times 10^3\ \mathrm{m}^3\,\mathrm{yr}^{-1}$ and deciduous losses are $3.1 \times 10^4\ \mathrm{m}^3\,\mathrm{yr}^{-1}$, or just over 1% of AAC. There seems to be no way to reduce these losses further without forcing the scheduler to ignore prices and costs, which defeats its purpose.

Incidental conifer volumes are not quota chargeable, and do not count towards satisfaction of specified wood demands. However, incidental deciduous wood is part of APFIs AAC.

2.4 Cost accounting

2.4.1 New or altered cost structures

Four substantial changes were made to the original prices.

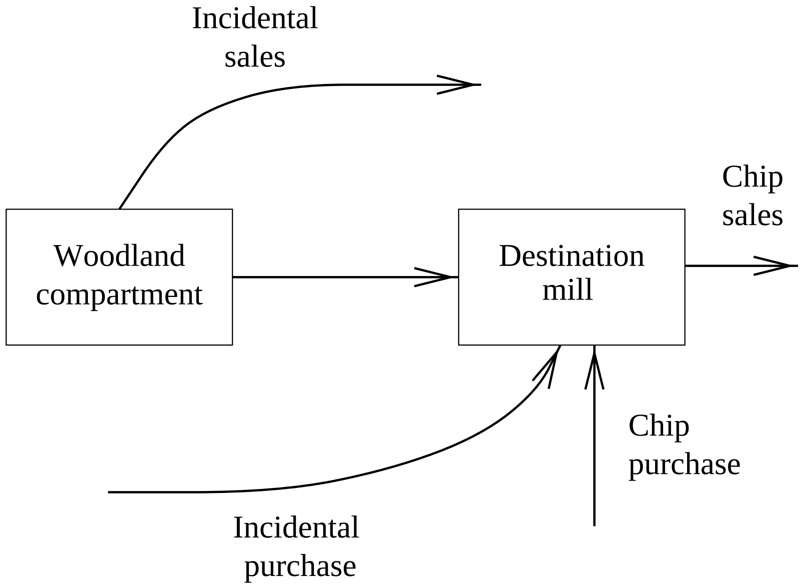
1. APFI pays $12\ \$\,\mathrm{m}^{-3}$ for all incidental deciduous, at the landing.
2. conifer regeneration charges are assessed to all parties at the rate of $12\ \$\,\mathrm{m}^{-3}$ per unit volume harvested.
3. APFI sells incidental conifer at the landing for the pro-rated cost of harvest, including dues.
4. The cost of extending the capital road network to a new township, and of providing adequate roading within the township, has been raised to an average of one million dollars. The original estimate was one hundred thousand dollars.

2.4.2 Calculation of delivered wood costs

Figure 2 illustrates the flows of material between the forest and mills, and between mills. Each of these flows has an associated cost or payment structure. As different rules apply to different mills (*e.g.,* some sell chips, some do not) cost calculations have become much more complicated. This is especially so because total costs and various subtotals must be computed, and these values must be compareable between scenarios.

At each five year time step, for each mill, I compute three different cost estimates. Gross and net delivered wood costs are computed for all quota chargeable volumes. Gross delivered wood costs include all woodlands charges (planning, roading, tree to truck, regeneration and dues), haul costs, and payments for any delivered quota-chargeable incidental wood or delivered chips. Net delivered wood costs are gross

Figure 2: Schematic of wood flows from woodland operations and between mills.



costs, less any payments received for chip sales or incidental sales. A net cost is also computed for all delivered wood, including non-quota chargeable incidental wood. Subtotals of all three costs are computed for all Quota holders and for all pulpmills (were there to be more than one). Total costs over all users are also computed. Costs are all expressed as $\$\mathrm{m}^{-3}$.

3 Simulation of wildfire

In `TARDIS`, wildife is simulated by four processes: ignition, initial spread, final size, and effect. Ignition models the spatial pattern of fire starts—more precisely fires that, having started, become large enough to be detected by present surveillance methods. Initial spread models the probability that a detected ignition will achieve a certain minimum size, in this case $9\ \mathrm{ha}$. Fires reaching this size are “free to grow.” Once a final size is determined, the last step in modelling is to determine the fire effect, measured by the areas of different forest types that are burnt. The first three processes are random, that last (fire effect) is determined by the forest composition of the area where the fire started.

3.1 Ignitions

The number of igntions per township per five year time step is a Poisson random variable whose expected value (mean) depends on the size of the township and also on the composition of the township. By "composition" I mean the proportional areas of deciduous, white spruce, black spruce and pine dominated forest, and of "other" types. The "other" category is mainly wetland areas, but also includes recent burns and clearcuts. The current implemenatation in `TARDIS` is based on unpublished data and analysis of mine. I presented the basic results at Biological Sciences seminar at the University of Alberta in fall 1997. Notes to this talk are available on request. I have recently conceived a better estimation method, which should be developed and included in any future extension of this work.

3.2 Initial spread

Each ignition has an independent, constant probability of exceeding the threshold size of $9\ \mathrm{ha}$. This probability was estimated from fire history databases available on the Alberta Environment Protection web site. The probabilities have changed over time, in a fashion consistent with increasingly effective fire suppression (Cumming *et al.*, 1998). In these simulations, I used $p = 0.084$, estimated from the counts of all lightning fires in the study area between 1971 and 1993. The corresponding value from 1983–1998 is $p = 0.045$. I did not use this value, as it seems optimistic for a 200 year simulatiom, it presumes continued very high investments in fire suppression, and ignores any contribution from human caused fires.

3.3 Fire size

For fires larger than $9\ \mathrm{ha}$, the logarithm of final size is distributed as a truncated exponential random variable (Cumming, 1999b). The truncation places a bound on the maximum size of a fire. Using methods described in the paper, I estimated that this maximum is about $310,000\ \mathrm{ha}$. For each ignition which passes the $9\ \mathrm{ha}$ threshold, a simulated fire size is drawn from the truncated exponential distribution, using standard methods.

My statistical models indicate that fire size depends on forest composition at the township scale. In particular, fires are larger in areas with much pine forest, and smaller in areas where there is much recently disturbed forest (logged or burnt with the past $15\ \mathrm{yr}$.) These results are preliminary, and are not employed in the present study.

3.4 What do fires burn?

Having determined that a fire of a given size starts in a particular township, the last step is to decide what the fire burns. Fires do not burn all forest types equally, nor do they burn in direct proportion to what is available in the area. Fires are highly selective. This selectivity can be modelled using multivariate statistical methods (Cumming, 1999a). These methods show that fire composition strongly depends on forest compostion in the area where the fire starts, but is independent of fire size. I re-estimated the multivariate statistical model described in Cumming (1999a) so that it could be used for prediction in the current application. The resulting model explains over 60% of between-fire variation in composition, based on a sample of 48 mapped fires.

From the fire size and predicted composition, the model determines how many ha of each of four timber types (leading deciduous, white spruce, pine and black spruce) are to be burned. It then "grows" the fire outwards from the township of ignition, until the required areas of all types have been burnt. Provision is made for large fires starting near the FMA boundary to partly cross the boundary. Burnt stands are treated much as recently logged stands, and go back on their original successional trajectory.

All burnt areas are treated as though the fire killed all living trees: there is no representation of spatial variation in fire severity. `TARDIS` makes no provision for salvage logging at the present time.

4 Results

4.1 Without fire

Here I revisit the principal results of Cumming and Armstrong (1998), under the revised model formulation, but without fire. Aggregate delivered wood costs under both scenarios are summarised in Table 1. The main points are

1. under business as usual, Quota holders face shortfalls;
2. change in policy is nearly cost-neutral for APFI;
3. global planning reduces net costs to Quota holders by $2.81\ \$\,\mathrm{m}^{-3}$.

Over a 40 year planning horizon, the results are even more favourable. Net costs to Quota holders are reduced by $3.65\ \$\,\mathrm{m}^{-3}$ and net costs to APFI are reduced by $0.30\ \$\,\mathrm{m}^{-3}$. The GP scenario also ensures greater stability in delivered wood costs to the Quota holders (Figure 3).

Under BAU, many Quotas can not be sustained in the long term (Figure 4), although APFI requirments are always at least 99.5% satisfied. Shortfalls to some individual Quota holder of 30% or more begin about 2065. Under GP, all periodic volumes of conifer and hardwood are satisfiable over the 200 year planning horizon. BAU is more expensive, and is unable to guarantee wood supply.

4.2 With fire

Because fire is a random process, its effects on timber supply must be evaluated by monte-carlo trials. I did this my running the model 100 times, under each of BAU

Table 1: Mean delivered wood costs for Quota holders, APFI and totals, for BAU and GP scenarios, over a 200 year planning horizon. Qg and Qn are gross and net delivered wood costs for quota chargeable volumes. Tn is net delivered wood cost over all volumes. Costs are computed as in Section 2.4.

Business as usual			
	Qg	Qn	Tn
APFI	28.83	24.97	24.97
Quotas	52.33	45.33	42.75
Total	33.80	30.25	30.26
Global planning			
	Qg	Qn	Tn
APFI	24.94	24.83	24.83
Quotas	48.99	42.52	42.39
Total	31.43	29.61	29.61

and GP scenarios, in order to estimate the probabilities of achieving specified periodic volumes of delivered wood.

Simulated rates of burn were approximately 0.0035. That is, roughly 0.35% of the study area should be expected to burn in the “average” year. This simulated value is consistent with my expectations based on Cumming (1997) and Cumming (1999a). Even this low rate of burn severely reduces timber supply to the Quota holders (Figure 5). Under BAU, most Quota holders are very likely to experience persistent sharp decreases in delivered wood volume, starting in 2045. In many cases, there are periods of several decades years where the probability of realising even 50-75% of quota volumes is less than 50%. APFI is not similarly effected. Over the planning horizon, APFI wood supply is satisfied at 95% levels or higher, with probability 0.99. The results concerning the Quota holders are conservative, because the spatial constraints they face under BAU are actually more severe than were simulated. This is because many FMUs are aggregated in the harvest specification file (*e.g.,* A5, A7 and A8, S4 and S8; see the Appendix of Cumming and Armstrong (1998)).

Under GP, no shortfalls in Quota volumes occurred during any simulation run. GP is robust in the face of my model of the fire regime in the study area. On average over 100 runs, net delivered wood costs are not much altered when fire is included in the simulations.

5 Conclusions

On the APFI Forest Management Agreement Area, the allocation of softwood to Quota holders is not sustainable under the existing arrangements of divided land-bases and overlapping tenures, even without any losses due to wildfire. When a realistic risk of fire is incorporated into a harvest schedule simulator, the situation becomes much worse. Most Quota holders should anticipate substantial and persistent reductions in delivered wood volume, beginning about 2045. This problem is entirely an artifact of existing tenure arrangements. Under a global planning environment, no shortfalls in delivered wood volume are predicted, either to Quota holders or to APFI. In addition, delivered wood costs to Quota holders are expected to be lower under global planning, with or without the risk of fire, by at least $2.50 \ \$\,\mathrm{m}^{-3}$. The risk to timber supply under current tenure arrangements in entirely born by the Quota holders. APFI's wood supply is not substantially at risk under my simulated fire regime. A change in policy from Business as Usual to Global Planning does not substantially alter delivered wood costs for APFI. Most of the tangible benefits of a change in tenure arrangements would accrue to the Quota holders.

It must be emphasised that the conclusions of the present study depend on my models of forest harvesting and of fire. `TARDIS` does not model the impacts (additive or compensatory) of other activities in the forest. In particular, alienation of productive forest land by the energy sector is not considered in this analysis.

Figure 3: Time series of mean net delivered wood costs for APFI and all Quota holders, under BAU and GP scenarios, without fire.

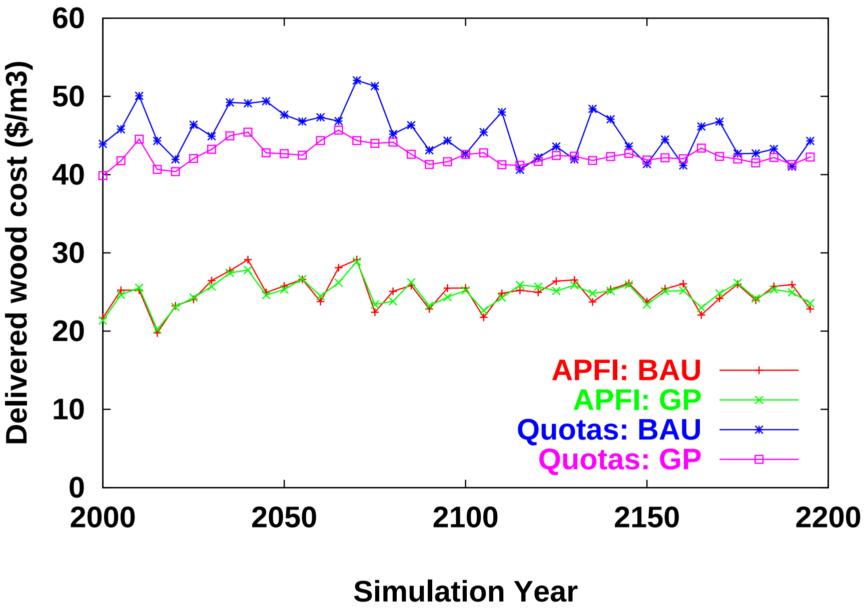


Figure 4: Proportion of total quota volumes achieved under BAU and GP scenarious, without fire.

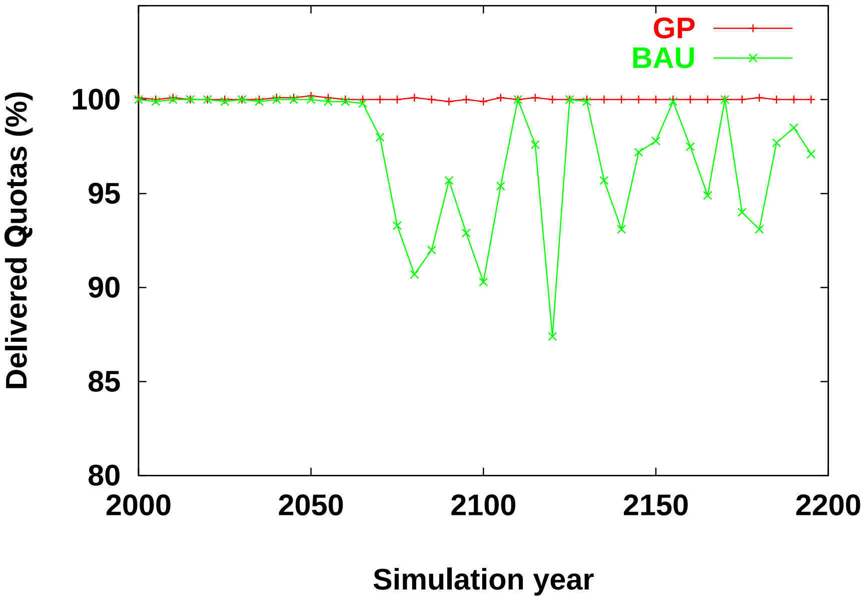
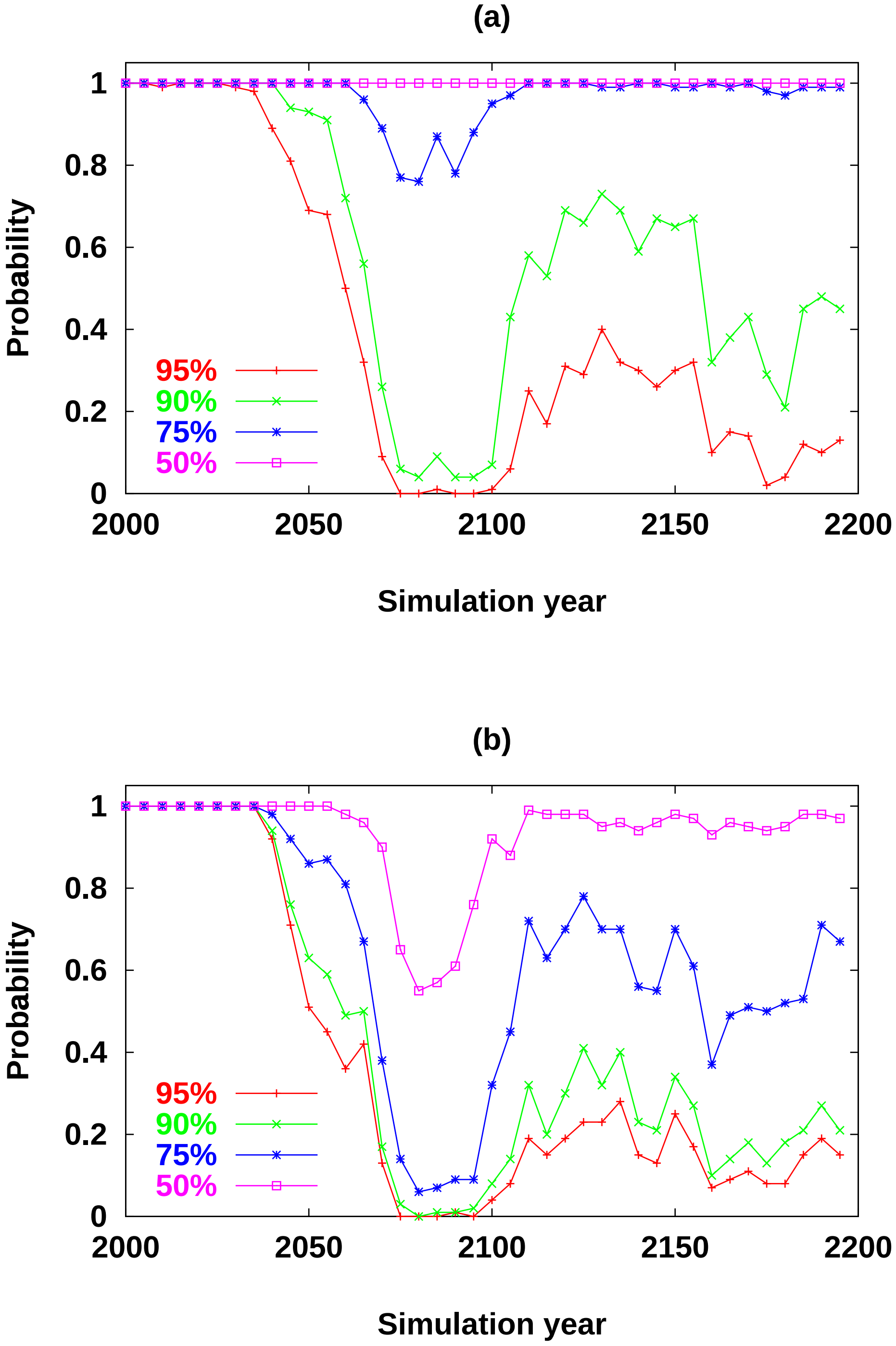


Figure 5: Failures in wood supply under a stochastic fire regime. The graphs indicate the annual probabilities of achieving stated percentages of Quota volumes, for Quota holders in aggregate (a) and for a typical large Quota holder (b).



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