Supplementary material

The economic impact of fire management on timber production in the boreal forest region of Quebec, Canada

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Supplementary material 1. Timber harvest scheduling optimization model

This model aims to maximize the net present value from the sale of primary-processed products resulting from the processing of the harvested timber at the closest sawmill. Let,

Indices:

\( s \) stratum (1..S; S= 38, 52, and 66 in FMUs 026-65, 085-51 and 094-52, respectively),

\( a \) age class (1..30, 5-year intervals),

\( t \) period (1..30, 5-year periods),

\( p \) product (1..3; lumber, chips and sawdust),

Decision variables:

\( H_{sat} \) planned harvested area (ha) in stratum \( s \) and age class \( a \) during period \( t \), \( \forall \ s, a \) and \( t \)

\( X_{sat} \) area of age class \( a \) of stratum \( s \) at start of period \( t \) (ha), \( \forall \ s, a \) and \( t \).

Parameters:

\( x_{s0a} \) initial condition: area (ha) in stratum \( s \) in age class \( a \) in (ha), \( \forall \ s, a \),

\( v_{sa} \) merchantable volume in stratum \( s \) in age class \( a \) (m\(^3\) ha\(^{-1}\)), \( \forall \ s \) and \( a \),

\( v_{psa} \) product volume (m\(^3\) ha\(^{-1}\)), \( \forall \ p, s \) and \( a \),

\( a_{s}^{\min} \) minimum harvest age (period), \( \forall \ s \),

\( b_{f} \) constant periodic burn rate,

\( d_{s} \) distance between the centroid of landscape unit to which a stratum belongs and the closest primary processing mill, \( \forall \ s \),

\( r_{p} \) product selling price at the delivery site for forest product \( p \) produced in the closest mill ($ m^{-3} $), \( \forall \ p \),
The objective function is structured to maximize the net present value (NPV) from the sale of wood products processed at the closest primary processing mill as:

\[ NPV_{prod} = \max \sum_{t=1}^{2} \left[ \gamma_t \sum_{p=1}^{3} \sum_{s=1}^{S} \left( r_p - c^{fo} - c^{tr} - c^{pr} - t^{tr} \right) \sum_{a=a_{min}}^{30} v_{sa} H_{sat} \right] \]  

Constrained to:

Periodic even flow of harvest volume:

\[ \sum_{s=1}^{S} \sum_{a=a_{min}}^{30} v_{sa} H_{sat(t-1)} = \sum_{s=1}^{S} \sum_{a=a_{min}}^{30} v_{sa} H_{sat(t)} \quad \forall t \in \{2..30\} \]  

The planned harvest area is limited to be less than or equal to the area available in each stratum, age class and period, after accounting for the impact of fire with a constant periodic average burn fraction \( (b_f) \) by period over the planning horizon:

\[ H_{sat} \leq (1 - b_f) X_{sat}, \quad \forall s, a \text{ and } t \]
Following Reed and Errico (1986), we also assumed that fire occurs uniformly and proportionally over all of the strata and the age-classes within each FMU. Accordingly, the area accounting constraints in Model III structure are given as:

in the youngest age class:

\[ X_{s1t} = \sum_{a=1}^{30} H_{sa(t-1)} + b_f \sum_{a=1}^{30} X_{sa(t-1)}, \quad \forall \ s, a \text{ and } t \in \{2..30\} \]  \[ S4 \]

in the upper collecting age class:

\[ X_{sat} = (1 - b_f) \sum_{a=29}^{30} X_{sa(t-1)} - \sum_{a=29}^{30} H_{sa(t-1)}, \quad \forall \ s \text{ and } t \in \{2..30\} \]  \[ S5 \]

and, in the intermediate age classes:

\[ X_{sat} = (1 - b_f) X_{s(a-1)(t-1)} - H_{s(a-1)(t-1)}, \quad \forall \ s, a \in \{2..29\} \text{ and } t \in \{2..30\} \]  \[ S6 \]

We used the mean of \(b_t\) (eq. 2) as the constant burn rate \(b_f\) required for our optimization model for each presuppression scenario. Although there were only 441 possible cases for random draws of two independent variables from a pool of 21 years of observations, 10 000 random draws were conducted for each presuppression scenario to generate the probability distribution function of \(b_t\) and achieve consistent estimations of the mean values (\(b_f\)).

Lumber has the highest value among the three products we used as the primary-processed products. Therefore, to avoid depleting the lumber resource with the lowest processing costs, we also added an even-flow constraint of lumber yield and an even flow of distance-weighted lumber yield:

\[ \sum_{s=1}^{S} \sum_{a=a_{min}}^{30} v_{psa} * H_{sa(t-1)} = \sum_{s=1}^{S} \sum_{a=a_{min}}^{30} v_{psa} * H_{sat}, \quad p = \text{lumber}, \forall \ t \in \{2..30\} \]  \[ S7 \]

\[ \sum_{s=1}^{S} \frac{1}{d_a} \sum_{a=a_{min}}^{30} v_{psa} * H_{sa(t-1)} = \sum_{s=1}^{S} \frac{1}{d_a} \sum_{a=a_{min}}^{30} v_{psa} * H_{sat}, \quad p = \text{lumber}, \forall \ t \in \{2..30\} \]  \[ S8 \]

References

Bureau du forestier en chef (BFEC) 2013 Manuel de détermination des possibilités forestières 2013-2018. Gouvernement du Québec, Roberval, QC. Available at


Supplementary material 2. Determination of the required number of simulations: coefficient of variation of the 5th, 50th and 95th percentiles of marginal net revenue between the two lowest presuppression expenditure scenarios ($0.40 and 0.60 ha\(^{-1}\) y\(^{-1}\)). The percentiles for each simulation sample size are constructed by 1,000 random draws from a pool of 1,500 simulations.