Using survival analysis to predict the harvesting of forest stands in Quebec, Canada

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Forest management Planning

- **environment protection**
- **economic interests**
- **social demands**
- **mixed forests**

Complex decision making

Strategic-level decisions

- **large areas**
- **long-term time horizons**
- **silvicultural policies**
- **legislation issues**

Martell et al., 1998
Hernandez et al., 2014

Forest management Planning

Complex decision making

Strategic-level decisions

Harvest

Harvest decision

✓ **Harvest algorithms** difficult task

✓ **Harvest Models** LR : temporal information

- tree- or plot-level probability -> **logistic regression**
- limitations
  - Exact date of the harvest is unknown
  - Intervals overlap
  - Changes in sampling intensity
  - Uneven time intervals

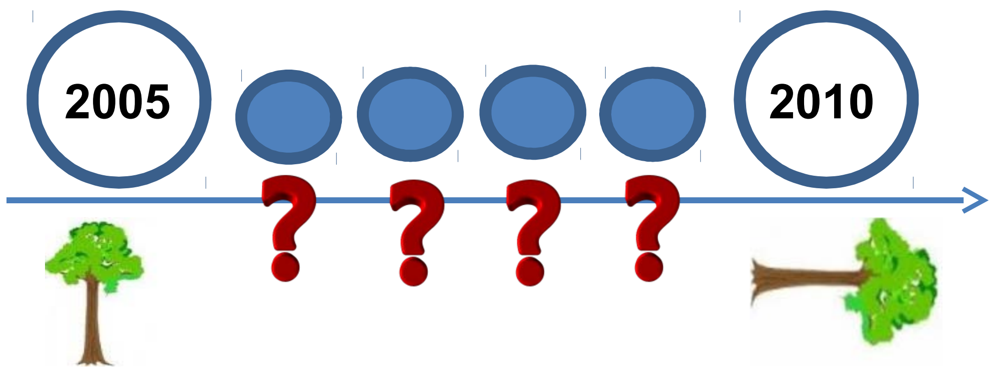
Wang et al., 2013
Thurnher et al., 2011

Harvest decision

- ✓ **Harvest Algorithms** difficult task
- ✓ **Harvest Models : Logistic Regression** does not effectively use temporal information

- ✓ **Harvest Models: Survival Analysis**

deal with interval-censored data



Lawless, 2003

Harvest decision

- ✓ **Harvest Algorithms** difficult task
- ✓ **Harvest Models : Logistic Regression** does not effectively use temporal information

✓ **Harvest Models:** **Survival Analysis**

- deal with interval-censored data
- time-varying explanatory variables
  - Basal Area: between intervals
  - AAC: within intervals

Lawless, 2003

Harvest decision

- ✓ **Harvest Algorithms** difficult task
- ✓ **Harvest Models : Logistic Regression** does not effectively use temporal information

✓ **Harvest Models:** **Survival Analysis**

- deal with interval-censored data
- time-varying explanatory variables
- multiple levels of explanatory variables
  - Exchange rate
  - Management strategy changes

Lawless, 2003

Develop a survival model to predict the plot-level harvest occurrence

HYPOTHESES

1

Survival Analysis approach provides unbiased predictions of harvest occurrence

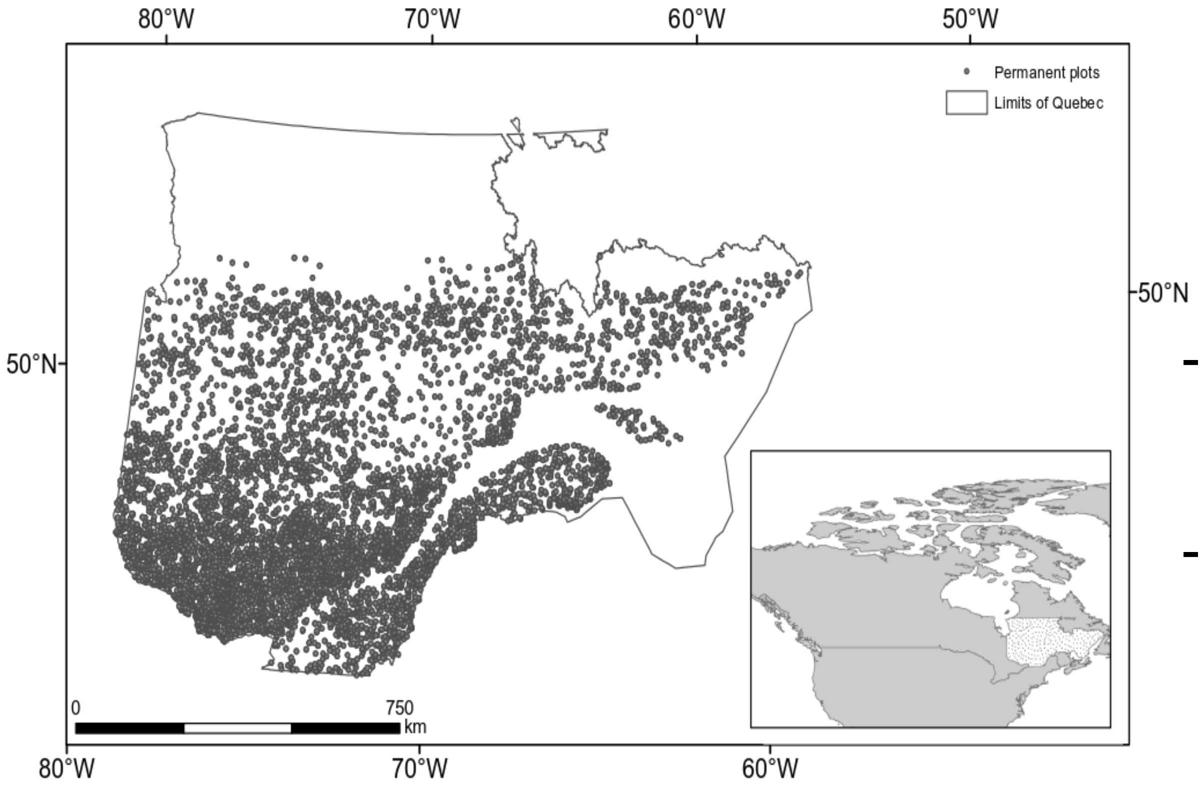
2

Regional variables have an effect on harvest occurrence

3

Time-varying covariates contribute to increasing the model likelihood

Dataset



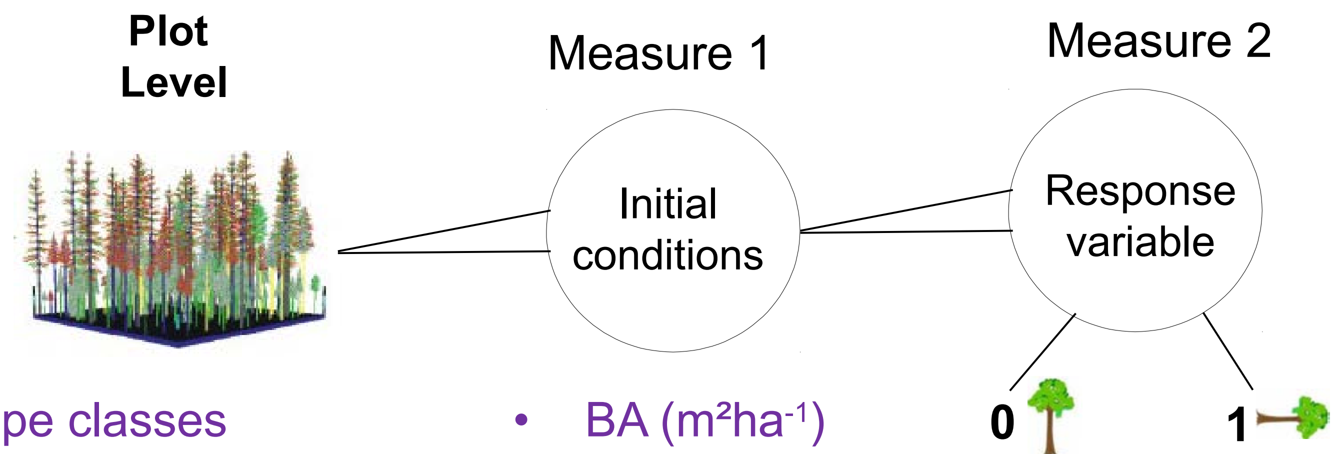
Provincial Forest Inventory Quebec:

- Nordic temperate zone: broadleaved and mixed stands
- Boreal zone: coniferous stands

- **12,596 intervals – 1988:2014**
- **Uneven intervals: 2 to 6 measures/plot**

Dataset

Explanatory Variables



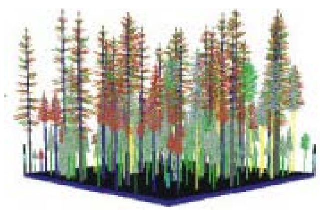
- Slope classes
- Cover type (B, M, C)
- Interval length (years)
- Spatial Correlation

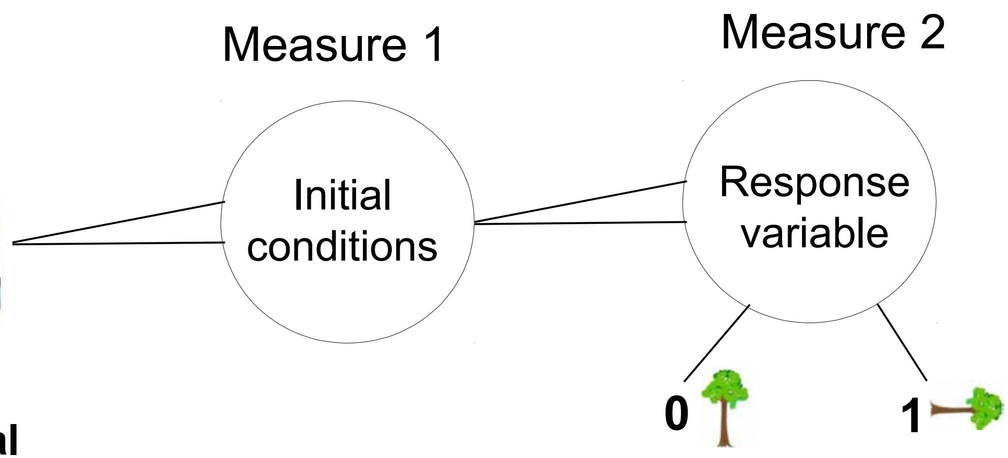
- BA ($m^2 ha^{-1}$)
- SD (stem ha^{-1})

Dataset

Explanatory Variables

Plot Level





Regional/National Level

- AAC – Regional annual allowable cut volumes
- Countervailing duty
- Exchange rate

Statistical development

Proportional hazard model

$$h_{ijk}(t) = h_0(t, \boldsymbol{g}_{ijk}\boldsymbol{\gamma})e^{\boldsymbol{x}_{ijk}\boldsymbol{\beta}}$$

Probability of harvest

Baseline: time, spatial, AAC

Proportional: stand covariates

Model evaluation

$$h_{ijk}(t) = h_0(t, \boldsymbol{g}_{ijk}\gamma)e^{\boldsymbol{x}_{ijk}\boldsymbol{\beta}}$$

- **AIC**
- **10-fold cross-validation**
- **Hosmer-Lemeshow test**
- **ROC – AUC**

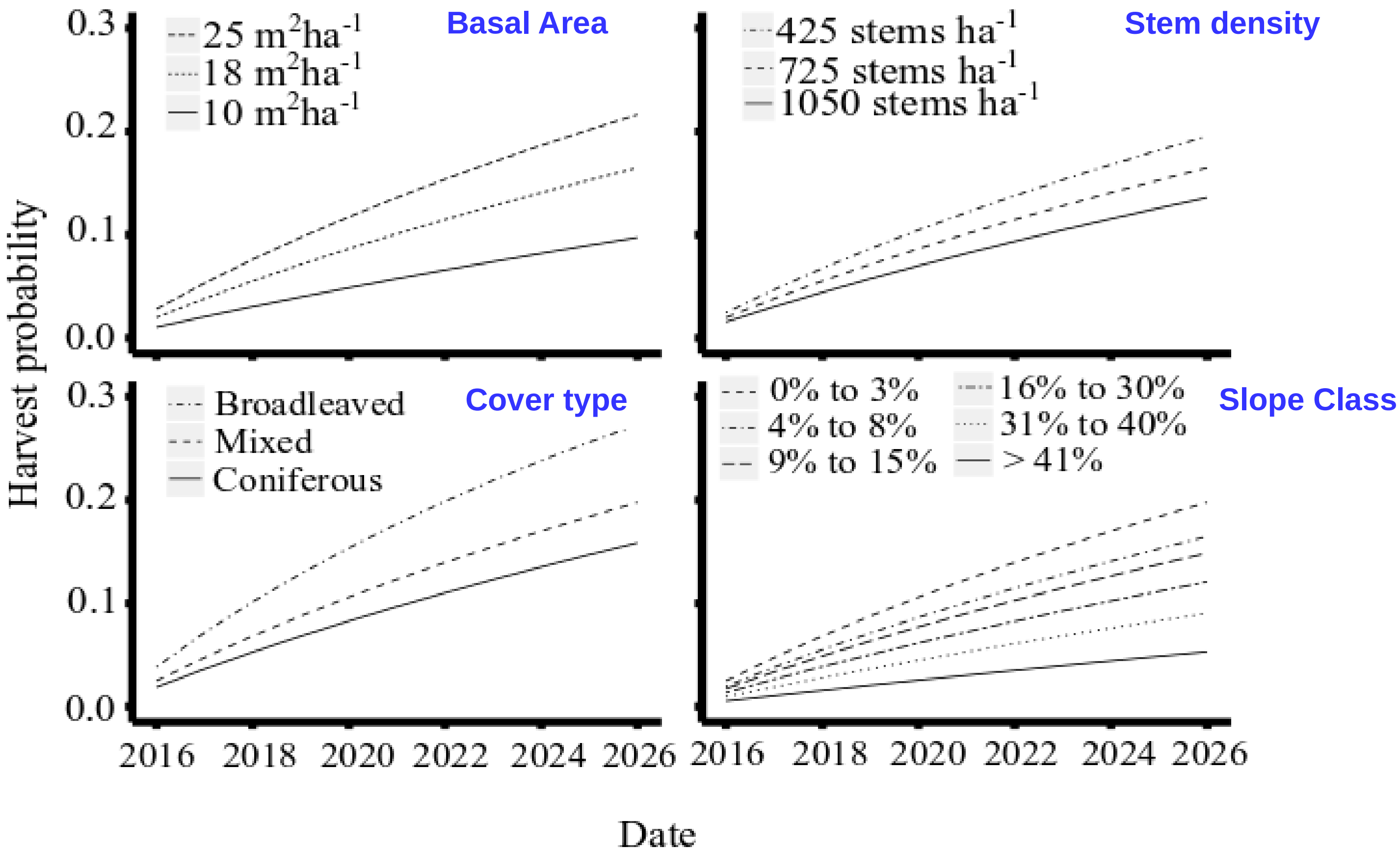
Short-term forecasts (10-year) of harvest probabilities

The final model

$$\Pr(y_{ijk}=1) = 1 - e^{-e^{\beta_1 \ln(\mathrm{BA}_{ijk}) + \beta_2 \mathrm{N}_{ijk} + \beta_{3,s} + \beta_{4,v}} \sum_{z=t_1}^{t_2} e^{\gamma_0 + \gamma_1 \mathrm{AAC}_z + u_i}}$$

- Basal area: +
- Stem density: −
- Cover type: + Broadleaved
- Slope class: −
- AAC: +
- Cruise line: +

Forecasts



Basal Area
25 m²ha⁻¹
18 m²ha⁻¹
10 m²ha⁻¹
Stem density
425 stems ha⁻¹
725 stems ha⁻¹
1050 stems ha⁻¹
Cover type
Broadleaved
Mixed
Coniferous
Slope Class
0% to 3%
4% to 8%
9% to 15%
16% to 30%
31% to 40%
> 41%
Harvest probability
0.0
0.1
0.2
0.3
2016
2018
2020
2022
2024
2026
Date

DISCUSSION

Potential of SA to provide annual predictions of harvest occurrence

- Changes: economic conditions, legislation, management practices and length of intervals (Antón-Fernandez, 2012; Thurner et al., 2011).

- Deal with uneven intervals and time-varying regional variables.

Variables

- Low stem density = High probability of harvest (Antón-Fernandez, 2012) } mature stands

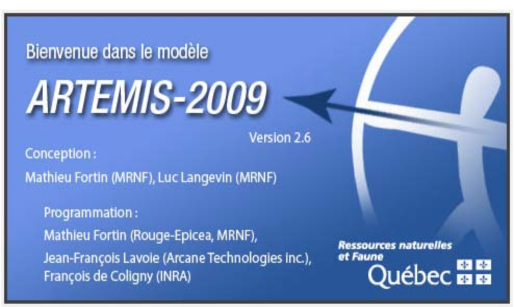
- Spatial correlation improved the model fit (BoWang and Gadow, 2006)

Limitations

- Random effects to account for spatial correlations
- Multiple random effects

Contributions

- Strategic level: harvesting probability on a long-term planning horizon
- Applicable to a wide range of forest types
- Coupled to a growth model: generate large-area growth predictions



Capsis4

Capsis

Computer-aided projection of strategies in silviculture

Contributions

Melo, L.C.; Schneider, R.; Manso, R.; Saucier, J-P.; Fortin, M. Using Survival Analysis to predict the harvest occurrence in forest stands in Quebec, Canada. *Canadian Journal of Forest Research*, **accepted March/2017**.

Merci de votre attention!

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