SPECIES AND STAND DYNAMICS IN THE MIXED-WOODS OF QUEBEC'S BOREAL FOREST: A GUIDE FOR ECOSYSTEM MANAGEMENT

Boreal Mixedwoods 2012–Ecology and Management for Multiple Values

June 17-20, 2012
A definition of Ecosystem Management

« A management approach that aims to maintain healthy and resilient forest ecosystems by focusing on the reduction of differences between natural and managed landscapes to ensure long term maintenance of ecosystem functions and thereby retain the social and economic benefits they provide to society »

(Gauthier et al. 2009)
Sustainable forest development Act (April 2010)

- **Art 1:** (1) implement sustainable forest development, in particular through **ecosystem-based development**;

- **Art 4:** “ecosystem-based development” means development that consists in ensuring the preservation of the biodiversity and viability of ecosystems by **reducing the differences** between **developed and natural forests**;
How to maintain biodiversity?

Keep forest ecosystems in their natural range of variability is the best hypothesis we have for maintaining biodiversity.

We should avoid putting species in an environment they never faced.
To maintain biodiversity, we must retain habitats

• Most species are retained by the **coarse filter**

• Some species need special attention: **fine filter**
Outline

Steps required for ecosystem management implementation

- Reconstruction of the **natural disturbance regime** and **long term evolution** of forest stands following a **disturbance**
- **Comparative analysis** of **natural** and **managed landscapes** and identification of the **main differences**
- Development of **management objectives** and **silvicultural activities** to minimize differences between **forest management** and **natural forest dynamics**
- Implementation of **silvicultural, social and economic values activities** in the context of **management plan** that take into account social and economic values
- **Monitoring** of interventions to **evaluate** management objectives and **modify silvicultural activities** if necessary

Modified from Jetté, J-P., MRNFQ
Boreal mixedwoods across Canada

Varying canopy dominance by broadleaf and conifer trees
Vegetation zones in Quebec

- Arctic tundra
- Forest tundra
- Taiga
- Boreal Mixedwood
  - Black spruce-feathermoss
  - Balsam fir – white birch
  - Sugar maple: 11 million ha
  - Boreal Zone: 107 million ha
  - Boreal Mixedwood: 13.9 million ha
### Bioclimatic domains

**Continuous forest in Quebec**

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Area</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maple-Hickory</td>
<td>13 700 km²</td>
<td>1 %</td>
</tr>
<tr>
<td>Maple-basswood</td>
<td>30 100 km²</td>
<td>4 %</td>
</tr>
<tr>
<td>Maple-yellow birch</td>
<td>65 600 km²</td>
<td>9 %</td>
</tr>
<tr>
<td>Fir-yellow birch</td>
<td>97 500 km²</td>
<td>13 %</td>
</tr>
<tr>
<td><strong>Fir-white birch</strong></td>
<td><strong>139 000 km²</strong></td>
<td><strong>19 %</strong></td>
</tr>
<tr>
<td>Black spruce-feather moss</td>
<td>402 500 km²</td>
<td>54 %</td>
</tr>
<tr>
<td><strong>Québec forested</strong></td>
<td><strong>748 400 km²</strong></td>
<td><strong>100 %</strong></td>
</tr>
</tbody>
</table>
Balsam fir-white birch domain

Main species
- Abies balsamea
- Picea glauca
- Picea mariana
- Betula papyrifera
- Populus tremuloides

Temperature
0.0°C to 1.0°C

Natural disturbances
- Insect (spruce budworm)
- Fire

Land uses
Crown (private) lands
Large intense fires control forest dynamics in Canadian boreal forest.

Fires completely replace forest stands.
Methods

1880-today

→ archives (since 1940---)

→ aerial photographs (since 1920)

Before 1880

→ dating post-fire tree cohorts

→ fire scars

→ Jack pine snags

The study area (15 793 km²)
Mainly age of living trees or snags
% of the area occupied by stands initiated in each decade

mean age: 139 years

57% > 100yrs

23% > 200yrs
Old-growth forests through the holocene

Paleoecological reconstruction of fire frequency using lake sediments

(Carcaill et al. (2001) J. Ecol.)
Paleoecological reconstruction – Methods


- Laminated lake sediment sampling
  - 302-584 cm cores

- Radiocarbon dating
  - 6-9 AMS dates per profile
  - 6800-7650 y.-long chronologies

- Meso-charcoal profiles
  - Charcoal > 150 μm (local origin)
  - 1cm resolution

- Age/Depth models
  - Equally spaced-time transformation
  - Detrending of charcoal accumulation rate
  - Identification of individual peaks

- Millenia-scale local fire history
Paleoecological reconstruction

- Lac à la Pessière
  - Coniferous boreal
  - 49°30’N

- Lac Pas-de-Fond
  - Mixed boreal
  - 48°50’N

- Lac Francis
  - Mixed boreal
  - 48°30’N

Fire activity since 7650 bp in Abitibi
Boreal mixedwood dynamics

- **Fire**
  1. Severity
  2. Frequency, (3) Size

- **Pre-fire composition**
- **Landscape composition**
- **Site conditions & Climate**

- **Availability of reproductive propagules**
- **Regeneration microsites**
- **Micro-environment**

**Post-disturbance Regeneration**

**Ongoing stand development**

- **Herbivory**
- **Competition**
- **Insect & disease outbreaks**

**Natural life-span**

**Small-scale disturbances**
Chronosequence

Similar environmental conditions

Time since fire

Images from “Wildfire and Wildlife” pamphlet, Alaska Department of Fish and Game
Natural forest succession in the Lake Duparquet mixedwood boreal forest
(Bergeron, 2000)
Sites used for Dendro reconstruction
Prefered micro-sites for conifers
Natural stand dynamics

Aspen (mesic-subhydric)

W. birch (mesic)

broadleaf  mixedwood  conifer
Mixedwoods in time

- **Young Mixed** (broadleaf dominated)
- **Mature Mixed** (broadleaf-conifer)
- **Old Mixed** (conifer-dominated)

Conifer regeneration peaks after fire but constant recruitment between fires (Eastern Canada)
Most of the **conifer regeneration** occurring **immediately after fire**
Low conifer recruitment between fire (**Western Canada**)
Spruce budworm outbreaks in the mixedwoods
• Fire has been intensively studied (frequency, impact, variability in time...)

• In some parts of Eastern North America, impacts of spruce budworm outbreaks are more important than fire.

• For example: in Eastern Canada, the last outbreak (1974-88) has destroyed more than 55 000 000 ha of forest and between 139 and 238 millions of m³ of spruce and fir.
Outbreak Identification

Index

1880 1900 1920 1940 1960 1980 2000

O4 O3 O2 O1

Host
Non-host
Corrected
Pres. Abs.
Balsam fir mortality

vs basal area

\[ y = 12.516 + 4.638x - 0.078x^2 \]
\[ R^2 = 0.237 \]

vs % of mixed coniferous stands in mosaic

\[ y = 14.41 + 1.544x \]
\[ R^2 = 0.329 \]
Impact on the forest dynamics
Natural stand dynamics

Aspen (mesic-subhydric)

W. birch (mesic)

broadleaf

mixedwood

conifer
Tent Caterpillar on aspen and birch

(adapted from Bergeron et al 1999, Harvey et al. 2002)
Outbreaks in east-central Canada
Impacts of severe tent caterpillar defoliation

In absence of conifer regeneration:
Lengthening of the deciduous phase of succession

Abundant conifer regeneration:
Acceleration of transition towards conifer dominance
18 YRS OF CANOPY CHANGES IN THE BOREAL MIXEDWOOD OF EASTERN QUEBEC

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Introduction
The boreal mixedwood is a complex ecosystem representing a mosaic of stands varying in size and composition. Forest fires, which are also irregular in shape, size and severity, play a key role in shaping this mosaic, notably by initiating forest succession. Other disturbances such as insect outbreaks also strongly influence the dynamics of this ecosystem.

Boreal forest succession is difficult to study because it spans several hundreds of years and can be affected by stochastic environmental conditions. The methods for understanding this temporal dynamic can be direct, thus allowing real-time study of the changes occurring in the forest (e.g. repeated observations in permanent plots), or indirect, by examining attributes of forest stands along an age gradient (e.g. chronosequence).

Fig.1: Fire map of the Lake Duparquet Research and Teaching Forest (FERLD) where we studied forest composition between 1991 and 2009 in a chronosequence of 249 yrs in 7 fires (labeled with red stars) in 2005. Forests were burnt in 1760 (249 yrs old), 1797 (212 yrs old), 1826 (186 yrs old), 1847 (162 yrs old), 1870 (149 yrs old), 1916 (90 yrs old) and 1944 (65 yrs old).

Methodology
We studied the changes in forest canopy composition with both direct and indirect methods in the Lake Duparquet Research and Teaching Forest (FERLD), Abitibi, Québec, eastern Canada. The combination of the direct and indirect methods allowed us to assess the reliability of the chronosequence in better understanding forest succession.

We sampled 439 plots in 1991 and revisited the same plots in 2009, allowing us to characterize changes in the forest mosaic over nearly 20 years in seven areas forming a chronosequence of 249 years.
Basal area over the chronosequence (blue) and over time between samples (red)
Basal area over the chronosequence (blue) and over time between samples (red)
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Trembling aspen
Basal area over the chronosequence (blue) and over time between samples (red)

Trembling aspen

Time since fire (yrs)
Basal area over the chronosequence (blue) and over time between samples (red)

Paper birch
Basal area over the chronosequence (blue) and over time between samples (red)

Paper birch
Basal area over the chronosequence (blue) and over time between samples (red)

White spruce

Time since fire (yrs)

$\text{m}^2/\text{Ha}$
Basal area over the chronosequence (blue) and over time between samples (red)

White spruce
Basal area over the chronosequence (blue) and over time between samples (red)

White cedar

- X-axis: Time since fire (yrs)
- Y-axis: \(m^2/Ha\)

Graph showing the basal area of white cedar over time since fire, with a significant increase after 150 years.
Basal area over the chronosequence (blue) and over time between samples (red).
Forest composition in different fire cycles in Canadian boreal forest
Mixedwoods – at what scale?

E. Macdonald

P. Lee
Fires tend to be large and well distributed in the landscape
Fire size distribution

**Number of fires**

- Coniferous (N=68)
- Mixedwood (N=1060)

<table>
<thead>
<tr>
<th>Fire size classes (ha)</th>
<th>Number of fire (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>50</td>
</tr>
<tr>
<td>10-100</td>
<td>40</td>
</tr>
<tr>
<td>100-1000</td>
<td>30</td>
</tr>
<tr>
<td>1000-10000</td>
<td>20</td>
</tr>
<tr>
<td>10000-100000</td>
<td>10</td>
</tr>
</tbody>
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**Area burned**

- Coniferous (area: 70 847 ha)
- Mixedwood (area: 82 370 ha)

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(Bergeron et al. 2004 Ecology)
Steps required for ecosystem management implementation

- Reconstruction of the natural disturbance regime and long term evolution of forest stands following a disturbance
- Comparative analysis of natural and managed landscapes and identification of the main differences
- Development of management objectives and silvicultural activities to minimize differences between forest management and natural forest dynamics
- Implementation of silvicultural, social and economic values activities in the context of management plan that take into account social and economic values
- Monitoring of interventions to evaluate management objectives and modify silvicultural activities if necessary

Modified from Jetté, J-P., MRNFQ
Clear-cut with advance growth protection (claag/cprs)

Residual stems < 10cm dbh

Skid tracks 25% of the cutting area
Modern myth

Given that the boreal forest is controlled by fires, large scale clear-cutting with short rotations adequately emulates natural forest mosaics.
Fire cycle vs forest rotation period

100 yrs Fire cycle

100 yrs forest rotation period

Mean stand age = 100 yrs
Stands > 100 yrs = 37%

Mean stand age = 50 yrs
Stands > 100 yrs = 0%
Age distribution of managed vs natural forests

- **Fire cycle = 140 yrs**
- **Forest rotation = 100 yrs**

Average age of **natural forests** = 140 yrs
Average age of **managed forests** = 50 yrs
Old-growth forest were abundant during all the Holocene

Current conditions are outside Natural range of variability (NRV)
A wave from south to north
Steps required for ecosystem management implementation

<table>
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<th>Steps</th>
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<td>Reconstruction of the natural disturbance regime and long term</td>
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<td>evolution of forest stands following a disturbance</td>
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Modified from Jetté, J-P., MRNFQ
Mixedwood stand dynamics and emulation sylviculture
Fitting FEM principles into 80km²

Fire size X
Forest age structure ✓
Forest composition ✓
Stand dynamics in silviculture ✓

“Forest microcosm”
Forest-level targets for each cohort based on fire cycle and maximum harvest age
(Adapted from Bergeron et al. 1999)

<table>
<thead>
<tr>
<th>Maximum harvest age</th>
<th>50 cohort (%)</th>
<th>100 cohort (%)</th>
<th>200 cohort (%)</th>
<th>300 cohort (%)</th>
<th>500 cohort (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>50</td>
<td>63</td>
<td>23</td>
<td>14</td>
<td>39</td>
<td>24</td>
</tr>
<tr>
<td>80</td>
<td>86</td>
<td>12</td>
<td>2</td>
<td>55</td>
<td>25</td>
</tr>
<tr>
<td>100</td>
<td>91</td>
<td>8</td>
<td>1</td>
<td>63</td>
<td>23</td>
</tr>
<tr>
<td>120</td>
<td>95</td>
<td>5</td>
<td>0</td>
<td>70</td>
<td>21</td>
</tr>
<tr>
<td>150</td>
<td>98</td>
<td>2</td>
<td>0</td>
<td>80</td>
<td>12</td>
</tr>
<tr>
<td>180</td>
<td>97</td>
<td>2</td>
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<td>1</td>
<td>63</td>
<td>23</td>
</tr>
</tbody>
</table>

Alberta: Abitibi: Labrador
Setting cohort objectives

1. Mean forest age (139 yrs) ≈ fire cycle
2. Negative exponential age distribution
3. Cohort structure: $f$ (cycle & rotation age)

Cohort 1: 45-55%
Cohort 2: 23-26%
Cohorts 3+: 20-30%
Integrating forest-level and stand-level objectives

Uneven-aged silviculture

1st cohort 45-55 %

2nd cohort 23-26 %

3rd+ cohort 20-30 %

55 % clear-cut (fire)

45 % partial cut (succession)

50 % partial cut (succession)

33 % selection cut (succession)

50 % clear-cut (fire)

67 % clear-cut (fire)

Even-aged silviculture
“SAFE”
Sylviculture et aménagement forestier écosystémique
Silviculture and Forest ecosystem management

Uneven-aged silviculture
Even-aged silviculture

Integrating forest-level and stand-level objectives
Partial harvesting in winter 1998-99 of fire-origin (1923) aspen stands

Control  1/3 low thin  2/3 crown thin
<table>
<thead>
<tr>
<th>Cohort</th>
<th>Years since stand initiation</th>
<th>Even-aged silviculture</th>
<th>Uneven-aged silviculture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COHORT 1</strong></td>
<td>(45-55%)</td>
<td>0 - 100</td>
<td>55%</td>
</tr>
<tr>
<td><strong>COHORT 2</strong></td>
<td>(23-26%)</td>
<td>75 - 175</td>
<td>50%</td>
</tr>
<tr>
<td><strong>COHORT 3+</strong></td>
<td>(20-30%)</td>
<td>150 - 250+</td>
<td>33%</td>
</tr>
</tbody>
</table>

- **Even-aged silviculture**
  - Cohort 1: 45-55%
  - Cohort 2: 23-26%
  - Cohort 3+: 20-30%

- **Uneven-aged silviculture**
  - 55%
  - 50%
  - 33%

**Legend**

- **A**: Mesic-subsurface
- **B**: Subhydric
- **C**: Mesic tills
- **D**: Xeric-mesic thin tills, sands
- **E**: Xeric thin tills, sands
- **F**: Xeric thin tills, sands
- **G**: Oligotrophic
- **H**: Eutrophic
- **I**: All sites

(Source: Harvey et al. 2002. FE&M)
Conclusions

- Current forest management is driving eastern mixedwood boreal forest outside its natural range of variability

- Mixedwoods should be maintained both in space and time

- Important diversification of silvicultural treatments is needed to meet sustainable forest management objectives
Thanks to students and collaborators
Fig. 3. Predicted changes in Monthly Drought Code (MDC) between (a) 2046–65 and 1961–99 and (b) 2081–2100 and 1961–99. See Fig. 2 for definition.
Effects of climate change
Future fire frequency will remain in the natural range of variability.