Sustainable forest management and biodiversity
There's more to it than forest age structure

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1. Introduction

Biodiversity itself is a very hard concept to quantify: it has a compositional, a structural and a functional component, which can be further spatially classified as alpha (local diversity), gamma (regional diversity) and beta diversity (spatial differentiation) (1). Within temperate and boreal forest management, forest age structure is one of the main indicators of biodiversity (e.g. Montréal Process). This indicator was mainly designed for the conservation of a subset of rare or sensitive species related to the oldest age classes (2): it was not designed to capture variability across the entire biodiversity spectrum, but is often considered as such. **In this study, we assessed how forest age classes captured variability in plot-level alpha and landscape-level beta tree diversity to examine the need to develop complementary biodiversity indicators.**

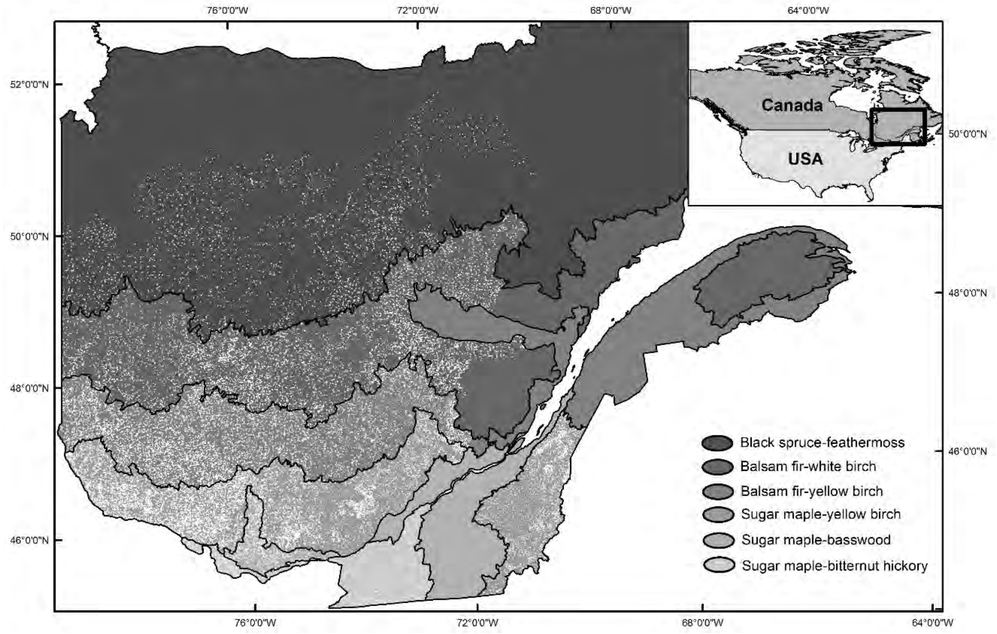

Fig. 1. Map of the study area: western Québec, Canada. White points represent temporary sample plots. Black lines delimit bioclimatic domains.

2. Methodology

Study area: Western Québec, Canada
Data: 99,429 circular temporary plots 400m^2 wide
Software: R software environment v. 3.2.3. (3)

Tree beta diversity (landscape-level)

1. Estimate each plot's Local Contribution to Beta Diversity **(LCBD)**, which is a comparative indicator of site ecological uniqueness across the landscape (4)
2. Build linear regression models with LCBD as the response variable and age, height, cover type, density and climate (average annual temperature and total annual precipitation) as explanatory variables (Table 1). Climate variables were estimated using BioSIM (ver. 10) (5), a software tool that interpolates climate data from the nearest weather stations
3. Model selection based on the Akaike Information Criterion (AIC)

Tree alpha diversity (plot-level)

1. Estimate each plot's species richness, Shannon's diversity and functional dispersion (FD R package v. 1.0-12) (6)
2. Group plots according to stand age, height and cover type
3. Compare the 3 biodiversity measures across all all 2-way combinations of stand groups by bootstrapping Mann-Whitney U tests 1000 times (N = 100)
4. Network analysis-based approach (igraph R package v.1.0.1) (7) to visualize results. Nodes were linked if for each of the 3 biodiversity indicators over 50% of the replicates were not significantly different at a p-value of 0.05

3. Main findings

- Considered individually, cover type and height are better predictors of LCBD than age
- Plots belonging to different age classes can be similar in terms of tree diversity
- Height frequently complemented age to better explain the observed diversity patterns
- Some mature secondary stands can provide significant contributions to biodiversity

Table 1. Linear regression models of plot-level local contribution to beta diversity (LCBD). ΔAIC is the AIC difference between the top model and the corresponding model.

Model structure	R squared	Δ AIC
LCBD ~ T_{avg} * Precip * Height * Cover	**28.81**	**0.0**
LCBD ~ T_{avg} * Precip * Age * Cover	28.30	709.2
LCBD ~ T_{avg} * Precip * Density * Cover	26.63	2983.3
LCBD ~ T_{avg} * Precip * Height * Density	25.43	4611.1
LCBD ~ T_{avg} * Precip * Cover	25.38	4635.9
LCBD ~ T_{avg} * Precip * Age * Height	25.15	4990.0
LCBD ~ T_{avg} * Precip * Age * Density	23.25	7480.6
LCBD ~ T_{avg} * Precip * Height	23.13	7585.6
LCBD ~ Age + Height + Cover + Density	22.13	8859.6
LCBD ~ Height * Cover	20.92	10389.4
LCBD ~ T_{avg} * Precip * Age	19.96	11587.4
LCBD ~ T_{avg} * Precip * Density	19.41	12269.9
LCBD ~ Age * Cover	17.43	14674.7
LCBD ~ Height * Density	17.39	14729.7
LCBD ~ T_{avg} * Precip	17.18	14971.7
LCBD ~ Density * Cover	16.41	15890.6
LCBD ~ Cover	14.79	17784.9
LCBD ~ Age * Height	14.78	17818.1
LCBD ~ Height	13.57	19197.1
LCBD ~ Age * Density	8.84	24496.6
LCBD ~ Density	4.83	28764.1
LCBD ~ Age	1.34	32340.3

4. Take-home messages

Forest age structure targets are not the best indicators of ecosystem function and resilience

How can forest management be made more sustainable?

- **Forest age structure targets should be complemented by cover type and stand height**
- **Complementary biodiversity indicators more directly related to ecosystem sustainability and resilience should be included in forest management**

What should further research focus on?

- **Relationships between variables easily available from forest inventories and biodiversity indicators of other taxa**
- **Integrating indicators of ecosystem sustainability in the design of forest management strategies and models of estimation of annual allowable cut**

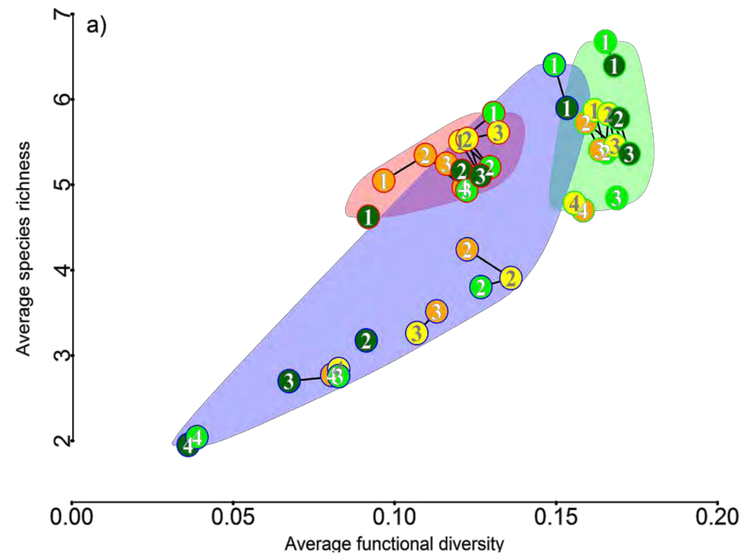

Fig. 2. Stand tree diversity plotted per cover type according to: **(a)** functional diversity and species richness; and **(b)** functional diversity and Shannon's structural diversity.

Node colours represent stand age classes
- ***orange:*** 41-60 years
- ***yellow:*** 61-80 years
- ***green:*** 81-100 years
- ***dark green:*** over 100 years old

Numbers represent height classes
- ***1:*** height ≥ 22m
- ***2:*** 17m ≤ height < 22m
- ***3:*** 12m ≤ height < 17m
- ***4:*** 7m ≤ height < 12m

Nodes linked by *black lines* have non-significant differences in terms of tree species richness, Shannon's structural diversity and functional dispersion

Background shading and node frame colour represent cover type
- **red:** deciduous stands
- **green:** mixedwood stands
- **blue:** coniferous stands

Acknowledgments
This work was funded by the Fonds de recherche du Québec, Nature et technologies (FRQ-NT). We would like to thank the Forest Complexity Modelling program, which is funded by NSERC through it's CREATE program, and the Fonds Produits forestiers Résolu for supporting this project. We would also like to thank the Canada Foundation for Innovation (CFI), the Ministère de l'Économie, de l'Innovation et des Exportations du Québec (MEIE), the RMGA and the Fonds de recherche du Québec - Nature et technologies (FRQ-NT) for funding the operation of the Guillimin supercomputer.

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