Forest processes from stands to landscapes: Incorporating local stand heterogeneity in landscape models

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Introduction

The ability to capture spatial variability in stand structure and species composition in our management practices could permit the maintenance of key processes that in turn maintain biodiversity and productivity in managed landscapes.

Concerns for multiple uses of forest resources span scales that are typically treated separately. To make effective forest management decisions, it is critically important that we develop tools that reconcile landscape-scale planning with stand-scale practices in order to improve our confidence that the sum of all the stand-scale operational decisions will meet the long-term landscape objectives.

We use an approach that makes use of information generated by two models designed to explore forest dynamics at different scales. Without data arbitrating among models no tests based on model comparisons can be used to decide unambiguously which model is better. Rather, comparisons of competing models can be used to (i) increase confidence in our understanding of ecosystem dynamics as represented by the models, and (ii) improve model structure.

Objectives

This is a simulation experiment that explores the ability of two modeling approaches to forecast the consequences across a landscape of compositional and structural complexity that is generated by local stand-scale forest management practices.

Study Area

The study area covers 11,061 forested ha in the Lake Duparquet Research and Teaching Forest (FERLD) (~48°30' N, 79°22' W) in the southern region of the Great Clay Belt in western Quebec, Canada. It is classified into 5 forested landtypes : poorly-drained, moist-clay, mesic, mesic-clay and well-drained coarse soils that determine species regeneration (Table 1). Composition is characteristic of the eastern boreal mixed wood, including the six species used in our simulations for which SORTIE has been parameterized : trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), jack pine (*Pinus banksiana*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), and eastern white cedar (*Thuja occidentalis*).

Results

Stand-scale variation

ND model

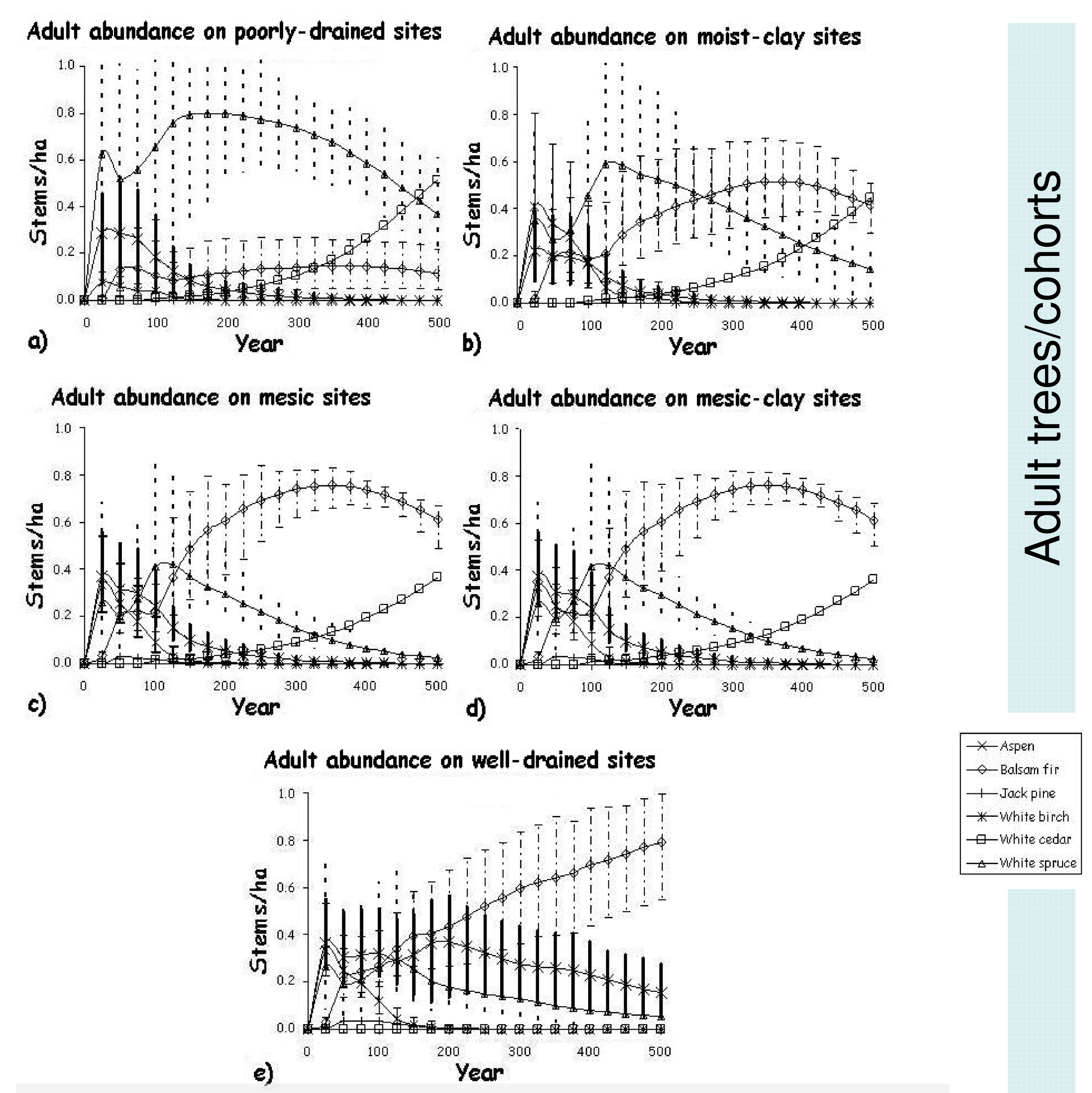

Figure 2. Variation in succession within and among landtypes. The modest, factor of 2, differences in the relative abundance of small saplings within landtypes generates considerable variation in relative species abundance, but does not lead to long-term changes in the pattern of succession.

Variation among landtypes is determined by varying species establishment characteristics in an analogous manner to LANDIS, Table 1. Results are consistent with empirical data (Bergeron 2000, Chen and Popadiouk 2002), for (c) mesic (where SORTIE was parameterized), (b) moist-mesic and (d) mesic-clay sites, but diverged from expected as the sites tended toward (a) more poorly-drained or (e) more well-drained soils.

Landscape-scale variation

Adult trees/cohorts

S-ND adult trees

AC/SR mature cohorts

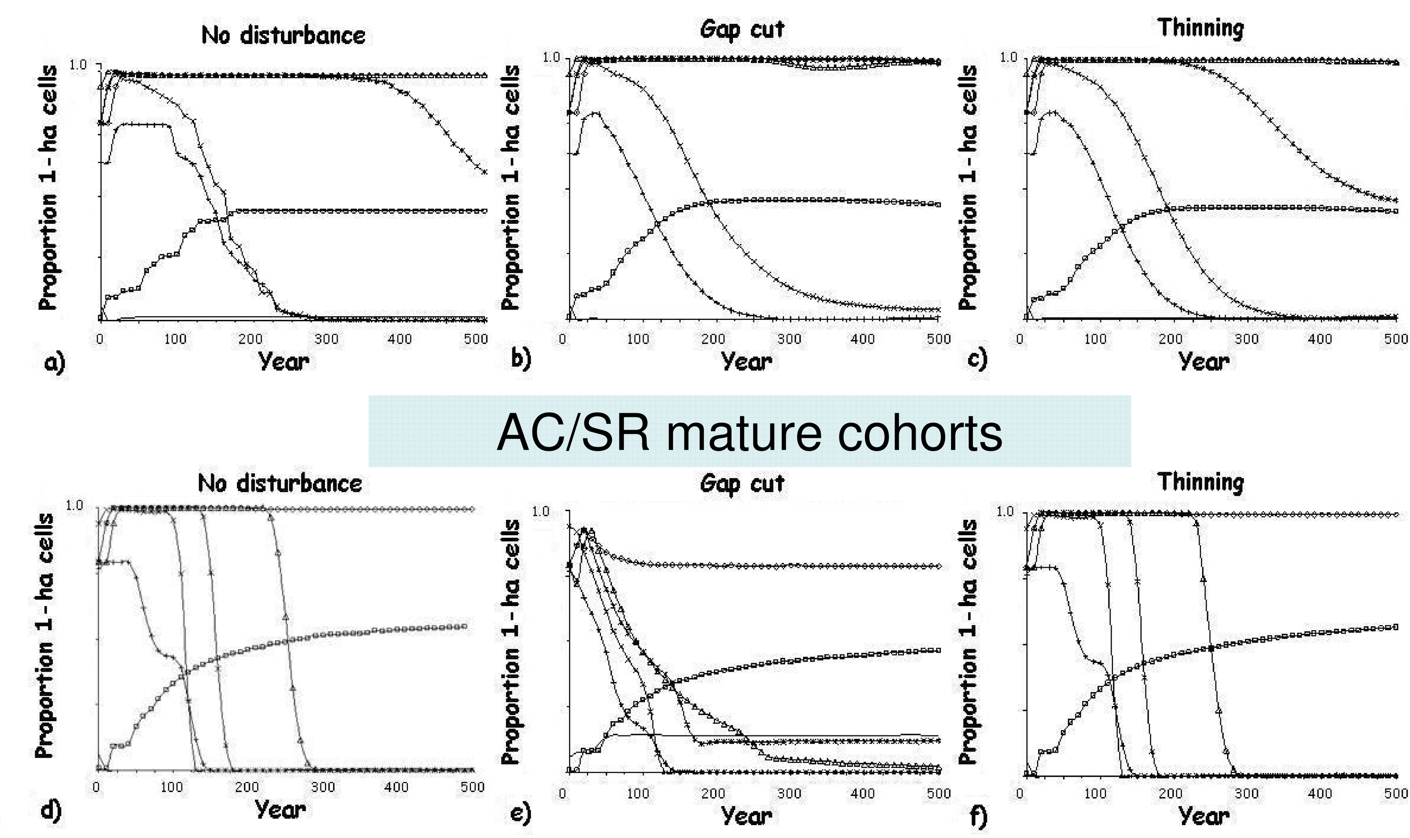

Figure 3. Presence per ha of (a-c) >1m^2/ha of adult (≥10 cm DBH) trees (S-ND) or mature cohorts (AC/SR) in landscape. Two results, both dependent on differences in sapling dynamics of the two models, are worth noting :

1) The rank order of when species start to decline below 80% of the maximum presence is the same for both models, although white spruce never begins to decline in the S-ND model. However, the time to onset of decline is significantly different between the two models.

2) S-ND and AC/SR forecasts agree that early-successional species persistence decreases under either partial harvest regime.

The two models disagree most in their forecasts of species persistence of mid-successional species under the gap harvest regime. Mid-successional persistence increases with S-ND but decreases with AC/SR.
In addition the AC/SR forecasts an equilibrium condition that ~15% of the landscape has no adult trees.

Saplings

S-ND saplings

AC/SR sapling cohorts

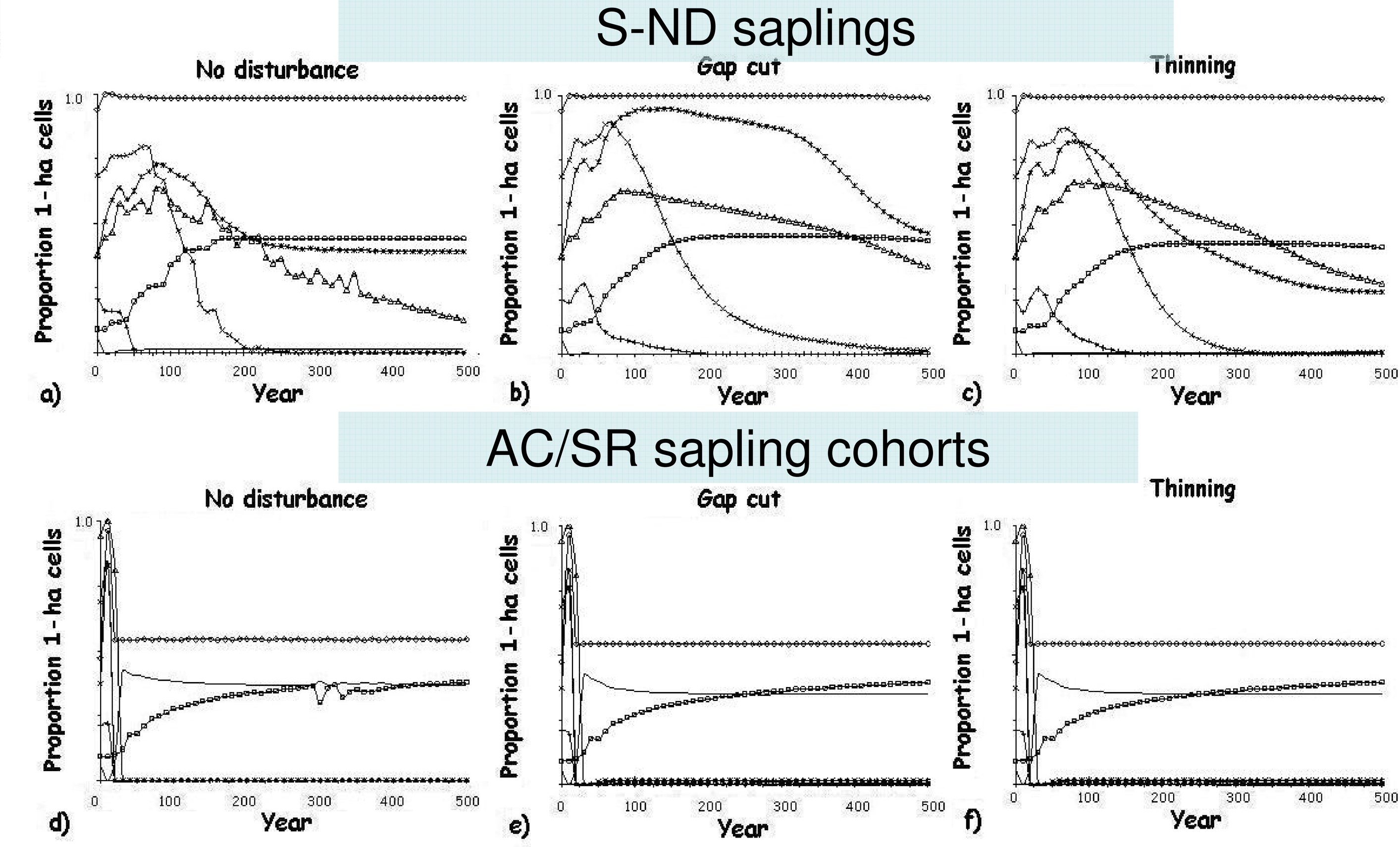

Figure 4. Presence per ha of trees <10 cm DBH (saplings) in landscape.

The most important result is the difference in the complexity of the understory between the two models.

1 a) As a direct consequence of the strict shade tolerance hierarchy rules of the AC/SR model, there is no regeneration of any species, except the two most shade tolerant, once a mature cohort of balsam fir is present (after 25 years).

b) an equilibrium condition of ~35% of the landscape is devoid of any understory regeneration.

2) In contrast, S-ND forecasts the persistence in >20% of the landscape of all species for the full simulation time except jack pine (35 years) and trembling aspen (150 years).

Methods – A simulation experiment with strict controls to isolate different consequences of two approaches to modeling succession

Neighborhood dynamics (ND)

Our ND approach is based on a version of SORTIE parameterized for Lake Duparquet to forecast stand-scale population dynamics that result from species-specific functions that determine competitive interactions among individual trees for light. The model has a very flexible user interface and harvest specification module that permits precise specification of initial population composition and structure as well as a broad range of harvest regimes.

Initial conditions

2000 trees per ha varying between 1.3 and 1.35 cm DBH.
Relative abundance of each species per landtype was weighted by establishment proportions (Table 1) after doubling the value for one species ("initial dominant").
Ignore white cedar – no initial presence

Example for poorly drained soils:
Initial dominant : Trembling aspen
Weight : 0.44
Sum : 0.2 + 1 + 0 + (2*0.22) + 0.9 = 2.54
weight/sum = 0.173 => rel. abundance
0.173 * 2000 = 346 => initial abundance.

Harvest regimes (3)

1) None
2) Gap - every 80 years, a block consisting of 60% of a 4-ha plot is cleared.
3) Thinning - every 80 years, 60% of basal area is removed.

300 simulations

5 (landtypes) x 5 (initial conditions) x 3 (harvest regimes) x 4 (long-distance regimes for white cedar)

Table 1. Relative species establishment values that control differences in dynamics among landtypes. These values are applied to both the neighborhood dynamics model and the age cohort/shade tolerance hierarchy model.

Landtype	White Cedar	Balsam Fir	White Spruce	Jack Pine	Trembling Aspen	White Birch
Poorly-drained	1	0.2	1	0	0.22	0.9
Moist clay	1	0.45	1	0	2	0.9
Mesic	1	1	1	1	1	1
Mesic clay	1	1	1	1	1.11	1
Well-drained	0	0.2	0.22	5	0.22	0.9

Landscape experiment

We assembled the 300 ND succession trajectories into 1 look-up table (LUT) to form the basis of scaled-neighborhood dynamics landscape model (S-ND).
We used the FERLD stand age map to set equivalent initial conditions for both the S-ND and age cohort/succession rank model (AC/SR) derived from LANDIS.
We specified equivalent harvest regimes for both S-ND and AC/SR models.
We let both models follow their successional trajectories and compared presence/absence results of each.

Comparison of relevant model components

	ND	S-ND	AC/SR
Trees	Individual trees with DBH, species-specific allometric functions, and spatially-explicit (x, y) positions	Results from ND simulations Stems / ha for seedlings; basal area, stems / ha for saplings and adults of each species for each 5-year timestep.	5-year age cohorts 1st cohort seedlings, subsequent species cohorts of saplings up to age of maturity, remaining cohorts adults
Local dispersal, regeneration	Spatially-explicit, species-specific fecundity and seedbed establishment	NA	Presence of seed from vegetative sprouts or seeding from mature cohorts Establishment of 1st sapling cohort determined by : i) shade tolerance rules, then if tolerance rules allow establishment, (ii) species-specific probability of (based on Table 1)
Long-distance dispersal (LDD)	White cedar only. 4.5 seedlings per 100m^2 per 5-years. Four scenarios: (i) none, starting at (ii) 50, (iii) 100 and (iv) 150 years.	NA	All species at different rates
Sensitivity to landtype	Tree fecundity is a function of the relative probability of establishment on different landtypes taken from AC/SR approach	NA	If tolerance rules allow establishment, then species-specific probability of establishment
Growth	Species-specific function of available whole season light	NA	Simple aging of cohorts
Mortality	Probabilistic function of growth	NA	None until 80% of expected lifetime,then linear increasing probability of mortality until 100% when cohort is removed

Discussion

This is a simulation experiment that explores the ability of two modeling approaches to forecast the consequences across a landscape of compositional and structural complexity that is generated by local stand-scale forest management practices. As such, it is a methods rich paper and I apologize for the length of the text.

There are 7 conclusions we can make from this study :

1) Incorporating the effects of spatial interactions among trees within a stand adds important details that impact spatial heterogeneity of species composition at the landscape scale.

2) The concordance of adult tree dynamics between the two models in the timeframe that is important to forest managers reinforces our confidence that the general average forecasts of both approaches is likely reliable.

3) Unfortunately, the lack of understory response in the AC/SR approach to variations in partial harvest represents a serious shortcoming from a management perspective, because understory vegetation critically influences successional patterns, particularly following forest harvesting. Understory vegetation is also a major component determining habitat quality for a variety of biodiversity values (e.g., songbirds, small mammals) (Simon 1998) and game species (e.g., moose (*Alces alces*) (Berger et al. 2001)).

4) The importance of model forecasts of understory dynamics is all the more critical when we consider the importance of disturbance to boreal forests (Chen and Popadiouk 2002), and emulating natural disturbance is considered one important strategic approach to sustainable management of our forest resources (Cissel et al. 1999).

5) The impoverished understory dynamics of the AC/SR approach illustrate the need for the inclusion of more process detail that accounts for important fine-scale interactions among individual trees that can cascade up to the landscape scale. We suggest that a suitably parameterized probability-based rule would improve the ability of the AC/SR model to represent sapling dynamics.

6) This approach is practical, accessible to forest managers, does not incur undue computational costs or increase model complexity and, by carefully comparing different models, offers an approach for error analysis in the absence of long-term broad-scale empirical data.