Slow demography constrains the northward expansion of the temperate forest under climate change

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Short title: Simulate the eastern boreal-temperate forests ecotone under climate change.

Keywords: states and transitions model, patch occupancy, landscape dynamics, forest inventory databases, community range shift.

Abstract

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1 Introduction

Species distribution models (SDMs) are one of the most popular tool to predict impact of climate change on species geographical range [3]. Predict forest species range shift under climate change is limited as trees are sessile, long-lived and slow to mature [5] while SDMs based on correlative methods predict instantaneous vegetation responses; therefore species migration rates are often overestimated using this approach. Integrate ecological processes using process based-model are primordial to improve this prediction [7]. Strong biotic interaction, slow demography and dispersal limitation can conduct to local extinction or prevent species colonization at the leading edge of the species distribution (Source). These ecological mechanisms could limit species spread rate over the forest landscape and could explain why many individual species are failure to migrate [10].

Lead unpace with bioclimatic niche Increase tension Lead to catastrophic shift with management scenario

In this present study, we investigated the range shift and migration rate of the temperate forest at his ecotone using a states and transitions model. We simulated the ecotone dynamic using different versions of the state and transition model over different climate change scenarios (RCP 8.5, AR5). We compared the models outputs to assess which ecological processes - dispersion, demography, propagule effect and biotic interaction - are limiting or increasing the migration ability of the temperate forest.

2 Methods

The temperate-boreal forests ecotone can be seen at the landscape scale as a macro-mosaic filled by three different forest stand patches; Boreal stand dominated by coniferous species, Temperate stand dominated by broadleaf species and finally Mixed stand as a mid-succesionnal patch [2]. In the first section, we present how we collected and classified forest plots surveys into those three regional forest biomes and how we linked the climatic data with the plot location. In the second section, we described the model allowing us to simulate the dynamic of the boreal-temperate forest ecotone and then focused on the model calibration. In the last section, we explained the simulation plan and the different model versions we ran to assess which ecological mechanisms constrains the migration rate of the temperate forest.

Table 1: Transition and none-transition (diagonal) observed between two measurements through all plots surveys extract from databases.

	B	**M**	**R**	**T**
B	**15 358**	794	203	0
M	302	**14 433**	51	960
R	485	57	**209**	80
T	0	891	40	**15 216**

2.1 Data

2.1.1 Classifying forest plot surveys

We used 4 forest inventory databases widely distributed in Eastern North America, from West-Virginia (US) to Quebec (CAN) (include plots distribution and study area in figs). We selected N plot surveys located at the boreal temperate ecotone (*add coordinates of the study area*) and then classify each plot measurement in the four states following the species composition. *add description on measurements*. A forest state is defined as mature stand characterized by a specific species community which is the result of the local climatic conditions.

In our case, the temperate community consists of 8 different species (*full species list*) and the boreal community 7 species (*species list*). If both species types are present then the patch is classified as a mixed state.

We filtered out all trees with diameter at breast height lesser than 12,7 cm.

Then we computed a transition matrix within N states transition occurred between two measurements.

2.1.2 Linking abiotic conditions

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2.2 The states and transitions model approach

2.2.1 Model description

To reproduce and simulate the dynamic of this ecotone, we used a state and transition model as a patch occupancy model [4]. We incorporated the three different forest stand types as states: Boreal (B), Temperate (T), Mixed (M) (Fig. 1). The disturbance regime is one of the important component of this natural system dynamic [1, 8]; consequently, we added the regeneration state (R, Fig. 1) to represent a post-disturbance stand.

Among the states, transitions occur by ecological processes and are formulated in the present model as a

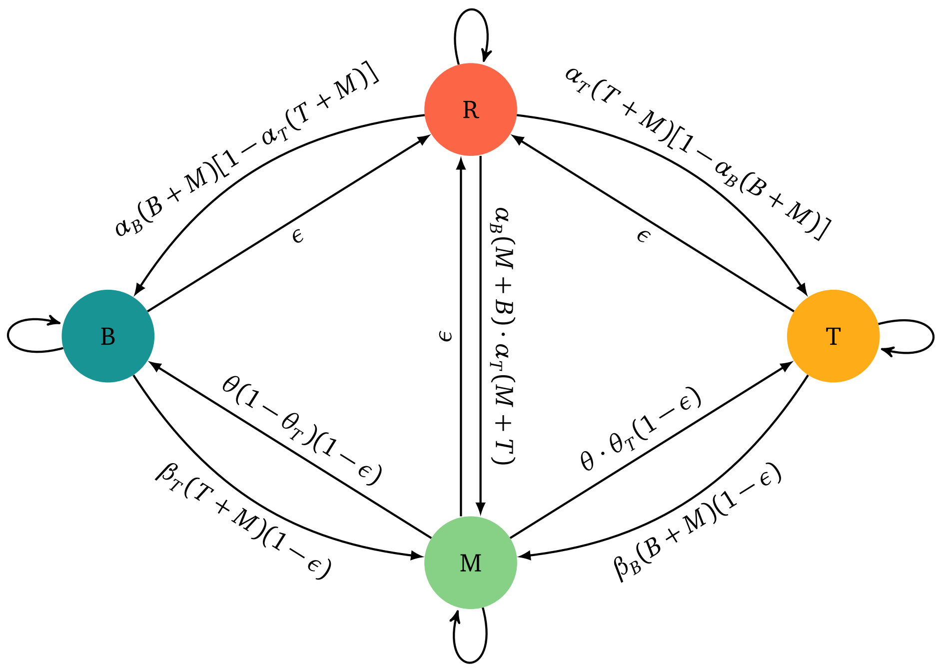


Figure 1: The states and transitions model illustrating all states and possible transition in the boreal-temperate forest system. B, T, M and R respectively mean; Boreal, Temperate, Mixed and Regeneration. Each arrow represent a transition between state.

transition probability. All transitions between states are possible except the direct transition between a temperate and boreal stand, which requires an intermediate step through the state mixed.

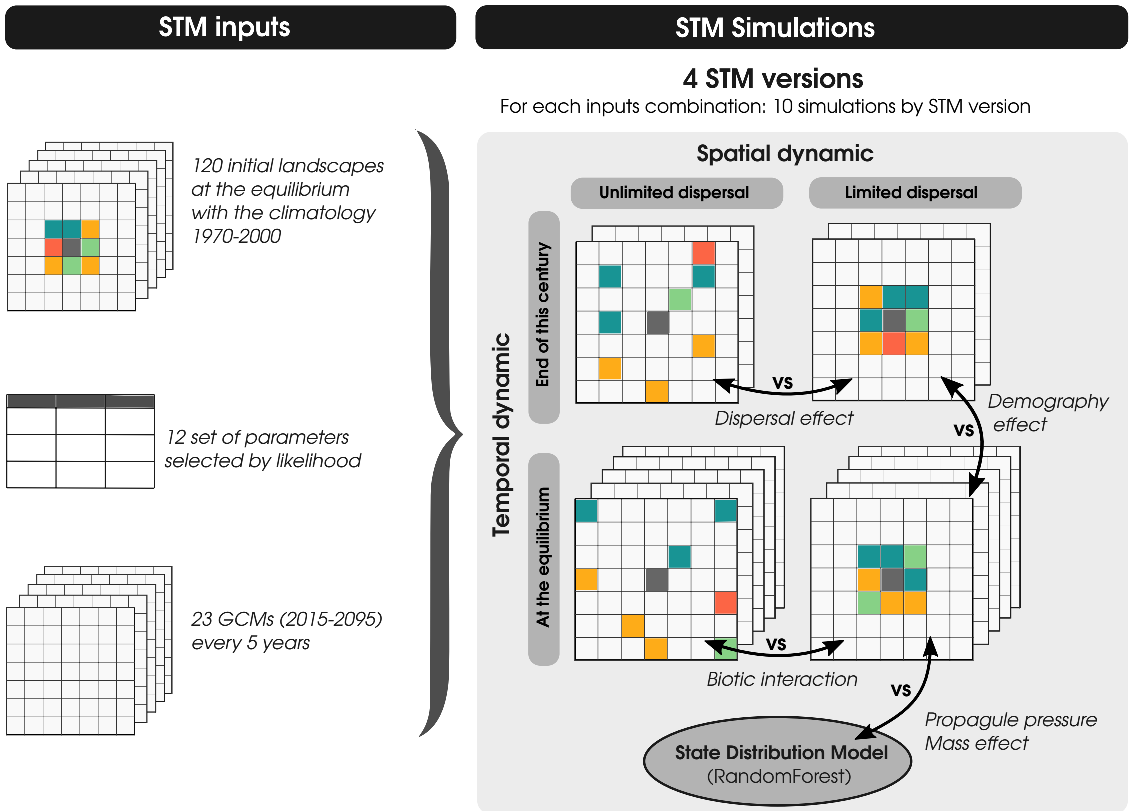
Boreal patch is converted as a mixed patch by colonization rate (β_T, fig. 1) of temperate species. This colonization rate depends on the proportion of temperate species propagules present in the neighbors ($T+M$) but also the probability of the patch to be none-disturbed ($1-\epsilon$). Hence, transition of boreal patches toward mixed patches can be formulated as $\beta_T \cdot (T+M) \cdot (1-\epsilon)$. Then, a mixed patch can transfer to a pure temperate patch by competitive exclusion of boreal species (θ_T, Fig. 1). When a disturbance appears on the patch such as fire, wind throw or insect outbreak, the patch is transferred has a regeneration state. The disturbed patch can recover from this disturbance to a boreal, temperate or mixed stand by successional dynamic. Each of those transition probabilities between states are climate-dependant calibrated on two climatic variables: annual precipitation (mm) and annual mean temperature (°C).

2.2.2 Calibration of the transition probabilities

We estimated each transition probabilities with logistic regression (GLM) on climatic conditions - characterized by annual mean temperature (TP) and the annual precipitation (PP) scaled using the linear and quadratic terms (eq. 1).

$$logit(\alpha_b) = \alpha_{b0} + \alpha_{b1} \cdot TP + \alpha_{b2} \cdot PP + \alpha_{b3} \cdot TP^2 + \alpha_{b4} \cdot PP^2 \tag{1}$$

Transition probabilities were fitted simultaneously searching for the global optimum of each function with



the simulating annealing method (GenSA package [9]). For each set of parameters converged, we computed the likelihood of each functions using the prevalence and

We selected 12 set of parameters whose converged and had the best likelihood value in order to perform the simulations on each set and evaluate the sensitivity of the model.

To calibrate the transition probabilities between states based on climate and plot neighbors, we used R (version 3.2.0) and the classification algorithm Random Forest (RandomForest package, version 4.6-10) [6], we incorporated three information types: (1) state transitions observed between plot measurements, (2) the average climate of the 15 years before each measurements for the two climatic variables of interest and finally the (3) the proportion of states available in the neighbors using a SDM (RandomForest) approach as a proxy.

2.3 Simulations and analysis

1. How the model is implemented as spatial explicit ? Moore neighbors Describe the initial simulation landscape and the choice of the resolution

We performed the simulations using 10 several initial landscape, and 12 different sets of parameters. For each parameters set and initial landscape, we ran simulations over the climate predicted by the 23 Global Climate Models (GCM) downscaled at 10 km^2 by the Ouranos consortium in clmatology in Quebec. For each of those combinations, we replicated 10 times the simulation in order to take in account the model stochasticty.

3 Results

A. Approximation of the neighbors (SDM) Ajouter la stats du HK pour la validation croisé du modèle.

B. Model simulations

Facultatif. We found that the STM was able to almost reproduce the actual distribution of the temperate forest and boreal forest. 1. Replacement of mixed forests by temperate forest 2. Long term simulations suggest a further but extremely slow colonization of the temperate forest northward

Figure 2. Boxplot with test

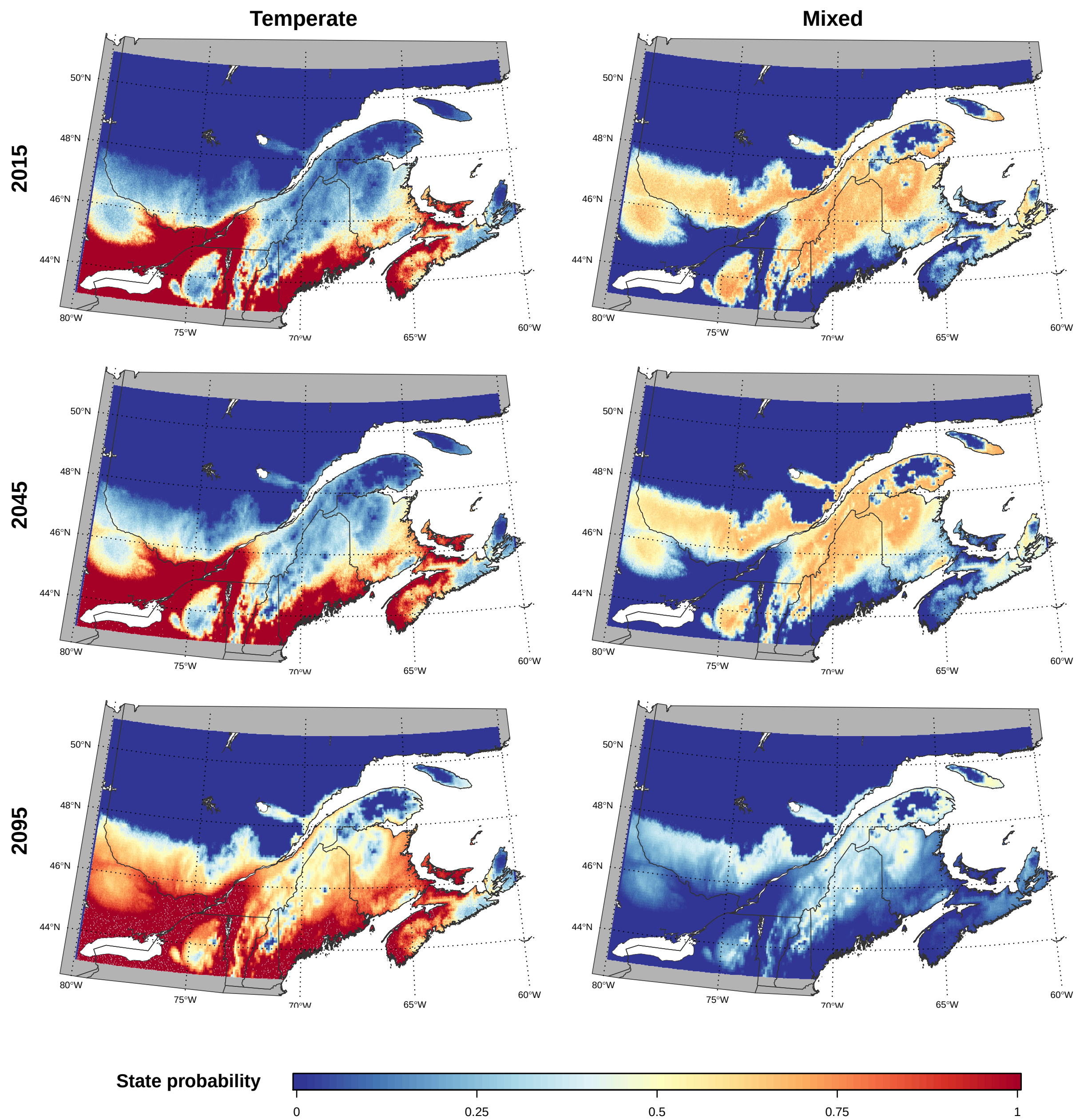
Slow temperate forest demography constrains migration rate more than dispersal limitation. Using the unlimited dispersion version, we predicted that the temperate forest

Spatial interaction prevents the temperate forest to fullfil its predicted niche (SDM) within an ecological timescale.

Complementary analysis on boxplot: We identified that the STM version explains 90 % of the latitudinal variance.

The model stochasticity (10 replicates) The environnemental stochasicity (GCM's; n=23) Parameters sensitivity (n=12)

New response curve: No leading edge but a higher abondances at the edge. This respond form is uncovered in the [5] article.


Temperate
Mixed
2015
2045
2095
50°N
48°N
46°N
44°N
80°W
75°W
70°W
65°W
60°W
State probability
0
0.25
0.5
0.75
1

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