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

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**Short title:** The future distribution of the northern temperate forest under climate change

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

**Abstract**

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# Introduction

Most studies use correlative approaches to predict impact of CC on future distribution range shift leading to instantaneous vegetation responses.

Firstly, we investigate the migration rate of the temperate forest using a states and transitions model. Secondly, we used different versions of the state and transition model to investigate which ecological processes such as the dispersion, or either demography is limiting or increasing the migration ability of the temperate forest.

The demography, the limited dispersion of temperate species and the spatial dynamics are delaying the temperate forest migration.

J'ai besoin de définir ce que c'est que la dynamique spatiale de la forêt tempérée.

# 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. In the first section, we present how we extract and classified plots surveys into those three regional forest biomes and linked the plots locations to climatic data. 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 will constrained the migration rate of the temperate forest.

## Plot surveys into community patches

### Forest Inventory databases

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

**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** |

the four states following the species composition. *add description on measurements.* A state is defined as mature stand characterized by a specific species community. In our case, the temperate community consists of 8 different species (*full species list*) and the boreal community 7 species ( *species list*). If one those species is present in the stand, then the patch is classified as a mixed state.

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

### Climatic database

For each plot location, we extract the climate of the last 15 years previous the year of measurement.

## The states and transitions model approach

### States description

To reproduce and simulate the dynamic of this ecotone, we used a state and transition model as a patch occupancy model [1] including 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 [4]; consequently, we added the regeneration state (R, Fig. 1) to represent a post-disturbance stand characterized by early successional species and a low basal area. Among the states, transitions occur by ecological processes. For instance, a temperate patch is converted as a mixed patch by colonization of boreal species. Then this mixed stand can transform to a pure temperate patch by competitive exclusion of boreal species. 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 these ecological mechanisms are formulated in the present model as a 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 (*Need to give an example or cite something ?*). Transition probabilities between states are climate-dependant based on two climatic variables: annual precipitation (mm) and annual mean temperature (°C). Except for the colonization probability, transition probabilities vary with the proportion of coniferous or deciduous found in the neighborhood to represent propagule pressure. Hence, the transition of a boreal patch towards a mixed patch depends on local environmental condition and on the availability of temperate seeds present in mixed and temperate patches surrounding the temperate patch.

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

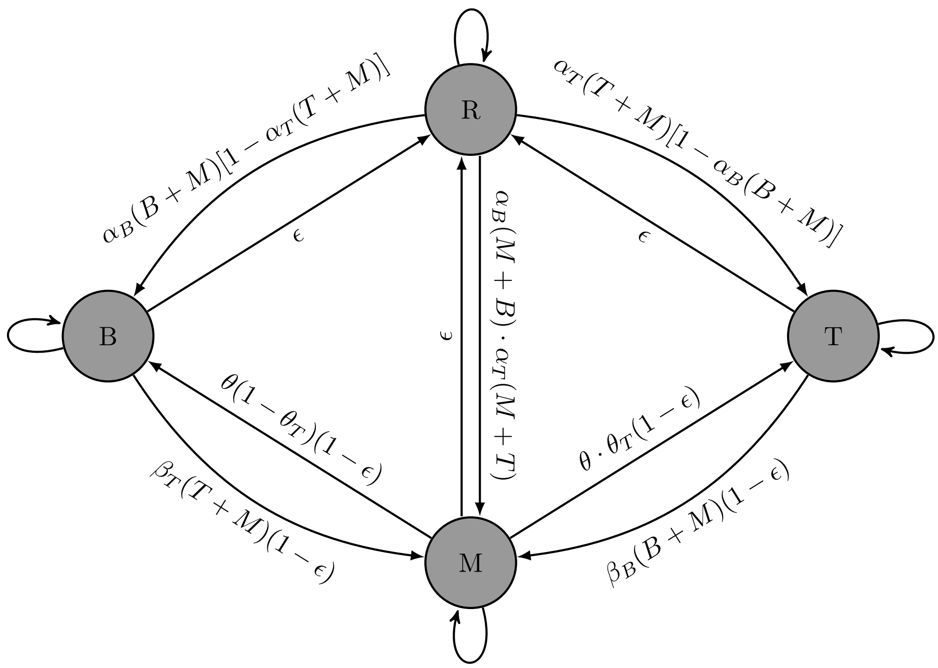


**Figure 1:** The states and transitions model illustrating all states and possible transition in the boreal-temperate forest system. B, T, M and R respectively mean; Boreal, Temperate, Mixed and Regeneration. Each arrow represent a transition between state.

### Transition probabilities

We estimated each transition probabilities using logistic regression with the annual mean temperature and the annual precipitation as independent variables.

The seven model parameters were fitted simultaneously using simulating annealing (GenSA package [5]).

We used all transitions observed and selected the second degree polynomial as the best model fitted.

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

The combination of temperature and precipitation are the best set of climatic variables to explain the distribution of the boreal forest [3].

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 ) [2], 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.

## Simulations and analysis

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