Difficult transition for sugar maple in Boreal forest under climate change?
Impact of alternative stable states on Sugar maple migration.

Research proposal

Master in Wildlife management

By

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February 4, 2014

1 Introduction

Context. The boreal region is warming twice as fast as the global average and will inevitably alter species composition in boreal forest [14, 6]. Sugar maple is one of those species expected to migrate northward towards it's nordic temperate forest limits [8, 2]. Predict shifts in the repartition of sugar maple under climate change is an important challenge whereas this species is highly coveted by hardwood and maple syrup producers, two main economic sectors in Quebec. Indeed, Sugar maple is a widespread and abundant tree in north- eastern North America and one of the most representative species of northern temperate forests [4, 9, 7]. This northward migration will result in increasing the surface of the ecotone between the boreal and temperate forest of Quebec. Nevertheless, the expansion of species distribution occuring in Nordic temperate forest could be difficult and explain by the fact than microclimatic conditions found in boreal forests are different from those present in temperate forest. Colder temperatures from shading and excess soil moisture due to snow melt cause litter to be more acidic and fibrous during the spring. Therefore, even if the regional climate conditions are favorable [7], the microbiota conditions found in the boreal forest could affect the establishment of sugar maple[7, 10, 1]. In this case, the sugar maple could be unable to migrate in boreal forests as a result of negative soil feedback. This phenomen could increase the tension between the boreal forest and the nordic temperate forest and generating abrupt changes in the community composition (H_0). **Objectives.** This project aim to develop a state and transition model (STM) between the boreal and temperate nordic forest in order to investigate shifts in the distribution of sugar maple into the boreal-temperate forest dynamical system.To assess this main objective, we will (1) generate a transitional model between the temperate and the boreal forest; (2) investigate the spatial structure of the transitonnal zone; and finaly (3) run simulations based on different climate change scenarios. To realized those objectives, we will use the alternative stable states theory as a framework. In order to define the context of this study, the first section is a review subdivided into two paragraphs. The first part will present the theorical context on the alternative stable states and abrupt changes in ecosystems functionning. Second part of this section will focus on the Sugar maple and his community and thus explain why is alternative stable states a relevant framework to study the dynamic of the boreal-temperate forests ecotone. The second section of this document will describe the model and the methodology employed to assess the objectives. To conclude, the last part will present the general timeline associated to this project.

2 Review

Theorical framework. Many ecotone studies and modeling efforts on transition between forest to none-forest ecosystems (e. i. Boreal - Toundra) [14, 13, 5] but little attention has been given to evaluate the transitional dynamics of forest- forest ecotone [3, 4]. At large scale, transition between the temperate nordic and the boreal forests can be approach as a dynamic system where each forest biomes is a state. The presence of different states at a location or a time depends on environmental conditions (e. i. Soil, temperature) encountered by the system. When small environnemental fluctuations occurs, mostly dynamical system can respond almost linearly with no particular threshold to observe drastic changes in state of the ecosystem (Figure 1 .A) [13, 12]. Thus, increase the soil moisture might cause favorable conditions to a new species, but doesn't affect the functionning of the ecosystem. In this case, only one equilibrium can be observed given a specific environnemental condition [13, 12, 11]. Another kind of system response occurs more frequently in nature. Natural systems are rather insensitive over certain ranges of environnementals conditions while responding strongly when a treshold is reached by the system (Figure 1 .B) [11]. Tree mortality can increase sharply when a specific toxicant level is added in the environment. [11]. Thus small forcing in the natural system can conduct at large changements as the entire transformation in species community composition. In an other hand, the respond curve can be folded backwards and the same threshold can conduct the system into catastrophic changes (Figure 1 .C). In this situation, the system present alternative stable states who mean the possibility to get two different contrasted stable state for a certain range of environnemental conditions, called hysteresis zone (Figure 1 .C). When a system present a state on . In the Boreal-temperate nordic forest ecotone, there is no distinct boundary instead, a broad transition zone exists composed of mixed stands of coniferous and deciduous species [3]. At large scale, a macromosaic landscape with pure stands of deciduous trees on favorable sites and pure coniferous stands on less favorable sites found on poor soils [3]. Assuming this fact, the alternative stable states is a relevant framework to study this ecotone dynamic therefore the soil seems to have a negative feedback on the temperate forest establishment and need to be investigate has a main attractor in alternative stable states.

Natural system. L'écotone entre la forêt boréal et la forêt tempérée nordique. La répartition des espèces caractéristiques de ces milieux ne sui pas un gradient climatique mais concorde avec un gradient lié à la texture et à la composition du sol. Plusieurs espèces clés représentent fortement les communautés végatles rattachés à ces biomes. Ces espèces germent sur des conditions de sols contrastés contribuant à maintenir la présence
Partir sur les principaux facteurs drivant la dynamique d'un écotone Détailler les communautés; Justifier le choix des espèces; Reprendre l'anayse préliminaire sur les ALSST e

3 Methods

Models. This state and transition model will be based on four differents states characterizing the boreal and nothern temperate forests landscape: **(D)** Decidious; **(C)** Coniferious; **(M)** Mixed stand and finaly **(T)** Transitional stand (Figure 2). We will assume that all space is occupied by one state, so that the proportions of land cover occupied by all types of patch sum to 1. Each patch contained within the model could be disturbe (i. e. fire in boreal forest or gaps dynamic in temperate nordic forest) with a rate of e. Following a perturbation, the patchs will composed by transitional species and recovered to a specific states C, D or M with a rate of ϕ. This parameter take in account a patch specific recovery rate, called $\alpha_{C,D,M}$ varying with the proportion of this available in the neighborhood and the rate which this hasn't been convert to an another type of stand. Whereas parameters previously enumerated, this model can be formally describe by this set of differential equations:
Paramerization. The parameterization of this model will be conducted on the QUICC-FOR database containing large permanent sample plots surveys. Those data are provided by several forest offices and cover multiple canadian provinces ($\pm$16000 plots) and states (**Ask at Miranda** plots). These inventories started since the 1970s and include all stems measurements and forest stand informations relative to a specific plot location and year. In a first time, the basal area will be compute to provide a measure of relative growth by species present in the plots.

Simulation. This model will be incorporated in a spatially explicit cellular automaton or lattice in order to evaluate the velocity of the transition into differents patches and differents climate

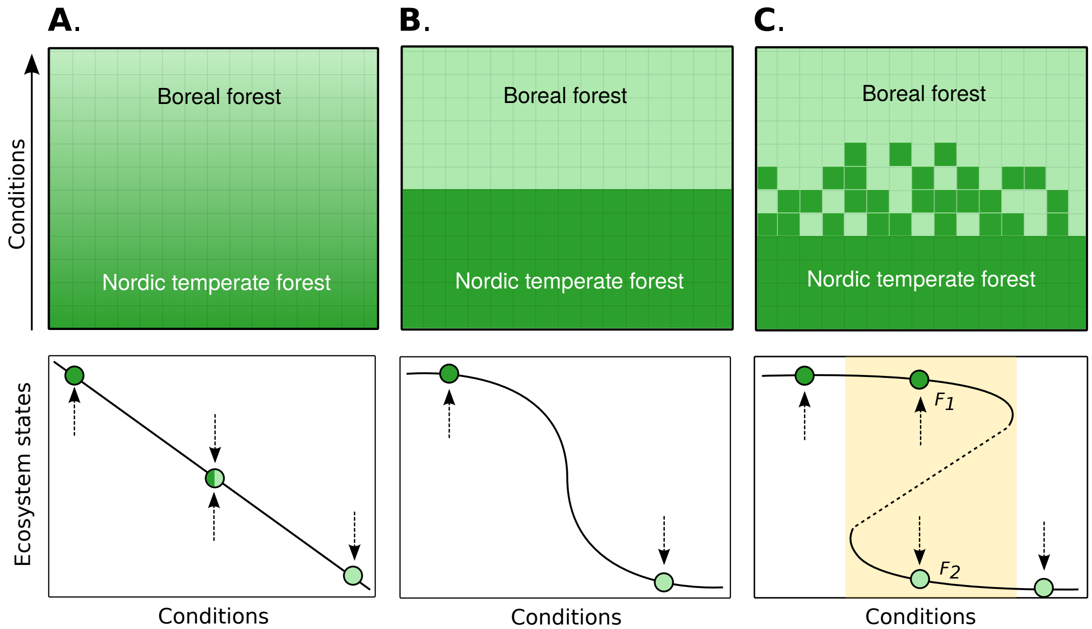
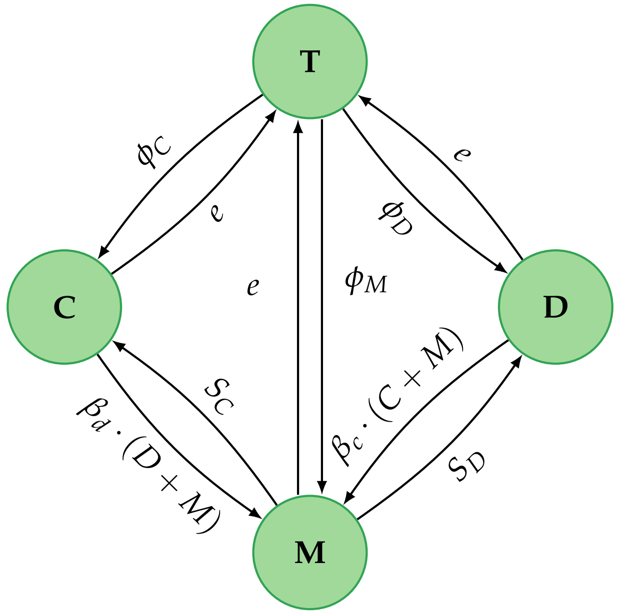


Figure 1: Schematic representation of different ways in which the equilibrium state of a system can vary with conditions such as temperature, precipitation or soil moisture. Three differents kinds of respond are presented, **(A)** gradual, **(B)** basic fold, **(C)** catastrophic fold. The first panels line is a conceptualization of a transitional landscape between the boreal (light green) and the nordic temperate forests (dark green). The second panels line presents the stable states rise by the forest given a specific environnemental condition. Each arrows in graphs indicate the point toward the system moves if it's not at the equilibrium. Every point on the plain line could be a stable state encounter by the boreal-temperate forests system, excepted for the dashed line (in yellow highlight). This zone, called hysteresis, are particulary unstable and little fluctuations in environnement conditions give rise to a contrasted state representing an alternative stable states. (F_1 or F_2).

change scenario.
- Temps discrets - Cellulaire automate

Validation. - Matrice de confusion sur la classification des patchs (M,D,C,T) - Matrice de confusion (TSS) et AUC sur un jeux de données indépendants - Spatialement explicit à l'aide de l'automate cellulaire.



$$\frac{\delta T}{dt} = T - T \cdot (\phi_C + \phi_D - \phi_M) \tag{1}$$

$$\frac{\delta M}{dt} = \phi_M \cdot T + \beta_C \cdot (C+M) \cdot D + \beta_D \cdot (D+M) \cdot C - S_C \cdot M - S_D \cdot M - e \cdot M \tag{2}$$

$$\frac{\delta C}{dt} = \phi_C \cdot T + S_C \cdot M - D \cdot (D+M) \cdot C - e \cdot C \tag{3}$$

$$\frac{\delta D}{dt} = \phi_D \cdot T + S_D \cdot M - \beta_C \cdot (C+M) \cdot D - e \cdot D \tag{4}$$

Figure 2: Conceptual transition model between forest stands deciduous (D), mixte (M) and coniferious (C). T corresponds to a transitionnal state where a perturbation are occurred with a frequence of e. Parameters β and S are referred as the colonisation and the succession rates respectively. We defined the recovery rates (ϕ_C et ϕ_D) as $\phi_C = \alpha_C \cdot (M + C) \cdot [1 - \alpha_D \cdot (D + M)]$ and $\phi_D = \alpha_D \cdot (D + M) \cdot [1 - \alpha_C \cdot (C + M)]$, to finaly get this equation $\phi_M = \phi_C \cdot \phi_D$. The parameter α mean the recovery rate after a patch has been disturbe.

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