

**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

Steve Vissault

For

**Richard Cloutier, Pr.**  
Director of the program committee

**Dominique Arsenault, Pr.**  
President of the jury

**Matt Talluto, PhD**  
Research Co-director

**Dominique Gravel, Pr.**  
Research Director

Université du Québec à Rimouski  
February 4, 2014

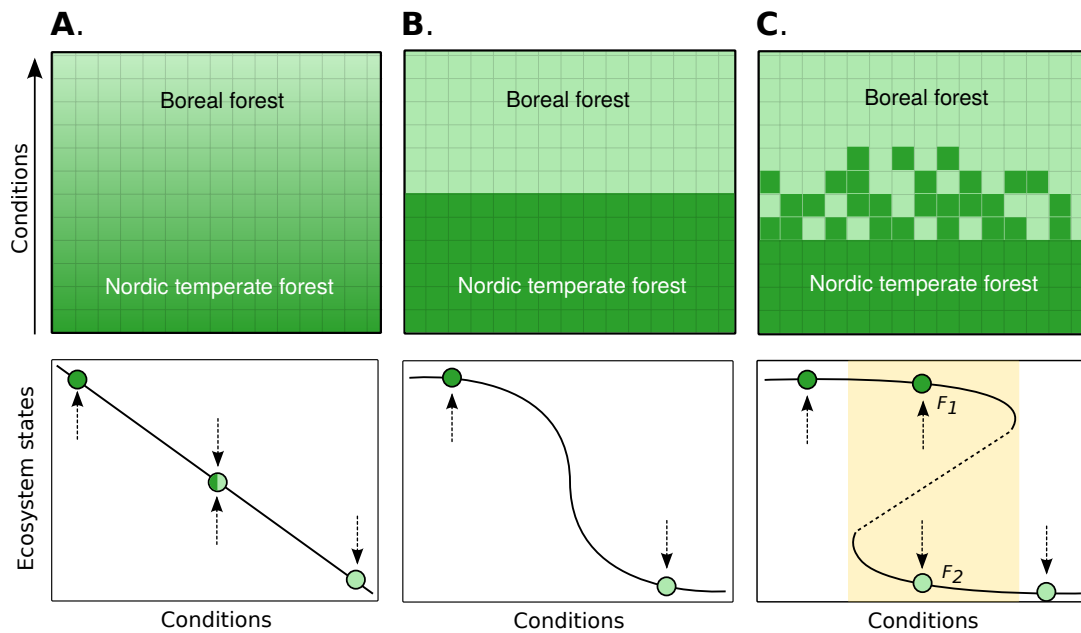
# 1 Introduction

**Context.** The boreal region is warming twice as fast as the global average and will inevitably alter species composition in boreal forest [15, 7]. Sugar maple is one of those species expected to migrate northward towards its nordic temperate forest limits [9, 3]. 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 [5, 10, 8]. 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 occurring in Nordic temperate forest could be difficult and explain by the fact that 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 [8], the microbiota conditions found in the boreal forest could affect the establishment of sugar maple [8, 11, 2, 1]. In this case, the sugar maple could be unable to migrate in boreal forests as a result of negative soil feedback. This phenomenon 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 aims 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 transitional zone; and finally (3) run simulations based on different climate change scenarios. To realize 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 theoretical context on the alternative stable states and abrupt changes in ecosystems functioning. 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

**Theoretical framework.** Many ecotone studies and modeling efforts on transition between forest to non-forest ecosystems (e. i. Boreal - Tundra) [15, 14, 6] but little attention has been given to evaluate the transitional dynamics of forest-forest ecotone [4, 5]. At large scale, transition between the temperate nordic and the boreal forests can be approached as a dynamic system where each forest biome 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 environmental fluctuations occur, mostly dynamical system can respond almost linearly with no particular threshold to observe drastic changes in state of the ecosystem (Figure 1 .A) [14, 13]. Thus, increase the soil moisture might cause favorable conditions to a new species, but doesn't affect the functioning of the ecosystem. In this case, only one equilibrium can be observed given a specific environmental condition [14, 13, 12]. Another kind of system response occurs more frequently in nature. Natural systems are rather insensitive over certain

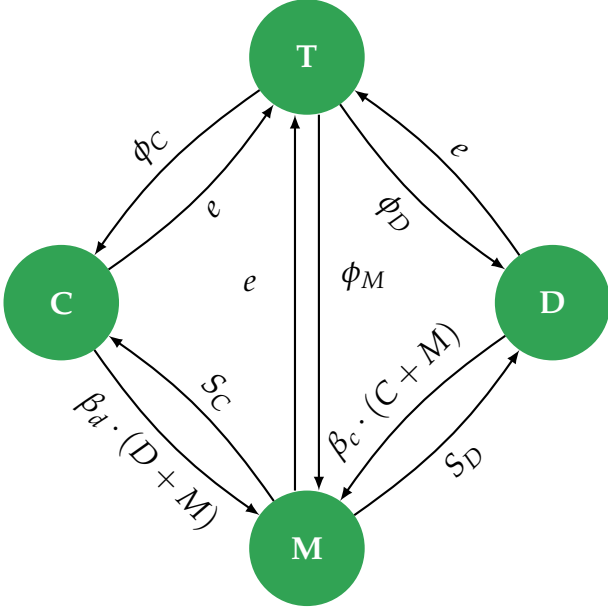


**Figure 1:** Schematic representation of different ways in which the equilibrium state of a system can vary with conditions such as temperature, precipitation or soil moisture. Three different kinds of response are presented, **(A)** gradual, **(B)** basic fold, **(C)** catastrophic fold. The first 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 environmental 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 particularly unstable and little fluctuations in environment conditions give rise to a contrasted state representing an alternative stable states. ( $F_1$  or  $F_2$ ).

ranges of environmental conditions while responding strongly when a threshold is reached by the system (Figure 1 .B) [12]. Tree mortality can increase sharply when a specific toxicant level is added in the environment. [12]. In this case, the response curve of the natural system is lightly folded but small forcing can conduct at large changes as the entire transformation in species community composition. In another hand, response curve can be folded backwards and the same threshold can conduct the system into catastrophic changes (Figure 1 .C). In this situation, the system presents alternative stable states who mean the possibility to get two different contrasted stable states for a certain range of environmental conditions, called hysteresis zone (Figure 1 .C). **More description** 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 [4]. Instead, a macromosaic landscape can be observed with pure stands of deciduous trees on favorable sites and pure coniferous stands on less favorable sites found on poor soils [4]. 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 investigated has a main attractor in alternative stable states [8, 11, 2, 1].

## Natural system.

### 3 Methods



**Figure 2:** Conceptual transition model between forest stands deciduous (D), mixte (M) and coniferous (C). T corresponds to a transitionnal state where a perturbation are occurred with a frequency of  $e$ . Parameters  $\beta$  and  $S$  are referred as the colonisation and the succession rates respectively. We defined the recovery rates ( $\phi_C$  et  $\phi_D$ ) 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 finally get this equation  $\phi_M = \phi_C \cdot \phi_D$ . The parameter  $\alpha$  mean the recovery rate after a patch has been disturbe.

tions:  $\frac{\delta T}{\delta t} = e \cdot (C + M + D) - T \cdot (\phi_D + \phi_C + \phi_M)$ . If this patch C is undisturbed, deciduous species (D + M) can spread over the patch with a colonisation rate  $\beta_d$  giving a new mixed patch. This mixed stand M might be transform later into a coniferous stand with a sucesional rate  $S_C$ . We can also summarize the coniferous dynamic by this differential equation:  $\frac{\delta C}{\delta t} = \phi_C \cdot T + S_C \cdot M - \alpha_D \cdot (D + M) \cdot C - e \cdot C$ . At this stage of this project, this model is spatially implicit and 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.

**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

**Models.** This state and transition model will be based on three differents states characterizing the boreal and nothern temperate forests landscape: (D) Deciduous; (C) Coniferous; (M) Mixed stand (Figure 2) and finally Transition patch (T). The general overview allow to say that all states can be convert to another state excepted the direct transition between a deciduous and coniferous stands who don't appear frequently in natural system considering the contrasted environnement (i.e. soil, moisture). Simulations of this model aims to assess the transition rate between each state in the overall landscape and identify if deciduous and coniferious patches are present as alternative stable states. To embed the climat component, each model parameters will be calibrate as a function of probability based on climatic conditions. Climat is a main driver in the distribution of those biomes, but their dynamics are strongly related to their own disturbance regimes (i. e. Fire in boreal forest, frost in temperate forest) [4]. Thus the disturbance component has been integrated within the model accross the transitional patch (T) (Figure 2). When a coniferous patch C has been disturbed with a rate  $e$ , this can be recovered to another state following  $\phi_C$ . This term is taking in account a specific patch recovery rate ( $\alpha_C$ ), the availability of coniferous species ( $M + C$ ) and the proportion of paths unconverted into a deciduous state ( $1 - \alpha_D \cdot (D + M)$ ). In making the assumption that perturbation rate is similar between states, dynamic of a patch T can be formally describe by this differential equation:

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 different patches and different climate change scenario.

**Validation.**

## References

- [1] N. BARRAS AND M. KELLMAN, *The supply of regeneration microsites and segregation of tree species in a hardwood-boreal forest transition zone*, Journal of Biogeography, (1998), pp. 871–881.
- [2] P. DE FRENNE, F. RODRÍGUEZ-SÁNCHEZ, D. A. COOMES, L. BAETEN, G. VERSTRAETEN, M. VEL-LEND, M. BERNHARDT-RÖMERMAN, C. D. BROWN, J. BRUNET, J. CORNELIS, G. M. DECOCQ, H. DIERSCHKE, O. ERIKSSON, F. S. GILLIAM, R. HÉDL, T. HEINKEN, M. HERMY, P. HOMMEL, M. A. JENKINS, D. L. KELLY, K. J. KIRBY, F. J. G. MITCHELL, T. NAAF, M. NEWMAN, G. PETERKEN, P. PETRÍK, J. SCHULTZ, G. SONNIER, H. VAN CALSTER, D. M. WALLER, G.-R. WALTHER, P. S. WHITE, K. D. WOODS, M. WULF, B. J. GRAAE, AND K. VERHEYEN, *Microclimate moderates plant responses to macroclimate warming.*, Proceedings of the National Academy of Sciences of the United States of America, (2013), pp. 1–5.
- [3] D. GOLDBLUM AND L. RIGG, *Tree growth response to climate change at the deciduous boreal forest ecotone, Ontario, Canada*, Canadian Journal of Forest Research, 2718 (2005), pp. 2709–2718.
- [4] D. GOLDBLUM AND L. S. RIGG, *The Deciduous Forest - Boreal Forest Ecotone*, Geography Compass, 4 (2010), pp. 701–717.
- [5] N. GRAIGNIC, F. TREMBLAY, AND Y. BERGERON, *Geographical variation in reproductive capacity of sugar maple (Acer saccharum Marshall) northern peripheral populations*, Journal of Biogeography, (2013), pp. n/a–n/a.
- [6] M. HIROTA, M. HOLMGREN, E. V. NES, AND M. SCHEFFER, *Global Resilience of Tropical Forest and Savanna to Critical Transitions*, Science, (2011), pp. 232–235.
- [7] L. HUGHES, *Biological consequences of global warming: is the signal already apparent?*, Trends in Ecology & Evolution, 15 (2000), pp. 56–61.
- [8] M. KELLMAN, *Sugar maple (Acer saccharum Marsh.) establishment in boreal forest: results of a transplantation experiment*, Journal of Biogeography, 31 (2004), pp. 1515–1522.
- [9] D. W. MC KENNEY, J. H. PEDLAR, K. LAWRENCE, K. CAMPBELL, AND M. F. HUTCHINSON, *Potential Impacts of Climate Change on the Distribution of North American Trees*, BioScience, 57 (2007), p. 939.
- [10] Y. MESSAOUD, Y. BERGERON, AND A. LEDUC, *Ecological factors explaining the location of the boundary between the mixedwood and coniferous bioclimatic zones in the boreal biome of eastern North America*, Global Ecology and Biogeography, 16 (2007), pp. 90–102.
- [11] J.-D. MOORE, L. DUCHESNE, AND R. OUIMET, *Soil properties and maple–beech regeneration a decade after liming in a northern hardwood stand*, Forest Ecology and Management, 255 (2008), pp. 3460–3468.
- [12] M. SCHEFFER, *Critical transitions in nature and society*, Princeton studies in complexity, Princeton University Press, Princeton, 2009.
- [13] M. SCHEFFER, J. BASCOMPTE, W. A. BROCK, V. BROVKIN, S. R. CARPENTER, V. DAKOS, H. HELD, E. H. VAN NES, M. RIETKERK, AND G. SUGIHARA, *Early-warning signals for critical transitions.*, Nature, 461 (2009), pp. 53–9.

- [14] M. SCHEFFER, S. CARPENTER, J. A. FOLEY, C. FOLKE, AND B. WALKER, *Catastrophic shifts in ecosystems.*, Nature, 413 (2001), pp. 591–6.
- [15] M. SCHEFFER, M. HIROTA, M. HOLMGREN, E. H. VAN NES, AND F. S. CHAPIN, *Thresholds for boreal biome transitions.*, Proceedings of the National Academy of Sciences of the United States of America, 109 (2012), pp. 21384–9.