**Difficult transition for sugar maple in Boreal forest under climate change?**  
**Impact of alternative stable states on Sugar maple migration.** 2em Research proposal 1em Master in Wildlife management By Steve Vissault For **Richard Cloutier**, Pr.  
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# Introduction

**Context.** The boreal region is warming twice as fast as the global average and will inevitably alter species composition in boreal forest . Sugar maple is one of those species expected to migrate northward towards it’s nordic temperate forest limits . 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 . 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 , the microbiota conditions found in the boreal forest could affect the establishment of sugar maple . 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.

# Review

**Theorical framework.** Many ecotone studies and modeling efforts on transition between forest to none-forest ecosystems (e. g. Boreal - Toundra) but little attention has been given to evaluate the transitional dynamics of forest- forest ecotone . 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. g. 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 [fig1] .A) . 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 . 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 [fig1] .B) . Tree mortality can increase sharply when a specific toxicant level is added in the environment. . In this case, the respond curve of the natural systeme is lightly folded but small forcing can conduct at large changements as the entire transformation in species community composition. In an other hand, respond curve can be folded backwards and the same threshold can conduct the system into catastrophic changes (Figure [fig1] .C). In this situation, the system present alternative stable states who mean the possibility to get two different contrasted stable states for a certain range of environnemental conditions, called hysteresis zone (Figure [fig1] .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 . 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 . 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.**

# Methods

**Models.** This state and transition model will be based on four differents states characterizing the boreal and nothern temperate forests landscape: **(D)** Deciduous; **(C)** Coniferous; **(M)** Mixed stand and finaly **(T)** Transition patch (Figure [Model]) .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 (e. g. 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 alternaFtive 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 (e. g. Fire in boreal forest, frost in temperate forest) . Thus the disturbance component has been integrated within the model accross the transitional patch (T) (Figure [Model]). When a coniferous patch *C* has been disturbed with a rate *e*, this can be recovered to another state following *ϕC*. This term is taking in account a specific patch recovery rate (*αC*), the availability of coniferous species (*M* + *C*) and the proportion of paths unconverted into a deciduous state (1 − *αD* ⋅ (*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 equations: $\frac{\delta T}{\delta t} = e \cdot (C+M+D) - T \cdot (\phi\_D + \phi\_C + \phi\_M)$. If this patch *C* is undisturbed, deciduous species (*D* + *M*) can spread over the patch with a colonisation rate *βd* giving a new mixed patch. This mixed stand *M* might be transform later into a coniferous stand with a sucessional rate *SC*. 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.