Forest Management Affect Colonization Credit, but not Extinction Debt, to Reduce Delayed Range Shifts under Climate Change

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# Introduction

**Forest dynamics under climate change**

There is a growing concern in how species will respond to climate change. Correlative statistical models, which are based in the niche concept, have projected species’ range to shift following warming temperature, and trees are expected to migrate hundreds of meters by the end of this century (Malcolm et al. [2002](#ref-Malcolm2002); Mckenney et al. [2007](#ref-Mckenney2007)). However, despite the observed shift of many species’ range following warming temperature (Chen et al. [2011](#ref-Chen2011)), many tree species have undergone no change (Harsch et al. [2009](#ref-Harsch2009); Zhu, Woodall, and Clark [2012](#ref-Zhu2012)). For instance, trees of the eastern North America have shifted their range limits to fewer than 50% of the required to keep pace with warming temperature (Sittaro et al. [2017](#ref-Sittaro2017)). This mismatch between climate conditions and forest composition leads us to anticipate maladaptation, and therefore a possible loss of forest productivity (Aitken et al. [2008](#ref-Aitken2008)) Quantify the mechanisms determining species range limits is critical to understanding species response to climate warming, and the potential actions to mitigate this perturbation (Becknell et al. [2015](#ref-Becknell2015)).

Conceptual hypothesis. The left panel is the result of the forest states at equilibrium with climate extracted from the State and Transition Model parametrized for the North American forest. In this panel we can see how boreal trailing edge and temperate/mixed leading edge are expected to shift northward after climate change (CC). The left panel of the hypothesis 1 box shows the five metrics to characterize the transient dynamics of a system after perturbation: initial resilience (-R_0), asymptotic resilience (R_{\infty}), exposure (\Delta_{state}), sensitivity (\Delta_{time}) and cumulative amount of changes (\int S(t)dt). Our first question is how forest management will affect these five metrics and our hypothesis is described in the right panel. On the hypothesis 2 box we show the first (before CC) and last (after CC) landscape of a simulation using the spatially-explicit version of the model. The bars limit the trailing edge of boreal and the leading edge of temperate states. We question if forest management can increase the northward shift of the boreal trailing edge which is lagging behind CC. Our hypothesis is that forest management will increase the northward shift and smooth the transition between boreal and mixed states.

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# Methods

## State and Transition Model with forest management

We used a State and Transition Model parameterized for the eastern North American forest (Vissault et al. [2020](#ref-Vissault2020)), in which we integrated four practices of forest management to test their impact in the response of forest states to climate change. The model has four states defined by succession and species composition: (R)egeneration, (T)emperate, (M)ixed and (B)oreal (Figure @ref(fig:model)). The transition probabilities between states are defined by four ecological processes. Succession () promotes the transition from regeneration state to either boreal, mixed or temperate; the opposite process is disturbance (), increasing the transition of matures states to regeneration. Colonization () of either boreal or temperate species in the opposite state promotes the transition to mixed state. Competitive exclusion ( and ) between boreal and temperate species increases the probability of mixed stands become either boreal or temperate. Disturbance () of boreal, temperate or mixed promotes the transition to the regeneration state. The first two processes ( and ) and the last two ( and ) are grouped in the colonization-extinction mechanisms of the metapopulation theory, respectively. The probability of each of these processes is calculated based in temperature, precipitation and the states neighbors’ proportion. Details in the classification of the four states and parameterization of the model using data from the eastern North American forest inventory can be found in Vissault et al. ([2020](#ref-Vissault2020)). Plantation, harvest, thinning and enrichment planting are the four practices of forest management implemented in the model. The rationale of these four management practices is to favor the spread of the temperate forest when the climate context allows temperate tree regeneration. The following sections details how each practice is implemented in the model.

# References

Aitken, Sally N., Sam Yeaman, Jason A. Holliday, Tongli Wang, and Sierra Curtis-McLane. 2008. “Adaptation, migration or extirpation: climate change outcomes for tree populations.” *Evolutionary Applications* 1 (1): 95–111. <https://doi.org/10.1111/j.1752-4571.2007.00013.x>.