PhD project

Linking forest management and species distribution models: a theoretical approach under climate change

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Abstract

Abstract section

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Ecology may provide many of the answers — but only if it is holistic enough to incorporate the human element as part and parcel of the ecosystem.

(Pfister, 1993, p. 231)

1 What is going on?

Climate change is an increasing trending topic both in non-scientific (Capstick et al., 2015) and scientific environment (Figure 1), transforming our world as a metamorphosis of practice and acting (Beck, 2016). According to IPCC (Cubasch et al., 2013), humans activities are contributing to increase the concentration of greenhouse gases, which can lead to increase the mean temperature and the strength of extreme climate events. This global change has an impact in different biological processes, from local species constraints (e.g. low regeneration Treyger and Nowak, 2011), shift in species' range (Boisvert-Marsh et al., 2014; Monleon and Lintz, 2015) and in community composition (Dieleman et al., 2015) to range retractions and extinction (Thomas et al., 2006), impacting biodiversity at different scales (Peñuelas et al., 2013).

Species distribution models (SDM; defined in section 6.1.1) is one of the most popular method to predict species' range shift under climate change, providing a wide range of applications, as in biodiversity conservation and management (Guisan and Thuiller, 2005; Guisan et al., 2013). However, these models are generally phenomenological and distributed at equilibrium with climate (e.g. Pigot and Tobias, 2013), being an issue when species observation does not reflect its niche (Schurr et al., 2012). Hence, they do not consider important determinants of range limits as demography (Louthan et al., 2015), ecological constraints (Wisz et al., 2013; Pigot and Tobias, 2013) and species absences data (Koshkina et al., 2017), inducing non-accurately projection of the future spatial distribution of a species (Tavecchia et al., 2016). Considering this ecological constraints, trees' migration rate following climate change will be slower than predicted (Bertrand et al., 2011; Sittaro et al., 2017), increasing the climatic debt (Bertrand et al., 2016).

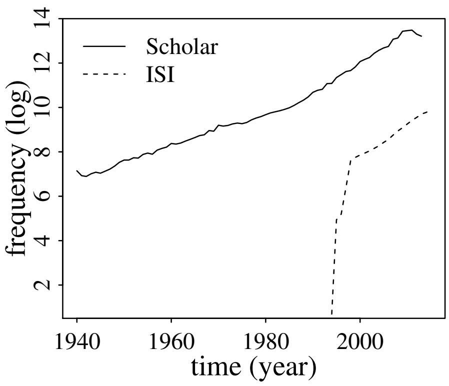

Figure 1: Frequency of the keyword "Climate change" used in publication indexed on Google Scholar (1940 - 2013) and Web of Science (1994 - 2015)

The climatic debt is a measure of the lag (or disequilibrium) of plant communities with climate change, integrated in an environmental context (Bertrand et al., 2016). Essl et al. (2015) has listed twelve mechanisms that contribute to delayed biodiversity responses, among them, changes appears at ecosystem (loss and degradation), community (secessional, biotic interaction, species removal and invasion) and population (evolutionary and adaptive) levels. Abiotic changes cause biotic changes that directly and indirectly promotes species' persistence and species' migration (Bertrand et al., 2016). This mechanisms of persistence (measured by resistance) and migration (measured by recovery) leads to a climate debt and migration credit, respectively (Bertrand et al., 2016) but also a concept of resilience (Oliver et al., 2015, see section 4.2). Therefore, this lag under climate change promotes extinction debt, being a challenging for biodiversity conservation (Kuussaari et al., 2009) and productivity (Lasch et al., 2002). Identify the mechanisms shaping delayed biotic response of systems to environment, its resilience as well as alternatives to mitigate ecological constraints, is crucial to access the vulnerability of biodiversity to climate change and improve forecasts and biodiversity management (Essl et al., 2015; Oliver et al., 2015; Bertrand et al., 2016).

2 Preliminary objectives

The primary objective of my thesis is to study if forest management can increase the speed of transition (i.e. recovery resilience) from temperate to boreal forests observed in the North Eastern America. To achieve, I will use theoretical models parameterized from a forest inventory database, focusing on tracking uncertainty using Bayesian approach. As an outcome, I will create a decision make tool to improve management strategies that take climate change into account.

My PhD is based in three questions so far:

(i) Which mechanisms are affecting the delayed biotic response to climate change? What is the origin, direction, intensity and interaction of these mechanisms?

(ii) How can forest management affect these mechanisms to increase resilience and therefore speed up the response?

(iii) How can these mechanisms be used to inform applied management to enhance the resilience and productivity?

3 Mitigating ecological constraints

Ecological constraints act by different biotic and abiotic mechanisms at all scales, being difficult to track and therefore to mitigate. To start, our work aims to identify how we can increase forest resilience, or more specific, how to decrease the recovery time of a system from a disturbance to a steady state (theories described in section 4). Here, I present some mechanisms that may be affecting the delayed response to climate change, as well as increase forest resilience, in which may become possible topics I will be testing during my thesis using SDM, acting both at local and large scale.

3.1 Biotic Mechanisms

Species with a high intrinsic rate of increase will recover more quickly from environmental perturbations (Mechanisms contributing to stability in ecosystem function depend on the environmental context. Ecol. Lett.)

Species interaction Explain the role species interaction can play on its distribution range. http://www.sciencedirect.com/science/article/pii/S0169534715002475 The perceived threat of climate change is often evaluated from species distribution models that are fitted to many species independently and then added together. This approach ignores the fact that species are jointly distributed and limit one another (Clark et al., 2014).

Joint species distribution?

Interactions between land-use and climate also can underestimate species resilience in distribution models (Goring and Williams, 2017).

3.2 Abiotic Mechanisms

3.3 Forest management

Lessons from large-scale environmental management successes, for example measures to reduce the causes of 'acid rain' (Fowler et al. 1982), show that action at local and global scales must complement each other if wide-scale environmental management efforts are to be successful. Present some motivations, advantages and disadvantages in considering forest management. (in Rhodes 2015)

It is clear that some factors will be more amenable to management (e.g., population-level genetic variability, landscape structure [18,31]) than others (e.g., environmental sensitivity of individual species, presence of alternative stable states). In Olivier 2015

Four major strategies are available to mitigate carbon emissions through forestry activities: (i) to increase forested land area through reforestation (6), (ii) to increase the carbon density of existing forests at both stand and landscape scales, (iii) to expand the use of forest products that sustainably replace fossil-fuel CO2 emissions, and (iv) to reduce emissions from deforestation and degradation. in Managing forests for climate change mitigation (Science)

http://onlinelibrary.wiley.com/doi/10.1111/j.1752-4571.2010.00157.x/full
http://www.sciencedirect.com/science/article/pii/S0006320715301762

Interesting argument about who should peak do winners from Webster et al. (2017). They say that *Predict-and-prescribe management may erode diversity by focusing on 'winners'*.

Forest management in a theoretical view was actually not very much explored and so I consider it a kind of gap we should better explore. Read Becknell et al. (2015) for an overview.

paper:Temporal stability in forest productivity increases with tree diversity due to asynchrony in species dynamics

However, this translation is limited by significant knowledge gaps including the following: (i) difficulties in detecting changes in resilience (Batt et al. 2013), (ii) a lack of evidence and agreement to support successful preventative management actions (Barrett et al. 2014) and (iii) the need to work across multiple geopolitical scales to achieve effective management (Servos et al. 2013). (In Rhodes 2015 at app eco)

An operational model for resilience-based management Step 1: Detecting ecological sensitivity to pressures Step 2: Developing more effective resilience-based management measures Step 3: Achieving adaptive governance

3.4 Forest productivity

Robert m'a envoyé quelques articles qui discutent des facteurs qui contrôlent la dominance des arbustes éricacées en forêt boréale et de leur possible impacte sur la productivité forestière.

4 Theoretical approach

Read the section *recent developments in predicting changes in species distribution* from Ehrlen and Morris (2015)

4.1 Disturbance

Pass through the main disturbance theories basing mainly in Pulsford et al. (2016)

4.2 Resilience

A classical definition of resilience in ecology is the ability of ecosystems to absorb changes and still persist (Holling, 1973). The concept was further developed in other context (e.g. social-ecological systems), and a more contemporary definition considers resilience as (i) the amount of disturbance the system can absorb, (ii) the degree the system is able to self-organize and (iii) the degree of learning capacity to adapt to disturbance (Cumming, 2011). We have therefore two concepts, the time to **recovery** to stability and accommodated external changes (Pimm, 1984; Folke et al., 2002) and the **resistance** of a particular ecological state to change (Peterson et al., 1998). Although Oliver et al. (2015) treat both resistance and recovery as related aspects of resilience, I prefer to keep these concepts separated in (i) recovery resilience (or engineering resilience) and (ii) resistance where both are englobed in ecological resilience (Hodgson et al., 2015; Nimmo et al., 2015). Ecological resilience can be affected by different mechanisms from species to landscape levels, but biodiversity shows to be crucial to maintain long-term resilience of ecosystem services (Oliver et al., 2015).

It is also important to not confuse recovery resilience with stability of a system. Recovery resilience is the rate and extent of "restoration" of a system while stability is when the system maintains stable following small perturbations over time. Before introduce the method to calculate recovery resilience, we must know what is the equilibrium (Box 1) and stability (Box 2) of a system, as well as these measures are relative and careful must be taken when choosing *resilience of what to what* (Carpenter et al., 2001).

Box 1. Equilibrium

$$E = mc^2 \quad \text{Formula of the universe} \tag{1}$$

Box 2. Stability

$$E = mc^2 \quad \text{Formula of the universe} \tag{2}$$

(iii) But how to calculate it in a analytical way? To implement the results from these or other studies in management projects, it is necessary to disentangle the many meanings and measures of resilience and related stability concepts (In Mori at TREE). Now introduce the calculus of λ by Jacobian matrix. The Jacobian matrix has been used in different applications, from local models [...] to meta-ecosystems models (Gravel et al., 2016)

4.3 Transition period - Alternative Stable States?

The existence of single equilibria is still often assumed in the literature, with critical implications for conservation and restoration. – An important feature of this concept (resilience) is the emphasis on possible alternative system properties that are associated with renewal and reorganization after disturbance (In Mori 2016 at TREE)

Resilience-based management does not typically seek to increase the rate of return to an original state, which often implicitly assumes the existence of a single equilibrium, but instead recognizes that many natural systems could have multiple attractors [2, 3]. (In Mori 2016 at TREE)

4.4 Early warnings?

Resilience indicators: prospects and limitations for early warnings of regime shifts

4.5 Range dynamics theory

What theories can help us to describe species range under climate change?
How to integrate forest management in this theory?
-> Matapopulation dynamics theory <-

5 Study case: the Quebec forest resource

Explain here where I am going to work and also why I am choosing this area.

6 Methods

Here we see a briefly presentation of possible methods will be used in the thesis.

6.1 Modeling

Why and how modeling?
Morin et thuiller 2009:What then are the best strategies for obtaining accurate predictions for changes in the distributions of deciduous temperate trees? At the scale of the geographic distribution of species, no experiments in situ can be reasonably carried out to predict possible range shifts (Woodward 1987). Modeling therefore appears the most feasible and efficient way to establish useful predictions (Lovejoy and Hannah 2005, Thuiller 2007), and several kinds of models have been developed during the previous decade for this purpose. As reviewed by Midgley et al. (2007), these models fall into two main classes: vegetation-type models (dynamic global vegetation models [DGVMs]) and species-specific models (niche-based and process-based).

6.1.1 Species Distribution Models

Nice resume about SDM in Morán-Ordóñez et al. (2016).

6.1.2 Integral Projection Models

the predictive powers of state and transition models are relatively low and their ability to deal with uncertainty is limited (Bashari, Smith and Bosch, 2008; Phillips, 2011).

6.2 Bayesian approach

I should be writing and not playing with LaTeX

7 Thesis structure

The first part of the thesis will be a general introduction in French where I will probably use a part of this document and present the big picutre of my thesis.

The first chapter will try to answer the question *Can forest management increase forest resilience to climate change?*. The paper will work with an analytical and sensitivity analysis in a metapopulation dynamics model to understand the impact of forest management on increasing forest resilience.

In the second chapter I am going to build a landscape model that will consider both forest management and species interaction.

The third chapter I am going to build another model but in a local scale. *I have to find a good biological reason for that.*

The fourth chapter will then integrate both landscape and local model into one. Here I will also track the uncertainty of the model by bayesian approach.

TODO:
- Automate box labels
- Short reference style

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