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

Willian Vieira[1,*]

[1] *Département de Biologie, Université de Sherbrooke, Sherbrooke, Québec, Canada*
[*] *w.vieiraw@gmail.com*

Abstract

Abstract section

UNIVERSITÉ DE SHERBROOKE

[IE] Integrative Ecology Lab
Laboratoire d'écologie intégrative

CENTRE DE LA SCIENCE DE LA BIODIVERSITÉ DU QUÉBEC
QUEBEC CENTRE FOR BIODIVERSITY SCIENCE

Contents

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).

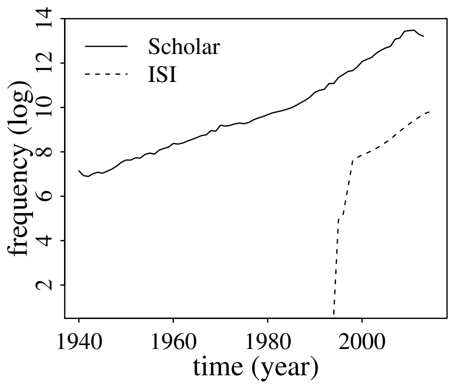

Figure 1: Frequency of the keyword "Climate change" used in references indexed on Google Scholar (1940 - 2013) and Web of Science (1994 - 2015)

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. Disturbance regime was also listed but it may not by related to climate debt (Bertrand et al., 2016). 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 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 methods. 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 and intensity of these mechanisms?
(ii) How can forest management affect these mechanisms to 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, together with abiotic and biotic mechanisms, act at different scales, being difficult to track and hence to mitigate. To start, our work aims to identify how we can increase forest resilience, or more specific, how to decrease the time needed to recover from a disturbance (theories described in section 4). Here, I present some mechanisms that could be affecting the delayed response to climate change, as well as possible topics I will be testing through my thesis using SDM, acting both at local and large scale.

3.1 Biotic Mechanisms

3.2 Abiotic Mechanisms

3.3 Species interaction

3.4 Forest management

Present some motivations, advantages and disadvantages in considering forest management.

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.

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). In other words, resilience is basically external changes accommodated (or absorbed) that do not modify ecosystem structure (Folke et al., 2002) or the resistance of a particular ecological state to change (Peterson et al., 1998). Resilience can be incrased by multiple factors as ...., 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 resilience with stability of a system. Resilience is the rate and extent of recovery of a system while stability is the moment the system stops to change over time. Before introduce the method to calculate resilience, we must have an idea of what is the equilibrium (Box 1) and stability (Box 2) of a system.

(iii) But how to calculate it in a analytical way? Now introduce the calculus of λ by Jacobian matrix.

Box 1. Equilibrium

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

Box 2. Stability

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

4.3 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 <-

4.4 Transition period - Alternative Stable States?

4.5 Species Interaction: why is it important?

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).

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

References

U. Beck. *The metamorphosis of the world: How climate change is transforming our concept of the world*. Polity Press - John Wiley & Sons, Cambridge, UK, 2016. ISBN 0745690254.

J. M. Becknell, a. R. Desai, M. C. Dietze, C. a. Schultz, G. Starr, P. a. Duffy, J. F. Franklin, a. Pourmokhtarian, J. Hall, P. C. Stoy, M. W. Binford, L. R. Boring, and C. L. Staudhammer. Assessing Interactions Among Changing Climate, Management, and Disturbance in Forests: A Macrosystems Approach. *BioScience*, 65(3):263–274, 2015. ISSN 0006-3568. doi: 10.1093/biosci/biu234. URL http://bioscience.oxfordjournals.org/cgi/doi/10.1093/biosci/biu234.

R. Bertrand, J. Lenoir, C. Piedallu, G. Riofrío-Dillon, P. de Ruffray, C. Vidal, J.-C. Pierrat, and J.-C. Gégout. Changes in plant community composition lag behind climate warming in lowland forests. *Nature*, 479(7374):517–520, 2011. ISSN 0028-0836. doi: 10.1038/nature10548. URL http://www.nature.com/doifinder/10.1038/nature10548.

R. Bertrand, G. Riofrío-Dillon, J. Lenoir, J. Drapier, P. de Ruffray, J.-C. Gégout, and M. Loreau. Ecological constraints increase the climatic debt in forests. *Nature Communications*, 7(August):12643, 2016. ISSN 2041-1723. doi: 10.1038/ncomms12643. URL http://www.nature.com/doifinder/10.1038/ncomms12643.

L. Boisvert-Marsh, C. Périé, and S. de Blois. Shifting with climate? Evidence for recent changes in tree species distribution at high latitudes. *Ecosphere*, 5(7):art83, 2014. ISSN 2150-8925. doi: 10.1890/ES14-00111.1. URL http://doi.wiley.com/10.1890/ES14-00111.1.

S. Capstick, L. Whitmarsh, W. Poortinga, N. Pidgeon, and P. Upham. International trends in public perceptions of climate change over the past quarter century. *Wiley Interdisciplinary Reviews: Climate Change*, 6(1):35–61, jan 2015. ISSN 17577799. doi: 10.1002/wcc.321. URL http://doi.wiley.com/10.1002/wcc.321.

J. S. Clark, A. E. Gelfand, C. W. Woodall, and K. Zhu. More than the sum of the parts: Forest Climate response from join specise distributions. *Ecological Applications*, 24(5):990–999, 2014. ISSN 10510761. doi: 10.1890/13-1015.1.

U. Cubasch, D. Wuebbles, D. Chen, M. C. Facchini, D. Frame, N. Mahowald, and J. G. Winther. Introduction. In T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, B. V, and P. M. Midgley, editors, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, chapter Introducti, pages 119–158. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

G. S. Cumming. *Spatial resilience in social-ecological systems*. Springer Science & Business Media, London, 2011. ISBN 9400703074.

C. M. Dieleman, B. A. Branfireun, J. W. Mclaughlin, and Z. Lindo. Climate change drives a shift in peatland ecosystem plant community: Implications for ecosystem function and stability. *Global Change Biology*, 21(1):388–395, 2015. ISSN 13652486. doi: 10.1111/gcb.12643.

J. Ehrlen and W. F. Morris. Predicting changes in the distribution and abundance of species under environmental change. *Ecology Letters*, 18(3):303–314, 2015. ISSN 14610248. doi: 10.1111/ele.12410.

F. Essl, S. Dullinger, W. Rabitsch, P. E. Hulme, P. Pyšek, J. R. U. Wilson, and D. M. Richardson. Delayed biodiversity change: No time to waste. *Trends in Ecology and Evolution*, 30(7):375–378, 2015. ISSN 01695347. doi: 10.1016/j.tree.2015.05.002.

C. Folke, S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A journal of the human environment*, 31(5):437–440, 2002. ISSN 0044-7447.

S. J. Goring and J. W. Williams. Effect of historical land-use and climate change on tree-climate relationships in the upper Midwestern United States. *Ecology Letters*, pages 461–470, 2017. ISSN 1461023X. doi: 10.1111/ele.12747. URL http://doi.wiley.com/10.1111/ele.12747.

A. Guisan and W. Thuiller. Predicting species distribution: Offering more than simple habitat models. *Ecology Letters*, 8(9):993–1009, 2005. ISSN 1461023X. doi: 10.1111/j.1461-0248.2005.00792.x.

A. Guisan, R. Tingley, J. B. Baumgartner, I. Naujokaitis-Lewis, P. R. Sutcliffe, A. I. T. Tulloch, T. J. Regan, L. Brotons, E. Mcdonald-Madden, C. Mantyka-Pringle, T. G. Martin, J. R. Rhodes, R. Maggini, S. A. Setterfield, J. Elith, M. W. Schwartz, B. A. Wintle, O. Broennimann, M. Austin, S. Ferrier, M. R. Kearney, H. P. Possingham, and Y. M. Buckley. Predicting species distributions for conservation decisions. *Ecology Letters*, 16(12):1424–1435, 2013. ISSN 1461023X. doi: 10.1111/ele.12189.

C. S. Holling. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, 4(1):1–23, 1973. ISSN 0066-4162. doi: 10.1146/annurev.es.04.110173.000245. URL http://www.annualreviews.org/doi/10.1146/annurev.es.04.110173.000245.

V. Koshkina, Y. Wang, A. Gordon, R. M. Dorazio, M. White, and L. Stone. Integrated species distribution models: combining presence-background data and site-occupany data with imperfect detection. *Methods in Ecology and Evolution*, 8(4):420–430, 2017. ISSN 2041210X. doi: 10.1111/2041-210X.12738.

M. Kuussaari, R. Bommarco, R. K. Heikkinen, A. Helm, J. Krauss, R. Lindborg, E. Öckinger, M. Pärtel, J. Pino, F. Rodà, C. Stefanescu, T. Teder, M. Zobel, and I. Steffan-Dewenter. Extinction debt: a challenge for biodiversity conservation. *Trends in Ecology and Evolution*, 24(10):564–571, 2009. ISSN 01695347. doi: 10.1016/j.tree.2009.04.011.

P. Lasch, M. Lindner, M. Erhard, F. Suckow, and a. Wenzel. Regional impact assessment on forest structure and functions under climate change—the Brandenburg case study. *Forest Ecology and Management*, 162(1):73–86, 2002. ISSN 03781127. doi: 10.1016/S0378-1127(02)00051-8.

A. M. Louthan, D. F. Doak, and A. L. Angert. Where and When do Species Interactions Set Range Limits? *Trends in Ecology and Evolution*, 30(12):780–792, 2015. ISSN 01695347. doi: 10.1016/j.tree.2015.09.011. URL http://dx.doi.org/10.1016/j.tree.2015.09.011.

V. J. Monleon and H. E. Lintz. Evidence of tree species' range shifts in a complex landscape. *PLoS ONE*, 10(1):1–17, 2015. ISSN 19326203. doi: 10.1371/journal.pone.0118069.

A. Morán-Ordóñez, J. J. Lahoz-Monfort, J. Elith, and B. A. Wintle. Evaluating 318 continental-scale species distribution models over a 60-year prediction horizon: what factors influence the reliability of predictions? *Global Ecology and Biogeography*, pages 1–14, 2016. ISSN 1466822X. doi: 10.1111/geb.12545. URL http://doi.wiley.com/10.1111/geb.12545.

T. H. Oliver, M. S. Heard, N. J. B. Isaac, D. B. Roy, D. Procter, F. Eigenbrod, R. Freckleton, A. Hector, C. D. L. Orme, O. L. Petchey, V. Proença, D. Raffaelli, K. B. Suttle, G. M. Mace, B. Martín-López, B. A. Woodcock, and J. M. Bullock. Biodiversity and Resilience of Ecosystem Functions. *Trends in ecology & evolution*, 30(11):673–684, 2015. ISSN 18728383. doi: 10.1016/j.tree.2015.08.009.

J. Peñuelas, J. Sardans, M. Estiarte, R. Ogaya, J. Carnicer, M. Coll, A. Barbeta, A. Rivas-Ubach, J. Llusià, M. Garbulsky, I. Filella, and A. S. Jump. Evidence of current impact of climate change on life: A walk from genes to the biosphere. *Global Change Biology*, 19(8):2303–2338, 2013. ISSN 13541013. doi: 10.1111/gcb.12143.

G. Peterson, C. R. Allen, and C. S. Holling. Original Articles: Ecological Resilience, Biodiversity, and Scale. *Ecosystems*, 1(1):6–18, 1998. ISSN 1432-9840. doi: 10.1007/s100219900002. URL http://link.springer.com/10.1007/s100219900002.

R. D. Pfister. The need and potential for ecosystem management in forests of the inland west. In G. N. Aplet, N. Johnson, J. T. Olson, and V. A. Sample, editors, *Defining sustainable forestry*, chapter The need a, pages 217–239. Island Press, The Wilderness Society, Washington, DC, 1993.

A. L. Pigot and J. A. Tobias. Species interactions constrain geographic range expansion over evolutionary time. *Ecology Letters*, 16(3):330–338, 2013. ISSN 1461023X. doi: 10.1111/ele.12043. URL http://doi.wiley.com/10.1111/ele.12043.

S. A. Pulsford, D. B. Lindenmayer, and D. A. Driscoll. A succession of theories: Purging redundancy from disturbance theory. *Biological Reviews*, 91(1):148–167, 2016. ISSN 1469185X. doi: 10.1111/brv.12163.

F. M. Schurr, J. Pagel, J. S. Cabral, J. Groeneveld, O. Bykova, R. B. O'Hara, F. Hartig, W. D. Kissling, H. P. Linder, G. F. Midgley, B. Schröder, A. Singer, and N. E. Zimmermann. How to understand species' niches and range dynamics: A demographic research agenda for biogeography. *Journal of Biogeography*, 39(12):2146–2162, 2012. ISSN 03050270. doi: 10.1111/j.1365-2699.2012.02737.x.

F. Sittaro, A. Paquette, C. Messier, and C. A. Nock. Tree range expansion in eastern North America fails to keep pace with climate warming at northern range limits. *Global Change Biology*, pages 1–10, 2017. ISSN 13652486. doi: 10.1111/gcb.13622.

G. Tavecchia, S. Tenan, R. Pradel, J. M. Igual, M. Genovart, and D. Oro. Climate-driven vital rates do not always mean climate-driven population. *Global Change Biology*, 22(12):3960–3966, 2016. ISSN 13652486. doi: 10.1111/gcb.13330.

C. D. Thomas, A. M. A. Franco, and J. K. Hill. Range retractions and extinction in the face of climate warming. *Trends in Ecology and Evolution*, 21(8):415–416, 2006. ISSN 01695347. doi: 10.1016/j.tree.2006.05.012.

A. L. Treyger and C. A. Nowak. Changes in tree sapling composition within powerline corridors appear to be consistent with climatic changes in New York State. *Global Change Biology*, 17 (11):3439–3452, 2011. ISSN 13541013. doi: 10.1111/j.1365-2486.2011.02455.x.

M. S. Webster, M. A. Colton, E. S. Darling, J. Armstrong, M. L. Pinsky, N. Knowlton, and D. E. Schindler. Who Should Pick the Winners of Climate Change? *Trends in Ecology & Evolution*, 32(3):167–173, 2017. ISSN 01695347. doi: 10.1016/j.tree.2016.12.007. URL http://linkinghub.elsevier.com/retrieve/pii/S0169534716302415.

M. S. Wisz, J. Pottier, W. D. Kissling, L. Pellissier, J. Lenoir, C. F. Damgaard, C. F. Dormann, M. C. Forchhammer, J. A. Grytnes, A. Guisan, R. K. Heikkinen, T. T. Høye, I. Kühn, M. Luoto, L. Maiorano, M. C. Nilsson, S. Normand, E. Öckinger, N. M. Schmidt, M. Termansen, A. Timmermann, D. A. Wardle, P. Aastrup, and J. C. Svenning. The role of biotic interactions in shaping distributions and realised assemblages of species: Implications for species distribution modelling. *Biological Reviews*, 88(1):15–30, 2013. ISSN 14647931. doi: 10.1111/j.1469-185X.2012.00235.x.