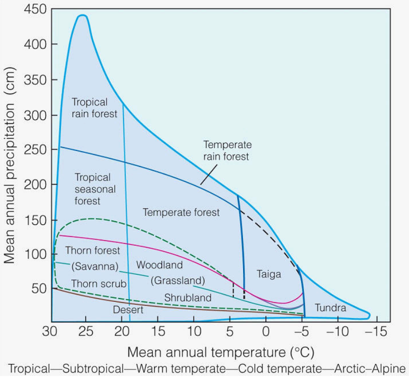
How vegetation-herbivores feedbacks mediate vegetation transitions?

Isabelle Boulangeat, Matthieu Leblond, Tanguy Daufresne, Dominique Gravel

August 14, 2014

Biomes distribution (Whittaker 1975)



Strong effect of the climate but...

Other drivers

Treeline is largely influenced by grazing sheep

Other drivers

Forest-savanna transitions are driven by fire and herbivores

Ecology, 92(5), 2011, pp. 1063–1072

Tree cover in sub-Saharan Africa: Rainfall and fire constrain forest and savanna as alternative stable states

A. Carla Staver,[1,3] Sally Archibald,[2] and Simon Levin[1]

Oikos 122: 441–453, 2013
doi: 10.1111/j.1600-0706.2012.20735.x

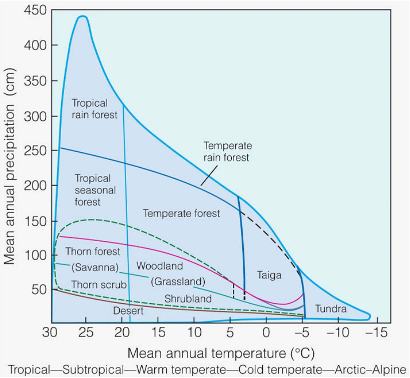
Subject Editor: Karin Johst. Accepted 15 May 2012

Herbivore–vegetation feedbacks can expand the range of savanna persistence: insights from a simple theoretical model

Ricardo M. Holdo, Robert D. Holt and John M. Fryxell

Objectives

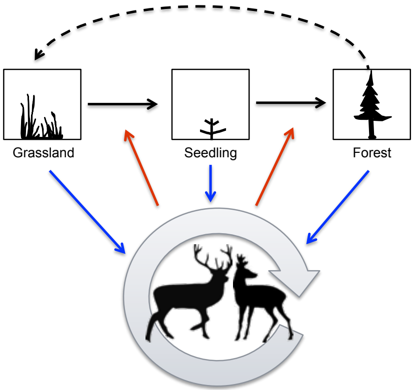
What is the effect of $\overbrace{\textbf{trophic interactions}}^{\text{wild animals}}$ on the distribution of the vegetation?

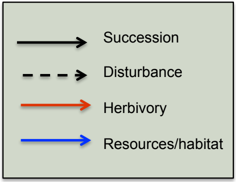


Investigating distributions along the temperature gradient at

- Treeline ecotone
- Temperate/boreal forest ecotone

Part 1: Forest-grassland transition





Part 1: Forest-grassland transition

Proportions of landscape

G = Grasslands

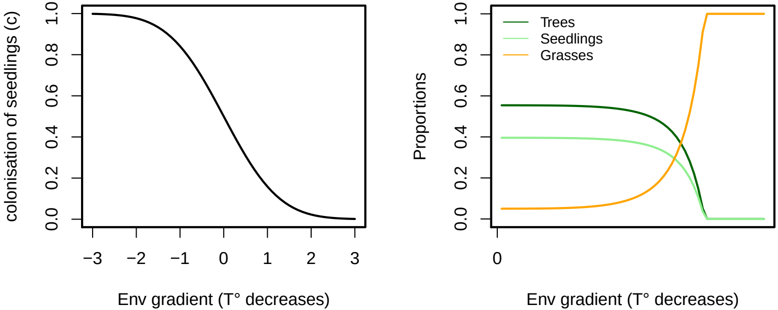
S = Seedling-dominated

T = Forest

$$\begin{tikzcd}
G \arrow[r, "cfT"'] & S \arrow[r, "\alpha"'] & T \arrow[ll, bend right, "\delta"']
\end{tikzcd}$$

$$\begin{cases}
G = 1 - T - S \\
\dfrac{dT}{dt} = \overbrace{\alpha S}^{\text{succession}} - \overbrace{\delta T}^{\text{disturbance}} \\
\dfrac{dS}{dt} = \overbrace{fT}^{\text{seeds}} \; \overbrace{cG}^{\text{colonisation}} - \overbrace{\alpha S}^{\text{succession}}
\end{cases}$$

Climate effect implementation



Herbivore dynamics

Based on metaphysiological model Owen-Smith 2002
The herbivore dynamic is modelled as a **total biomass**.

$$\frac{dH}{dt} = \overbrace{H * I}^{\text{biomass gains}} \; - \overbrace{H * (p + qe^{-zI} + m))}^{\text{biomass losses}}$$

p	metabolic attrition rate
q	maximum mortality rate due to starvation
m	minimum mortality rate when food is abundant
I	vegetation intake rate

Vegetation-herbivore interactions

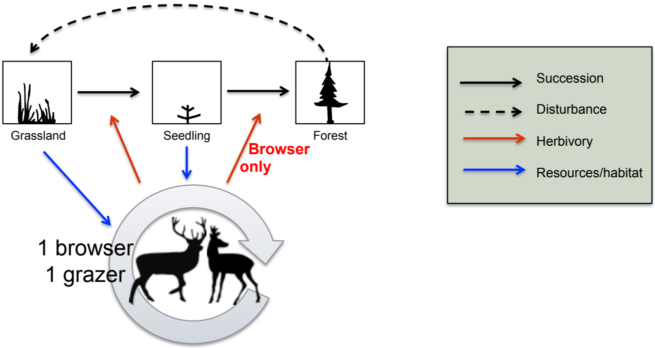
$$I = \overbrace{\frac{\tau R_1}{\mu + R_1}}^{\text{intake rate of preferred resource}} + \overbrace{\frac{\theta R_2}{\nu + R_2} \frac{1}{1 + e^{r\left(\frac{\tau \boldsymbol{R_1}}{\mu + \boldsymbol{R_1}} - p - m\right)}}}^{\text{intake rate of secondary resource}}$$

Feedback effects of herbivores on the vegetation

Herbivore pressure (P_G and P_S) $= \frac{\text{Total intake}}{\text{Available biomass}}$

Herbivores impact **colonisation by seedlings (c)** and **succession(α)**

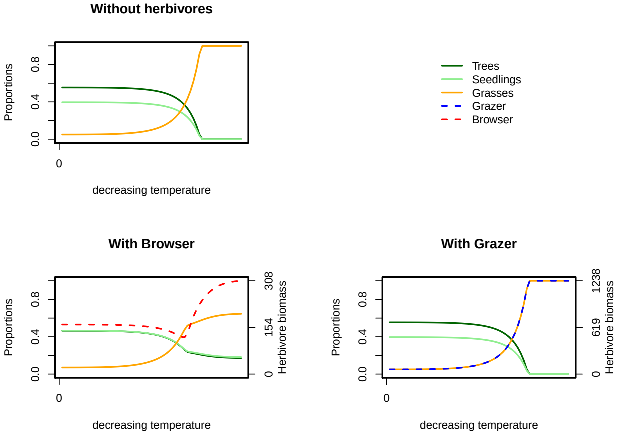
Assumptions of the analysis



- The two herbivores have the same demographic parameters
- Grasses provide 4 times more eatable biomass than seedlings
- Herbivores **compete**, according to their total biomass, on grass ressource

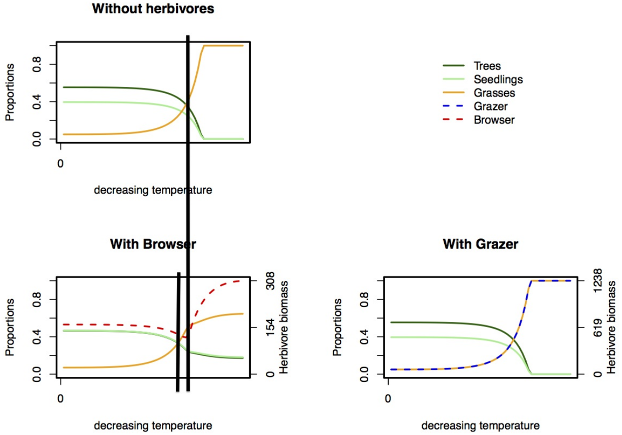
Steady state analysis

Browser vs grazer effect on vegetation distribution



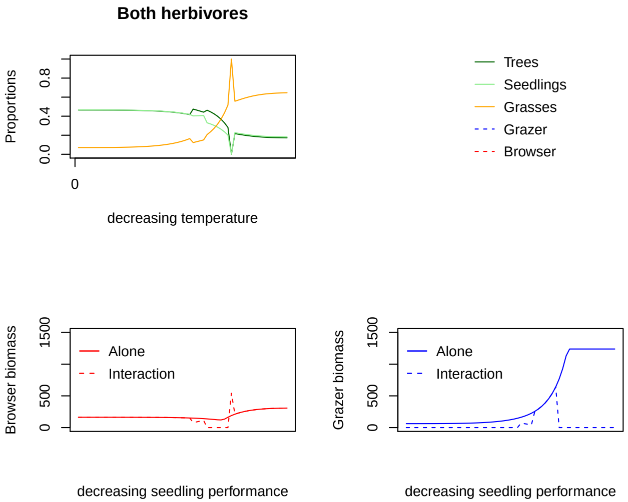
Steady state analysis

Browser vs grazer effect on vegetation distribution



Steady state analysis

Indirect interactions between herbivores



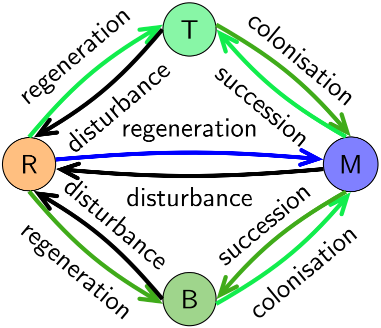
Part 1: conclusions

1. The herbivores induce a **shift** in the distribution of the vegetation
2. The herbivores **modify the proportion** of vegetation states along the gradient
   - The browser **favors open environments where seedlings perform well**
   - The browser **limits grasslands dominance where seedlings have low performance**
3. There are climatic conditions where **indirect facilitation** between herbivores are more important than direct competition.

Part 2: Temperate-boreal forest transition

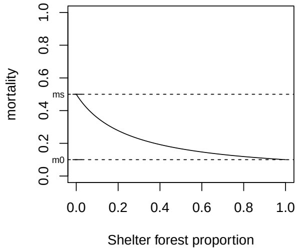
R = post-disturbance forest
T = temperate forest

B = boreal forest
M = mixed forest

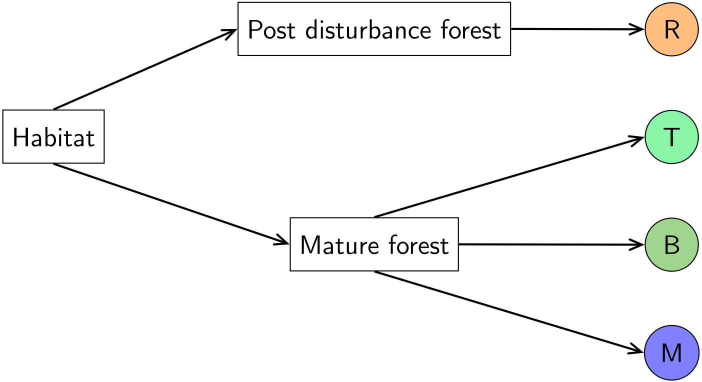


Shelter effects

The mortality dependents on the proportion of **mature boreal and mixed** forests



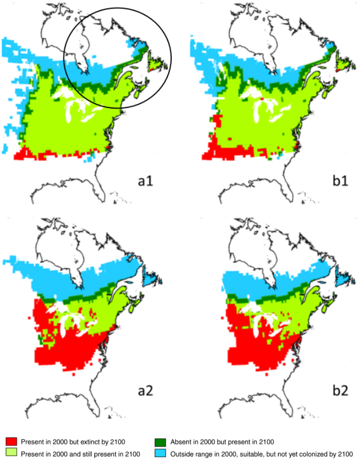
Herbivore habitat and species preferences



In each habitat, there is also species preferences (κ_T and κ_B)

Application in Québec

1. Québec region

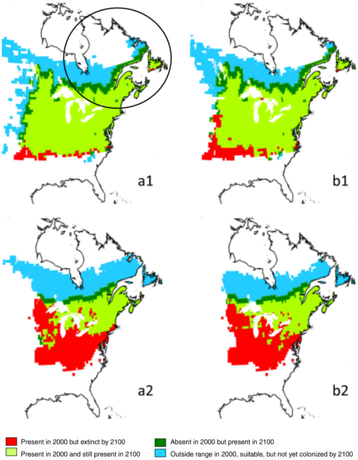


***Acer saccharum*, Morin and Thuiller 2009**

Application in Québec

1. Québec region
2. Two competing browsers:
   - **White-tailed deer**.

   - **Moose**



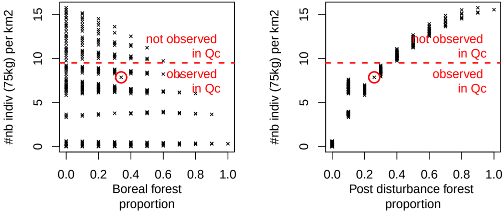
***Acer saccharum*, Morin and Thuiller 2009**

Parameterisation for herbivores and interactions

Data from literature:

- digestibility
- habitat preferences
- diet
- metabolic rates
- intake rates
- home range size
- distance travelled per day
- forage availability

Deer carying capacity



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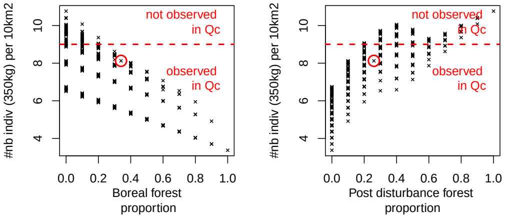


Parameterisation for vegetation

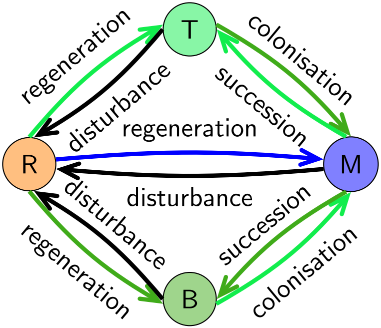
Input data:

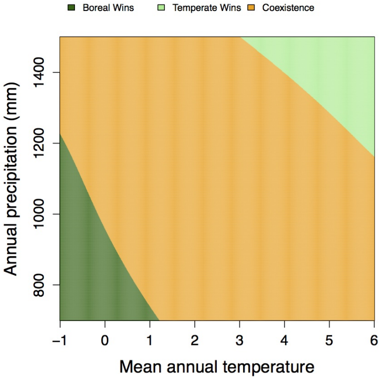
- permanent plots (repeated measures of all trees >9cm dbh)
- associated climatic data
- moose and deer densities in whole Québec

Parameter estimation:

- customized **likelihood function**
- **simulated annealing** to estimate maximum likelihood

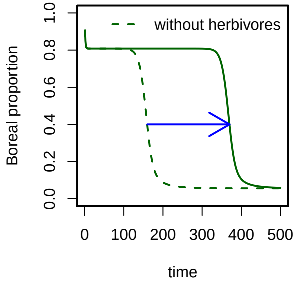
Estimated parameters

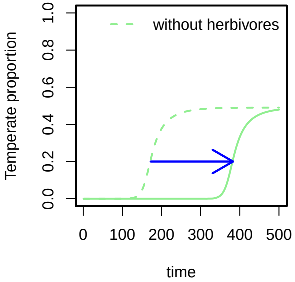




Simulated climate change

Simulated increase in 3 ° C in the vegetation coexistence zone.





Take home messages

1. Herbivores can **favor species coexistence** (for the 2 trophic levels)
2. Herbivores can induce a **shift** in vegetation distributions
3. Herbivores can **delay** the effect of climate change on the vegetation