Use of a multi-species grassland model for analysing the response of phenology to climate change

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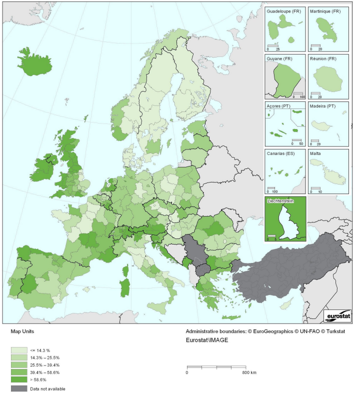
Biodiversity in semi-natural permanent grasslands

- At the world scale, grasslands and agricultural land used for forage production:
  $\rightarrow$ 80% of the total agricultural area (Statistical Office of the European Union, 2010)
- In France, grasslands (both permanent and temporary):
  $\rightarrow$ 42% of the agricultural area (Service de l'Observation et des Statistiques, 2010)



Biodiversity in semi-natural permanent grasslands

Definition: permanent grassland

- Mown / grazed grassland, not ploughed or sowed for several years (≥ 5), with mainly a natural origin of the composition [a]

[a] (Mazoyer, 2002; Petit *et al.*, 2005)

"Hot spot" of plant biodiversity...

- **World record of plant species richness**
  - At fine scale with up to 89 species on $1m^2$ [a]
- **A high species richness at the regional scale:**
  - A pool of more 1000 species in Franche-Comté
  - In average, 30 species per grassland (3 to 92) [b]

[a] (Wilson et al. 2012)
[b] (Mauchamp et al. 2014)

Biodiversity in semi-natural permanent grasslands

... facing many disturbances...

- Anthropogenic disturbances: grazing, mowing, fertilizing
- Climatic disturbances: drought and heat waves
- Biotic disturbances: invasive species, pest outbreaks

... and providing important ecosystem services

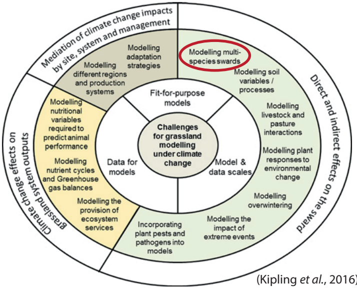
- Ecosystem services provided by biodiversity:
  - Resilience to extreme climatic events
  - Higher carbon sequestration, Support of soil quality
  - Better control of soil water content
- Multi-species swards tend to show:
  - An extended plant growing season
  - Higher nutritional values
  - A tendency to higher milk protein content

Biodiversity in semi-natural permanent grasslands

- The high diversity of permanent grasslands sustaining important ecological services is strongly affected by the type and intensity of management.
- Increases in temperature and in aridity lead to long-term shifts in botanical composition.
- The response of the overall phenology of a grassland assemblage to climate variability and change directly depends on the composition.

Could a process-based model simulating explicitly community dynamics in multi-species managed grasslands be useful to better understand the phenology of the assemblage?

Explicit modelling of multi-species swards



(Kipling *et al.*, 2016)

- High potential of species rich grasslands highlights the need to model the composition of those assemblage in response to different managements and climates.
- Modelling Diversity: one on the 15 keys challenges for grasslands models [a]
- Diversity: only poorly included in grasslands models without an explicit dynamics

[a] (Kipling *et al.*, 2016)

Building the *DynaGraM* model

Approach

Modeling the **diversity - productivity- stability** relationships

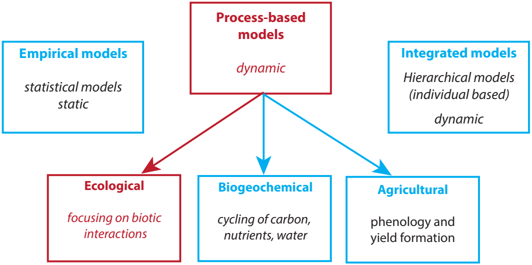
Build a model of herbaceous cover in response to **management** & **climate**

Scientific challenges

High priority for explicit modeling of **multi-species** swards

Simulating the **botanical composition** under various managements

Process-based models: functional and taxonomic composition



(Van Oijen *et al.*, 2018)

Building the *DynaGraM* model

→ Modelling diversity & productivity with the main ecological processes

Modelling frame

- Ordinary differential equation integrating the main ecological processes
- Inter-specific competition on mineral resource Nm
- Herbaceous aboveground biomass of n species or species groups

Key model assumptions:

- Absence of specific description of phenological stages of plants
- Exclusion of the plant allocation strategies:
  - absence of a root system dynamics
  - no distinction between leaves and stems
- Growth and senescence mechanisms:
  - an isolated system: no recruitment from seed bank and no colonization
  - only a vegetative reproduction
- Soil mineral resource: absence of N acquisition by legumes

Building the *DynaGraM* model

→ Modelling diversity & productivity with the main ecological processes

MODEL INPUTS

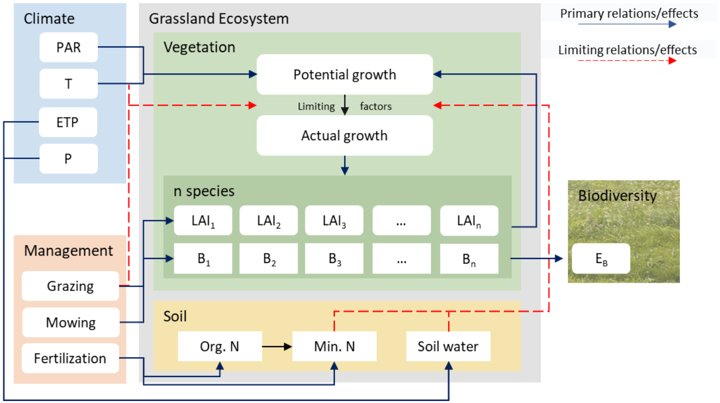
→ climate data (T, PAR, Precipitation, PET)

→ number and identity of initial species

→ management form

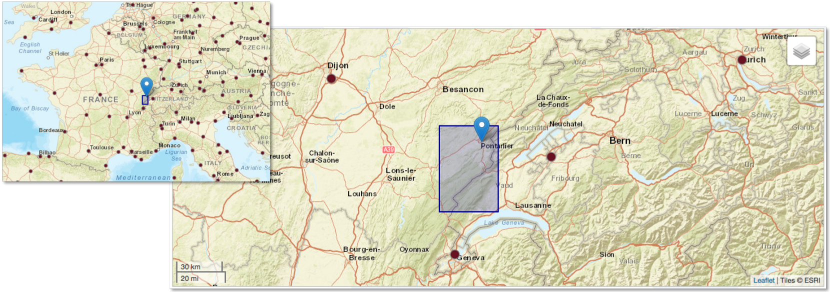
MODEL OUTPUTS

→ $B_i(t)$ biomass of the herbaceous species in kg.ha^{-1}



Case study: grasslands of the Jura Mountains

→ Simulation of a theoretical grassland in Pontarlier, Jura, France (900m)



Mosaic of wood-pastures and grasslands used for dairy farming

- define typical vegetation, management, soil and climatic conditions
- climate: repetition of the standard year 2004

Case study: grasslands of the Jura Mountains

→ Simulation of a theoretical grassland in Pontarlier, Jura, France (900m)

7 plant functional types described by representative species

A

Lolium perenne

B

Poa trivialis

C

Trisetum flavescens

D

Deschampsia cespitosa

E

Ranunculus acris

R

Taraxacum officinale

L

Trifolium pratense

(Ansquer et al. 2004, *Fourrages;* Moulin et al. 2018, *Ecological Modelling*)

- **4 grass functional types**

  A early and fast-growing grasses in fertile and frequently disturbed grasslands

  B competitive and productive grasses in fertile and unfrequently disturbed grasslands

  C late and slow-growing grasses in infertile and frequently disturbed grasslands

  D late and slow-growing grasses in infertile and unfrequently disturbed grasslands

- **3 lifeforms of dicots**

  E tall erect forbs

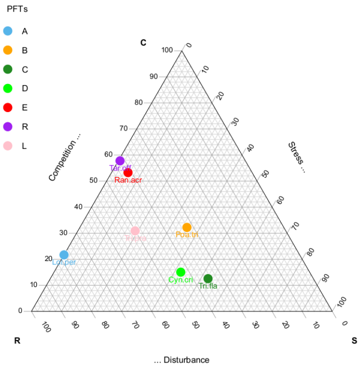
  R small rosette or creeping forbs

  L legumes

Case study: grasslands of the Jura Mountains

Table: Viable strategies according to two gradients perturbation-stress (Grime, 1977)

Intensity of perturbations	Intensity of stress	
	Low	High
Low	C - competitive	S - stress tolerant
High	R - ruderal	(No viable strategy)



Anthropogenic disturbances

Extensive grazing: 0.5 ABU.ha^{-1} along 134 days per year

Intensive grazing: 1.5 ABU.ha^{-1}, mineral fertilization (90 kg Nm ha^{-1} a^{-1})

Extensive mowing: 2 cuts per year (26 June, 23 September)

Intensive mowing: 3 cuts per year with mineral fertilization of 180 kg ha^{-1} y^{-1}

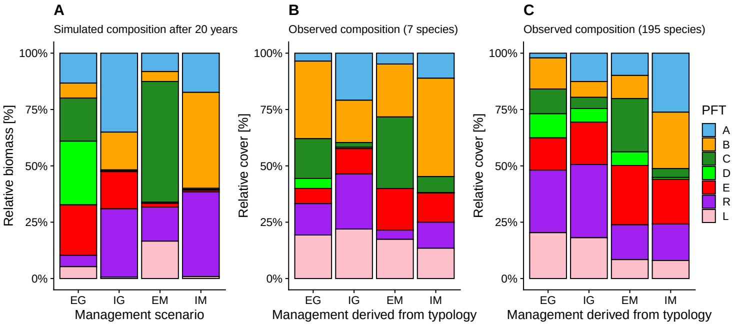
Results. Impact of management on community composition

Identical **initial species distributions**, 20 years simulations for each scenarios

Markedly distinct community **patterns** emerged in response to **type** - **intensity**

68 floristic relevés of permanent grasslands sampled at 800–900 m in the French Jura Mountains

Comparison of model outputs to expected species or functional compositions revealed, in spite of obvious divergences in the details, **common overall features**



Moulin *et al.*, 2020, Ecological Modelling)

Climate change: increases in temperature and aridity

Context

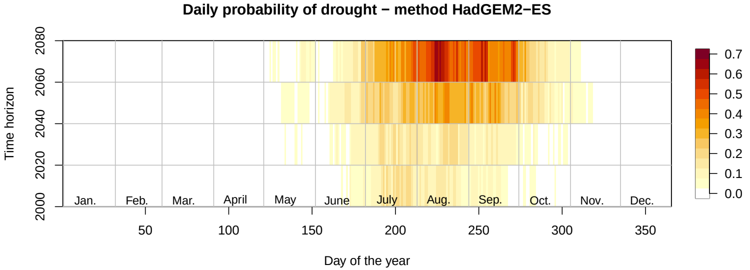
How the overall phenology responds to increases of temperature and aridity?

Approach

As the phenology response strongly depends on the botanical composition
→ application of the *DynaGraM* model, even with weak phenological description

Scientific challenges

Generation of a likely future climate: scenario RCP 8.5, model HadGEM2-ES
How increasing summer aridity affects the species composition of pastures?
Key requirement for gauging climate change effects on forage quality



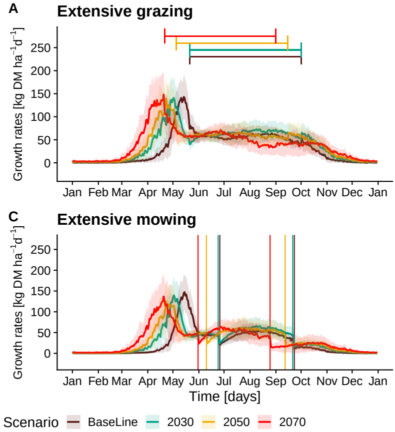
Response of the vegetation to climate changes scenarios

Results. Climatic impact on growth rates

Progressive **impacts** of summer **aridity** on **intensive forms** of managements

Multi-species swards better endure **extreme** droughts, with **extensive form** of land uses

Challenge: **schedule** and **level of disturbances** for intensive forms for far future



(Moulin and Calanca, 2021, Fourrages)

Results. Climatic impact on species composition

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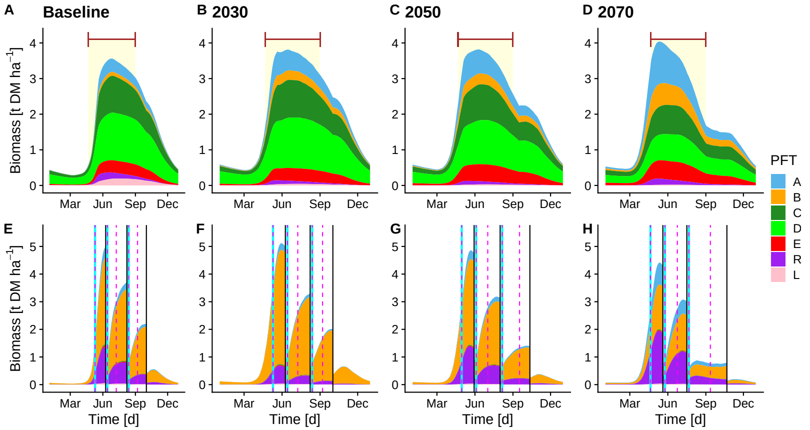

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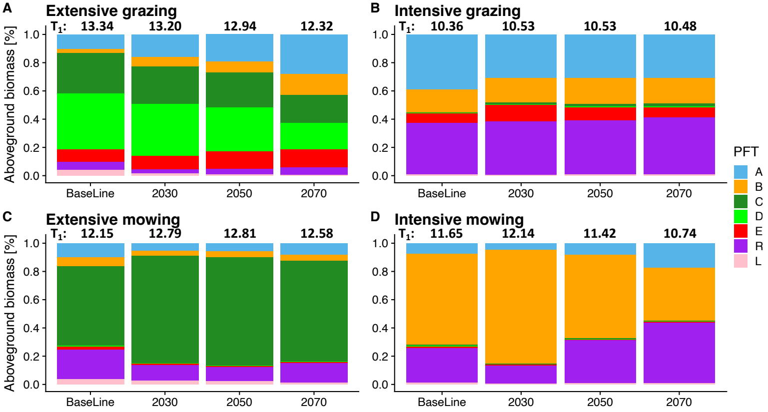

(Moulin and Calanca, 2021, Fourrages)

Conclusions

Key messages

- Composition is strongly influenced by type / intensity forms of the land use
- Botanical composition responds to both short-term climatic fluctuations and long-term shifts
- Even a moderate climate change scenario induces significant changes on grassland biodiversity
- Climate change impacts are mediated by management
- Unclear response of the management form to the phenology:
  $\rightarrow$ potentially related to the selection of the 7 representative species

Conclusions

Interest of our approach for phenology modelling

- Could this process-based model help appreciating the response of the overall phenology of a grassland assemblage to climate variability and change?
- **Phenology description:** integrating the phenological stages of the herbaceous plants?
  - ⇒ Ecodormancy, chilling/forcing accumulation
  - ⇒ subdivision of the biomass in several growing stages
- **Sum of temperatures** are closely connected with the phenology of the cover
  - ⇒ sophistication of the model dependence to the sum of temperatures, currently only describe with a single seasonal effect term

Thank you for your attention!