Vulnerability of Grassland Systems in Europe to Climate Change

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Grassland ecosystems

In EU-27...

... grassland ecosystems are permanent for ~85%
... they cover 67 million ha, i.e. ~40% of agricultural surface
... they are run by ~5.4 millions of farmers
... they provide the feed basis of 78 million herbivores, producing ~25% of milk and meat

(Peyraud, 2013)
Climate change impacts on grasslands

Climatic & atmospheric changes → Impacts

- CO₂ concentration
- Precipitation
- Temperature

Impacts:
- Photosynthesis
- Water use efficiency
- Plant water status
- Length of the cycle
Adaptations to climate change impacts

- Daily growth rate
- Evolution of yearly productivity of a grassland (Durand et al., 2010)
- Start of grass growing season
- Nitrogen input
Soil water balance

Soil moisture (mm)

Accessibility
Water stress

End of field capacity
Return to field capacity

Observed Dry Year

Future Dry Year

(Rivington et al., 2013)
Adaptations to climate change impacts / 2

Impacts

- End of grass growing season
- Summer water deficit

Adaptations

- Length of grazing time
- Number of cuts
- Forage stocks
- Irrigation requirements
- Plant diversity

(Thau et al., 2010)

- Lignin
- Cellulose
- Crude protein
- Nonstructural carbohydrates
The uncertainty cascade

**Emission scenarios (GHG, aerosols)**

Emissions $\Rightarrow$ Concentrations

Climate models

Downscaling

**IMPACT MODEL(S)**

**UNCERTAINTIES**

The envelope of uncertainty

Range of emission and socio-economic pathways (after 2050, projections vary with pathways)

Range of climate models and downscaling techniques (e.g. anomalies, weather types, quantiles)

Range of impact models (further uncertainties: soil, vegetation, management)

Ensemble of models to assess local impacts and adaptation responses

(Boe, 2007)
Systemic approach to grassland vulnerability

Agro-ecosystem
Plot scale

Modelling

Inputs
(climate, soil, management)

PaSim
SPACSYS
AnnuGrow

STICS
EPIC
ARMOSA

Biome-BGC MuSo
LpJmL
CARAIB
ORCHIDEE

Outputs
(GHG, GPP, yield, ...)

Vulnerability indicators
exposure, sensitivity, adaptive capacity

(Lardy et al., 2014)

Initial values
Parameters

Grassland specific
Crop generic
Dynamic global vegetation
Impact projections in France / 1

Extensive permanent grasslands

New opportunities for annual forage production with risks of forage losses in summer (and risks of milk production losses in summer-autumn)

(Graux et al., 2013)
Impact projections in France / 2

Simulated grassland yield (kg DM m$^{-2}$ yr$^{-1}$)

A: low-production area
B: high-production area

(Vital et al., 2013)

Extreme aridity
Vulnerability to climate change

- IPCC definition (IPCC 3rd AR)
  The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

- Conceptualisation of vulnerability for climate change research
  The definition accounts for the long-term nature of the climate problem (by including the adaptive capacity) and for the heterogeneity and complexity of the hazard (by including an exposure factor).
Vulnerability assessment

Characterisation of the pressure of climate on grasslands

Estimation of grassland responses to climatic pressure

Characterisation of evolution scenarios

Context: technical, economic, social, etc.

Coping capacity

Potential impacts

Vulnerability

Adaptation strategies

Evaluation of adaptation measures / social dialogue
### Exposure metrics

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Quantile</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry spell length</td>
<td>25%</td>
<td>Maximum number of consecutive dry days in a year</td>
</tr>
<tr>
<td>Number of heat waves</td>
<td>75%</td>
<td>No. of &gt;six consecutive days when $T_{\text{max}} &gt; T_{\text{max}}$ (baseline) + 3 °C</td>
</tr>
<tr>
<td>Aridity index</td>
<td>25%</td>
<td>$b &lt; 5$: extreme aridity ... $b &gt; 59$: strong humidity</td>
</tr>
</tbody>
</table>

\[
= \frac{1}{2} \cdot \left( \frac{1}{10} + 12 \cdot \frac{1}{10} \right)
\]

(Confalonieri et al., 2010)

### Sensitivity metrics

(Bellocchi et al., 2012; Lardy et al., 2013)

<table>
<thead>
<tr>
<th>Category</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Gross primary production</td>
</tr>
<tr>
<td>Carbon stocks</td>
<td>Total soil carbon</td>
</tr>
<tr>
<td>Nitrogen fluxes</td>
<td>Nitrogen leaching</td>
</tr>
</tbody>
</table>
**Exposure to aridity**

Difference between the mean values of the aridity index ($b_i$) calculated for years of P2 (2011-2060) and P1 (1961-2010) with $b < 25^{th}$ percentile, as represented by the scenario A1B.

**Sensitivity to aridity**

PaSim-simulated grasslands: average values of gross primary productivity (kg C m$^{-2}$) for years experiencing conditions of aridity ($b < 25^{th}$ percentile).

PaSim-simulated grasslands: variances of gross primary productivity (kg C m$^{-2}$) for years experiencing conditions of aridity ($b < 25^{th}$ percentile), represented by the scenario A1B.
## Vulnerability metrics

<table>
<thead>
<tr>
<th>Index</th>
<th>Equation</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Proportional vulnerability</td>
<td>( = - )</td>
<td>Proportion of vulnerable years in a series of years</td>
</tr>
<tr>
<td>Vulnerability gap</td>
<td>( = \frac{1}{d} \cdot \left( \frac{\text{---}}{\text{---}} \right) )</td>
<td>Mean deficit in vulnerable years</td>
</tr>
<tr>
<td>Vulnerability severity</td>
<td>( = \frac{1}{d} \cdot \left( \frac{\text{---}}{\text{---}} \right) )</td>
<td>As ( V_1 ), with more weight given to the most vulnerable years</td>
</tr>
<tr>
<td>Most vulnerable individual</td>
<td>( = 1 - \text{-----} )</td>
<td>Distance to threshold of the most vulnerable year</td>
</tr>
<tr>
<td>Luers-based index</td>
<td>( = \left( \frac{\delta}{\delta} \right) )</td>
<td>Explicit account of the sensitivity of the system</td>
</tr>
</tbody>
</table>

(Lardy et al., 2014)
Luers-based metric: vulnerability maps in Europe

\[ V_L = f \left( \frac{|\partial w/\partial x|}{w/w_0} \right) / f \left( \frac{|\partial w/\partial x|}{w/w_0} \right) \]

- sensitivity
- state
- future
- threshold
- intensification
- past
- extensification

(Lardy, 2013)
Adaptive capacity

(Metzeger et al., 2006)
New vulnerability maps...

Management

nitrogen fertiliser

Climate

Initialisation

Cycle

Finalisation

PaSim

New vulnerability maps...
Vuln-Indices: software to assess vulnerability to climate change

(Lardy et al., 2014)


Thank you!