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growR: R Implementation of the Vegetation Model ModVege

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Summary and Statement of Need

Grasslands constitute one of Earth's most widespread terrestrial ecosystems (Zhao et al., 2020) and managed grasslands are a core element in global agriculture, providing roughly half the feed inputs for global livestock systems (Herrero et al., 2013). Beside their contribution to global food production, they provide a catalogue of other ecosystem services, such as water flow and erosion regulation, pollination service, carbon sequestration and climate regulation (Zhao et al., 2020). The latter have become particularly important in light of anthropogenic climate change (Bezner Kerr et al., 2022).

There is thus ample motivation to study the properties and dynamics of grasslands. Mathematical models are widely used to assess climate change impacts on grassland functioning. Additionally, such models can be employed in agricultural and political decision support, see e.g. GrazPlan (Moore et al., 1997). Dozens of models have been formulated and tested in recent decades. Each of these models has been created with different applications in mind and thus comes with its own focal points and a set of advantages and disadvantages. To give just a few examples:

- The Hurley Pasture Model(Thornley, 1998) is a detailed mechanistic model for managed pastures.
- BASGRA (Van Oijen et al., 2015) and its descendant BASGRA_N (Höglind et al., 2020) are multi-year grassland models which include tiller dynamics.
- PROGRASS (Lazzarotto et al., 2009) was developed to capture the interactions in grass/clover mixtures.
- The focus of PaSim (Graux et al., 2011) is the investigation of livestock production under climate change conditions.
- ModVege (Jouven et al., 2006) is a mechanistic model that is designed to capture the dominant processes with a minimum of required input parameters.
- The Moorepark St Gilles (Ruelle et al., 2018) and Gras-sim (Kokah et al., 2023) models both extend ModVege in terms of soil water and nitrogen dynamics and management.

The existing grassland models vary not only in their formulation and structural complexity, but also in the manner in which they are implemented and distributed, ranging from sets of zipped script files being shared bilaterally among researchers to professionally developed and maintained (open or closed) software suites. With this large variability in implemented models, version control, transparency and clear traceability of employed model implementations becomes challenging, which is detrimental for the reproduction of scientific results.

This paper describes the software package `growR`. `growR` is an implementation of the vegetation model ModVege (Jouven et al., 2006) in the `R` language (R Core Team, 2021). It is packaged and distributed via the comprehensive R archive network (CRAN) with the source code freely and openly available and thus presents a contribution to the above formulated need for reproducible practices in ecosystems modelling.

Package Description

The origin of `growR` lies in an existing, unpublished `R` implementation of the same vegetation model. This original code base has been used to simulate grass growth dynamics and the effects of drought in Switzerland (Calanca et al., 2016). It has since been refactored into an `R` package which is currently being used to investigate the impacts of climate change on Swiss agriculture in the framework of the National Center for Climate Services' *Impacts* program.

The `growR` package contains classes which define data structures and functionalities for parsing the model inputs, carrying out the grass growth simulations and providing different forms of output. These classes and their functionalities are wrapped in high level functions which streamline the most common use cases. In addition to this core functionality, the package contains utilities for some common tasks that arise in ecosystem modelling (and beyond), like setting up a clean directory structure, assessing model performance when compared to a set of validation data and carrying out sweeps over parameter space in order to aid model calibration.

Model Extensions

The core model implementation follows the description by Jouven et al. (2006) but it contains a number of extensions that have proven valuable. Use of any of these additions is optional, so the user is free to work with the model in its original formulation or with any combination of the provided extensions. These additions include:

- Simulation of snow cover by use of a model by Kokkonen et al. (2006) and Rango & Martinec (1995), important when modelling grassland in mountainous regions.
- A cut decision algorithm, which allows the model to simulate management decisions in the absence of such input data. The decision process is based on work by Huguenin-Elie et al. (2017) and Petersen et al. (2021).
- Plant responses to elevated CO_2 conditions: The evapotranspiration (Kruijt et al., 2008) and photosynthetic rates (Kellner et al., 2017; Soltani & Sinclair, 2012) of plants can be modified by the atmospheric CO_2 concentration.
- Use of the multicriterial thermal definition of the growing season, as proposed by Schaumberger (2011).
- All model parameters default to the values provided by Jouven et al. (2006), but are accessible to adjustments by the user.

Publications discussing and validating these extensions are in preparation.

Conclusion

The `growR` package enhances the grassland modelling landscape with a model implementation complete with analysis tools and utilities. The distribution as an `R` package on CRAN ensures an easy installation procedure and a relatively high standard of code quality and documentation through CRAN's submission policies.

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