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A regional assessment of functional diversity in heterogenous grassland with different agricultural management

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Keywords

functional diversity, remote sensing, grassland management

Summary

The characteristics, range, and relative abundance of plant traits present in a given community, are key parameters in quantifying ecosystem properties and derived ecosystem services. Capturing this diversity in differently managed grasslands at landscape scale remains challenging because of limited data availability. To overcome this issue we inverted a physical-based radiative transfer model with remotely sensed Sentinel-2 multispectral datasets of the Swiss National Park that has been free from anthropogenic influence for the last 100 years, and a cultural landscape with agricultural management in its surroundings.

Introduction

Functional diversity based on plant traits controls mechanisms in grassland particularly important for ecosystem service delivery and ecosystem service vulnerability (LALIBERTÉ et al., 2012; SONNIER et al., 2012; GRIGULIS et al., 2013). However, only around 2% of vascular plant species have any trait measurements available at a landscape scale (JETZ et al., 2016) and functional diversity indices are so far for the majority defined on local observations and measured from field samplings (MOUCHET et al., 2010, ROCCHINI et al., 2016). Moreover, the dependency between the indices and spatial resolution is unexplored. Earth observation techniques may provide a solution to overcome the above-mentioned limitation (OLLINGER, 2011; HOMOLOVÁ et al., 2013). The advent of freely available multispectral Sentinel-2 data (DRUSCH et al., 2012) with their high spatial and temporal resolution, as well as optimization of the inversion process of a physical-based model (RIVERA et al., 2013), should provide a valid approach for the quantification of physiological plant traits in grassland. This allows us to study the impact of anthropogenic practices on landscape functional diversity.

Methods

The study was conducted across an approximately 900 km^2 area and includes protected grassland, and grassland subject to organic as well as traditional agricultural management in the Swiss canton of Grisons.

A total of 39 reference plots were established on the different agricultural management areas. In each plot plant trait data were collected once during the vegetation period between end of June and mid of September. The field work was divided into two separate years, 2016 and 2017. Plant trait sampling was conducted in 25 equidistant locations along a 10-m-long transect (GAUCHERAND & LAVOREL, 2007). Standardized trait measurement (CORNELISSEN et al., 2003) were used to quantify specific leaf area (SLA) and leaf dry matter content (LDMC).

To predict plant traits from the remotely sensed data across our study area we took advantage of the inversion of the PROSAIL radiative transfer model (JACQUEMOUD et al., 2009). Parameters of the model are, amongst others, leaf dry mass per unit area (Cm), leaf water mass per unit area (Cw) and leaf chlorophyll content (Cab), where SLA = 1/Cm, and LDMC = Cm/(Cw + Cm).

As model input we used Sentinel-2 atmospherically corrected data with 20 m spatial resolution and 10 bands acquired on the same day as the field samples. An inversion of the model is needed if the trait data is the desired output: a look up table of reflectance spectra (LUT) was randomly generated by running the model multiple times in the forward mode, varying the input parameters in each run. To find the solution to the inverse problem each modeled reflectance spectrum of the LUT was compared to the remotely sensed spectrum and the one providing the smallest deviation, evaluated by a cost function, was selected. SLA, LDMC and Cab values that generated the selected spectrum were the solutions of the inversion process. Multiple solutions and cost functions, as well as the addition of gaussian noise were tested to optimize the inversion results. The modelling and optimization process was carried out using the ARTMO (Automated Radiative Transfer Models Operator) GUI toolbox (VERRELST et al., 2011).

Functional diversity indices on a landscape scale were calculated for each management zone by performing multiple runs and increasing each time the number of randomly selected pixels. Single trait indices, the functional divergence (MASON et al. 2003) and functional regularity (MOUILLOT et al. 2005), multitrait indices, the functional richness and evenness (VILLÈGER et al. 2008;) were determined based on three standardized physiological traits captured by the radiative transfer Model (i.e., SLA, LDMC, Cab). Furthermore, functional diversity was calculated for different landscape scenarios by leaving one management practice each time out and with the others equally sized.

Results

The optimization of the inversion process enabled the comparison of estimated trait values with measured values. Especially the estimated SLA from the model showed a strong quantitative agreement with the field measurement (R^2=0.68). Less accuracy was achieved for the LDMC (R^2=0.43). For the proposed model configuration, SLA explains around 40% of the output variance in the Red Edge (Band 6 and 7) and the leaf water content, used to calculate LDMC, around 30% in the SWIR (Band 11).

Due to the utilization of multiple solutions it was possible to indicate an accuracy measure for both traits, based on the coefficient of variation (RIVERA et al 2013). Only a poor quantitative estimation was possible for extreme trait values and the estimation inaccuracy of the model was positively correlated (ρ=0.52) to single trait functional diversity indices. Management practices resulting in high trait values (e.g., heavy fertilization) and high functional diversity (e.g., mowing and slight fertilization) delivered less accurate results. We could conclude that two major aspects contributed to the model inaccuracy and deviation from infield measured values: (i) saturation effects of the model and (ii) heterogeneity of the target (i.e., grassland).

Functional diversity indices and mean trait values on a landscape scale showed statistically significant differences (p<.001) between the different management types. Post hoc testing revealed that protected grassland with no management equals summer grazed pasture in case of water and dry matter content of the leaves. Higher values of chlorophyll content were present in the National Park area instead. Overall, protection acts as a distinguishable practice, producing intermediate levels of mean trait values compared to all other managements on a landscape scale. Concerning the single trait indices, the variance of Cab was the highest for the National Park among all management types. The functional richness was growing with the analyzed area for all management zones. On an area of 20 km^2, protected grassland showed a functional richness value slightly higher than heavy fertilized meadows. When simulating different landscape scenarios the lowest functional richness was found in the scenario without protected grassland and the highest values in a landscape without heavily fertilized meadows. Functional evenness for each management practice was slightly decreasing with larger area, with the heavily fertilized meadows decreasing even more rapidly.

Discussion

Grassland management is known to affect plant traits (QUÉTIER et al., 2007). Fertilization increases SLA and Cab and decreases LDMC. Different grazing intensities seem to have a lower impact reducing just the LDMC for high grazing intensities (LALIBERTE et al., 2012).

Consequently, the accuracy of trait estimation through model inversion depends on the management practices in each field. The underestimation of extreme trait values (i.e., values close to the upper limit of the model) can be attributed to a saturation effect (FRAMPTON et al., 2013) and is pronounced in areas with high community weighted mean values. Heterogeneity in a canopy cannot be simulated by the PROSAIL model, which assumes the canopy to be a turbid medium (DARVISHZADEH et al. 2007). It emerged from our results that heterogeneity, from a spectral perspective, is better explained by functional trait indices than the number of species. Taking into account that trait variations influence the spectral response of plant communities (LAUSCH et al., 2016) our results are consistent and lead to the conclusion that less accurate trait estimations are to expect for areas with higher functional trait diversity.

While trait values are clearly influenced by the management, this is not always the case for functional diversity (NIU et al. 2014). In our study the effects of land use intensification are more highlighted on a landscape scale than on a plot level, where fertilization seems not to be the key driver for functional diversity. The observed decline of functional evenness with increasing area in highly fertilized meadows leads to noneffective utilization of available resources, a decrease in productivity and increased opportunities for invaders (MASON et al. 2005).

Differing trait values between protected and managed grassland and the high value of Cab variance in the protected area can be attributed to selective grazing pressure by wildlife (SCHÜTZ et al. 2003), whereas cattle apply a more general grazing behavior which is limited to the summer months. Currently, we can not exclude that higher Cab values and their variance in certain areas of the Swiss National Park depend on the bedrock composition. Nonetheless, the fact remains that the Swiss National Park has a high diversity of habitats in terms of different chlorophyll content. Moreover, diversity is the relevant factor influencing functional richness of a landscape. The presence of protected grassland could therefore act as a buffer to environmental fluctuations (PATCHEY 2003) and contribute towards higher ecosystem service supply on a landscape scale (DE BELLO et al., 2010).

References

JHC Cornelissen, S Lavorel, E Garnier, S Diaz, N Buchmann, DE Gurvich, PB Reich, H Ter Steege, HD Morgan, MGA Van Der Heijden, et al. A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Australian journal of Botany, 51(4):335–380, 2003.

Roshanak Darvishzadeh, Andrew Skidmore, Martin Schlerf, and Clement Atzberger. Inversion of a radiative transfer model for estimating vegetation lai and chlorophyll in a heterogeneous grassland. Remote Sensing of Environment, 112(5):2592–2604, 2008.

Francesco de Bello, Sandra Lavorel, Sandra Díaz, Richard Harrington, Johannes HC Cornelissen, Richard D Bardgett, Matty P Berg, Pablo Cipriotti, Christian K Feld, Daniel Hering, et al. Towards an assessment of multiple ecosystem processes and services via functional traits. Biodiversity and Conservation, 19(10):2873–2893, 2010.

M Drusch, U Del Bello, S Carlier, O Colin, V Fernandez, F Gascon, B Hoersch, C Isola, P Laberinti, P Martimort, et al. Sentinel-2: Esa's optical high-resolution mission for gmes operational services. Remote Sensing of Environment, 120:25–36, 2012.

William James Frampton, Jadunandan Dash, GaryWatmough, and Edward James Milton. Evaluating the capabilities of sentinel-2 for quantitative estimation of biophysical variables in vegetation. ISPRS journal of photogrammetry and remote sensing, 82:83–92, 2013.

Stephanie Gaucherand and Sandra Lavorel. New method for rapid assessment of the functional composition of herbaceous plant communities. Austral Ecology, 32(8):927–936, 2007.

Karl Grigulis, Sandra Lavorel, Ute Krainer, Nicolas Legay, Catherine Baxendale, Maxime Dumont, Eva Kastl, Cindy Arnoldi, Richard D Bardgett, Franck Poly, et al. Relative contributions of plant traits and soil microbial properties to mountain grassland ecosystem services. Journal of Ecology, 101(1):47–57, 2013.

Lucie Homolová, Zbynek Malenovsky, Jan GPW Clevers, Glenda García-Santos, and Michael E Schaepman. Review of optical-based remote sensing for plant trait mapping. Ecological Complexity, 15:1–16, 2013.

Stéphane Jacquemoud, Wout Verhoef, Frédéric Baret, Cédric Bacour, Pablo J Zarco-Tejada, Gregory P Asner, Christophe François, and Susan L Ustin. Prospect+ sail models: A review of use for vegetation characterization. Remote Sensing of Environment, 113:S56–S66, 2009.

Walter Jetz, Jeannine Cavender-Bares, Ryan Pavlick, David Schimel, FrankWDavis, Gregory P Asner, Robert Guralnick, Jens Kattge, Andrew M Latimer, Paul Moorcroft, et al. Monitoring plant functional diversity from space. Nature plants, 2:16024, 2016.

Etienne Laliberté, Bill Shipley, David A Norton, and David Scott. Which plant traits determine abundance under long-term shifts in soil resource availability and grazing intensity? Journal of Ecology, 100(3):662–677, 2012.

A Lausch, L Bannehr, M Beckmann, C Boehm, H Feilhauer, JM Hacker, M Heurich, A Jung, R Klenke, C Neumann, et al. Linking earth observation and taxonomic, structural and functional biodiversity: Local to ecosystem perspectives. Ecological Indicators, 70:317–339,2016.

Norman WH Mason, Kit MacGillivray, John B Steel, and J Bastow Wilson. An index of functional diversity. Journal of Vegetation Science, 14(4):571–578, 2003.

Maud A Mouchet, Sébastien Villéger, Norman WH Mason, and David Mouillot. Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. Functional Ecology, 24(4):867–876, 2010.

David Mouillot, WH Norman Mason, Olivier Dumay, and J Bastow Wilson. Functional regularity: a neglected aspect of functional diversity. Oecologia, 142(3):353–359, 2005.

Kechang Niu, Philippe Choler, Francesco de Bello, Nicholas Mirotchnick, Guozhen Du, and Shucun Sun. Fertilization decreases species diversity but increases functional diversity: a three-year experiment in a tibetan alpine meadow. Agriculture, ecosystems & environment, 182:106–112, 2014.

SV Ollinger. Sources of variability in canopy reflectance and the convergent properties of plants. New Phytologist, 189(2):375–394, 2011.

Owen L Petchey. Integrating methods that investigate how complementarity influences ecosystem functioning. Oikos, 101(2):323–330, 2003.

Fabien Quétier, Sandra Lavorel, Wilfried Thuiller, and Ian Davies. Plant-trait-based modeling assessment of ecosystem-service sensitivity to land-use change. Ecological Applications, 17 (8):2377–2386, 2007.

Juan Pablo Rivera, Jochem Verrelst, Ganna Leonenko, and José Moreno. Multiple cost functions and regularization options for improved retrieval of leaf chlorophyll content and lai through inversion of the prosail model. Remote Sensing, 5(7):3280–3304, 2013.

Duccio Rocchini, Matteo Marcantonio, and Carlo Ricotta. Measuring rao's q diversity index from remote sensing: An open source solution. Ecological Indicators, 72:234–238, 2017.

Martin Schütz, Anita C Risch, Eliane Leuzinger, Bertil O Krüsi, and Gérald Achermann. Impact of herbivory by red deer (cervus elaphus l.) on patterns and processes in subalpine grasslands in the swiss national park. Forest Ecology and Management, 181(1):177–188, 2003.

GRÉGORY SONNIER, MARIE-LAURE NAVAS, ADELINE FAYOLLE, AND BILL SHIPLEY. Quantifying trait selection driving community assembly: a test in herbaceous plant communities under contrasted land use regimes. Oikos, 121(7):1103–1111, 2012.

J VERRELST, JP RIVERA, L ALONSO, AND J MORENO. Artmo: an automated radiative transfer models operator toolbox for automated retrieval of biophysical parameters through model inversion. In Proceedings of EARSeL 7th SIG-Imaging Spectroscopy Workshop, Edinburgh, UK, pages 11–13, 2011.

SÉBASTIEN VILLÉGER, NORMAN WH MASON, AND DAVID MOUILLOT. New multidimensional functional diversity indices for a multifaceted framework in functional ecology. Ecology, 89(8):2290–2301, 2008.

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