Ecological Indicators 88 (2018) 232–240

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Are remotely sensed traits suitable for ecological analysis? A case study of long-term drought effects on leaf mass per area of wetland vegetation

Hannes Feilhauer[a,*], Thomas Schmid[b], Ulrike Faude[c], Salvador Sánchez-Carrillo[d], Santos Cirujano[e]

[a] Institute of Geography, FAU Erlangen-Nürnberg, Wetterkreuz 15, 91058 Erlangen, Germany
[b] Department of Environment, Centre for Energy, Environment and Technology (CIEMAT), Avda. Complutense 40, E-28040-Madrid, Spain
[c] Andreas-Paulus-Str. 57, 91080 Spardorf, Germany
[d] Dep. Biogeochemistry and Microbial Ecology, Museo Nacional de Ciencias Naturales, MNCN-CSIC, Serrano 115 dpdo, 28006 Madrid, Spain
[e] Real Jardín Botánico, RJB-CSIC, Pza. de Murillo 2, 28014 Madrid, Spain

ARTICLE INFO

Keywords:
LMA
Specific leaf area (SLA)
Hyperspectral
Imaging spectroscopy
PROSAIL
Trait plasticity

ABSTRACT

Plant and community traits provide valuable insights in ecosystem functioning. Yet, such traits are costly to sample. Existing trait data bases give access to species-specific traits and help to reduce the sampling effort and costs. However, many traits show a high intra-specific plasticity due to the variability of environmental conditions, which is not fully accounted for in the data bases. As an alternative approach, remote sensing is able to retrieve some traits from the spectral reflectance signal of the canopy. Here we test whether remotely sensed traits provide the level of detail to trace the trait plasticity in response to changing environmental conditions.

For this proof of concept study, we selected the example of leaf mass per area (LMA), a key trait for ecosystem functioning and good negative correlate of potential growth rate, in our study site Las Tablas de Daimiel National Park (Spain). This wetland was affected by a long-term drought, which introduced a pronounced trait plasticity as part of the adaptation mechanisms of the vegetation to reduced water availability as well as a decrease in photosynthetic activity. Imaging spectroscopy (HyMap) data of the wetland at peak drought intensity were acquired in 2009 simultaneous to a field campaign. We applied an inversion of the PROSAIL radiative transfer model on these data to map the LMA distribution across the wetland. Further, we quantified trends in photosynthetic activity and changing species composition across the wetland by analyzing time series of the normalized difference vegetation index (NDVI) as calculated for multispectral remote sensing data. The retrieved LMA values were analyzed within and between stands of different species and communities along a gradient of changing photosynthetic activity and species composition.

Results show that LMA values retrieved for stands of species with high photosynthetic activity at peak drought intensity closely meet the values reported in data bases. The observed intra-specific LMA variability is in line with the expected plasticity of this trait along a moisture gradient that is reflected in a change in photosynthetic activity and species composition. We thus conclude that LMA values retrieved from imaging spectroscopy data provide sufficient detail to trace the response of wetland vegetation to long-term drought stress.

1. Introduction

Analyses of plant and community traits provide valuable insights into ecosystem functioning (Wijk 2007). The assessment of these traits in the field is, however, hard and costly as plant samples have to be processed elaborately in the laboratory. To take advantage of trait analyses with a reduced sampling effort, several data bases offering species-related information on functional traits with a regional to global coverage have been developed (Kattge et al., 2011; Kleyer et al., 2008). The species-specific records allow to use sets of traits for further analysis of functional properties of single species or mixed plant assemblages.

It is, however, well known that several plant traits show a high degree of plasticity to variable environmental conditions (Albert et al. 2010). This trait plasticity determines the species persistence, which depends on the adaptability of plant species to their environment as well as on species interactions (Sultan, 2000). Trait data bases thus frequently include a range of measurements per trait and species,

* Corresponding author.
E-mail address: hannes.feilhauer@fau.de (H. Feilhauer).

https://doi.org/10.1016/j.ecolind.2018.01.012
Received 10 August 2017; Received in revised form 17 December 2017; Accepted 5 January 2018
1470-160X/

therewith accounting for differences due to biogeographical origin and genotype. Despite these multiple species entries, the resulting spatio-temporal variability of traits is not well reflected in trait data bases as sampling protocols aim to minimize these effects (Cornelissen et al., 2003). Several studies come to the conclusion that a consideration of trait plasticity is urgently needed for a comprehensive assessment of, for example, functional diversity and for a better understanding of ecological processes (Albert et al., 2010, 2011; de Bello et al., 2011). The need for such analyses includes wetland vegetation which is subject to a high variability of environmental conditions (De Wilde et al., 2014; Li et al., 2014; Rychnovská, 1967). This demand is, however, hardly ever met. The few available studies are mostly focused on single species (De Wilde et al., 2014). The reasons for this research gap are manifold but mostly related to the fact that the sampling of traits – in particular in species-rich communities and for various environmental conditions – is very costly. It may thus be worth testing alternative approaches for trait analyses that are able to capture the trait variation with a reduced sampling effort.

Optical remote sensing approaches provide a promising alternative to assess some functional traits (Homolová et al., 2013). These approaches enable the analysis of the solar electromagnetic radiation that is reflected from vegetation canopies towards information on biochemical and biophysical properties. Profound knowledge on the relationships between these biophysical and -chemical properties and the reflectance spectrum have led to the development of several physical leaf and canopy radiative transfer models (RTMs). RTMs simulate the physical processes of light scattering and absorption in a vegetation canopy. They are able to estimate a very close approximation of the canopy reflectance spectrum based on a set of leaf and canopy traits that determine the optical properties of the vegetation. This trait set includes among others the concentration of pigments, leaf mass per area (LMA, the leaf dry weight per one-sided leaf area), the leaf water content, and the leaf area index of the canopy (Jacquemoud et al., 2009). An inversion of RTMs allows for the retrieval of trait values from canopy reflectance spectra as measured by Earth observation sensors (Baret and Buis, 2008) in a spatially continuous manner going beyond the point measurements of traditional approaches. Leaf traits that can be directly retrieved from such RTM inversions can be combined and enable an assessment of additional leaf or community related traits (Ali et al., 2016a,b). Leaf related traits can be upscaled to the canopy level by multiplying the retrieved values with the canopy leaf area index (Schaepman et al., 2004). Retrieved values for mixed stands correspond to weighted mean values of the traits of the occurring species. The influence of an individual leaf or plant on this mean value is, however, a function of its exposure towards the sensor. Remotely sensed community trait values may thus differ from community weighted mean values.

While several studies have successfully used RTM inversions to map trait distributions (Ali et al., 2016b; Atzberger et al., 2015; Darvishzadeh et al., 2011), further analyses of such trait maps towards the functional response of ecosystems to changing environmental conditions are largely missing (but see, e.g., Kattenborn et al., 2017). An assessment on whether remotely sensed traits actually provide the required detail to trace ecological responses to variable environmental conditions are missing. We thus conducted a proof of concept study and address the example of LMA in a wetland under long-term water stress with the following research question: Do LMA values retrieved from spectral data with an inverted RTM provide sufficient detail to trace the vegetation response to long-term water scarcity?

We selected the example of LMA in wetland vegetation for the following reasons: (1) Wetland vegetation is frequently subject to environmental dynamics, such as repeated cycles of flooding and drought, thus allowing for an analysis of effects of changing environmental conditions over short time scales. The LMA of wetland species is well known for a pronounced plasticity induced by these variable environmental conditions (De Wilde et al., 2014; Li et al., 2014; Rychnovská, 1967). (2) LMA is a good negative correlate of potential growth rate, a key functional ecosystem property. LMA or its inverse, specific leaf area (SLA = 1/LMA) are considered key traits in ecosystem studies (see, e.g., Westoby, 1998; Wright et al., 2004, but also the response by Osnas et al., 2013). The indicative value of LMA (or SLA) is thus frequently used for a description and identification of functional types, analyses of functional diversity, as input for climate, carbon, and vegetation models from global to local scales, as well as for investigations regarding relations between plants and their environment (see Cornelissen et al., 2003 for a review of applications). Other than leaf pigmentation that shows a short-term response to plant stress, LMA promises to indicate long-term trends in the vegetation response. (3) LMA is closely related to the reflectance signal of vegetation canopies and an input parameter to RTMs (Jacquemoud et al., 2009). Obviously, similar analyses could be conducted for other traits like leaf pigments, leaf water content or leaf area that can be retrieved from spectral data and likewise indicate vegetation responses to environmental changes.

2. Material and methods

2.1. Overview

To address our research question, a study in Las Tablas de Daimiel National Park (TDNP, Fig. 1), Spain (39° 9′ N, 3° 40′W) was carried out. The northern parts of TDNP were selected as study site as a result of image and field data availability. Time series of Earth observation data were used to quantify temporal dynamics in the photosynthetic activity of the vegetation for an assessment of the vegetation response to the drought. To map the LMA distribution at the peak of the drought, we used an inversion of the coupled leaf and canopy RTM PROSAIL. PROSAIL simulates the physical principles of scattering and absorption due to leaf and canopy properties on the reflectance spectrum. An inversion allows to retrieve the optical properties of the vegetation, including LMA, from image data with sufficient spectral information. Here, we used airborne imaging spectroscopy data with a very high spectral information content to map the LMA distribution across the study area. The resulting maps of LMA distribution and change in photosynthetic activity were then jointly analyzed.

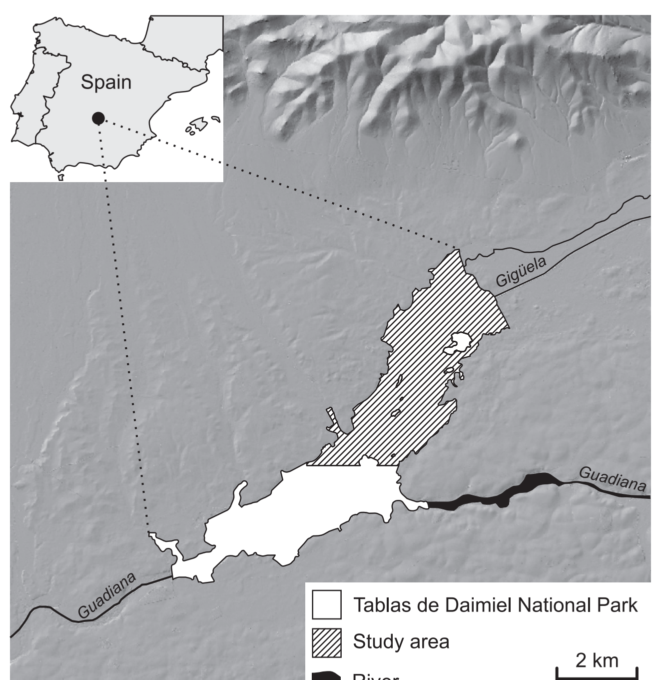

Fig. 1. Location of the study site within the TDNP in Central Spain.