



Can wetland plant functional groups be spectrally discriminated?

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ABSTRACT

Plant functional traits (PFTs) underpin ecosystem processes and therefore ecosystem service provision. If PFTs are possible to detect and discriminate spectrally, then it may be possible to use remote sensing applications to map ecosystem processes or services within and across landscapes. As a first step towards this application, we explored whether functional groups of 22 dominant South African wetland species were spectrally separable based on their PFTs. We measured 23 biochemical and morphological PFTs in combination with spectra from 350 to 2349 nm using a handheld radiometer. First, we evaluated the possibility of accurately predicting morphological and biochemical PFTs from reflectance spectra using three approaches: spectrum averaging, redundancy analysis (RDA), and partial least squares regression (PLSR). Second, we established whether functional groups and species were spectrally distinguishable. We found seven PFTs to be important in at least two of the three approaches: four morphological and three biochemicals. Morphological traits that were important were leaf area (PLSR: $r^2 = 0.40$, regression: $r^2 = 0.41$), specific leaf area ($r^2 = 0.67$), leaf mass ($r^2 = 0.43$, $r^2 = 0.38$), and leaf length/width ratio ($r^2 = 0.62$). Biochemical traits that play a role in the structural composition of vegetation, like lignin content ($r^2 = 0.98$, $r^2 = 0.54$), concentration ($r^2 = 0.45$) and cellulose content ($r^2 = 0.57$, $r^2 = 0.49$), were found to be important by at least two of the analyses. Three other traits were important in at least one of the analyses: total biomass ($r^2 = 0.56$), leaf C/N ratio ($r^2 = 0.99$), and cellulose concentration ($r^2 = 0.76$). Redundancy analysis suggests that there is a large percentage (52%) of the spectrum not explained by the PFTs measured in this study. However, spectral discrimination of functional groups, and even species, appears promising, mostly in the ultraviolet A part of the spectrum. This has interesting applications for mapping PFTs using remote sensing techniques, and therefore for estimating related ecosystem processes and services.

1. Introduction

Plant functional traits (PFTs) are those characteristics of a plant that may both respond to (response traits), and shape (effect traits) their environment (de Bello et al., 2010; Tilman, 2001). It has been suggested that PFTs are the key ecological attributes by which organisms and communities affect ecosystem processes and functioning (Díaz et al., 2007; Lavorel et al., 2007). For example, PFTs such as leaf dry matter content (LDMC) and specific leaf area (SLA) underpin soil fertility among others, whereas canopy size and architecture underpin climate and water regulation (Díaz et al., 2007). Since ecosystem processes are known to underpin ecosystem service provision, it is potentially possible to use PFTs to understand ecosystem service supply in ecosystems. Therefore mapping functional groups, species clustered according to

PFTs, could potentially be used in mapping ecosystem services. Plant functional traits also determine the optical properties of plants, which can have important implications for remote-sensing applications.

Canopy reflectance is determined by leaf, stem, and litter optical properties as well as attributes of canopy structure (Ali et al., 2015; Asner, 1998; Ross, 1981). There has been much research on trees at each of these scales, both deciduous (Asner and Martin, 2008; Baltzer and Thomas, 2005) and coniferous (de Marín et al., 2016), and less research on herbaceous species (Roelofsen et al., 2014). Herbaceous/understorey vegetation presents an interesting case due to lower coherence of chemistry-reflectance relationships as a result of often not being in direct sunlight (Roelofsen et al., 2014). There is a need for more research on the link between PFTs and reflectance spectra for other ecosystem types, such as shrublands, grasslands and wetlands,

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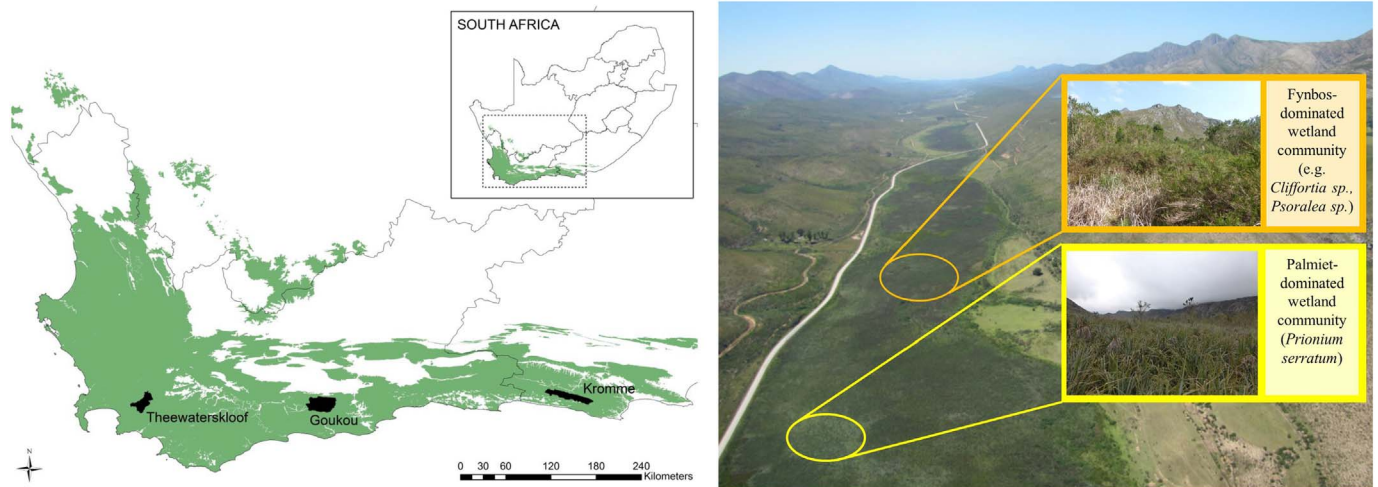


Fig. 1. (Left) The catchments of the three study palmiet wetlands, located within the Cape Floristic Region of South Africa (shown in green). (Right) The Kromme Palmiet wetland, showing the patchy nature of the vegetation communities (light gray and dark green), with the two main plant communities indicated and described.

and particularly for African systems (Adam et al., 2010).

Leaves are optically interesting since plant species have differentially evolved unique properties to both optimise energy capture from the sun while minimizing sun damage and water loss. Leaf traits can influence their optical properties and the importance of specific traits in doing so varies within a species (Poona and Ismail, 2013), among growth forms (Klančnik et al., 2012) and between species (Klančnik et al., 2014b; de Marín et al., 2016). Different PFTs also affect different regions of the spectrum, for example the cuticle affects reflection and absorption in the visible and ultraviolet (UV) ranges (Krauss et al., 1997), whereas leaf thickness affects reflection and transmittance in the near-infrared (NIR) range (Knapp and Carter, 1998). Leaf pigments have been shown to affect the visible part of the spectrum (Asner and Martin, 2008; Klančnik et al., 2015a; Ustin et al., 2009; Zhang et al., 2008).

There has been much research on the use of leaf reflectance to predict PFTs, both biochemical (Carter and Spiering, 2002; Castro and Sanchez-Azofeifa, 2008; Klančnik et al., 2015b; de Marín et al., 2016; Roelofsen et al., 2014; Serbin et al., 2014; Van Cleemput et al., 2018; Zhang et al., 2008) and anatomical/morphological (Klančnik et al., 2015b; de Marín et al., 2016). At the leaf scale, specific leaf area (SLA), an index of leaf density, has been shown to be highly correlated ($r^2 = 0.90$) with the NIR and short-wave infrared (SWIR) part of the leaf spectrum for tropical forests (Asner and Martin, 2008), and coniferous trees (Lukeš et al., 2013), but poorly related ($r^2 = 0.26$) for herbaceous species (Roelofsen et al., 2014). Leaf dry matter content (LDMC) is well correlated with reflectance ($r^2 = 0.67$), even for herbaceous species (Roelofsen et al., 2014). Other studies have found biochemical traits to be more important for explaining spectral variation in aquatic plants, and morphological traits more important for terrestrial plants (Klančnik and Gaberšček, 2016). Specifically trichome density and the thickness of the epidermis were most important in influencing the reflectance spectra of wetland species (Klančnik et al., 2015b). For aquatic plants, chlorophyll *a* and *b* and SLA cumulatively explained 60% of the reflectance spectra (Klančnik et al., 2015b). More plastic PFTs, such as nutrients in plant tissues also affect reflectance (Asner and Martin, 2008; Baltzer and Thomas, 2005; Lukeš et al., 2013; Roelofsen et al., 2014; Serbin et al., 2014), as does tissue water content, particularly in the NIR region (Asner and Martin, 2008; Sims and Gamon, 2003).

It is important to establish the key PFTs influencing reflectance at various scales in different ecosystems, and whether functional groupings of species can be used to simplify this information (Roth et al., 2016). To date, most research of this nature has focussed on broad,

conventional functional types or groups (e.g. growth form), and not on specific functional types derived from trait data. In addition, most research has been concentrated in Europe and the Americas. There is a need to examine relationships between traits and spectra in African ecosystems, particularly wetlands (Adam et al., 2010).

We analysed PFTs and spectra of dominant species in a South African palmiet wetland system to determine whether any relationships could be used to map functional groups. Wetlands are key ecosystems where understanding ecosystem function, and quantifying ecosystem services, are important for society (Rebelo et al., 2015). Wetlands are also extreme environments that have distinct community patterns, such as monospecific dominance in patches, making them interesting and important case study systems (Sieben, 2012). We ask two main research questions: can plant (or canopy)-level reflectance be used to predict morphological and biochemical PFTs in wetland vegetation? and; are wetland communities spectrally distinguishable (by functional groups, species)? If clear relationships exist between PFTs and spectra of these wetland species, then it may be possible to use hyperspectral methods to map ecosystem service hotspots in these wetlands.

2. Methods

2.1. Study wetlands

South African palmiet wetlands are small valley-bottom systems underlain by 0.5–8 m of peat and occurring throughout the Cape Floristic Region of South Africa, a biodiversity hotspot (Job, 2014; Nsor, 2007). Due to their position in important strategic water-providing catchments in South Africa (Nel et al., 2011), and their peat accumulation, they are thought to provide important ecosystem services to society (Rebelo et al., 2015). Palmiet wetlands are so named after the species that dominates them: *Prionium serratum*, or Palmiet, thought to be an ecosystem engineer (Sieben, 2012). However other plant communities occur within these wetlands, giving them a patchy appearance that may be possible to classify using hyperspectral remote-sensing techniques. In this study, dominant species were determined from vegetation surveys in three palmiet wetlands: Theewaterskloof, Goukou and Kromme (Fig. 1). In places the wetlands have become invaded by alien weeds, such as Bramble (*Rubus fruticosus*), as well as trees such as Black Wattle (*Acacia mearnsii*). These palmiet wetlands typically occur at elevations of 100–400 masl, with mean annual precipitation ranging from ± 614 mm (Kromme) to ± 600 – 1000 mm (Goukou) to ± 1600 – 2000 mm (Theewaterskloof) (Job, 2014; Midgley et al., 1994; Rebelo et al., 2006).

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