Leaf spectral properties track variability in leaf traits across the canopy vertical profile

Introduction

Leaf traits play a key role in ecosystem functioning, resilience and ecophysiology. On the realization that leaf traits are a critical component of essential biodiversity variables (EBVs); quantifying leaf traits improves our spectroscopic monitoring efforts of EBVs towards the Aichi Biodiversity Targets (Skidmore *et al*., 2015). EBV models are often calibrated based on spectra-trait relationship for mature, sunlit leaves at the top of canopy. The implicit assumption is that variability in leaf traits concentration and leaf spectral properties within a canopy is very small and consequently top of canopy foliar samples are representative of the canopy as a whole. However, the distribution of leaf traits within vegetation canopies is complex and often vary across the canopy vertical profile. To this end, the vertical heterogeneity in leaf traits across the canopy is often not accounted for in most modelling approaches. The vertical distribution in leaf traits is an attempt to maintain a balance between Rubisco-limited rate of carboxylation and electron transport limited rate of carboxylation (Chen *et al*., 1993). This intrinsic mechanism results in marked effects on leaf morphological, chemical as well as physiological traits across the canopy vertical profile. The aim of this study was to identify key wavelengths that enhance spectral discrimination of leaf samples collected at different canopy positions. This study is a follow-up from our previous study in which we demonstrated that the position of a leaf in a canopy affects leaf optical properties.

Methods

- Four plant species (*Camellia japonica, Ficus Benjamina, Chamaedorea elegans,* and *Fatshedera lizei*) with different leaf forms and canopy structure were selected. Three soil nitrogen treatments [high, medium and no fertilizer treatment] were administered for an eight week period in order to create variation in leaf spectral properties.
- Leaf directional hemispherical reflectance from 350 to 2500 nm for leaf samples collected from upper, middle and lower canopy layers (Figure 1A) were measured using an ASD FieldSpec-3 Pro FR coupled with an ASD RTS-3ZC Integrating Sphere (Figure 1B).
- We also measured the following leaf traits for each sample in the laboratory; nitrogen, chlorophyll, carbon, specific leaf area and effective water thickness. Leaf nitrogen (% dry weight) and carbon were determined by dry combustion-reduction elemental analysis using the Perkin Elmer 2400 CHNS/O Elemental Analyzer (Figure 2).
- Partial Least Squares-Discriminant Analysis (PLS-DA) and validated using leave one out cross validation (LOOCV) was performed to identify key wavelengths that enhance spectral separatibility of leaf samples collected at different canopy positions. PLS-DA is a classification technique that integrate Partial Least Square regression and the properties of discriminant analysis. This techniques is suitable for high dimensional and collinear datasets such hyperspectral remote sensing.

Figure 2: Dry combustion-reduction elemental analysis of leaf samples to determine foliar nitrogen and carbon.

Results

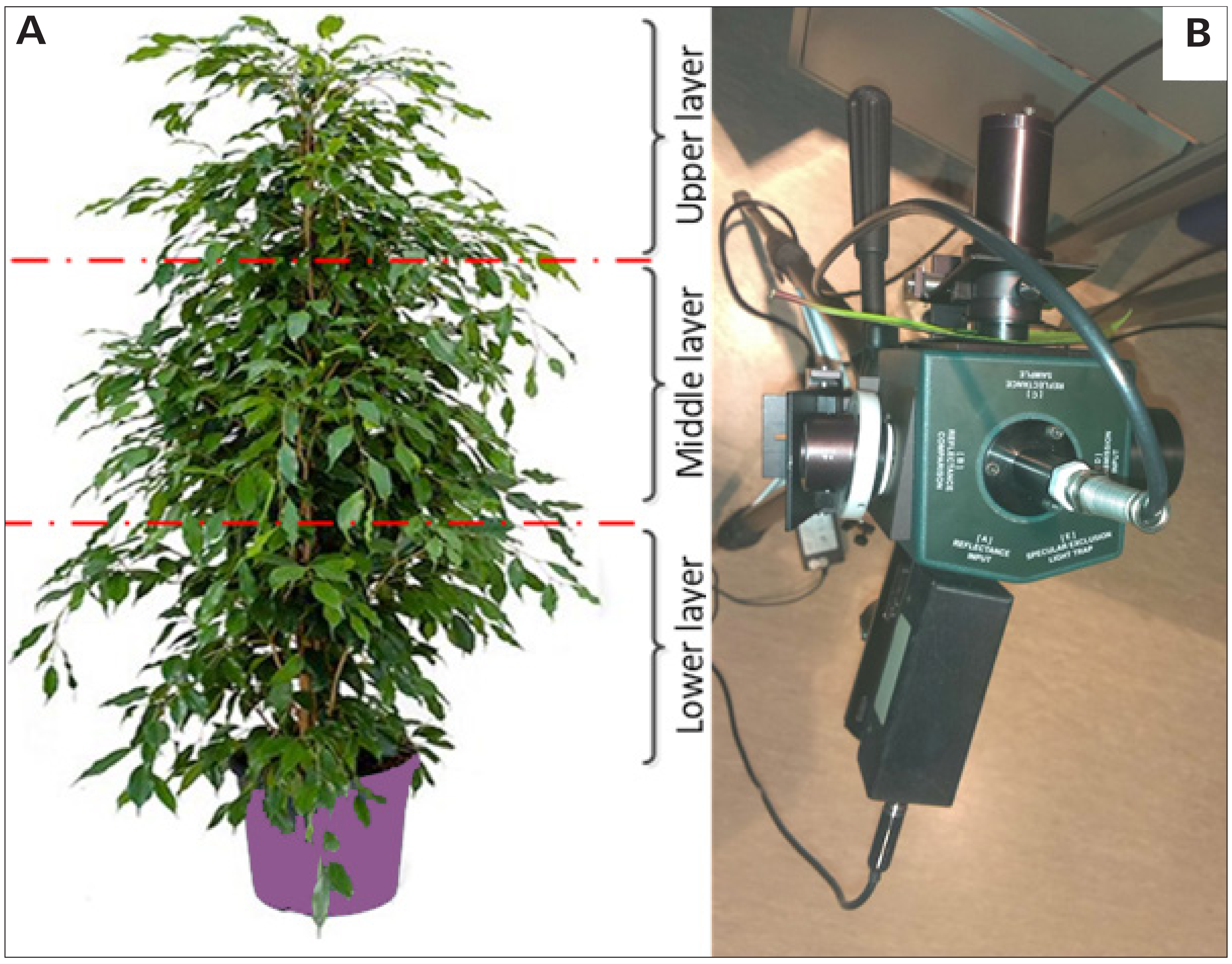

Figure 1: The demarcation of the three canopy layers (A) and the ASD RTS-3ZC Integrating Sphere connected to the ASD FieldSpec-3 Pro FR.

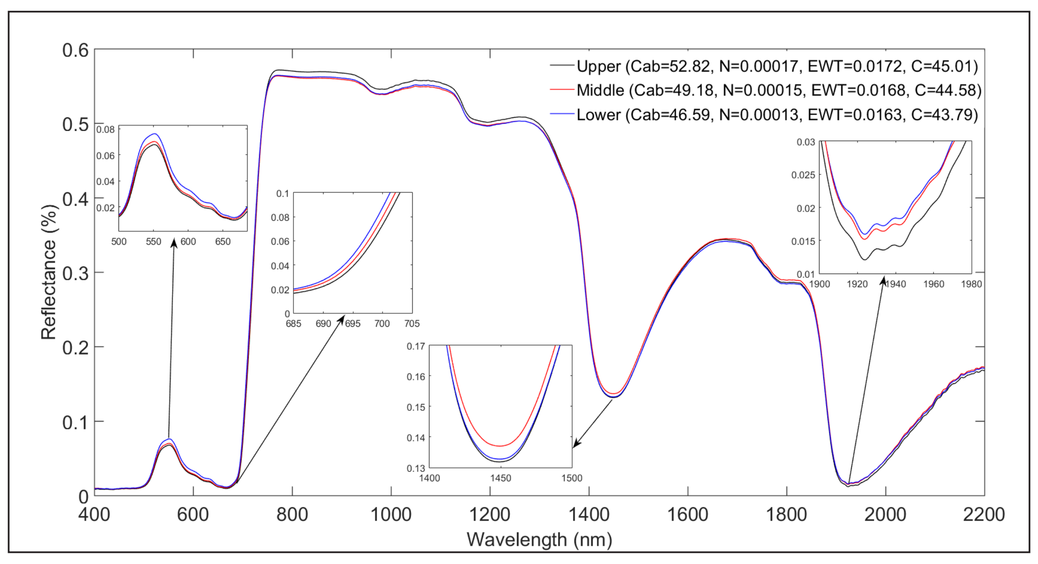

Figure 3: Mean leaf spectral reflectance at each canopy position. Note that the red edge shifts to longer wavelengths with increasing chlorophyll and nitrogen.

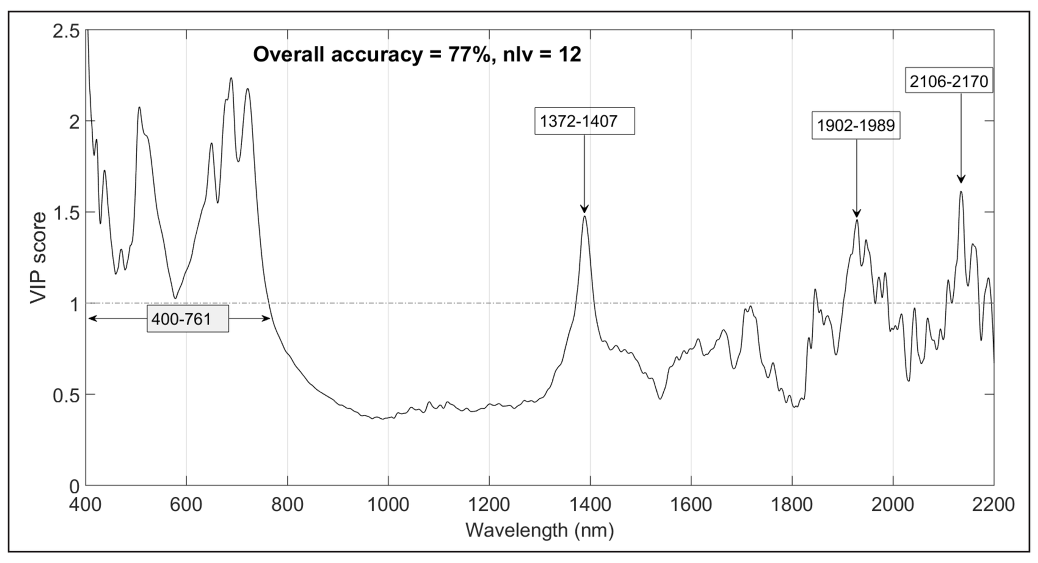

Figure 5: Key wavelengths for leaf samples discrimination based on the PLS-DA VIP score.

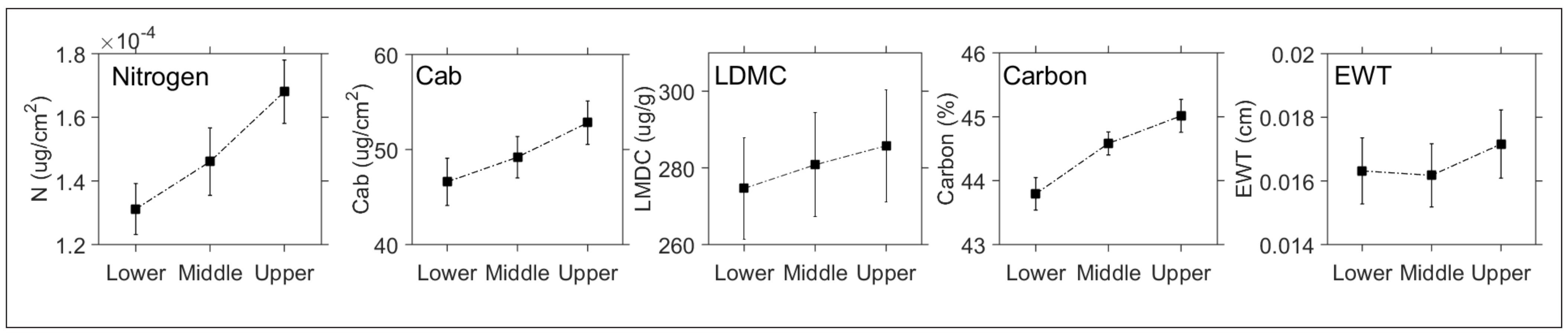

Figure 4: Variation in leaf functional traits across the vertical canopy profile. Error bars represent standard errors.

Table 1: Contingency matrix obtained from the PLS-DA classification.

	Lower	Middle	Upper	PA
Lower	30	3	7	75
Middle	5	29	6	72.5
Upper	2	5	33	82.5
UA	81.1	78.4	71.73	

n=120, nlv = 12 , Overall accuracy = 76.67%

Conclusion

1.Results demonstrated the capability of leaf spectra to track variability in leaf traits across the canopy vertical profile.
2.Key wavebands (400-761,1372-1407,1902-1989 and 2106-2170 nm [30.37% of wavebands) that enhance leaf samples discrimination are documented to be sensitive to the chlorophyll, EWT, N, carbon and SLA (Curran, 1989). Our results imply that failure to account the vertical heterogeneity in key traits across the vertical canopy profile can potentially lead to considerable inaccuracies in upscaling leaf traits to canopy level, canopy reflectance modelling and subsequent canopy traits retrieval.

References

Chen, J.-L., Reynolds, J., Harley, P. & Tenhunen, J. 1993. Coordination theory of leaf nitrogen distribution in a canopy. Oecologia, 93, 63-69.
Curran, P. J. 1989. Remote sensing of foliar chemistry. Remote Sensing of Environment, 30, 271-278.
Skidmore, A. K., Pettorelli, N., Coops, N. C., Geller, G. N., Hansen, M., Lucas, R., Mücher, C. A., O'Connor, B., Paganini, M., Pereira, H. M., Schaepman, M. E., Turner, W., Wang, T. & Wegmann, M. 2015. Environmental science: Agree on biodiversity metrics to track from space. Nature, 523, 403-405.

For more information

Tawanda W Gara (t.w.gara@utwente.nl); Roshanak Darvishzadeh (r.darvish@utwente.nl); Andrew K. Skidmore (a.k.skidmore@utwente.nl);
Tiejun Wang (t.wang@utwente.nl)
Faculty of Geo-Information Science and Earth Observation (ITC),
University of Twente, Enschede, The Netherlands
P.O. Box 217, 7500 AE, Enschede, The Netherlands

UNIVERSITY OF TWENTE.

ITC