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Discrimination of liana and tree leaves from a Neotropical Dry Forest using visible-near infrared and longwave infrared reflectance spectra

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ABSTRACT

Increases in liana abundance in tropical forests are pervasive threats to the current and future forest carbon stocks. Never before has the need been more evident for new approaches to detect the presence of liana in ecosystems, given their significance as fingerprints of global environmental change. In this study, we explore the use of longwave infrared reflectance (LWIR, 8–11 μm) as a wavelength region for the classification of liana and tree leaves and compare classification results with those obtained using visible-near infrared reflectance data (VIS-NIR, 0.45–0.95 μm). Twenty sun leaves were collected from each of 14 liana species and 21 tree species located at the canopy or forest edge (n = 700) in Santa Rosa National Park, Costa Rica. LWIR and VIS-NIR reflectance measurements were performed on these leaves using a portable calibrated Fourier Transform Infrared Spectroscopy (FTIR) Agilent ExoScan 4100 and a UniSpec spectral analysis system, respectively. The VIS-NIR and LWIR data were first resampled. Then these two spectral libraries were pre-processed for noise reduction and spectral feature enhancement resulting in three datasets for each spectral region as follows: filtered only, filtered followed by extraction of the first derivative, and continuous wavelet transformation (CWT). Data reduction was then applied to these data sets using principal components analysis (PCA). The outputs obtained from the PCA were used to conduct the supervised classification of liana and tree leaves. In total, 21 classifiers were applied to datasets of training and testing to extract the classification accuracy and agreement for liana and tree leaves. The results suggest that the classification of leaves based on LWIR data can reach accuracy values between 66 and 96% and agreement values between 32 and 92%, regardless of the type of classifier. In contrast, the classification based on VIS-NIR data shows accuracy values between 50 and 70% and agreement values between 0.01 and 40%. The highest classification rates of liana and tree leaves were obtained from datasets pre-processed using the CWT or from the extraction of the first derivative and classified using either random forest, *k*-nearest neighbor, or support vector machine with radial kernel. The results using the LWIR reflectance highlight the potential of this spectral region for the accurate detection of liana extent in tropical ecosystems. Future studies should consider this potential and test the regional monitoring of lianas.

1. Introduction

Lianas -woody vines- are a diverse and abundant group of plants with a pivotal role in the structure and dynamics of tropical forest (Rodríguez-Ronderos et al., 2016; Sánchez-Azofeifa et al., 2017; Schnitzer and Bongers, 2011). In general, more than ~24% of plant species richness in many tropical forests is represented by lianas (Gentry, 1991). This group of plants is considered a non-self-supporting structural parasite (see Stewart and Schnitzer, 2017 discussion of their categorization) that uses host trees to reach the forest canopy (see Fig. S1 for a graphic representation). Compared to trees, lianas tend to have a higher proportion of photosynthetic biomass per whole-plant biomass which contributes significantly to the interception of light and consequently to carbon storage (Durán et al., 2015; Rodríguez-Ronderos et al., 2016; van der Heijden et al., 2015; Wyka et al., 2013). Several studies have reported a notable increase in liana abundance in tropical and temperate environments (DeWalt et al., 2010; Londré and Schnitzer, 2006; Phillips et al., 2002; Schnitzer, 2015, 2005). Likewise, other studies have shown significant detrimental effects by lianas on tree recruitment, growth, survival, and carbon stock (Durán and Gianoli, 2013; Martínez-Izquierdo et al., 2016; Schnitzer and Carson, 2010). These trends bring into question the accuracy of productivity models and highlight the need to document the footprint of lianas and understand their role in the dynamics of ecosystems (Verbeeck and

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Kearsley, 2016).

To better understand the implications of lianas on ecosystems, new technologies need to be exploited that enhance the detection of this life form in the landscape. In this regard, unmanned aerial vehicles, airborne, and satellite technologies that remotely sense canopy reflectance properties may provide feasible solutions to monitor liana cover on trees over large scales. Currently, several studies have addressed the differences in optical properties of lianas and trees from leaf and canopy observations (Asner and Martin, 2011; Avalos et al., 1999; Castro-Esau et al., 2004; Foster et al., 2008; Hesketh and Sánchez-Azofeifa, 2012; Kalacska et al., 2007; Marvin et al., 2016; Sánchez-Azofeifa et al., 2009; Sánchez-Azofeifa and Castro-Esau, 2006). Most of these studies were conducted using reflectance spectra encompassing the visible, near, and short-wave infrared regions (VIS-NIR-SWIR, 380–2500 nm) where spectral signatures of lianas and trees are separable. In these regions, liana and tree leaves tend to differ in their reflectance near 535, 688, 985, and 2252 nm due to the lower concentration of carotenoids and chlorophyll, the lower leaf thickness, and the higher leaf water content of liana leaves (Kalacska et al., 2007; Sánchez-Azofeifa et al., 2009). However as pointed out by Hesketh and Sánchez-Azofeifa (2012), seasonal or phenological effects on the reflectance of leaves for both life forms can have important implications for their automated classification across seasons. These effects can be associated with environmental drivers that may affect the allocation and removal of mobile compounds (i.e. pigments) and the water content of leaves.

The longwave infrared spectrum (LWIR, 8–14 μm) has not been explored for the separation of liana and tree leaves. LWIR investigations of trees and their leaves have shown that the spectra of leaves are controlled primarily by structural compounds at the leaf surface (Harrison et al., 2018; Ribeiro da Luz and Crowley, 2007). These compounds include cellulose, hemicellulose, cutin, silica, and terpenes imparting reflectance features that enhance the separability of species (Buitrago et al., 2018; Harrison et al., 2018; Meerdink et al., 2016; Ribeiro da Luz, 2006; Ribeiro da Luz and Crowley, 2010, 2007; Ullah et al., 2012a). This spectral region may be characterized by lower temporal variability of leaf spectral signatures as suggested from limited data by the seminal work of Salisbury (1986) comparing LWIR signatures of green leaves from late autumn and senescent leaves. This body of work suggests that LWIR signatures may not be significantly affected by seasonal or phenological effects. If these results apply to a wide range of biomes, detection in the LWIR would present a unique remote sensing advantage. An additional advantage of working in this region for the discrimination of lianas and trees rests on the observation that these life forms present contrasting leaf concentrations of lignin, cellulose, and hemicellulose (Asner and Martin, 2012, 2011) that may be detected in LWIR spectra of plants.

This study assesses the use of the VIS-NIR and LWIR spectral region for the discrimination of liana and tree leaves. We hypothesize that LWIR reflectance spectra of leaves may provide better discrimination of the two life forms. Because the pre-processing of spectral data may affect the spectral classification and its role in enhancing spectral features has been shown to improve spectral separability (Harrison et al., 2018; Rivard et al., 2008), this study also evaluates the impact of three common pre-processing methods in improving the classification of the two life forms. In addition, we evaluate 21 supervised-classifiers for the discrimination of liana and tree leaves. We do so to explore the quality of discrimination of some classifiers or "classifier families" in a field increasingly driven by data classification (Fernández-Delgado et al., 2014). We do not aim to identify the "best" classifier; our goal is to provide a broad perspective of considerations for future studies involving the classification of spectral libraries. This study highlights the LWIR region for future detection of these life forms in forests with the future aim to further understand the current role of lianas in ecosystem functioning.

2. Materials and methods

2.1. Study site and sample collection

This study was conducted in the Santa Rosa National Park (SRNP, 10°48″ N, 85°36″ W) located on the Pacific coast of northwestern Costa Rica. The SRNP is in a tropical dry forest (Sánchez-Azofeifa et al., 2005). This site presents a wet-season extending from the middle of May to late November while a dry-season, during which most of the trees lose their leaves, encompasses the remaining months (Kalacska et al., 2004). This site has an air temperature that varies from 26 °C in the wet-season to 29 °C in the dry season, and has a mean annual precipitation of 1720 mm (Kalacska et al., 2004). The SRNP is composed of a mosaic of forest patches in different successional stages of natural regeneration and with different land-use histories associated with anthropogenic fires, deforestation, and land clearing for pasture and agriculture (Arroyo-Mora et al., 2005; Calvo-Alvarado et al., 2009; Sánchez-Azofeifa et al., 2017). The SRNP has 96 species of trees of different life history (Hilje et al., 2015) and approximately ~18 species of lianas that can reach the forest canopy. The abundance and height of trees in the canopy depends on the successional stage of the forest patches (Hilje et al., 2015; Li et al., 2017).

Fully exposed sun leaves of 14 species of lianas and 21 species of trees (Table 1) were collected during the wet-season of 2017 between the months of May and July. Leaves were sampled in the forest canopy or at the forest edge using an extension pruner. For each species, five healthy and mature leaves were collected from each of four individuals for a total of 700 leaves. The number of individuals and leaves selected were based on the variability of the LWIR reflectance of tree leaves in prior research at our study area (Harrison et al., 2018) and the spatial distribution of individuals with low abundance. Leaves were then placed in moist paper and immediately stored in sealed plastic bags that were placed in a cooler and taken to the laboratory for collection of VIS-NIR and LWIR reflectance spectra within 2 h. Despite the importance of the shortwave infrared region (SWIR, 1.1–2.6 μm) for the discrimination of liana and tree leaves (Kalacska et al., 2007), we do not conduct measurements in the SWIR region because we did not have a spectrometer with that spectral range at the time we were in the field.

Table 1
Liana and tree species sampled at the Santa Rosa National Park, Costa Rica.

Trees		Lianas	
Family	Species	Family	Species
Apocynaceae	*Stemmadenia obovata*	Apocynaceae	*Forsteronia* sp.
Bignoniaceae	*Crescentia alata*		*Forsteronia spicata*
Burseraceae	*Bursera simarouba*	Bignoniaceae	*Arrabidaea chica*
Dilleniaceae	*Curatella americana*		*Cydista aequinoctialis*
Euphorbiaceae	*Jatropha curcas*		*Cydista diversifolia*
	Sapium glandulosum		*Paulinia* sp.
Fabaceae/Caes	*Bauhinia ungulata*	Cucurbitaceae	*Cayaponia racemosa*
	Hymenaea courbaril	Dilleniaceae	*Tetracera volubilis*
Fabaceae/Pap	*Gliricidia sepium*	Malpighiaceae	*Heteropterys panamensis*
Fagaceae	*Quercus oleoides*		*Heteropterys* sp.
Hippocrateaceae	*Semialarium mexicanum*		*Hiraea reclinata*
Lauraceae	*Ocotea veraguensis*	Rhamnaceae	*Gouania polygama*
Malpighiaceae	*Byrsonima crassifolia*	Sapindaceae	*Serjania atrolineata*
Malvaceae	*Guazuma ulmifolia*		*Serjania schiedeana*
Meliaceae	*Cedrela odorata*		
	Trichilia americana		
Nyctaginaceae	*Pisonia aculeata*		
Sapindaceae	*Cochlospermum vitifolium*		
Simaroubaceae	*Simarouba glauca*		
Tiliaceae	*Luehea speciosa*		
Verbenaceae	*Rehdera trinervis*		