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Differentiation of Tropical Tree Species with Leaf Measurements of Hyperspectral Reflectance †

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Abstract: The development of non-destructive indicators of leaf-level hyperspectral reflectance is the first step in mapping endangered tree species in the tropics. Therefore, hyperspectral reflectance at the leaf level was implemented to differentiate 15 tree species from Costa Rica's forests. The hyperspectral reflectance (310 to 1100 nm) was evaluated in six individuals per species (30 leaves per individual) in the rainy season. In addition, the specific leaf area (SLA) and leaf thickness (LT) were evaluated. The data were first analyzed by one-way ANOVA to identify differentiating bands between species. Then, linear discriminant analysis (LDA) was used to classify the species and define the degree of similarity, and the contribution of each narrow band to the classification was estimated with the absolute value of the standardized coefficients associated with the discriminant function (kappa value). Subsequently, we determined whether the SLA or LT correlated with the species differentiation. The results showed that the wavebands al 350, 700, 750, 780, 790, 800, and 1010 nm were key to differentiating the species, with an average kappa value of 0.88. Furthermore, the correlation of the hyperspectral reflectance with the SLA and LT was ruled out. Our results suggest the value of differentiating tropical tree species through non-destructive methods, which can facilitate the mapping of endangered populations and the development of conservation strategies.

Keywords: conservation; tree; species; tropics

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1. Introduction

The tropical forests in Costa Rica have more than 2000 species of identified trees organized on the national territory [1]. Many of these species have been little studied due to the lack of funding for research, the degree of complexity of the studies, and the fact that multiple evaluation campaigns by individuals in the field are required [2]. Of the influential aspects, most studies have focused on the evaluation of the biological aspects of rapid domestication [3], including botanical characterization, growth, abundance, and ecological dynamics [4].

The development of non-destructive indicators that can be used to differentiate tree species is the key to improving our knowledge of the distribution of populations and the ecological response to the phenomenon of climate change [5]. An option that has been shown to have viability is the hyperspectral reflectance of leaves [6]. It has been shown that in the range of 300 to 1100 nm, it is possible to acquire information on photosynthetic capacity, hydric stress, carotenoids, and chlorophyll production in real time, without affecting the individual [7].

Clark et al. [7] found that the signature is unique among 20 tropical species and suggested that the range from 540 to 600 nm is the point of differentiation for each species due to the availability of nitrogen. On their part, Ballanti et al. [8] determined the hyperspectral differentiations between 300 and 370 nm of three species of the Eucalyptus genus, as well as those from 530 to 580 nm, allowing the species to be differentiated with aerial multiband images, which facilitated the quantification and distribution of individuals in northern Australia. The potential uses of the spectral signature are wide-ranging. It can be used to differentiate species and understand the degree of health or nutrition of plants, since the shape of the curve is governed by the effects of the absorption of chlorophyll and other pigments of the leaves of the plant [9]. The study analyzed the differentiation of 15 tropical tree species through spectral reflectance at the leaf level.

2. Materials and Methods

The study analyzed 15 tropical species from Costa Rica (Table 1). They were selected based on their productive commercial interest or relevance in regard to conservation, and the selection criteria are detailed in Valverde et al. [10]. For each species, five individuals were analyzed and characterized as being unaffected by pathogens, water, or nutritional stress that affected their growth. In total, 30 leaves were selected per individual, and it was considered that they were partially or totally exposed to light and did not show damage or atypical colors in comparison to the rest of the treetop (n = 150 leaves per species).

Table 1. Differentiating bands of spatial reflectance, average kappa value, and Pearson correlation values of the bands with the SLA (specific leaf area) and LT (leaf thickness) for 15 tropical tree species (ns: no significative, * $p > 0.05$ and ** $p > 0.01$).

Botanical Family	Scientific Name	Diferenciative Bands (nm)	Kappa Value	*p*-Value	Correlation	
					SLA	LT
Bignoniaceae	*Handroanthus ochraceus*	350	0.90	0.001 **	0.22 ns	0.33 ns
Meliaceae	*Swietenia macrophylla*	700	0.88	0.001 **	0.26 ns	0.20 ns
Fabaceae	*Platymiscium pinnatum*	350, 780	0.92	0.001 **	0.33 ns	0.19 ns
Araliaceae	*Dendropanax arboreus*	780, 790	0.91	0.001 **	0.50 ns	0.10 ns
Fabaceae	*Inga marginata*	350, 800	0.89	0.002 **	0.33 ns	0.36 ns
Fabaceae	*Erythrina poeppigiana*	800	0.89	0.001 **	0.40 ns	0.41 ns
Apocynaceae	*Tabernaemontana litoralis*	800, 1010	0.92	0.001 **	0.26 ns	0.55 ns
Anacardiaceae	*Anacardium excelsum*	700, 1010	0.96	0.001 **	0.30 ns	0.56 ns
Meliaceae	*Trichilia havanensis*	800	0.95	0.003 **	0.33 ns	0.20 ns
Euphorbiaceae	*Croton draco*	350, 800, 1010	0.97	0.001 **	0.36 ns	0.14 ns
Euphorbiaceae	*Cronton niveus*	350	0.90	0.003 **	0.33 ns	0.33 ns
Solanaceae	*Acnistus arborescens*	750, 780	0.91	0.002 **	0.26 ns	0.40 ns
Verbenaceae	*Citharexylum donnell-smithii*	700, 800, 1010	0.92	0.004 **	0.21 ns	0.50 ns
Meliaceae	*Cedrela tonduzii*	1010	0.89	0.008 **	0.22 ns	0.56 ns
Rubiaceae	*Tocoyena pittieri*	750	0.88	0.005 **	0.20 ns	0.66 ns

Then, the characteristics were measured, including the leaf thickness (LT, with a micrometer), specific leaf area (SLA, with Valverde's [11] methodology), and leaf spectral reflectance, assessed with the UNISPEC SC hyperspectrometer model (with a range from 310 to 1130 nm and a minimum resolution of 3 nm). The statistical analysis was based on a mixed model, first using an analysis of variance (ANOVA) to identify the band lengths that showed significant differentiations, and later using a linear discriminant analysis (LDA) to classify the species and define the degree of similarities, following the methodology of [12]. The discrimination coefficient for each species (kappa value) was estimated and, subsequently, a Pearson correlation analysis was used to assess whether there was a correlation with the LT and SLA. The analyses were performed in the R program, with a significance of 0.05.

3. Results and Discussion

Significant differences were found in the 350, 500, 780, 790, 800, and 1010 nm bands (Table 1). Seven species showed only one significant differential band. In contrast, six species showed two differentiating bands, and only two species showed differentiation in three hyperspectral bands. For all the species, a discriminatory analysis kappa value greater than 0.88 was obtained, which evidenced the good accuracy of the differences between the species with respect to the specific points of the spectral signature. However, it was observed that the differentiation did not show a significant correlation with the SLA and LT, suggesting that neither variable has an influence role when identifying the species with this method.

The results obtained indicate the potential use of hyperspectral reflectance for species discrimination, a result similar to that proposed by Burkholder et al. [13], who found an accuracy between 60 and 85% for the tree species. The use of specific bands has traditionally been used for the development of indicators of hydric stress, chlorophyll production, and photokinetic production, among others [14]. However, its use to differentiate species has been limited to species in the tropics. The identification and differentiation of spectral bands by species at the leaf level is the first scaling step required to create identifiers so as to analyze populations through satellite images and flights with spectral cameras [15].

In addition, the use of techniques such as machine learning, deep learning, or neural networks can enable the development of highly accurate, non-destructive models. However, the limitations of tree hyperspectral collections (quantity and quality) and the financing for this type of research in the tropical region have limited their scale of use. This is an aspect that should be reconsidered, given the potential use of these techniques for the monitoring of species in danger of extinction or those vulnerable to climate change.

4. Conclusions

The development of non-destructive methods that can be used to identify and differentiate tropical tree species is key to understanding population dynamics in the context of climate change. The results obtained are a first step in the use of a system that can be scaled at the canopy level and connected with geographic information systems, which opens the door to the development of the spatiotemporal monitoring of species considered in danger of extinction or endemics.

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