Remote Sensing of Environment 158 (2015) 15–27

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Quantifying forest canopy traits: Imaging spectroscopy versus field survey

Gregory P. Asner *, Roberta E. Martin, Christopher B. Anderson, David E. Knapp

Department of Global Ecology, Carnegie Institution for Science, 260 Panama Street, Stanford, CA 94305, USA

ARTICLE INFO

Article history:
Received 16 June 2014
Received in revised form 13 November 2014
Accepted 14 November 2014
Available online xxxx

Keywords:
Amazon basin
Canopy chemistry
Carnegie Airborne Observatory
Chemometrics
Data fusion
Hyperspectral
LiDAR
Tropical forest

ABSTRACT

Spatial and temporal information on plant functional traits are lacking in ecology, which limits our understanding of how plant communities and ecosystems are changing. This problem is acute in remote tropical regions, where information on plant functional traits is difficult to ascertain. We used Carnegie Airborne Observatory visible-to-shortwave infrared (VSWIR) imaging spectroscopy with light detection and ranging (LiDAR) to assess the foliar traits of Amazonian and Andean tropical forest canopies. We calibrated and validated the retrieval of 15 canopy foliar chemicals and leaf mass per area (LMA) across a network of 79 1-hectare field plots using a new VSWIR-LiDAR fusion approach designed to accommodate the enormous scale mismatch between field and remote sensing studies. The results indicate that sparse and highly variable field sampling can be integrated with VSWIR-LiDAR data to yield demonstrably accurate estimates of canopy foliar chemical traits. This new airborne approach addresses the inherent limitations and sampling biases associated with field-based studies of forest functional traits, particularly in structurally and floristically complex tropical canopies.

© 2014 Elsevier Inc. All rights reserved.

1. Introduction

Plant functional diversity expresses many ecological processes ranging from natural selection to CO_2 exchange between the biosphere and atmosphere. Despite its central importance to evolutionary and ecological research, our knowledge of plant functional diversity remains very limited in space and time. Specifically, a major knowledge gap has developed between small-scale field studies (≤1 ha) of plant functional traits and broad-scale, remotely sensed estimates of vegetation properties. On the one hand, field studies provide an understanding of the inter-relationships between functional traits, and the ways that plants express those traits. In contrast, remotely sensed data from satellites have proven reliable for estimating changes in vegetation cover and structure, with far less success in measurements of functional diversity.

This scale-gap in functional ecology is exemplified in Amazonian forests. For example, an array of tree- and plot-scale studies have been undertaken to assess an important aspect of plant functional diversity — canopy chemistry (e.g., Cuevas & Medina, 1988; Fyllas et al., 2009; Reich, Ellsworth, & Uhl, 1995), yet collectively the literature has provided little spatial information on the chemical diversity of Amazon forest communities. Moreover, field-based foliar trait studies are highly susceptible to the contributions of mostly unknown, spatially-explicit environmental filters like the underlying geology and soils, and variable biological and structural diversity within and across communities, which when combined, may limit our understanding of plant functional diversity and assembly. Only one study has sampled the many thousands of Amazonian tree species required to resolve an assembly pattern of canopy chemical traits (Asner, Martin, et al., 2014), but like all other field studies, it could not provide spatially detailed information. As a result, potential changes in tropical forest functional patterns continue to go unobserved, with cascading limitations on our ability to model future changes in forest composition and functional processes (Simonson, Coomes, & Burslem, 2014).

In contrast to the limitations of field studies, remote sensing of Amazonian forests has provided spatially contiguous information over time, but the information has mostly been limited to forest cover, deforestation and disturbance (e.g., Achard et al., 2014; Souza, Roberts, & Cochrane, 2005). Far fewer studies have considered forest biomass and phenology (e.g., Baccini et al., 2012; Samanta et al., 2010), or plant community composition (Chambers et al., 2007; Tuomisto et al., 2003). None have quantitatively mapped forest canopy chemistry, leaving us with no direct way of linking leaf studies to large-scale processes or environmental gradients throughout the region.

Quantification of canopy chemical patterns in Amazonian ecosystems is needed to advance our understanding of functional biogeography, and to observe functional change over time. Given the enormous geographic extent of the Amazon region, remote sensing will be the only way to develop an understanding of changing functional diversity. However, remote sensing ultimately requires a connection to field

* Corresponding author. Tel.: +1 650 325 1521.
E-mail address: gpa@carnegiescience.edu (G.P. Asner).

http://dx.doi.org/10.1016/j.rse.2014.11.011
0034-4257/© 2014 Elsevier Inc. All rights reserved.

measurements for purposes of calibration, validation and interpretation. Like most tropical forest regions, Amazonia presents a great challenge to pair field measurements with remotely sensed data (Fig. 1). Bear in mind that these forest canopies reach 40 or more meters in height on variable terrain, and are found in structurally complex assemblages comprised of thousands of species, often with no two locally neighboring trees of the same species. It is simply infeasible to sample enough of the canopy — whatever the trait of interest — in a way that directly links field and remotely sense data at a scale commensurate to large-area mapping applications. We need new remote sensing techniques that are compatible with the relatively sparse way that forests are sampled in the field.

Here we focused our functional trait work on a wide variety of forest canopy chemical compounds synthesized in leaves to support multiple, interdependent functional processes. Chlorophylls and carotenoids facilitate light capture and photo-protection. Nitrogen (N) and phosphorus (P) are required for carbon fixation, growth metabolism and nucleic acids. Metabolic elements like rock-derived macronutrients (e.g., Ca, K, Mg) and micronutrients (e.g., B, Fe) support multiple leaf functions such as carbon allocation (Demarty, Morvan, & Thellier, 1984). Soluble carbon (C) — comprised of sugars, starch and pectin — is synthesized as the initial energy store for the plant (Chapin, 1991; Evans, 1989). Leaf structural compounds including lignin and cellulose are generated to support strength and longevity, and to decrease palatability to herbivores (Melillo, Aber, & Muratore, 1982). In tropical canopies, phenolic compounds are synthesized primarily for chemical defense of leaves (Coley, Kursar, & Machado, 1993). Light capture and growth chemicals are also coordinated with variation in leaf mass per

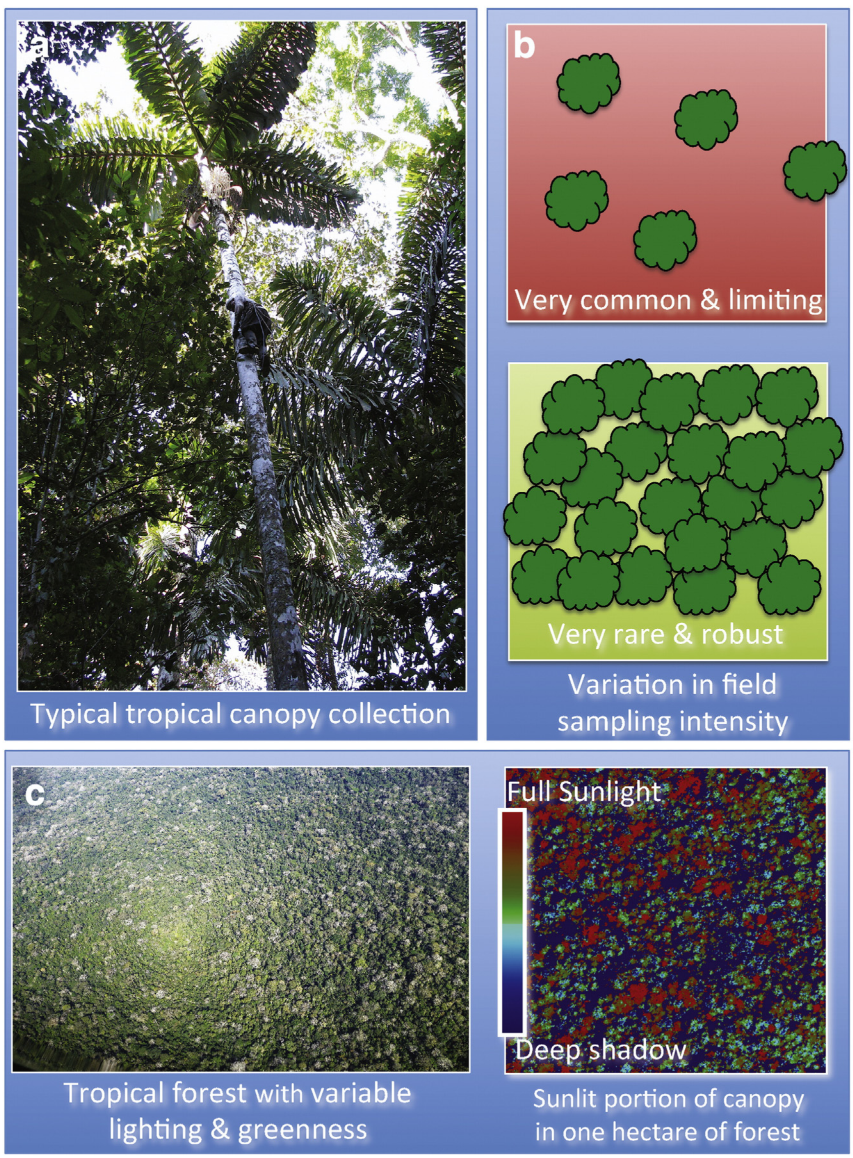

Fig. 1. There exists a fundamental mismatch between field and remote sensing studies of forest canopy traits. In tropical forests, which contain thousands of species coexisting as very tall canopies, and often in complex terrain and remote regions, fieldwork must necessarily be carried out in a tactical or selective fashion. Major sampling trade-offs exist at regional, landscape, plot, tree, branch and leaf levels. (a) In the case of canopy chemistry, individual trees such as this palm are climbed, and foliage from one or more branches is laboriously collected for transport and analysis in laboratories. (b) Field plots are sampled, often sparsely, due to issues of limited canopy access, as well as to control for vertical light gradients in the canopy that add uncertainty to canopy trait studies. Field sampling intensity, as shown here, may vary widely from plot to plot, from commonly sparse to rarely complete inventory. (c) From above, aircraft and satellite remote sensing instruments are also challenged by highly variable illumination conditions that are convolved to variable canopy structure. Additionally, some portions of most forest canopies are leafless at the time of observation, as shown in gray crowns in the aerial photography. Methods are needed to bridge the huge gap between the realities of field collection and those of remote sensing observations.

Download English Version:

https://daneshyari.com/en/article/6346219

Download Persian Version:

https://daneshyari.com/article/6346219

Daneshyari.com