Foliar Traits from Imaging Spectroscopy: What Foliar Traits Tell Us and How We Get There

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Motivation: Remote sensing provides the information we need to gap-fill other data sources: Diversity and Function of Ecosystems
What are plants doing?
What’s different among plants?
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What are foliar functional traits and why do we care?
What are plants doing?
What’s different among plants?

Photosynthesis
$\text{CO}_2 \rightarrow \text{carbohydrates}$

- Nitrogen
- Leaf Mass per Area (LMA)
- Sugars and Starches
- Chlorophyll, Pigments
- Water
- P, K, Ca, Mg

Decomposition
- Structural Compounds
- Lignin
- Cellulose

Defense
- Tannins
- Phenolics

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What are the causes?
How will plants respond to change?

Species
Diversity

Foster & Townsend 2005
What are plants doing?
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Species Diversity

Genotype Evolutionary Drivers (selection & phylogeny)

Foster & Townsend 2005

Mereiles, Cavender-Bares et al.

Madritch et al. 2014
What are plants doing?
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Species
Diversity

Genotype
Evolutionary Drivers (selection & phylogeny)

Phenotype
Environment
Remote sensing of canopy chemistry and nitrogen cycling in temperate forest ecosystems

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Wessman et al. 1988
Remote sensing of canopy chemistry and nitrogen cycling in temperate forest ecosystems

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Wessman et al. 1988
Matson et al. 1994

Martin and Aber 1997
Net Primary Productivity (NPP)
Bartlett Forest, NH

- Upper elevation Spruce-Fir forest (850 m)
- Early successional (~30 years) forest (504 m)
- Sugar Maple-Beech forest (~60 years), fine till soils (540 m)
- NPK Fertilizer (1983-1999)
- Hemlock-Spruce-Mixed Deciduous forest (200 m)

NPP (g m⁻² yr⁻¹)
- > 1300
- < 700

Asner and Vitousek 2005

Smith et al. 2002; Ollinger et al. 2005

1980s → 1990s → 2000s → 2010s → Now
models and data-gaps example, advances in macroevolutionary theory provides several relevant opportunities. For instance, traits and associated functions are in disparate (and often geographically distant) lineages evolution. Convergent evolution has pulled lineages together, enabling researchers to trace the evolutionary history of plant traits within the framework of a 'complete tree of life' for plants is becoming ever more exact and interpretable. The global phylogeny ('tree of life') can tell us about the distribution of traits for species lacking observations. Though not yet comprehensive, other sensors capture global spatial data on key functional attributes in time, including leaf mass per area (LMA), nitrogen concentration (N) and non-structural carbohydrates (NSC), among others. Although for some traits and functions convergent evolution has pulled lineages together, enabling researchers to trace the evolutionary history of traits for species lacking observations. The number of FLUXNET sites is now more than 100,000, and the data has now been collected on ecosystem vertical structure at the canopy scale. In combination, this extensive data can connect with trait, evolutionary and spatial biodiversity observations from the top layer of vegetation. Spectroscopic trait measurements combined with LiDAR (Light Detection and Ranging) imagery can enhance the ecological interpretation of plant functional biodiversity. Similarly, LiDAR data on ecosystem vertical structure at different spatial resolutions may dramatically improve the interpretation of trait diversity. Other sensors (such as LiDAR) may also contribute measurements. An informatics infrastructure and appropriate modelling techniques connect this information with trait, evolutionary and spatial biodiversity appropriate for the individual traits that make up overall plant functional diversity. Further, the strong phylogenetic signal in traits for species lacking observations, coupled with increasingly complete phylogenies, can allow for the prediction of traits for species lacking observations. In situ spectroscopy and LiDAR techniques can also connect plant structural components and thus readily provide a means to both directly and indirectly connect, through models, spectral information collected worldwide with traits observed from space. The envisioned 'global biodiversity observatory' (bottom) is an example of how in situ spectroscopy and LiDAR techniques can be integrated into a comprehensive biodiversity monitoring framework. The figure was created by the graphics team at the Jet Propulsion Laboratory. The figure and caption edits are approved.

Table 1: Key functional plant traits that are remotely observable from space (see Supplementary Table 4).

<table>
<thead>
<tr>
<th>Trait definition</th>
<th>Trait role (refs)</th>
<th>Remote observation (refs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf mass per area</td>
<td>A primary axis of the global leaf economics spectrum</td>
<td>34,35,68–70</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>Involved in the xanthophyll cycle for dissipating excess energy and avoiding oxygen radical damage under stress</td>
<td>78,79,82,83</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>Responsible for capturing light in the process of photosynthesis</td>
<td>67,71,72</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>Orange and yellow pigments</td>
<td>76,77</td>
</tr>
<tr>
<td>Non-structural carbohydrates</td>
<td>Direct products of photosynthesis (sugars and starches), not yet incorporated into plant structural components</td>
<td>68,69</td>
</tr>
</tbody>
</table>

Legend: GPP, total carbon storage, and FLUXNET sites.
Quantifying forest canopy traits: Imaging spectroscopy versus field survey

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

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Airborne laser-guided imaging spectroscopy to map forest trait diversity and guide conservation

G. P. Asner,1 R. E. Martin,1 D. E. Knapp,1 R. Tupayachi,1 C. R. Anderson,1 F. Sinca,1 N. R. Vaughan,1 W. Llactayo3

1980s → 1990s → 2000s → 2010s → Now
Dubois et al. 2018
Where are we now?

- **Strong foundation of science** and application make SBG/HyspIRI a low risk/high reward mission
- Spatial, temporal, spectral resolution \(\rightarrow\) functional resolution
- Address urgent questions about Earth’s biosphere, and model phenotypic, genotypic, and ecological community response to environmental / climate change
- Are we ready?
Draft Workflow

Operational with AVIRIS
Preliminary Results

- Traits observable by SBG / HISUI
- AVIRIS Classic on ER-2

Townsend et al. in prep., Singh et al. 2015; figure by Fabian Schneider
Emerging tools for synthesis and implementation

Data Life Cycle

EcoSIS.org – get your DOI, archive spectral data and measurements

EcoSML.org

Spectral Model Library

HyTools workflow

https://github.com/EnSpec/HyTools-sandbox
Networks for calibration and validation
Note need for data from tropics, Arctic
Sentinel-2: 100*100 km

NEON AOP: 10*10 km
Mapping of Plant Functional Diversity

Leaf Biochemistry from Spectroscopy

Canopy Structure from LiDAR

Physiological Diversity

Morphological Diversity

Schneider, et al. (2017) Nature Communications
We’ve come a long way. It’s time to use this information globally, and to have time series, look at phenology.

We can measure vegetation function and its variation.

The community will use these data.
Thank you!
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