Linking forest function, disturbance and watershed ecology using field measurements and imaging spectroscopy

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Overview:

Our research is focused on assessing three traits associated with forest foliar biochemistry and function -- cell structure, shade tolerance, recalcitrance -- using field measurements and hyperspectral imagery (Table 1).

Our work has involved intensive field sampling of forests across environmental and ecological gradients related to species composition, functional strategies, climate and disturbance regimes.

We link the field and laboratory measurements to image spectra via modeling with field spectroscopic measurements. The spatial measurements derived from AVIRIS imagery will then facilitate an analysis of the influence of forest functional properties on vegetation productivity and watershed nutrient cycling.

Our objective is to develop whole-ecosystem measurements of forest characteristics that relate to the major functions of forests, including nutrient uptake and retention, C accumulation, and maintenance of water quality.

We define **Forest Functional Types** in terms of four measurements related to nutrient cycling strategies of temperate species from Eastern North America (Table 1).

Although differences in these properties are largely related to species, we hypothesize that measurements of these properties can be related directly to spectroscopic measurements at the leaf level and hyperspectral measurements at the canopy level.

We are mapping these variables independent of species composition using NASA AVIRIS and Hyperion imagery.

What are Forest functional types? *FFT = Cs - (S + [R or M]) where:* Table 1

Functional Trait	Physiological trait	Field measurement	Remote sensing measurement	Assumption
Cell structure (Cs)	V_c/V_w = Ratio of leaf volume contained within cell membrane to that within cell wall	W_m = ratio of leaf water mass to leaf dry mass	GA-PLS (Li et al. 2007)	C_s ~= W_m (Shipley et al. 2006)
Shade tolerance (S)	Proportional amount of foliar N allocated to light harvesting	Ratio of Chlorophyll (Chl) to W_m	Chl index (Gitelson et al. 2005)	Chl/C_s ~= shade-tolerance (Niinemets 1997)
Recalcitrance (R)	Amount of lignin invested to retard decomposition	Foliar lignin	PLS regression (Wessman et al 1989)	Lignin slows decomposition (Mellilo et al 1982)
Mycorrhizal symbiosis (M)	Type of mycorrhizae that are feeding nutrients to tree in return for photosynthate	Foliar δN^{15}	PLS regression (Kleinebecker et al. 2007)	Higher foliar δN^{15} ~ Presence of mycorrhizal species capable of organic N uptake (Lilleskov et al. 2002)

Preliminary results 1 — Figure 1

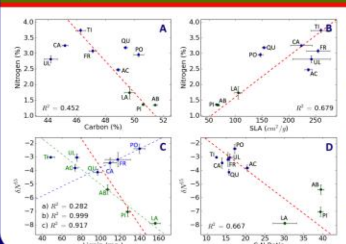


Figure 1. Relationships between key leaf chemical and morphological characteristics related to forest biogeochemical cycling as measured across our study sites.

Legend
- Hardwoods
- Conifers
- Linear model fits to pooled data.
- Linear model fit (b) PO, CA and FR
- Linear model fit (c) TI, UL , AC, QU, AB, PI and LA

Genus codes: AB: *Abies*, AC: *Acer*, CA: *Carya*, FR: *Fraxinus*, LA: *Larix*, PI: *Pinus*, PO: *Populus*, QU: *Quercus*, TI: *Tilia*, UL: *Ulnus*.

Leaf chemical and morphological properties such as nitrogen concentration (%N), lignin (mg), cellulose (mg), and specific leaf area (SLA, cm2 g-1) are key determinants of forest physiology and biogeochemical processes. As such, much of the spatial variability in ecosystem function can be explained by the distribution and proportional biomass of these characteristics within vegetation (Garnier et al. 2004).

Also, measurements of stable isotopes such as δN^{15} have been used increasingly to obtain information on relationships between plants and their environment (Craine et al. 2009). For instance, the δN^{15} ratio of leaves can serve as an integrator of terrestrial N cycling and highlight the adaptive strategies of nitrogen acquisition by plants, as well as indicate how disturbance alters nutrient retention in forests (McLauchlan et al. 2007).

A preliminary analysis of our data (Figure 1) substantiates the evidence for evolved inter-specific differences in resource allocation and retention (Daufresne and Hedin 2005, Shipley et al. 2006) across species and functional groups. For example, we are finding large variation in the carbon concentration in leaves, the foliar C:N, as well as lignin content highlighting the evolved differences in investment of structural versus metabolic compounds and subsequent rates of foliar decomposition between species and functional groups, particularly broadleaf and conifer species (McGroddy et al. 2004).

Study areas:

Linking field measurements to spectra

To characterize forest function (Table 1), we collect samples from sites spanning disturbance and environmental gradients in order to derive measurements of leaf traits related to forest function. Field plots include characterization of species composition, LAI and leaf angle distribution. We collect foliar samples from all levels of the canopy, from which we acquire both fully hydrated green-leaf and dry spectra using an ASD FieldSpec 3 Pro.

In the lab, we measure important leaf properties, including LMA and water content, and for a subset of leaves: C and N concentration, lignin and cellulose, and δN^{15} concentration. We calibrate the larger leaf-level spectral data set based on statistical relationships between the leaf chemical and structural properties and ASD spectra using a novel PLS routine (Figure 2).

Because of the robust relationships between spectra and field measures, this approach greatly reduces the time and effort in the lab required to characterize forest biochemical characteristics (Figures 1, A-D). Leaf level measurements are scaled to the plot based on species composition.

Understory species associations can have measurable influences on foliar chemistry, which in turn, can influence ecosystem response to insect-related disturbances.

Preliminary results 2 — Figure 2

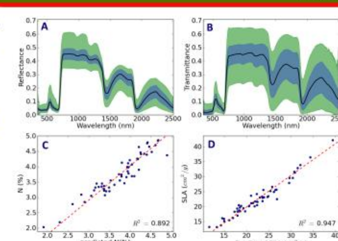


Figure 2 (A, B). Mean ± 1 standard deviation , minimum and maximum leaf reflectance (A) and transmittance (B) for trees sampled within the 14 study sites.

Figure 2 (C, D). Relationships between predicted and observed leaf nitrogen concentration (in %, C) and specific leaf area (SLA, g/m², D) using measured leaf reflectance spectra and a partial least-squares (PLS) regression modeling approach.

Linear model fit to pooled data

The relatively tight coupling between %N and SLA represents the differential allocation of N per unit leaf area across species, with a smaller variation among the more conservative conifer species, and is an indicator of inter-specific variation in photosynthetic capacity (Reich et al. 1998). Finally, we are finding evidence for the linkage between foliar lignin and δ15N which may be an indication of mycorrhizal strategy and/or inorganic N availability (Craine et al. 2009). Furthermore, we are observing that sites containing understory plants with potentially symbiotic N_2-fixing bacteria (Alnus spp.) are falling out of our preliminary trend, which may suggest an altered nutrient budget through increased input nitrogen through of atmospheric N fixation (Vogel and Gower 1998).

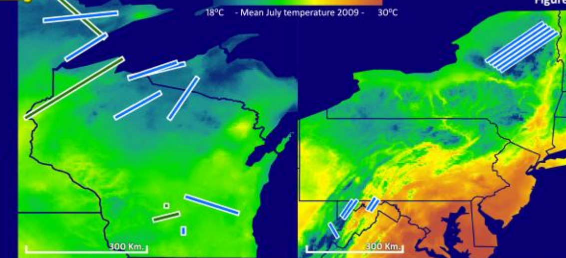
We are observing large variation in leaf optical properties of the trees sampled across the study sites (Figure 2). The large increase in the near-infrared (NIR) reflectance and transmittance is due to scattering of light by the spongy mesophyll and the observed variation is at least partially related to differences in leaf structure (i.e. SLA). Using fresh and dry leaf spectral data we are developing various leaf-level calibrations for several key leaf chemical and structural properties as well as our derived forest functional traits (Figure 2).

Image analysis:

We are scaling the plot level estimates of forest function to hyperspectral imagery. Our field and imagery data cover a wide range of species and environmental gradients (Figure 3). By covering a diversity of forest environments, we are developing generalizable relationships between the field measurements and hyperspectral response. The spatial measurements derived from AVIRIS will then be used to address important questions about forest functioning across the geographic range of our study areas, including:

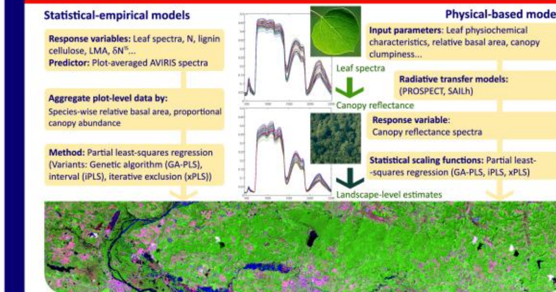
(1) How do variations in forest functional types and climate affect growth (Serbin, Upper Midwest)?
(2) How do forest functional characteristics vary across a gradient of nitrogen deposition (McNeil, Adirondacks)?
(3) How do forest functional traits vary in response to a history of of insect defoliation (Deel & McNeil, Appalachians; Singh, Upper Midwest)?
(4) How do forest functional traits affect nitrogen export from forested watersheds (Eshleman, Appalachians; McNeil, Adirondacks; Singh, Upper Midwest)

Figure 3

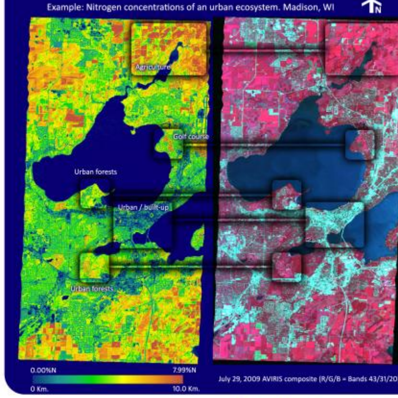


AVIRIS acquisitions (Green:2008, Blue: 2009) across latitudinal, longitudinal, elevational and climatic (shown, temperature) gradients

Scaling using models



Example: Nitrogen concentrations of an urban ecosystem. Madison, WI



July 29, 2009 AVIRIS composite (R/G/B = Bands 43/31/20)

Urban forests, Madison, WI

The general principles of forest functioning and nutrient cycling also apply in urban ecosystems. In Madison, WI, forests vary widely in functional types, but regional nutrient dynamics are driven by agriculture and fertilizer application.

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