Near Infrared Reflectance Across Scales Sheds Light on Forest Function and Structure

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Background and Overview

- Near infrared reflectance (NIRr) from forest canopies has been linked to estimates of photosynthesis and leaf nitrogen (%N). These relationships offer a useful means of scaling forest carbon assimilation over broad spatial scales using optical remote sensing, but they also pose a conundrum in that the traits in question have no direct effect on reflectance and because NIR light is not used by plants during photosynthesis.
- One hypothesis to explain these results points towards species-specific strategies to optimize light interception for different levels of foliar %N and photosynthetic capacity (e.g., by varying leaf angle), and associated patterns of carbon allocation that have a direct bearing on crown geometry. Although intriguing, our understanding of linkages between leaf traits and canopy structure, and how they relate to patterns of NIRr remains incomplete.
- Here, we made measurements of NIRr across leaf, branch, and individual tree crown scales to better understand how patterns of NIRr develop in forests, and how they are related to forest function and structure.

Field Data Collection

- During August 2021, we used a 75 ft. mobile canopy-access lift (Figure 1) to sample sun-lit branches from upper crowns of dominant trees at the Harvard Forest, Massachusetts.
- We collected 60 cm long branches (Figure 2) representative of typical branch morphology in the upper crown. Excised branches were immediately placed in a bucket of water and brought back to a nearby lab space for measurements.

Figure 1: (A) We used a 75 ft. canopy-access lift to sample sun-lit branches from the upper crowns of dominant tree species. **(B,C)** View of the forest canopy from lift platform.

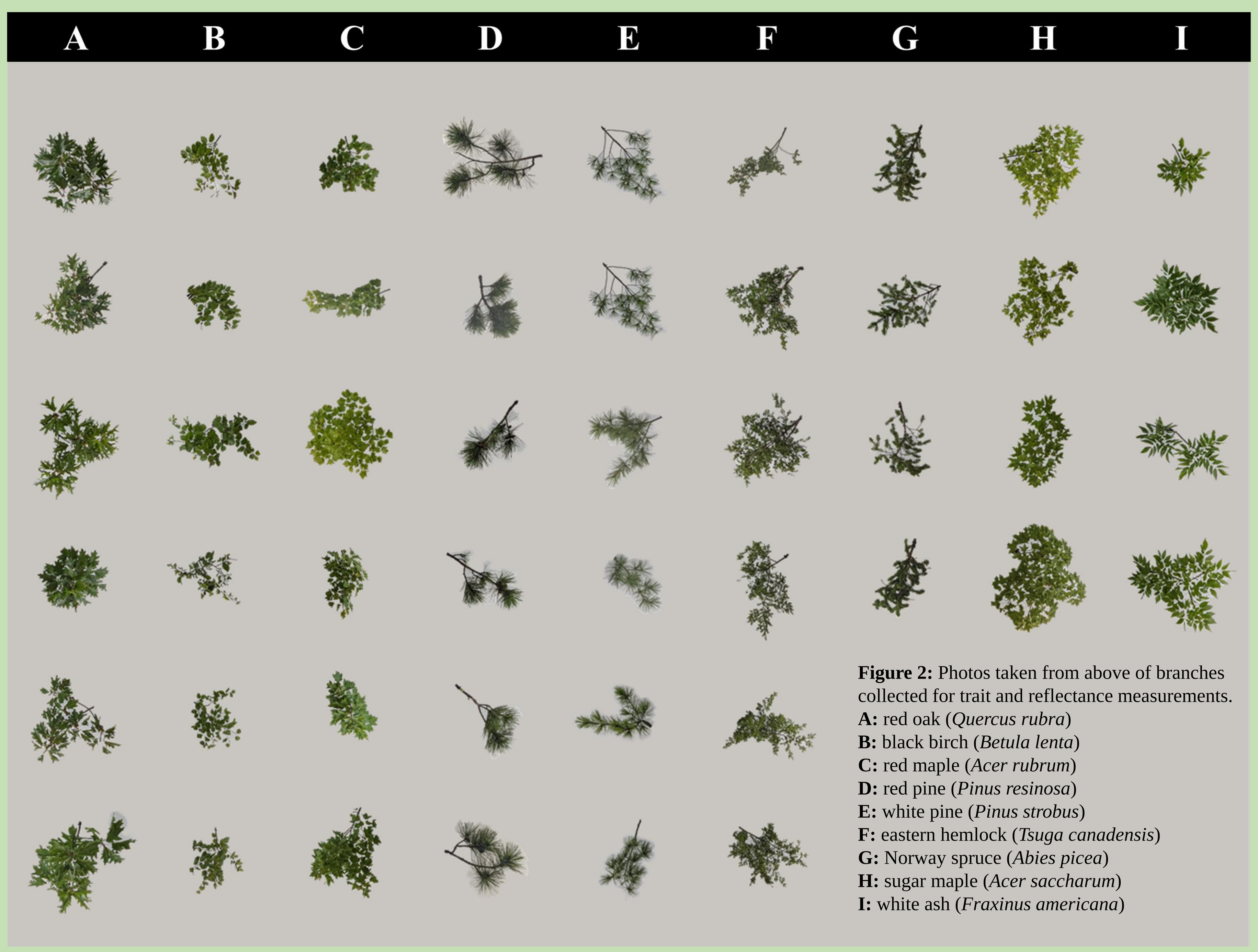

Figure 2: Photos taken from above of branches collected for trait and reflectance measurements.
A: red oak (*Quercus rubra*)
B: black birch (*Betula lenta*)
C: red maple (*Acer rubrum*)
D: red pine (*Pinus resinosa*)
E: white pine (*Pinus strobus*)
F: eastern hemlock (*Tsuga canadensis*)
G: Norway spruce (*Abies picea*)
H: sugar maple (*Acer saccharum*)
I: white ash (*Fraxinus americana*)

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References:
Hovi et al. (2020). Empirical validation of photon recollision probability in single crowns of tree seedlings . *ISPRS J. Photogramm. Remote Sens.* 169, 57–72
Hastings et al. (2020).Tree Species Traits Determine the Success of LiDAR-Based Crown Mapping in a Mixed Temperate Forest. *Remote Sens. 12*, 309.

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Measuring Reflectance Across Scales

LEAF

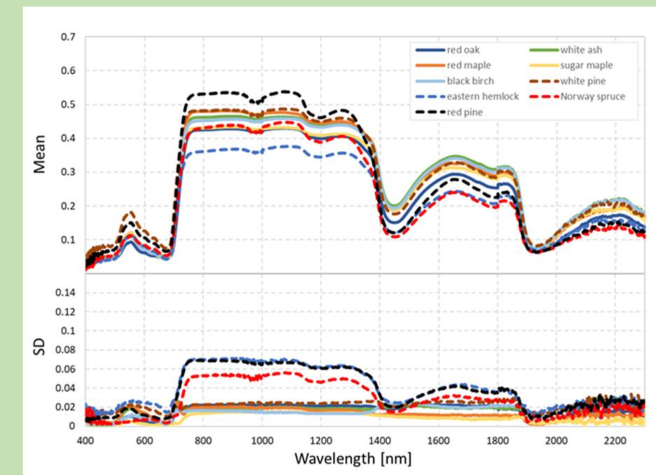
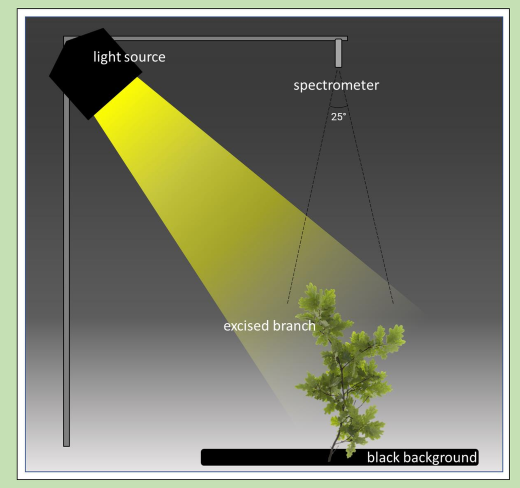


Figure 3: (Left) Red maple leaf in 'reference' position of integrating sphere. **(Right)** Species average and standard deviation of leaf-level reflectance.

- Leaf reflectance was measured on three separate leaves per sampled tree using an ASD Fieldspec 4 spectrometer equipped with an integrating sphere (Figure 3).
- For needleleaf species, where individual needles would not cover the reflectance port, we measured reflectance on multiple aligned needles and corrected the reflectance signal for non-vegetation gap fraction.

BRANCH



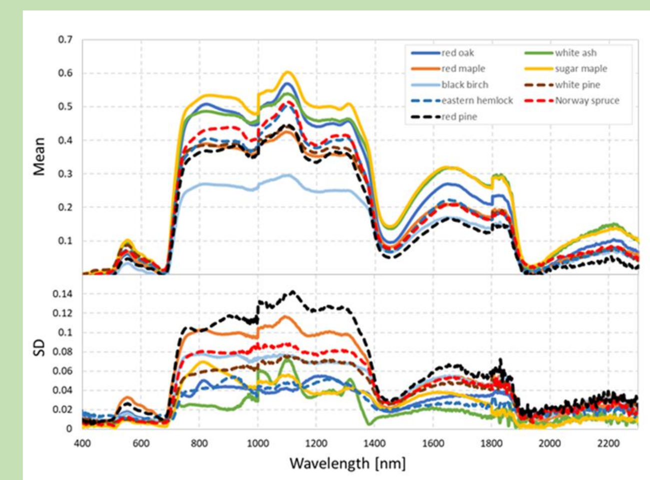
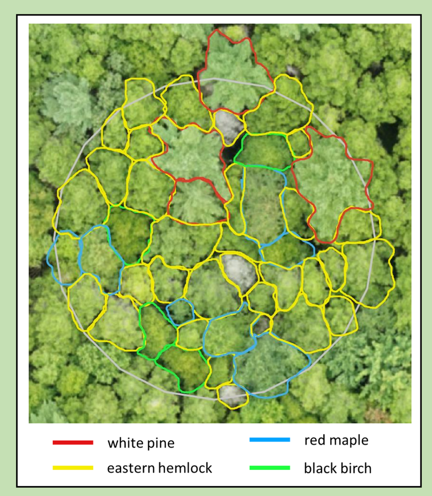


Figure 4: (Left) Diagram of branch reflectance darkroom setup. **(Right)** Species average and standard deviation of branch-level reflectance.

- Branch reflectance was measured in a darkroom setup (Figure 4) we developed to adapt methods presented in Hovi et al. (2020).
- Branches collected in the field were set up to match their native orientation (angle, azimuth) measured within the crown prior to collection.
- Simplified, reflectance was calculated as a ratio of the spectrometer signal of the branch to a white references signal after accounting for stray light and the portion of the field of view filled by the branch.

CROWN



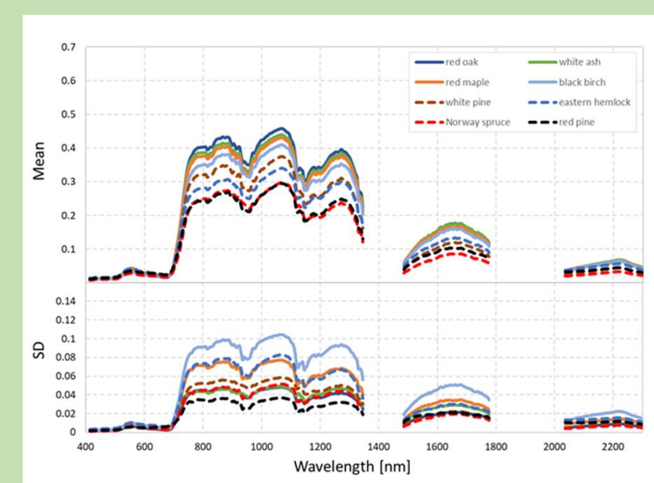


Figure 5: (Left) Hand delineated tree crowns used for crown reflectance measurements. **(Right)** Species average and standard deviation of crown-level reflectance.

- Crown reflectance was extracted from a set of hand-delineated tree crowns (Figure 5) from Hastings et al. (2020).
- We used hyperspectral imagery collected by the National Ecological Observatory Network during the 2016 growing season.

NIRr Across Scales in Relation to Foliar N

- Leaf-scale NIRr shows a neutral or slightly negative relationship with %N (R^2 : 0.0087; P = 0.81), which is constant across needleleaf and broadleaf plant functional types (PFTs) despite notable differences in internal leaf structure and transmittance.
- The positive %N – NIRr relationship is strongly developed at the crown-scale (R^2 : 0.80, P = 0.0026).
- Branch patterns are more complex; For example, most high—N deciduous species exhibited the highest NIRr at branch scale (layering of foliage), but black birch branch reflectance was a distinct outlier(Figure 6, lower right hand red circle). Including black birch, the branch %N – NIRr pattern is relatively weak (R^2 : 0.032, P = 0.64), but is stronger and significant (R^2 : 0.56, P = 0.033) when excluding it.
- We attributed the low black birch branch NIRr to steep leaf angle (Figure 7) and sparse foliage (Figure 2.) Given that black birch crown NIRr is not an outlier, this emphasizes that while branches may be the basic subunit of tree crown architecture, there is a distinct need to understand how leaves are arranged around individual branches, how and why those branches are distributed throughout a crown volume, and the resulting impact on reflectance signals.

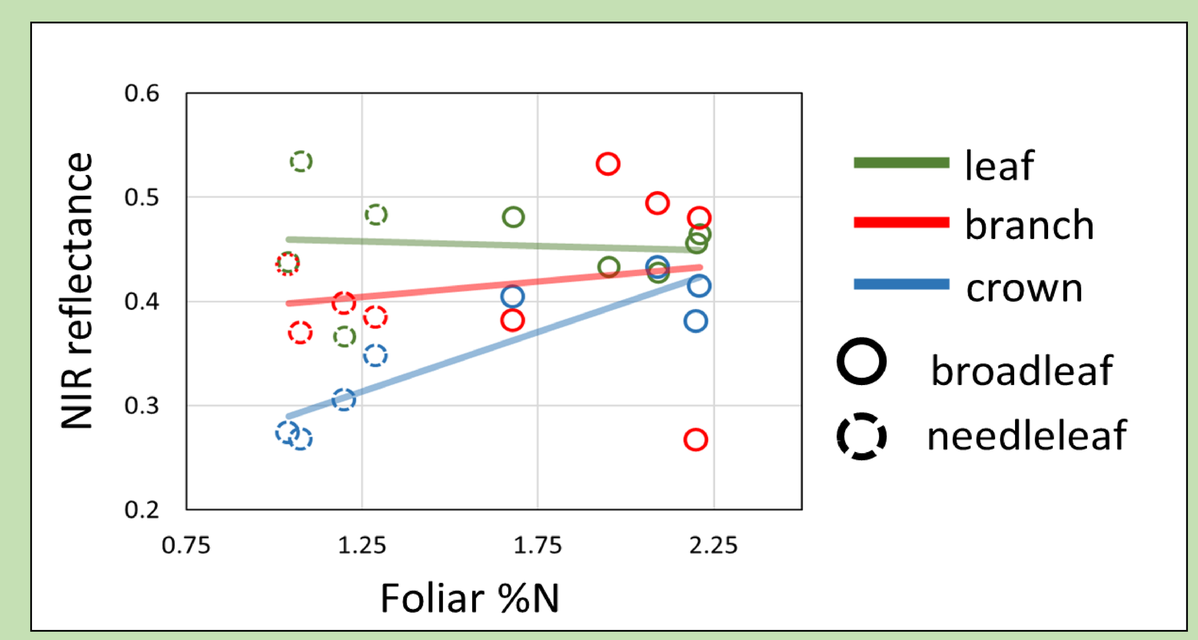


Figure 6: Patterns of near infrared reflectance (865nm) across leaf, branch, and crown in relation to average mass-based foliage nitrogen.

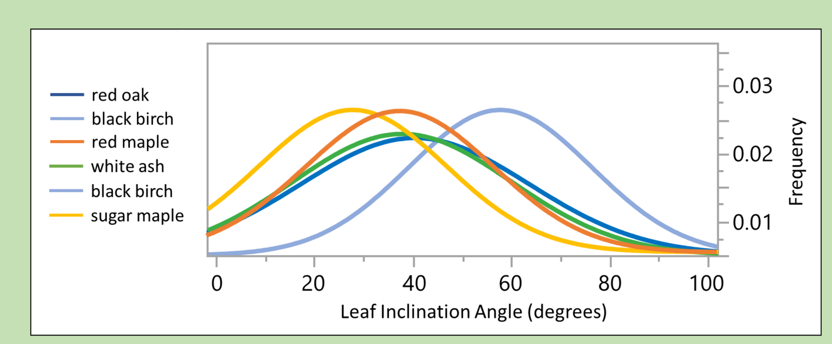


Figure 7: Leaf angle distribution for broadleaf species. We measured 50 leaves on each branch collected for branch reflectance.

Future Directions

- Here, we have begun to test the theory that species adjust canopy foliage display to optimize light capture, which affects top-of-the canopy near infrared reflectance patterns.
- This same adjustment should also affect through-the-canopy light environment and associate foliage traits (Figure 8).
- This summer, we will test this theory by using a canopy lift to measure light extinction profiles and traits within individual tree crowns.

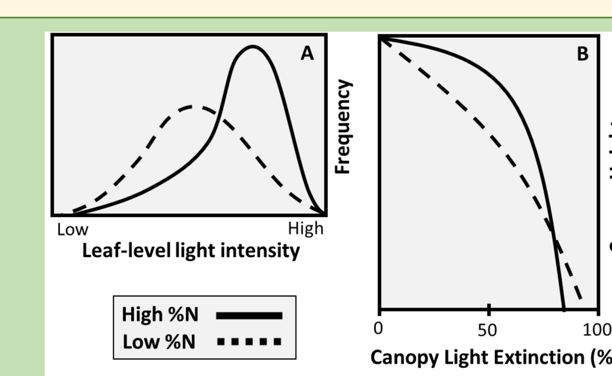


Fig. X: Hypothetical (A) leaf and (B) canopy light environment for low %N and high %N canopies.