

# Canopy nitrogen, carbon assimilation and NIR reflectance in North American forests in relation to leaf traits, canopy structure and species diversity

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## What we did

- We conducted a study of canopy reflectance and carbon assimilation in forested AmeriFlux sites in North America. Our goals were to
  - (1) evaluate factors influencing the widely observed relationship between foliar %N, carbon assimilation and NIR reflectance in forests, and
  - (2) determine whether canopy diversity influences carbon and water fluxes, after accounting for the effects of climate, foliar N and other biological drivers.
- Our analysis involved eddy flux data, airborne remote sensing, and field measurements of leaf traits, canopy structure and diversity.

## What we found

- Contrary to other recent studies, the foliar N—NIR reflectance relationship is not spurious, cannot be explained by the ratio of deciduous to evergreen species and also occurs in pure stands of both forest types.
- Detailed measurements at one site (Bartlett, NH) indicated that leaf traits and canopy structure both affect NIR reflectance, but their relative importance varies across forest types.
- A statistical analysis of canopy carbon and water fluxes across forested AmeriFlux sites in the U.S. and Canada indicated that canopy biodiversity has a significant, albeit relatively small effect on GPP and ET.
- Preliminary results also suggest that diversity reduces interannual variability in response to environmental fluctuations.

## New evidence from a wider range of field sites. The relationship occurs within as well as across forest types. Forest composition is not the answer.

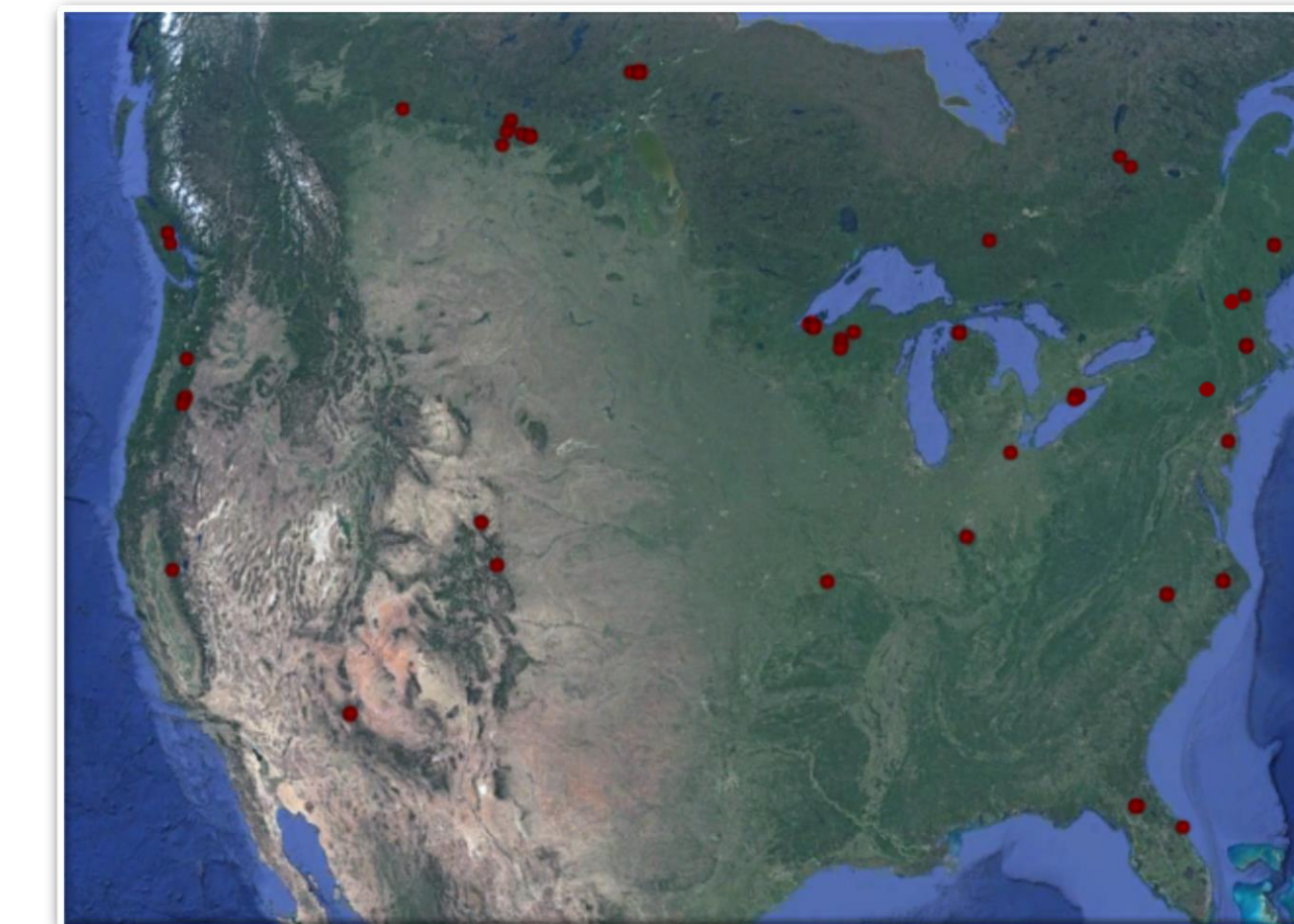
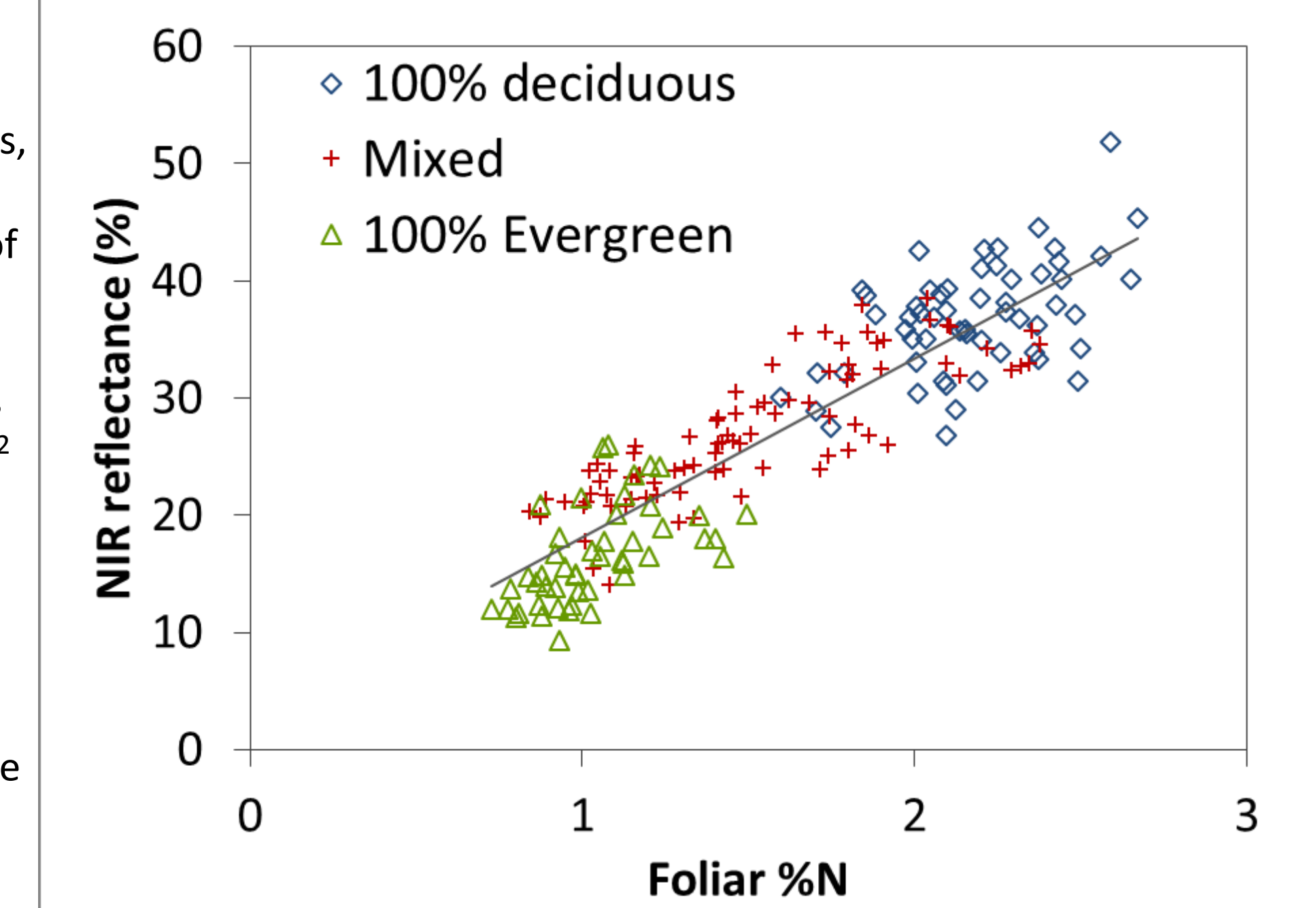


Fig. 4. Study sites for the present analysis, which extend a prior analysis of canopy reflectance and carbon assimilation (Ollinger et al. 2008, Lepine et al. 2016) and include a greater fraction of pure deciduous or evergreen stands.

Fig. 5. Whole-canopy NIR reflectance as a function of foliar %N for pure deciduous, pure evergreen and mixed stands using the %N value of each type. The relationship is significant within each group at  $p < .0001$ , as well as across the entire data set ( $r^2 = 0.89$ ). N itself cannot be a direct causal factor, but this provides evidence that the relationship is not spurious, is not caused by forest composition and is likely due to biologically mediated functional relations.



## Canopy %N, photosynthetic capacity and NIR reflectance in forests: A few examples

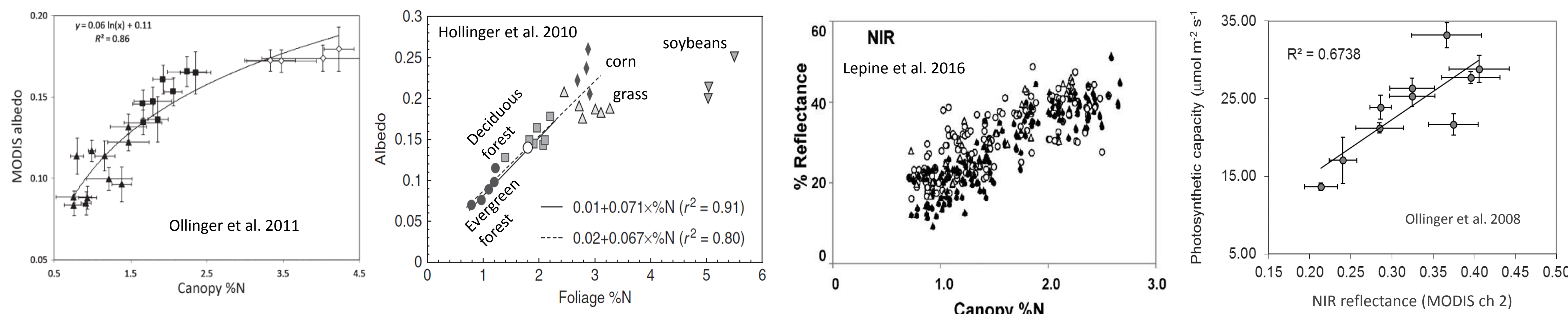
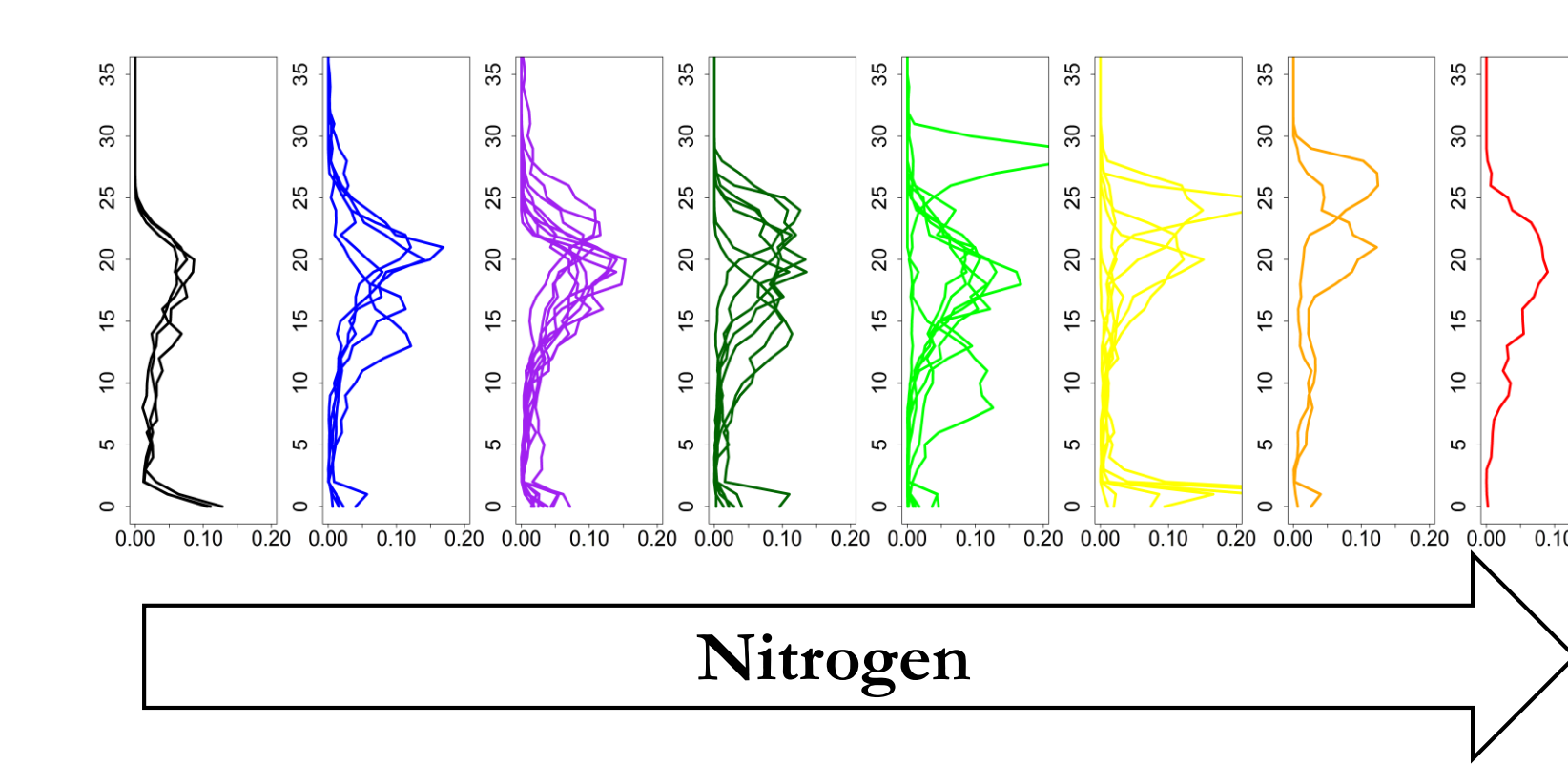
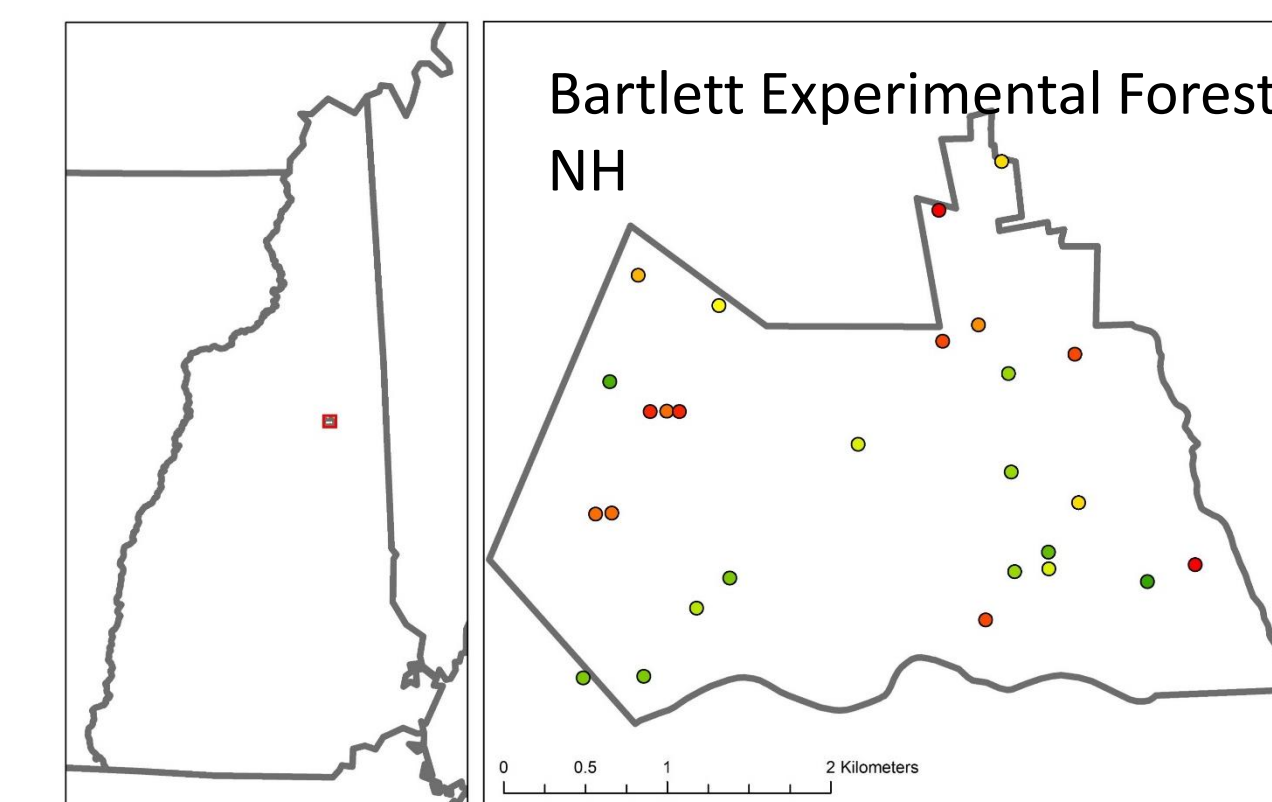


Fig. 1. Examples of the relationship between foliar %N and canopy NIR reflectance or NIR albedo, representing temperate forests in the U.S. and Europe as well as several sites dominated by grass or crops.

## A more detailed look at a single site



New measurements of:

- Vertical leaf profiles
- Leaf- and plant-area index
- Canopy height (lidar)
- Entropy and foliar diversity
- Leaf reflectance (ASD)
- Leaf size and number
- Leaf density (leaves  $m^{-3}$ )

Fig. 6. Location of the Bartlett Experimental Forest and data collected via the NEON AOP lidar instrument and intensive field measurements in 2017

## But N itself has no distinct spectral properties, so what causes this pattern?

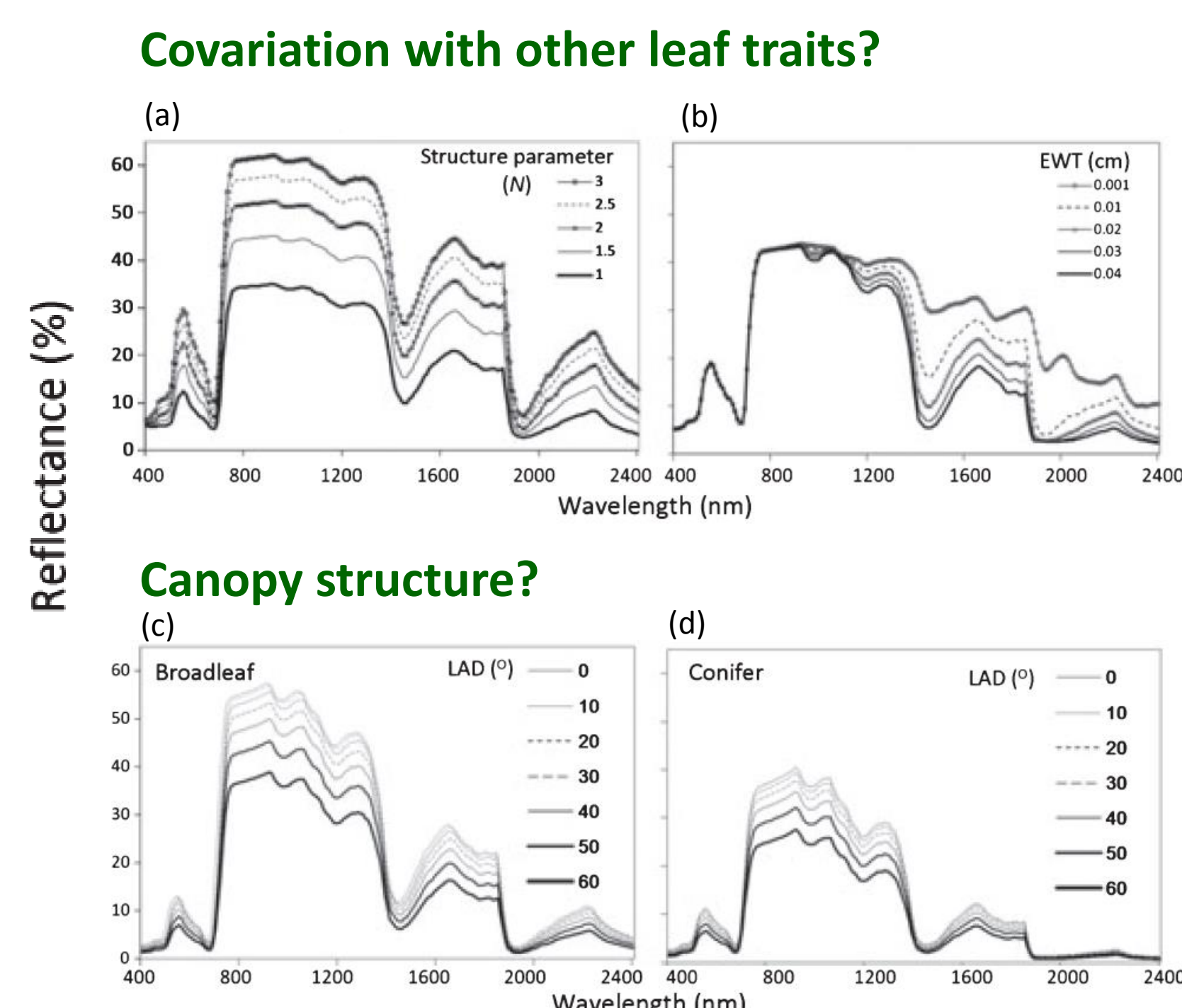


Fig. 2. Predicted influence of several leaf and canopy traits on reflectance spectra, generated by the SAIL leaf model and PROSPECT canopy model. Individual panels show results of sensitivity analyses testing for the influence of (a) a parameter representing leaf cell structure, (b) equivalent water thickness, (c) leaf angle distribution for broadleaf-dominated forests, and (d) leaf angle distribution for needleleaf-dominated forests.

## Or convergence among multiple plant traits that are influenced by N via its effect on carbon assimilation and allocation?

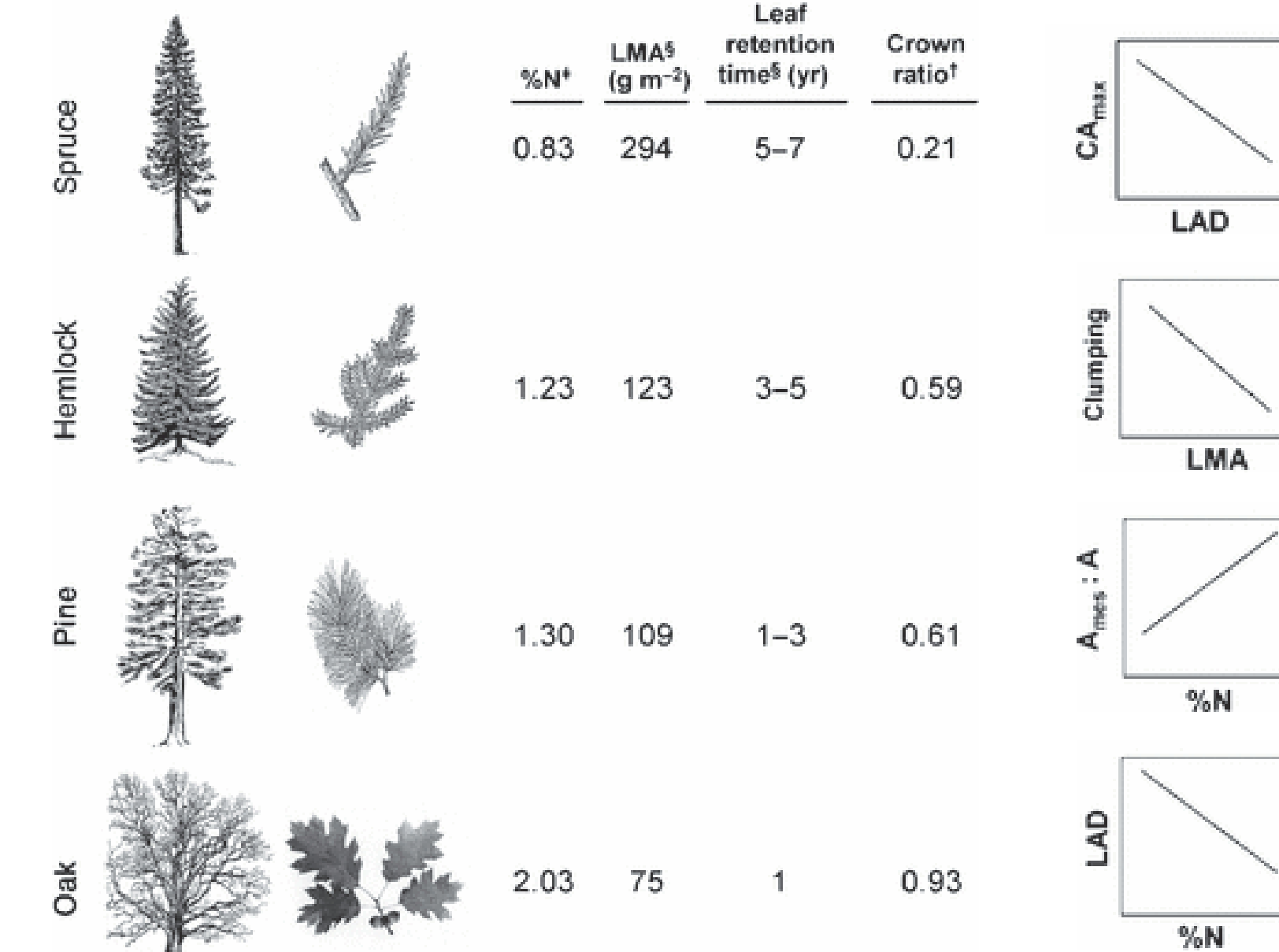


Fig. 3. Functional relationships among spectrally important plant traits, each of which can be influenced by leaf N via its effect on carbon assimilation and allocation. Panels at right show idealized relationships among other variables that exhibit convergence and are known to be related to NIR reflectance. Variables are:  $A_{mes}:A$ , ratio of cell surface area to leaf area; LMA, leaf mass per unit area; LAD, leaf angle distribution;  $CA_{max}$ , canopy photosynthetic capacity; and clumping (lower values corresponding to greater foliar clumping along the stem).

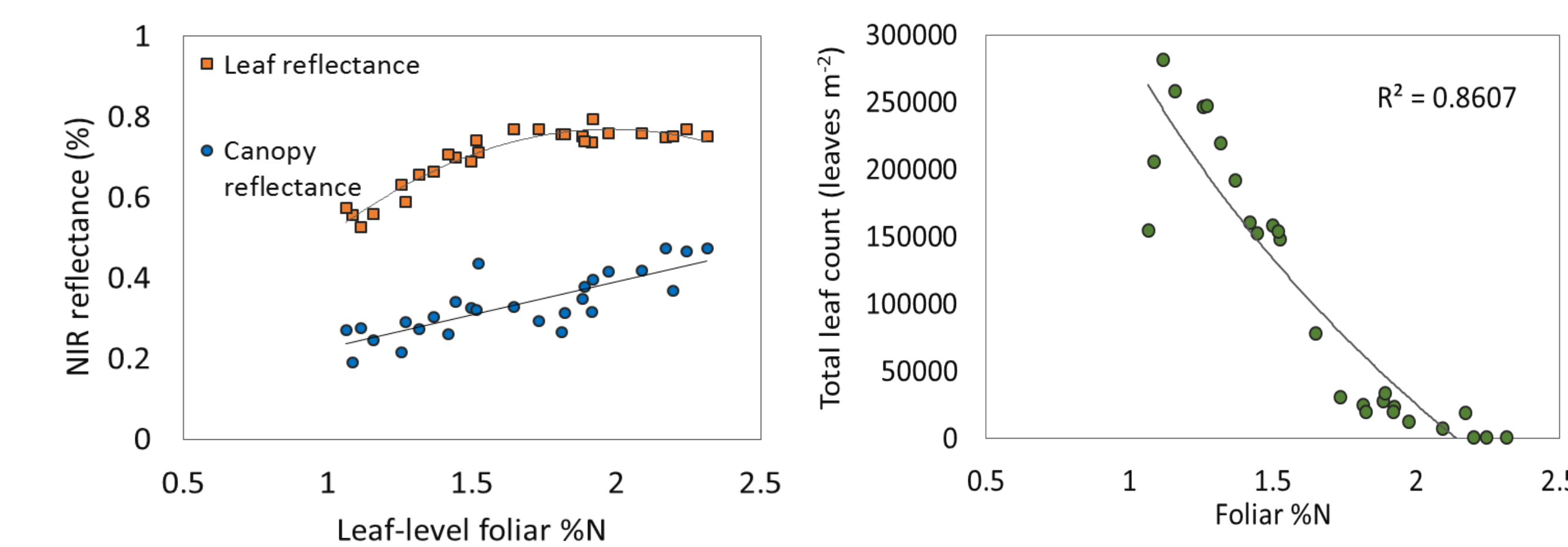
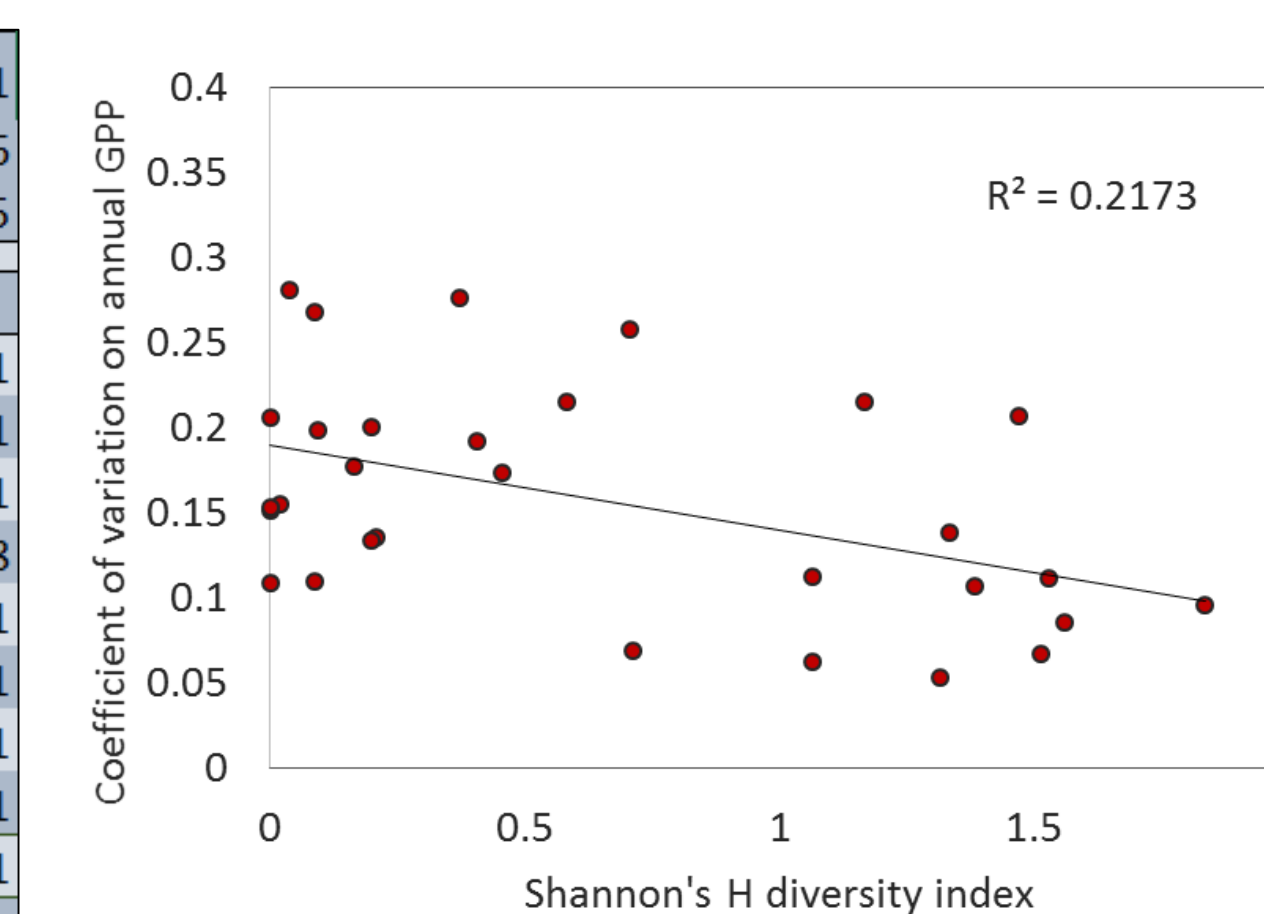


Fig. 7. (a) Foliar %N in relation to leaf-level and canopy level reflectance at BEF. Leaf and canopy reflectance show similar patterns at the low end of the range, but not in high-N broadleaf-dominated stands. This suggests a shift from leaf traits to canopy structure as relative drivers of NIR reflectance. (b) Foliar %N and NIR reflectance were more strongly related to the total number of leaves in the canopy than to any other structural variable we measured. A multi-variate analysis yielded a best-fit, two-term model comprised of leaf number and leaf %N as the best overall predictor of NIR reflectance. All other variables (including forest composition) dropped: NIR reflectance =  $-0.305 + 0.337*\%N + 1.754*(LND/10000)$

## How does this affect C assimilation? And what about canopy diversity?

Fig. 8. We evaluated the influence of foliar N along with climate, tree species diversity and other biological variables on monthly GPP using gap-filled data from the Fluxnet 2015 data set. Foliar %N came from field measurements and aircraft remote sensing (Lepine et al. 2016). Species diversity was characterized by Shannon's diversity index, derived from inventory data provided by a subset of the sites ( $n=45$ ). We considered growing season data only and forests of at least 10 years in age with at least 5 years of data. Stepwise regression indicated that foliar N had a strong, positive, influence on GPP. Species diversity had a highly significant, albeit weaker, effect. Diversity was also inversely related to the degree of interannual variability in GPP, consistent with the diversity-stability hypothesis.

Optimal GPP Model		
Independent variable	Coeff (95% C.I.)	P
PAR	0.096 (.0088-.010)	0.0001
T-Air	2.996 (.2846-.3146)	0.0001
VPD	-4.81 (-5.29 - -4.33)	0.0001
SPEI (drought index)	-0.99 (-.182 - -.017)	0.018
Foliar %N	2.77 (2.31 - 3.23)	0.0001
Shannon's H index	0.853 (.617 - 1.08)	0.0001
Biomass	-0.00037 (-.00006 - -.00002)	0.001
Age	0.071 (0.027 - 0.115)	0.001
Shannon's H	15.72 (6.78 - 24.66)	0.0001
Const.	-2.860 (-3.33 - -2.39)	0.0001



And others have argued that the relationship is purely spurious, has no biological underpinnings and only reflects the ratio of broadleaf to needleleaf plants (Knyazikhin et al 2013).

References: Hollinger, D.Y., S.V. Ollinger, A.D. Richardson, T.P. Meyers, et al. 2010. Albedo estimates for land surface models and support for a new paradigm based on foliage nitrogen concentration. *Global Change Biology*, 16(2): 696-710. | Knyazikhin Y, et al. (2013) Hyperspectral remote sensing of foliar nitrogen content. *Proc Natl Acad Sci USA* 110(3): E185-E192. | Lepine L.C., S.V. Ollinger, A.P. Ouimette, and M.E. Martin. 2016. Examining Spectral Reflectance Features Related to Foliar Nitrogen in Forests: Implications for Broad-Scale Nitrogen Mapping. *Remote Sensing of Environment*, 173: 174-186. | Ollinger S.V. 2011. Sources of Variability in Canopy Reflectance and the Convergent Properties of Plants (Tansley Review). *New Phytologist*. 189: 375-394. |