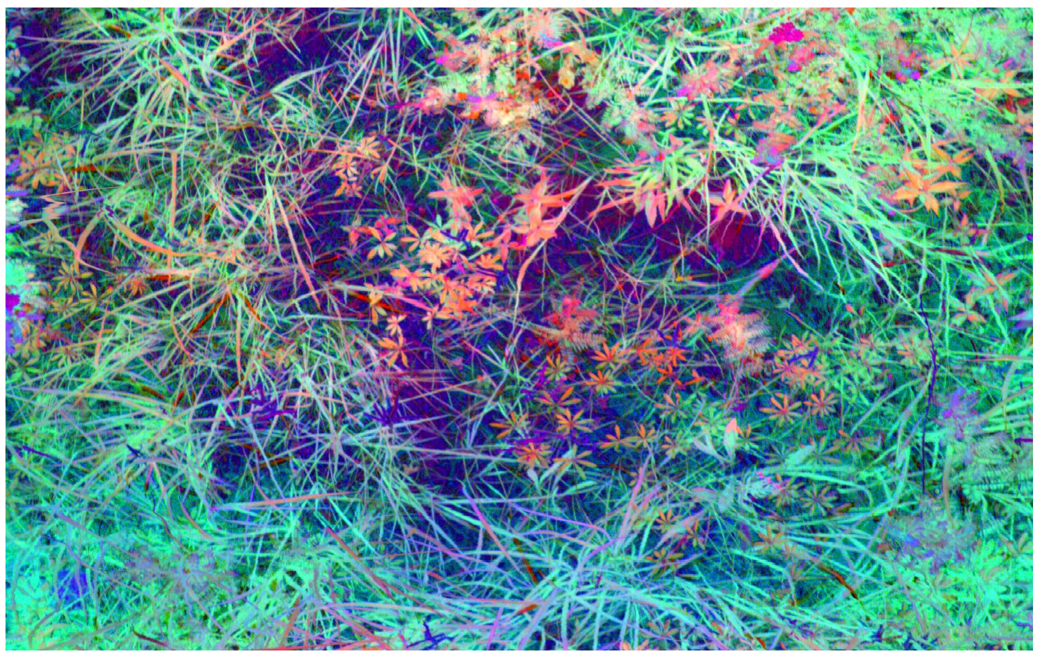
# Issues of Scale in Biodiversity Science

John A. Gamon, Ran Wang, Hamed Gholizadeh



R=Fluorescence, G=Chlorophyll, B=PRI

# What does “Remote Sensing of Biodiversity” mean, exactly?

- What *kind* of remote sensing?
- What *aspect* of biodiversity?
  - *Alpha* diversity?
  - *Beta* diversity?
  - *Functional* diversity? (e.g. plant traits)
  - *Genetic* diversity?
- What is our goal?
  - Monitor or map biodiversity?
  - Understand functional links?

# Types of Biodiversity Sampling Methods Found in the Literature

- Habitat Mapping (e.g. vegetation classification)
  - Species Distribution Mapping (based on dominant species)
    - Index-based methods (e.g. NDVI, variation in NDVI…)
      - Spectral Diversity:
        - Plant trait variability
        - Spectral information content

# Types of Biodiversity Sampling Methods Found in the Literature

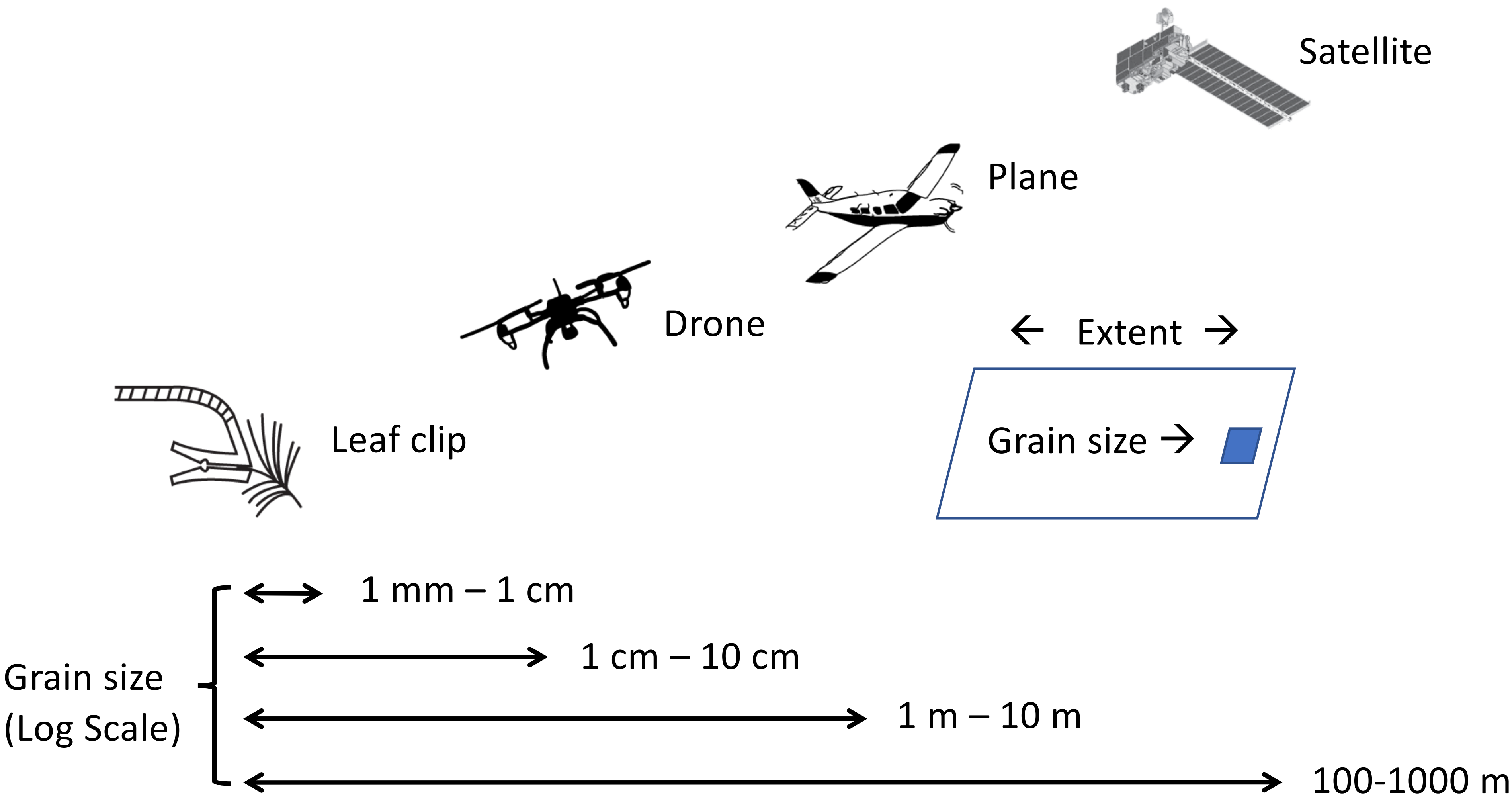
- Habitat Mapping (e.g. vegetation classification)
    - Species Distribution Mapping (based on dominant species)
        - Index-based methods (e.g. NDVI, variation in NDVI…)
            - **Spectral Diversity:**
                - **Plant trait variability**
                - **Spectral information content**

*All theses methods are highly scale dependent.*

# Scale Dependence:

- Biological scale – genes and molecules to ecosystems and biomes
- Spatial Scale – plot size, grain size (pixel size and extent)
- Temporal Scale – e.g. seasonal variation
- Spectral Scale – spectral range and resolution

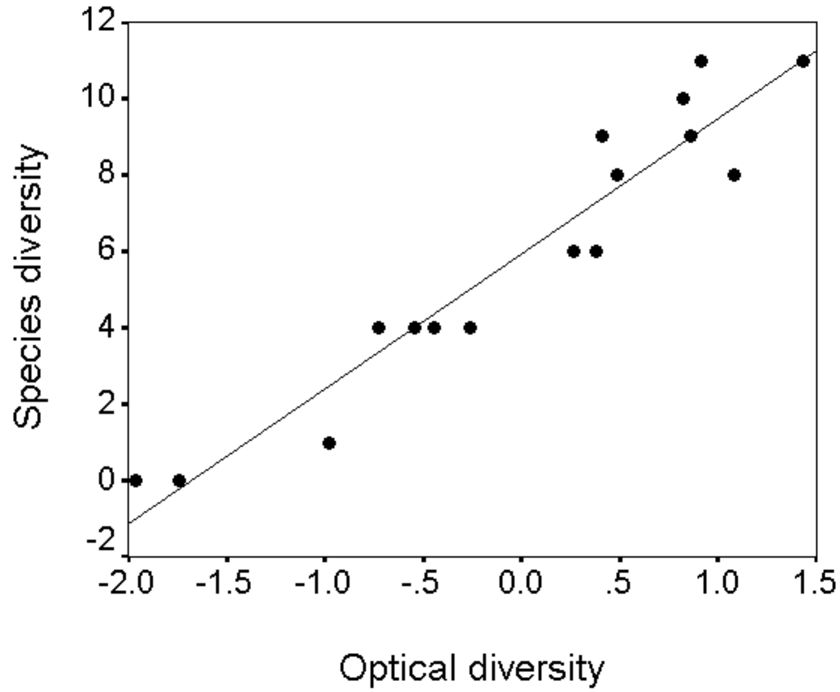
# Scale dependence in Remote Sensing: *Spatial Scale*

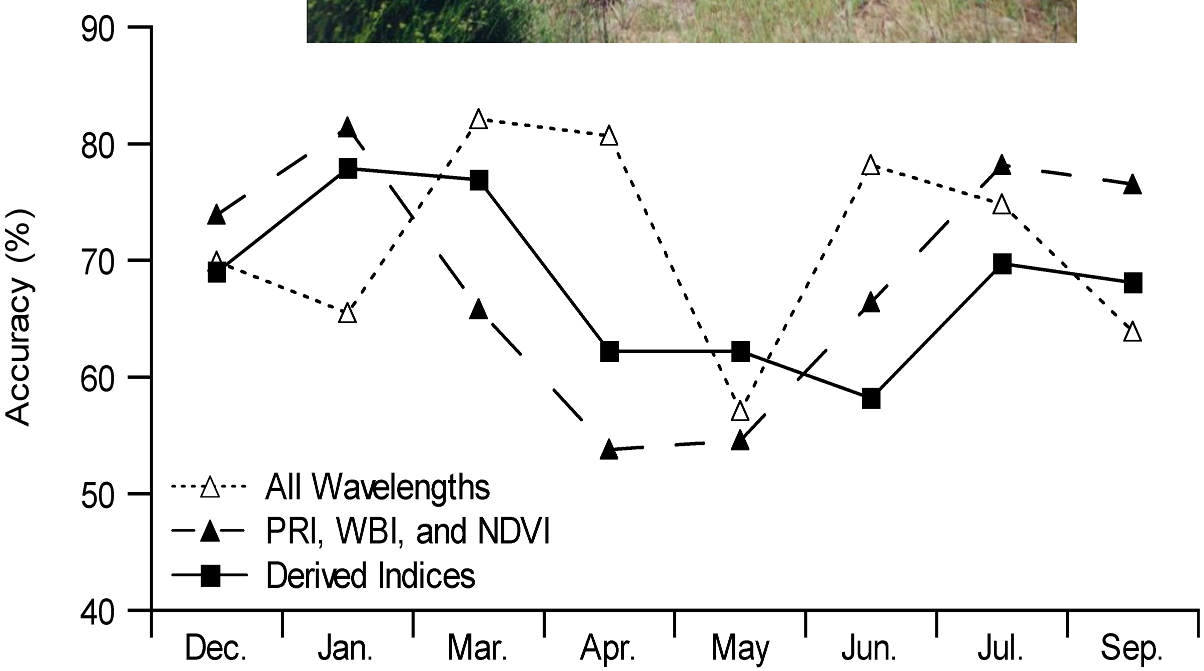



*Sampling resolution of spectral measurements span 5-6 orders of magnitude*

# Scale dependence in Remote Sensing: *Temporal scale* – e.g. seasonal variation

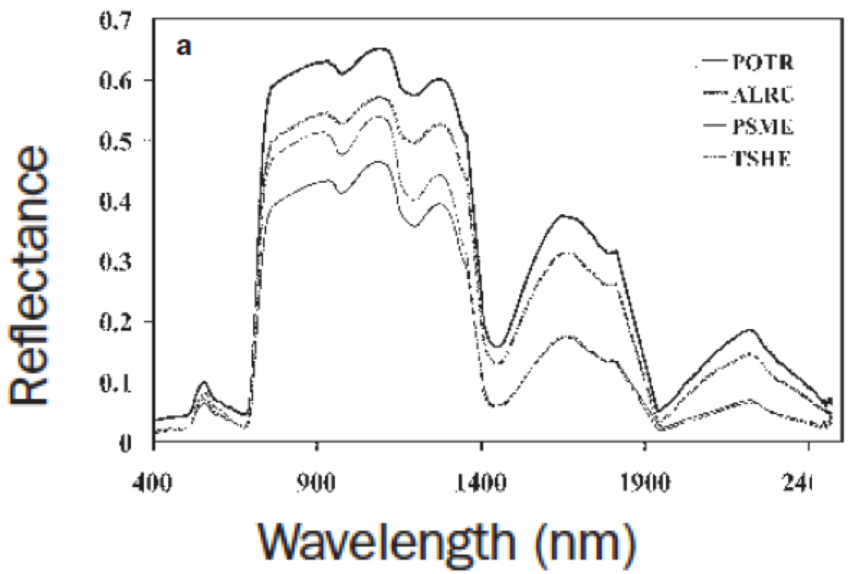
← Spectral diversity sampling, Santa Monica Mountains, CA

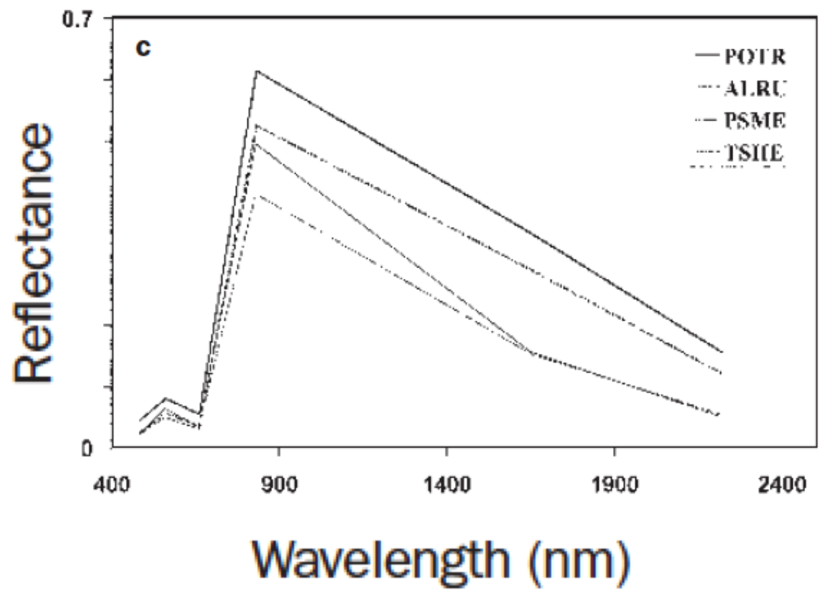



Zutta 2003

# Scale Dependence in Remote Sensing: *Spectral Scale*

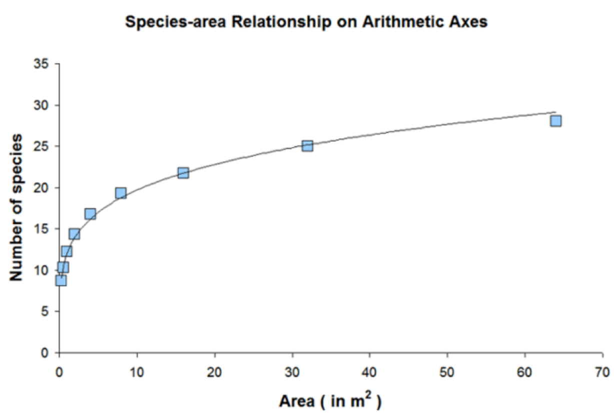


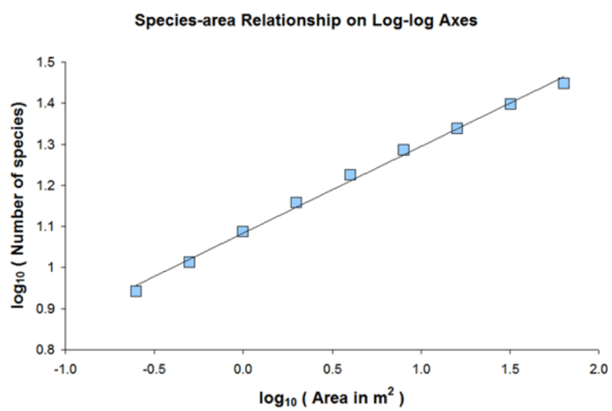




Ustin et al. (2004) *BioScience* 54:523-534

# Scale dependence - *Biological Scale*

<u>Species-Area Curves</u>:




https://en.wikipedia.org/wiki/Species%E2%80%93area_relationship

<u>Biodiversity definitions:</u>

Alpha Diversity
Beta Diversity
Gamma Diversity

Phylogenetic diversity
Species richness
Species evenness
Functional Diversity

*Biodiversity definitions and sampling methods also vary with scale.*

*Spectral (optical) diversity – measures some ill-defined combination of these*

# Challenges to Remote Sensing of Biodiversity:

- Both remote sensing and biodiversity are very scale-dependent (spatial, temporal and spectral scale matters)
- Sampling scales are often mismatched (often by several orders of magnitude).
- "Biodiversity" is often not defined (fundamental definitions and related sampling assumptions vary widely).

→ *Biodiversity definitions and sampling scale need attention!*

→ *Well-designed experiments & field campaigns are needed*

# Key Questions:

- Can we *really* detect biodiversity with remote sensing? (Yes, but we need to clarify definitions and scale)
- What are we really detecting? (perhaps not biodiversity *per se*, but a proxy)
- Can spectral information content (spectral diversity) provide a useful metric of diversity? ("optical diversity" or information content)

# Project Overview:
# Dimensions of Biodiversity

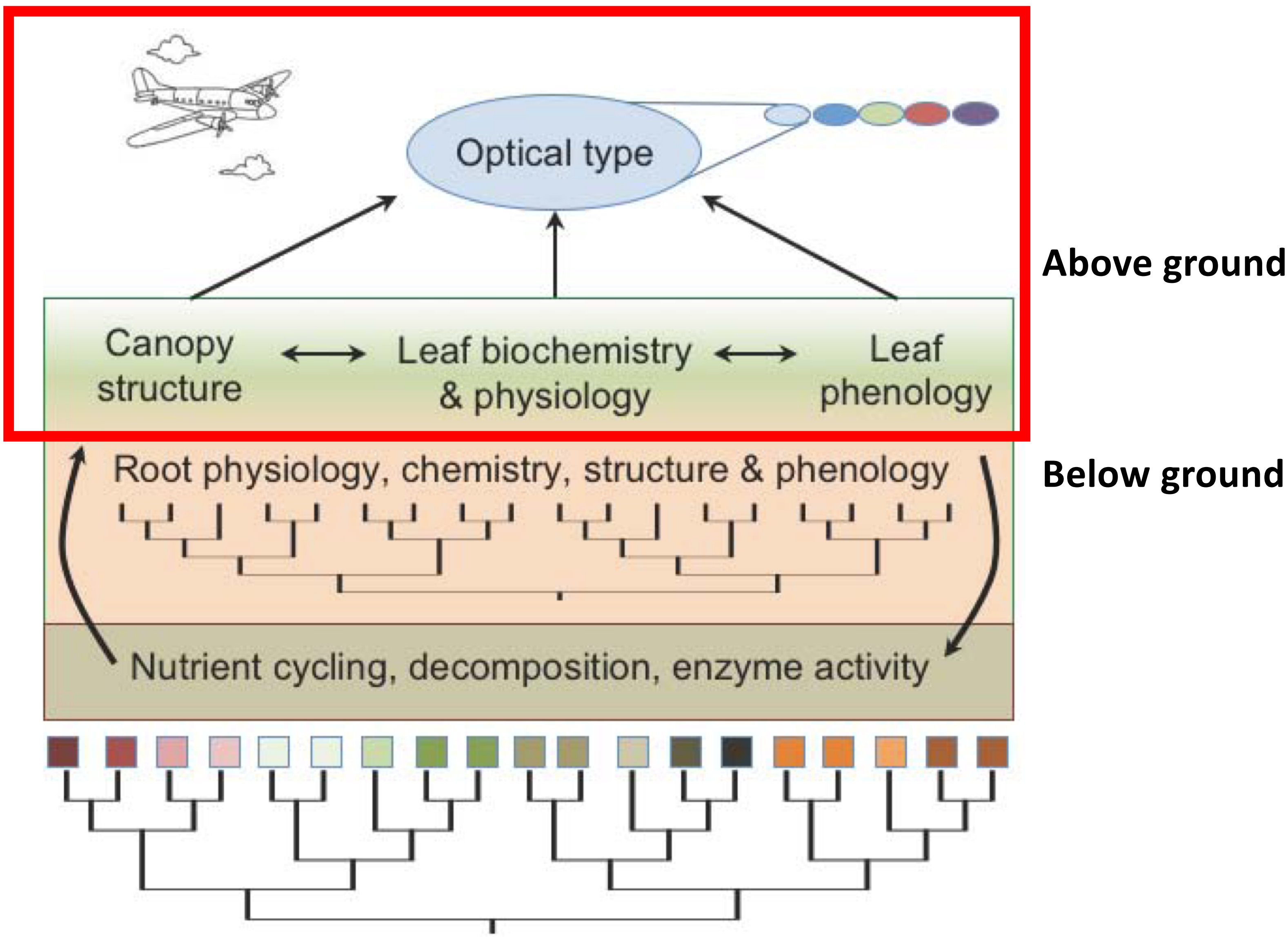



Figure: J. Cavender-Bares

Collaborators:
Jeannine
Phil
Anna
Dudu

# Study sites:

**Cedar Creek (U. Minnesota)**

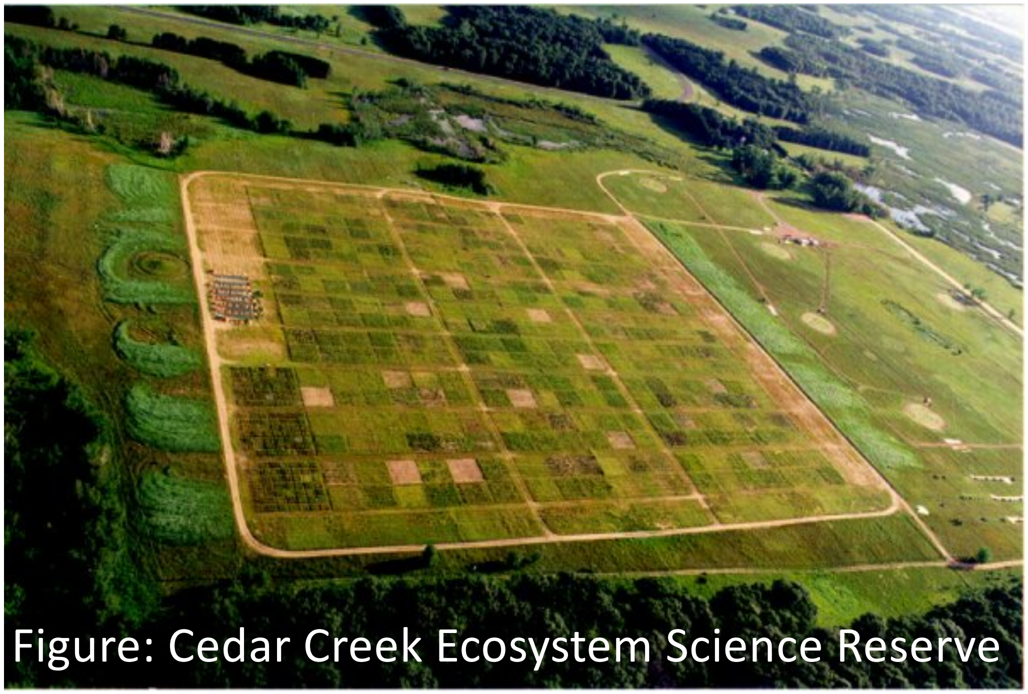


Figure: Cedar Creek Ecosystem Science Reserve

**Wood River (Nature Conservancy)**

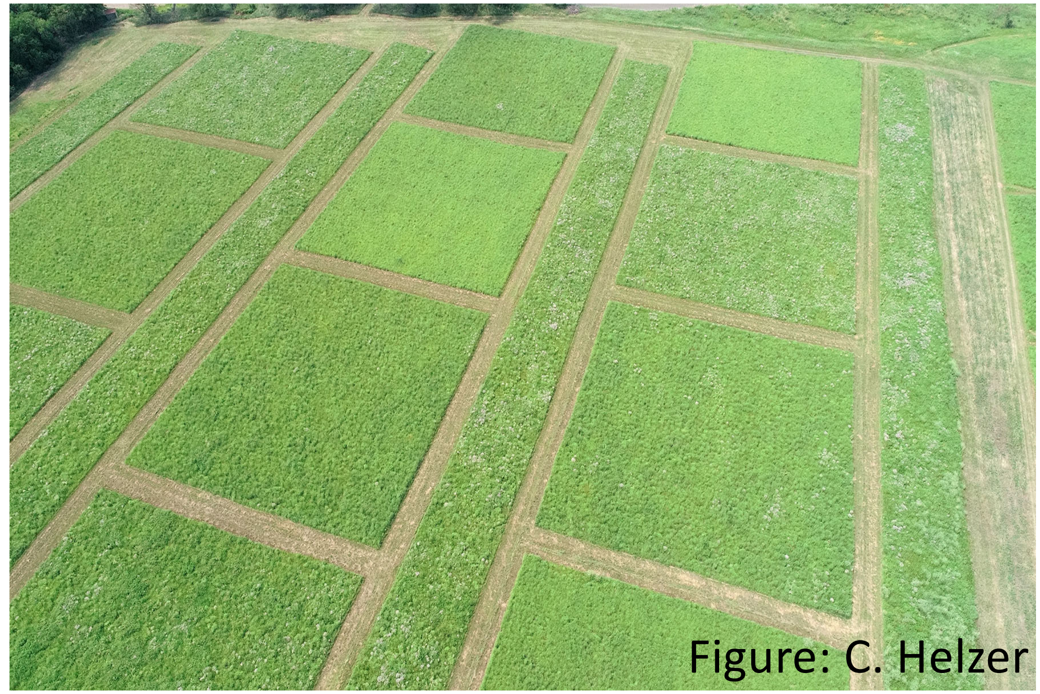


Figure: C. Helzer

# Methods Used:

1. Experiments: *multi-scale* field campaigns, combining proximal and airborne remote sensing (optical range – VIS-NIR):

    - Spectral diversity (information content) at different scales (pixel sizes and plot sizes)
        - coefficient of variation (CV)
        - spectral angle mapper (SAM)

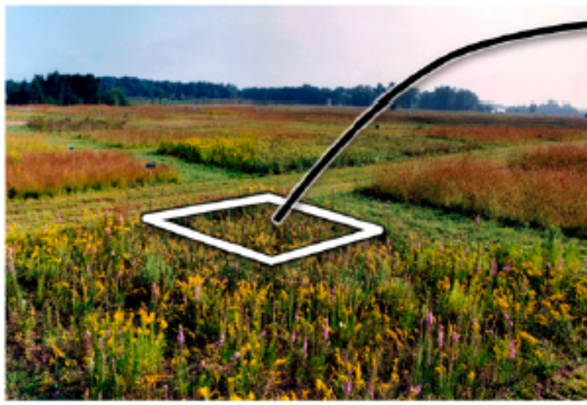
    - Alpha diversity of vegetation
        - Species richness
        - Species evenness

2. Modeling: synthetic landscapes with varying composition, grain size

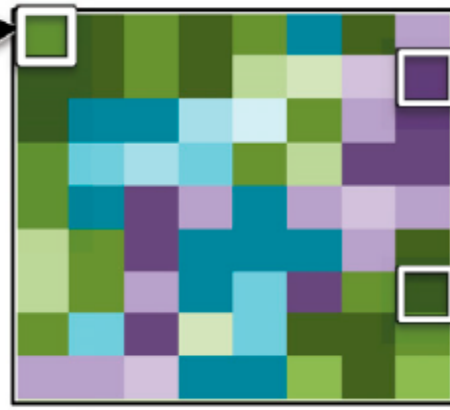
# Methods:

U. Nebraska-Lincoln Airborne Observatory ("CHAMP")

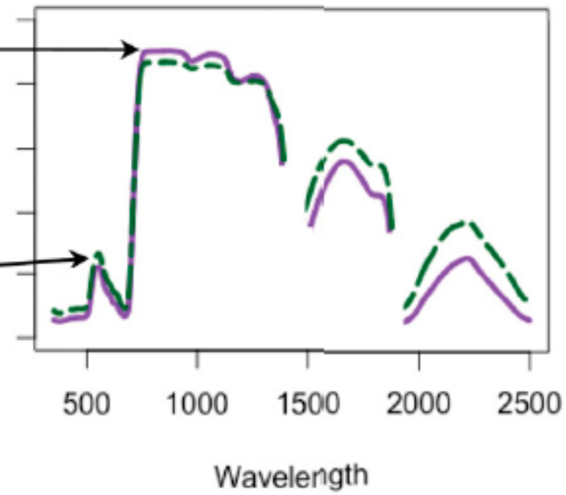
Individual plots



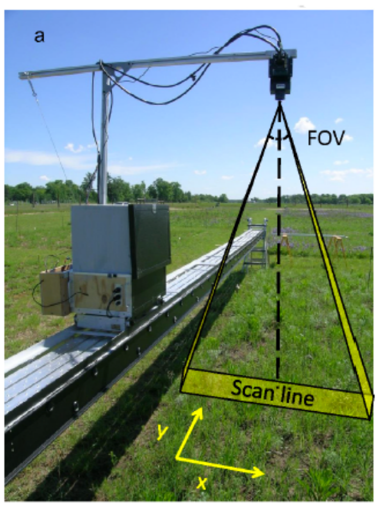
Spectral image of a plot

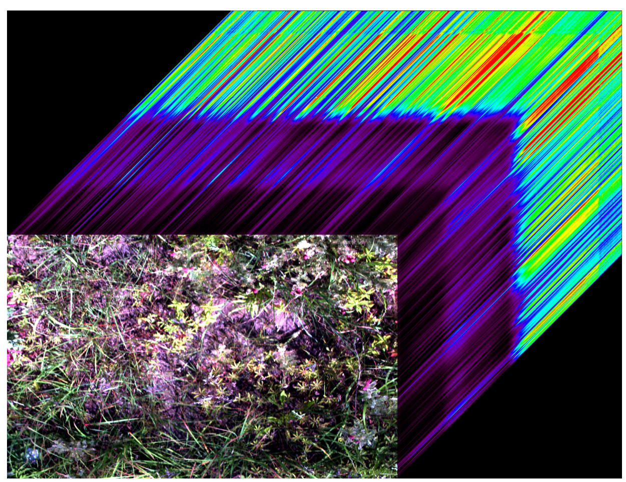


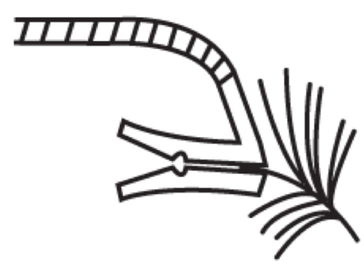
Spectra from contrasting vegetation patches




Cavender-Bares et al. (2017)

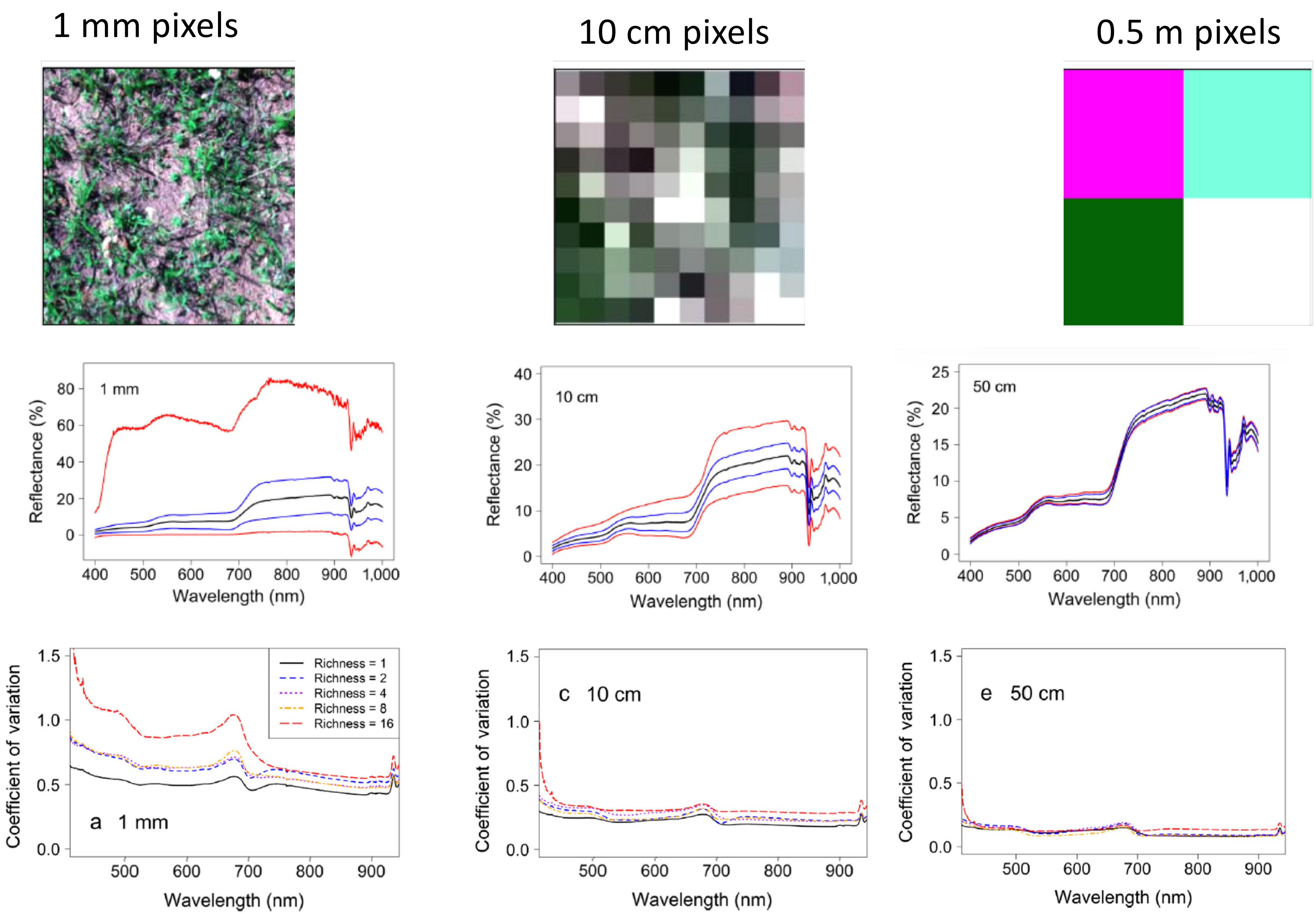




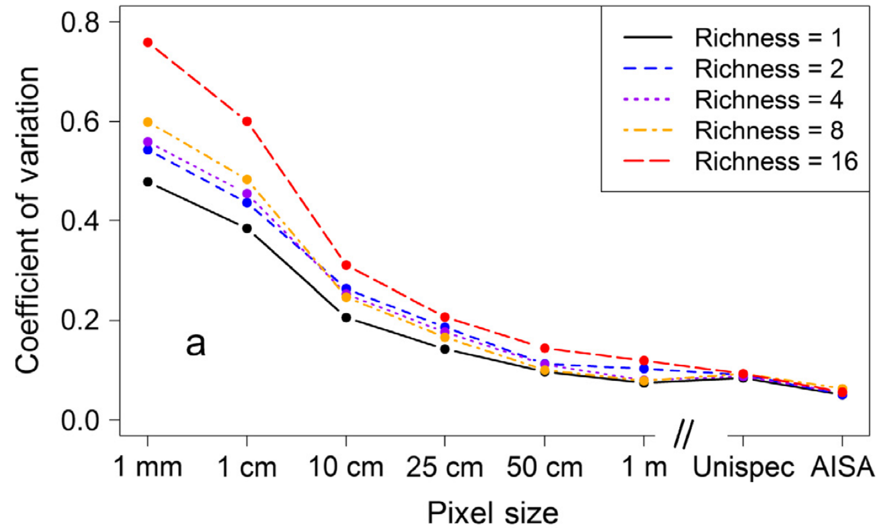
Wang et al. 2018 Ecological Applications

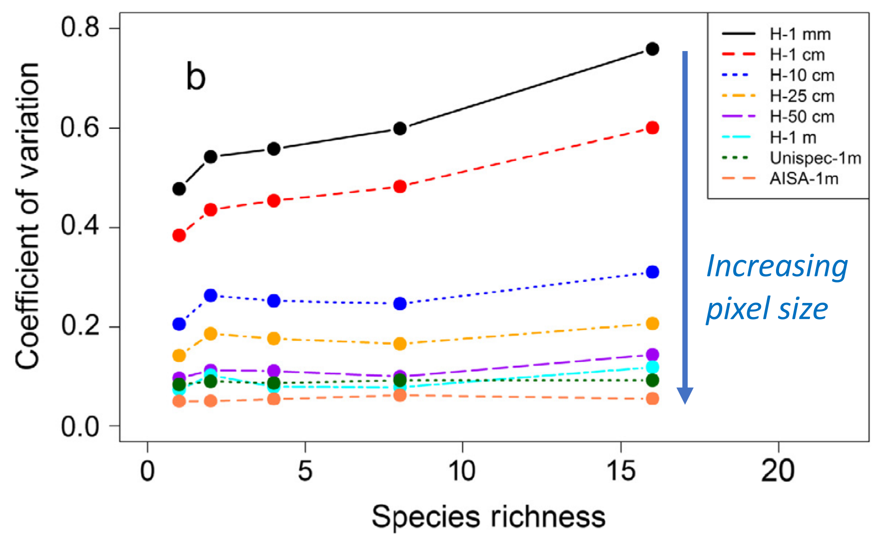
# Effects of Spatial Scale on Spectral Diversity




Wang et al. 2018 Ecological Applications

# Scale Dependence of Spectral Diversity
# Cedar Creek




Wang et al. 2018 *Ecological Applications*

# Experiment 2: Wood River, Nebraska

## New fields:

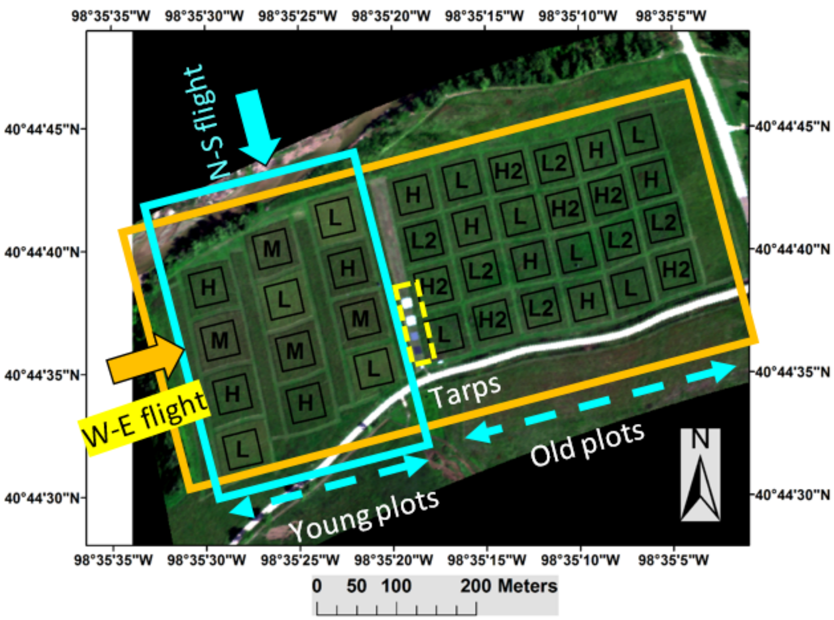
Low diversity

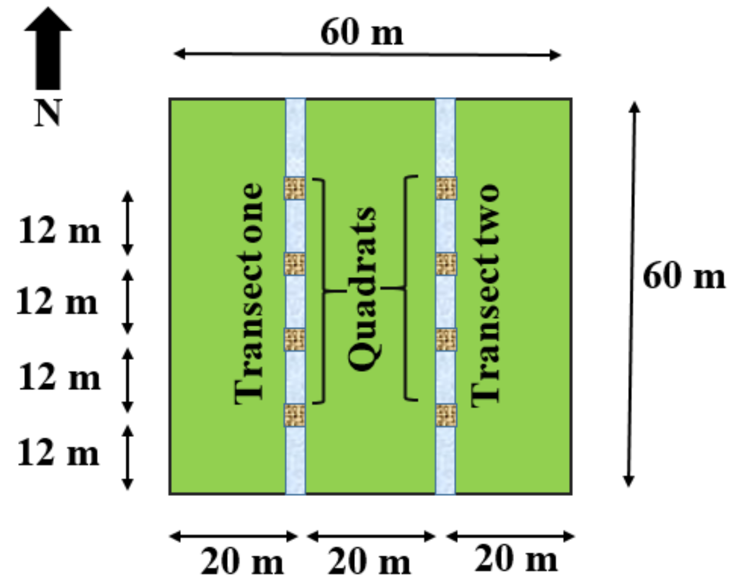
Medium diversity

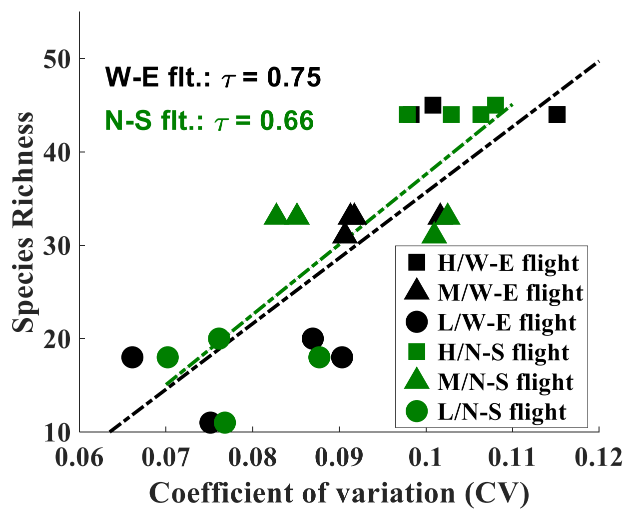
High diversity

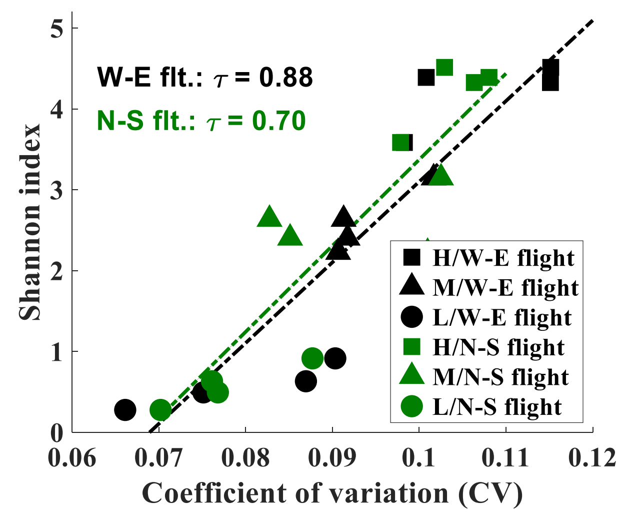
Figure: C. Helzer

# Experimental Design



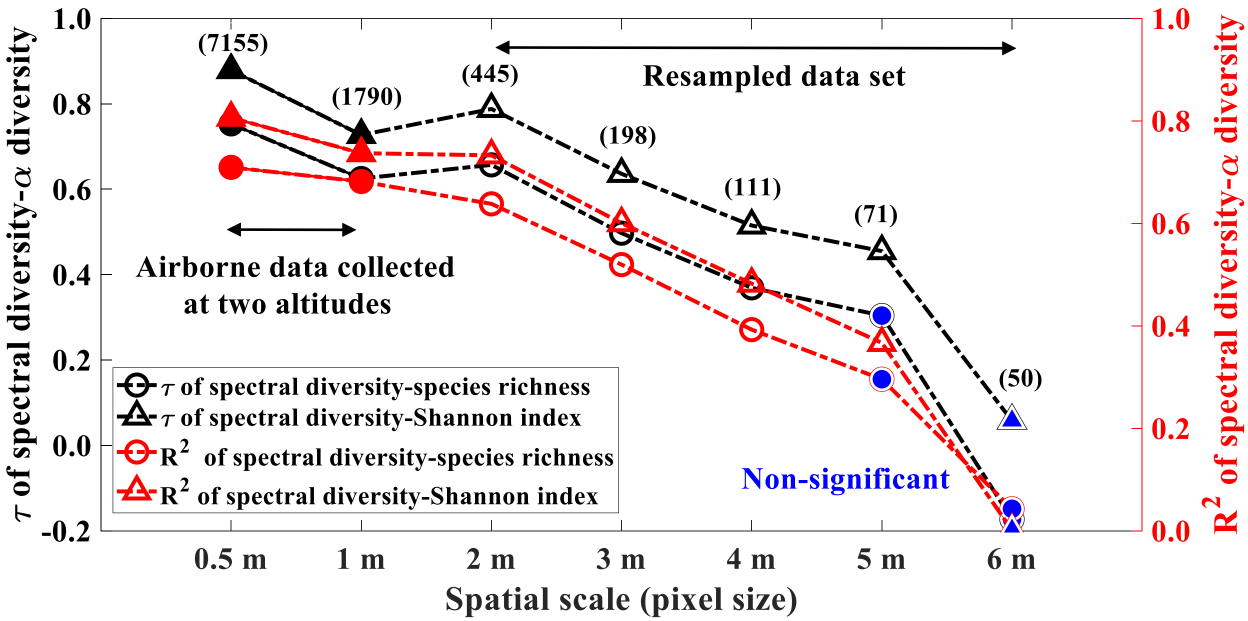




Gholizadeh et al. (in review)

# Spectral diversity-biodiversity is strongly scale-dependent




Gholizadeh et al. (in review)

# Comparison of Cedar Creek to Wood River

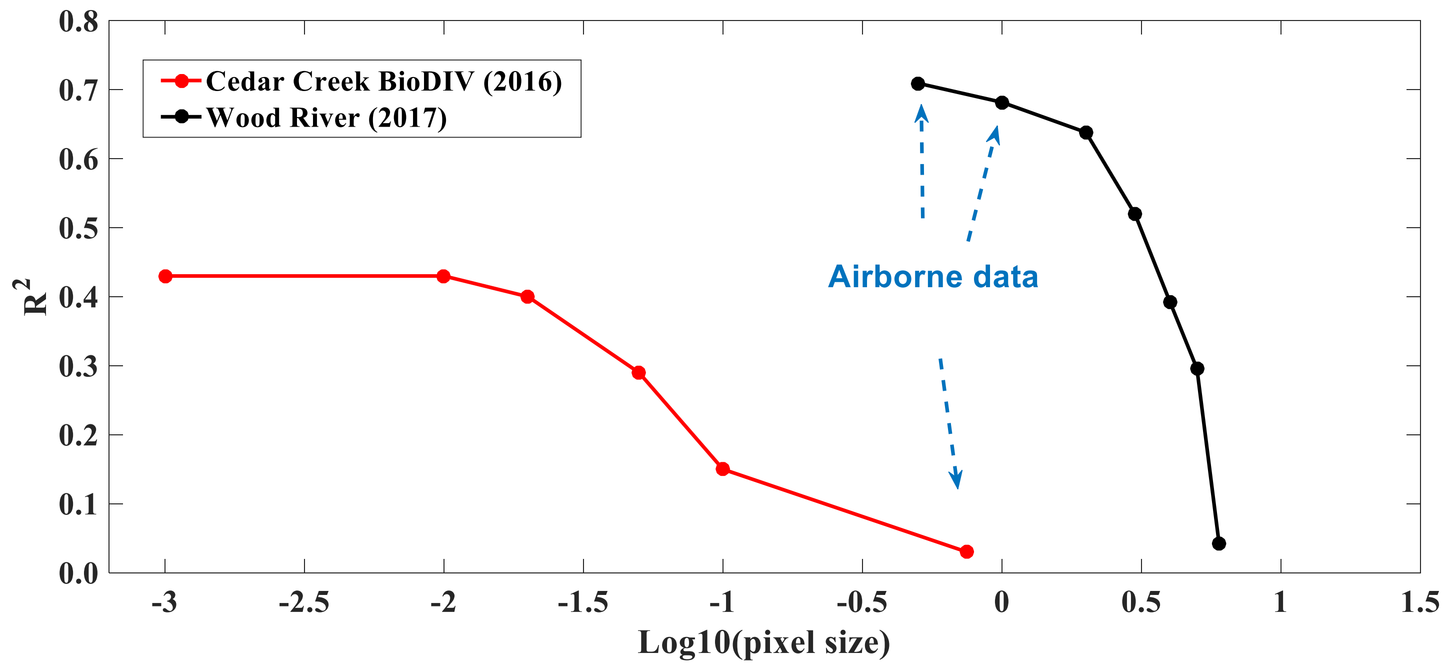
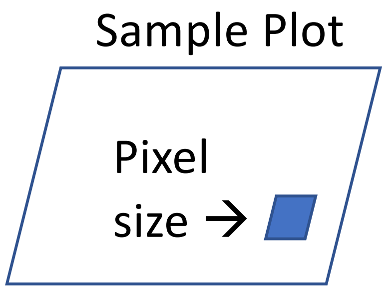



Image: H. Gholizadeh

Possible explanations for different results:

1) Different study designs (manipulations, plot size, # of species)
2) Alpha vs. Beta Diversity

# Normalized scale dependence




Sample size = pixel size/plot size
(# of pixels per plot)

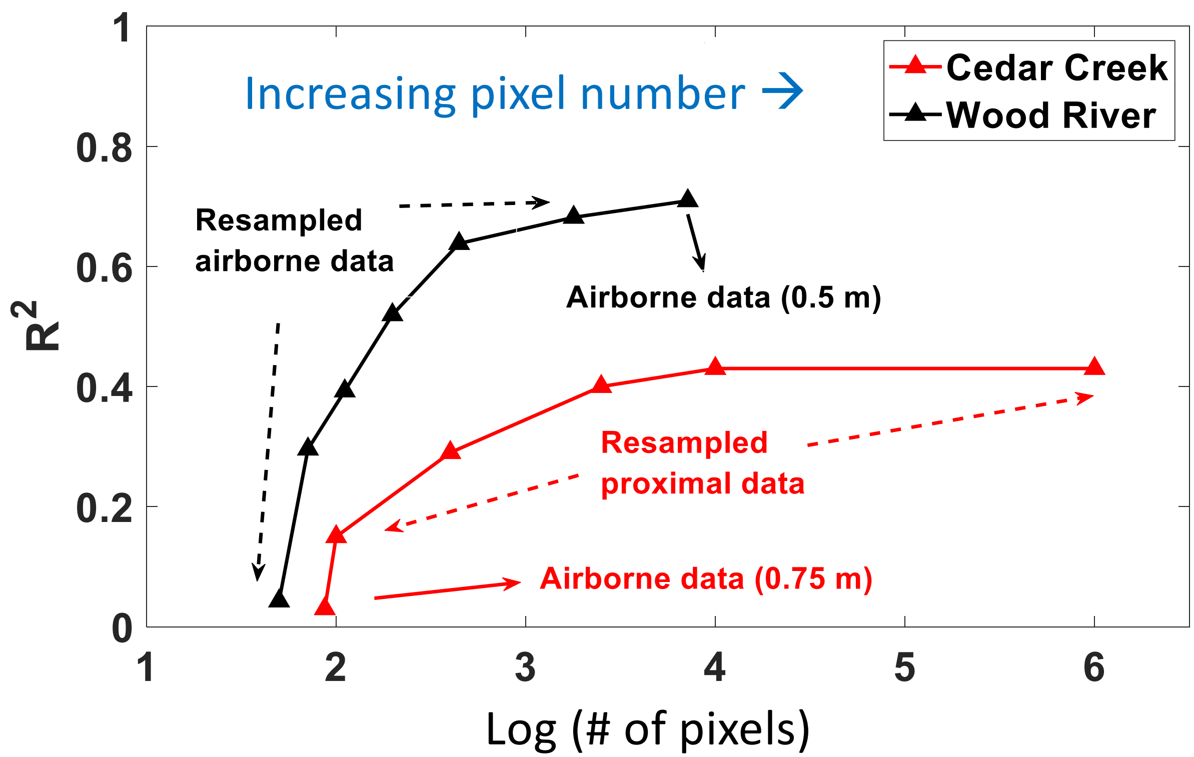
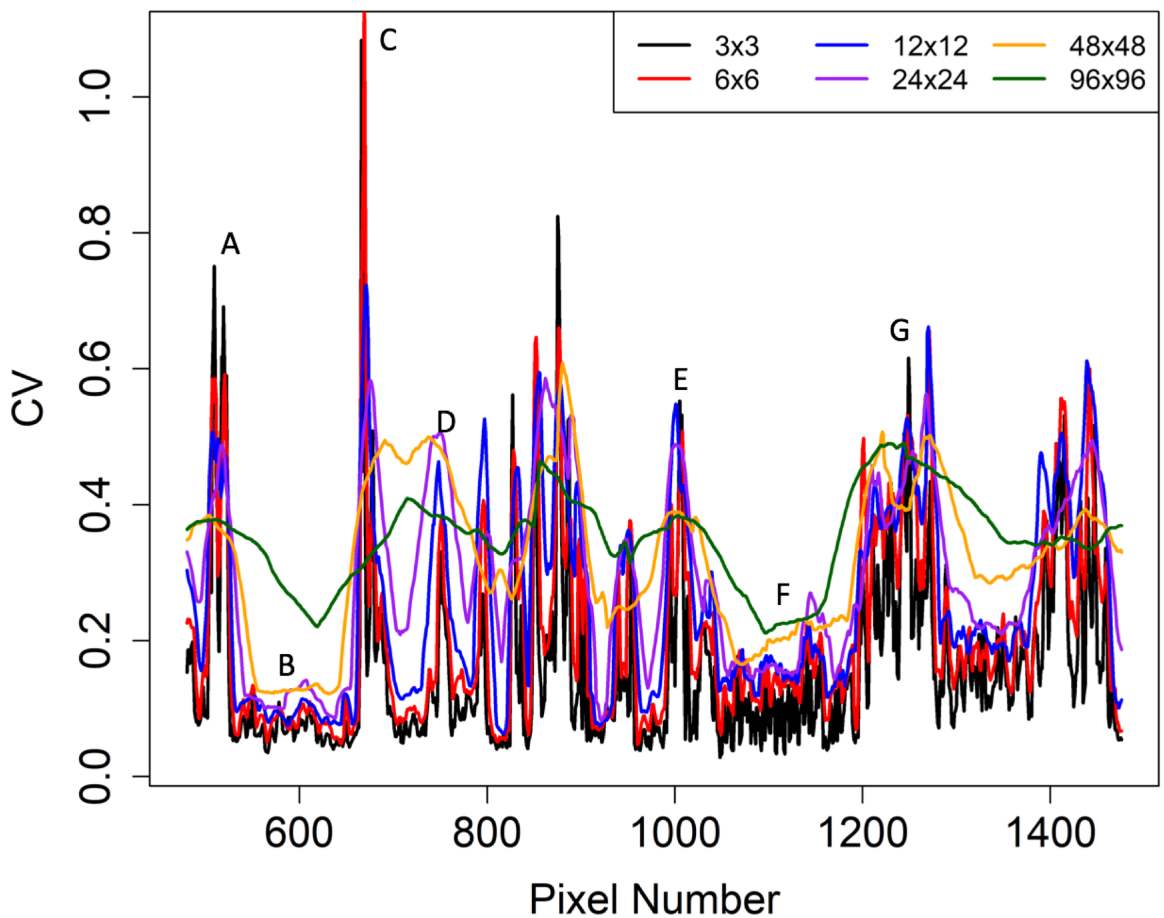
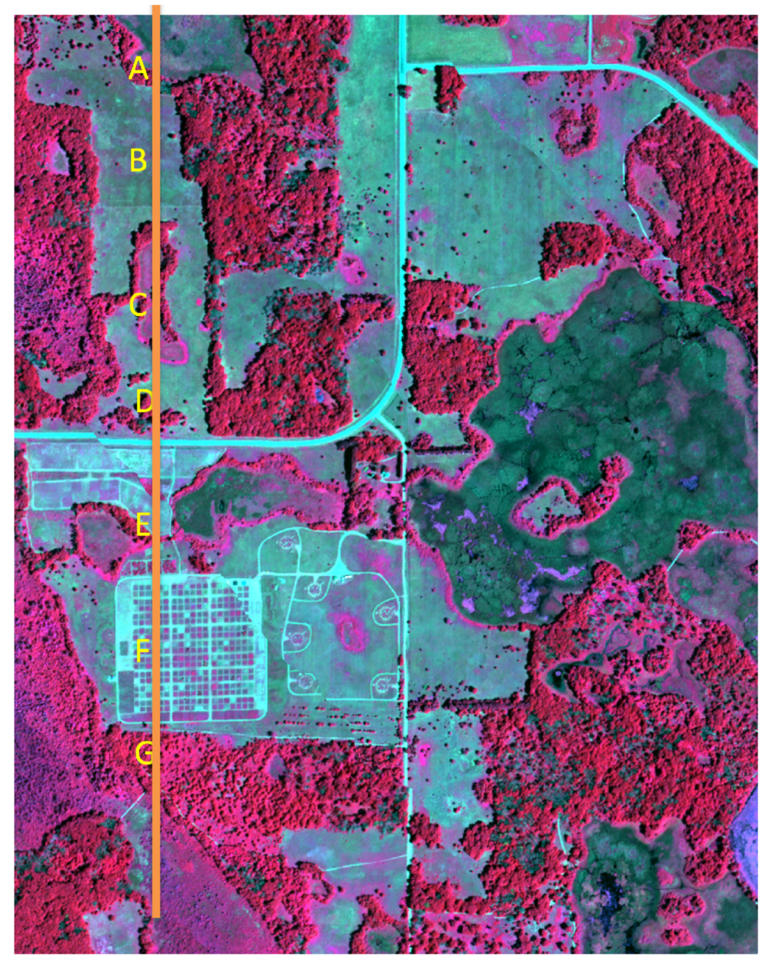



Image: H. Gholizadeh

# Optical Diversity variation across a complex landscape (Cedar Creek)



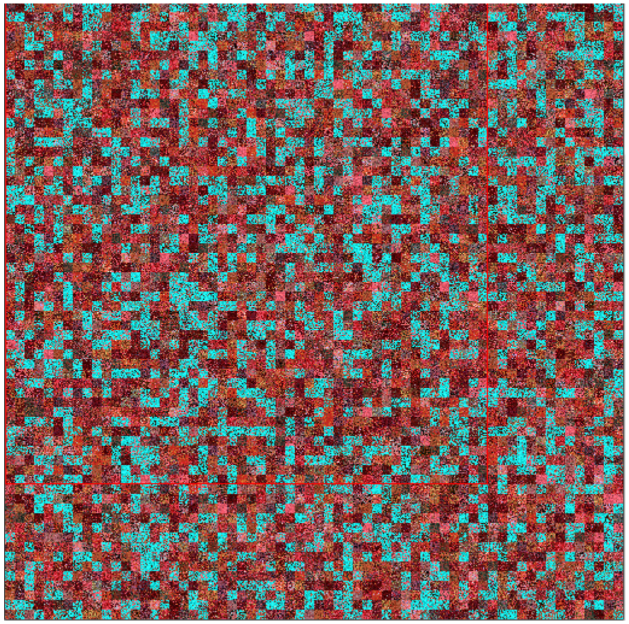

Images: Ran Wang

*Effects of spatial scale are evident in patterns of optical diversity*

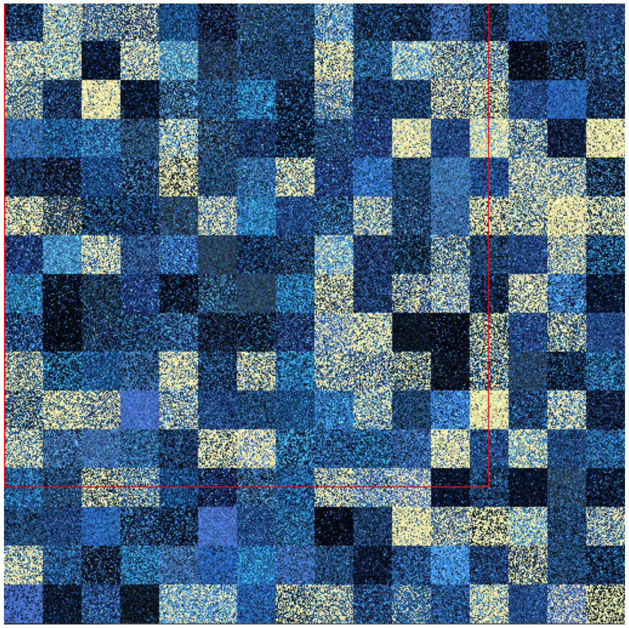
*Scale dependence varies across landscape units (forests vs. grasslands)*

*“Edges” (e.g. ecotones) have large impacts on the “diversity signal”*

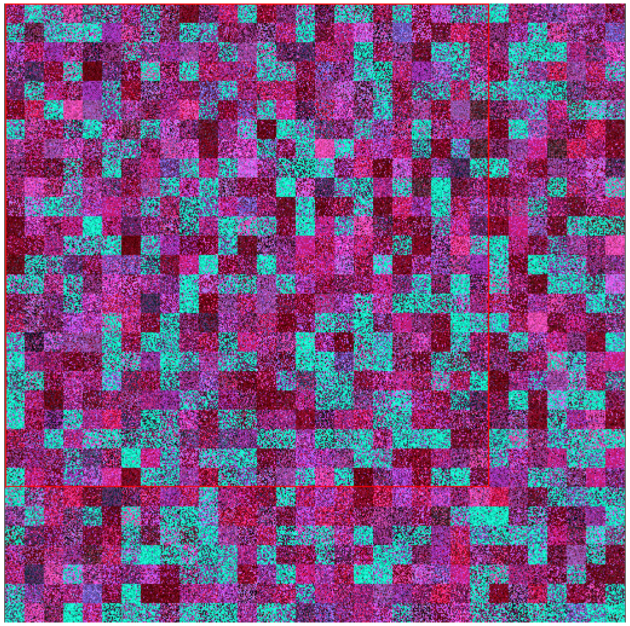
Modeled landscapes simulating different simulated crown sizes, pixel sizes and spatial extents



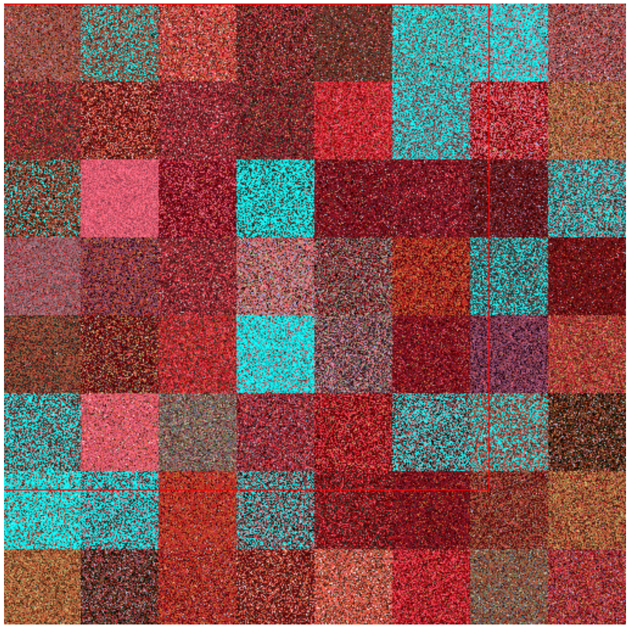
8 x 8



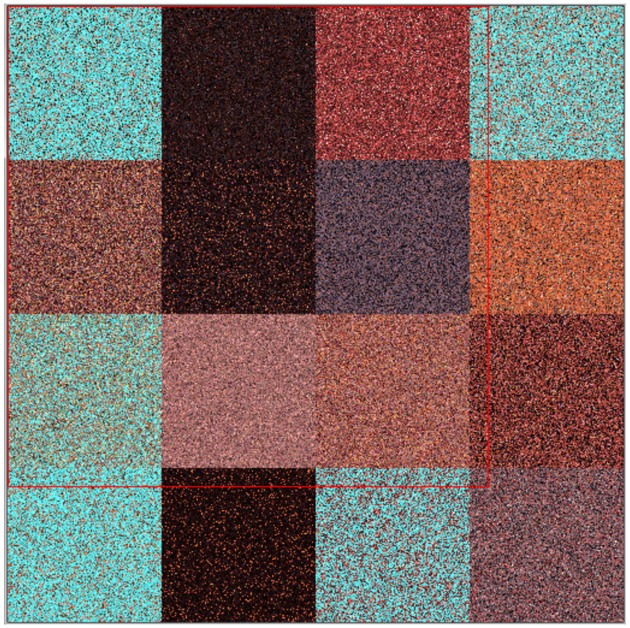
16 x 16



32 x 32



64 x 64



128 x 128

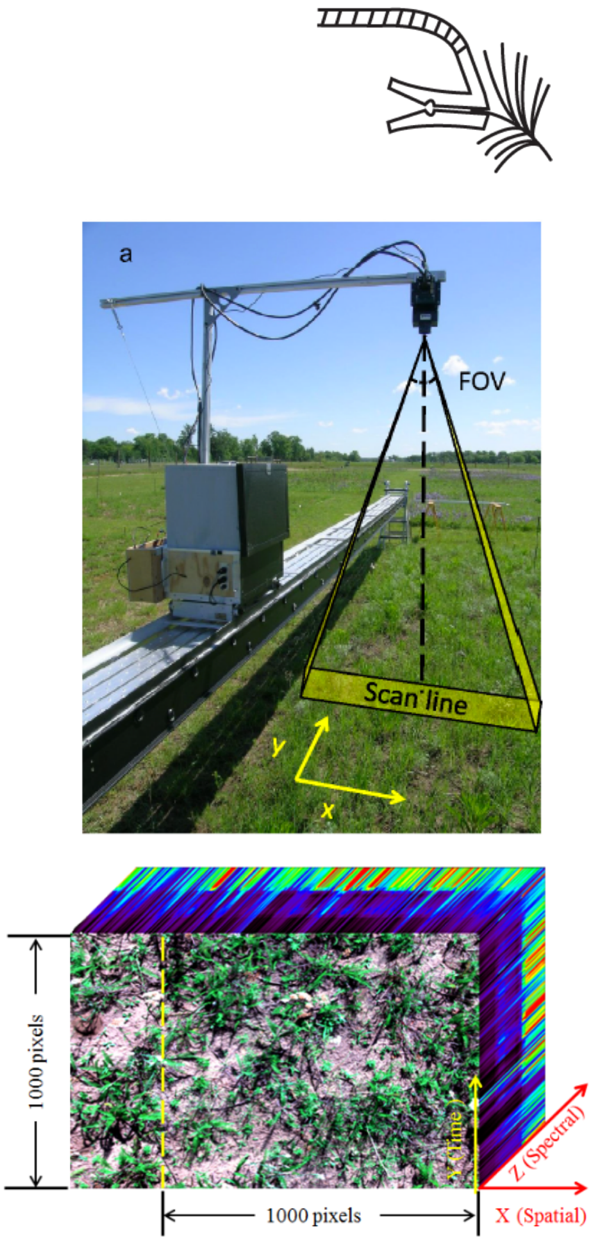
Images: Ran Wang

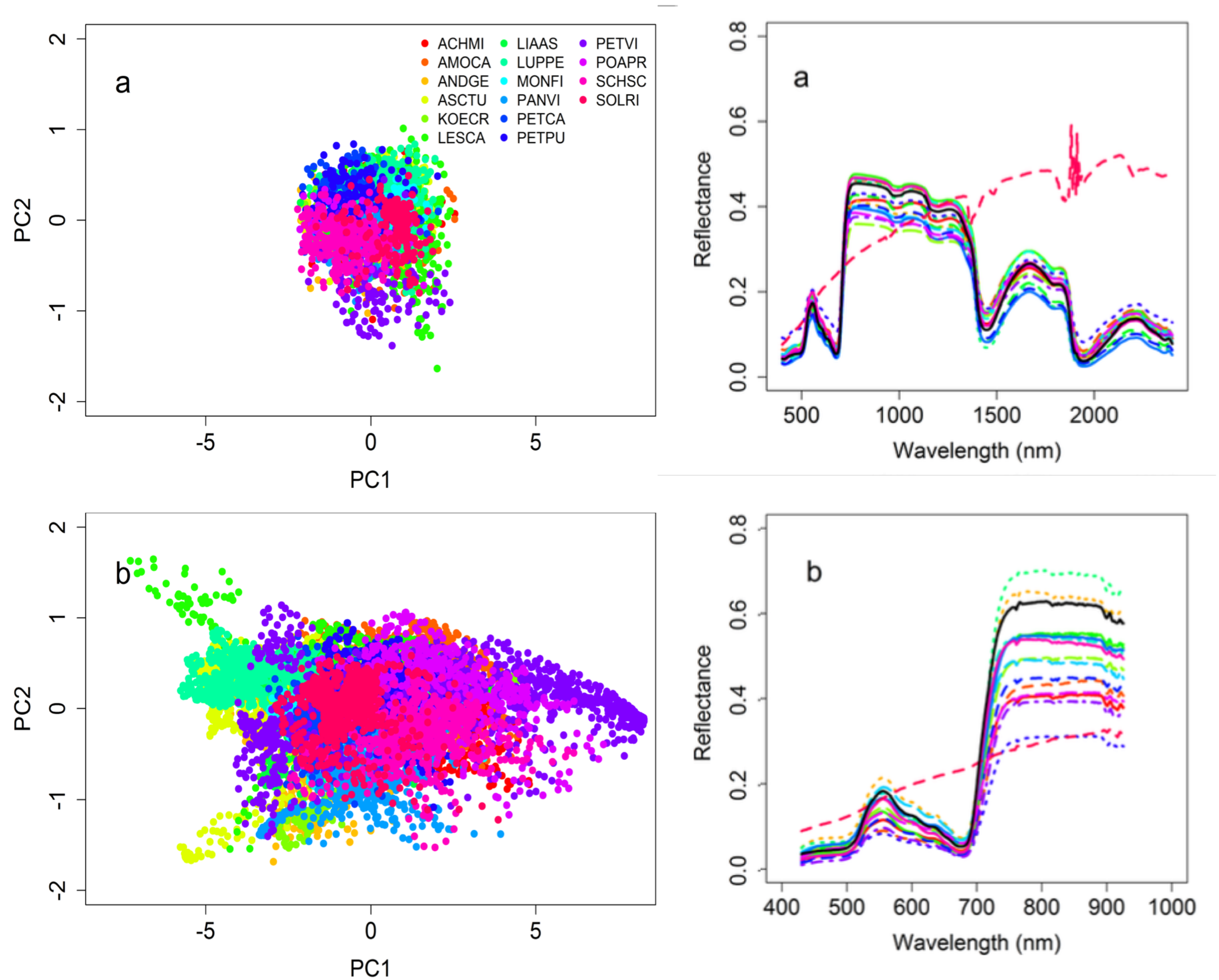
# A few words about "plant traits"

- Often measured at the leaf scale (1 mm-1cm). Most airborne sensors measure at $\pm$1m, and global sensors at $\pm$1 km pixels (2-6 orders of magnitude difference!)
- Legitimate questions remain about whether we can really detect leaf traits from remote sensing
  - Knyazakhin et al. 2012, *PNAS* vs.
  - Townsend et al. 2013, *PNAS*
- Effects of temporal scale (phenology) are poorly understood (Chavana-Bryant et al. 2017)

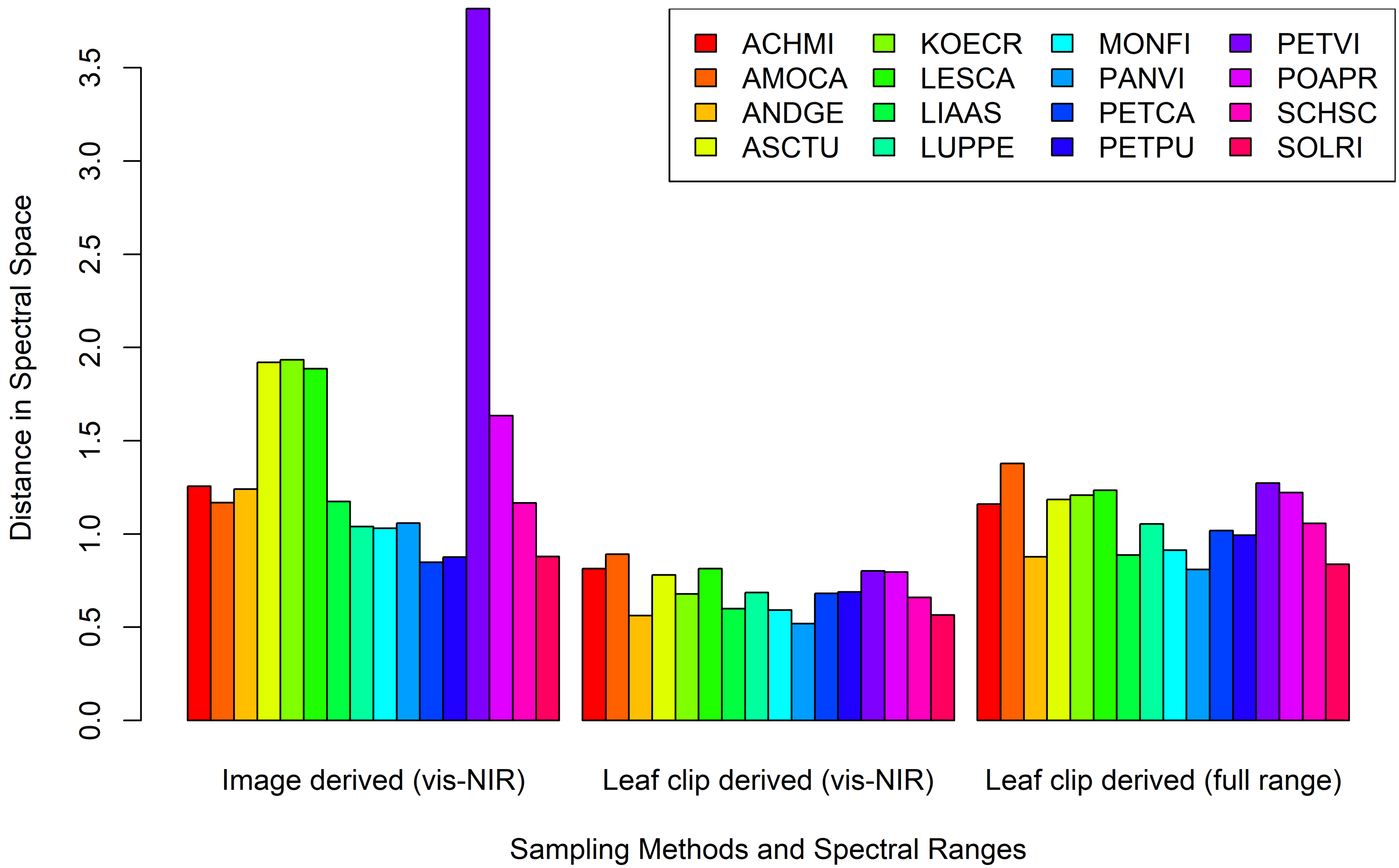
*Trait detection is scale dependent*

# Sampling methods affects spectral diversity (and trait distribution)



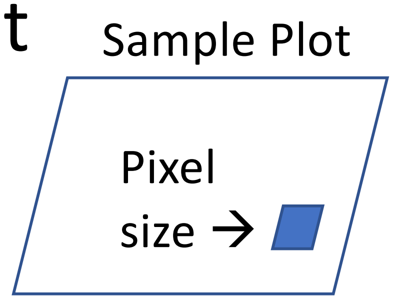

Wang et al. 2018 *Ecological Applications*




Wang et al. 2018 *Ecological Applications*

# Designing the ”ideal experiment”

- Attention to resolution (pixel size) and extent
  - Sample both biodiversity and spectral diversity across scales (express as a continuum)
  - Match pixel size to crown size

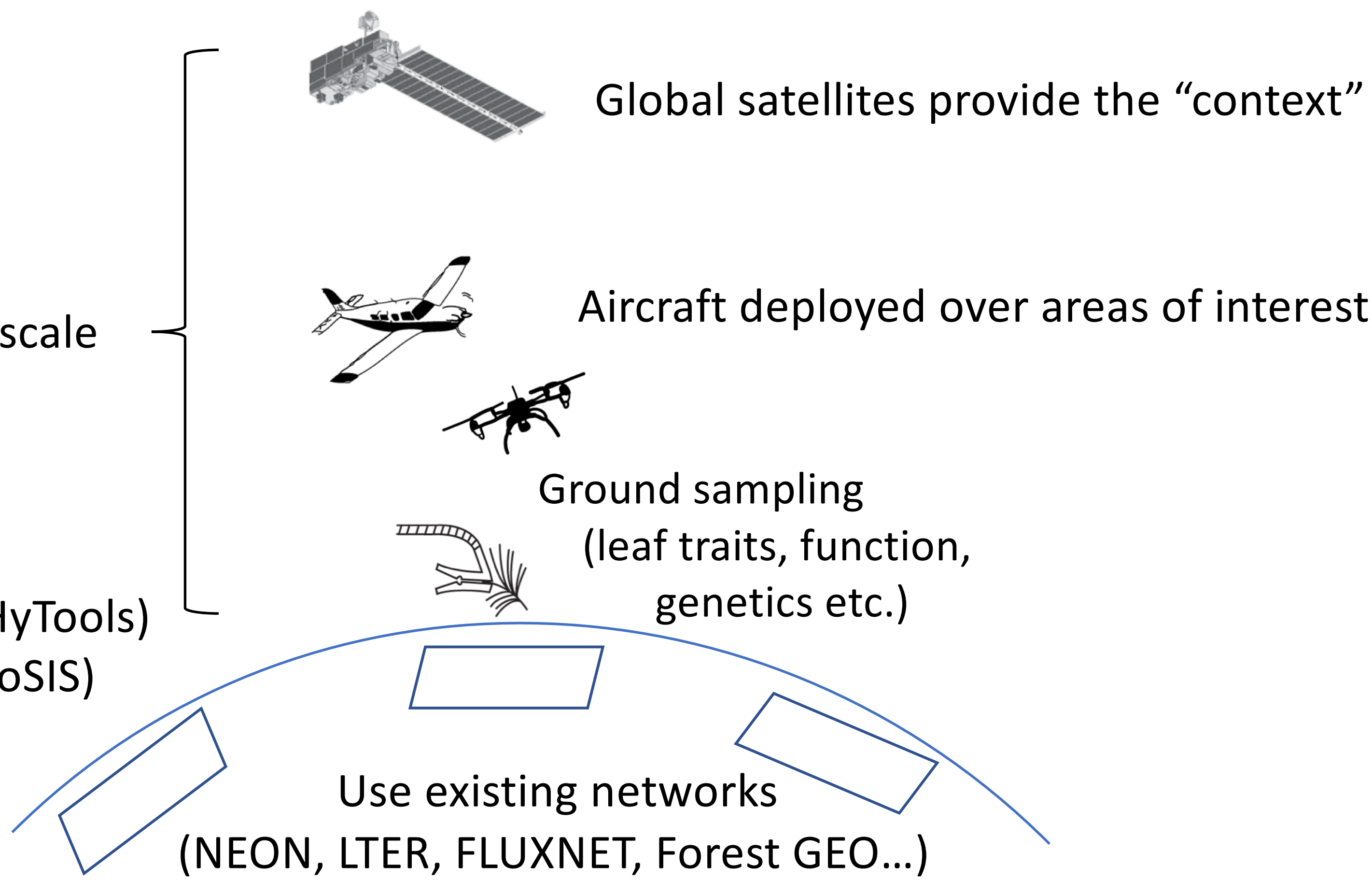



- Attention to landscape patterns and confounding factors such as soil exposure, invasive species, and other disturbances (alpha vs. beta diversity)
- Consider full phenology
- Conduct similar experiments across multiple ecosystems and biomes

# What would a “biodiversity observatory” look like?

- Network linking remote sensing to ground observations
- Standardized protocols & informatics
- Explicit consideration of scale

Multi-scale




<u>Informatics</u>:
Processing (e.g. HyTools)
Archiving (e.g. EcoSIS)
Models (TBD)