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 these 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**

- **Leaf clip**: 1 mm – 1 cm
- **Drone**: 1 cm – 10 cm
- **Plane**: 1 m – 10 m
- **Satellite**: 100-1000 m

Grain size (Log Scale)

Sampling resolution of spectral measurements span 5-6 orders of magnitude
Scale dependence in Remote Sensing: *Temporal scale* – e.g. seasonal variation

![Image of spectral diversity sampling, Santa Monica Mountains, CA](image)

[Graph showing relationship between accuracy and species diversity over time, with different wavelengths and indices represented.](graph)

Zutta 2003
Scale Dependence in Remote Sensing: *Spectral Scale*

Scale dependence - Biological Scale

Species-Area Curves:

Biodiversity definitions:

- 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*

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

Collaborators:
Jeannine
Phil
Anna
Dudu

Figure: J. Cavender-Bares
Study sites:

Cedar Creek (U. Minnesota)  Wood River (Nature Conservancy)

Figure: Cedar Creek Ecosystem Science Reserve
Figure: C. Helzer

Cedar Creek, MN

Wood River, NE
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:

- Individual plots
- Spectral image of a plot
- Spectra from contrasting vegetation patches

Cavender-Bares et al. (2017)

Wang et al. 2018 Ecological Applications

U. Nebraska-Lincoln Airborne Observatory ("CHAMP")
Effects of Spatial Scale on Spectral Diversity

1 mm pixels

10 cm pixels

0.5 m pixels

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

Possible explanations for different results:
1) Different study designs (manipulations, plot size, # of species)
2) Alpha vs. Beta Diversity

Image: H. Gholizadeh
Normalized scale dependence

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

Increasing pixel number →

Image: H. Gholizadeh
Optical Diversity variation across a complex landscape (Cedar Creek)

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

Images: Ran Wang
A few words about “plant traits”

- Often measured at the leaf scale (1 mm-1cm). Most airborne sensors measure at ±1m, and global sensors at ±1 km pixels (2-6 orders of magnitude difference!)

- Legitimate questions remain about whether we can really detect leaf traits from remote sensing
  - 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 affect spectral diversity (and trait distribution)
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

Informatics:
- Processing (e.g. HyTools)
- Archiving (e.g. EcoSIS)
- Models (TBD)

Global satellites provide the “context”

Aircraft deployed over areas of interest

Ground sampling (leaf traits, function, genetics etc.)

Use existing networks (NEON, LTER, FLUXNET, Forest GEO...)

Multi-scale