Mapping tropical forest diversity with hyperspectral imaging: how does species composition influence spectral variance?

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CONTEXT

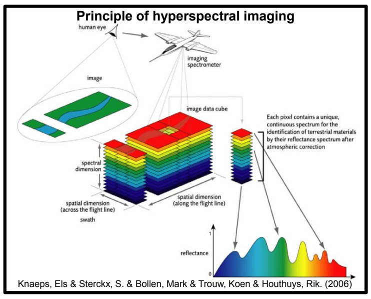
- **Biodiversity:** a measure of diversity is an indicator characterizing the species composition and structure of communities[3].
- **Erosion of biodiversity:** the Amazon rainforest is one of the main reservoirs of biodiversity[1]. Climate change and anthropic pressure[2] cause rapid biodiversity loss.
- **Satellite remote sensing (SRS):** provides rapid, frequent and cost-effective information over large areas.

→ Need for operational monitoring systems taking advantage of SRS information to assess tropical forest biodiversity & degradation.

→ Preparation of future hyperspectral satellite missions BIODIVERSITY, CHIME, SBG, EnMAP

HYPERSPECTRAL IMAGING

- Acquisition of images with high spectral dimensionality from visible to infrared domains:



Knaeps, Els & Sterckx, S. & Bollen, Mark & Trouw, Koen & Houthuys, Rik. (2006)

LINKING SPECTRAL INFORMATION TO SPECIES DIVERSITY

- **Hyperspectral imaging** has demonstrated strong potential for detecting changes in floristic and functional composition of temperate and tropical forests[4, 5, 6].
- **Spectral variability** integrates chemical and structural diversity of canopy.
- **Spectral Variation Hypothesis (SVH)**[7]: spectral variability expresses spatial heterogeneity in ecosystems, which can be linked to taxonomic & functional diversity of vegetation

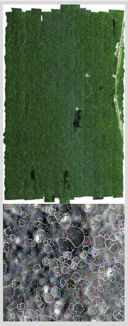
➔ Objective: Quantify the link between spectral diversity and taxonomic diversity.

MATERIAL AND METHODS

Ground information

- **Study site:** Paracou, French Guiana, ~500 ha. Several experimental plots of 6.25 ha.
- **Plot inventories:** All stems above 10 cm DBH inventoried every 1–2 years → ~750 tree species listed
- **Large ground truth dataset of individual tree crowns (ITCs) delineated using LiDAR data**[8].

Hyperspectral data preprocessing



1 - Extract pixels corresponding to delineated crowns

2 – Mask non-vegetated & shaded pixels

3 - Remove atmospheric water band

4 – Apply continuum removal to the reflectance data

5 - Remove all crowns including less than 10 pixels

6 - Random selection of 10 pixels per remaining crowns

ITC dataset:

123 spectral bands from 418 to 880 nm
1140 crowns corresponding to 163 species
11400 pixels

Generation of artificial populations

- **Objective:** produce a range of taxonomic diversity & composition
- **Method:** resample ITC dataset to generate artificial populations

MINIMUM DIVERSITY (MIN) → Artificial populations with **2 species and 100 individuals**

MAXIMUM DIVERSITY (MAX) → Artificial populations with **100 species and 100 individuals**

GRADUAL INCREASE OF DIVERSITY (MINTOMAX) → Artificial populations of increasing diversity

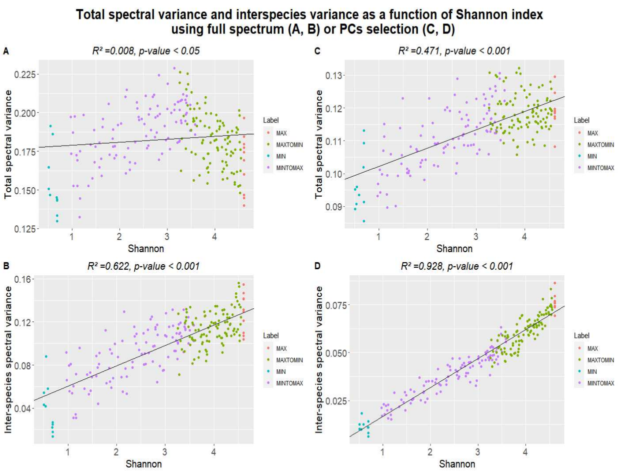
GRADUAL DECREASE OF DIVERSITY (MAXTOMIN) → Artificial populations of decreasing diversity

→Partitioning of spectral diversity[5] on these artificial populations

RESULTS

Relationship between spectral variance and taxonomic biodiversity is analyzed in two situations:

→ Spectral variance computed from full spectral information
→ Spectral variance computed from a selection of principal components (identified with random forest classification to maximize species discrimination)



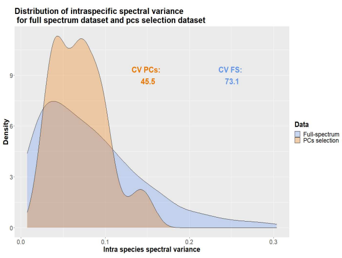
Full spectrum:

- Low correlation between spectral variance and taxonomic diversity indices.
- The taxonomic signal is not easily detectable in the whole spectrum.

PC selection:

- The correlation between spectral variance and taxonomic diversity indices is strongly improved.
- The scatter plot has a more linear shape: the selection of PCs keeps useful information and helps to reduce noise.

- **Inter-species variance corresponds to 40% of the total spectral variance.**
- **Intra-crown (residual) variance** is considered as **noise** and corresponds to **20% of the total spectral variance.**
- **Intra-specific variance is heterogeneous across species:** a limited number of species show high levels of intra-specific variance.
- **Intra-specific variance is not related to abundance.**
  →Populations including species with high intra-specific variance lead to higher total spectral variances[9].
- PCs selection results in more balanced intra-species variance distribution → **Explains the more linear shape of the point cloud**



CONCLUSIONS & PERSPECTIVES

- **PCs selection** improves the statistical relationship between **spectral variance** and **taxonomic diversity** indices. It opens perspectives for the identification of critical spectral domains and physical interpretation of the relationship between spectral and ecological information.
- **The generation of artificial populations may be improved.** The realism of low diversity populations is questionable in the context of tropical ecosystems, and the total spectral variance tends to saturate for higher levels of diversity.
- This method is applicable to explore statistical relationship between spectral variance and functional / genetic diversity if ground information available.
- **For operational and reproducible monitoring of forest biodiversity,** further analysis are necessary to :
  - Identify critical spectral domains / bands for species discrimination.
  - Identify optimal sensor characteristics (spatial resolution, spectral sampling)
  - Study different variations of very diverse simulated populations to understand the evolution of the spectral variance.
- An approach using **object classification and automatic segmentation of tree crowns** is considered to reduce the intra-crown variance.

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