Observation de la Terre par imagerie optique : de la mesure physique à l'indicateur écologique (part II)

Jean-Baptiste Féret
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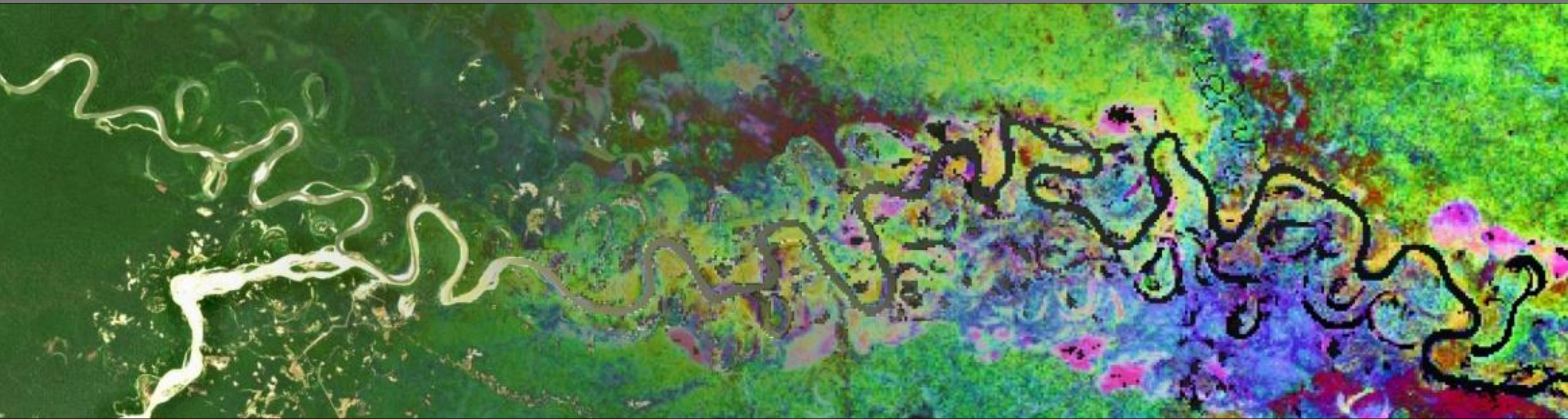

Apports, intérêts, limites de la télédétection pour mieux connaître la biodiversité

Atelier du métaprogramme BIOSEFAIR, 14 novembre 2023

- **Introduction**
- **Explore spatial, temporal and spectral dimensions from space**
- **A quick dive into the spectral space**
- **Current missions and forthcoming opportunities**
- **Earth observation and biodiversity : one approach among many**
- **Conclusions and perspectives**

From remotely sensed information to ecological information

- **What is needed to assess biodiversity metrics from space?**

  → Information related to composition, functions, structure…

  - species occurrence & species / species community distribution
  - Vegetation traits related to phenology, photosynthesis, LMA, nitrogen, water content…
  - …

- **What do we measure from space ?**
  - Signal reflected, emitted, backscattered from Earth surface
  - … combining multiple factors intrinsic and extrinsic to surfaces / objects of interest

- **How to translate satellite acquisition into ecologically meaningful information ?**
  - [physical & statistical] models to assess continuous vegetation biophysical properties
  - Classifiers to discriminate among vegetation types or species
  - Methods integrating spatiotemporal information to produce higher level metrics
    - Phenometrics related describing pixelwise seasonality
    - Spatial heterogeneity of spectral information (~ spectral variation hypothesis)
    - …

From remotely sensed information to ecological information

- **How to link reflectance & optical traits to ecological information?**

→ Identify a relationship between spatial heterogeneity in spectral information and environmental / ecological heterogeneity / biodiversity

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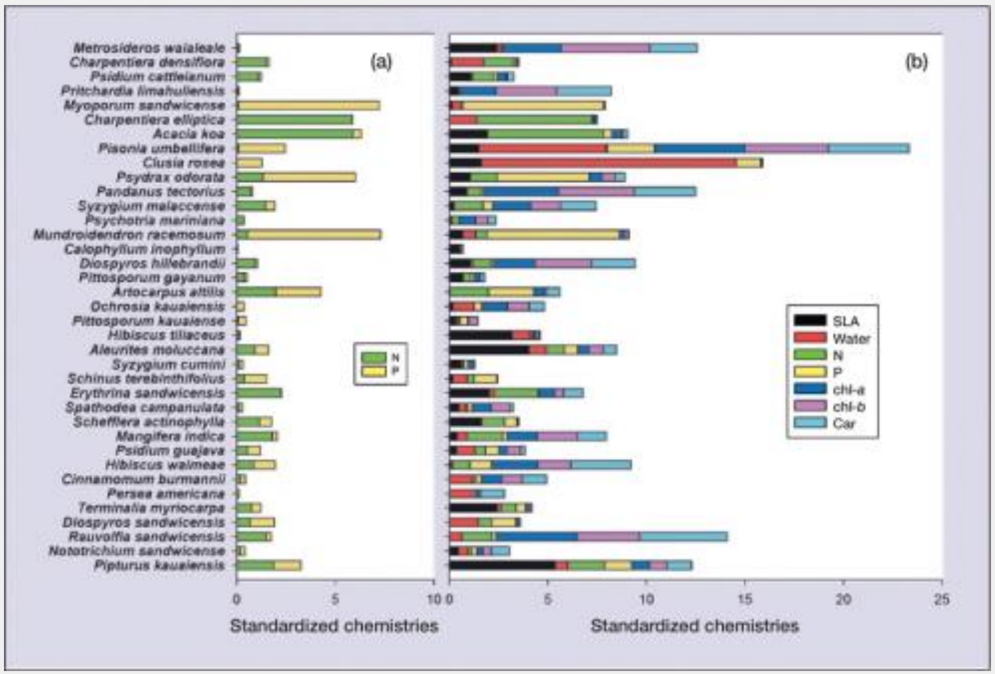
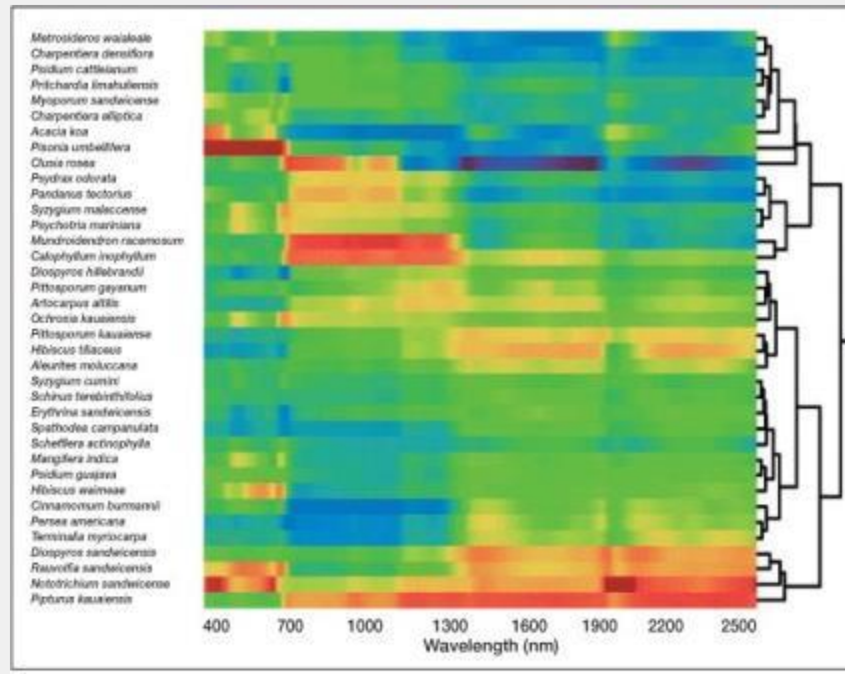




Asner & Martin (2009), *Frontiers in Ecology and the Environment*, 7:269-276.
Asner et al. (2009), *Ecological Applications*, 19:236-253.
http://spectranomics.stanford.edu/

From remotely sensed information to ecological information

- **How to link reflectance & optical traits to ecological information?**

  → Identify a relationship between spatial heterogeneity in spectral information and environmental / ecological heterogeneity / biodiversity

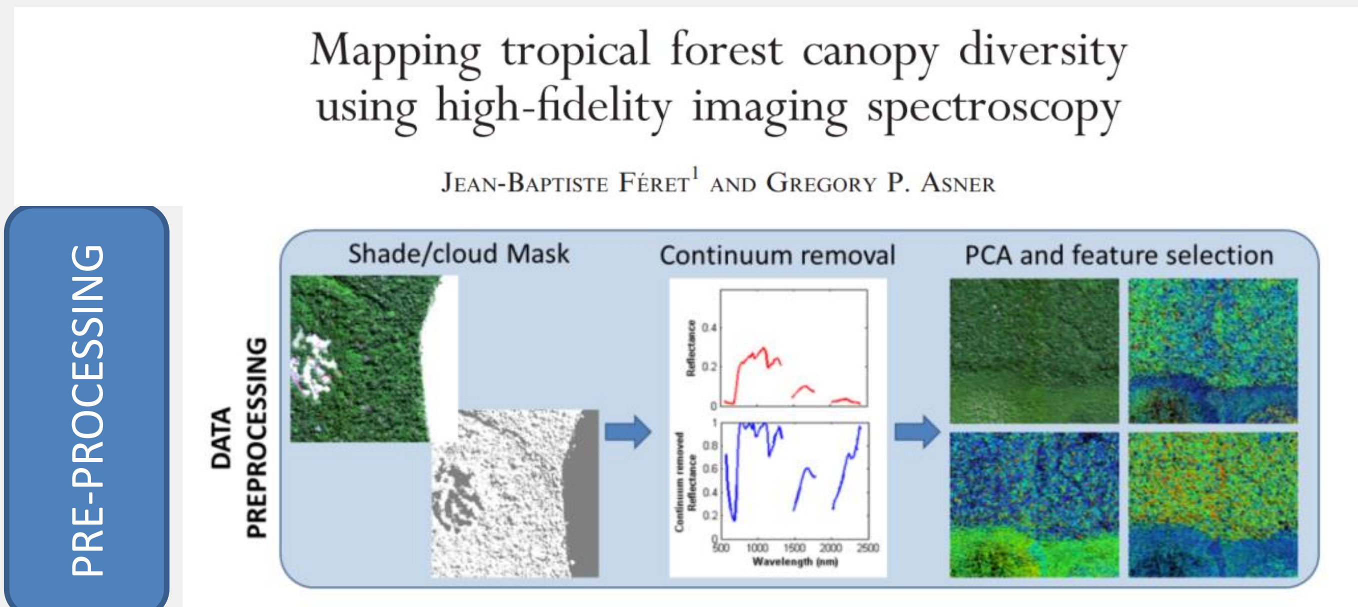
- **Which information should be used to approximate 'optical traits'?**
  - Transformed reflectance (Féret & Asner, 2014, Laliberté et al., 2020)
  - Spectral indices (Schneider et al., 2017)
  - Biophysical properties (Hauser et al., 2021)

- **How to express spectral variations ?**
  - Univariate / multivariate space
  - Discrete / continuous space

- **Which ground observations should be compared with spectral information ?**
  - Species / taxonomic diversity
  - Functional diversity
  - …

From remotely sensed information to ecological information

- **Which information should be used to approximate ‘optical traits’ ?**
  - Transformed reflectance (Féret & Asner, 2014, Laliberté et al., 2020)
    - No prior assumption on thematic relevance of spectral information
    - Data driven → possibly limiting when studying sites independently
    - Manual or automated feature selection (PCs or bands) may be needed
    - Transformation (PCA / MNF) may help reduce influence of sensor noise & artifacts



Féret & Asner (2014) Mapping tropical forest canopy diversity using high-fidelity imaging spectroscopy. *Ecological Applications*, 24 – 1289-1296 https://doi.org/10.1890/13-1824.1
Laliberté et al. (2020) Partitioning plant spectral diversity into alpha and beta components. *Ecology Letters*, 23(2) – 370-380 https://doi.org/10.1111/ele.13429

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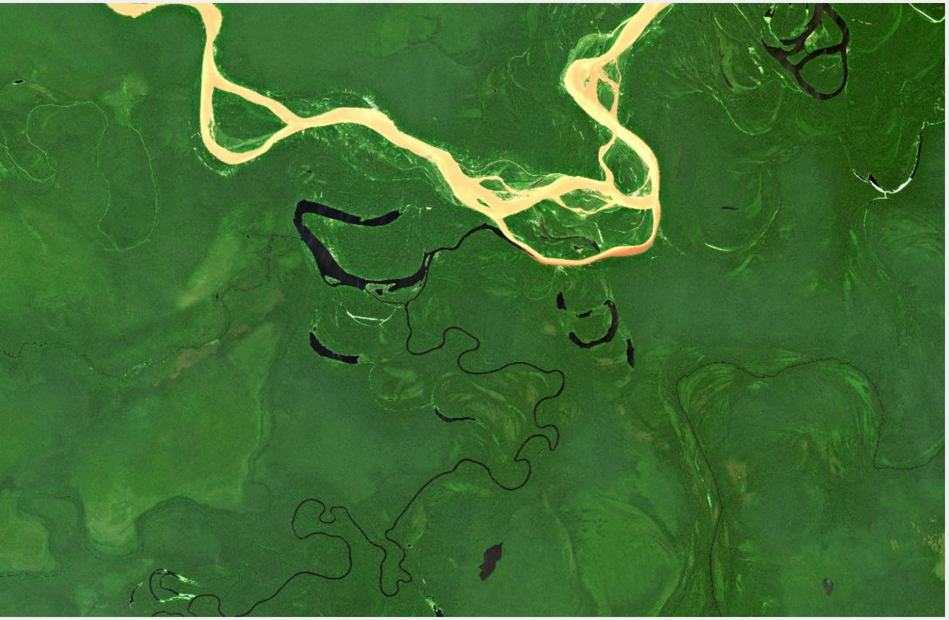
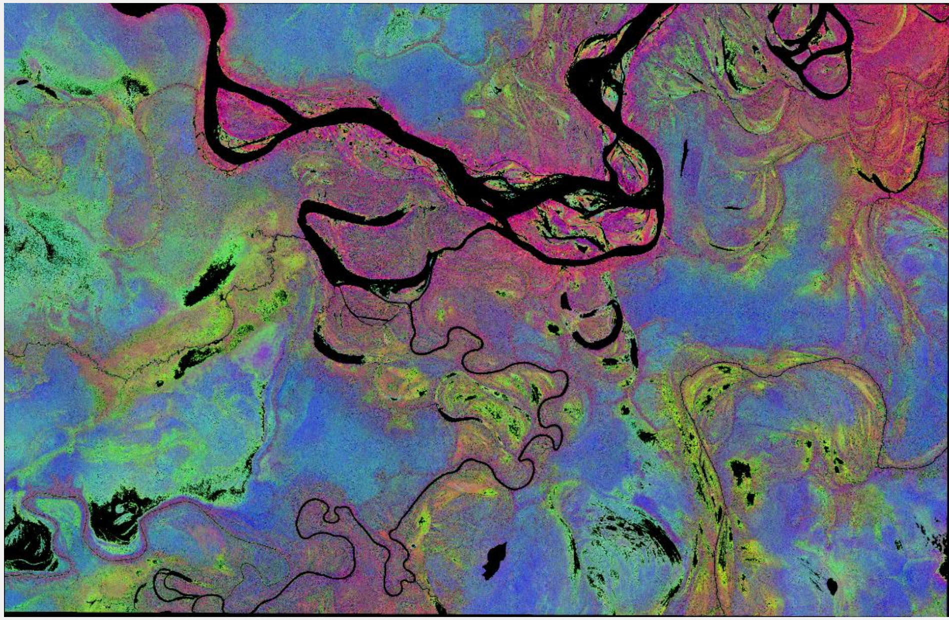
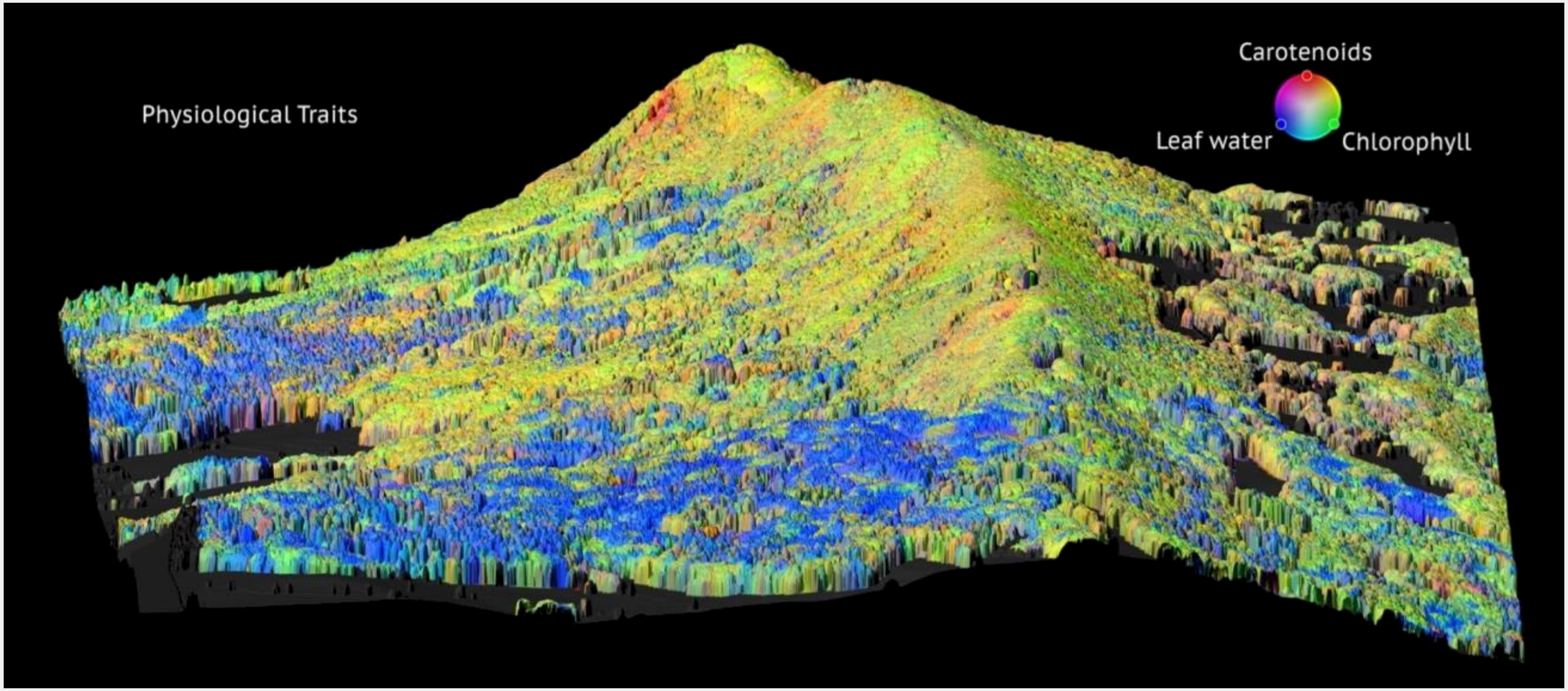
Application on Amazonian forest, Peru:
Continuum removal & SPCA performed on S2 image, three components selected for display





From remotely sensed information to ecological information

- **Which information should be used to approximate 'optical traits' ?**
  - Transformed reflectance (Féret & Asner, 2014)
  - Spectral indices ([Schneider et al., 2017](https://doi.org/10.1038/s41467-017-01530-3))
    - Selection of spectral indices based on their correlation with vegetation traits
    - Many SI identified in the literature, possibly strongly correlated
    - Influenced by multiple factors (structure & chemistry), sensitive to sensor noise



Schneider et al. (2017) Mapping functional diversity from remotely sensed morphological and physiological forest traits. *Nature Communications*, 8 – 1441 https://doi.org/10.1038/s41467-017-01530-3

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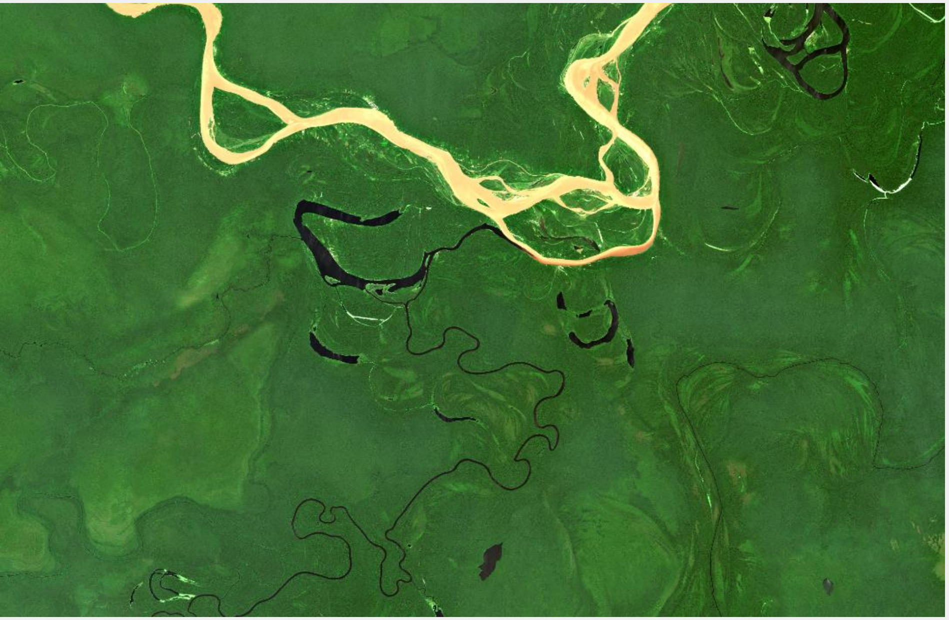
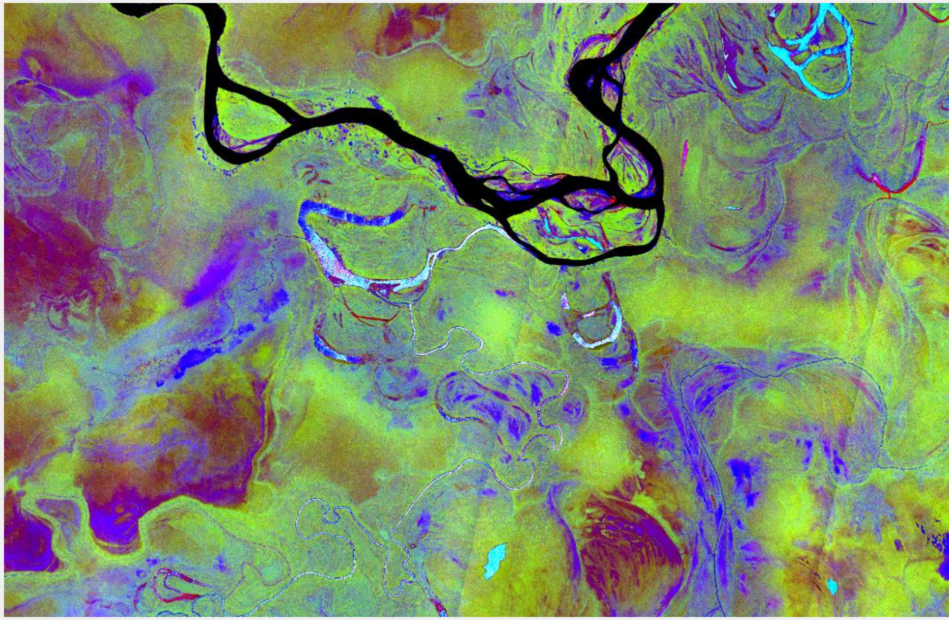
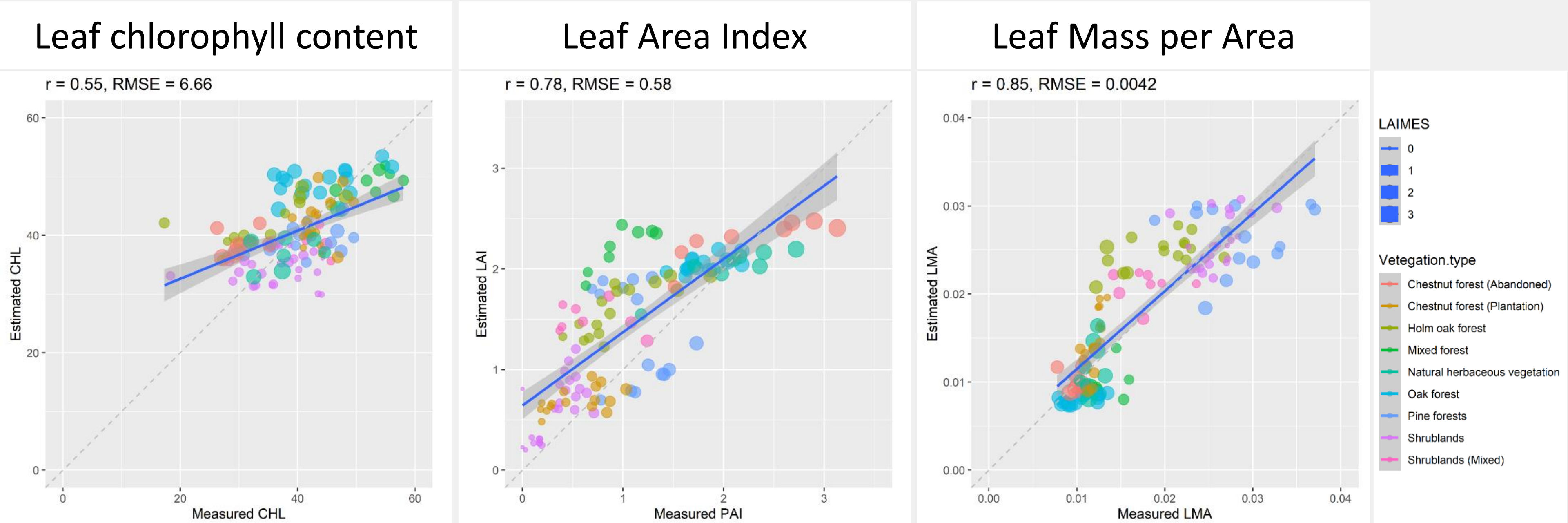
Application on Amazonian forest, Peru:
Color composite MCARI, $mNDVI_{705}$, $NDWI_1$





From remotely sensed information to ecological information

- **Which information should be used to approximate 'optical traits' ?**
  - Transformed reflectance (Feret & Asner, 2014)
  - Spectral indices (Schneider et al., 2017)
  - Biophysical properties (Hauser et al., 2021)
    - Estimate vegetation biophysical properties based on spectral information
    - Computationally more intensive than spectral indices
    - Easier interpretation by ecologists/agronomists (leaf chemistry, LAI…)



Hauser et al. (2021) Towards scalable estimation of plant functional diversity from Sentinel-2: In-situ validation in a heterogeneous (semi-) natural landscape, *Remote Sensing of Environment*, 265 – 112684 https://doi.org/10.1016/j.rse.2021.112684

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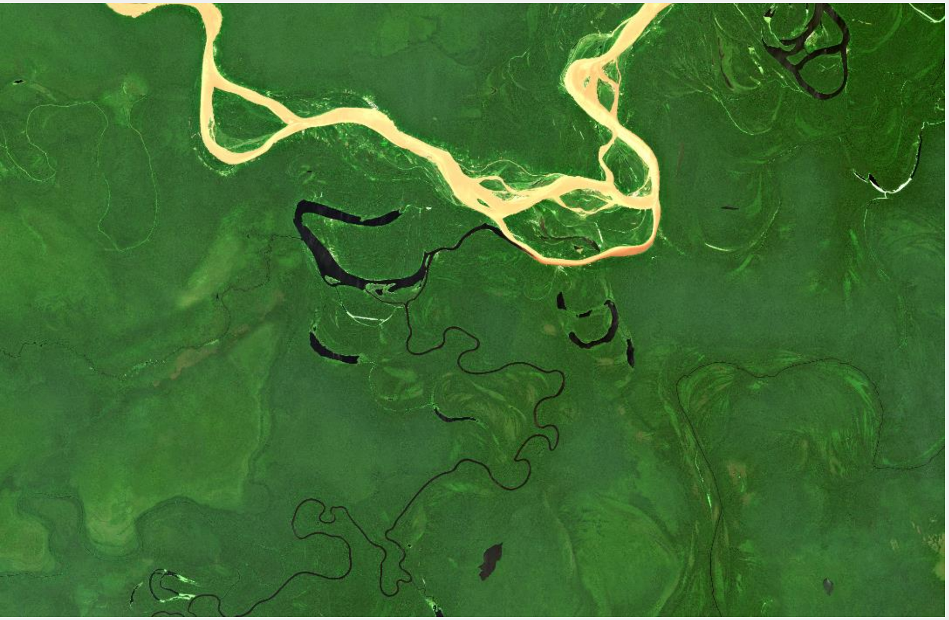
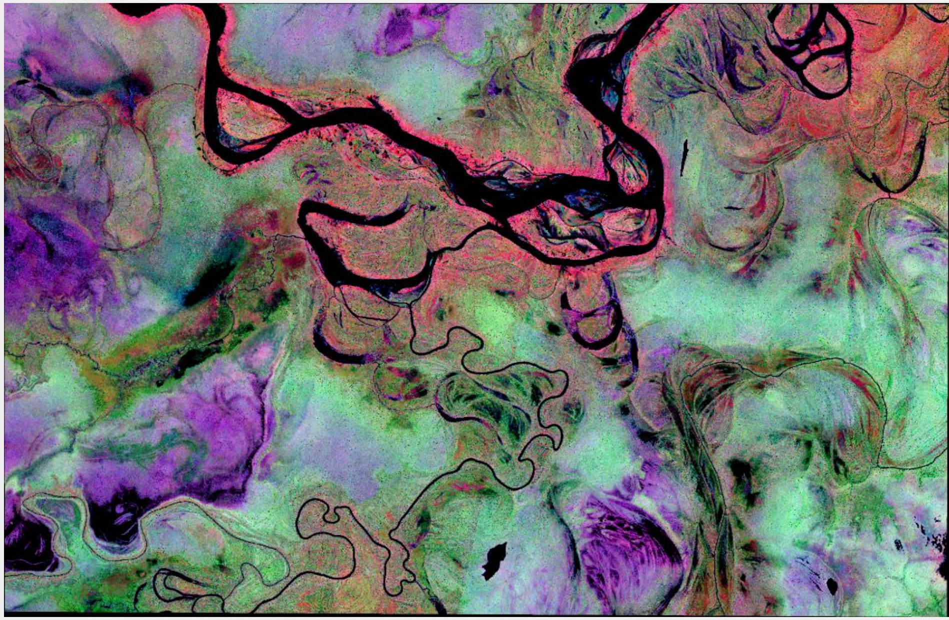
Application on Amazonian forest, Peru:
Estimation of LAI (red), CHL (green)& EWT (blue) from S2 image and PROSAIL hybrid inversion



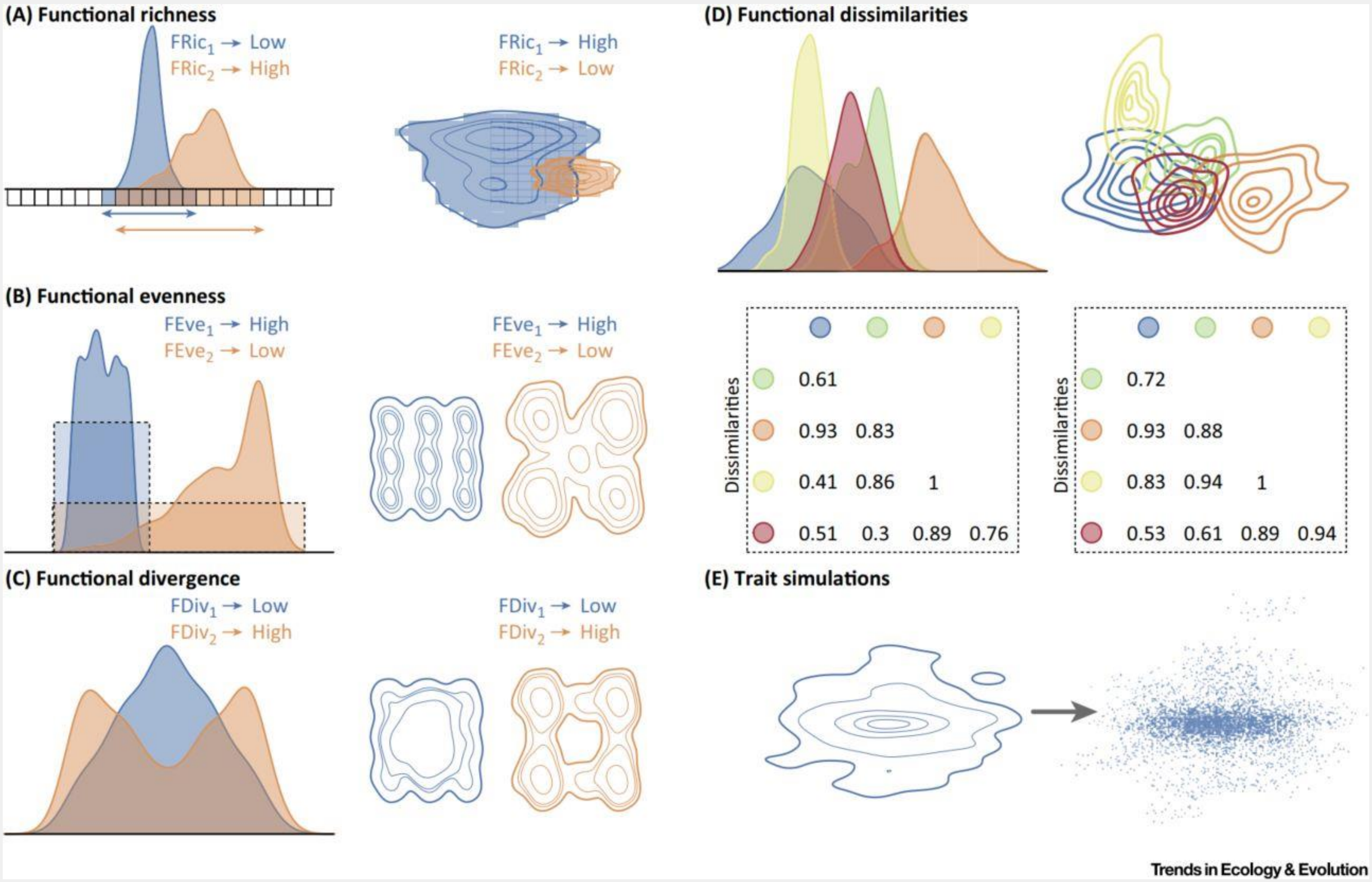


From remotely sensed information to ecological information

- **How to express spectral variations ? Integrating spectral variations over a spatial extent**
  - Define a <u>spatial extent</u> matching with ecological hypotheses, ground & RS observations
    - Forest ecosystems: surface of inventory plots ~ 0.25 – 1 ha
    - Statistics may need min number of pixels constraining surface unit from RS
    - Regular grid, moving window…
  - Explore feature space (spectral index, biophysical properties, principal components…)
    - Univariate space (potentially limiting for complex ecological processes):
      - Standard deviation, spectral range of feature over spatial extent
    - Multivariate space
      - Mean distance from centroid, mean coefficient of variation, entropy
  - **Discrete / continuous space**
    - Continuous space: trait space / spectral space
    - Discrete space: classification / clustering of trait space / spectral space

From remotely sensed information to ecological information

- **Analyzing <u>continuous feature space</u> to estimate functional metrics from trait distribution**
  - Functional richness, evenness, divergence, dissimilarity:
    → Villéger et al. (2008), Carmona et al. (2016)



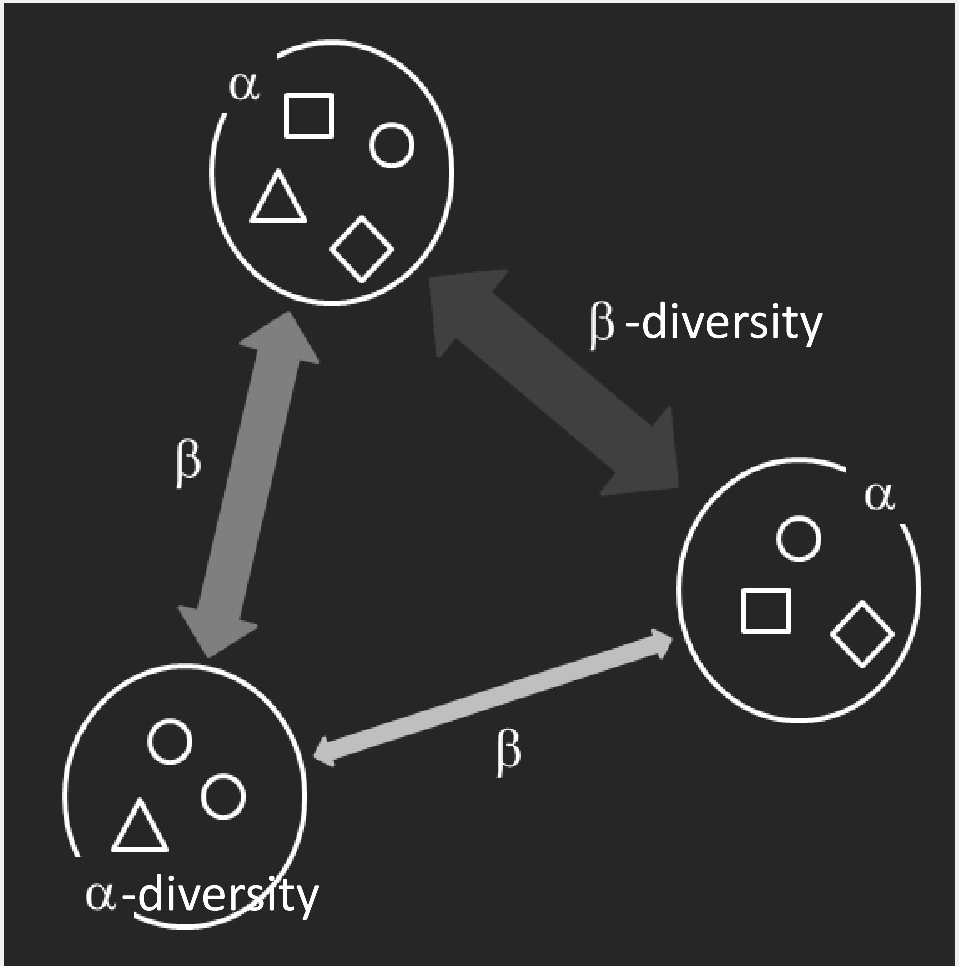
Carmona et al. (2016). Traits Without Borders: integrating functional diversity across scales, *TREE*

From remotely sensed information to ecological information

- **Analyzing <u>discrete feature space</u> to estimate taxonomic / species inventory metrics**
  - Clustering produces 'spectral species', similar to 'optical types' (Ustin & Gamon, 2010)
  - α- and β-diversity metrics based on cluster inventory
  - Analogy between species and spectral species is strongly scale dependent

<u>usual metrics for α-diversity :</u>

- Richness
- Shannon index
- Simpson index
- Fischer index
- …



<u>usual metrics for β-diversity :</u>

- Bray Curtis dissimilarity
- Jaccard distance
- …

From remotely sensed information to ecological information

Based on a 'naive' approach of the problem:

1. **Species diversity metrics are computed from plot inventories**
2. **Tree species can be discriminated based on spectral information**

→ Use cluster inventories to compute spectral diversity metrics

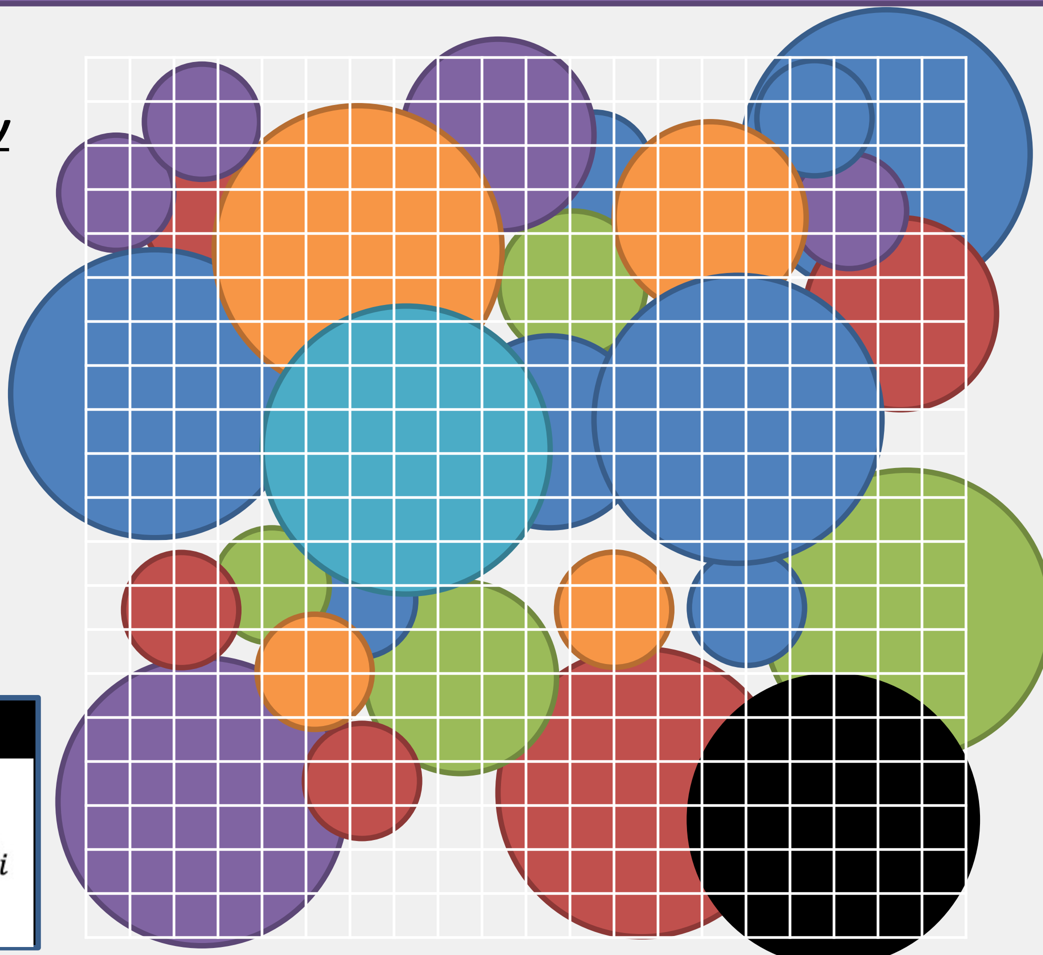
Species inventory

p_1 sp1
p_2 sp2
p_3 sp3
p_4 sp4
p_5 sp5
p_6 sp6

↓

Shannon index

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$



Cluster inventory

p_1 pixels cluster 1
p_2 pixels cluster 2
p_3 pixels cluster 3
p_4 pixels cluster 4
p_5 pixels cluster 5

↓

Shannon index

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From remotely sensed information to ecological information

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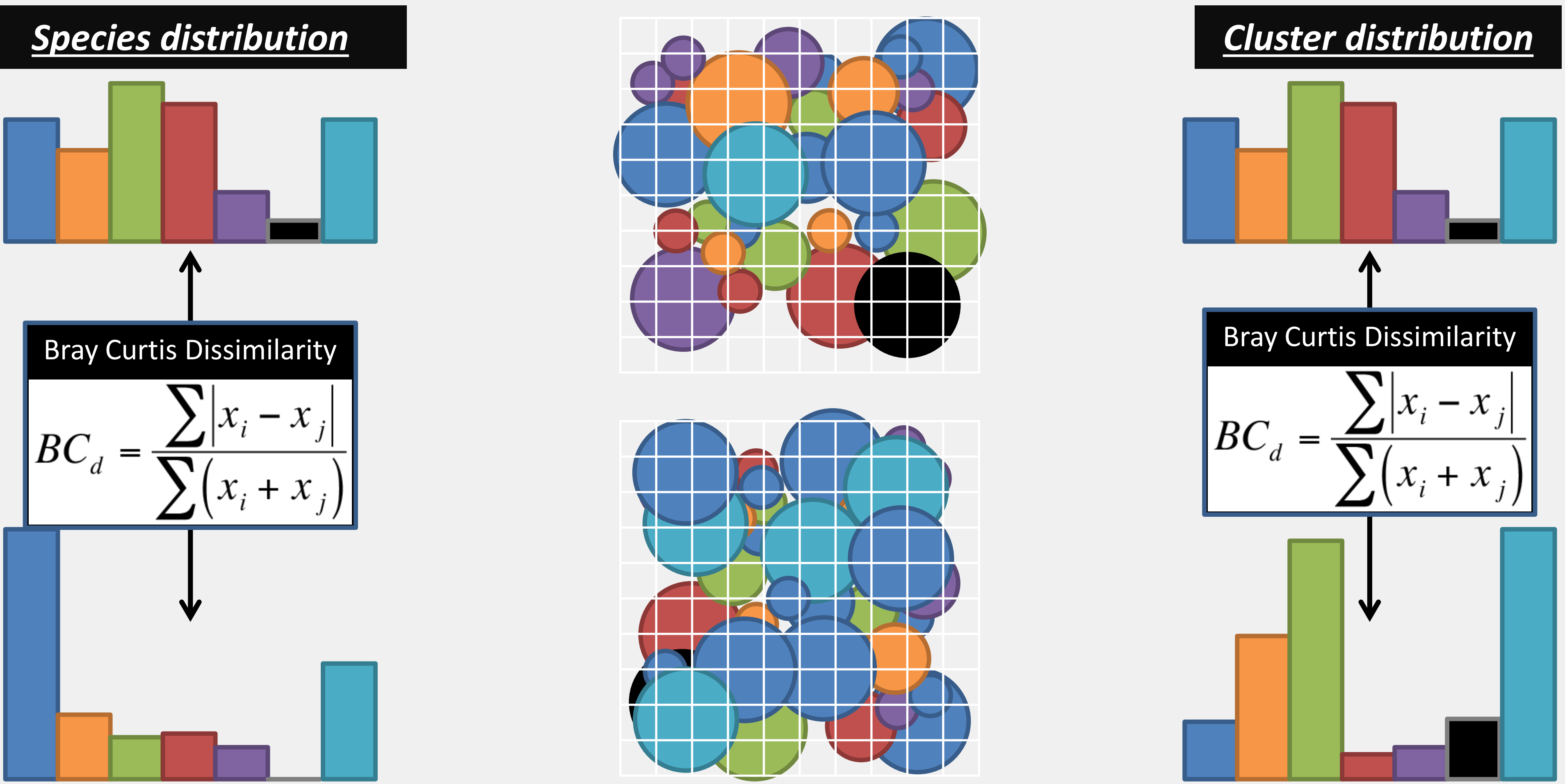


Mapping biodiversity using spectral diversity

Imaging spectroscopy

Multispectral Data

Multisource information

Diversity maps based on spectral diversity:

- ***Functional diversity (Villéger et al., 2008):***
  - FRic: Functional richness
  - FEve: Functional evenness
  - FDiv: Functional divergence
- ***Taxonomic diversity:***
  - α-diversity: Shannon's *H'*, Simpson
  - β-diversity : dissimilarity maps based on Bray Curtis

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

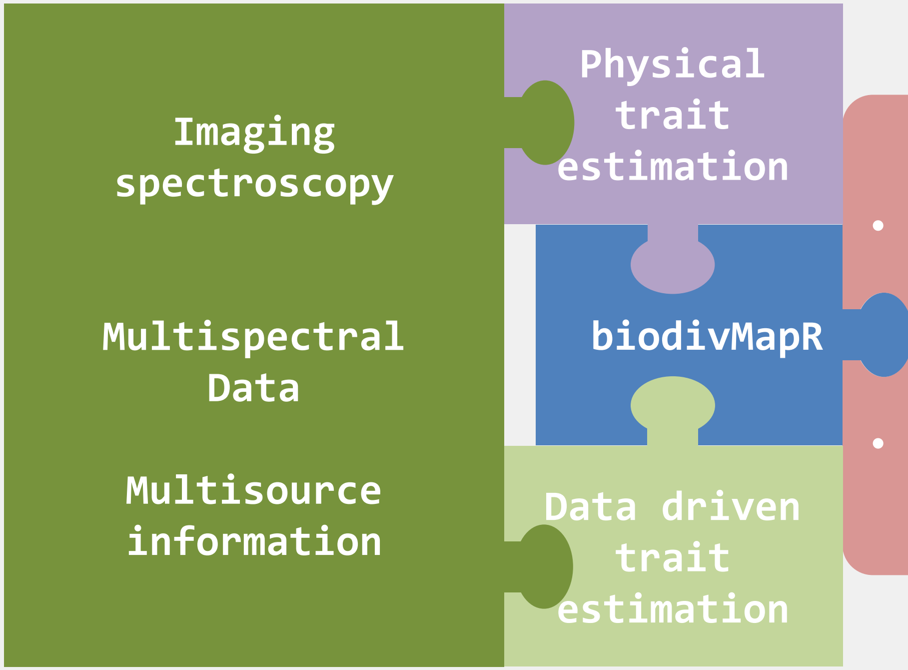
APPLICATION

biodivMapR: An R package for α- and β-diversity mapping using remotely sensed images

Jean-Baptiste Féret | Florian de Boissieu

https://jbferet.github.io/biodivMapR/index.html

Mapping biodiversity using vegetation traits estimated from RS



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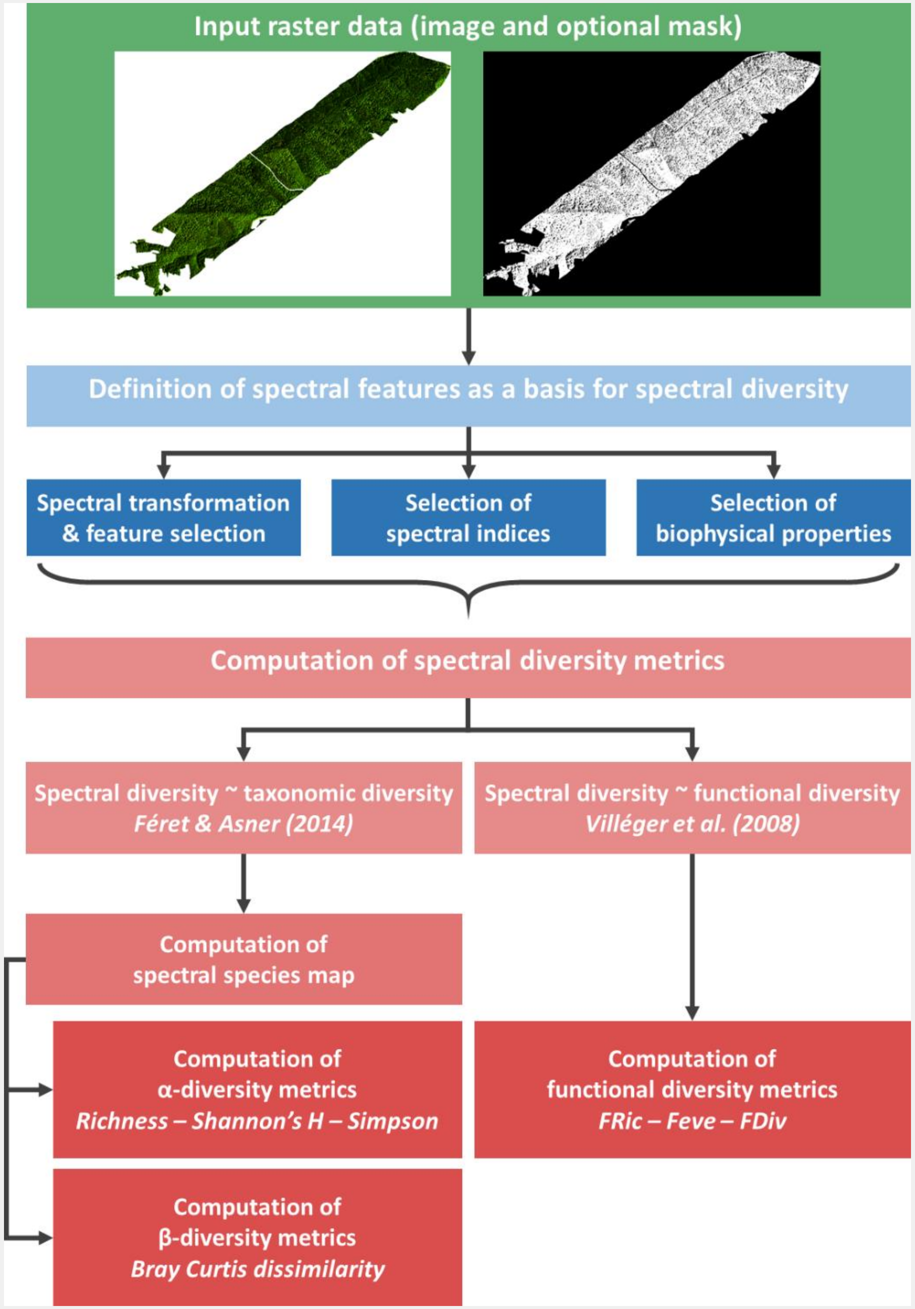
  - β-diversity : dissimilarity maps based on Bray Curtis

- **Spectral diversity / optical trait diversity can be useful indicators of biological diversity**
- **The link between remotely sensed indicators and diversity metrics collected on the ground is not systematic**

Mapping biodiversity using vegetation traits estimated from RS



Mapping biodiversity using biodivMapR on imaging spectroscopy

Ecological Applications, 24(6), 2014, pp. 1289–1296
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ECOLOGICAL APPLICATIONS
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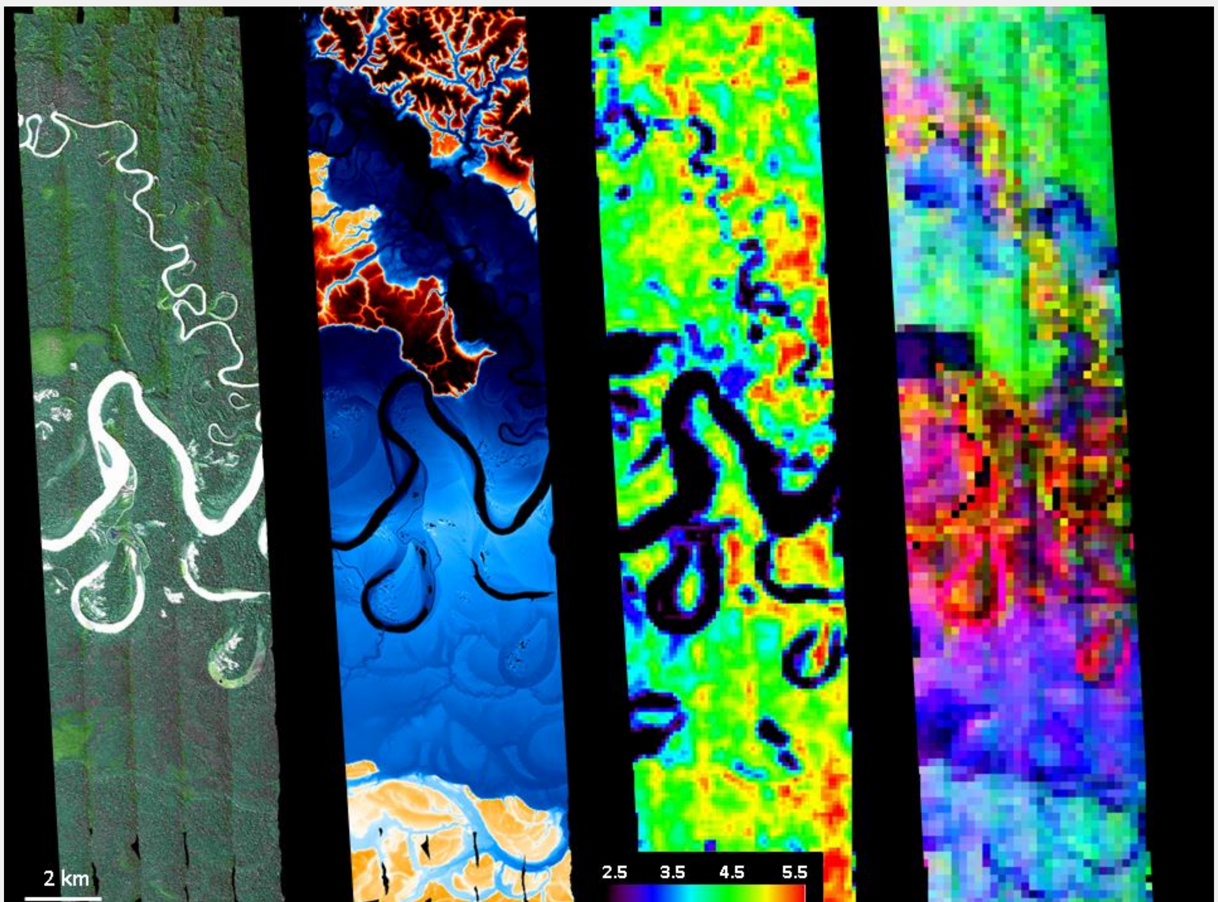
Mapping tropical forest canopy diversity using high-fidelity imaging spectroscopy

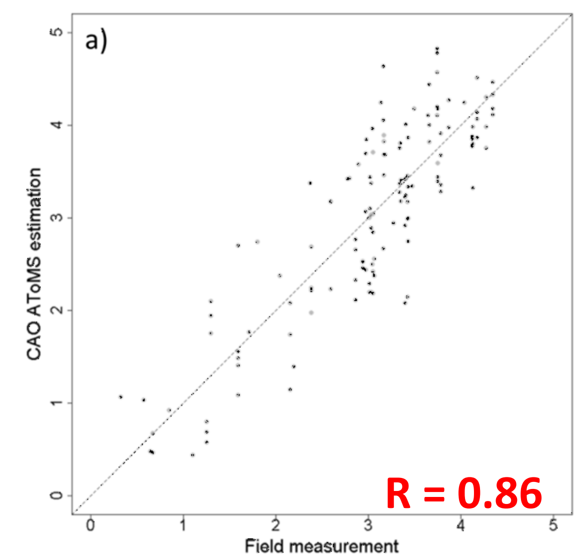
Jean-Baptiste Féret[1] and Gregory P. Asner

RGB **DEM** **α-diversity** **β-diversity**



Validation
(153 plots, 10+ sites)

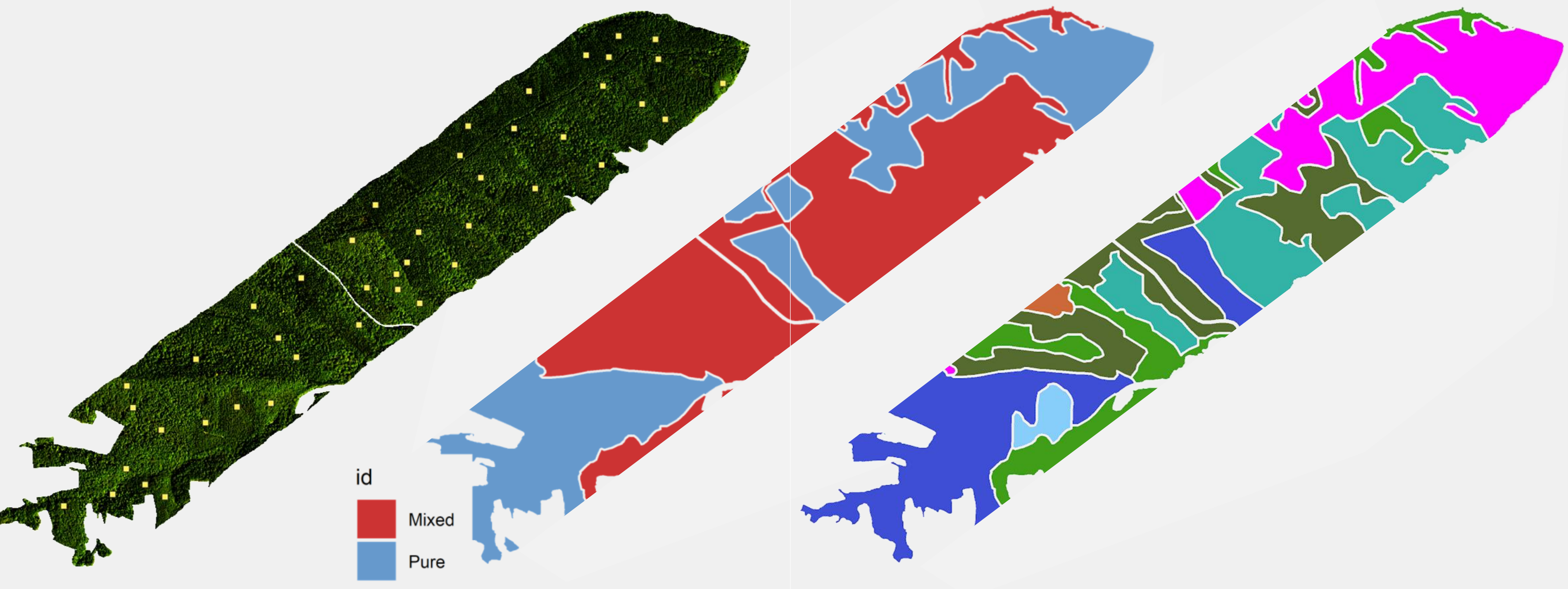
Shannon's *H'*



Mapping biodiversity using biodivMapR on imaging spectroscopy

- Temperate forest: Fabas forest (Southwest of France)
- 4m spatial resolution, spectral domain = VSWIR
- **Direct validation: 44 field plots inventoried**
- Indirect validation: BD Forêt (forest types inventoried between 2007 and 2018)

RGB color composition | Pure / mixed forest stands | Forest types



Feret, Lang et al. (in prep.) Mapping temperate species diversity using airborne imaging spectroscopy

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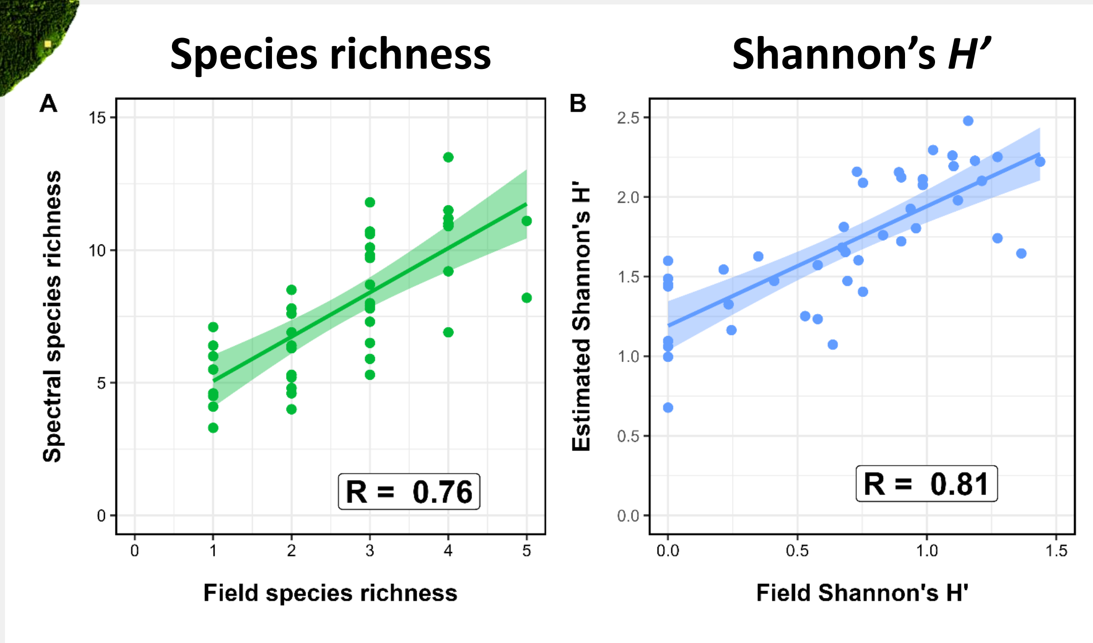
α-diversity



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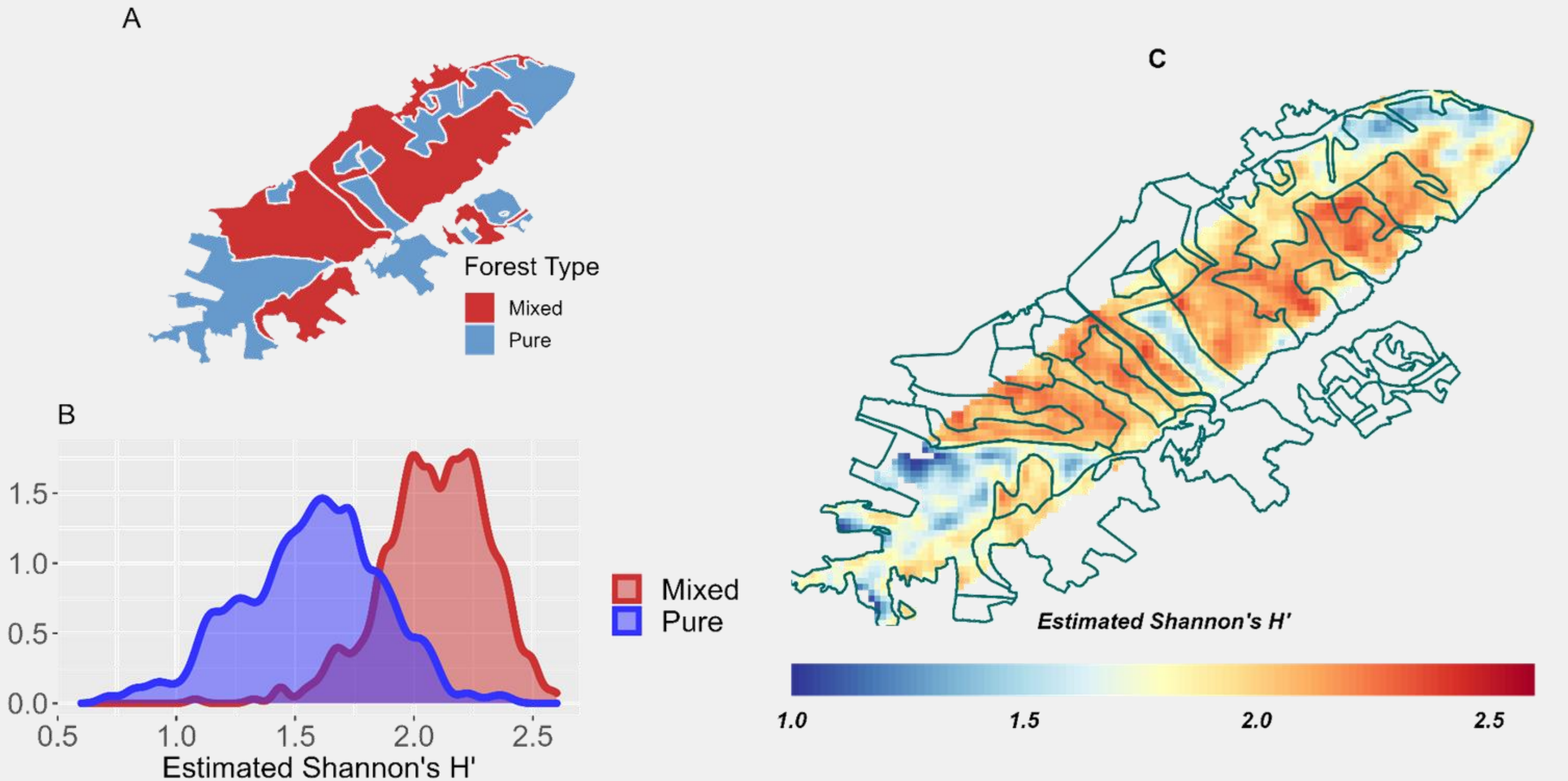

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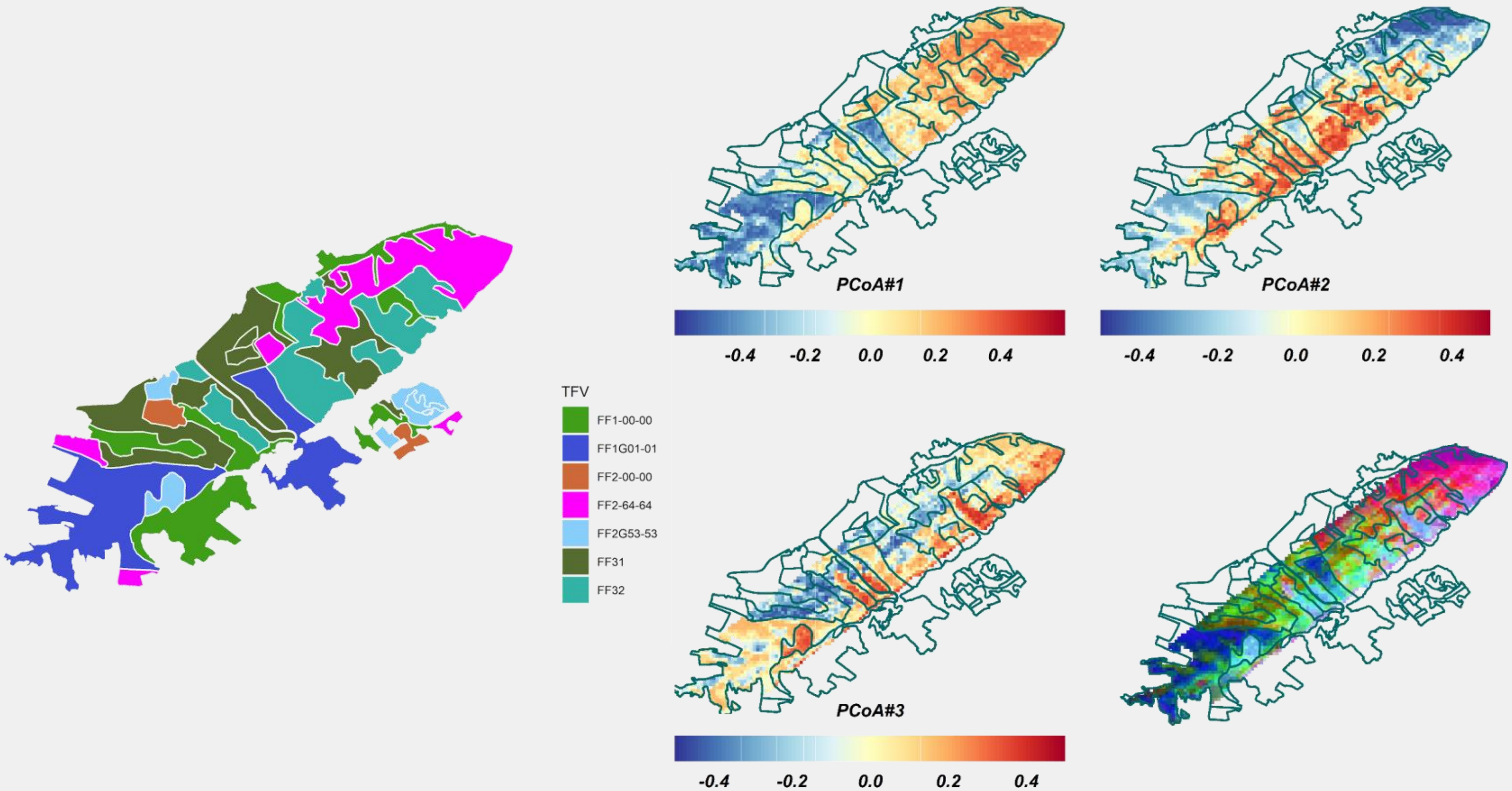
β-diversity



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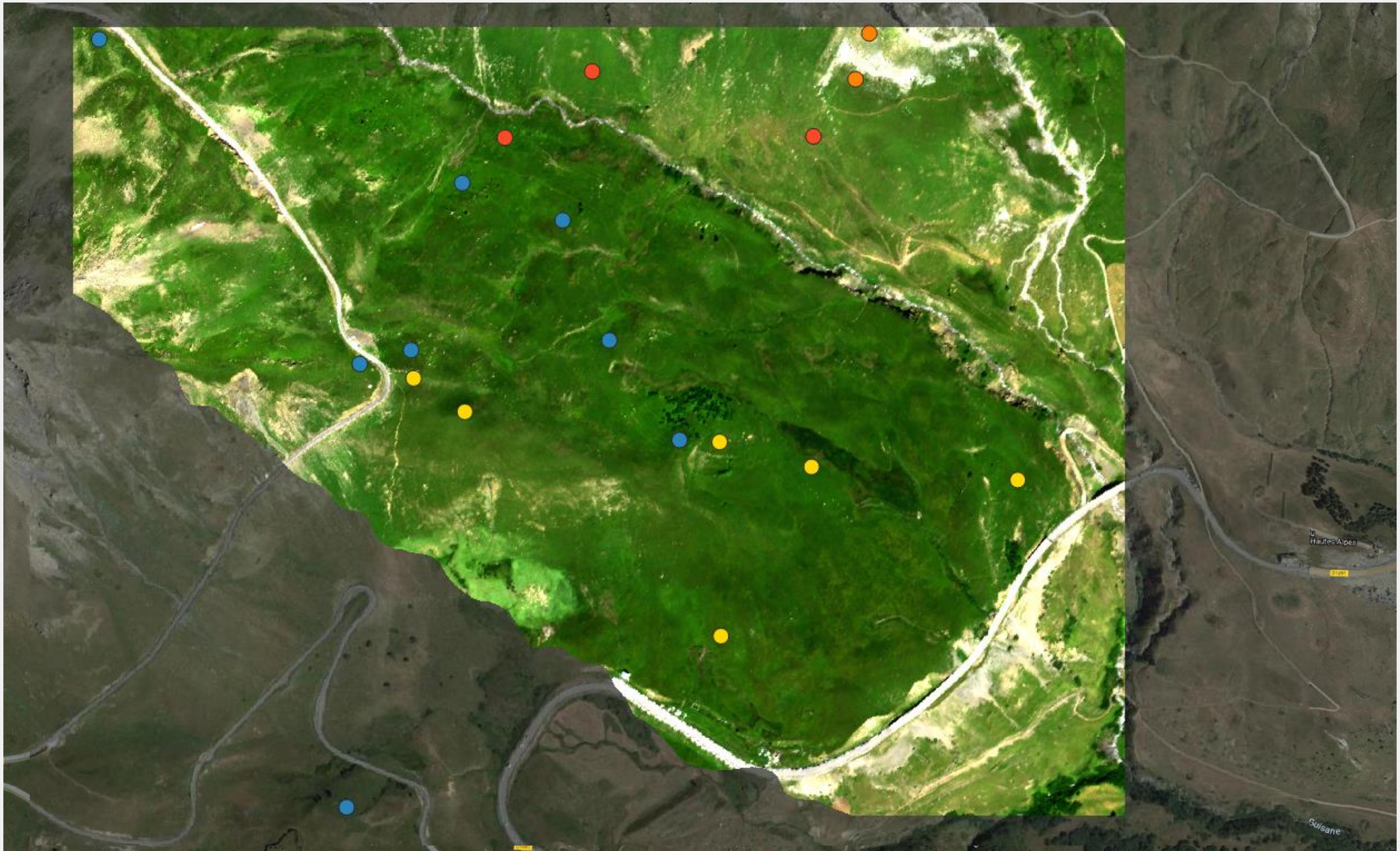
Mapping biodiversity using `biodivMapR` on imaging spectroscopy

- Subalpine grasslands : Lautaret pass (France, Hautes Alpes)

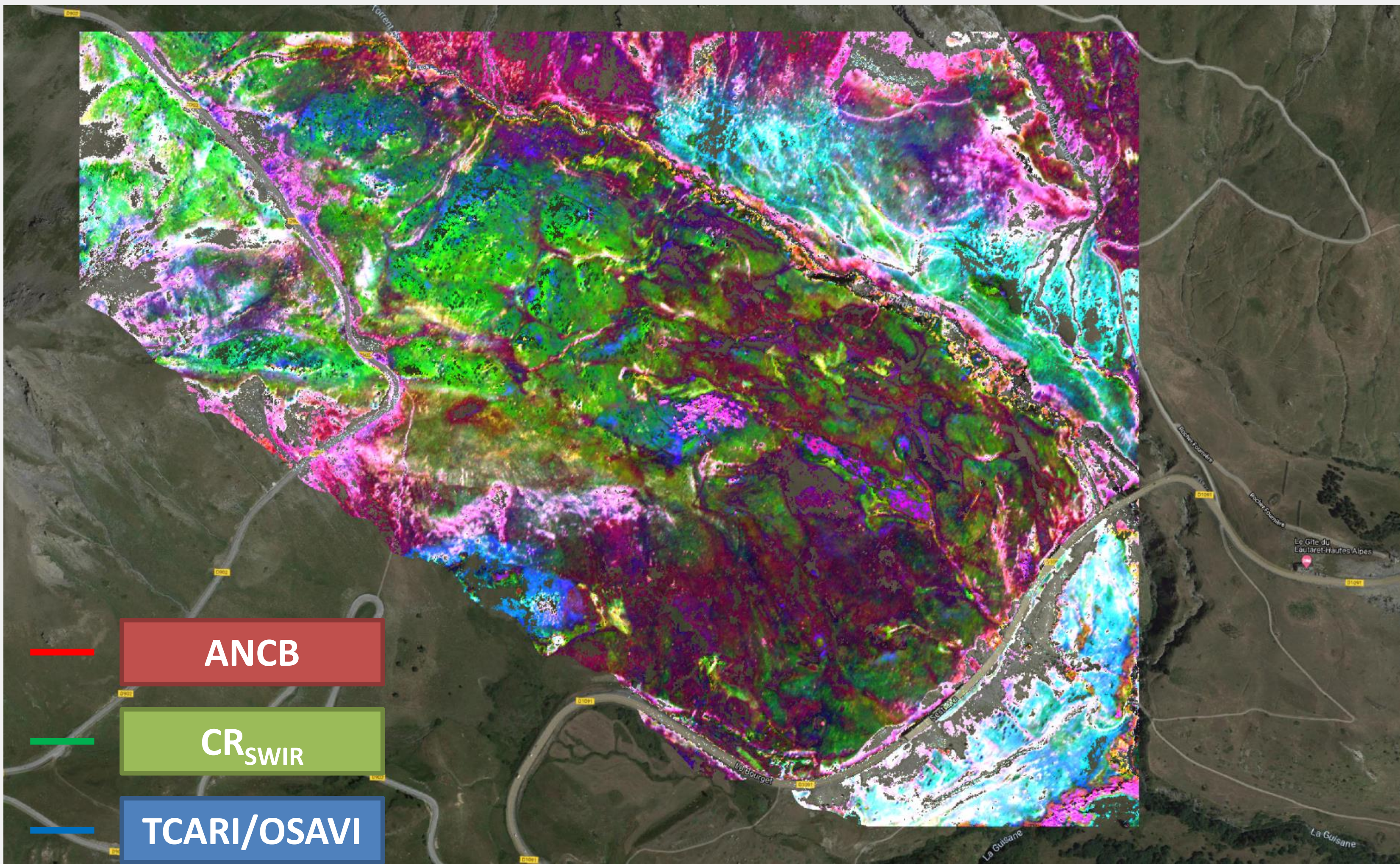
Mapping biodiversity using biodivMapR on imaging spectroscopy

- Subalpine grasslands : Lautaret pass (France, Hautes Alpes)
  - Imaging spectroscopy acquired over the study area



Mapping biodiversity using biodivMapR on imaging spectroscopy

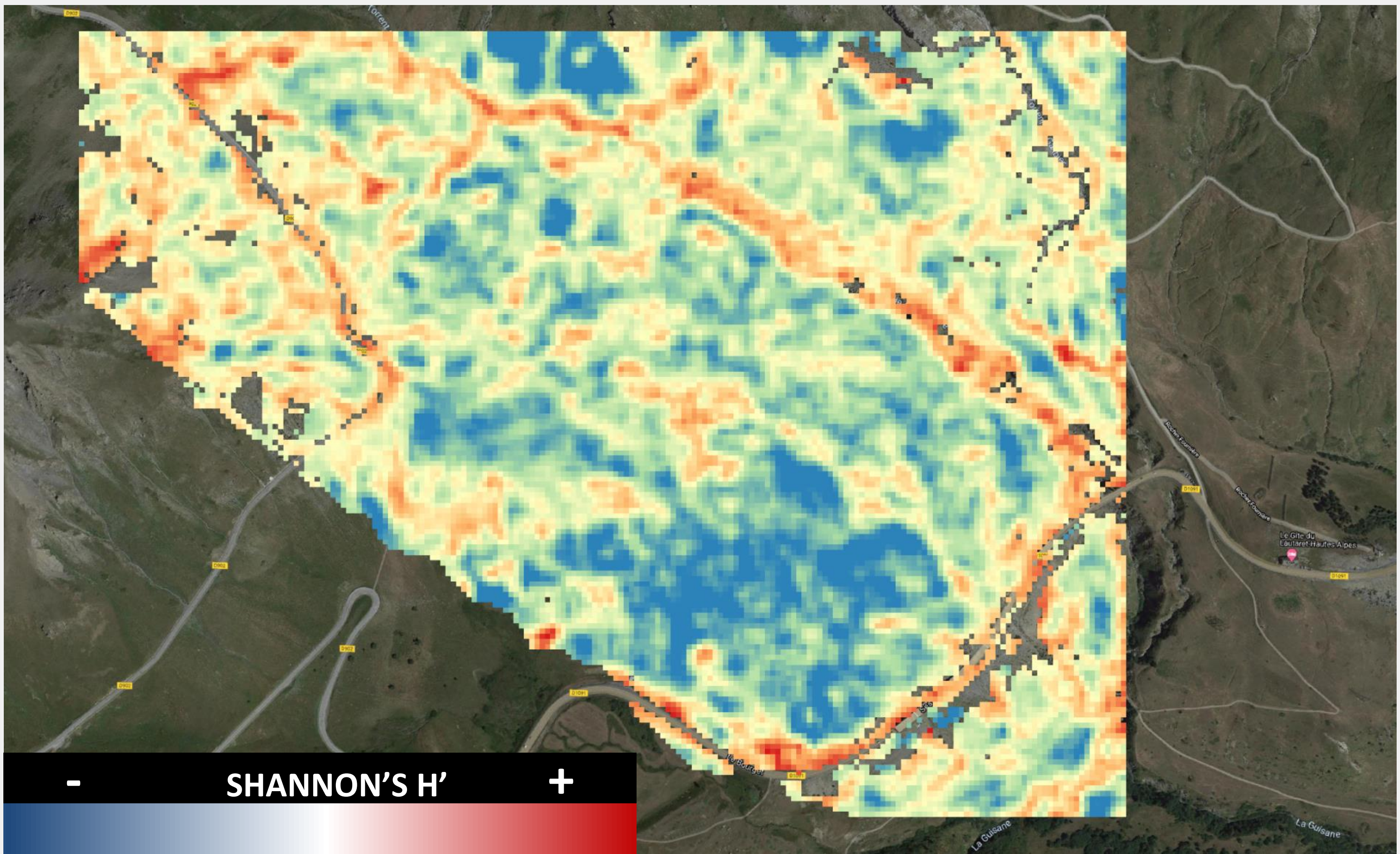
- Subalpine grasslands : Lautaret pass (France, Hautes Alpes)
  - Computation of three spectral indices related to vegetation traits (Pottier et al., 2014)



Mapping biodiversity using biodivMapR on imaging spectroscopy

- Subalpine grasslands : Lautaret pass (France, Hautes Alpes)
  - Shannon index estimated with *biodivMapR*

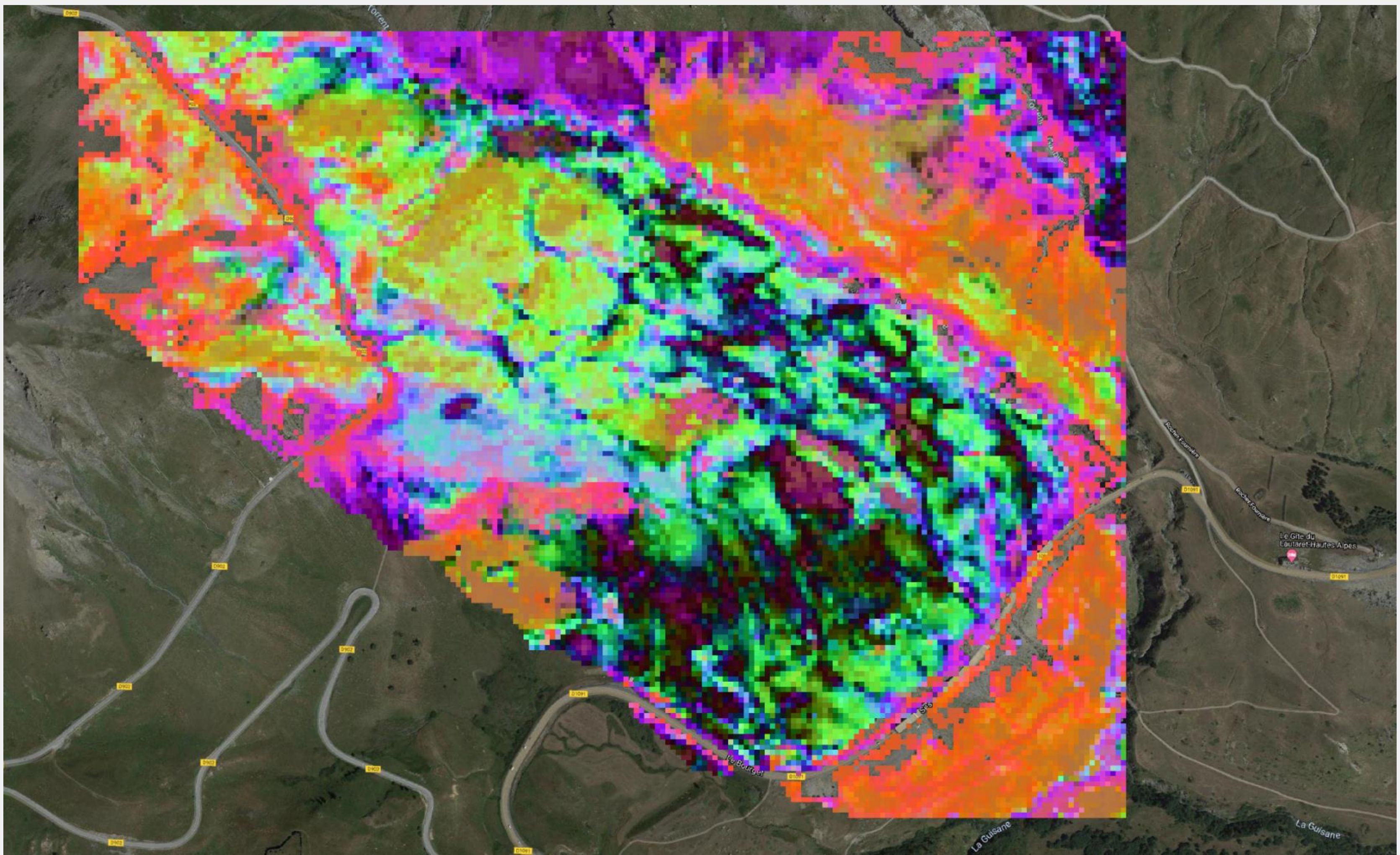
  → High diversity in the neighborhood of mountain path: artifacts due to mix of rocks and vegetation increasing variability



Mapping biodiversity using biodivMapR on imaging spectroscopy

- Subalpine grasslands : Lautaret pass (France, Hautes Alpes)
  - Bray Curtis dissimilarity + PCoA estimated with *biodivMapR*

  → Diversity patterns correspond to main plant communities



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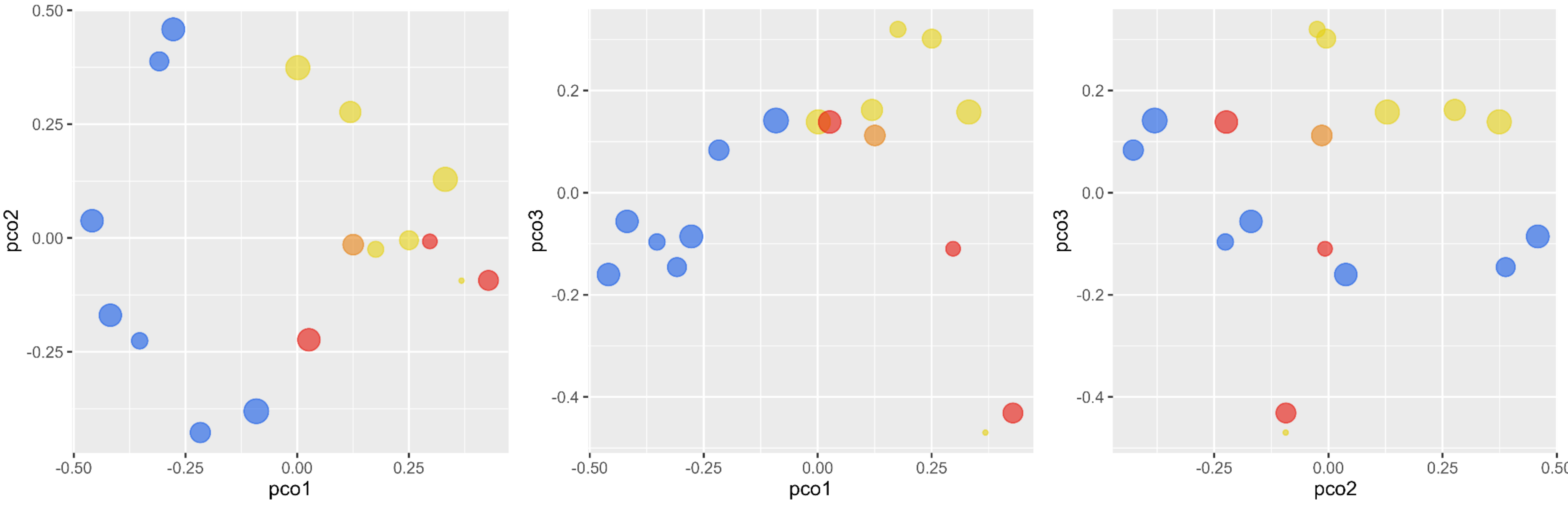


FG : open subalpine grasslands dominated by Festuca violacea, mostly found on south-facing steep slopes

FP : tall subalpine grasslands dominated by Patzkea paniculata (syn. Festuca paniculata), mostly found on south-facing gentle slopes with deep soil

SC : sparsely vegetated grasslands dominated by Sesleria caerulea on south-facing, debris-covered slopes

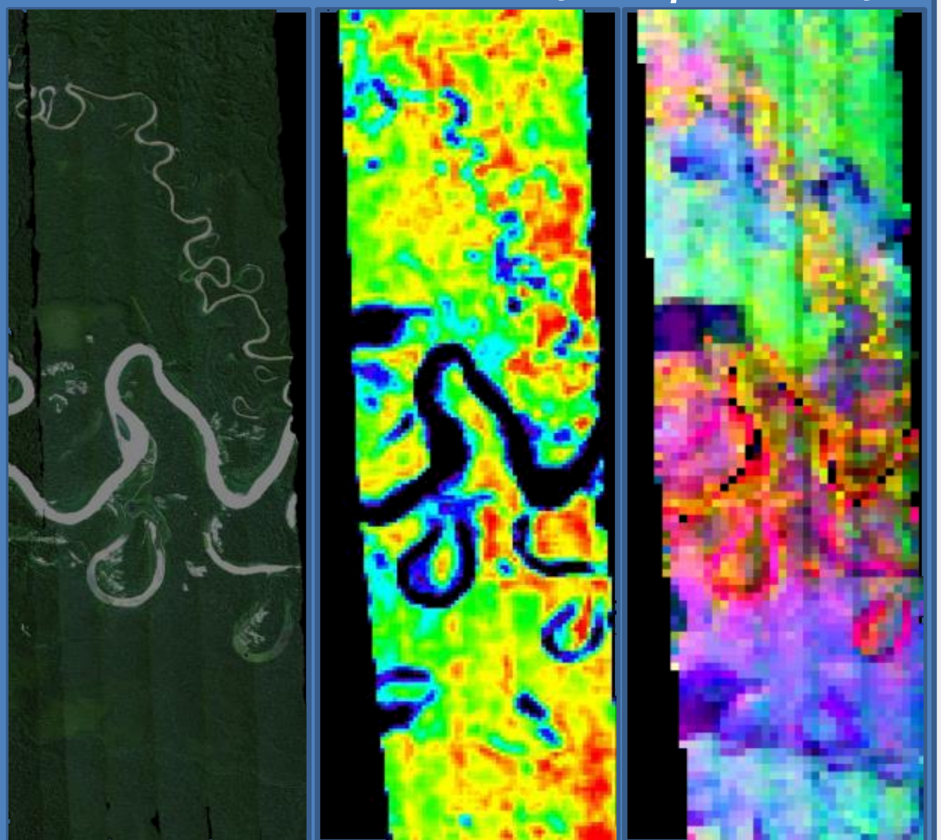
V: low stature heaths dominated by Vaccinium uliginosum and Vaccinium myrtillus, mostly found on north-facing slopes

Mapping biodiversity using biodivMapR on Sentinel-2 images

- Comparison between airborne imaging spectroscopy and Sentinel-2 satellite images

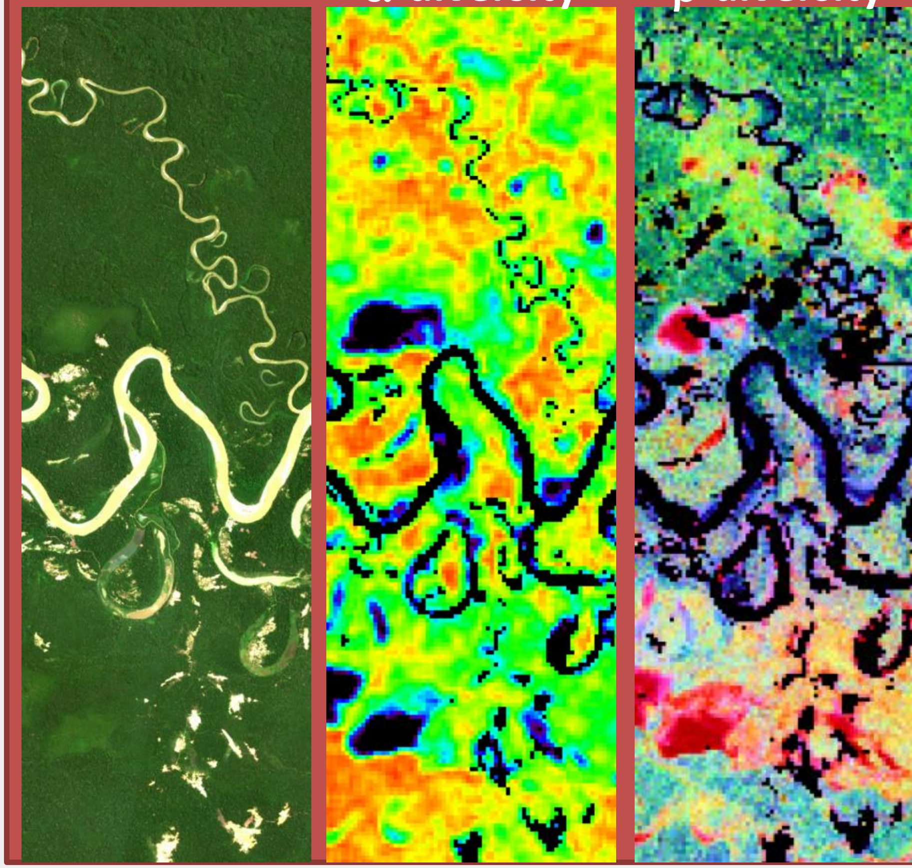
Airborne imaging spectroscopy, **biodivMapR v0.0**
(CAO AToMS: spatial resolution 2m)

RGB **α-diversity** **β-diversity**



Sentinel-2 image, **biodivMapR v1.13.0**
(spatial resolution 10m)

RGB **α-diversity** **β-diversity**



Need to perform more quantitative validation :
- On multiple dataset and forest/vegetation types
- With different methods & different diversity metrics

Mapping biodiversity using biodivMapR on Sentinel-2 images

- Comparison between floristic patterns obtained with biodivMapR and a supervised approach
  - Chaves et al. (2020) mapped floristic patterns of Peruvian rainforest
  - Supervised method taking advantage of forest inventory data, Landsat satellite data, climate, soil and elevation data
  - 10 floristic classes defined
  - Spatial resolution of the product : 450 m

remote sensing MDPI

Article

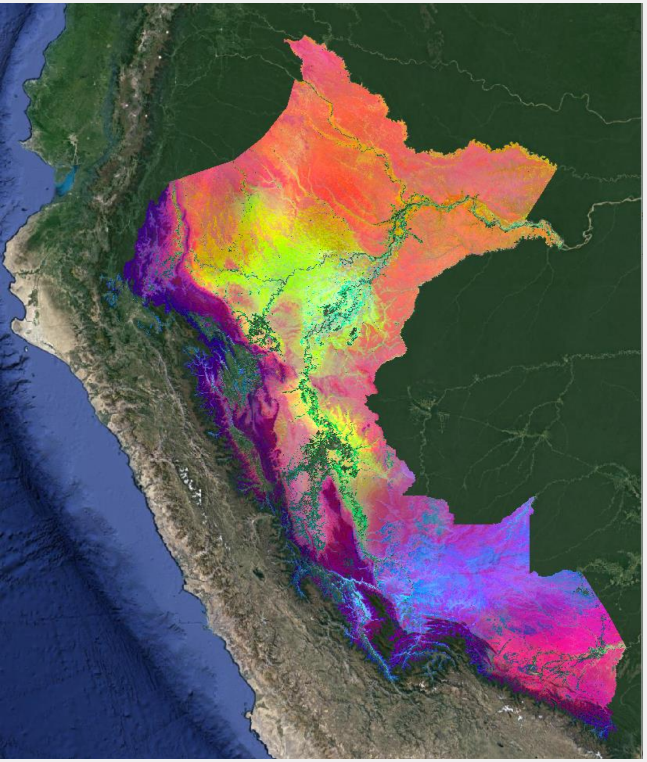
Mapping Floristic Patterns of Trees in Peruvian Amazonia Using Remote Sensing and Machine Learning

Pablo Pérez Chaves [1,*], Gabriela Zuquim [1,2], Kalle Ruokolainen [1], Jasper Van doninck [3], Risto Kalliola [3], Elvira Gómez Rivero [4] and Hanna Tuomisto [1]

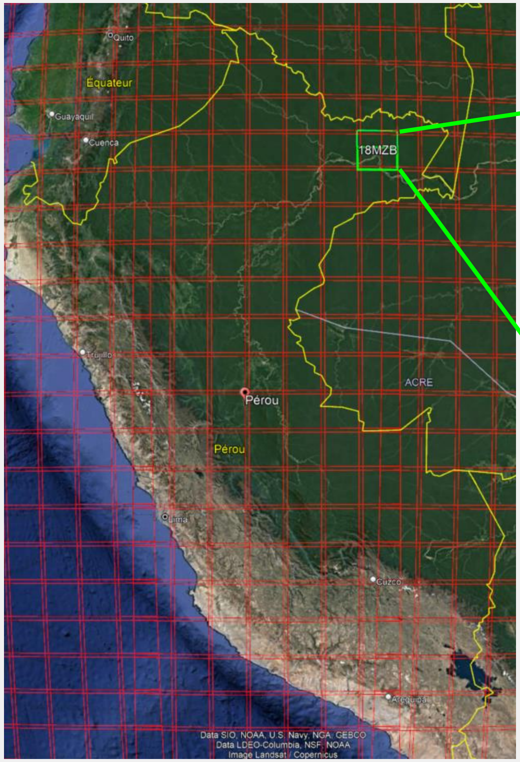
Received: 20 March 2020; Accepted: 9 May 2020; Published: 10 May 2020

Mapping biodiversity using `biodivMapR` on Sentinel-2 images

- Dowload floristic map [Chaves et al. 2020]
- Dowload Sentinel-2 data corresponding to a limited area
- Apply `biodivMapR` to produce diversity maps



Map of floristic patterns of trees in Peruvian Amazonia

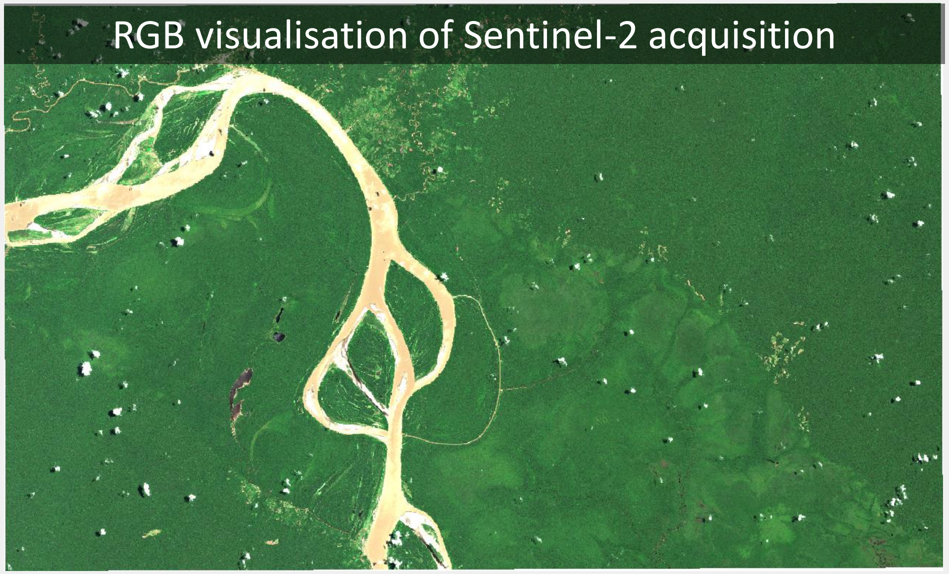


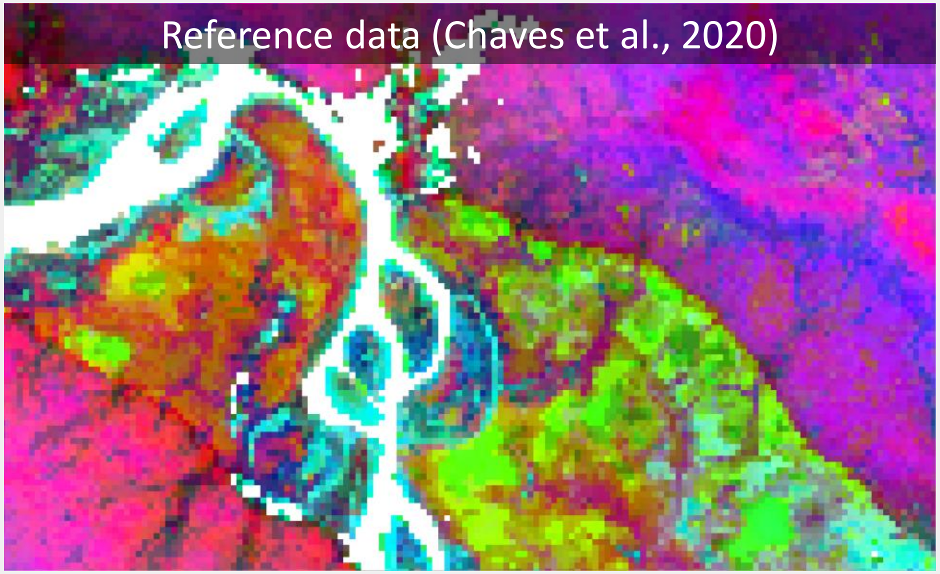
Sentinel-2 tiling grid over Peru

Extraction of a study area (yellow box)

Mapping biodiversity using biodivMapR on Sentinel-2 images

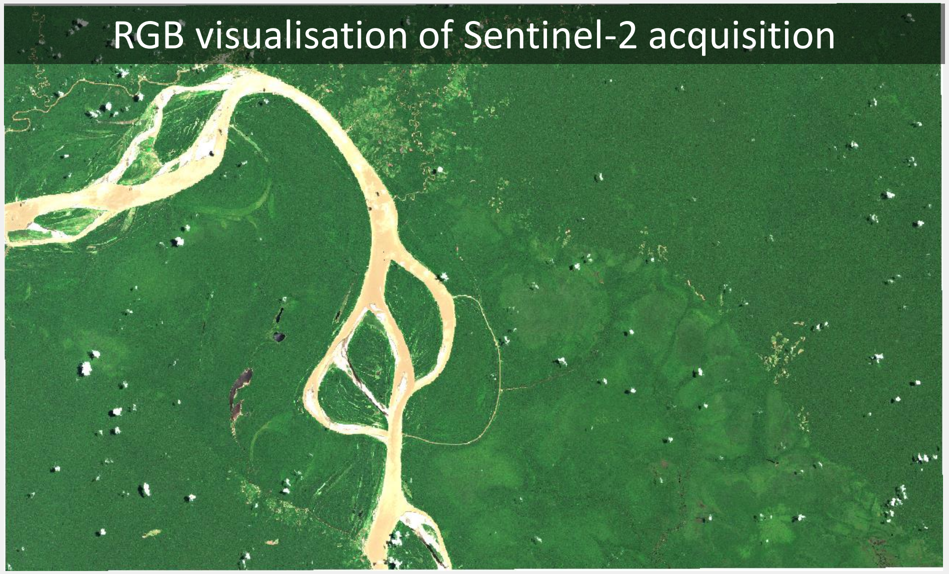
- Sentinel-2 image and corresponding floristic map

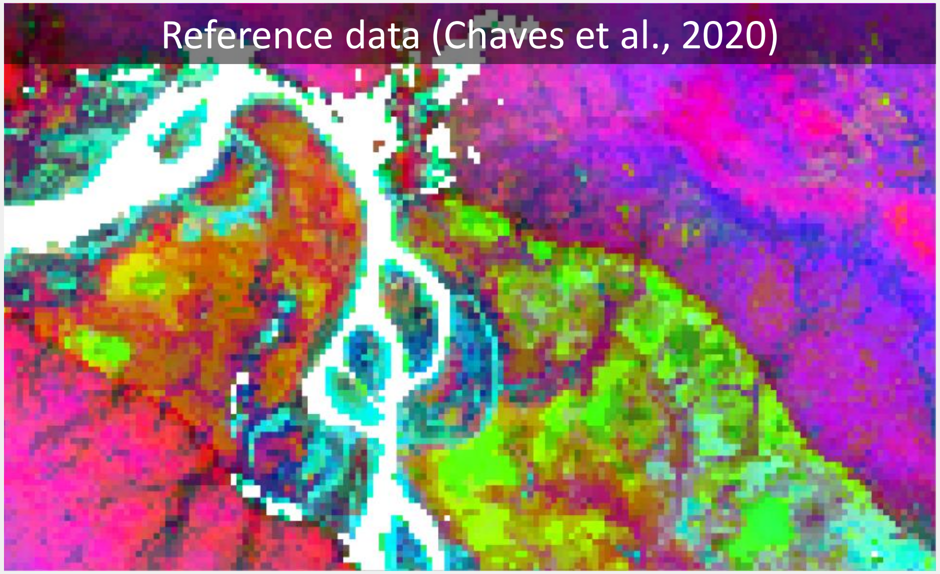


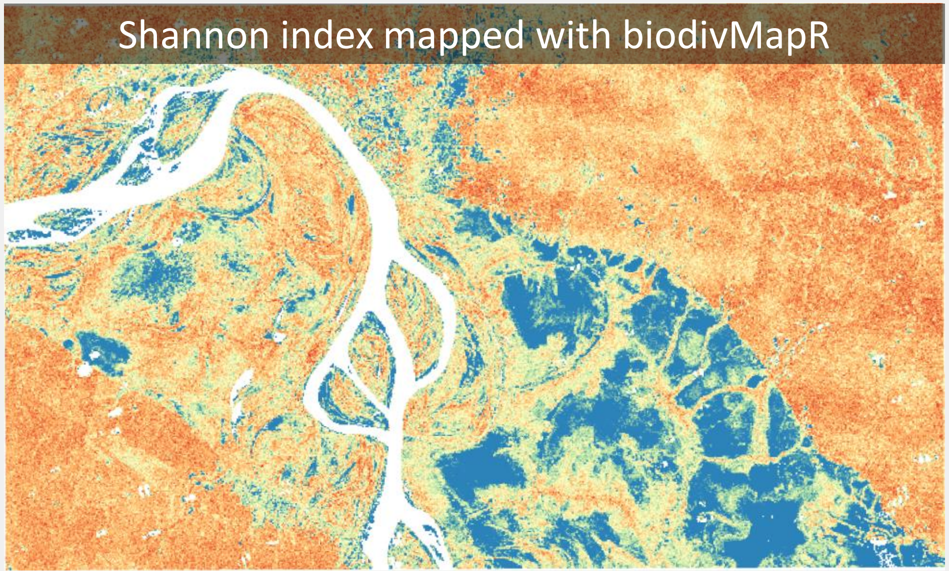


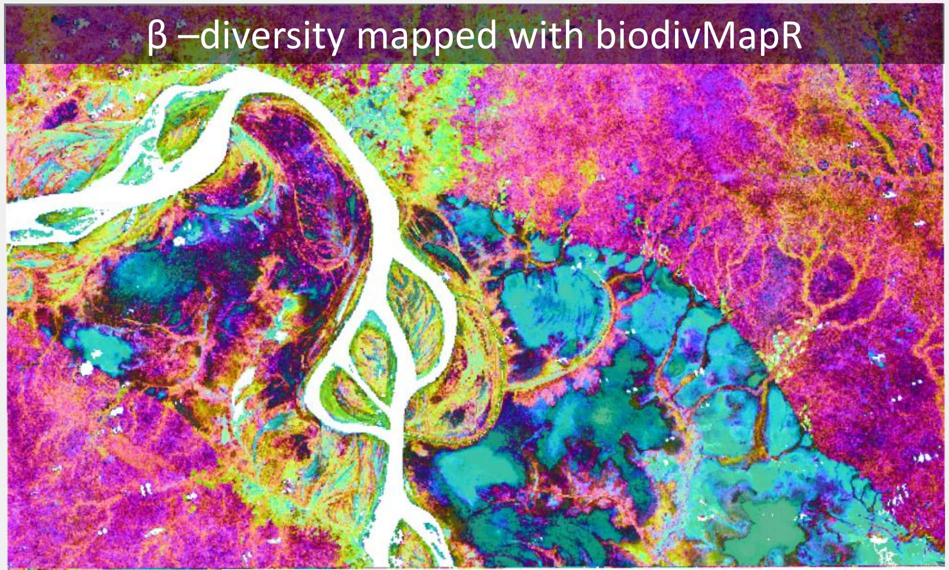
Mapping biodiversity using biodivMapR on Sentinel-2 images

- Sentinel-2 image and corresponding floristic map
- α and β diversity maps (Shannon index) produced with biodivMapR









- Introduction
- Explore spatial, temporal and spectral dimensions from space
- A quick dive into the spectral space
- Current missions and forthcoming opportunities
- Earth observation and biodiversity : one approach among many
- **Conclusions and perspectives**

Conclusions & perspectives

- Increasing amount of Earth observation data from multiple platforms (UAV, plane, satellite)
- Optical sensors acquire information related to various vegetation properties, allowing monitoring vegetation status, function, composition, stress through biophysical properties
- Multispectral sensors (Sentinel-2, Landsat) currently provide abundant information
- New spaceborne sensors (thermal infrared, LiDAR, hyperspectral, radar) open perspectives to assess relevant metrics for vegetation monitoring, biodiversity & ecological applications
- Multiple ways to convert RS information into ecologically meaningful information
  - Identify data type, sensor or sensor combination providing relevant info

  → Trade-off between spectral, spatial, temporal information
  - Identify a method and corresponding hypotheses acceptable for situation of interest

  → Spectral variation hypothesis, landscape metrics, phenometrics…
- Need to increase collaboration between ecologists & RS scientists

Thank you !

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