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## 6.1 Application: Biodiversity and Remote Sensing

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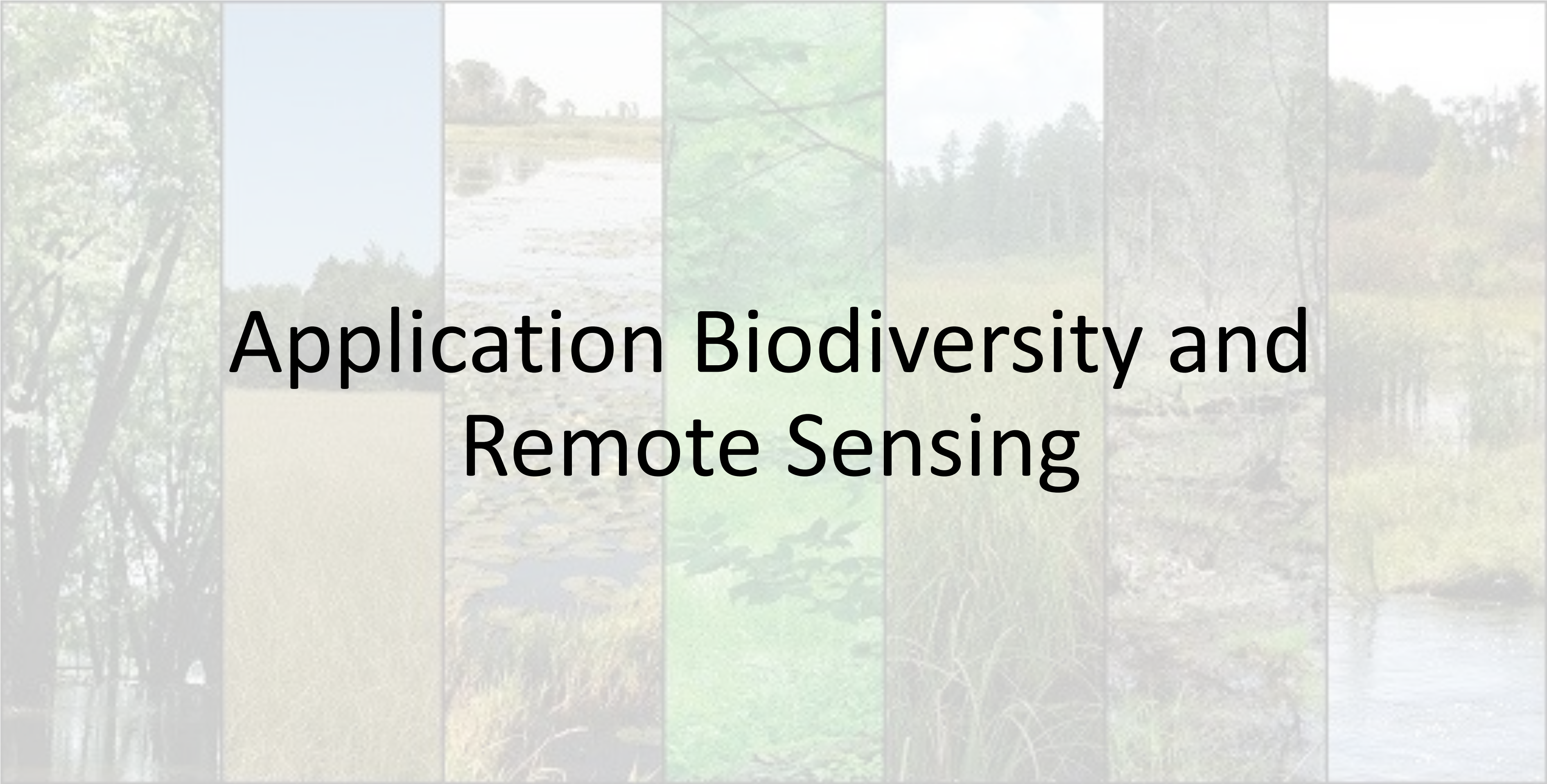
Recap

# Application Biodiversity



# Application Biodiversity and Remote Sensing

# Ecosystem

Critical questions to understand ecosystem stability:

- How stable is an ecosystem?

- How does the ecosystem contribute to human well-being?
- How useful is the ecosystem?
- How is the service output of the ecosystem changing?

# Ecosystem

Critical questions to understand ecosystem stability:

- Which efforts are undertaken by the ecosystem?
- What are the energy dynamics of the ecosystem?
- How does the exchange matter within the ecosystem look like, e.g. between biota and atmosphere?

# Ecosystem

Critical questions to understand ecosystem stability:

- How spatially variant / diverse is its structure?
- Where do species live?
- How do they spatio-temporally spread?

# Biodiversity

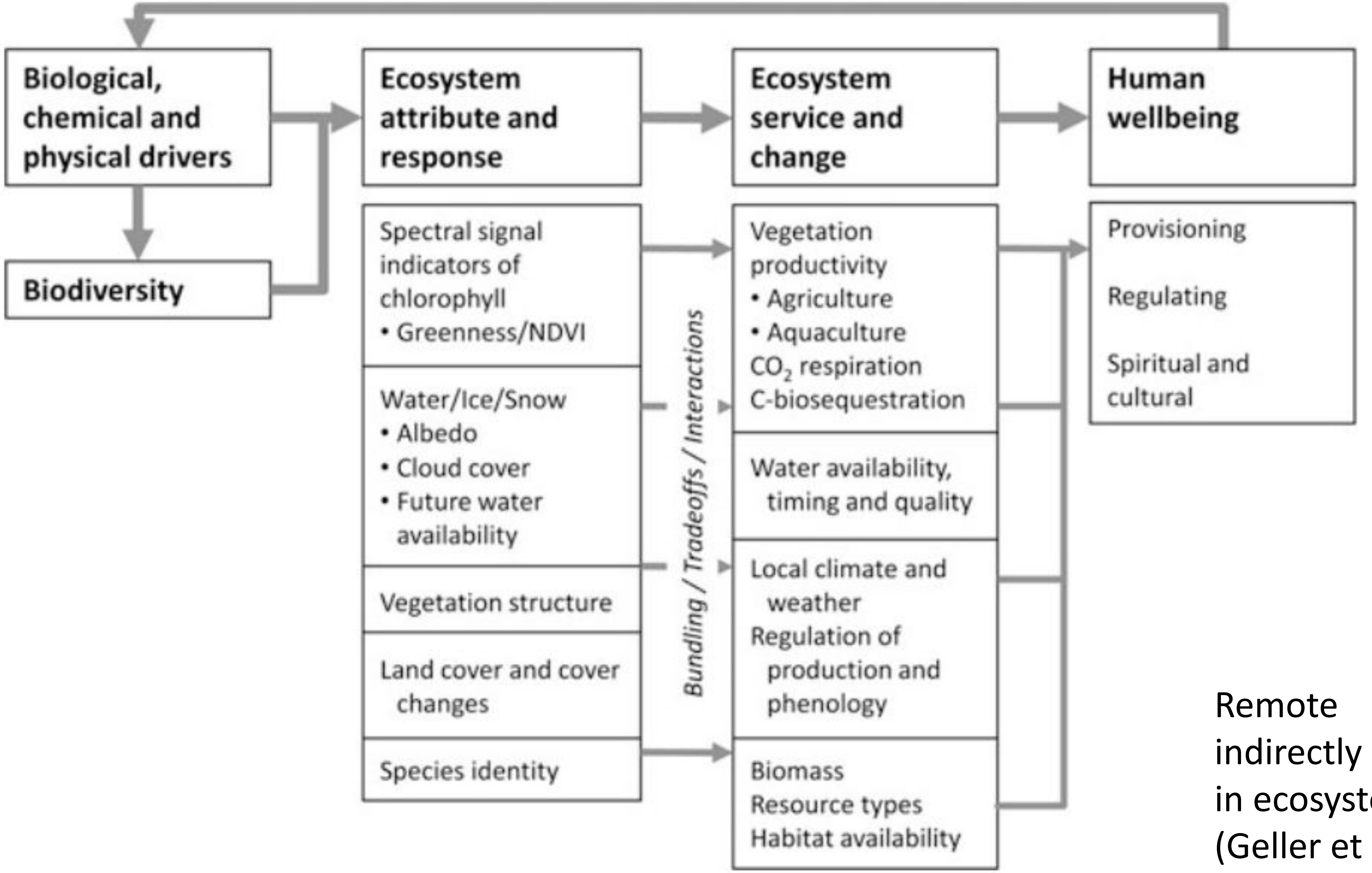
Biodiversity: Genetic and functional variability within all taxonomic ranks of life and their aggregates

# Biodiversity

Biodiversity: Genetic and functional variability within all taxonomic ranks of life and their aggregates

- Key element in provision of ecosystem services  ecosystem function / stability
- Ecosystem  link between species / population and land use, climatic influences etc.
- Thus: (measurable) changes to an ecosystem influence its biodiversity  feedback loop
- Trend: land use change, climate change, invasive species dispersal cause decline in global biodiversity

# Ecosystem services




Remote sensing is used indirectly to evaluate changes in ecosystem services.
(Geller et al. 2016)

# Biodiversity

How could one measure / quantify biodiversity?

# Biodiversity

**Local diversity** (alpha diversity)

- Mean diversity of species in different sites of habitats within a local scale
- Simplest measure: species richness (count of the number of species present in the area), does not account for relative abundance
- Chao index, Simpson index, Shannon index, ACE index, Good's coverage index

$$H = -\sum[(p_\mathrm{i}) \times \ln(p_\mathrm{i})]$$

The Shannon index

# Biodiversity

**Species turnover** (beta diversity)

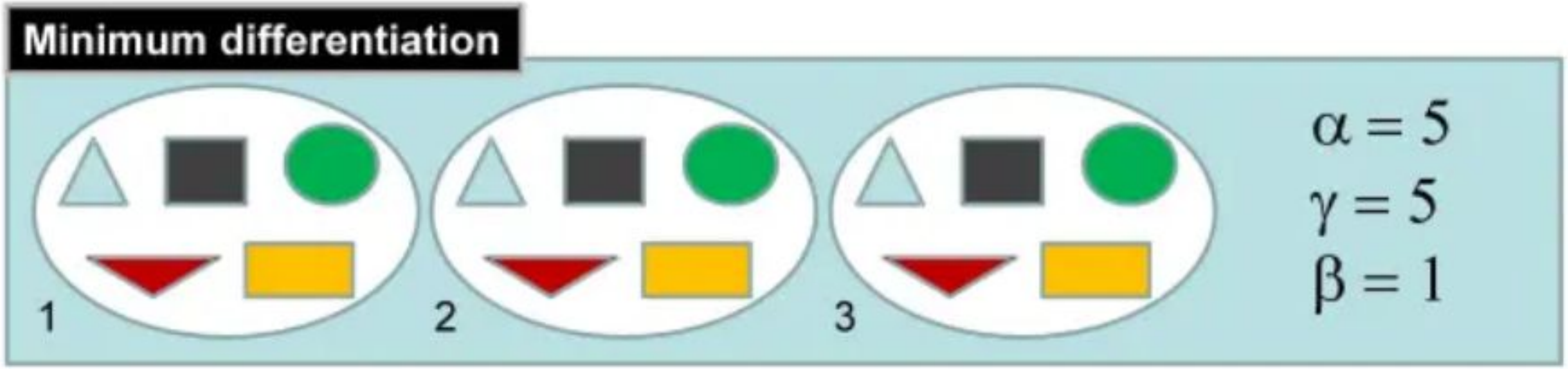
- "extent of change in community composition, or degree of community differentiation, in relation to a complex gradient of environment, or a pattern of environments"
- Example: measuring increase or decrease in species diversity along transects (e.g. environmental gradients)

# Biodiversity

**Species turnover** (beta diversity)

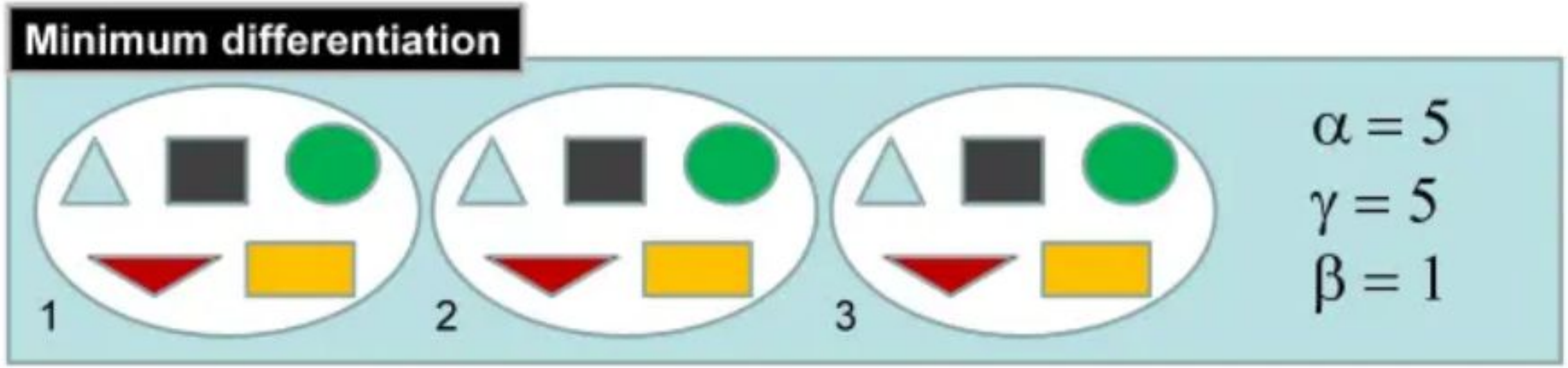
- “extent of change in community composition, or degree of community differentiation, in relation to a complex gradient of environment, or a pattern of environments”
- i.e. ratio between local and regional species diversity  how different are local communities (alpha diversity) across a larger region?
- Example: measuring increase or decrease in species diversity along transects (e.g. environmental gradients)

# Biodiversity




Minimum differentiation: No difference in diversity across locations  unity, i.e., only one community present. (Stephenson 2015)

# Biodiversity

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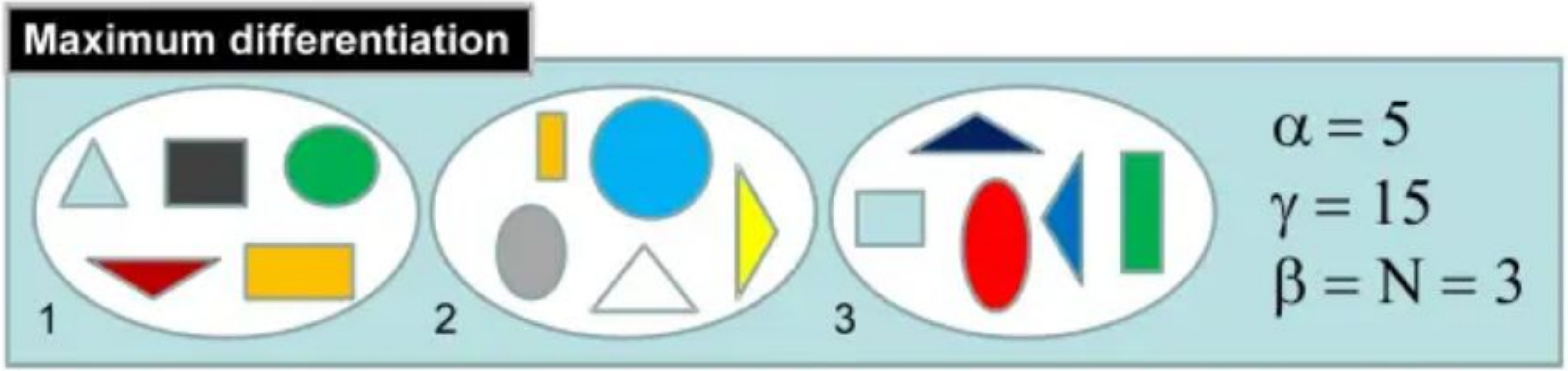



Maximum differentiation: No similarities in diversity across locations □ three communities (at least). (Stephenson 2015)

# Biodiversity

Species turnover (beta diversity)

- Measured best as a site-(location-)independent index (in the example, beta is dependent on how many locations are there
- Indices: Whittaker species turnover (Sørensen), Cody, Wilson and Schmida, Proportional species turnover (Jaccard)

# Biodiversity

| Diversity type | Index | Formula | References |
|---|---|---|---|
| Alpha-diversity | Species richness | $S$ | Colwell (2009) |
| | Simpson index | $I_S = 1/\Sigma p^2$ | Simpson (1949) |
| | Berger–Parker index | $I_{BP} = 1/(p_{max})$ | Berger and Parker (1970) |
| | Shannon–Wiener index | $H' = -\Sigma p \times \ln(p)$ | Shannon and Weaver (1948) |
| | Brillouin index | $I_B = (\ln N! - \Sigma n!)/N$ | Maurer and McGill (2011) |
| | McIntosh index | $I_{Mc} = (N - \sqrt{\Sigma n^2}/N - \sqrt{N})$ | McIntosh (1967) |
| | Pielou evenness | $J' = H'/H'_{max} = H'/\ln(S)$ | Pielou (1966) |
| Beta-diversity (turnover) | Jaccard index | $\beta_j = C/(A + B + C)$ | Jaccard (1912) |
| | Sørensen index | $\beta_{sor} = 2C/(2C + A + B)$ | Sørensen (1948) |
| | Wilson & Shmida index | $\beta_{ws} = (A + B)/(2C + A + B)$ | Wilson and Shmida (1984) |
| | Colwell & Coddington index | $\beta_{cc} = (A + B)/(A + B + C)$ | Colwell and Coddington (1994) |
| | Lennon index | $\beta_l = 2(A - B)/(2C + A + B)$ | Lennon et al. (2001) |

$S$ = total number of species, $n$ = number of individuals belonging to each species, $N$ = total number of individuals, $p$ = relative proportion of each species, $A$ = exclusive species composition of the sampling unit A, $B$ = exclusive species composition of the sampling unit B, $C$ = intersection of the species composition of sampling units A and B.

Traditional diversity indices. (Ramadhoan 2018)

# Scale & observability

Variance in scale (temporally, spatially, spectrally) is inherent in all ecosystems, species distributions, physical variables etc.

Challenge: Matching scales of ecosystem / species and environmental data. Poor detection conditions for process and condition that:

# Scale & observability

Variance in scale (temporally, spatially, spectrally) is inherent in all ecosystems, species distributions, physical variables etc.

**Challenge**: Matching scales of ecosystem / species and environmental data. Poor detection conditions for process and condition that:

- Run faster / slower as coverage span and /or repetition rate of data ( temporal scale)
- Are larger / smaller than covered region and / or pixel resolution ( spatial scale)
- Have a spectral specificity spanning larger than the covered spectral range or being narrower than the spectral resolution, being less intensive than the radiometric resolution ( spectral / radiometric scale)

# Scale & observability

**Disregarding matching scales**:

- Detection of change / trend / condition when none exists (false positive)
- Failure to detect change / trend / condition of significance (false negative)

# Scale & observability

**Matching scales** □ accounting for majority of variance of the observation target □ multiple-scale approach

- Multiple set of spatial and temporal scales to explain several matching portions of an ecological process
- Spectral scale often treated differently: accounting for as many spectral information as available, then discriminating by variable importance

# Scale & observability

**Conflict of scales**:

- Scale of observation target / process scale: Scale(s) on which a process runs
- Scale of observation / data scale: Scale(s) and coverage of observation

# Scale & observability

**Conflict of scales**:

- Management scale: Scale(s) on which decision makers / stakeholders operate to effectively cast informative decisions. E.g. conservation planning / landscape management.
  - Planning and decisions on landscape / regional scale
  - Scale too large for direct sampling, i.e., plat data to sparse
  - Continental / global data too coarse
  - additional scale requirement for applicability of results

# Biodiversity

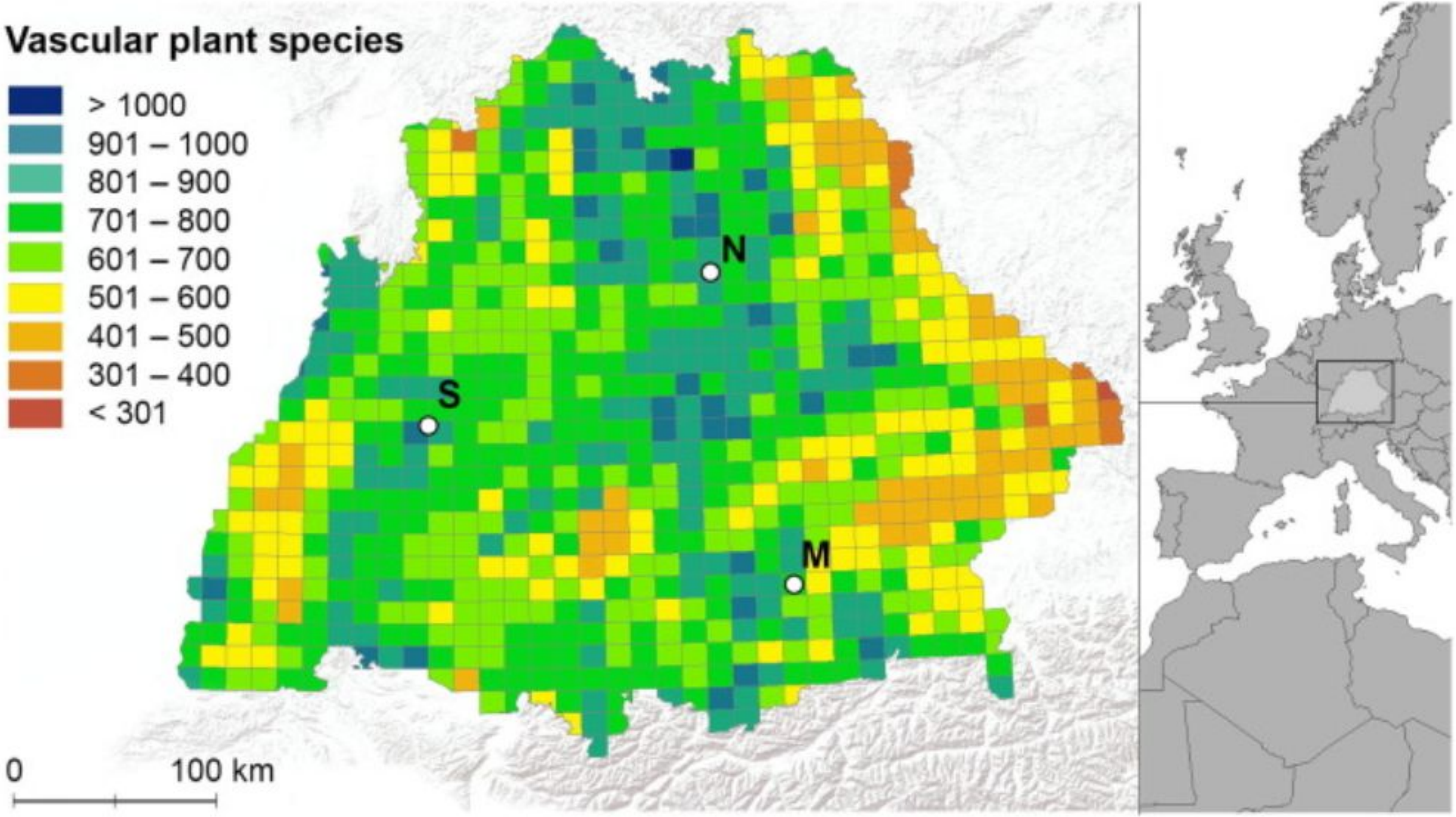
How could one biodiversity be measured / estimated using remote sensing?

# Biodiversity from remote sensing

**Assessing biodiversity from remote sensing**: Turner et al. 2003

- Direct approaches: relate biodiversity (e.g., species occurrences) to biochemical response signal in RS data (e.g., species-species spectral signature, phenology etc.)  *trying to "see" the species*
- Indirect approaches: relate biodiversity ground truth to environmental proxy variables from RS data (e.g., NPP, vegetation indices, habitat structure etc.)

# Biodiversity from remote sensing




A biodiversity index prediction based on the Spectral Variability Hypothesis (SVH). (Schmidtlein et al. 2017)

# Biodiversity from remote sensing: SVH

Estimating biodiversity using the Spectral Variability Hypothesis (SVH):

- Pixel-to-pixel variability of spectral response driven by multiple factors (e.g., environmental heterogeneity, diversity of leaf / canopy traits, also depending on the scale of observation
- These properties are related to species diversity
- Thus: spectral / textural variations are treated as a proxy of plant biodiversity
- Idea: areas with high spectral heterogeneity correspond to areas with a high environmental heterogeneity  higher number of available ecological niches that can host more species
- Assumption: the higher the spectral variability in a region, the higher its plant biodiversity

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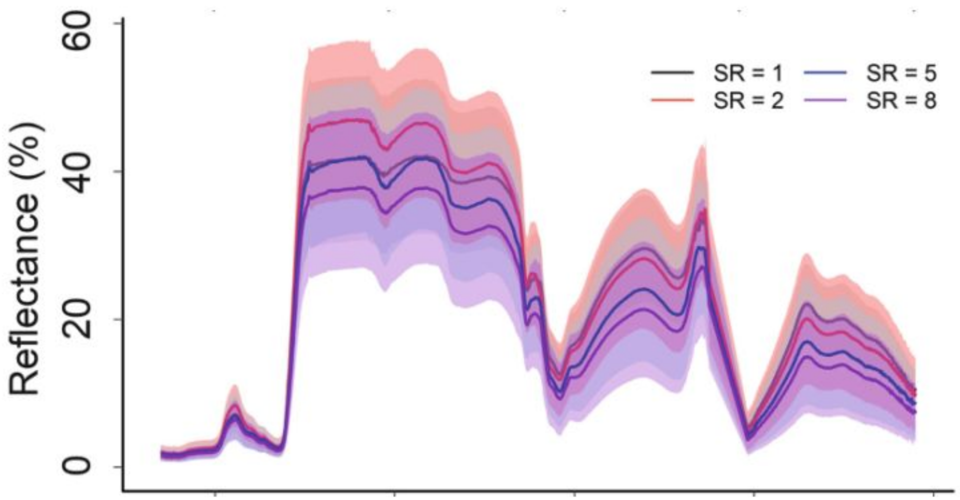
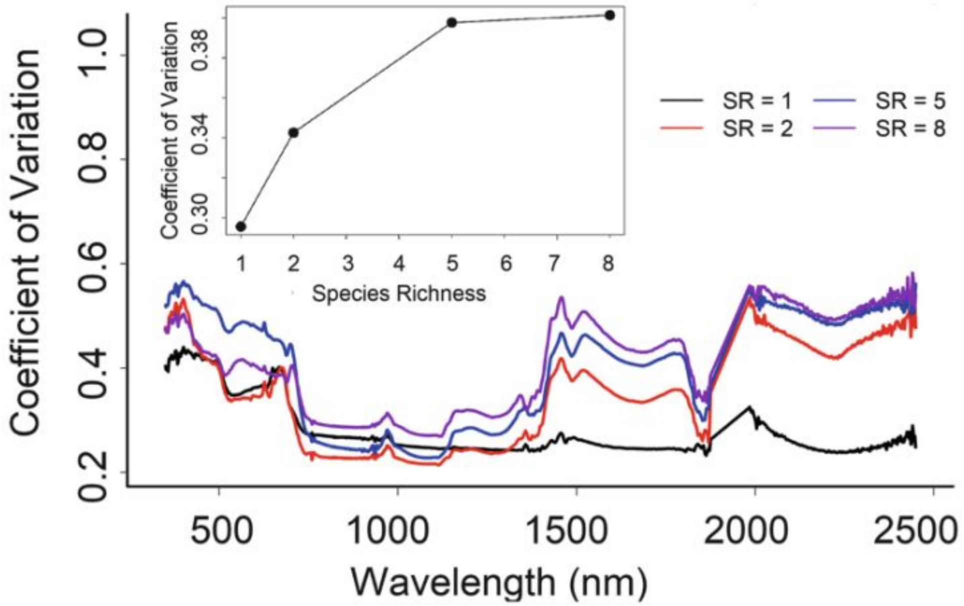
# Biodiversity from remote sensing: SVH

Can the spectral variability hypothesis be shown from simple measurements in the field?




Mean (+/- SD) of spectral responses measured at four plots with different species richness (1, 2, 5 and 8). (Gamon et al. 2020)



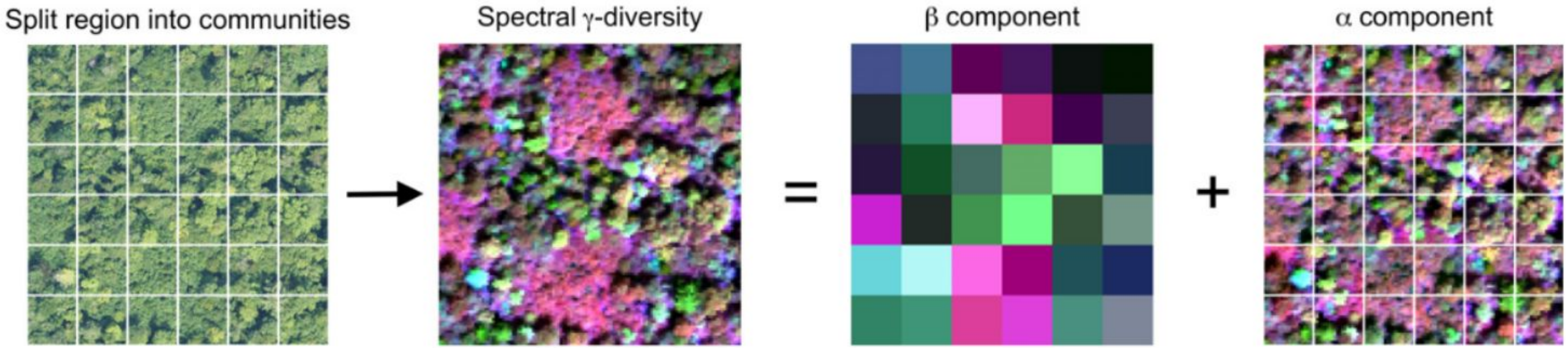

Coefficient of variation (spectral variability) of the same plots (high values = high variability in measured spectra). (Gamon et al. 2020)

# Biodiversity from remote sensing: SVH

**Testing of SVH**: Correlating field data (alpha diversity sampled in plots or inventory species data) with spectral heterogeneity of a larger region, e.g.

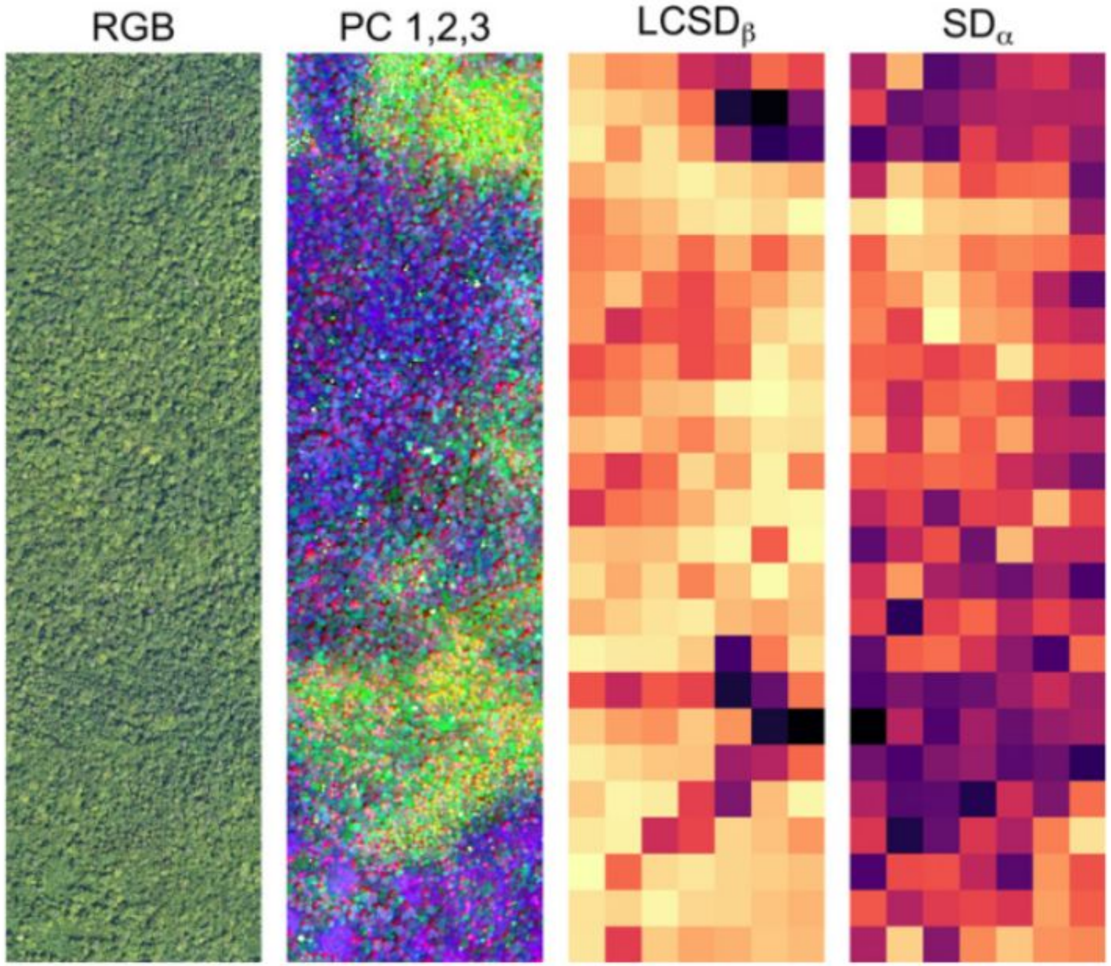
- **Wetlands** (Rocchini et al. 2004)
- Prairie vegetation (Palmer et al. 2002)
- Alpine forests (Torresani et al. 2019)
- **Grasslands** (Lopes et al. 2017)
- **Tropical forests** (Feret & Asner 2014)
- Mediterranean vegetation (Levin et al. 2007)
- And others

# Biodiversity from remote sensing: SVH




Plant biodiversity can be estimated from spectral heterogeneity and then differentiated into alpha and beta components using a decomposition method. This allows to derive biodiversity hotspots or hotspot communities. (Laliberte et al. 2020)

# Biodiversity from remote sensing: SVH



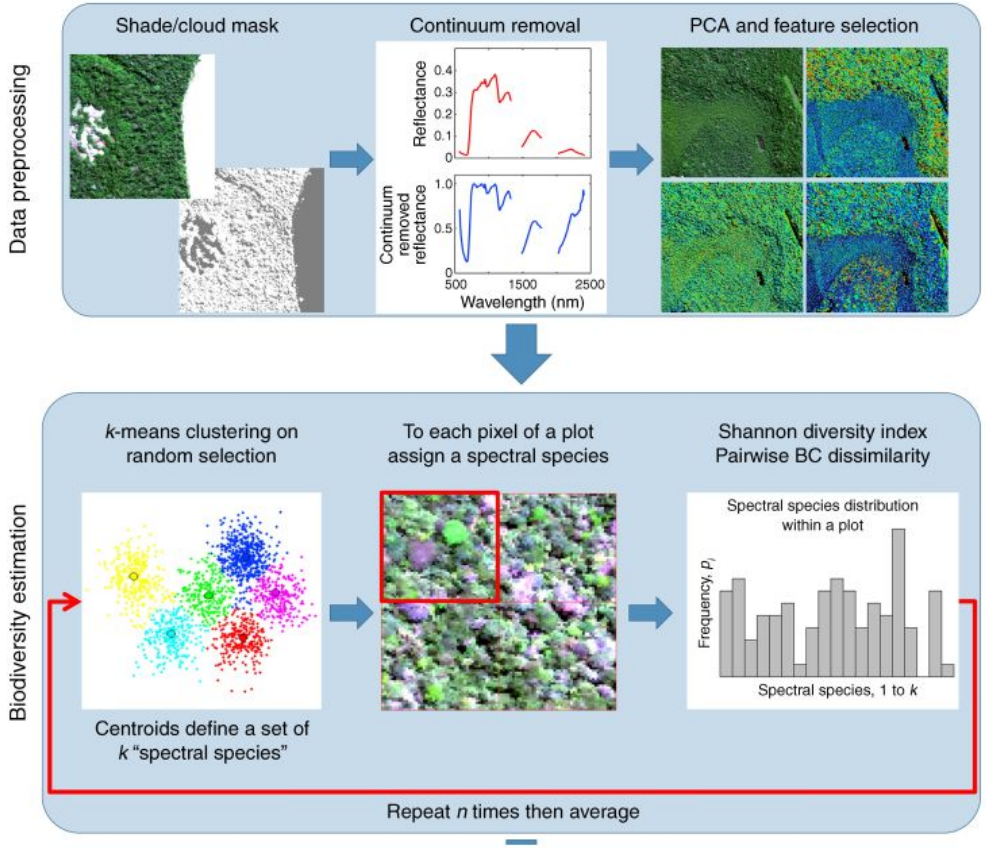

Instead of directly using spectral bands, a PCA can reduce dimensionality by keeping variance. LCSD = local contribution to spectral beta diversity. (Laliberte et al. 2020)

# Biodiversity from remote sensing: SVH

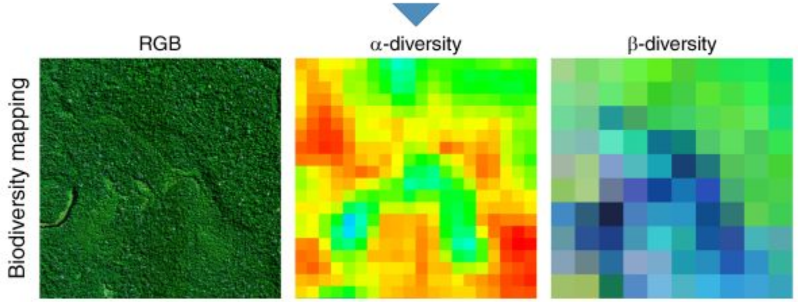
**Sensitivity of SVH**:

- Scale-sensitivity (and thus sensor-dependency): if spectral heterogeneity is low but species richness is actual high (i.e. observed habitat seems to be homogenous)  likely a scale issue (spatially to coarse)
- High spectral sensitivity (band composition and range)
- High time-of acquisition sensitivity ( due to seasons)
- Species diversity measures: if accounting for species relative abundance (choice of alpha index) as reference instead species richness, results may be better  e.g., Shannon index less affected by rare species Odeland et al. 2010, Ricotta et al. 2008

# Biodiversity from remote sensing: Spectral species

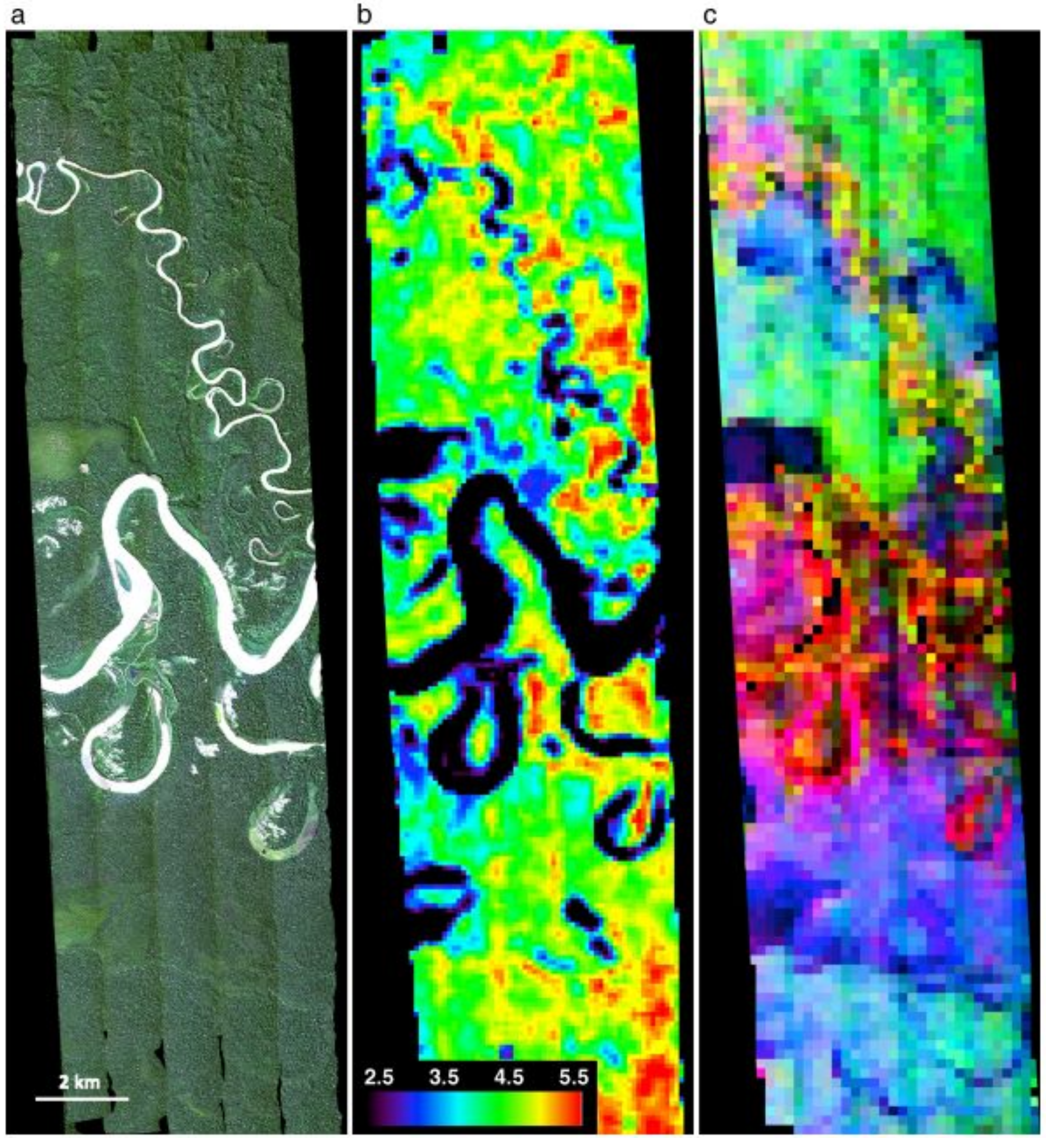



Refining SVH: Spectral species unsupervised clustering and then applying the cluster model on each pixel… (Feret & Asner 2014)




…then calculating the Shannon index (alpha) over 1-ha kernels and calculating a beta diversity index over 4-ha kernels (Feret & Asner 2014)

# Biodiversity from remote sensing: Spectral species




RGB (among the input features), alpha diversity index and beta diversity index (the more different the colors, the more different the diversity between kernels). (Feret & Asner 2014)

# Biodiversity from remote sensing: Spectral species

**“Spectral species” idea summarized**:

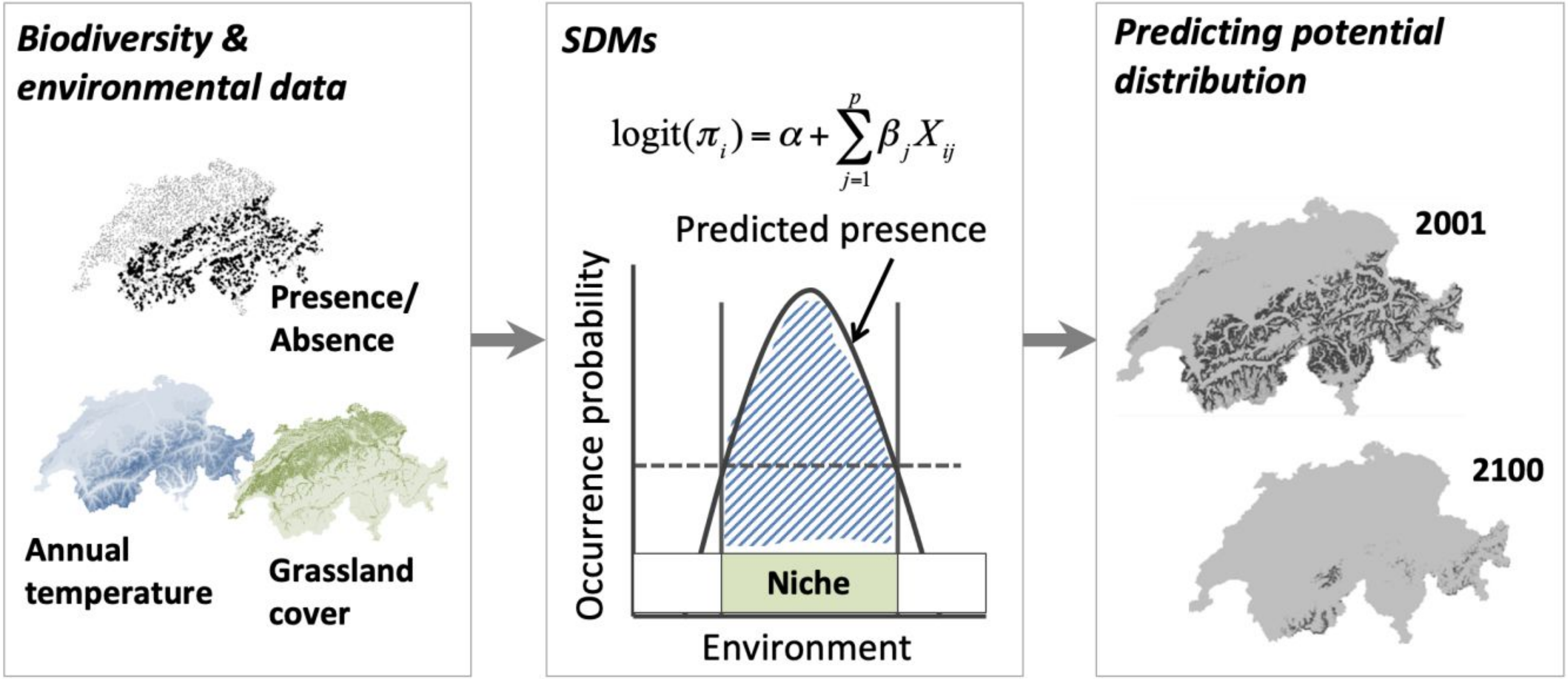
- Clustering features from spectral species, based on the assumption that differences in species are correlating with difference of their used niche (SVH)
- Classifying pixels using the cluster model
- Setting an alpha diversity scale (kernels / clumps), calculating alpha diversity index for each kernel
- Calculating diversity across kernels in larger beta kernels, than compare compositions

# Biodiversity from remote sensing: SDMs

Widely applied and conceptually understood:

- Allow to identify environmental variables critical for species or communities  in conservation and decision making used as explanatory models
- Allow to inter- and extrapolate potential geographic distributions of species or communities  in conservation planning used to minimize the impact of development
- Allow to provide scenarios for past and future species distributions (forecasting)  sustainability assessment, assessment of threatened, rare, flagship or invasive species
- Often linked to other biodiversity monitoring frameworks such as Essential Biodiversity Variables (EBVs)

# Biodiversity from remote sensing: SDMs




(1) Sampling in geographic space, (2) a statistical model (here, generalized linear model) is used to estimate the species-environment relationship. (3) the species-environment relationship can be mapped. (Zurell et al. 2020)

# Biodiversity from remote sensing: SDMs

Two types of SDMs:

- Statistical / statistical learning
- Process-based

# Biodiversity from remote sensing: SDMs

**Statistical SDMs**:

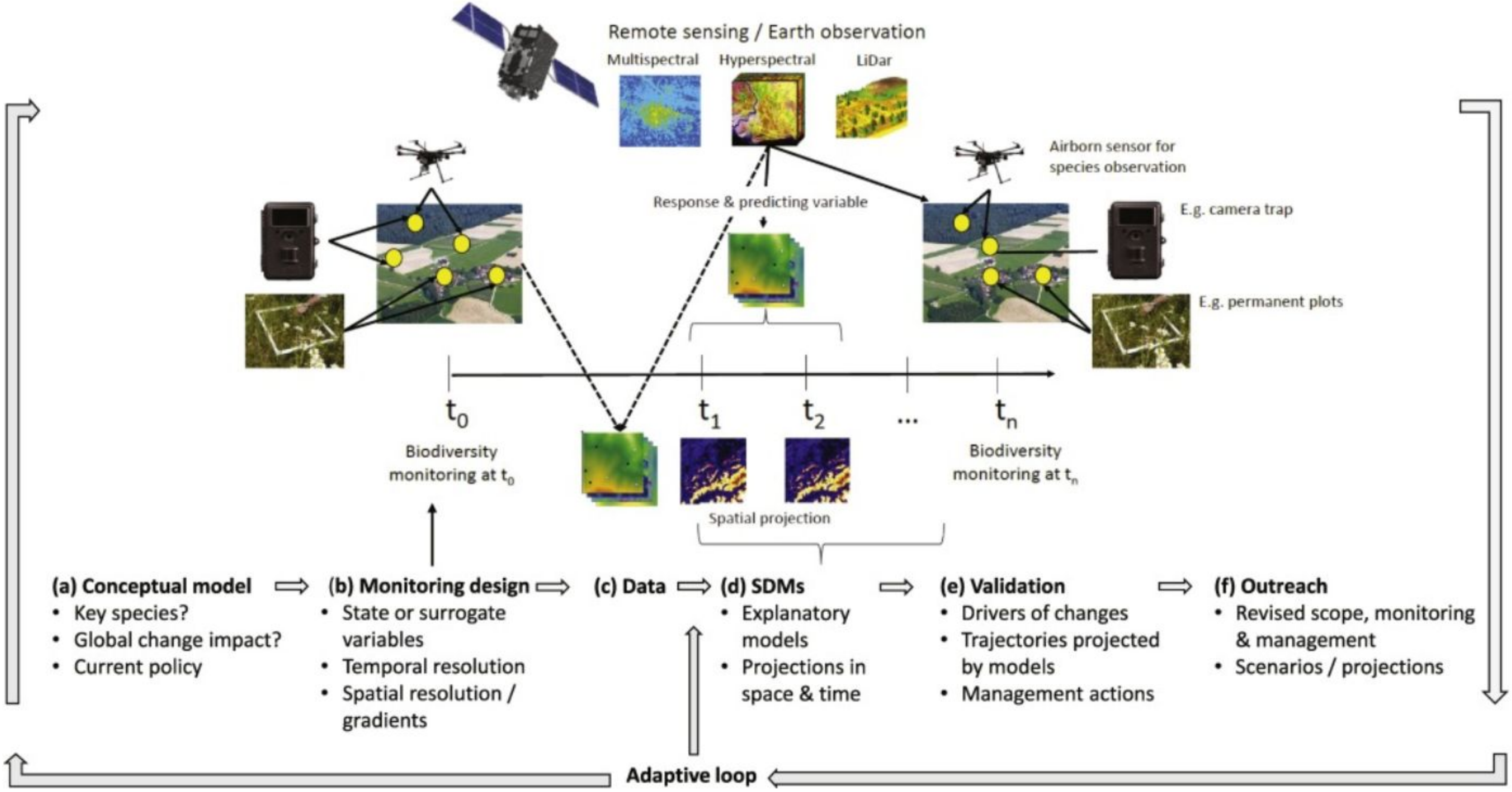
- Also called habitat suitability models
- Ground data: species occurrences, occurrence / abundance data or coarser such as taxonomic groups / communities etc.
- Predictor data: environmental covariates potentially relate to the species occurrence / composition, e.g., spectral reflectance, vegetation indices, topography indices, precipitation, surface temperature etc.
- Modelling: establishing relationship between species occurrence and covariates
- refinement / tuning by testing for variable importance
- Processes not explicitly modeled, but empirically inferred

# Biodiversity from remote sensing: SDMs

**Process-based SDMs**:

- Build on explicit causal relationships determined experimentally, e.g., phenology and distribution
- Makes it more reliable to extrapolate beyond the training area
- In between purely process-based SDMs and statistical SDMs: hybrids, dynamic range models, integrated models etc.

# Biodiversity from remote sensing: SDMs




A usual study design involving RS-fed SDMs to model species distribution (Randin et al. 2020)

# Biodiversity from remote sensing: SDMs

**Pitfalls /challenges of SDMs**:

- Do not comprehend biotic interaction
- Assume only the environment to be of effect (extrinsic view), but do not account for intrinsic motivation of distribution / movement
- Danger of only well-describing a statistical relationship that might not correspond with biological causalities

# Conclusions

**Biodiversity estimation from remote sensing**

- Quantifying biodiversity is not trivial, though a multitude of approaches exist of which we looked at four prominent ones
- Biophysical signatures, both spectral and structural, contained in remotely sensed signal relate to alpha biodiversity and can be exploited (direct approach)
- Environmental conditions (soil, precipitation, temperature etc.) as well as ecological variables (NPP, LAI) are proxies for species composition and can be exploited (indirect approach)
- Assumptions about relationships between spectral / structural signatures and species composition can be used for unsupervised biodiversity estimation
- Remote sensing can serve both the need to derive biodiversity indicators (i.e. proxies, e.g., for climate models) as well as further modelling alpha and beta diversity

Any questions?

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# Thank you for your attention!

**Dr. Insa Otte and colleagues**

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