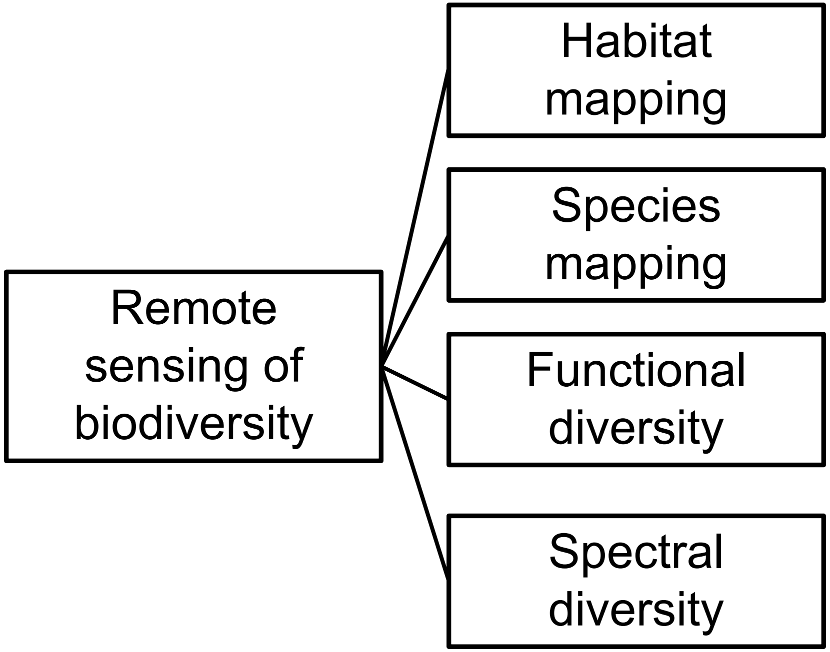
AVIRIS-NG for spectral diversity
Henry Frye

What we will cover in this session

- How spectral diversity fits in the broad biodiversity remote sensing picture
- The origin story of spectral diversity
- Ways to calculate spectral diversity

So you want to measure biodiversity with remote sensing…

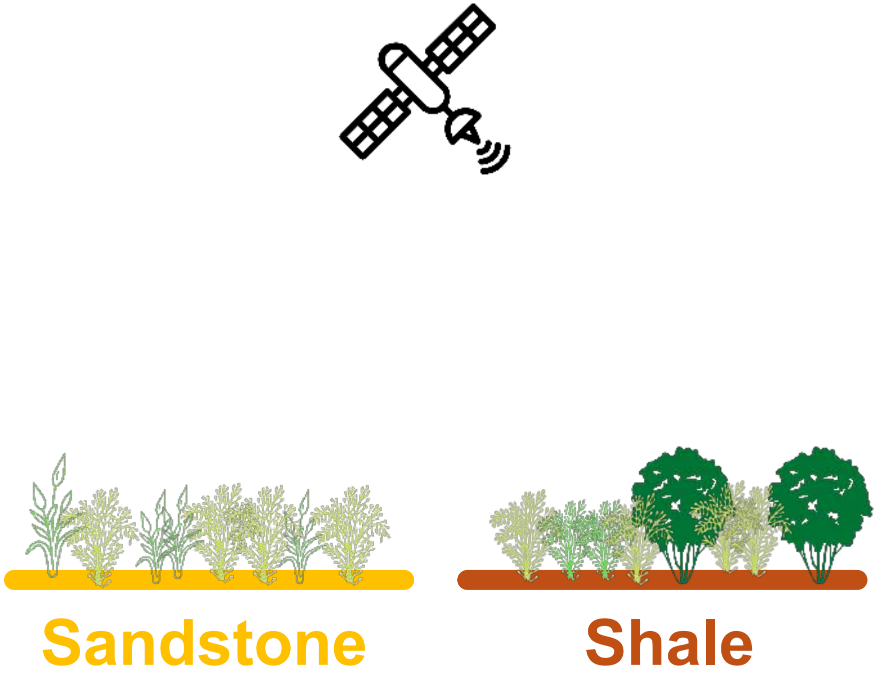


Adapted from Wang & Gamon 2019 RSE

Imagine mapping sandstone vs. shale derived fynbos with an RS product

Remote sensing of biodiversity

- Habitat mapping
- Species mapping
- Functional diversity
- Spectral diversity

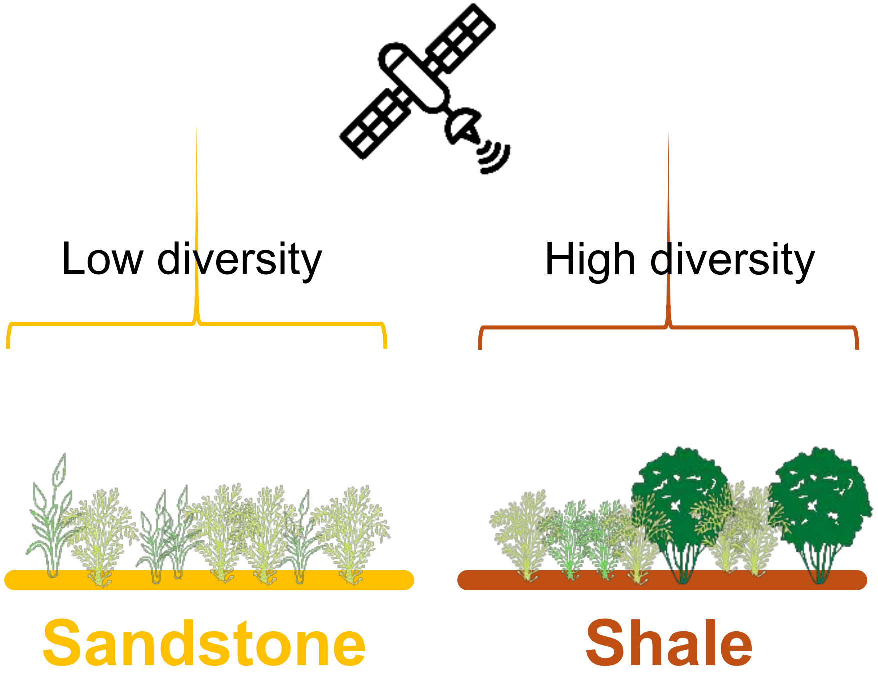


Adapted from Wang & Gamon 2019 RSE

Assuming one has higher vs. lower species richness, you've mapped biodiversity

Remote sensing of biodiversity

- Habitat mapping
- Species mapping
- Functional diversity
- Spectral diversity



Adapted from Wang & Gamon 2019 RSE

Species mapping works well in a few cases:

Remote sensing of biodiversity

- Habitat mapping
- Species mapping
- Functional diversity
- Spectral diversity

- Mapping pure patches of species, e.g., invasives

A large wattle patch

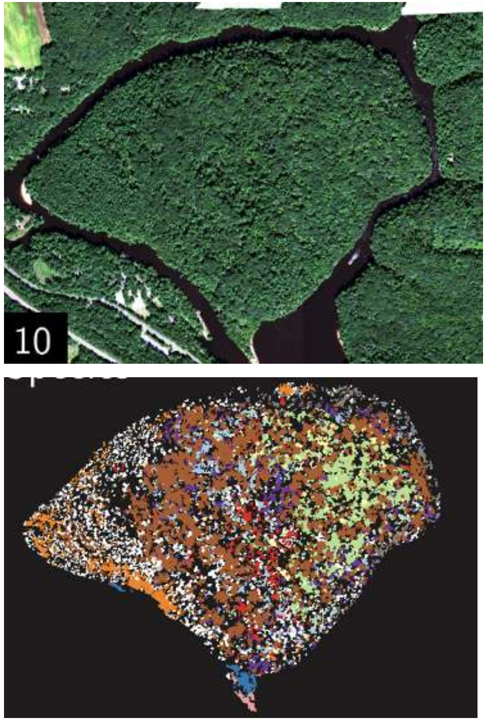
Adapted from Wang & Gamon 2019 RSE

Species mapping works well in these cases:

Remote sensing of biodiversity

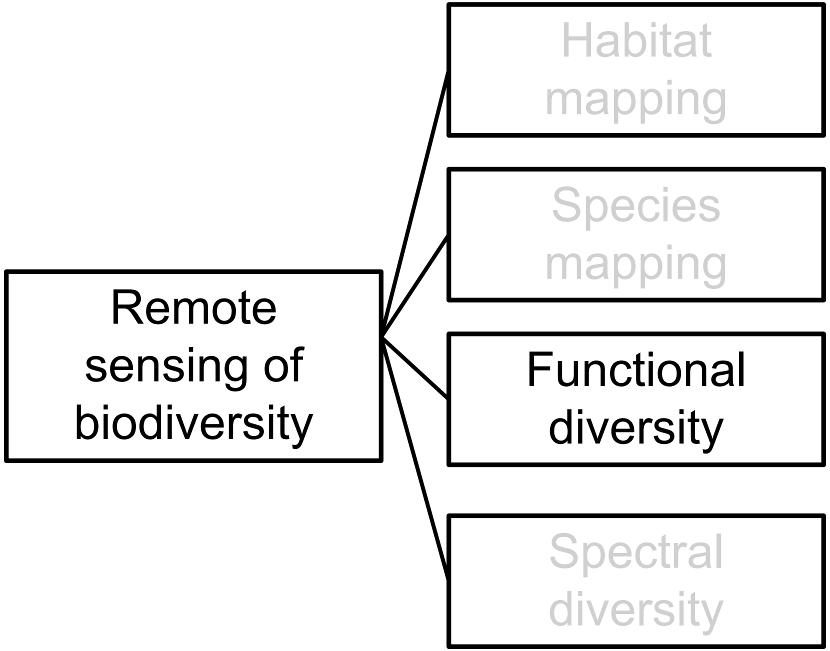
- Habitat mapping
- Species mapping
- Functional diversity
- Spectral diversity

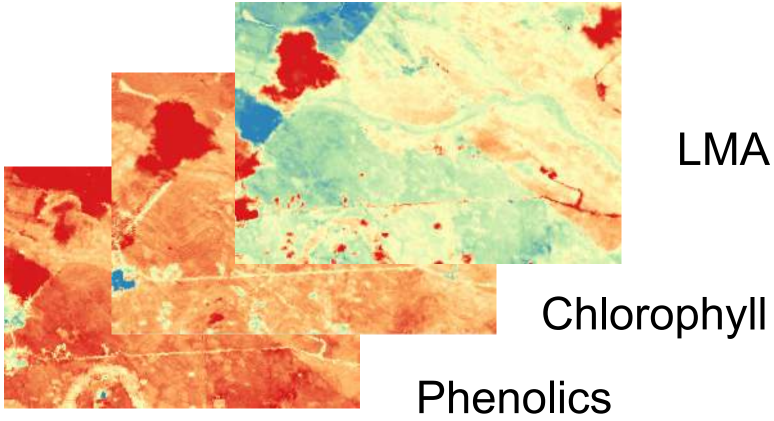
- Mapping pure patches of species, e.g., invasives
- When pixel size is equal to or smaller than individual size



Adapted from Chlus & Townsend 2022 RSE

The variability of plant traits predicted from RS can estimate functional diversity





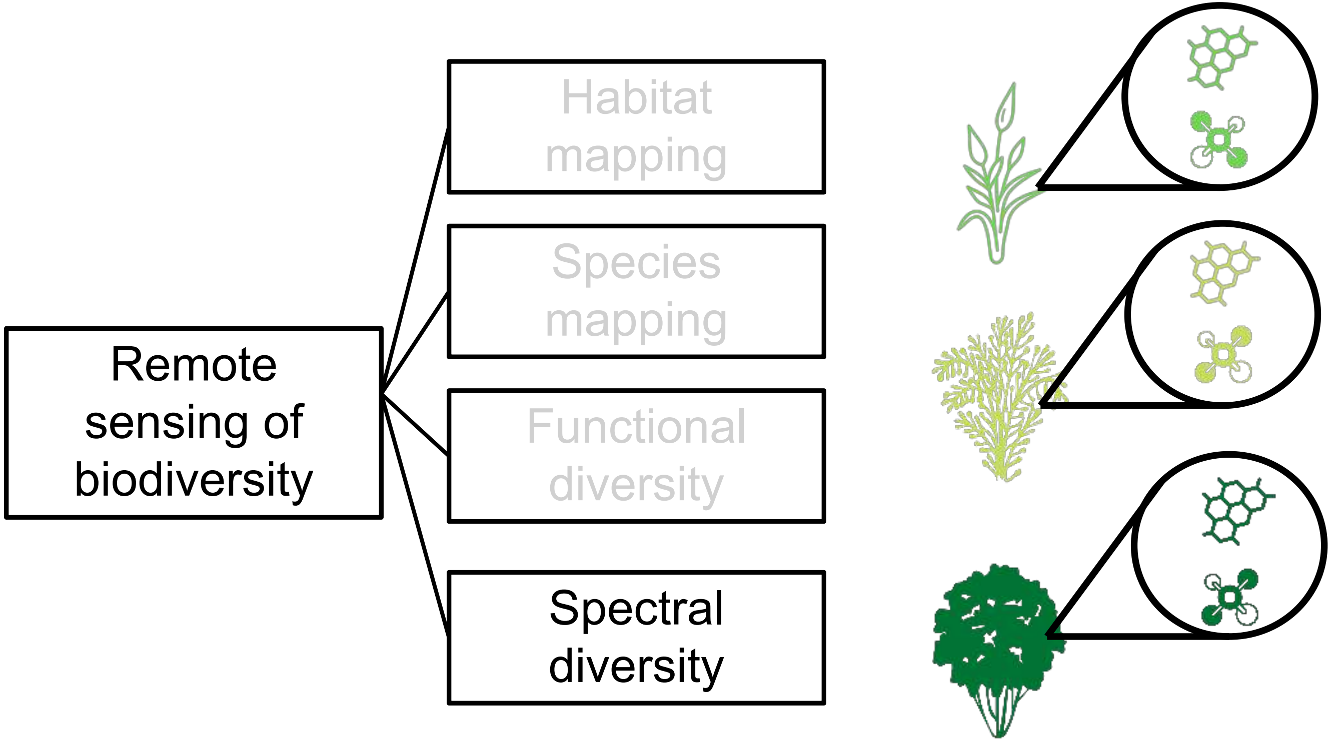
↓

Metric of trait variability

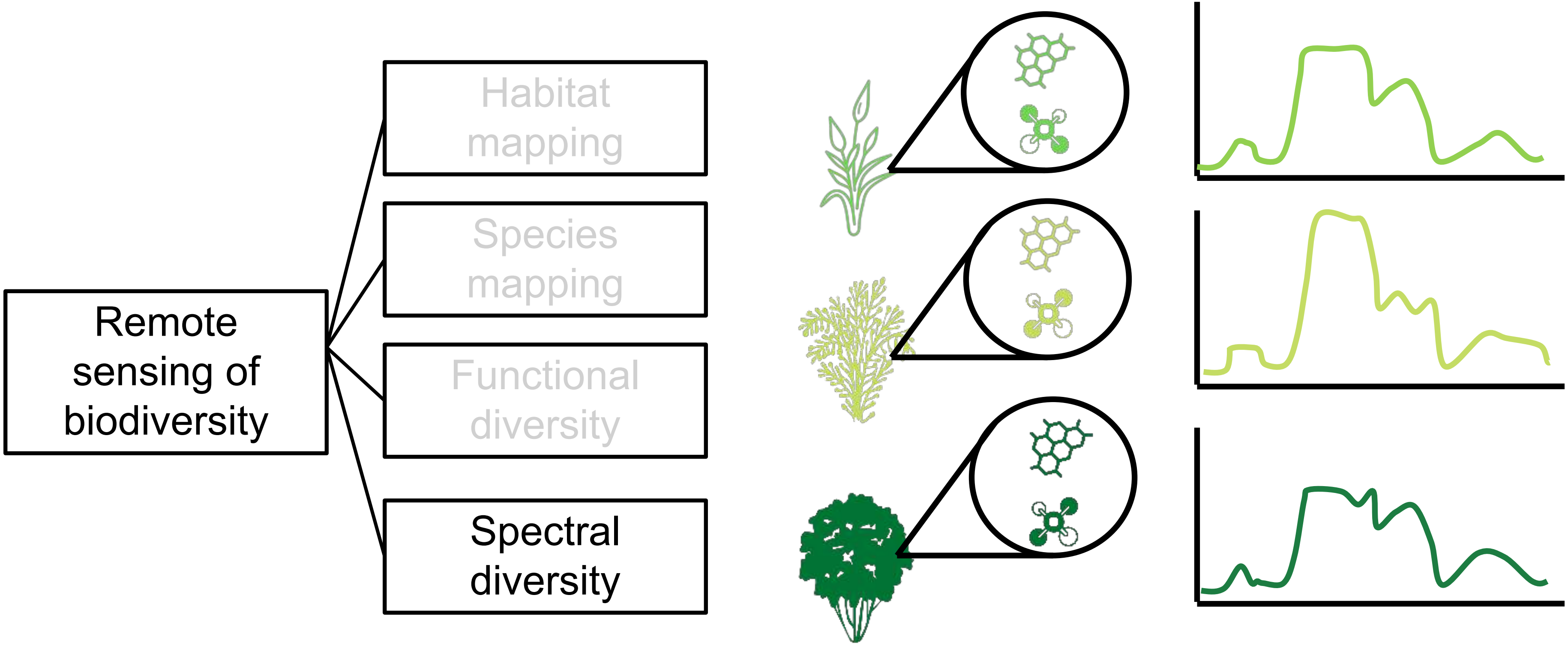
↓

Functional diversity map

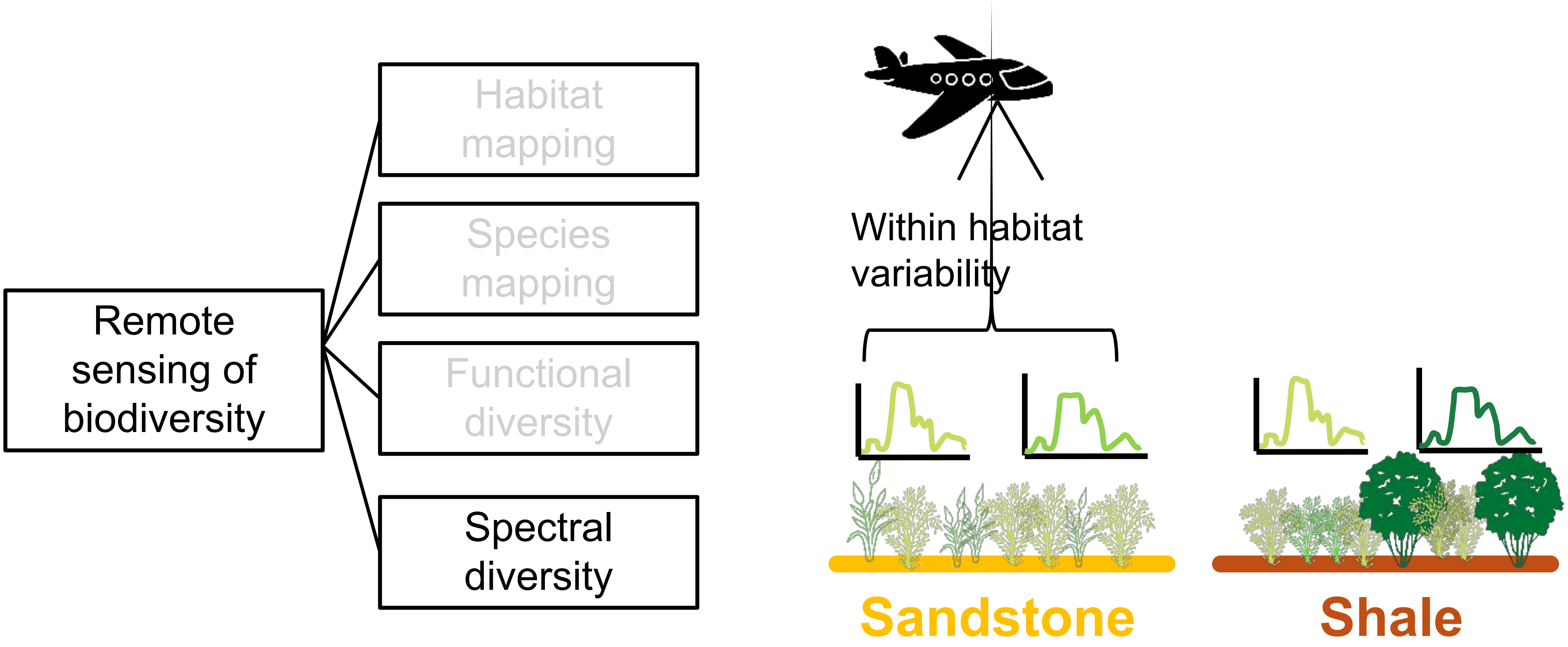
Spectral diversity relies on the idea that plants have unique chemistry, anatomy and structure



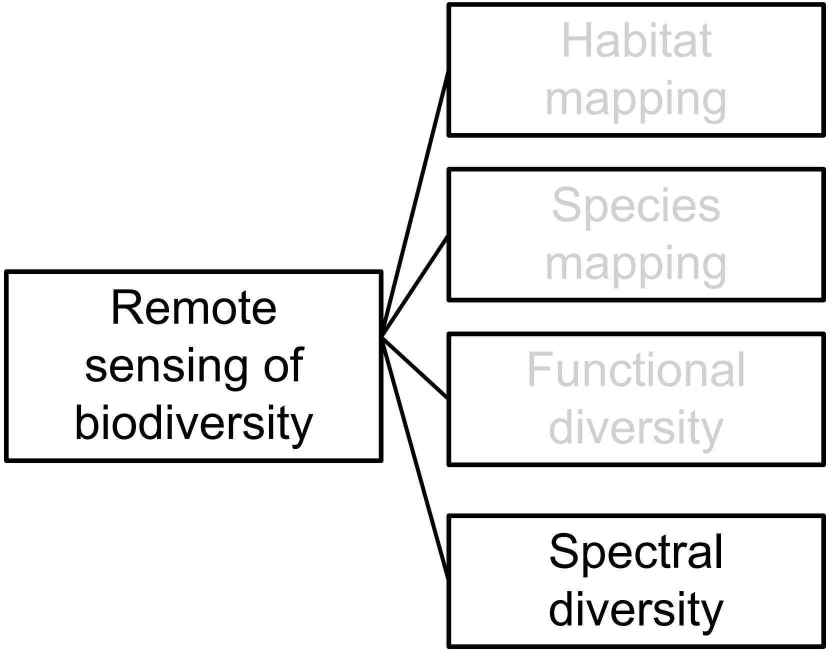
These chemistry, anatomy and structure features differentiate the spectral signatures of the plants

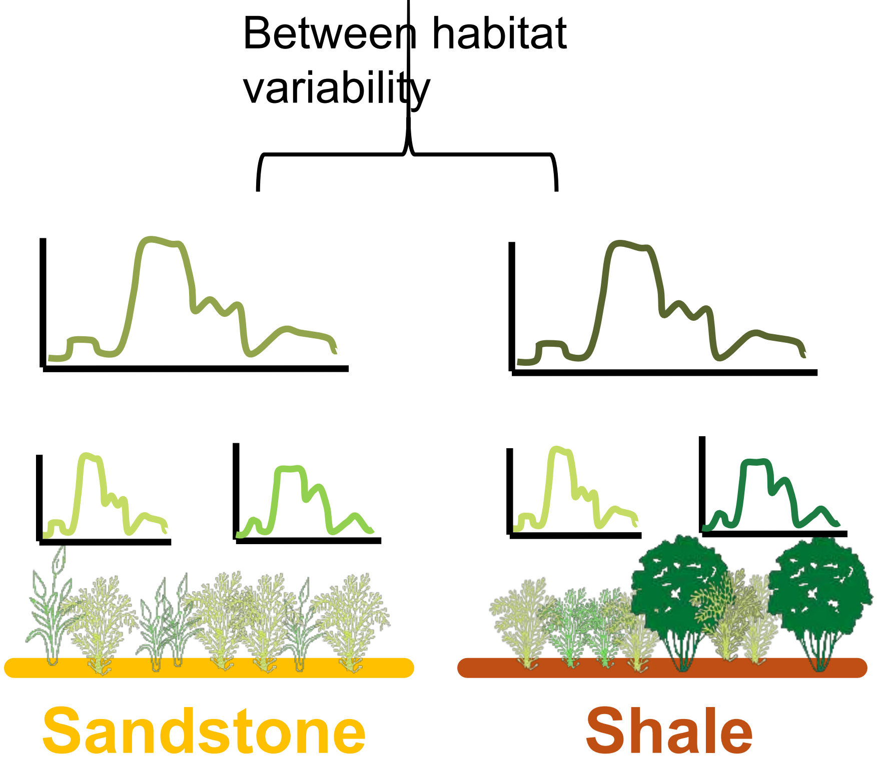


These unique spectral spectral signatures can be measured within and between habitats



These unique spectral spectral signatures can be measured within and between habitats





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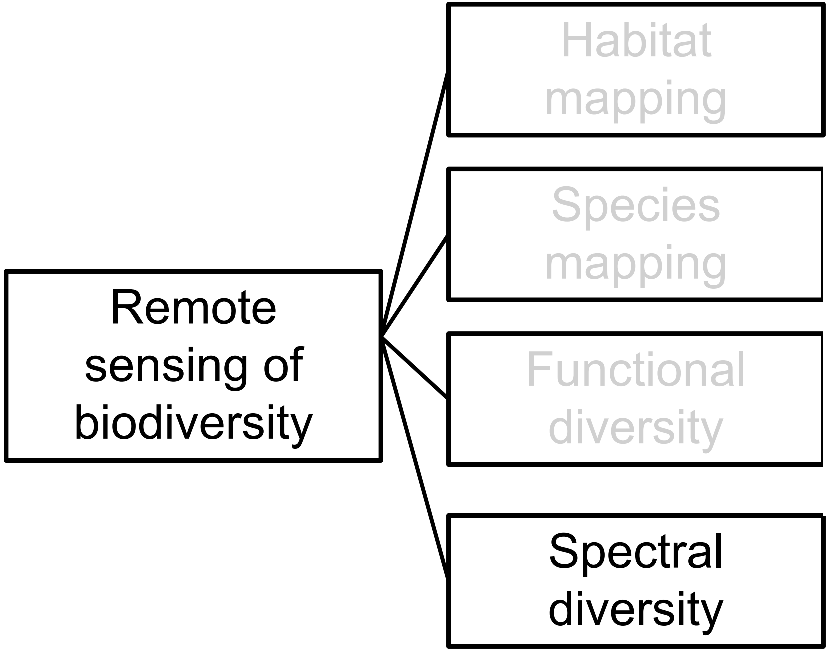

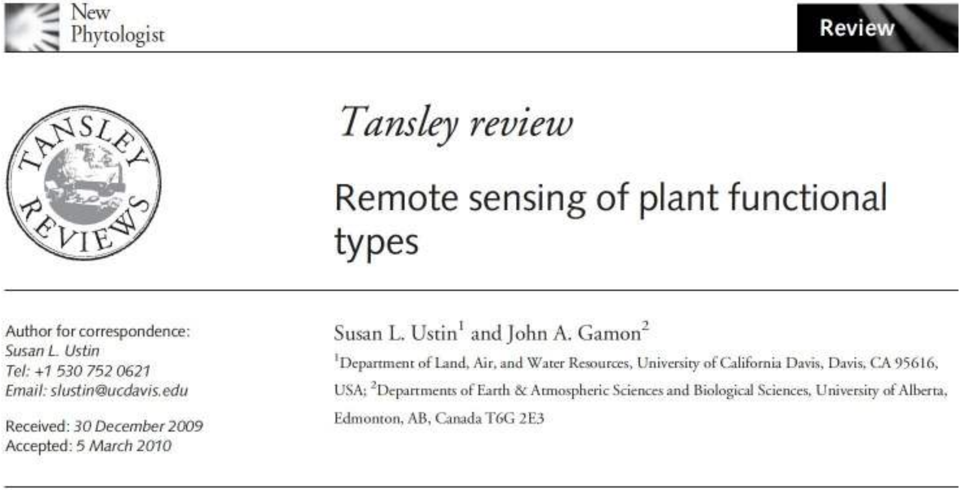
New Phytologist

Review

Tansley review

Remote sensing of plant functional types

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See Ustin & Gamon 2010 *New Phytologist*

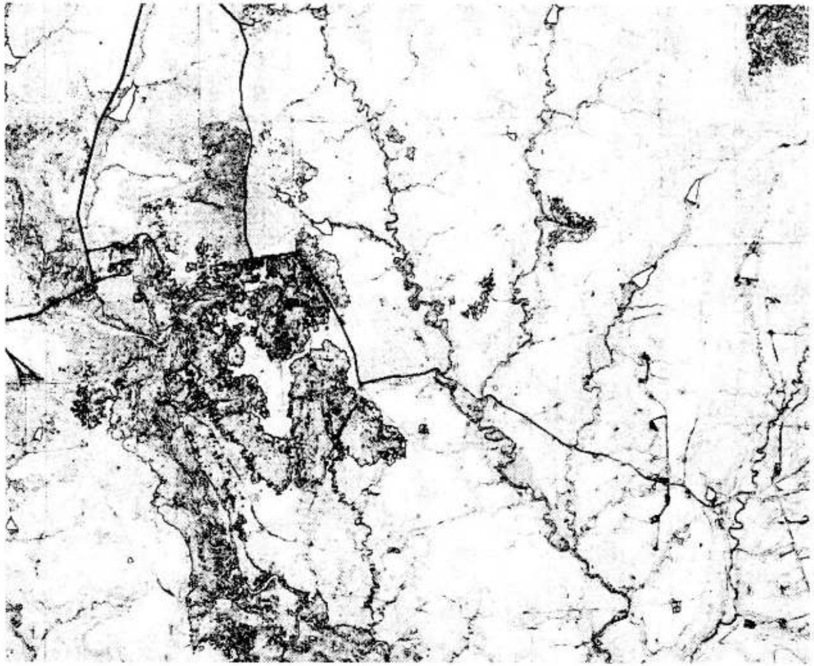
What we will cover in this session

- How spectral diversity fits in the broad biodiversity remote sensing picture
- The origin story of spectral diversity
- Ways to calculate spectral diversity

Origins of spectral diversity: spectral variation hypothesis

According to the spectral variation hypothesis:

"species richness will be positively related to any objective measure (e.g. standard deviation) of the variation in the spectral characteristics of a remotely sensed imagery" Palmer et al. 2000 *Proceedings of the ILTER regional workshop*



An aerial photograph over the tallgrass prairie preserve. Darker areas are more heterogenous, thus hypothesized to be more diverse.

Origins of spectral diversity: spectral variation hypothesis

According to the spectral variation hypothesis:

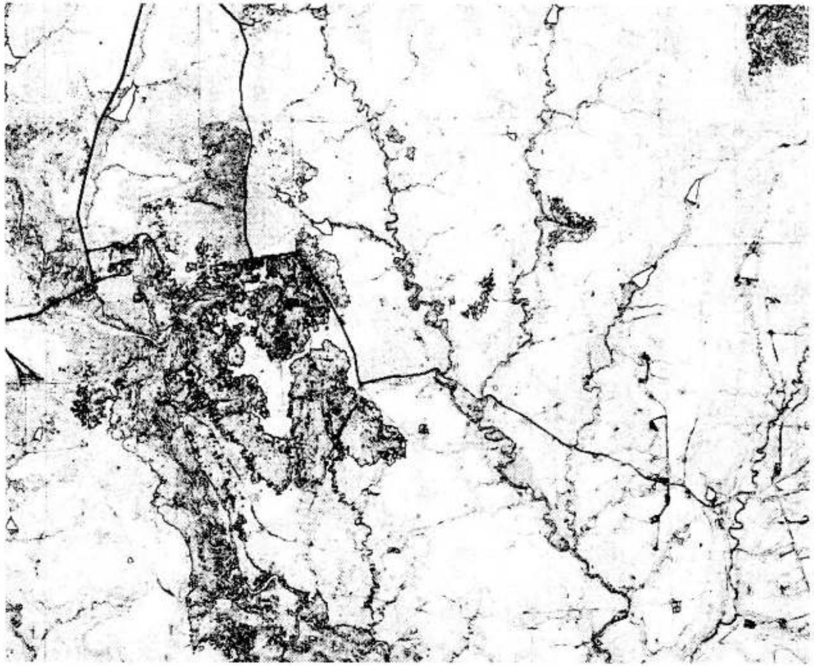
Spectral variation

↓

Habitat heterogeneity

↓

Species richness



An aerial photograph over the tallgrass prairie preserve. Darker areas are more heterogenous, thus hypothesized to be more diverse.

Research into the spectral variation hypothesis continues today

ELSEVIER

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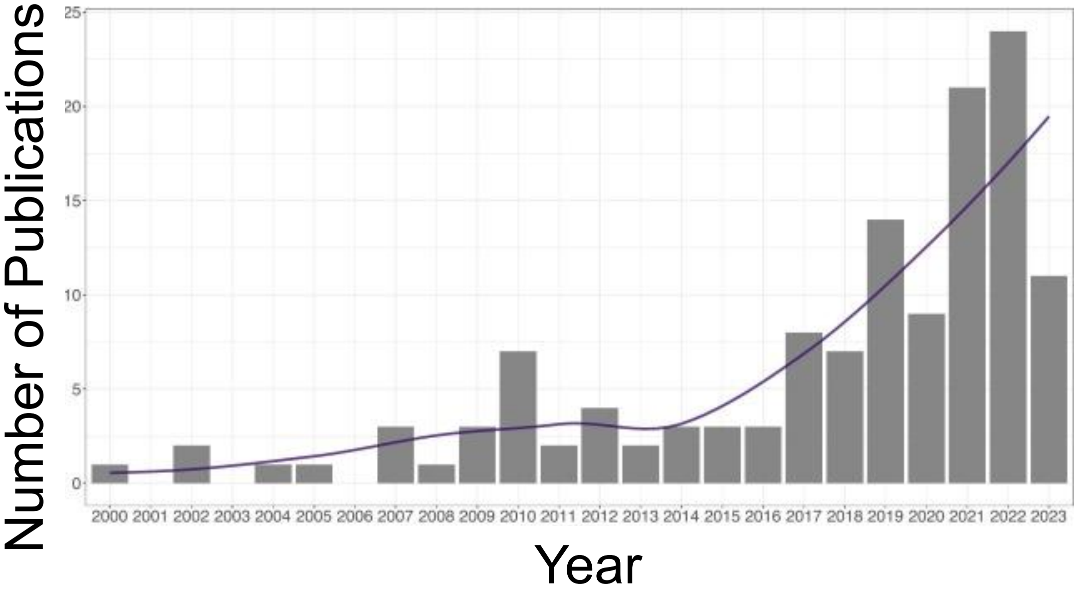
Reviewing the Spectral Variation Hypothesis: Twenty years in the tumultuous sea of biodiversity estimation by remote sensing

Michele Torresani [a], Christian Rossi [b], Michela Perrone [c], Leon T. Hauser [d], Jean-Baptiste Féret [e], Vítězslav Moudrý [c], Petra Simova [c], Carlo Ricotta [f], Giles M. Foody [g], Patrick Kacic [h], Hannes Feilhauer [i], Marco Malavasi [j], Roberto Tognetti [a], Duccio Rocchini [c k]



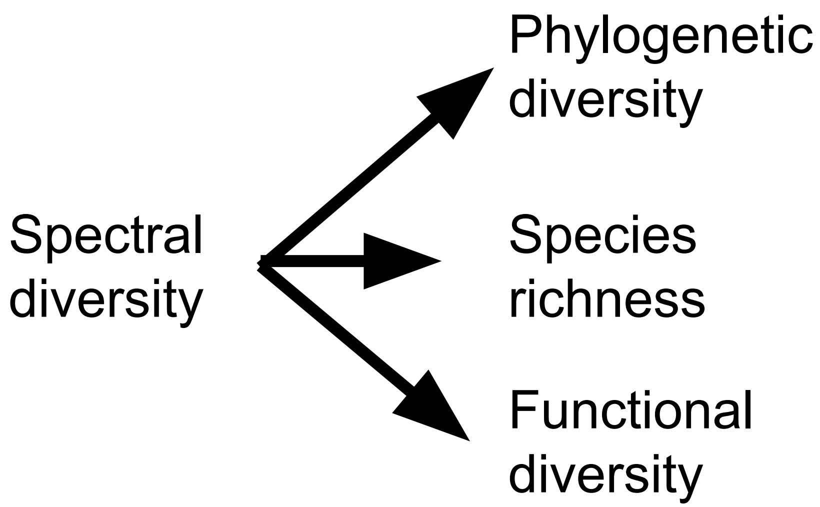
The surrogacy hypothesis: expanding the predictive power of spectral variation

Ecological theory and empirical evidence suggests that spectral diversity may work as an indicator of biodiversity at several dimensions, a term we refer to as the "surrogacy hypothesis," building on a history of observations that diversity at one taxonomic level often relates to diversity at another level (Wang and Gamon 2019, RSE)

The surrogacy hypothesis: expanding the predictive power of spectral variation

Spectral diversity $\longrightarrow$ Species richness

The surrogacy hypothesis: expanding the predictive power of spectral variation



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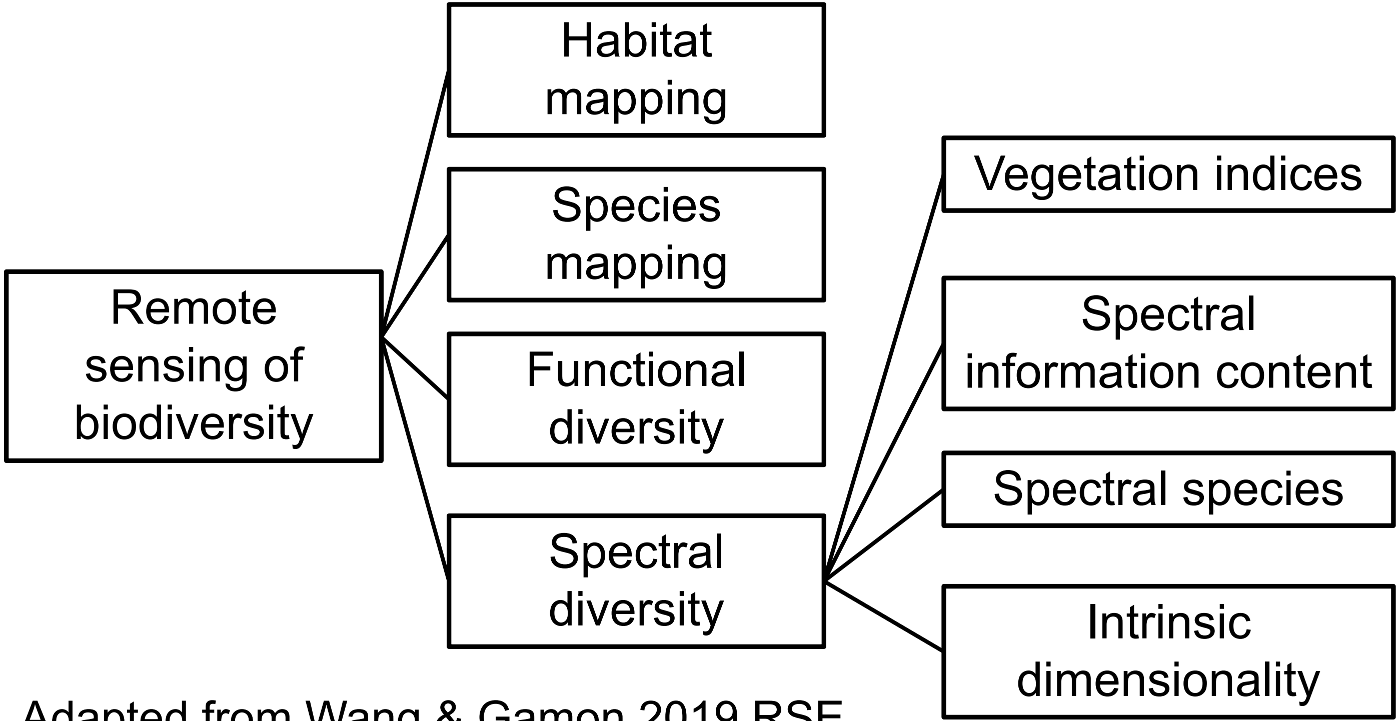
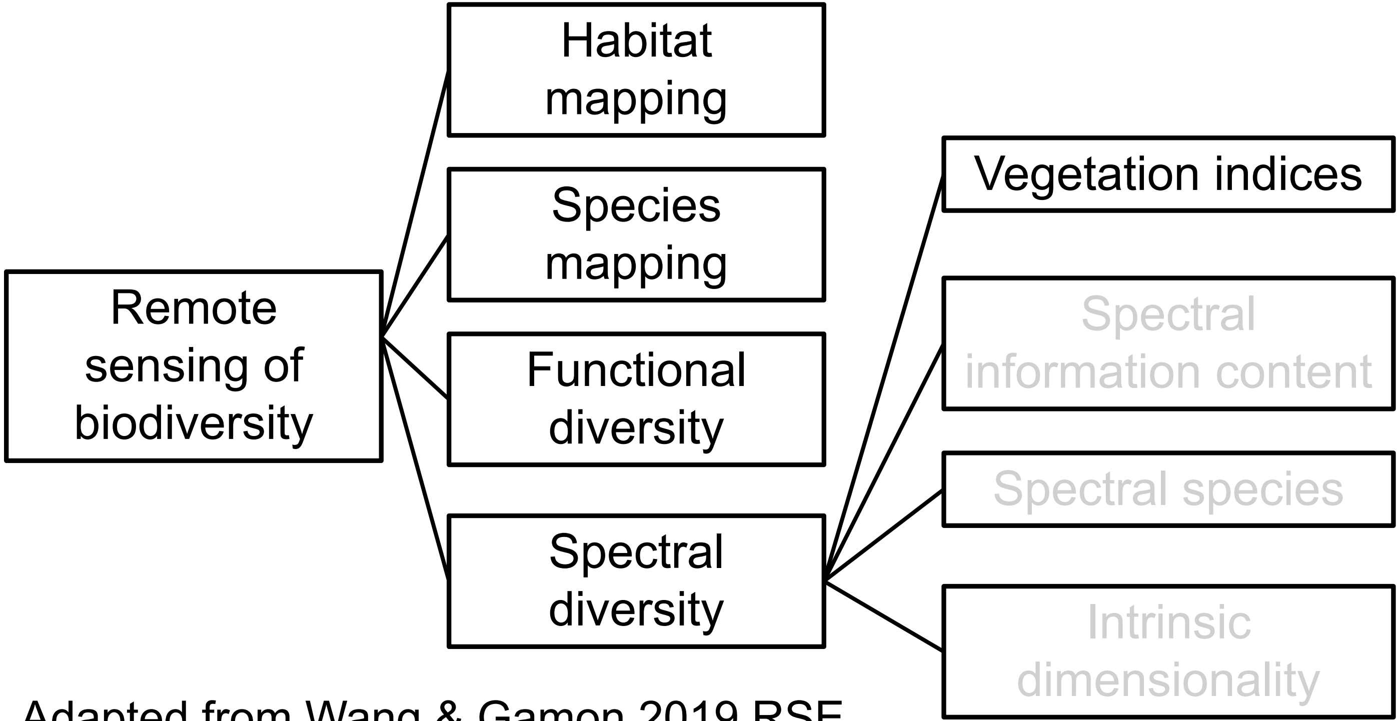
Subdivisions of spectral diversity



Adapted from Wang & Gamon 2019 RSE

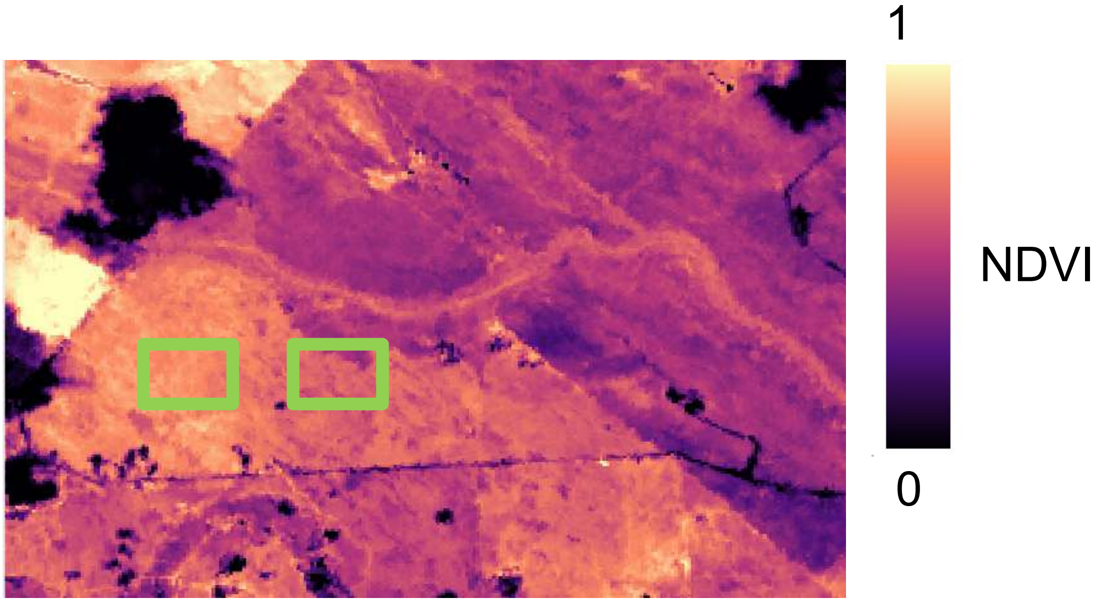
Subdivisions of spectral diversity



Adapted from Wang & Gamon 2019 RSE

Vegetation indices

A simple way to calculate spectral diversity is to: 1) **calculate a vegetation index**, e.g., normalized vegetation difference index (NDVI) and 2) **calculate the variability of the index within a fixed or moving window**

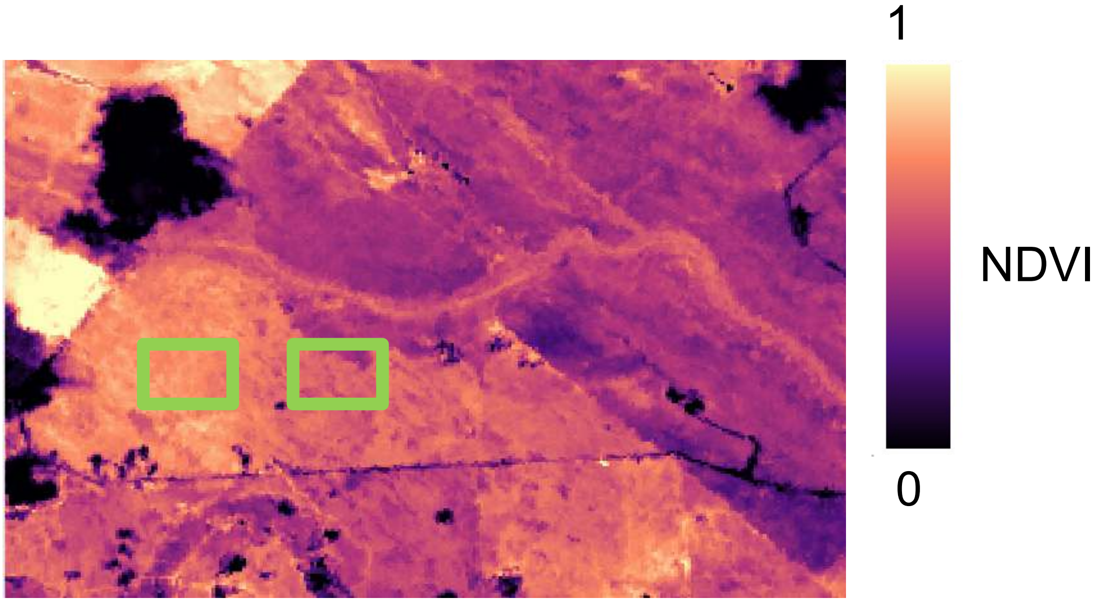


Which window has higher variability?

Vegetation indices

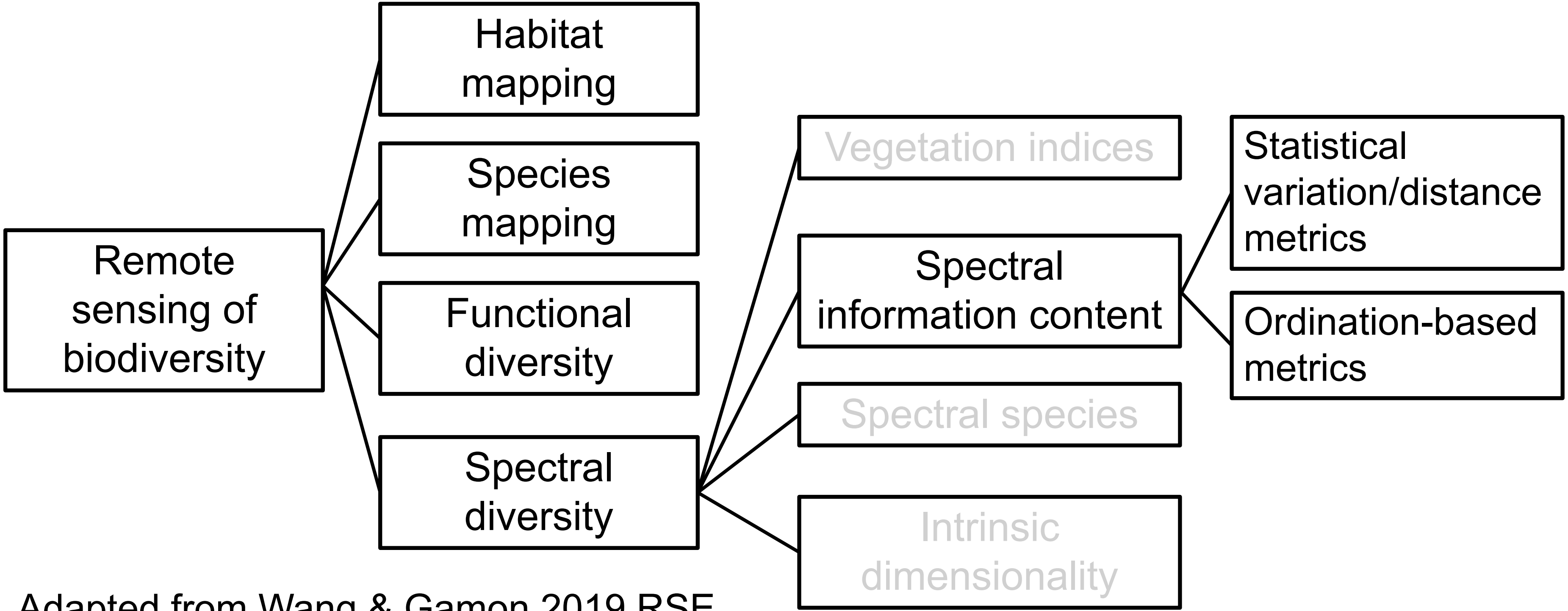
Pros of the approach:
Easy to calculate across a wide variety of imagery

Cons:
Large loss of information content in the case of image spectroscopy



Which window has higher variability?

Subdivisions of spectral diversity

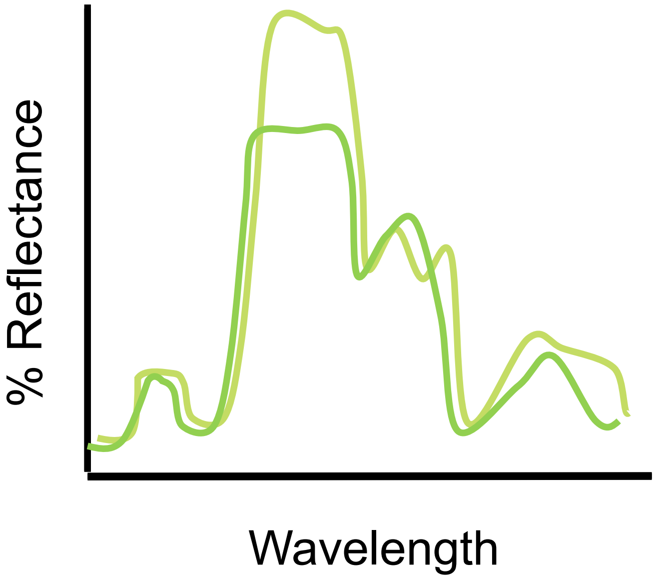


Adapted from Wang & Gamon 2019 RSE

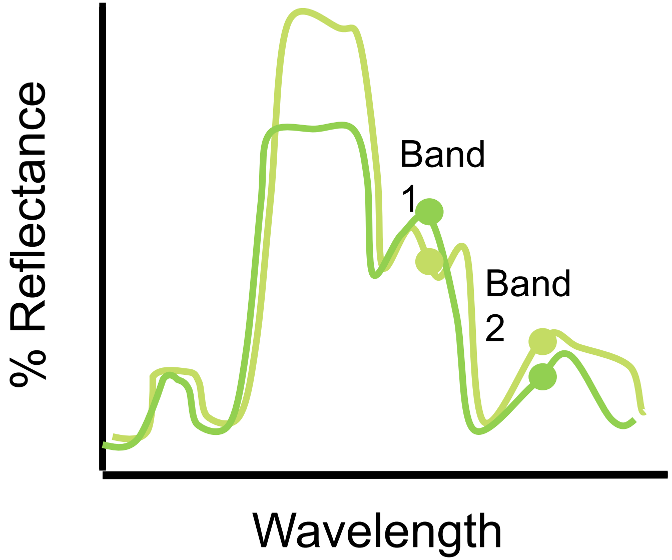
An example of a distance-based spectral diversity metric

Let’s walk through a short example of a distance-based approach using spectral angle.

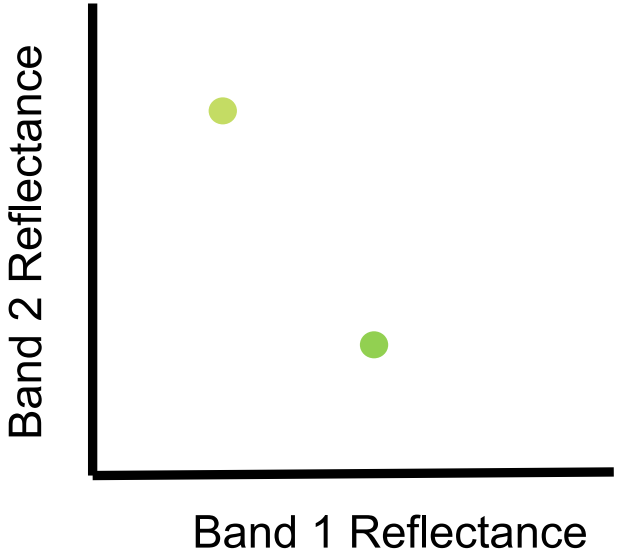
How different are these two spectra?



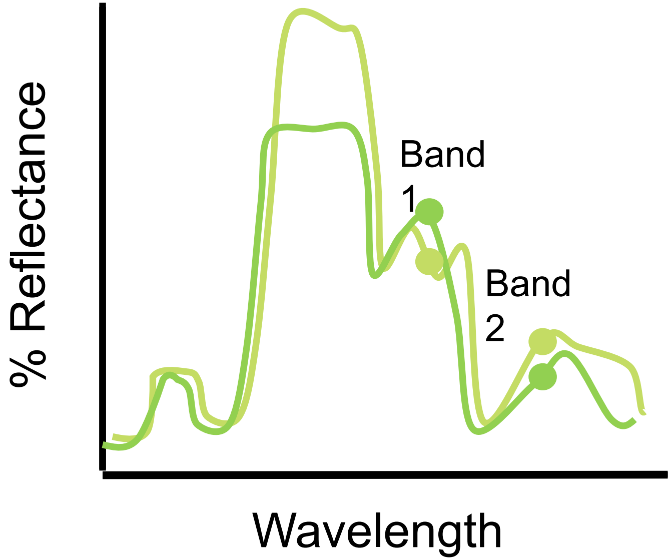
How spectral angle is calculated



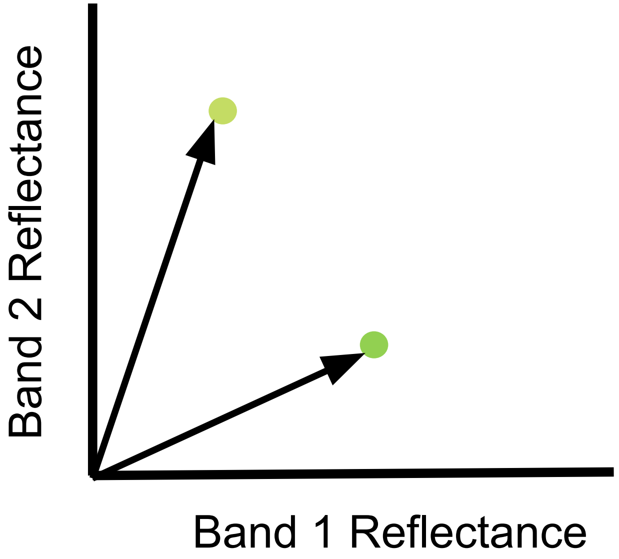
Let's plot the reflectance of 2 bands from 2 different spectra



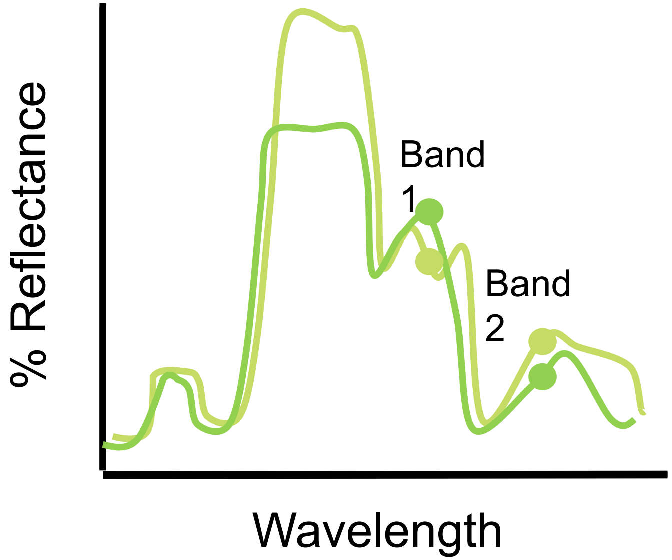
How spectral angle is calculated



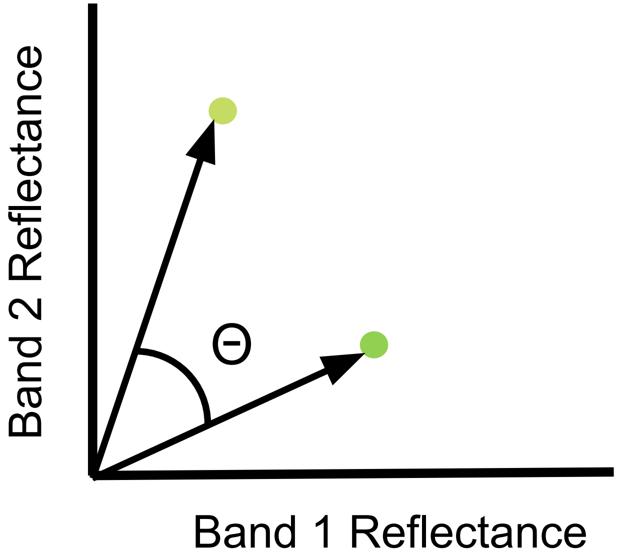
Draw a vector from the origin to each point.



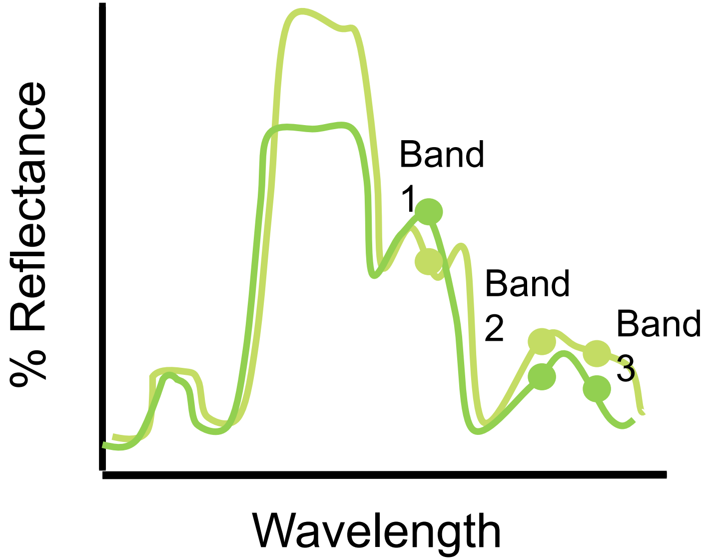
How spectral angle is calculated



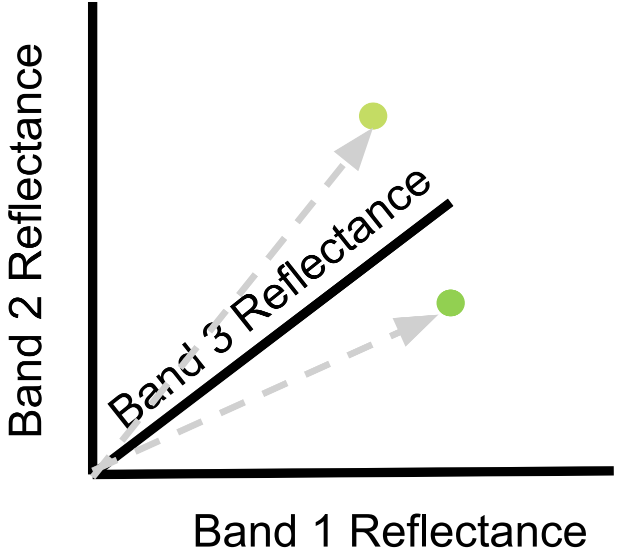
The angle between the two vectors is the variation of these spectra at between these two bands



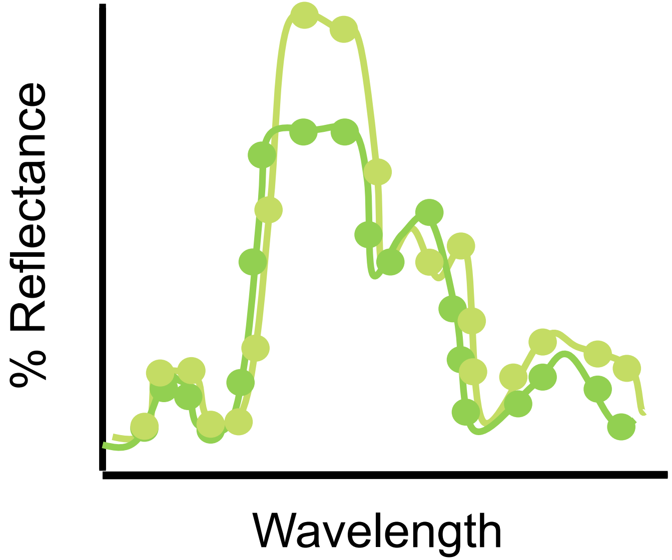
How spectral angle is calculated



We can add a third band and a third axis to calculate an angle over more spectral information

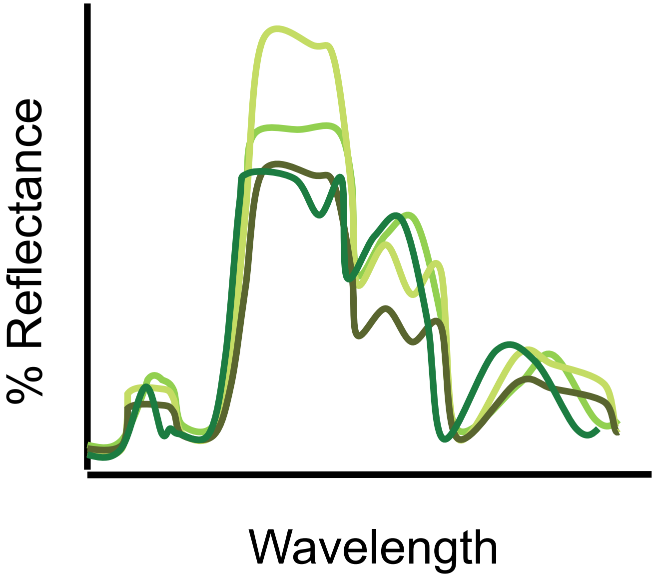


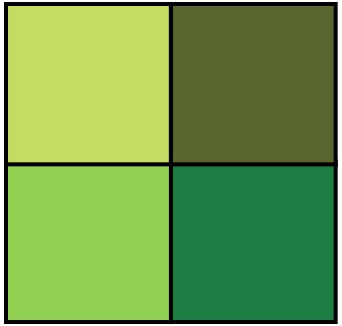
How spectral angle is calculated



More bands can be added in n-dimensional space to calculate spectral angle using all of the spectral information (we just can't visualize this!)

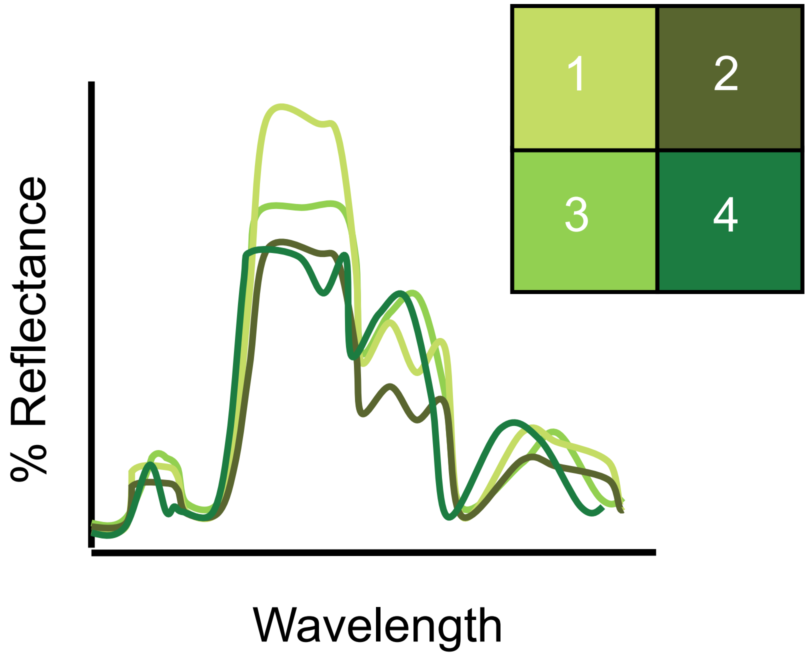
Calculating spectral diversity with spectral angle





Now that we can calculate a spectral angle, a simple distance between two spectra, let's calculate spectral diversity in a 2 x 2 neighborhood of pixels

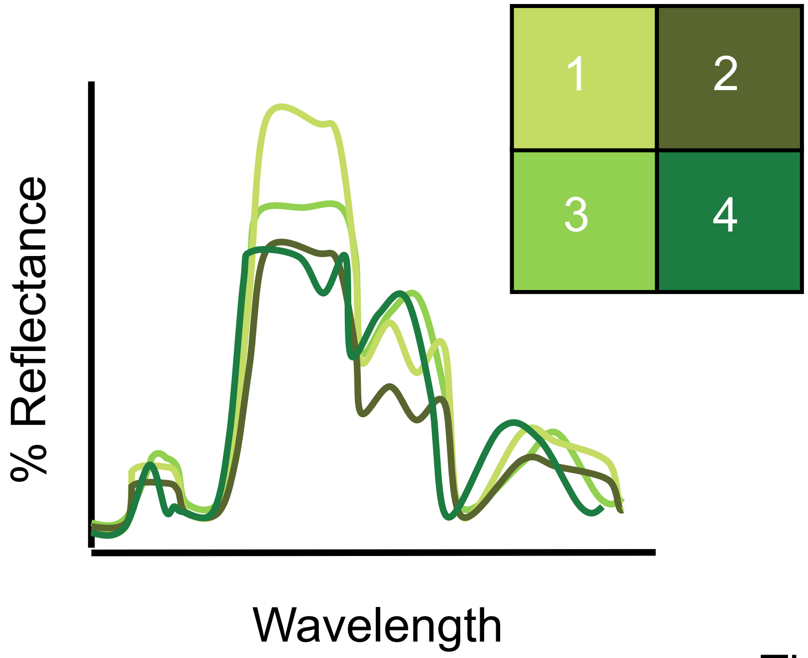
Calculating spectral diversity with spectral angle



	1	2	3	4
1				
2				
3				
4				

Above is a pair-wise distance matrix of spectral angles between all of the pixels

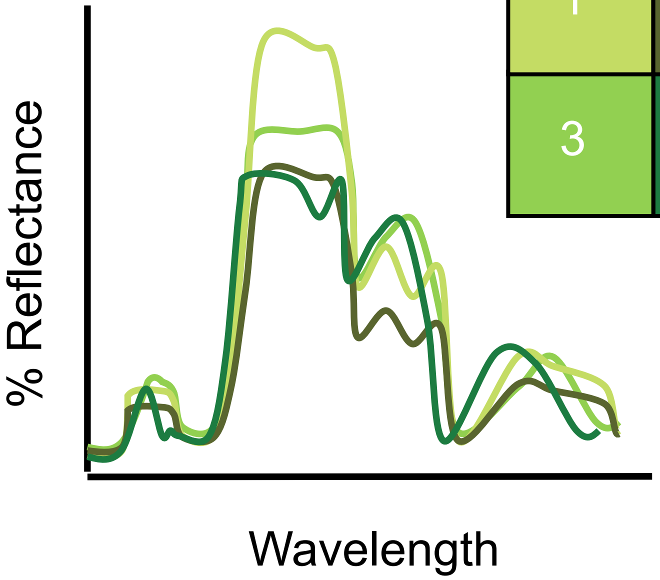
Calculating spectral diversity with spectral angle

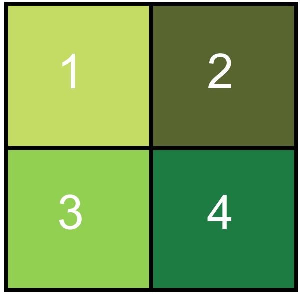


	1	2	3	4
1	0			
2		0		
3			0	
4				0

The diagonal is filled with 0's since there is no angle between vectors of the same spectra

Calculating spectral diversity with spectral angle

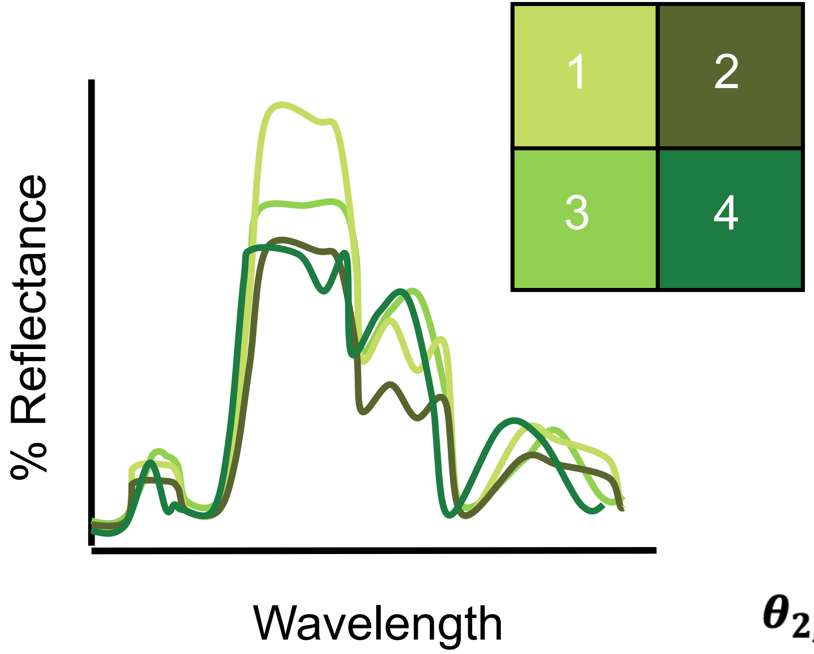




	1	2	3	4
1	0			
2	$\theta_{2,1}$	0		
3			0	
4				0

$\boldsymbol{\theta_{2,1}}$ is the spectral angle between pixels 2 and 1.

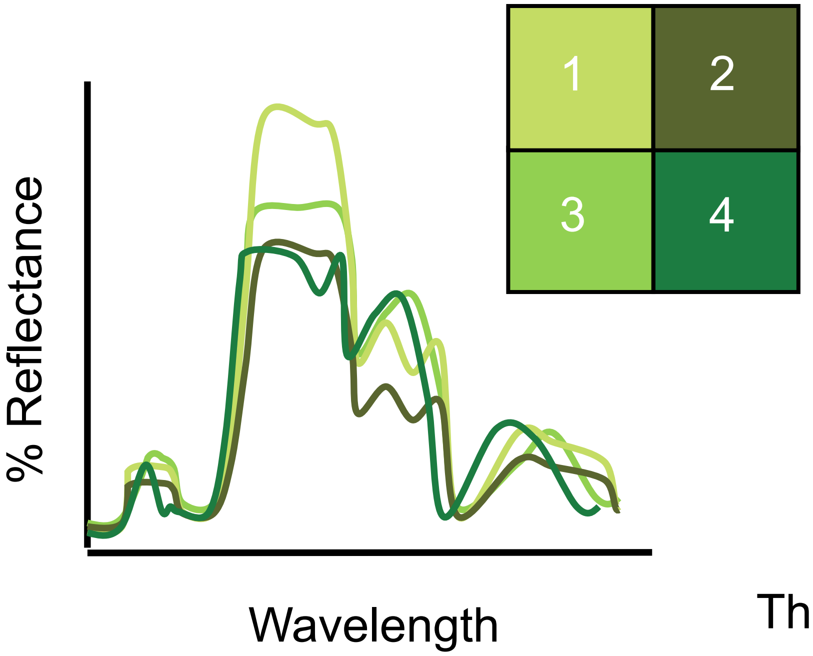
Calculating spectral diversity with spectral angle



	1	2	3	4
1	0	$\theta_{1,2}$		
2	$\theta_{2,1}$	0		
3			0	
4				0

$\boldsymbol{\theta_{2,1}}$ is the spectral angle between pixels 2 and 1. This value is identical to $\boldsymbol{\theta_{1,2}}$

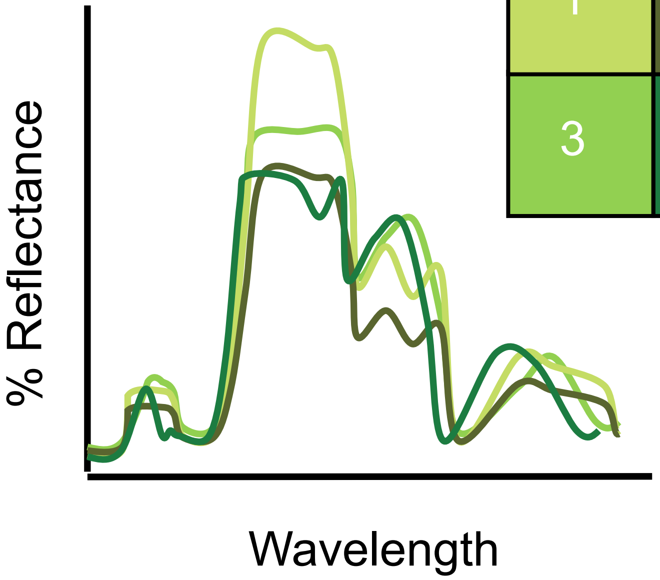
Calculating spectral diversity with spectral angle

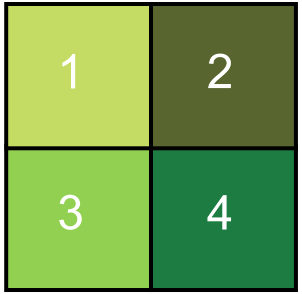


	1	2	3	4
1	0	$\theta_{1,2}$	$\theta_{1,3}$	$\theta_{1,4}$
2	$\theta_{2,1}$	0	$\theta_{2,3}$	$\theta_{2,4}$
3	$\theta_{3,1}$	$\theta_{3,2}$	0	$\theta_{3,4}$
4	$\theta_{4,1}$	$\theta_{4,2}$	$\theta_{4,3}$	0

The rest of the matrix is filled by repeating the same spectral angle calculation over every pairwise combination.

Calculating spectral diversity with spectral angle

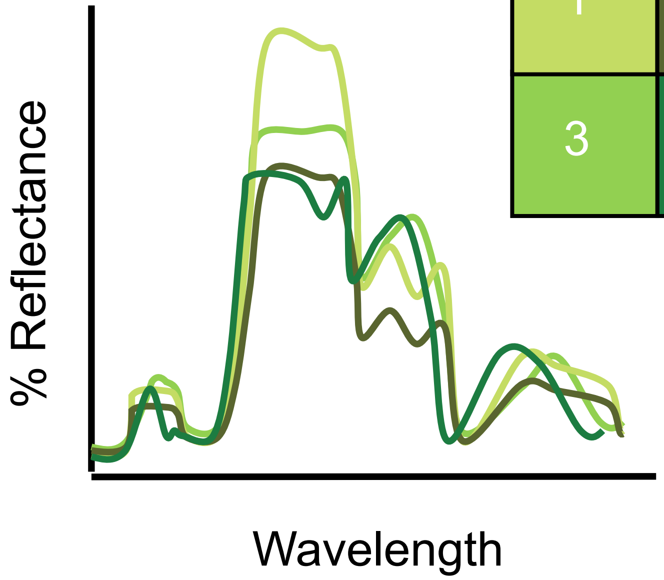


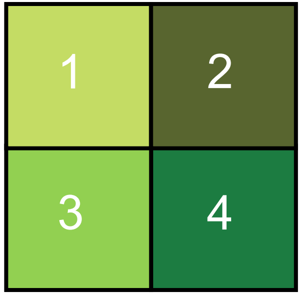


	1	2	3	4
1	0			
2	$\theta_{2,1}$	0		
3	$\theta_{3,1}$	$\theta_{3,2}$	0	
4	$\theta_{4,1}$	$\theta_{4,2}$	$\theta_{4,3}$	0

Note that the information in the lower and upper triangles are repeated. We will just focus on the lower triangle

Calculating spectral diversity with spectral angle



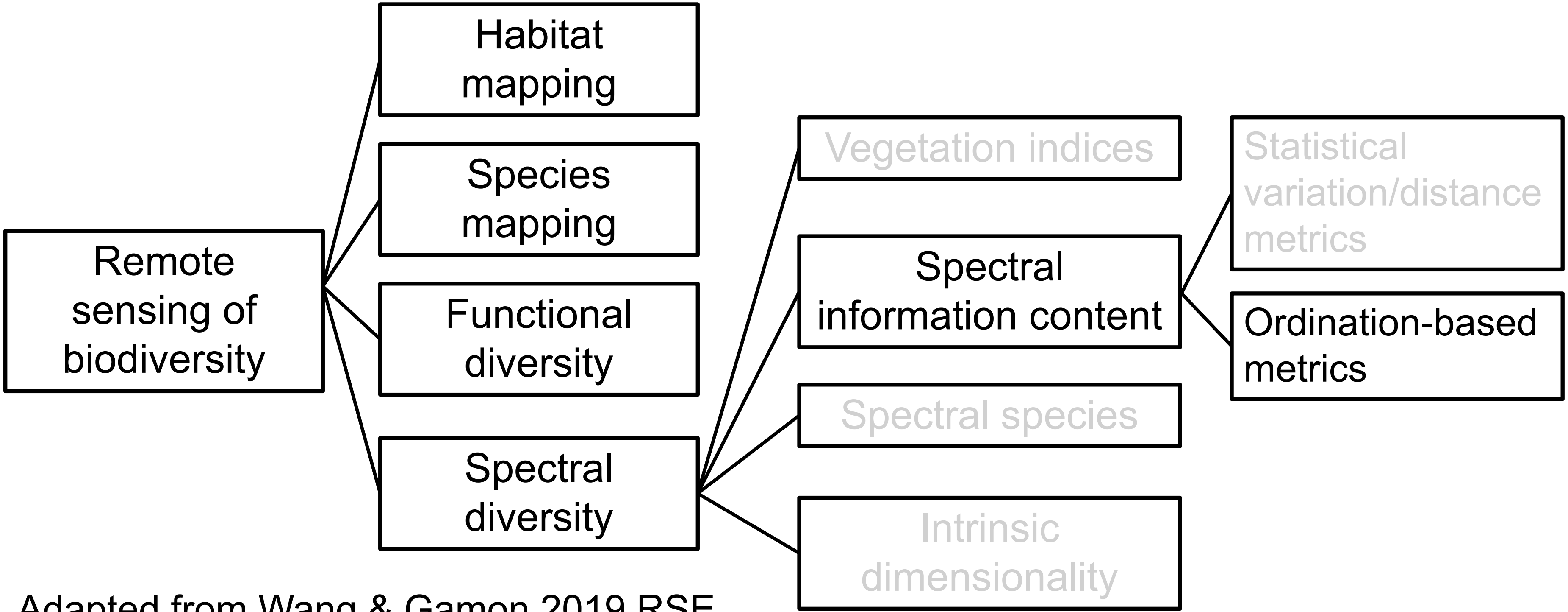


	1	2	3	4
1	0			
2	$\theta_{2,1}$	0		
3	$\theta_{3,1}$	$\theta_{3,2}$	0	
4	$\theta_{4,1}$	$\theta_{4,2}$	$\theta_{4,3}$	0

$$\bar{\theta} = \frac{\theta_{2,1} + \theta_{3,1} + \theta_{3,2} + \theta_{4,1} + \theta_{4,2} + \theta_{4,4}}{6}$$

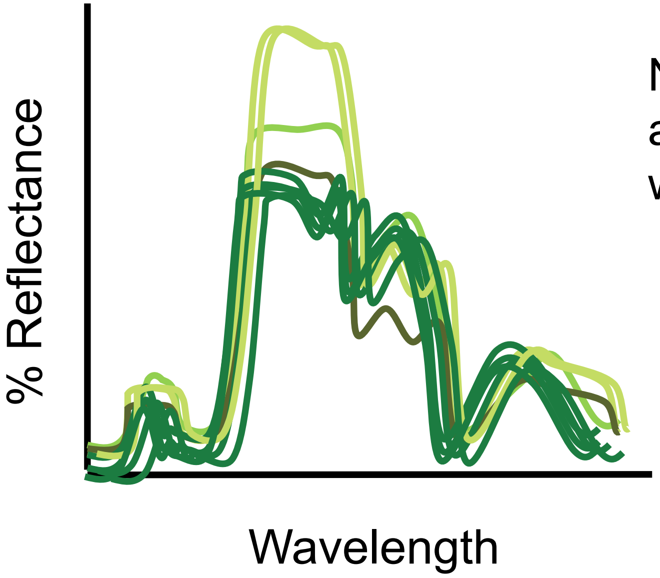
A quick way to calculate our spectral diversity is to take average of all the spectral angle pairwise differences. $\bar{\theta}$ is our spectral diversity value for these 4 pixels

Subdivisions of spectral diversity



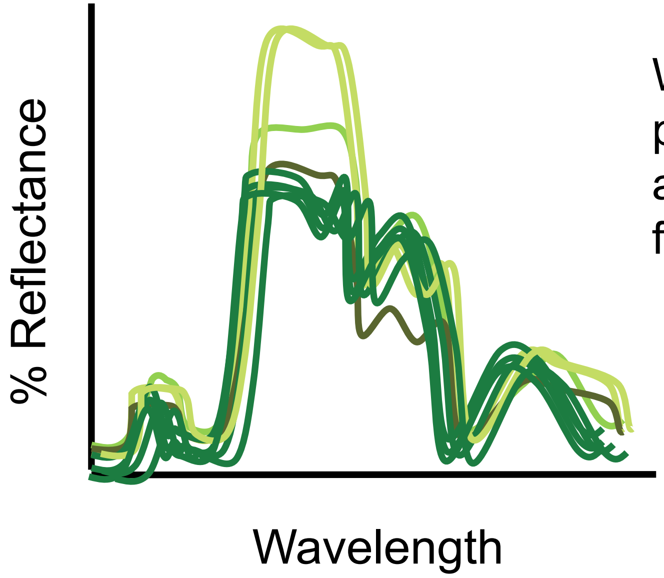
Adapted from Wang & Gamon 2019 RSE

A different approach with principal components

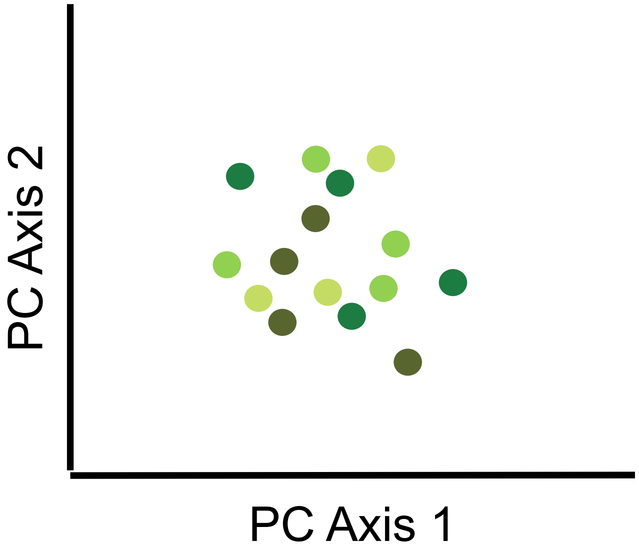


Now let's assume we used a larger window and incorporated more pixels, e.g., a 4 x 4 window for 16 total extracted spectra

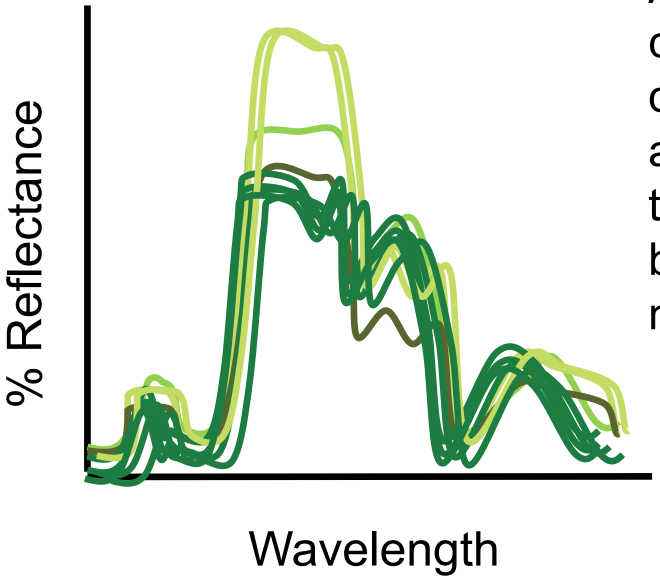
A different approach with principal components



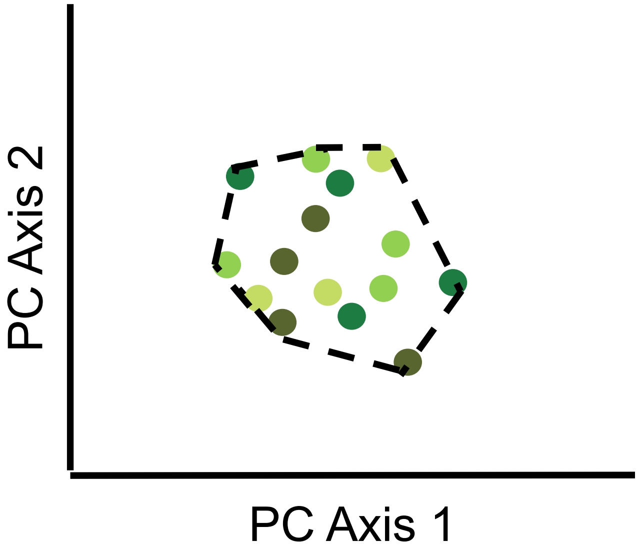
We can run a principal components analysis and plot the first two axes



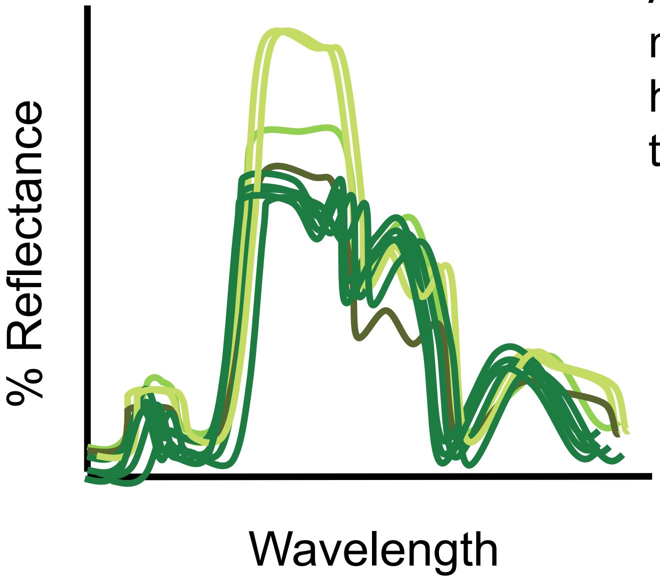
A different approach with principal components



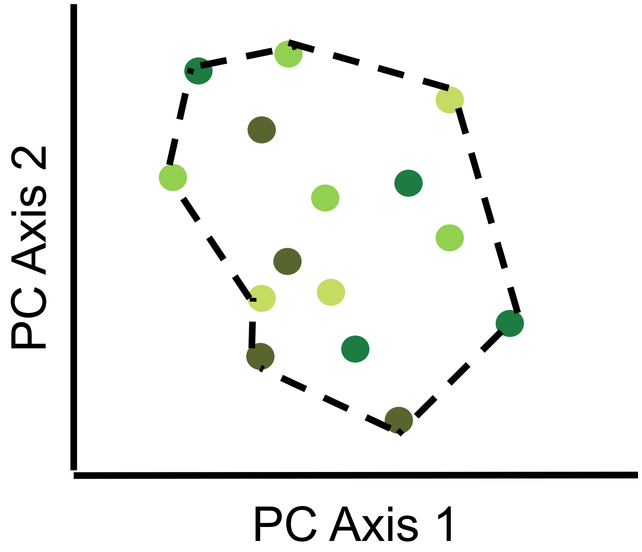
Another way to calculate spectral diversity is based on a convex hull area of these points (can also be done as volume in n-dimensional space)



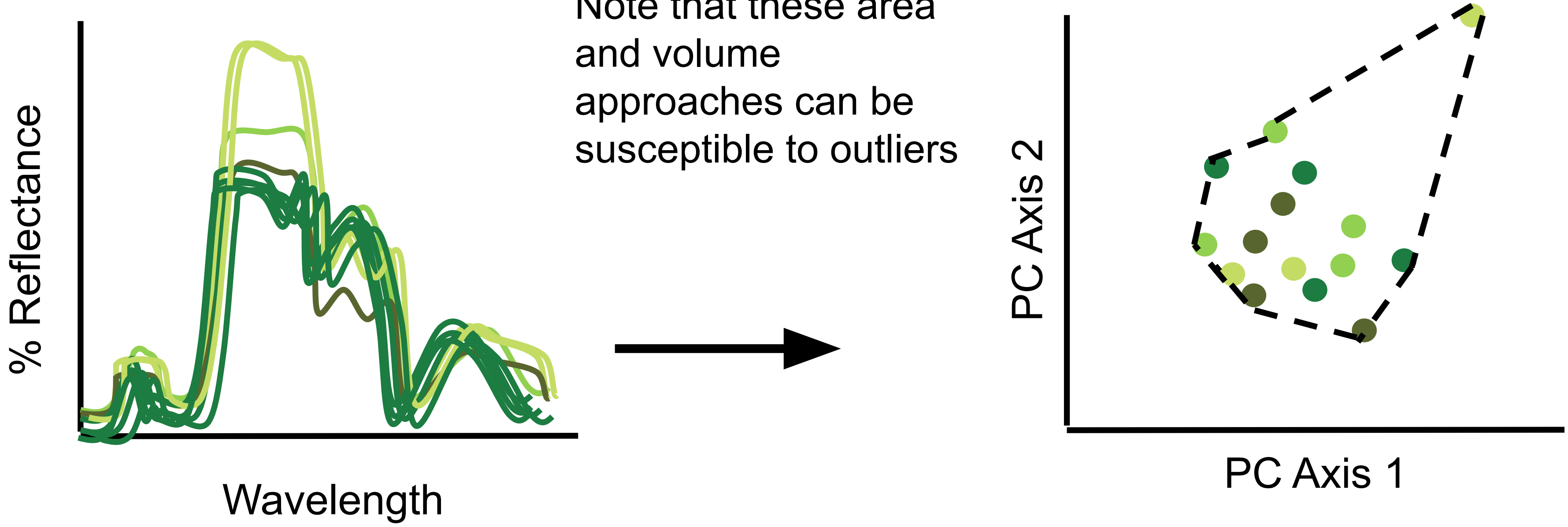
A different approach with principal components



A larger area may mean more heterogeneity and thus more biodiversity

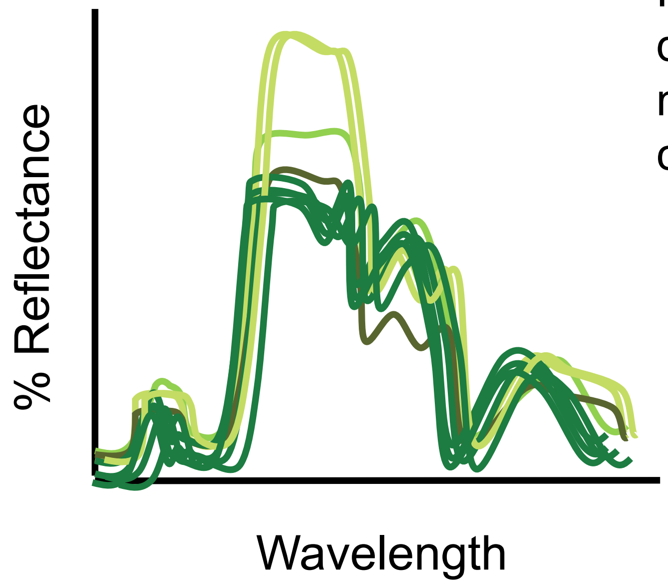


A different approach with principal components

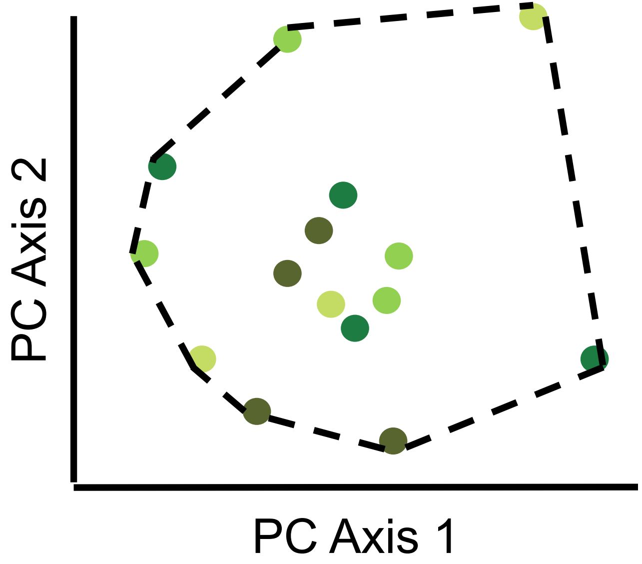


Note that these area and volume approaches can be susceptible to outliers

A different approach with principal components



Further, the dispersion of points may need to be considered as well



Summary of spectral information diversity metrics

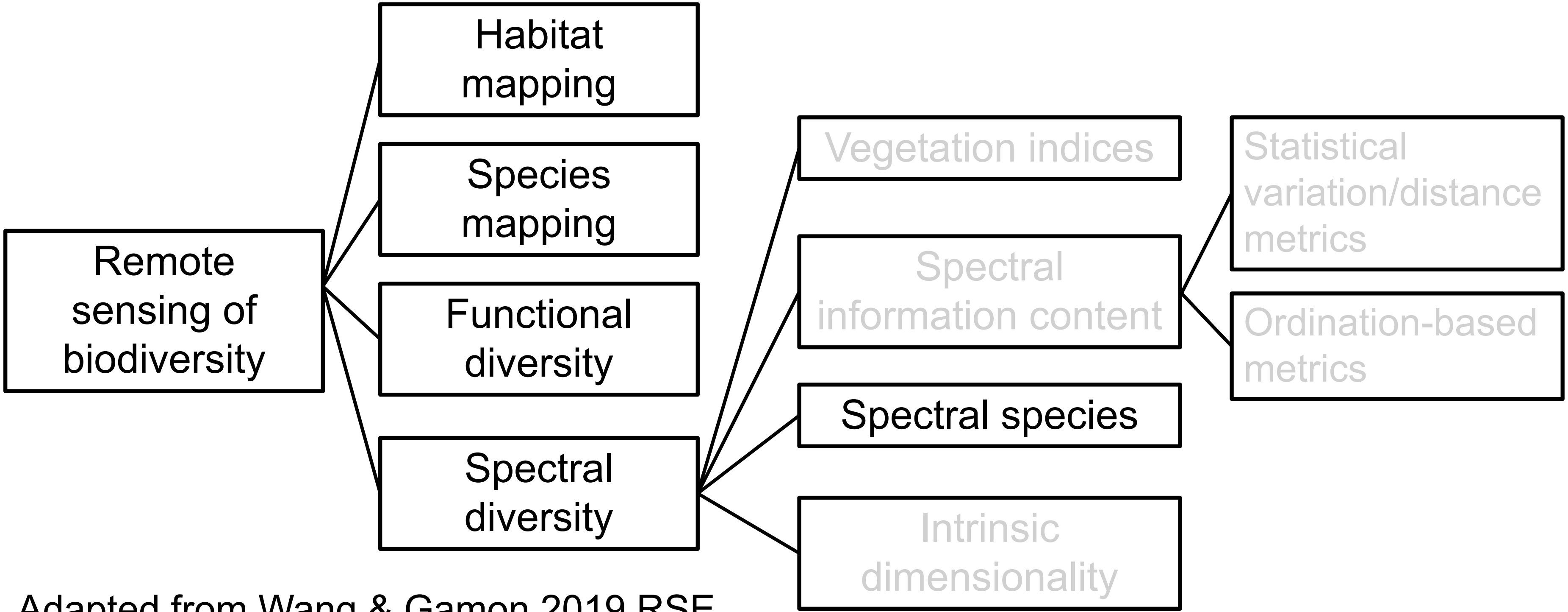
Pros

- These make far better use of spectral information than vegetation indices

Cons

- Some distance methods can double count distances or be susceptible to outliers.
- These methods can also be influenced by background signals such as soil and leaf litter. This also can artificially inflate diversity estimates

Subdivisions of spectral diversity

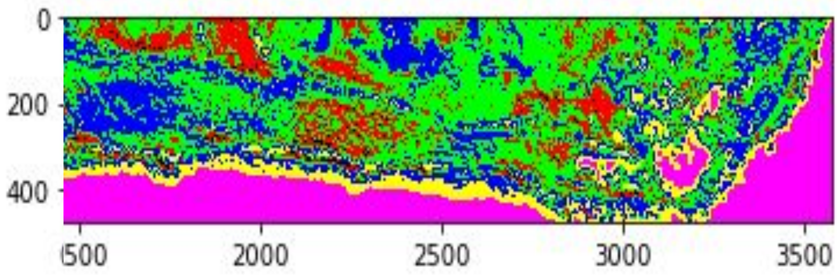


Adapted from Wang & Gamon 2019 RSE

The spectral species approach

This approach assumes that the spectra signals extracted from an image represent the unique combinations of chemical and structural properties of a plants and plant assemblages.

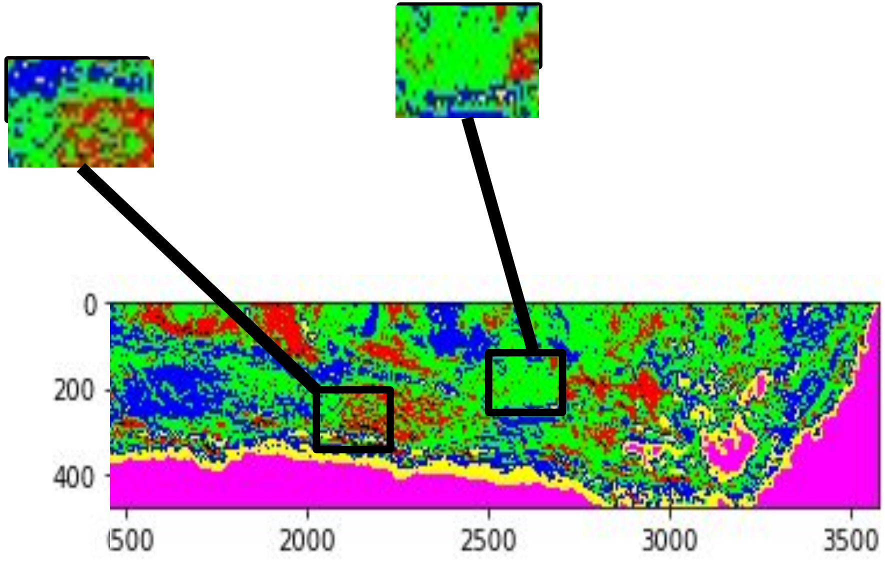
Supervised and unsupervised classifications of image spectroscopy can by used to assess diversity.



An example of an unsupervised classification with 6 classes using PRISM imagery in Florida, USA

The spectral species approach

In this approach, one could use moving or fixed windows to count the number/abundance of uniquely classified groups to measure spectral diversity.



An example of an unsupervised classification with 6 classes using PRISM imagery in Florida

The spectral species approach

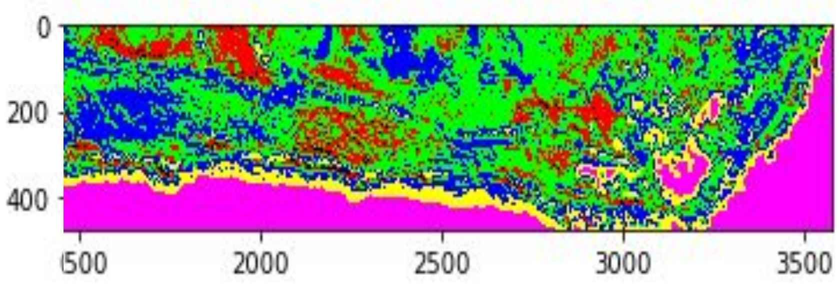
Pros:

Uses existing machine learning approaches.

Cons:

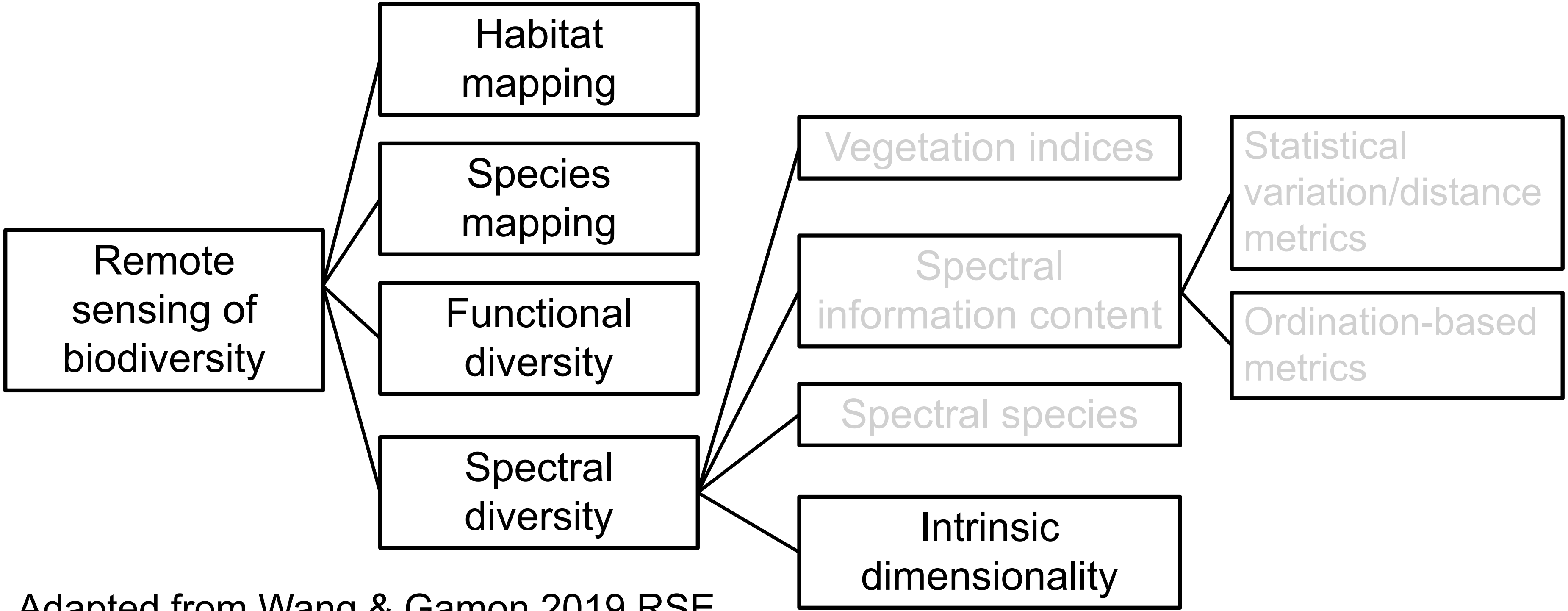
Assumes that the classification works well and is not picking up differences in substrate, leaf litter, and NPC.

Assumes output is linked to plant functional types or taxonomic level.



An example of an unsupervised classification with 6 classes using PRISM imagery in Florida

Subdivisions of spectral diversity



Adapted from Wang & Gamon 2019 RSE

Intrinsic dimensionality

- ID is a **measure of information content** that has been used to retrieve signal from noise in high dimensional data

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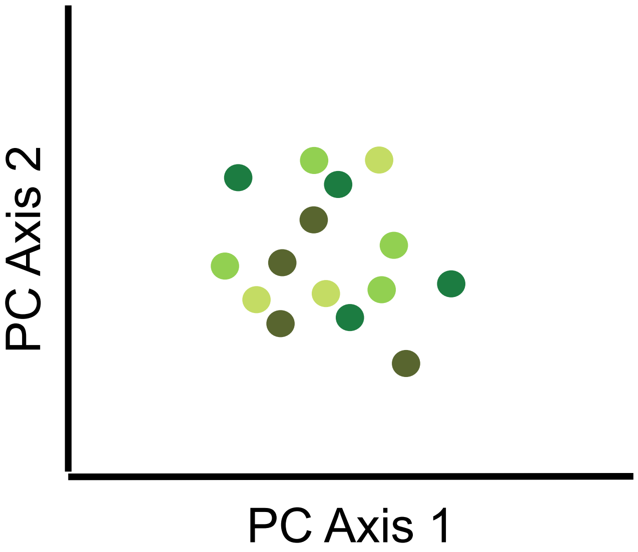
- In practice, it can be viewed as a means of determining the number of significant principal components in a spectral dataset



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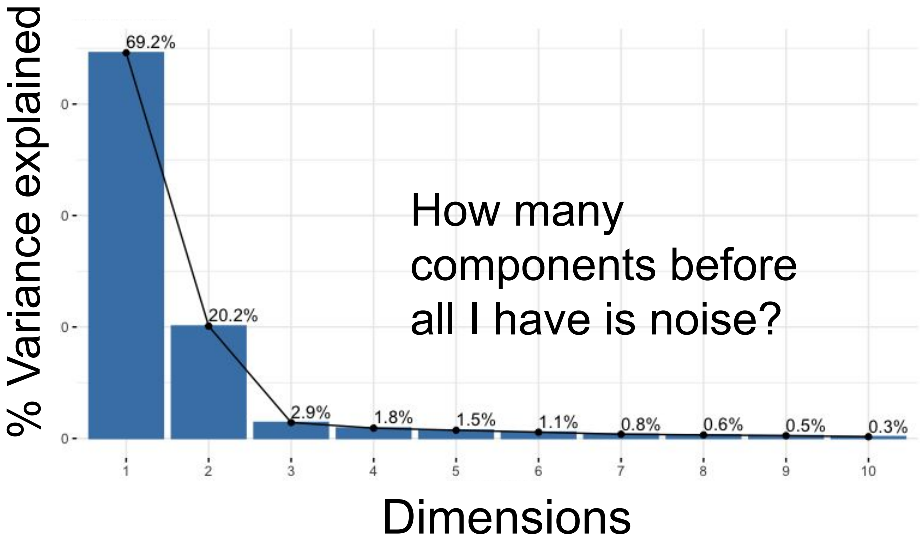
PCA Scree Plot



An example of ID over the Cape Peninsula. We will be generating something similar in the next tutorial!

Pixels with lower ID have less information content, or in other words, fewer important principal components.

Pros of the ID approach: **This approach is application-agnostic.** Which makes it highly comparable across datasets.

Cons: Like any other spectral diversity metric, surfaces that are not vegetation are included in the calculation. Be careful on how you interpret results!

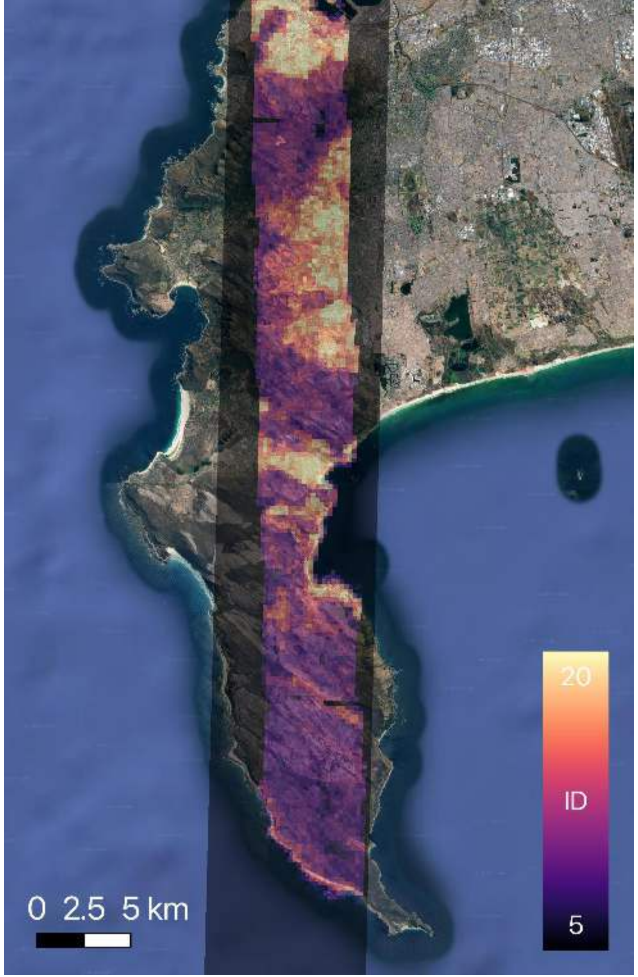


Image from Kerry Cawse-Nicholson


Questions?