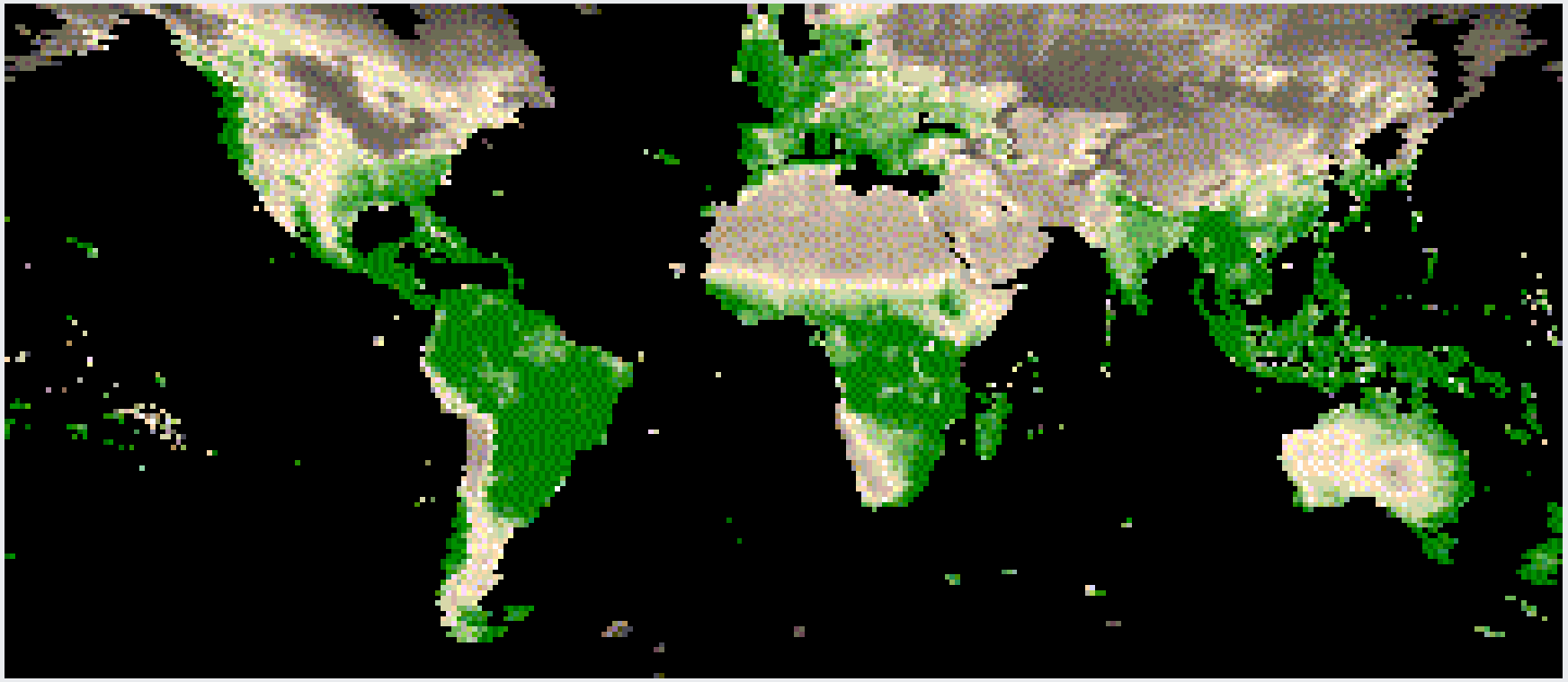
9. Remote Sensing of Biodiversity

Jasper Slingsby, BIO3018F

2024-01-28

We want to measure biodiversity everywhere, all the time...



Remote sensing is pretty much the only way this can be achieved...

It's a rapidly growing field

306 Review TRENDS in Ecology and Evolution Vol.18 No.6 June 2003

Remote sensing for biodiversity science and conservation

Woody Turner[1], Sacha Spector[2], Ned Gardiner[2], Matthew Fladeland[3], Eleanor Sterling[2] and Marc Steininger[4]

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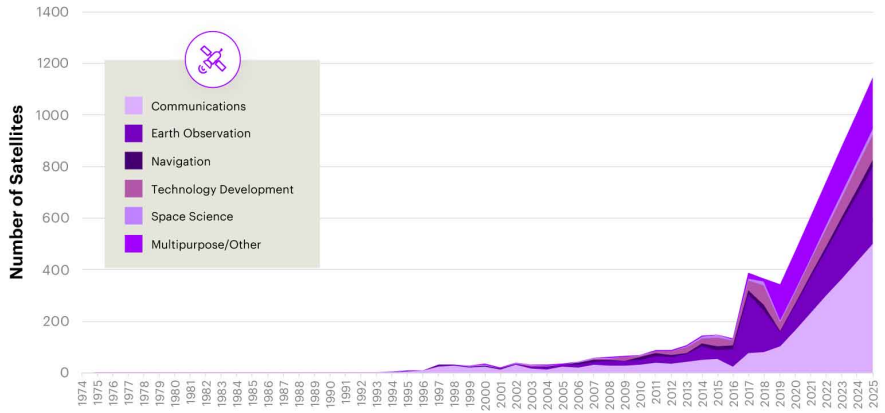
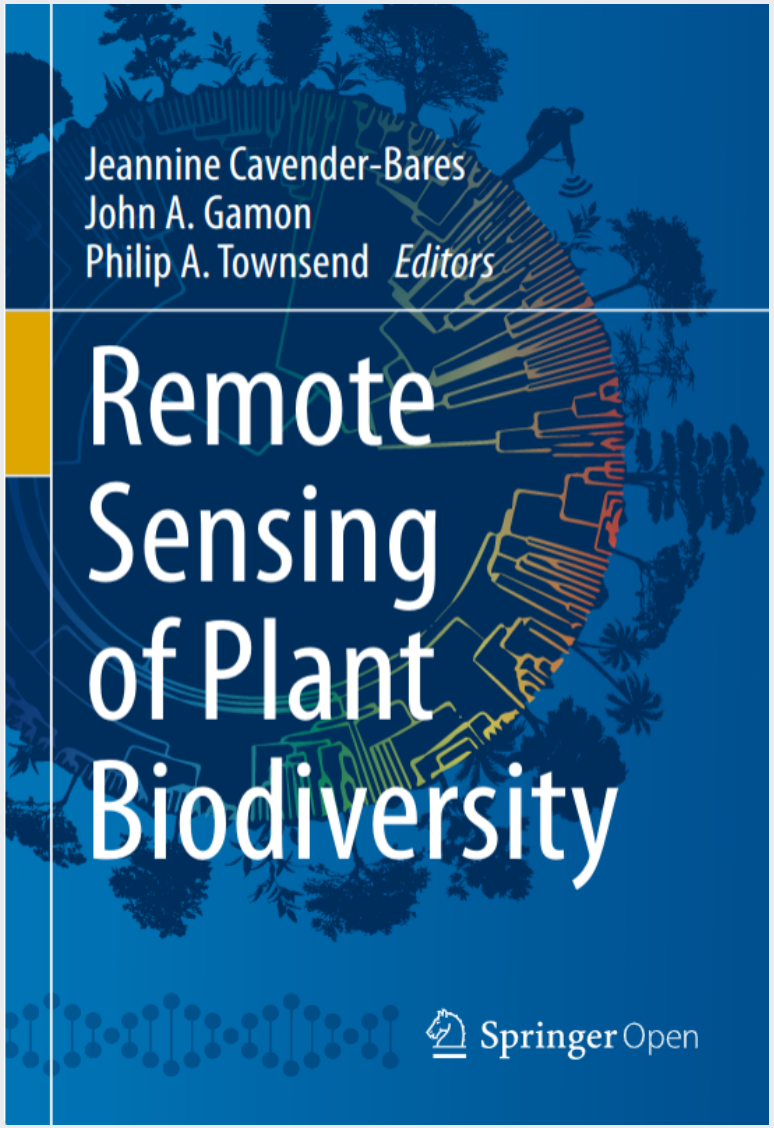
[2]Center for Biodiversity and Conservation, American Museum of Natural History, New York, NY, 10024, USA
[3]Earth Science Division, NASA Ames Research Center, Moffett Field, CA 94035, USA
[4]Center for Applied Biodiversity Science at Conservation International, 1919 M Street, NW, Suite 600, Washington, DC 20036, USA

Figure 2: Number of satellites launched per year (actual and projected, 1995 - 2025)



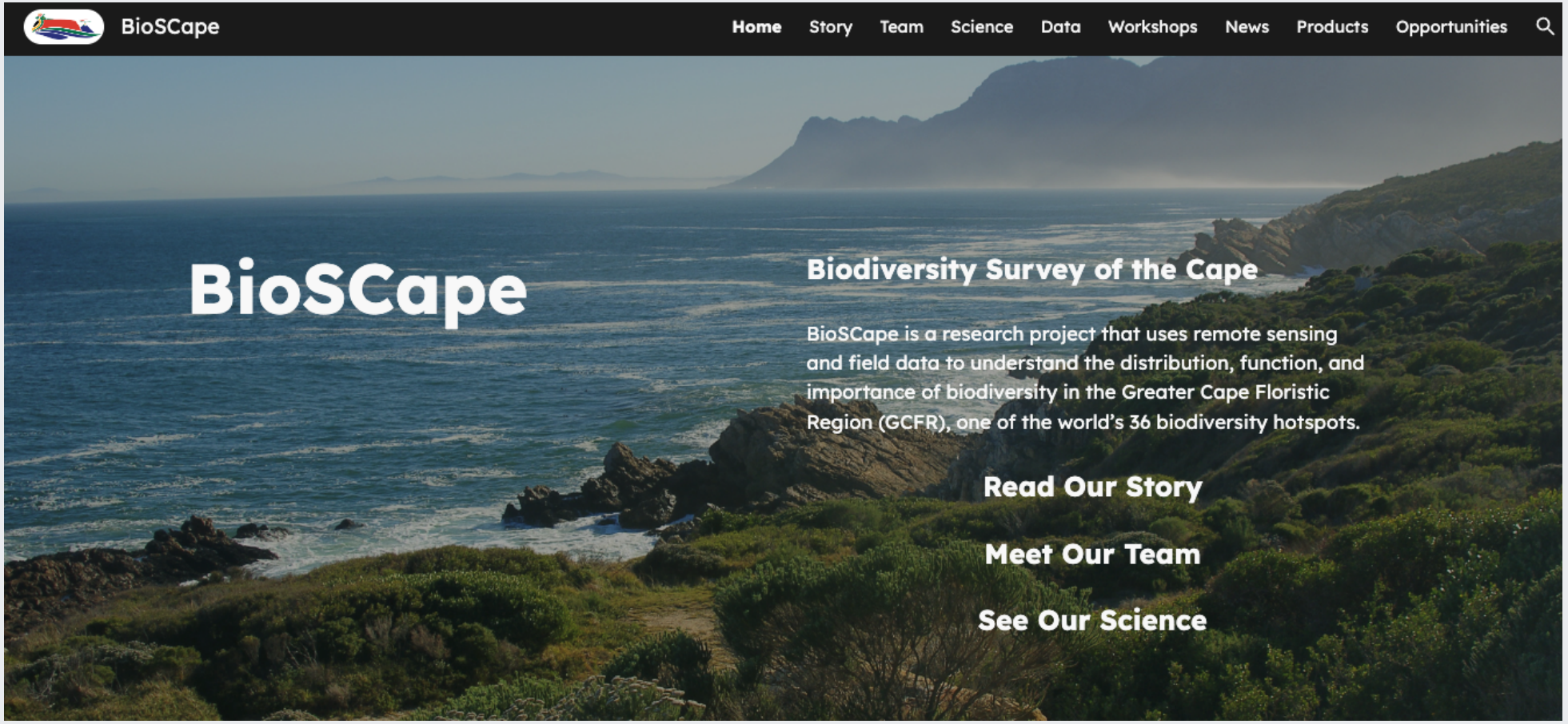
Data source: Union of Concerned Scientists, 2019.

Turner et al. 2003



Cavender-Bares et al. 2020

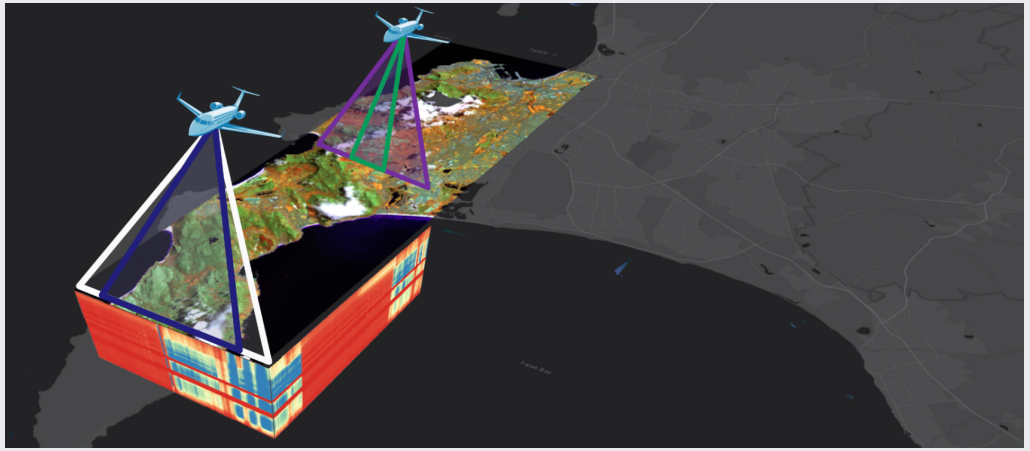
BioSCape: Biodiversity Survey of the Cape

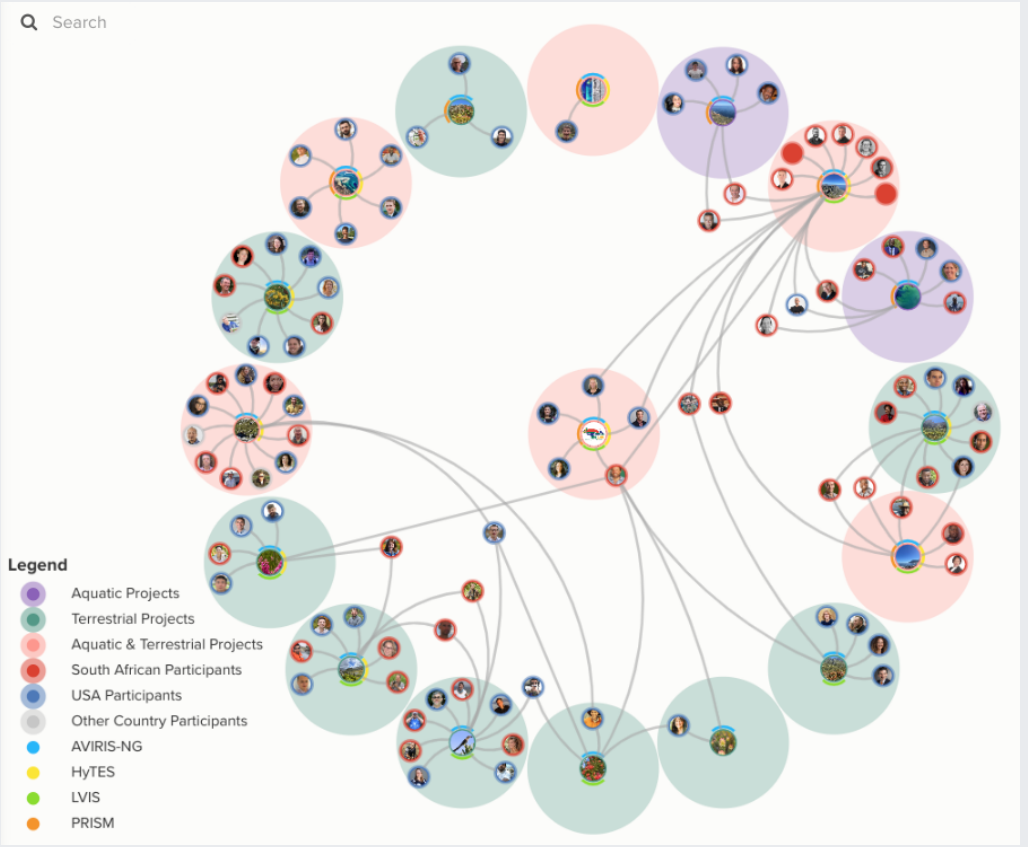


...and the Cape is currently the epicentre of this endeavour - https://www.bioscape.io/

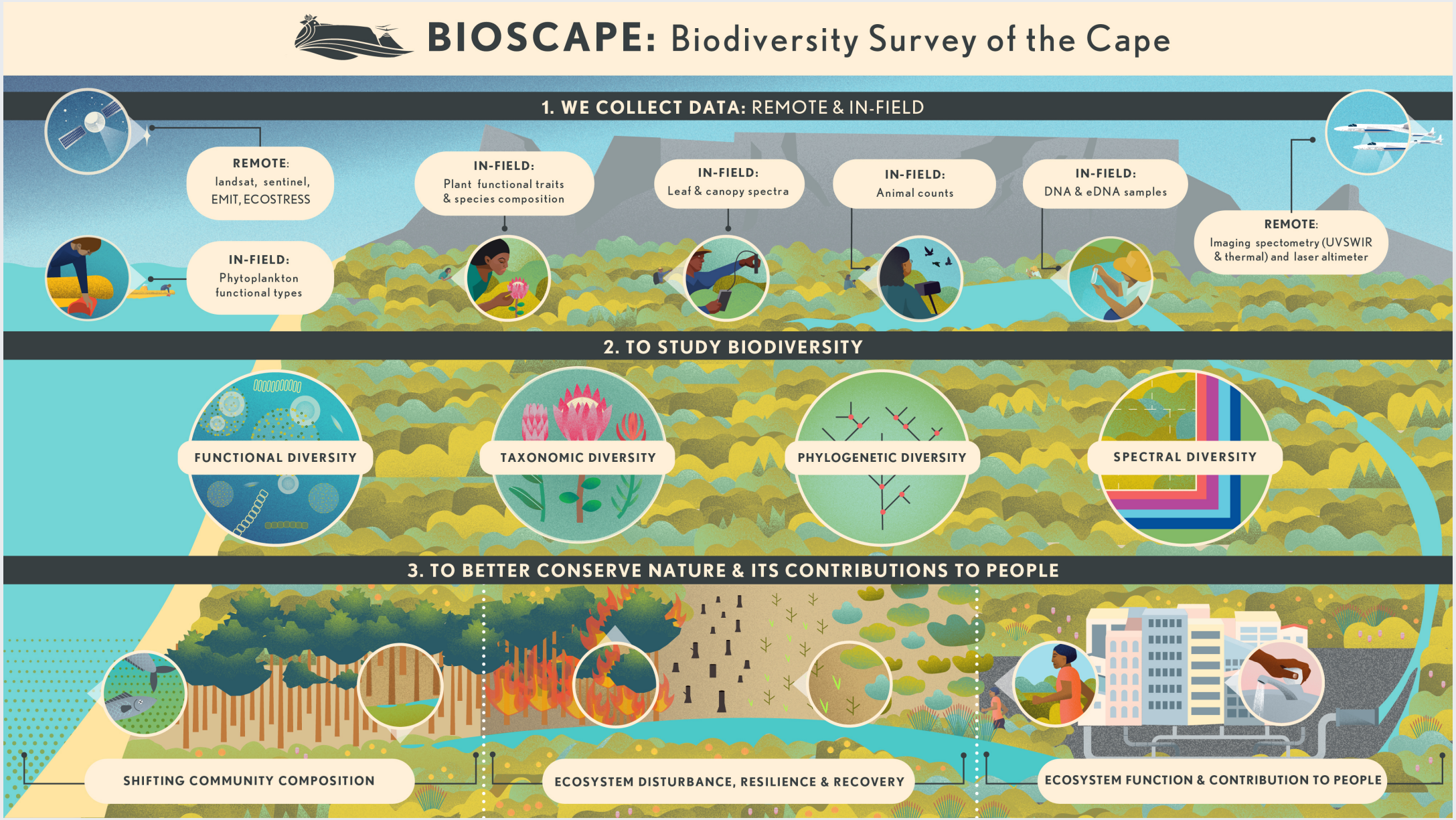
BioSCape: Biodiversity Survey of the Cape

- $>$ 150 scientists and conservation practitioners
- 19 teams (mixed US, RSA, other)
- terrestrial and aquatic
- 3 planes
- 6 instruments (2 x V-SWIR imaging spectrometers, hyperspectral thermal, multispectral (RGB + NIR) and 2 x LiDAR)
- fundamental and applied science
- mostly NASA funded





www.bioscape.io

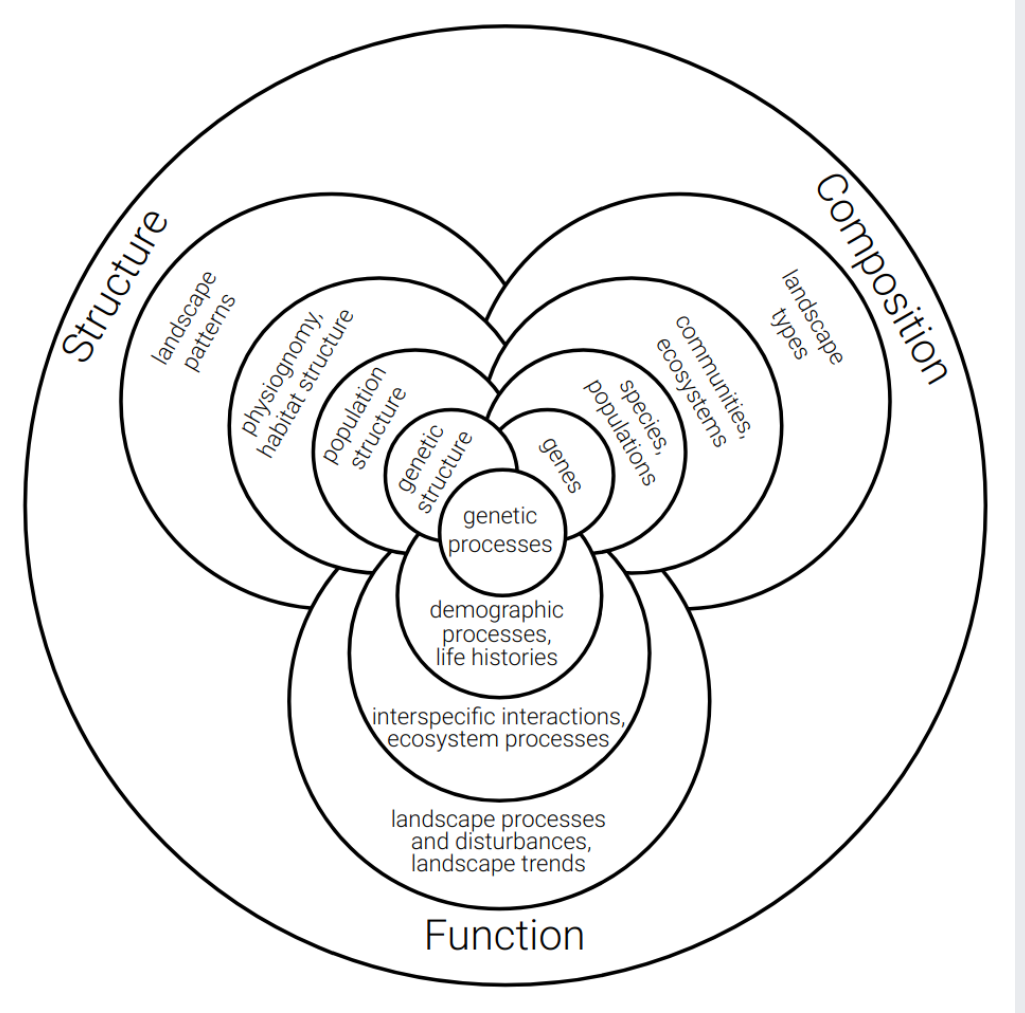

BIOSCAPE: Biodiversity Survey of the Cape
1. WE COLLECT DATA: REMOTE & IN-FIELD
REMOTE: landsat, sentinel, EMIT, ECOSTRESS
IN-FIELD: Phytoplankton functional types
IN-FIELD: Plant functional traits & species composition
IN-FIELD: Leaf & canopy spectra
IN-FIELD: Animal counts
IN-FIELD: DNA & eDNA samples
REMOTE: Imaging spectometry (UVSWIR & thermal) and laser altimeter
2. TO STUDY BIODIVERSITY
FUNCTIONAL DIVERSITY
TAXONOMIC DIVERSITY
PHYLOGENETIC DIVERSITY
SPECTRAL DIVERSITY
3. TO BETTER CONSERVE NATURE & ITS CONTRIBUTIONS TO PEOPLE
SHIFTING COMMUNITY COMPOSITION
ECOSYSTEM DISTURBANCE, RESILIENCE & RECOVERY
ECOSYSTEM FUNCTION & CONTRIBUTION TO PEOPLE

But how do we actually measure biodiversity with remote sensing?

There are many facets of biodiversity to measure!

An advantage of remote sensing is that it can directly measure the structure, composition and function of biodiversity...

...at least from the scale of individuals up...



Noss 1990, *Conservation Biology*

There are many facets of biodiversity to measure!

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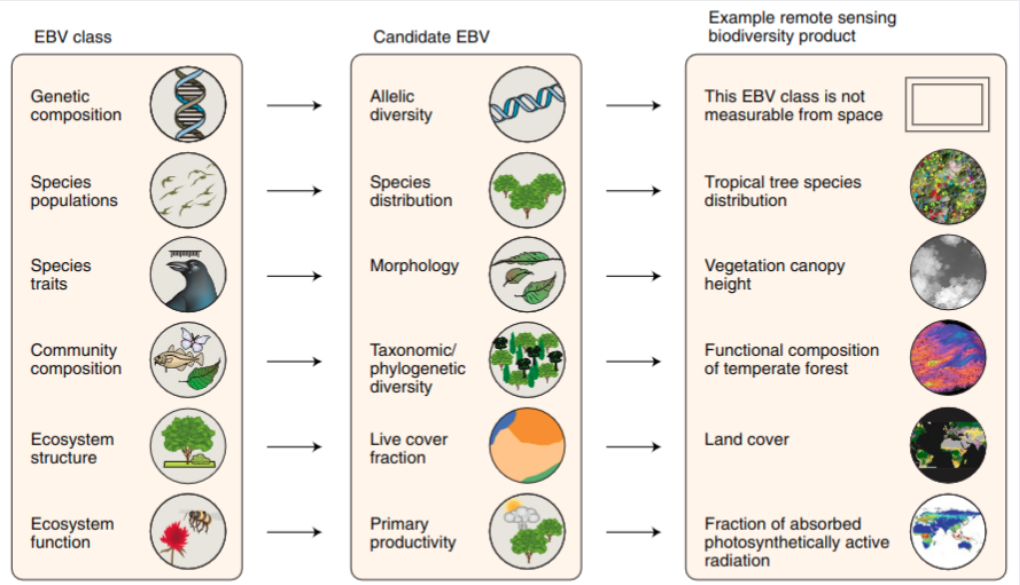
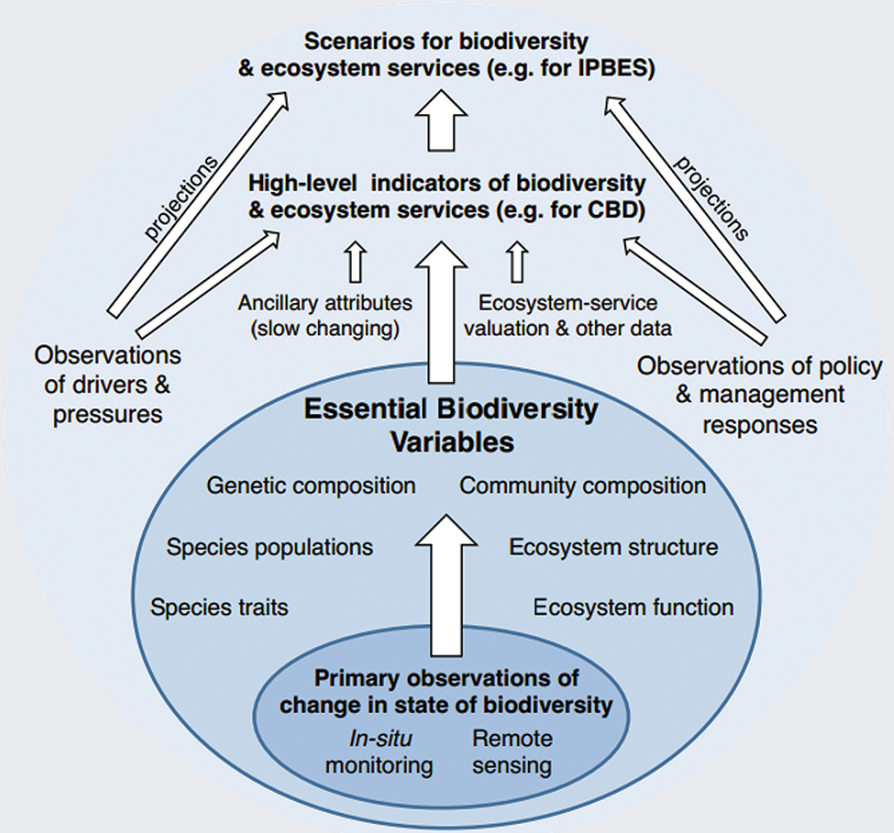


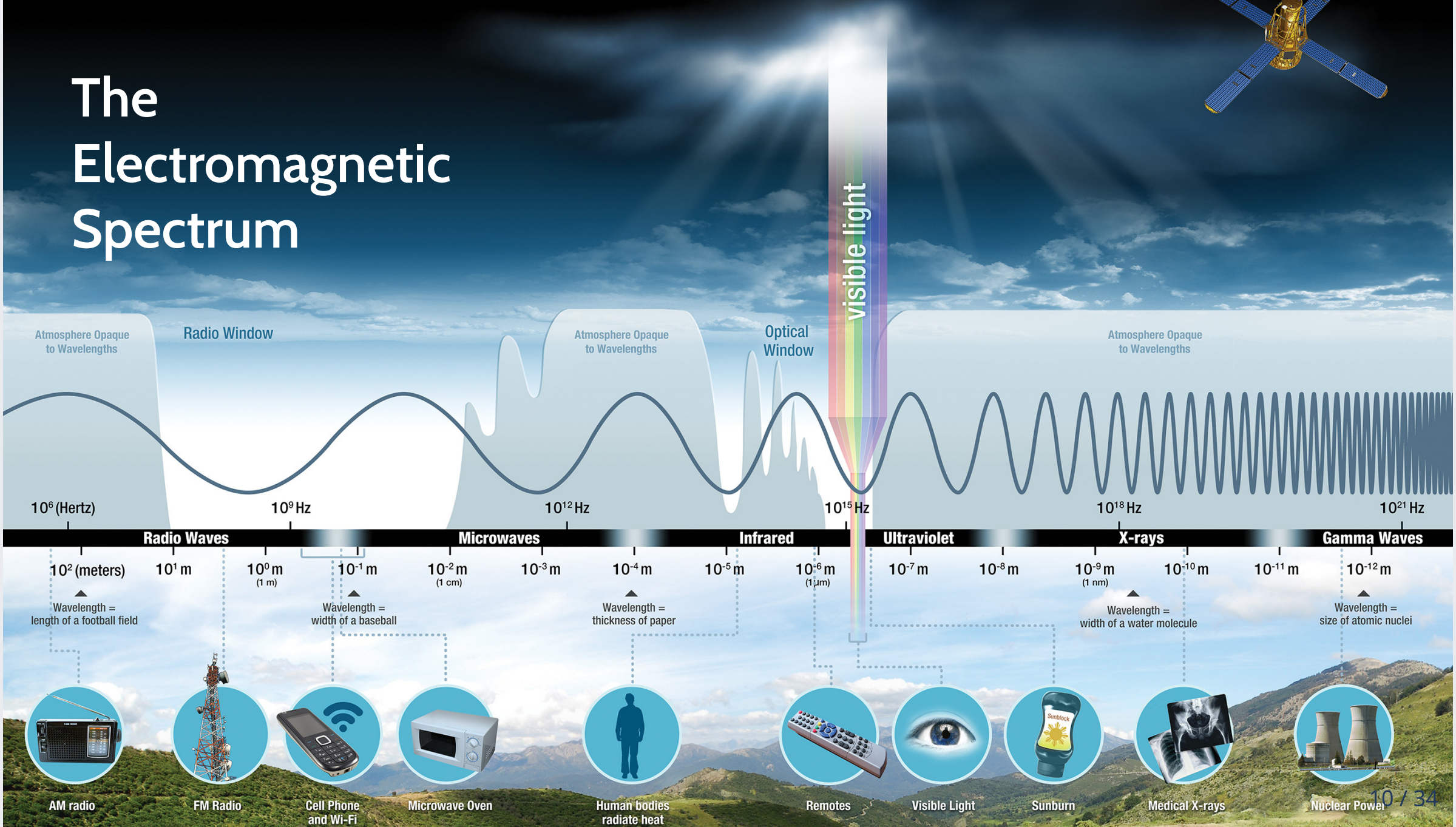
Skidmore et al. 2021



...at least from the scale of individuals up...

https://geobon.org/

The Electromagnetic Spectrum



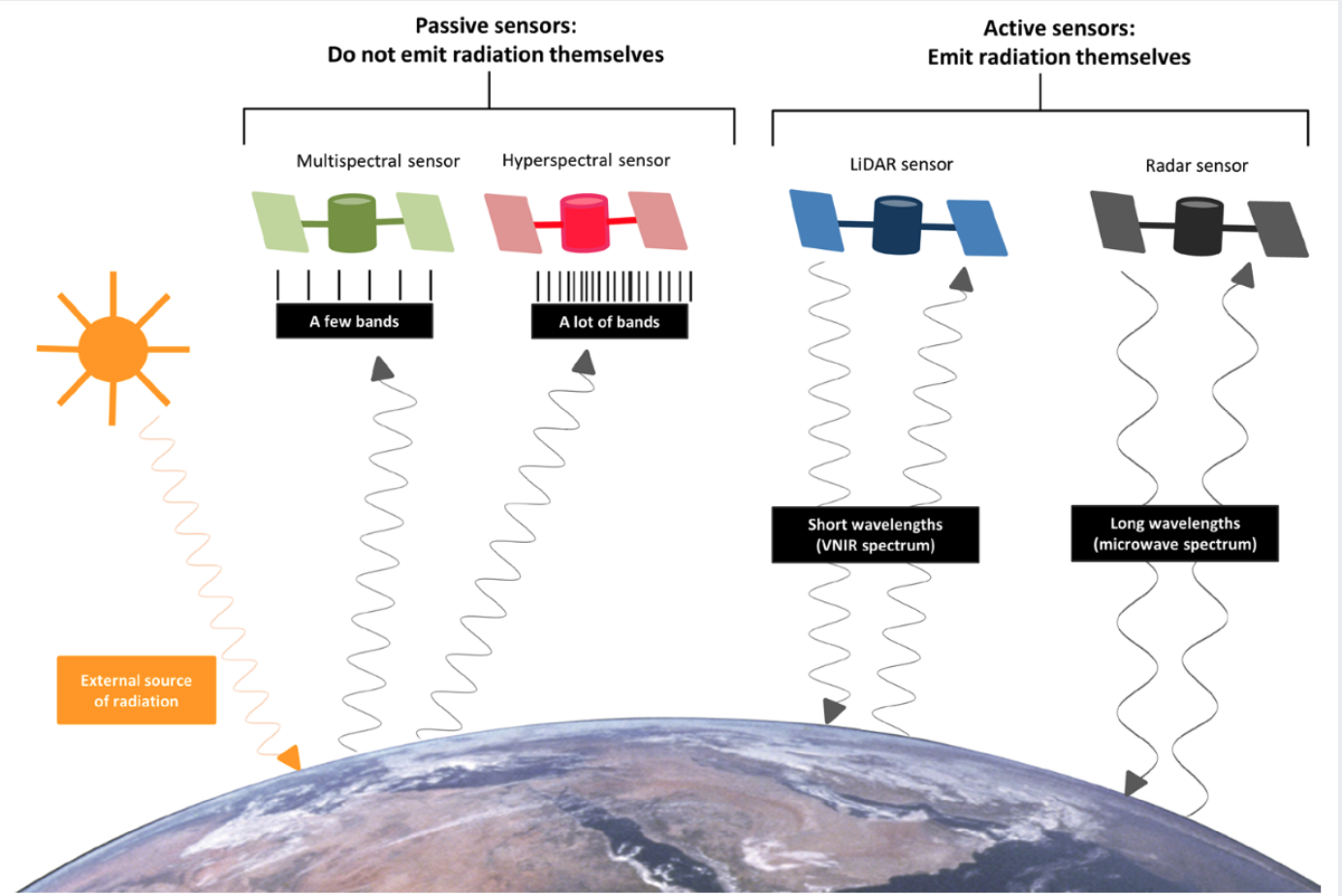
Many sensor types!

Active vs passive sensors

Multispectral vs hyperspectral (imaging spectrometers)

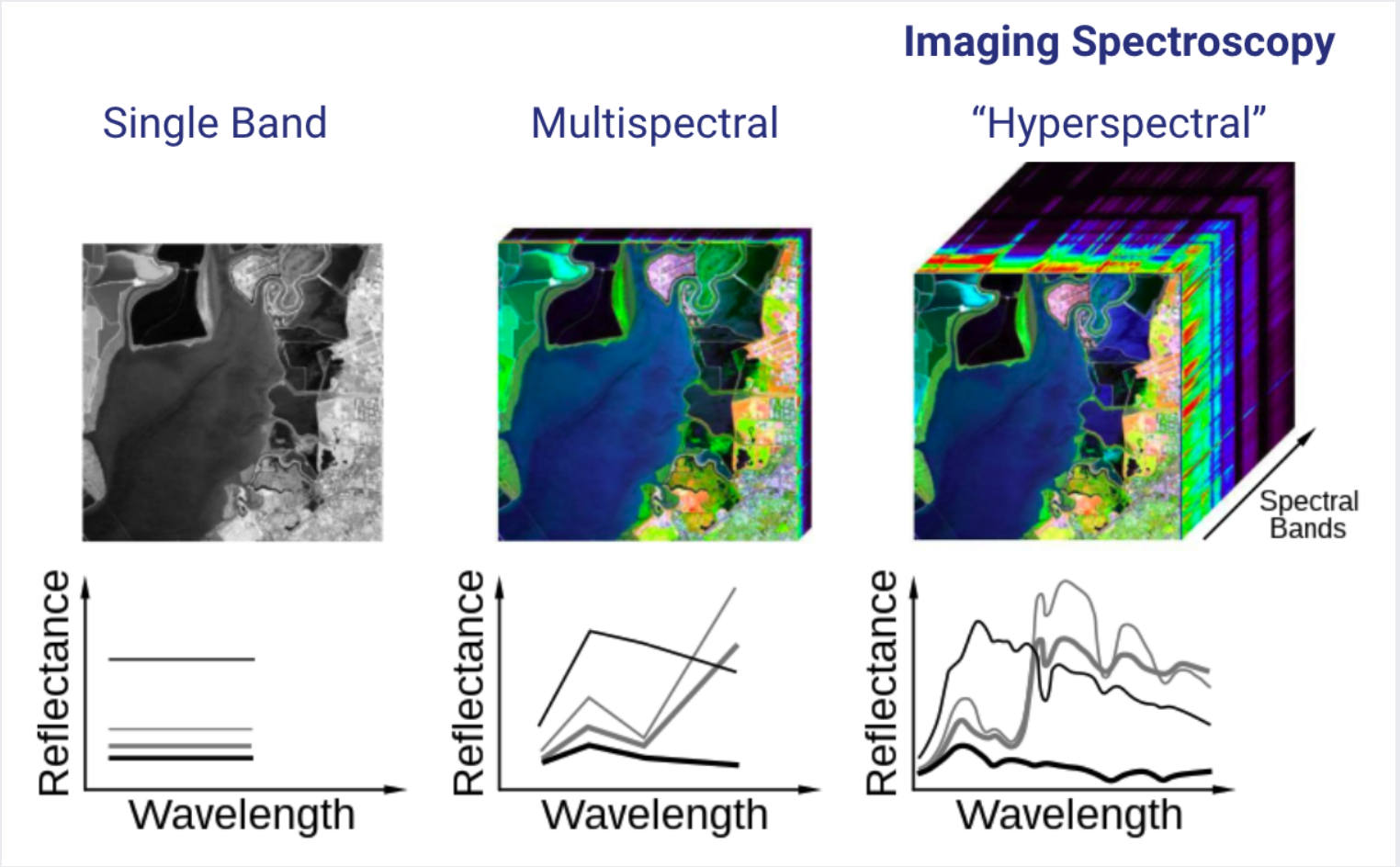
Much variation within each type

- Especially spectral range and resolution!

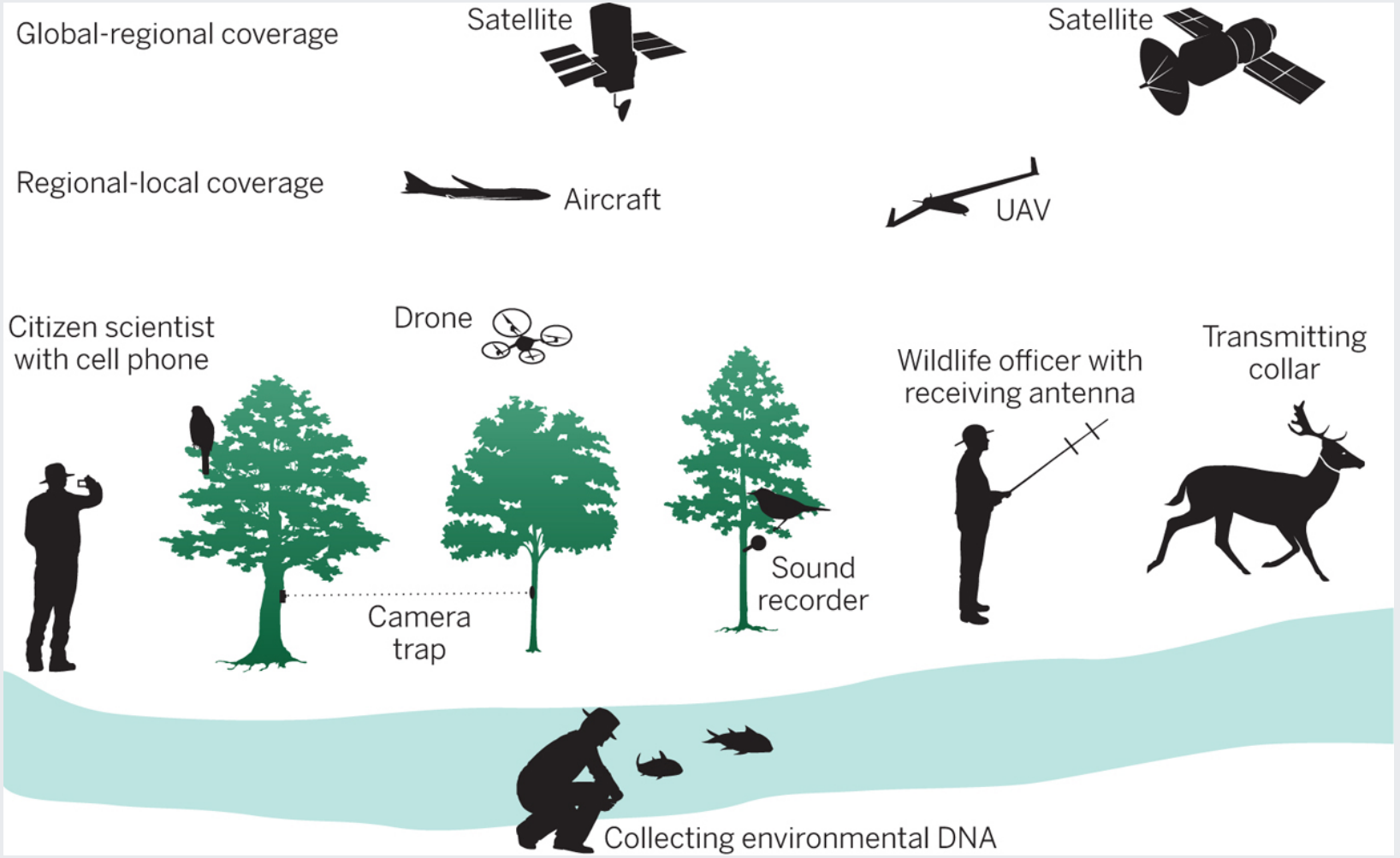


Pettorelli et al. 2018

Multispectral vs hyperspectral (imaging spectrometers)

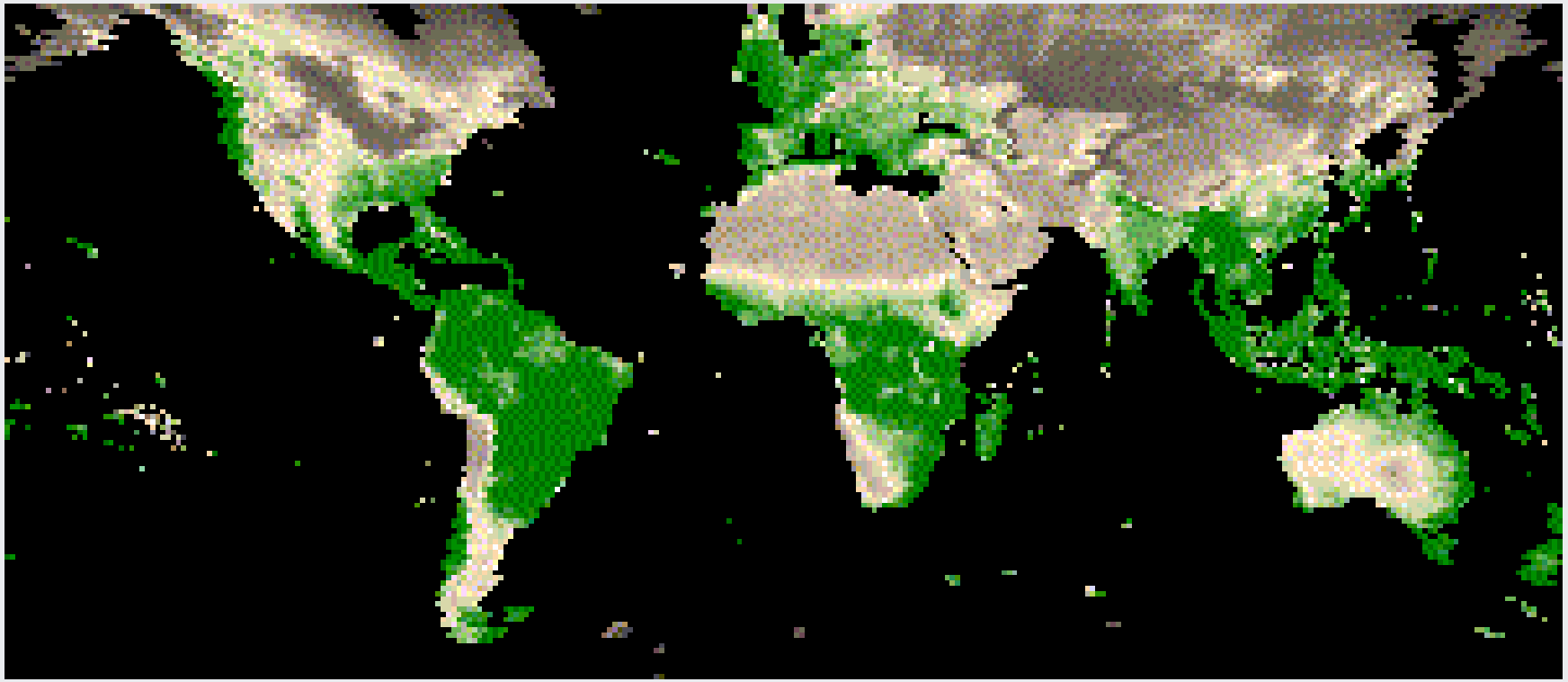


Remote sensing is particularly useful in combo with other observations

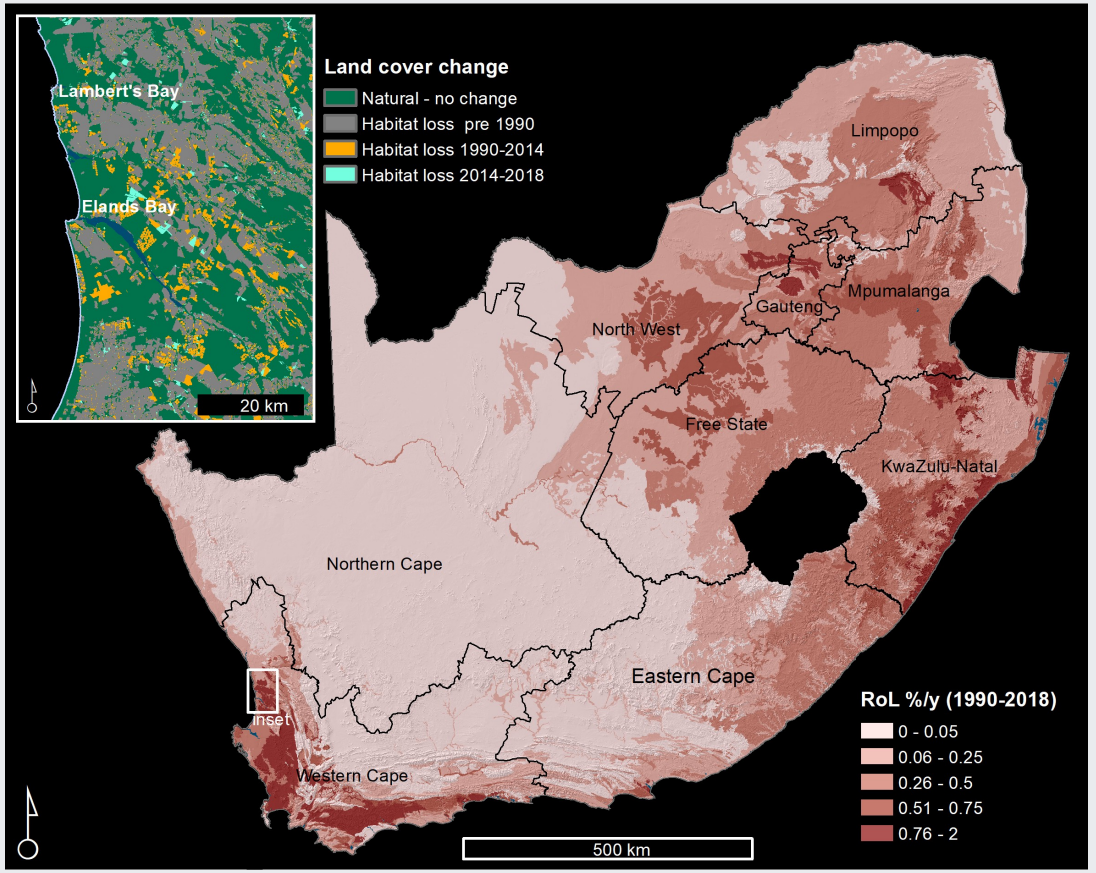


Turner 2014

Productivity and Seasonality



Land cover (and change)

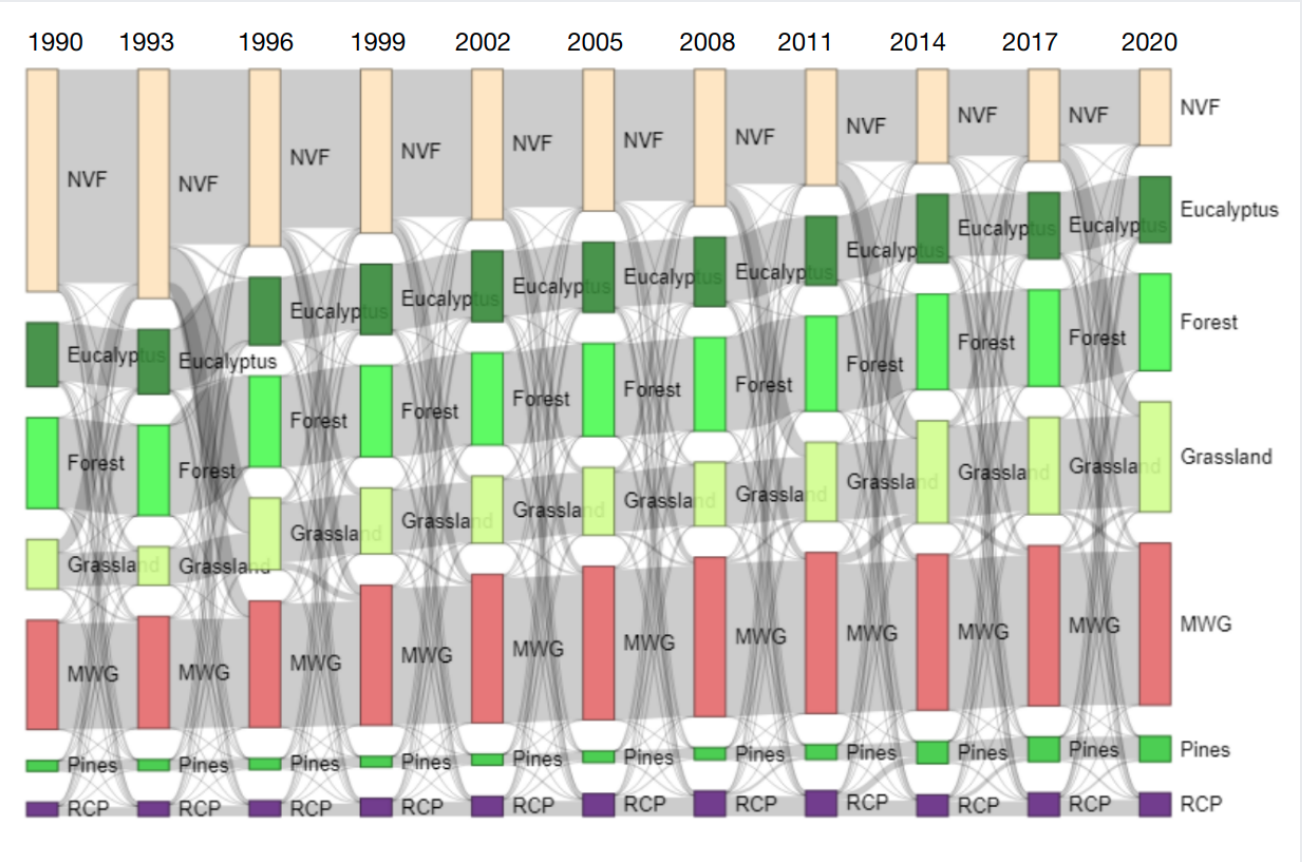


Skowno et al. 2021

Land cover change detection

Moncrieff 2022

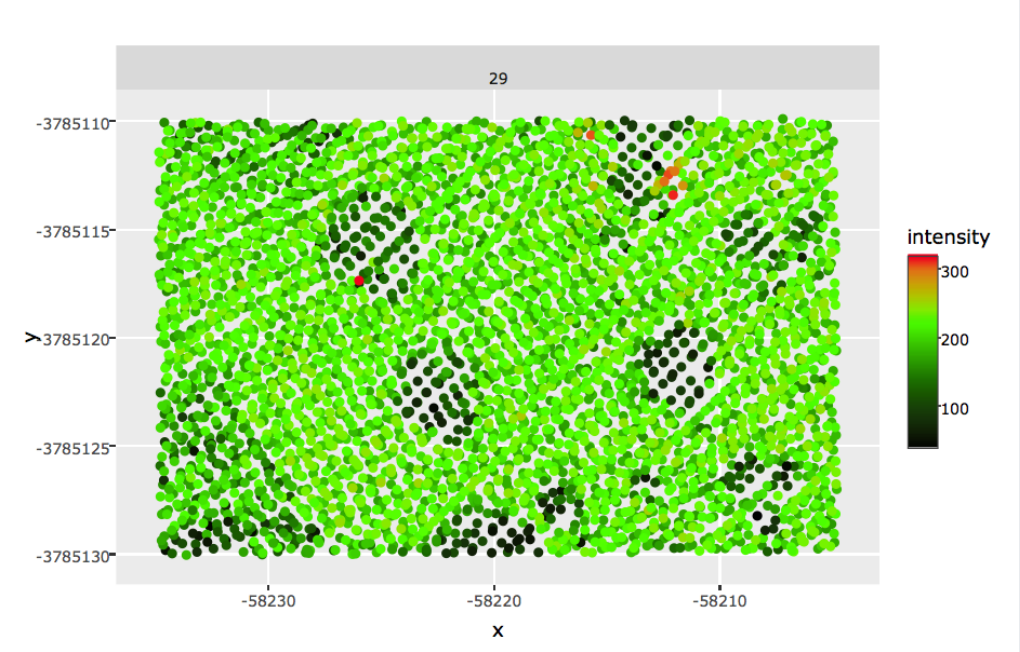
Land cover change time series



Moilwe et al. in prep

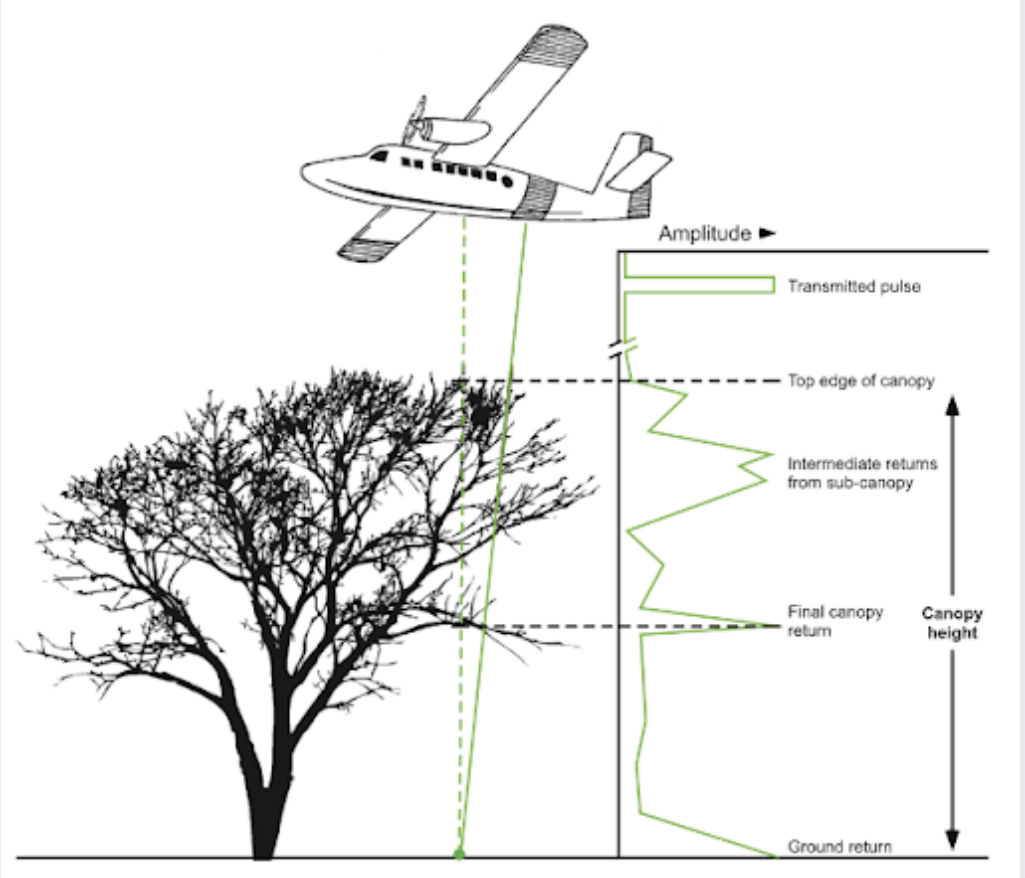
But what about metrics like species, functional and phylogenetic diversity?

Functional diversity?



Proteaceae shrubs (dark green) surrounded by low shrubs, forbs and graminoids at Silvermine, TMNP.

Data from City of Cape Town

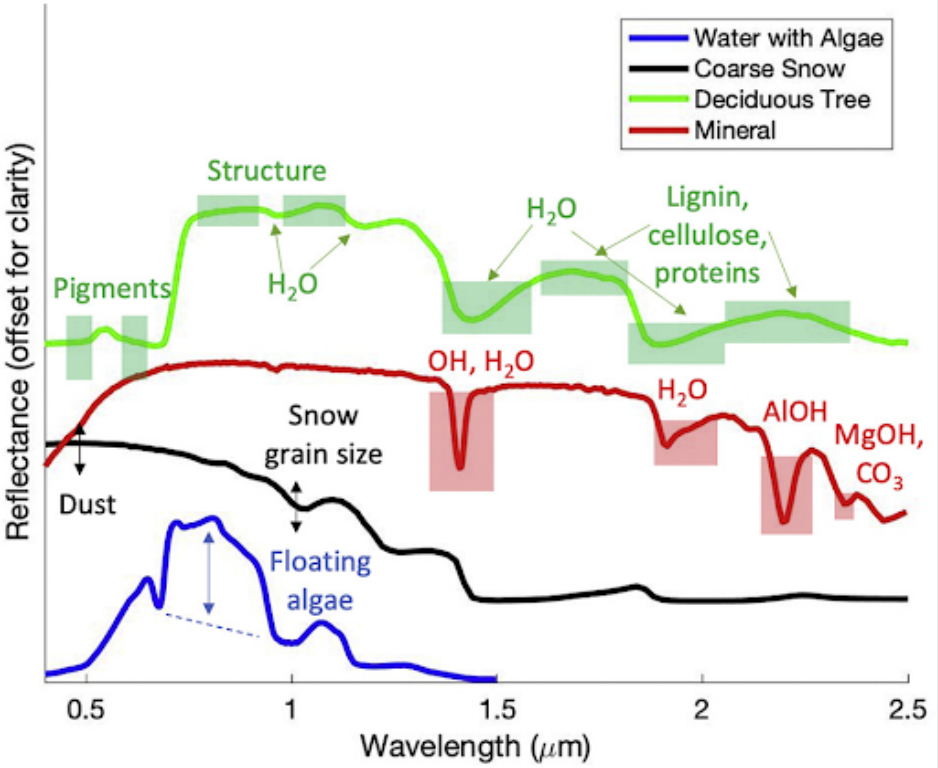


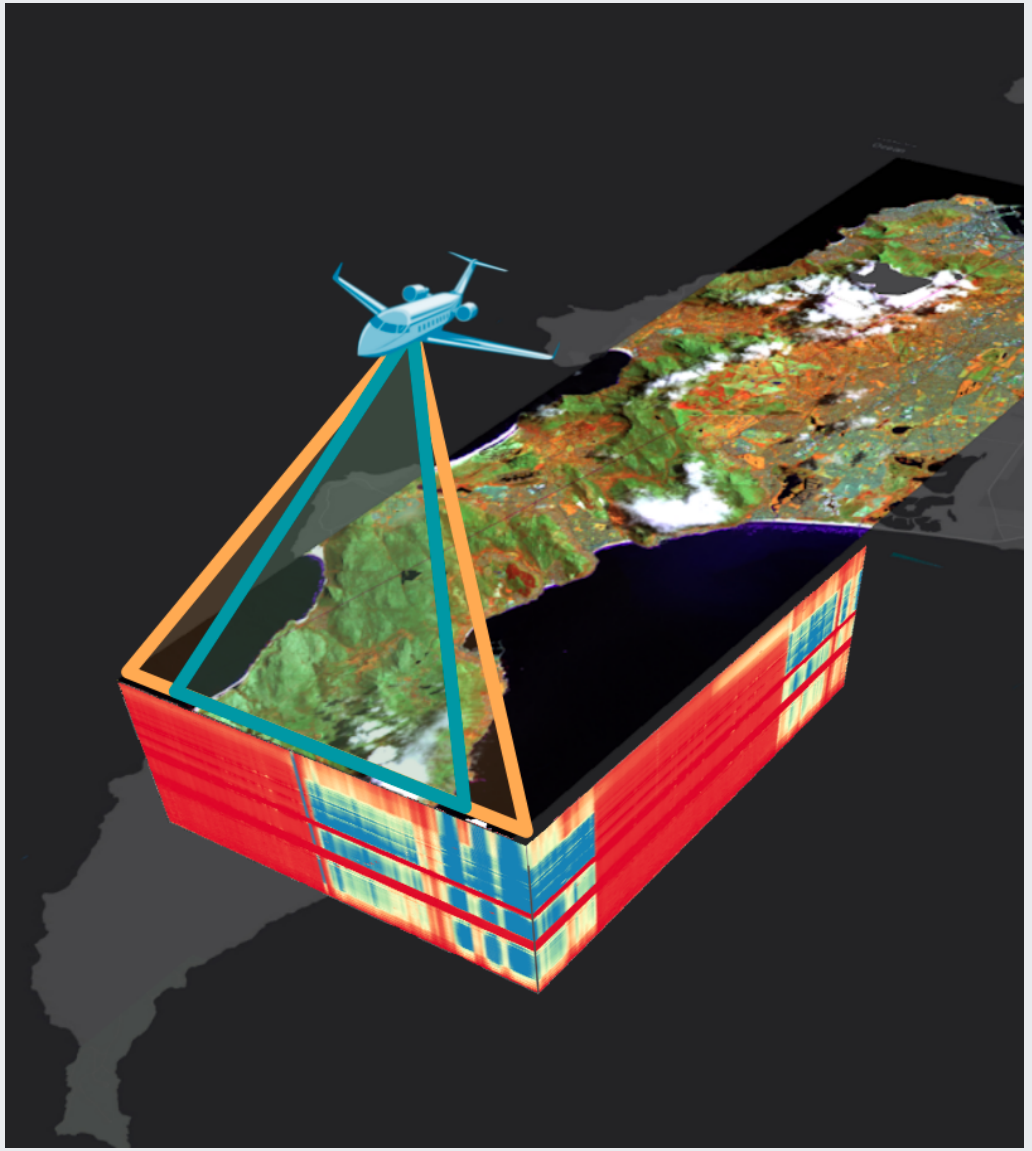
Light detection and ranging (LiDAR) allows you to measure topography and the vertical structure of vegetation.

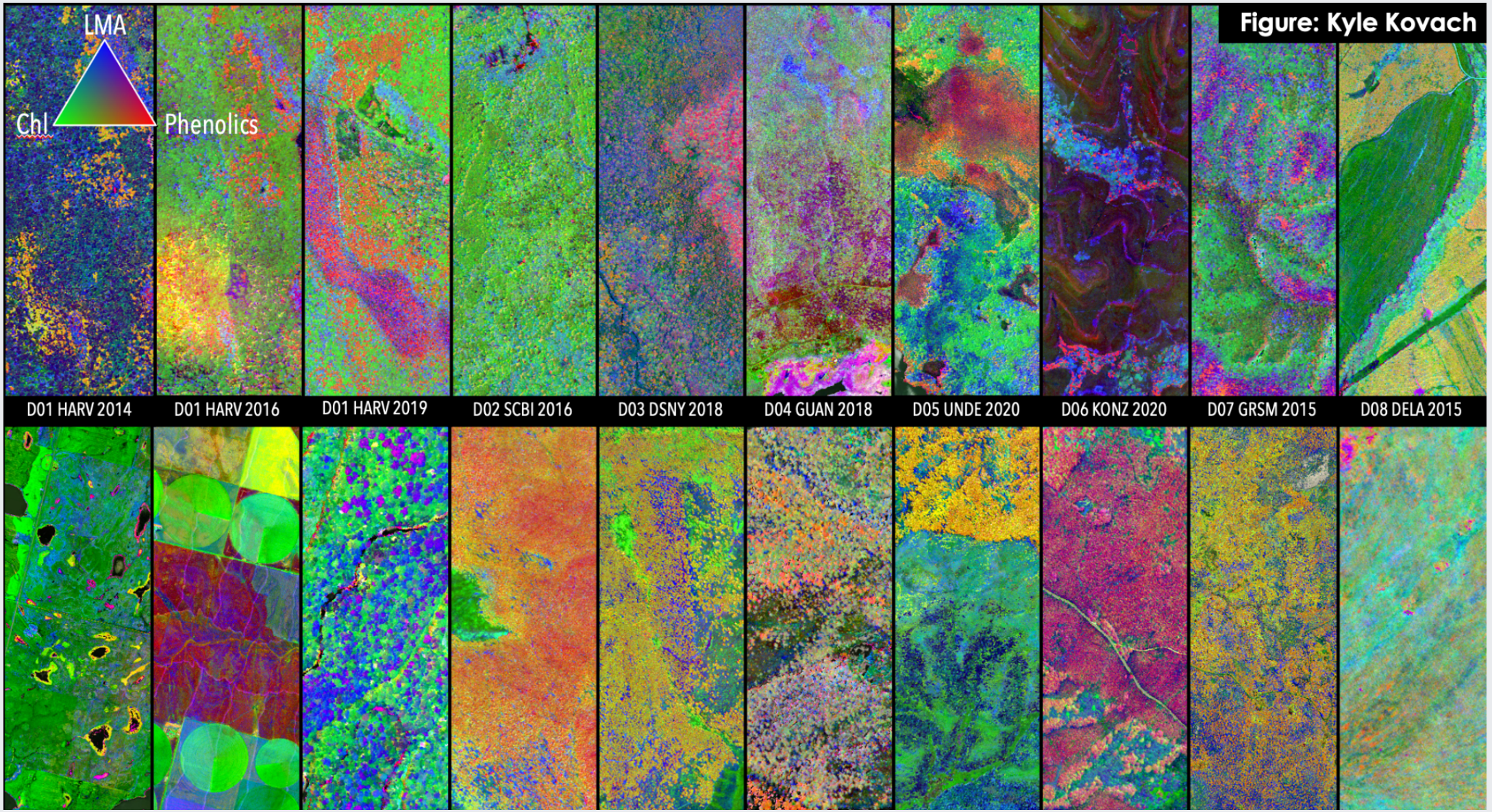
Purkis and Klemas 2011

Functional diversity?

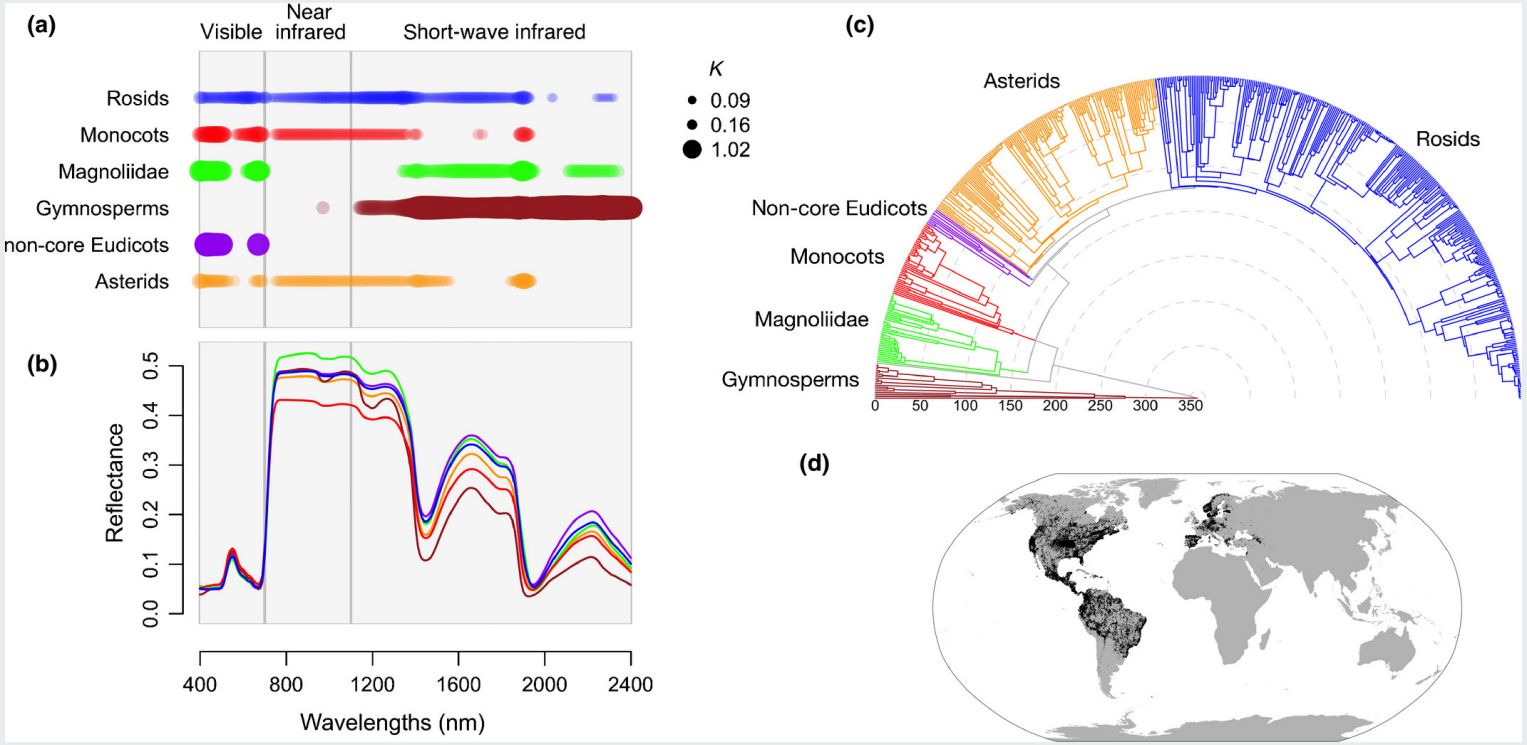
Imaging spectroscopy ("hyperspectral" remote sensing) allows direct measurement of leaf traits.






LMA
Chl
Phenolics
Figure: Kyle Kovach
D01 HARV 2014
D01 HARV 2016
D01 HARV 2019
D02 SCBI 2016
D03 DSNY 2018
D04 GUAN 2018
D05 UNDE 2020
D06 KONZ 2020
D07 GRSM 2015
D08 DELA 2015

Phylogenetic diversity?



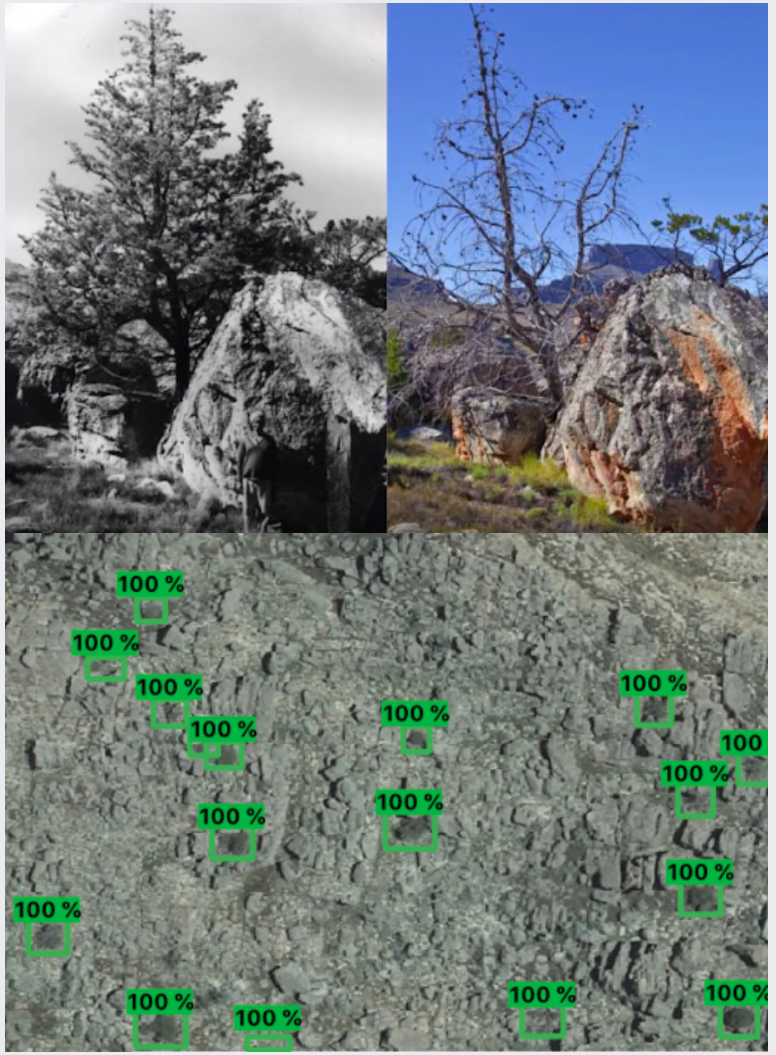
Leaf spectra are phylogenetically conserved for some regions, so it's possible that we'll be able to discern lineages using imaging spectroscopy...

Meireles et al. 2020

Identifying species?

We can monitor populations of large species..., but identifying all species present...?

https://xkcd.com/1838/



Hadebe 2021 MSc thesis

There are challenges and limitations...

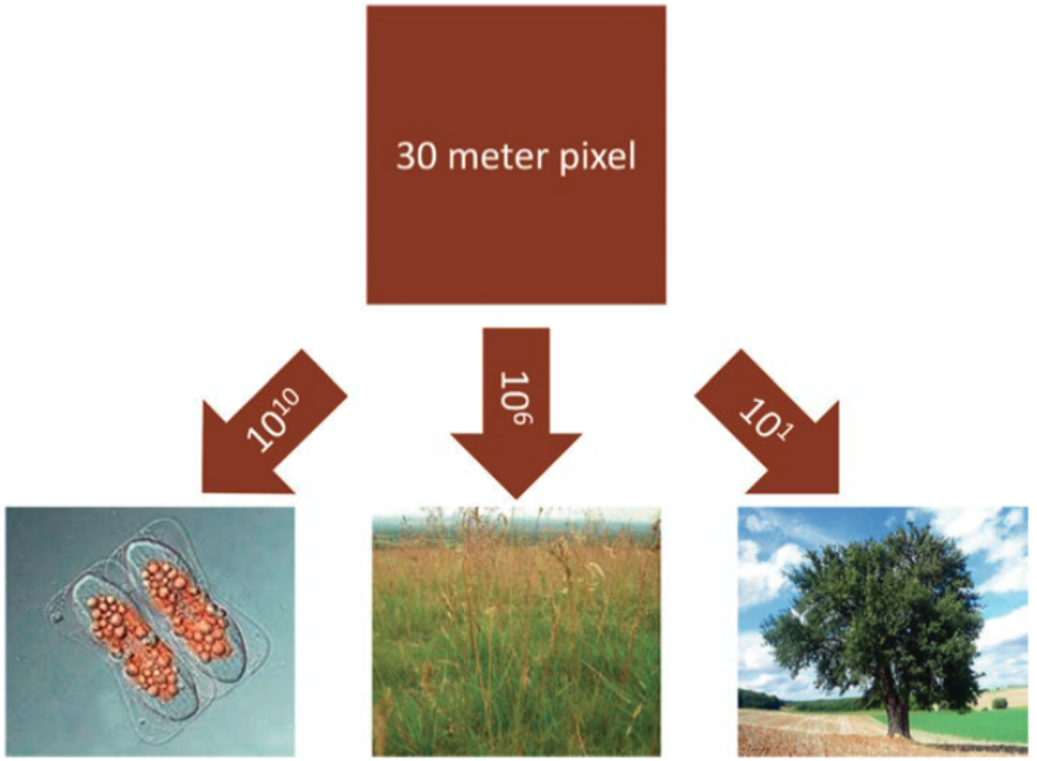
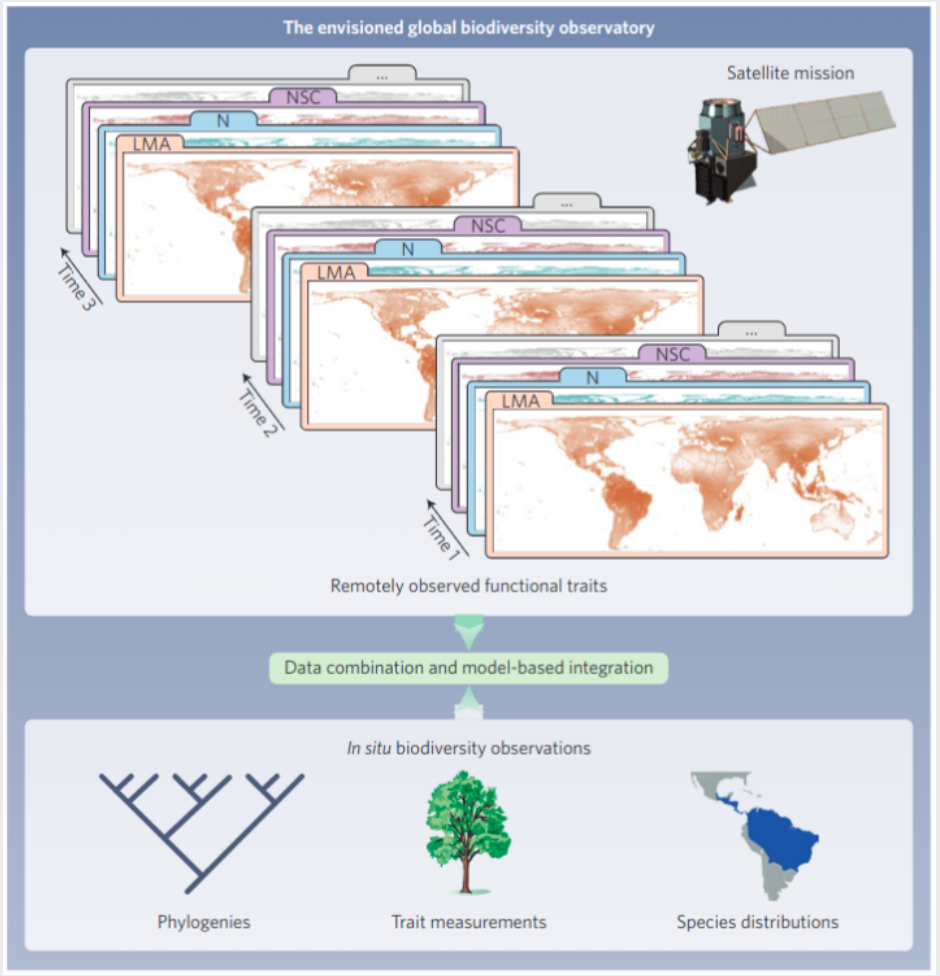


Fig. 19.2 The scale gap between organisms and the standard 30 m pixel ranges from 10^{10} to 10^{1}, depending on whether phytoplankton or large canopy trees are being imaged. When spectroscopic data are applied to address ecological and phylogenetic questions, this scale gap will have to explicitly factor into the analysis

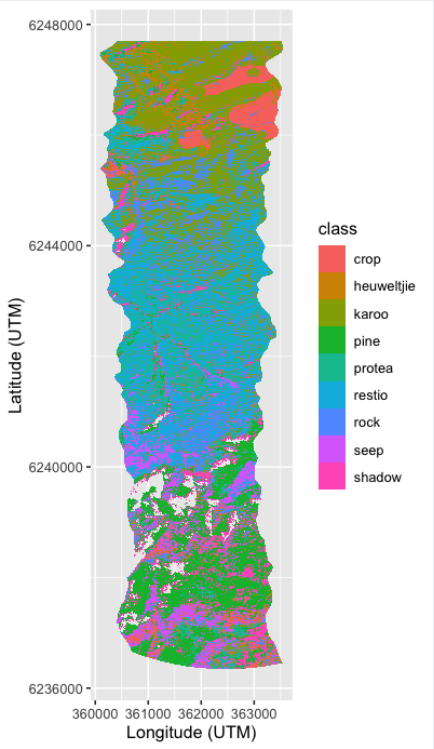
Schimel et al. 2020

But this is what fancy modelling and proxies are for...



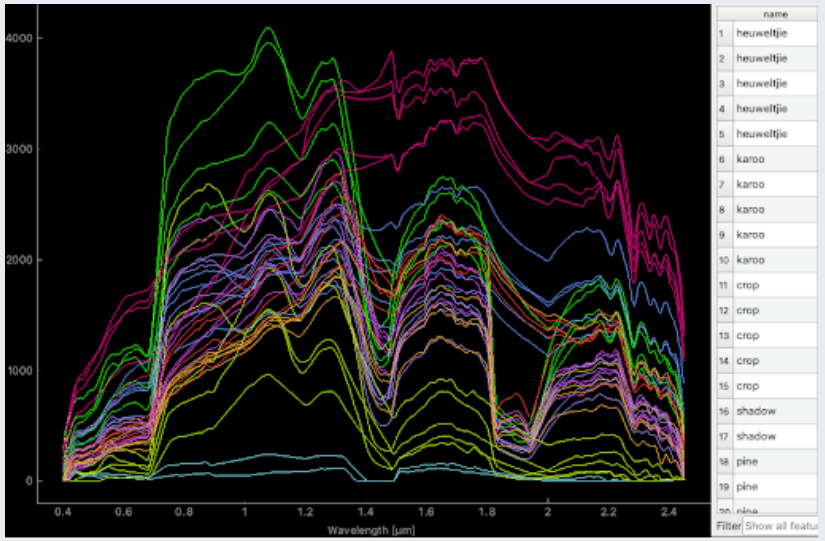
Jetz et al. 2016

Spectral unmixing can detect "spectral signatures"



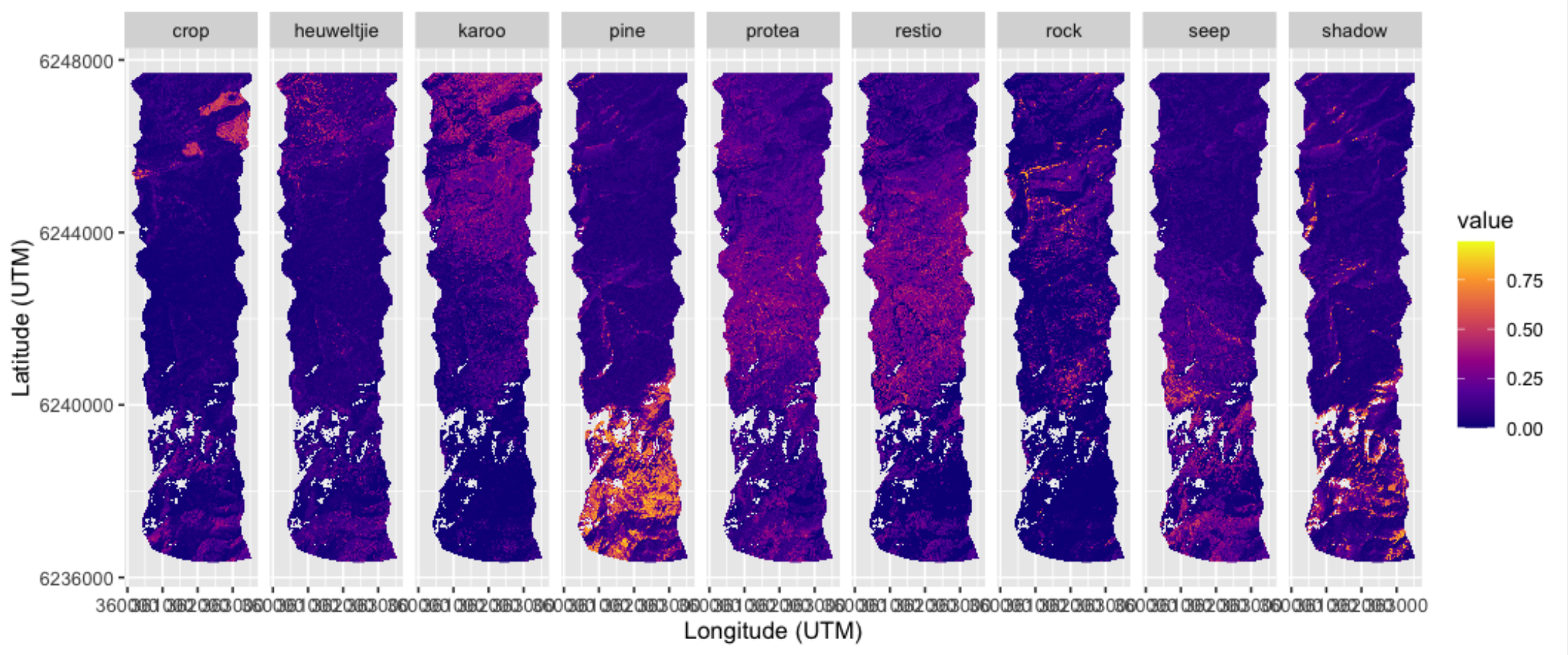
Jonaskop, Riviersonderend Mountains

Map species/types based on their reflectance of the electromagnetic spectrum!



Given a library of spectral signatures of different species and land cover types (endmembers), spectral unmixing infers the composition of each pixel from the possible mixes of endmembers. This gives a cover map of the majority endmember for each pixel (as here) and the fraction of each endmember for all pixels (next slide).

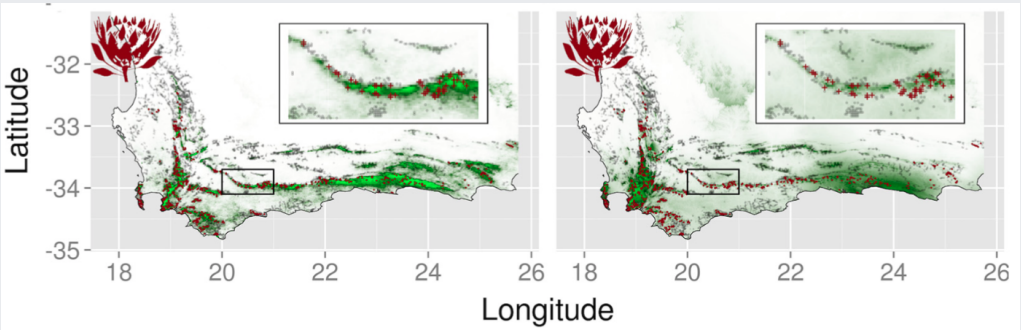
Spectral unmixing can detect "spectral signatures"



Fractional cover of species (e.g. pines), functional groups or land cover types!

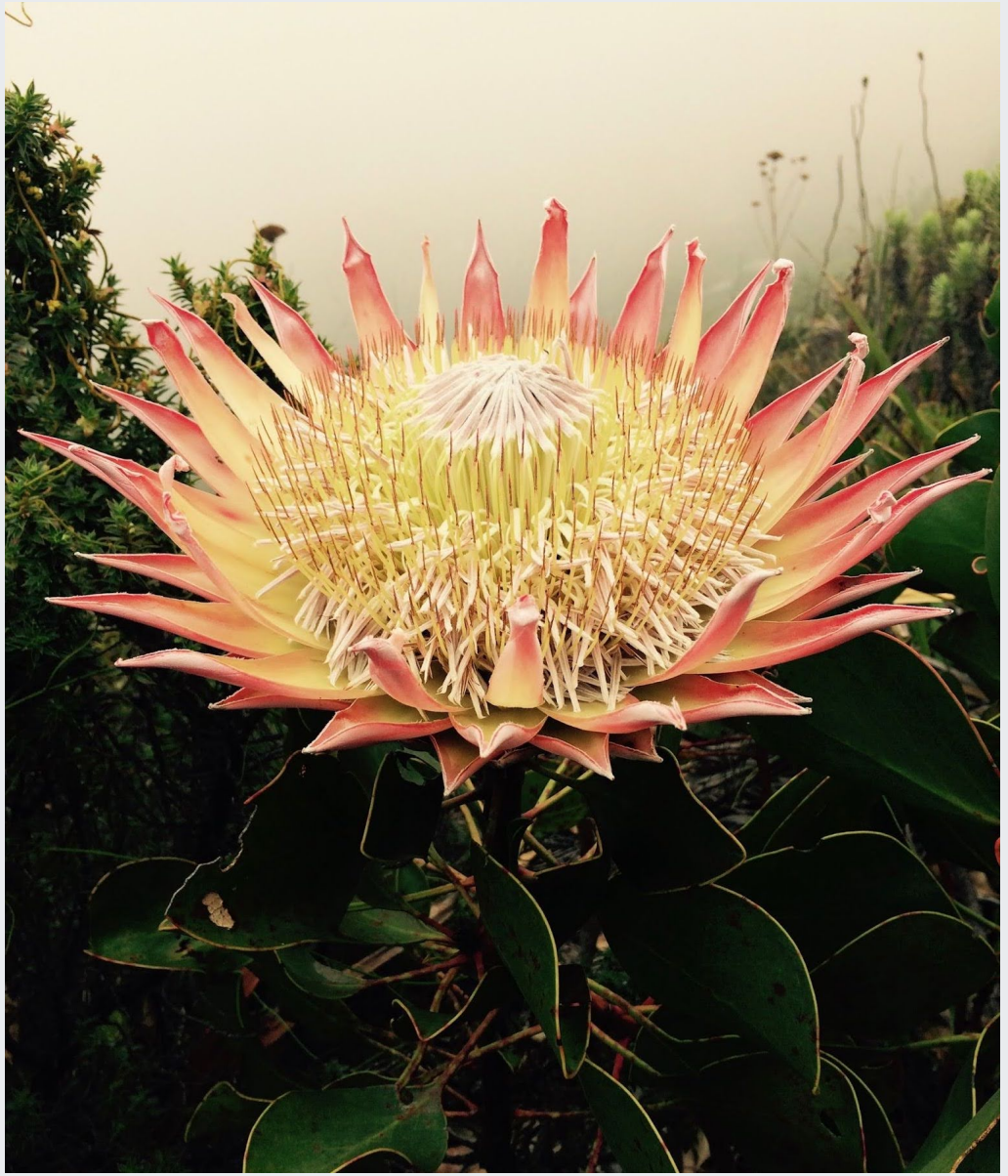
Combining remote sensing and in situ data

Using remotely sensed environmental data to inform species distribution models (SDMs)



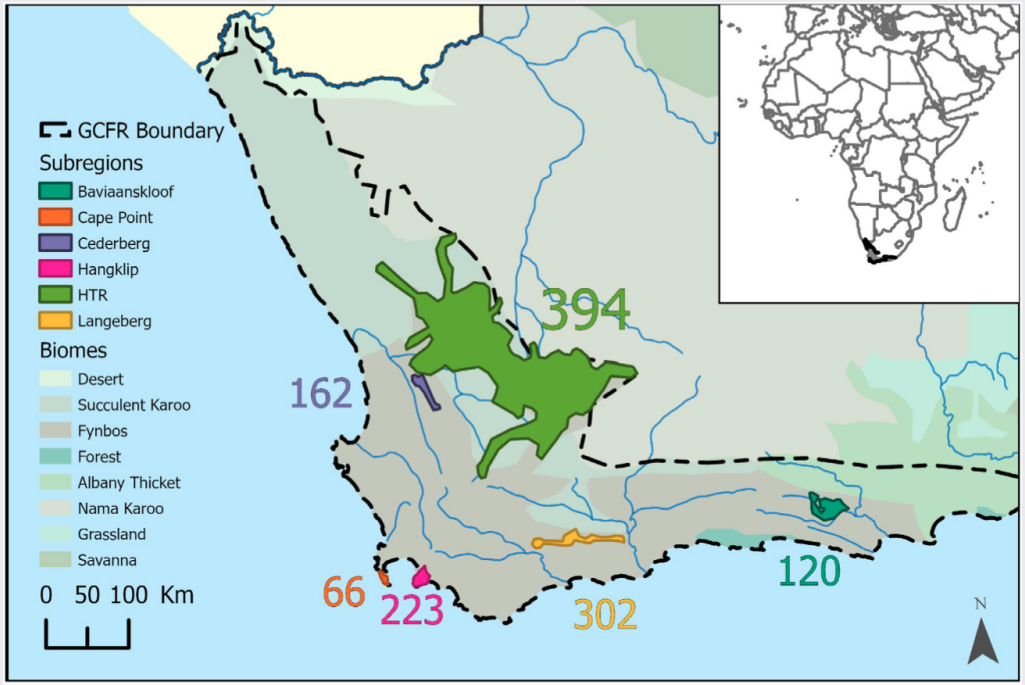
E.g. Observed cloud frequency from the MODIS satellite is a better predictor of the distribution of *Protea cynaroides* than interpolated precipitation.

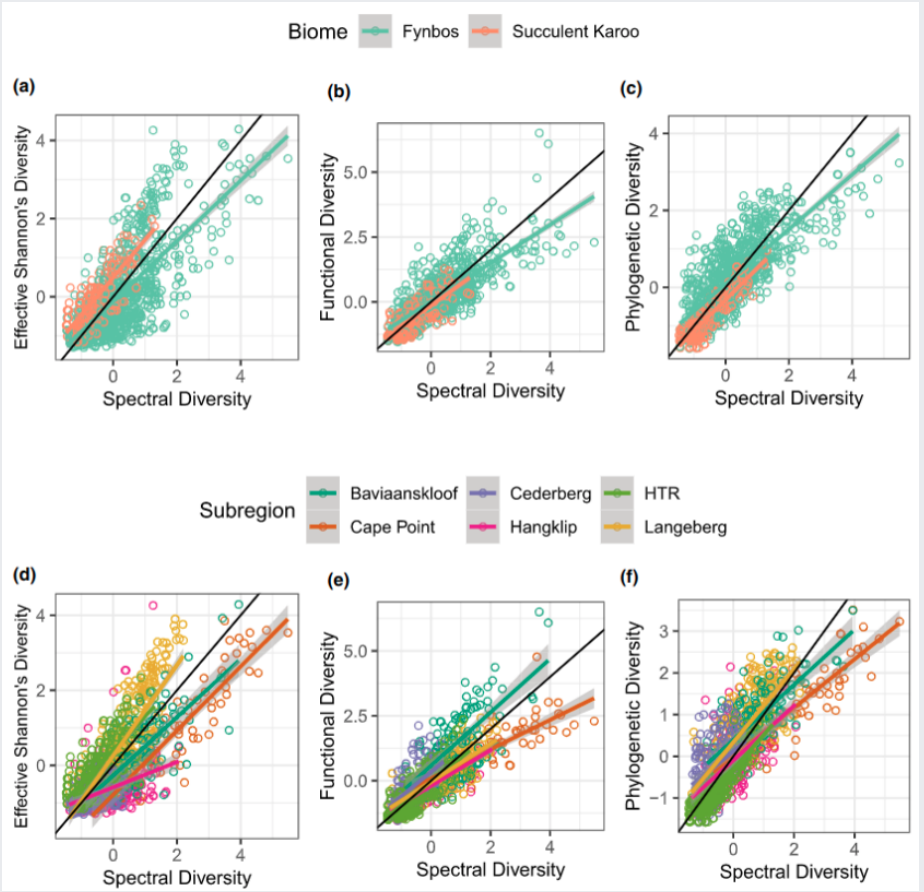
Wilson and Jetz 2016



The Spectral Diversity Hypothesis

Is spectral diversity a good proxy for biotic diversity?

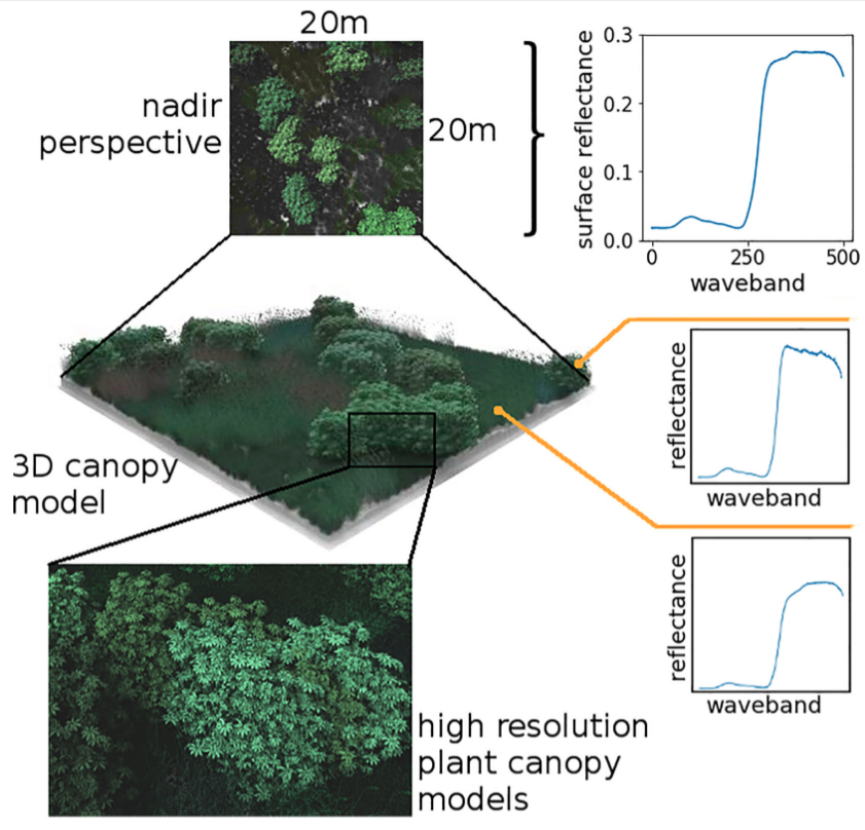


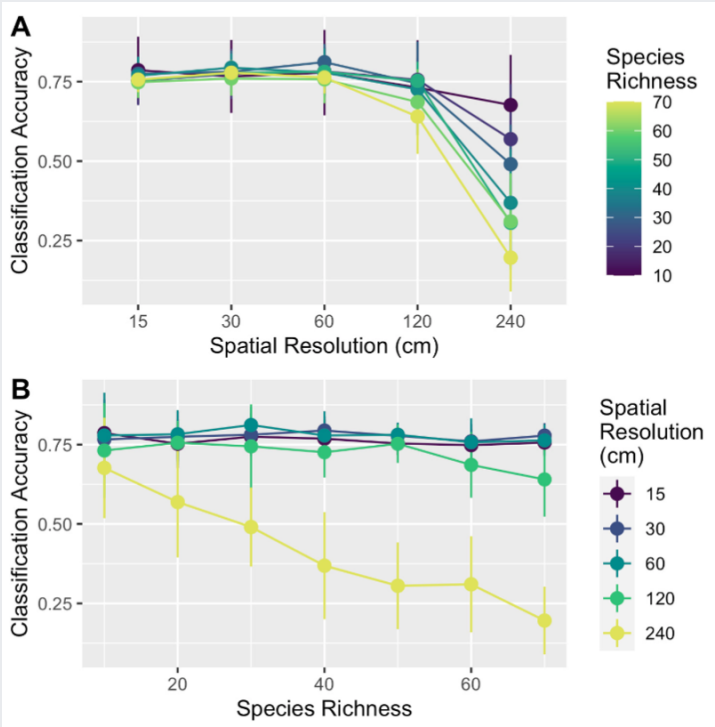


A test looking at spectral diversity from leaf spectra for 1210 species across 1267 plots supports the hypothesis **at the leaf level...**

Frye et al. 2021

The Spectral Diversity Hypothesis





But canopy reflectance is more complex...

Leaf angle, shadow, density, etc affect the spectral reflectance of vegetation, reducing our ability to identify and map species - especially as the resolution of the imagery coarsens.

van Leeuwen et al. 2021

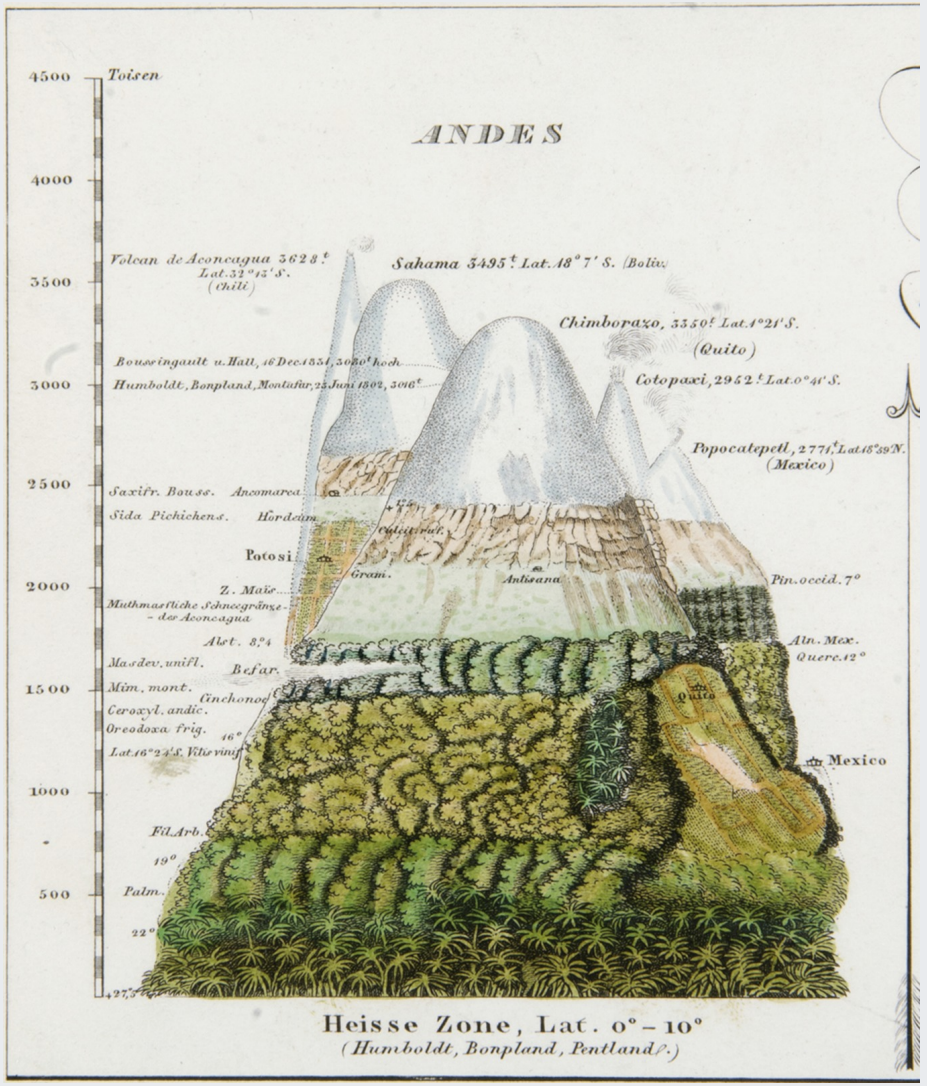
Environmental heterogeneity

Another approach is just to map and monitor environmental heterogeneity

"Conserving nature's stage"

The Nature Conservancy and others using this approach to identify parcels of Earth that are valuable for their capacity to support diverse life forms today and into the future

Typically identified based on their abiotic heterogeneity or geodiversity, much of which can be mapped and/or monitored with remote sensing - topography, climate, soils, etc



Alexander von Humboldt

Take-home

> *Remote sensing is a rapidly growing field that is seen as the holy grail for mapping and monitoring biodiversity (and Essential Biodiversity Variables) at high spatial resolution from local to global scales.*
>
> *There are many remote sensing methods and tools, and these are constantly improving.*
>
> *While there are many limitations (e.g. spatial resolution), many can be addressed with modelling approaches, and are being overcome as the technology and methods improve.*
>
> *Remote sensing approaches must be paired with in situ observations to "ground-truth" and calibrate/validate that they do reflect reality on the ground.*
>
> *Remote sensing can be valuable for mapping habitat variables such as climate, topography, etc that can inform inference about species distributions or other proxies for biodiversity like environmental heterogeneity or spectral diversity.*

References

Gotelli, N. J. and R. K. Colwell (2001). "Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness". In: *Ecology letters* 4.4, pp. 379-391. ISSN: 1461-023X, 1461-0248. DOI: 10.1046/j.1461-0248.2001.00230.x.

Slingsby, J. A., C. Merow, M. Aiello-Lammens, et al. (2017). "Intensifying postfire weather and biological invasion drive species loss in a Mediterranean-type biodiversity hotspot". En. In: *Proceedings of the National Academy of Sciences of the United States of America* 114.18, pp. 4697-4702. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.1619014114.

Whittaker, R. H. (1972). "Evolution and measurement of species diversity". En. In: *Taxon* 21.2-3, pp. 213-251. ISSN: 0040-0262, 1996-8175. DOI: 10.2307/1218190.

Thanks!

Slides created via the R packages:

xaringan
gadenbuie/xaringanthemer

The chakra comes from remark.js, **knitr**, and R Markdown.