The Case for a Global Biodiversity Observatory

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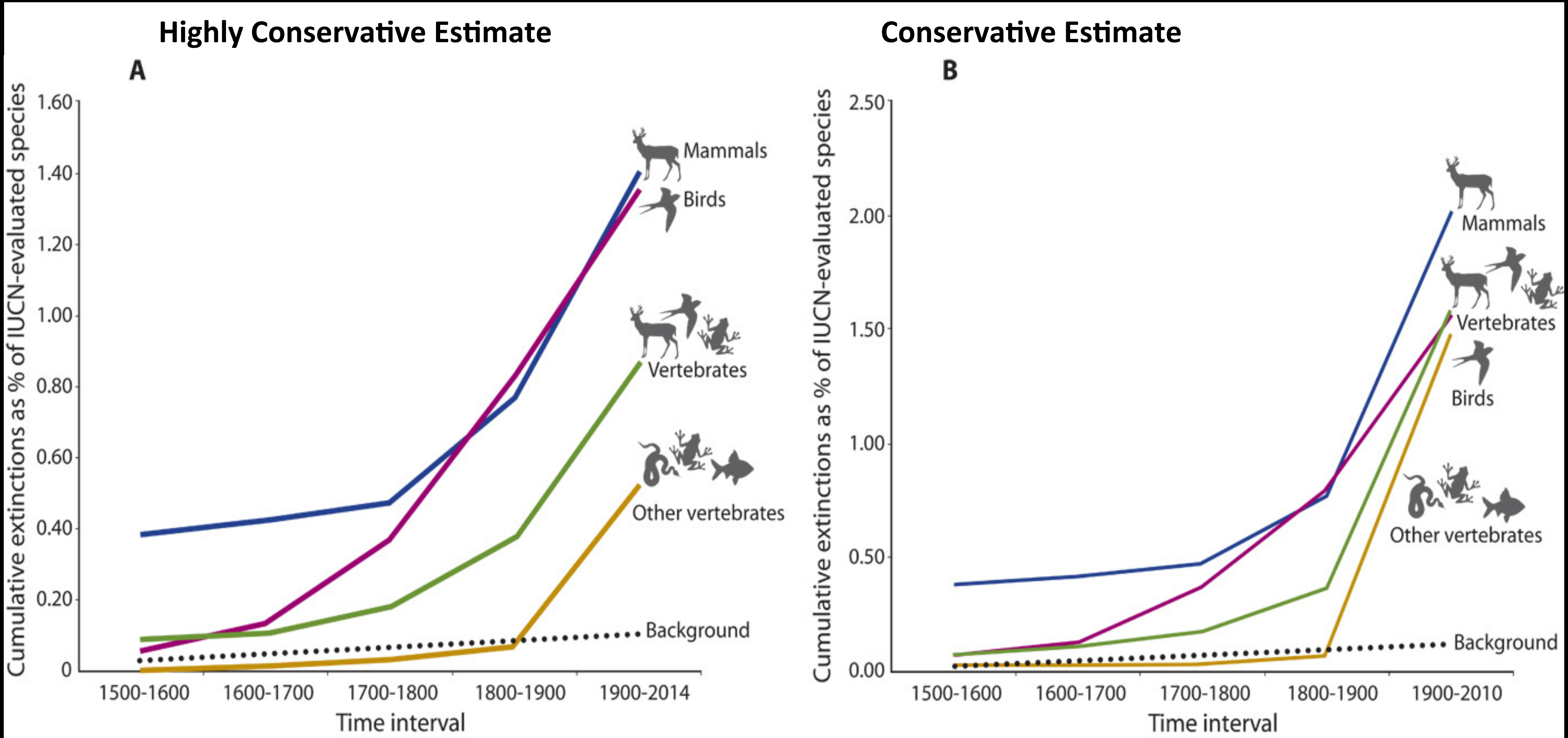
University of California Davis

Daintree National Park,
tropical rainforest wilderness in Far North Queensland, Australia

Cumulative Extinctions of Vertebrate Species
recorded by the International Union for Conservation of Nature (IUCN) 2012



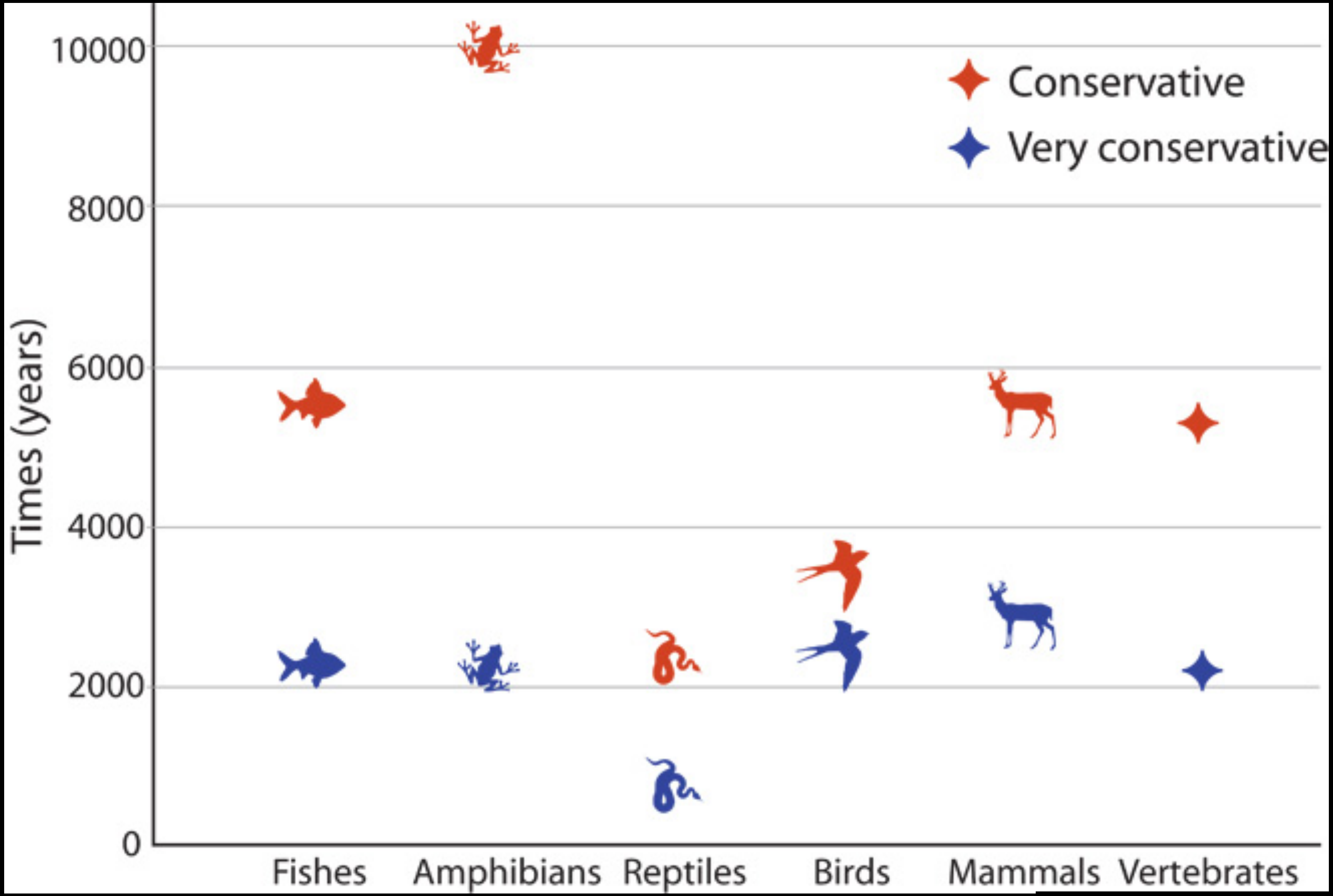
Gerardo Ceballos et al. Sci Adv 2015;1:e1400253
Fig. 1.

Science Advances

Published by AAAS

Years required for extinctions under the background rate (2E/MSY)

compared to vertebrate species extinctions in the last 114 years



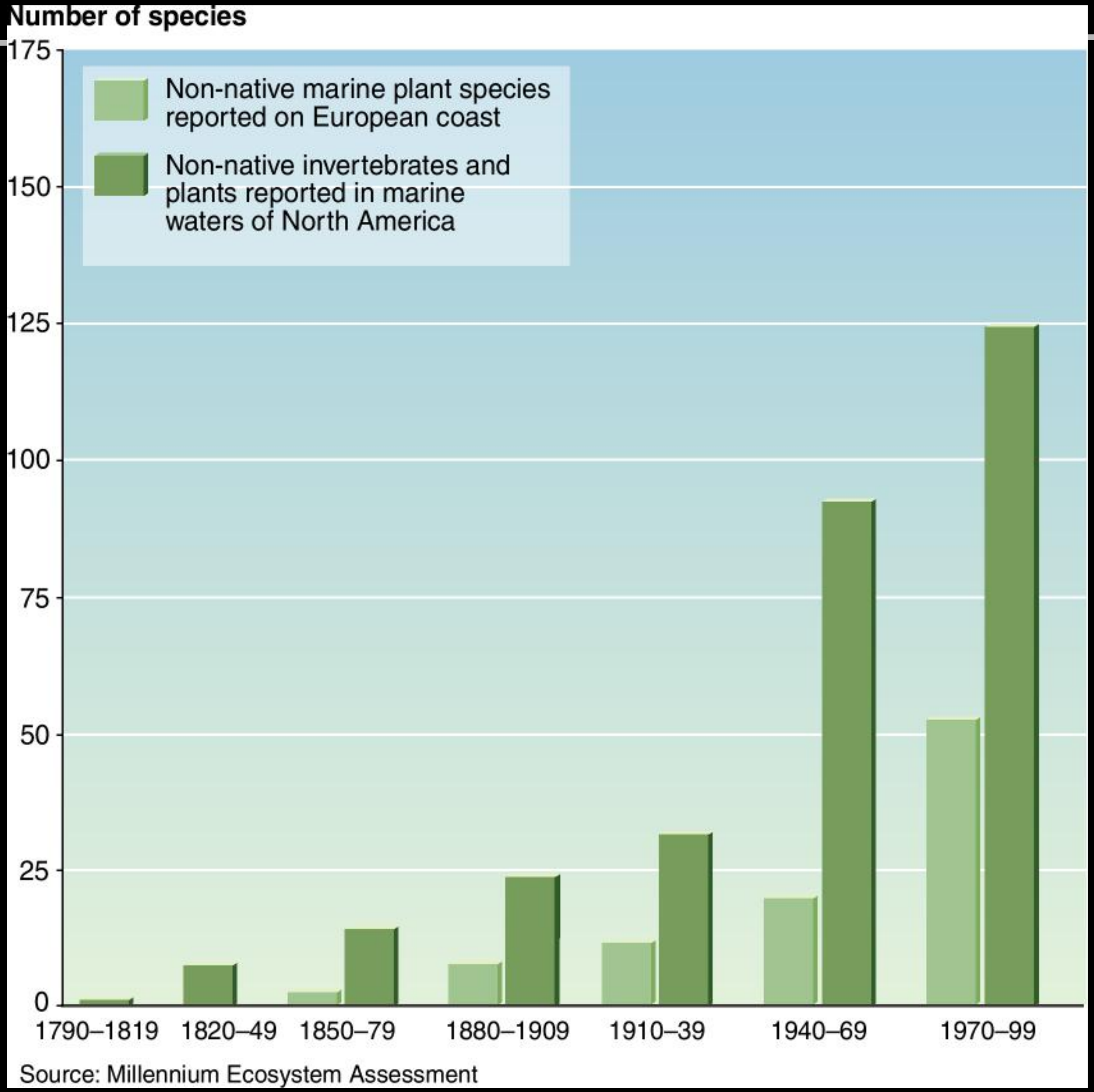
Gerardo Ceballos et al. Sci Adv 2015;1:e1400253
Fig. 2

Science Advances

Significant and largely irreversible changes to species diversity

- The distribution of species on Earth is becoming more homogenous
- The population size or range (or both) for the majority of species, across a range of taxonomic groups, is declining

Source: Millennium Ecosystem Assessment



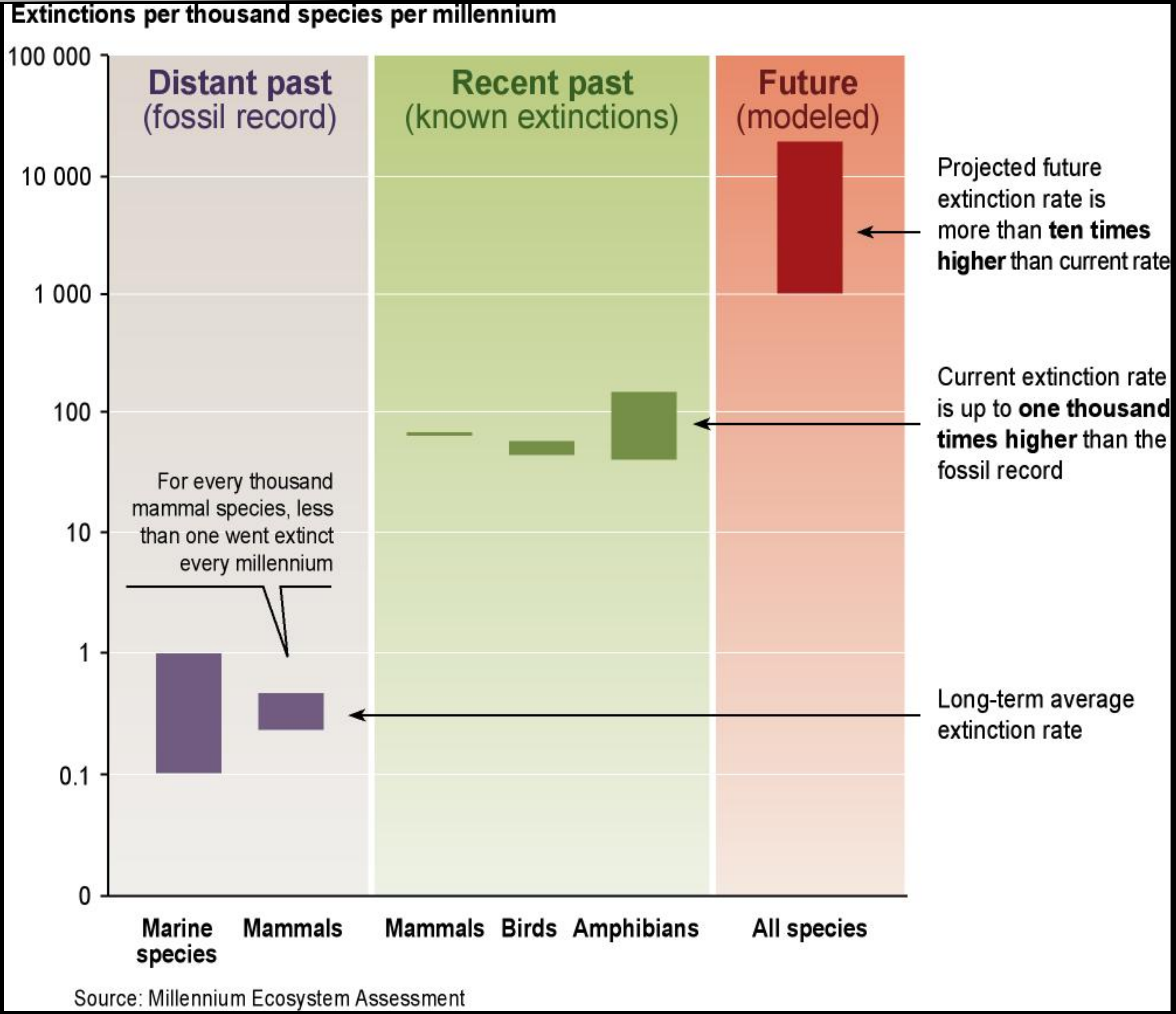
Growth in Number of Marine Species Introductions in North America and Europe

Significant and largely irreversible changes to species diversity

- Species extinction rate increased 1,000 times above background rates typical over the Earth's history (*medium certainty)*

- 10–30% of mammal, bird, and amphibian species are currently threatened with extinction (*medium to high certainty)*

Source: Millennium Ecosystem Assessment



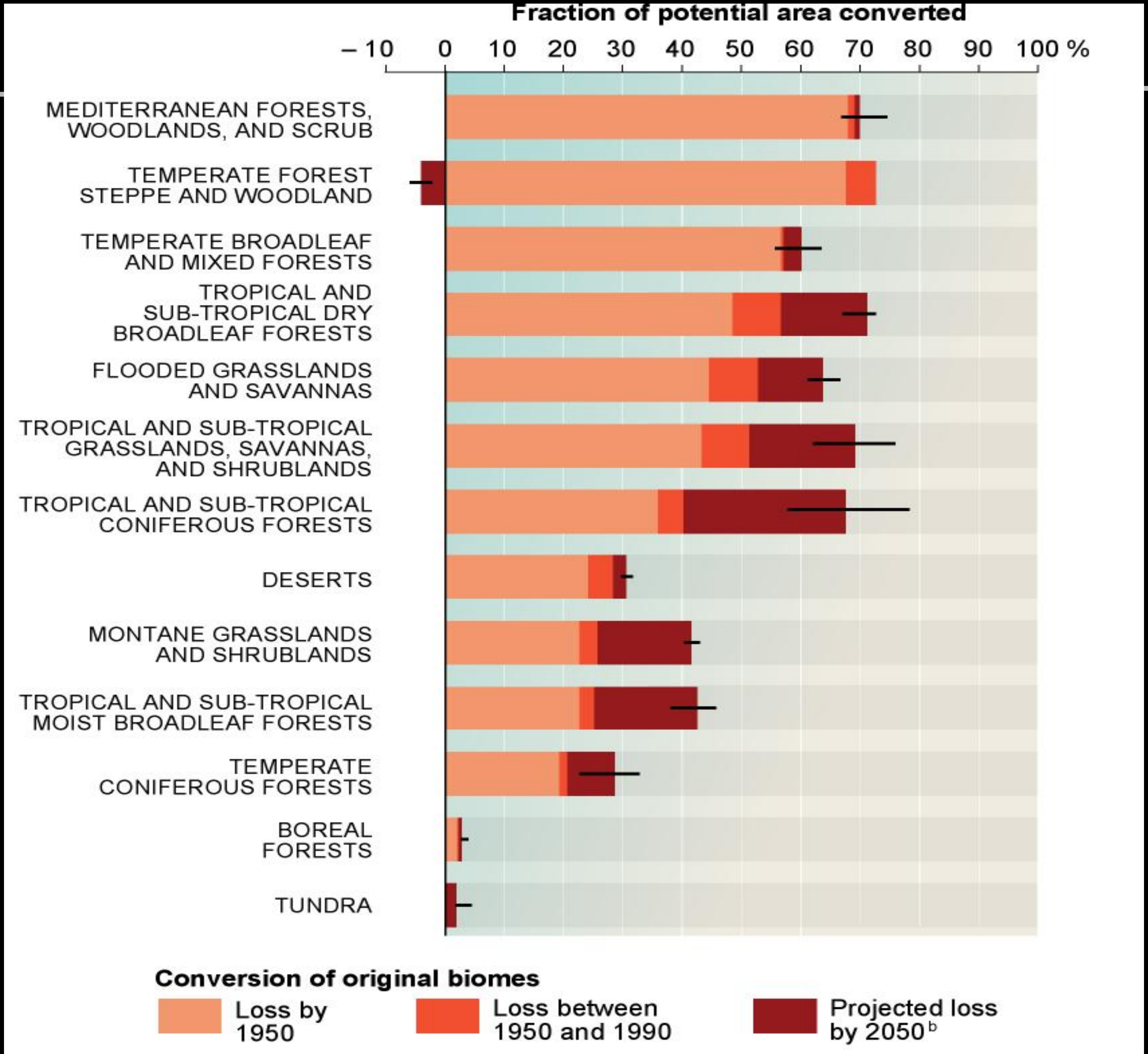
Changes in Direct Drivers

- **Habitat transformation:**
  - Further 10–20% of grassland and forestland is projected to be converted by 2050

Invasive alien species:

- Spread will continue to increase

Source: Millennium Ecosystem Assessment

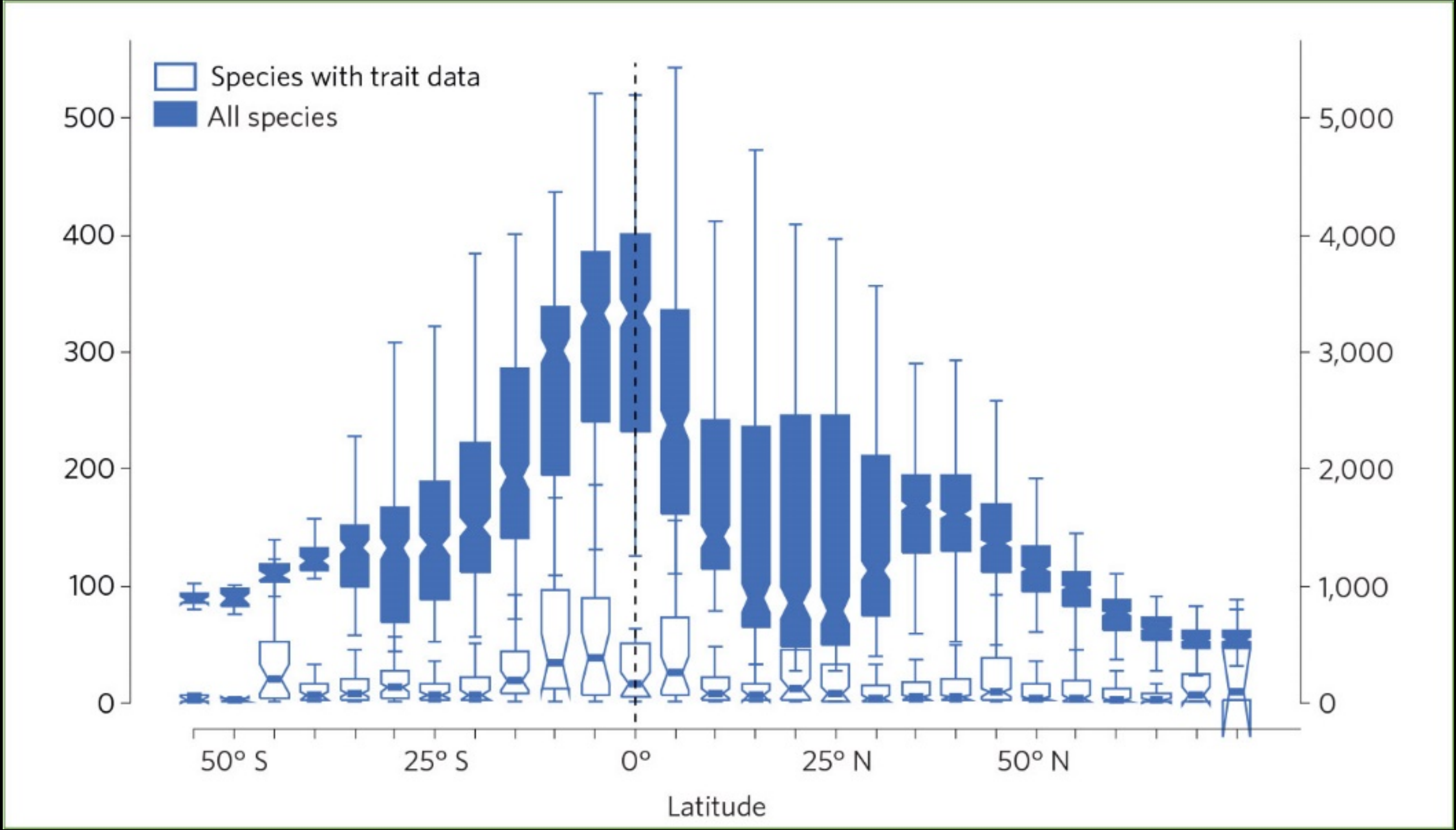


Despite Advances in Compiling Species Databases, Information from Field Surveys is Insufficient

TRY Database of plant traits

Latitudinal variation in the richness of all vascular plant species (BLUE; after Kreft & Jetz 2007)

Compared to TRY database (WHITE; from TRY, Jun 2015) among 110km grid cells (N = 11,626).

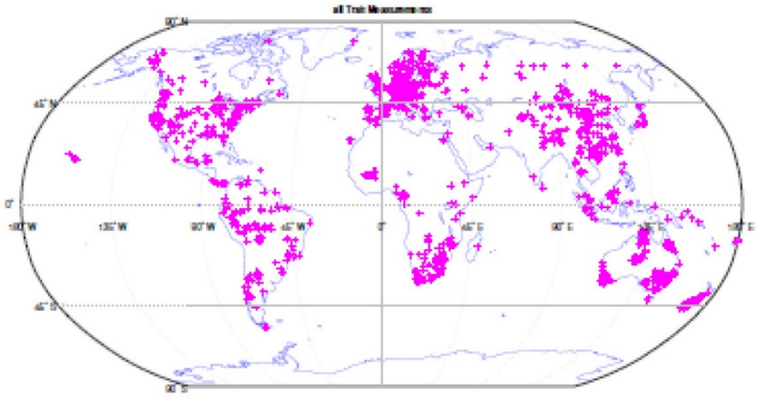


W. Jetz, J. Cavender-Bares, R. Pavlick, D. Schimel et al. 2016. Nature Plants 16024| DOI:10.1038.Nplants 2016.24

TRY Database: Subset Example Illustrating Incomplete Trait Data

Trait	Missing (%)
Specific leaf area (SLA)	57.85
Plant height	78.97
Seed dry mass	90.66
Leaf dry matter content (LDMC)	77.87
Stem specific density	88.26
Leaf area	49.63
Leaf nitrogen concentration (LeafN)	65.67
Leaf phosphorus concentration (LeafP)	84.71
Leaf nitrogen per area	89.55
Leaf fresh mass	85.33
Leaf nitrogen/phosphorus ratio	92.34
Leaf carbon per dry mass	89.63
Leaf δ^{15}N	88.48

Dataset Statistics:	
Plants	78,300
Traits	13
Missing Value	79.9%



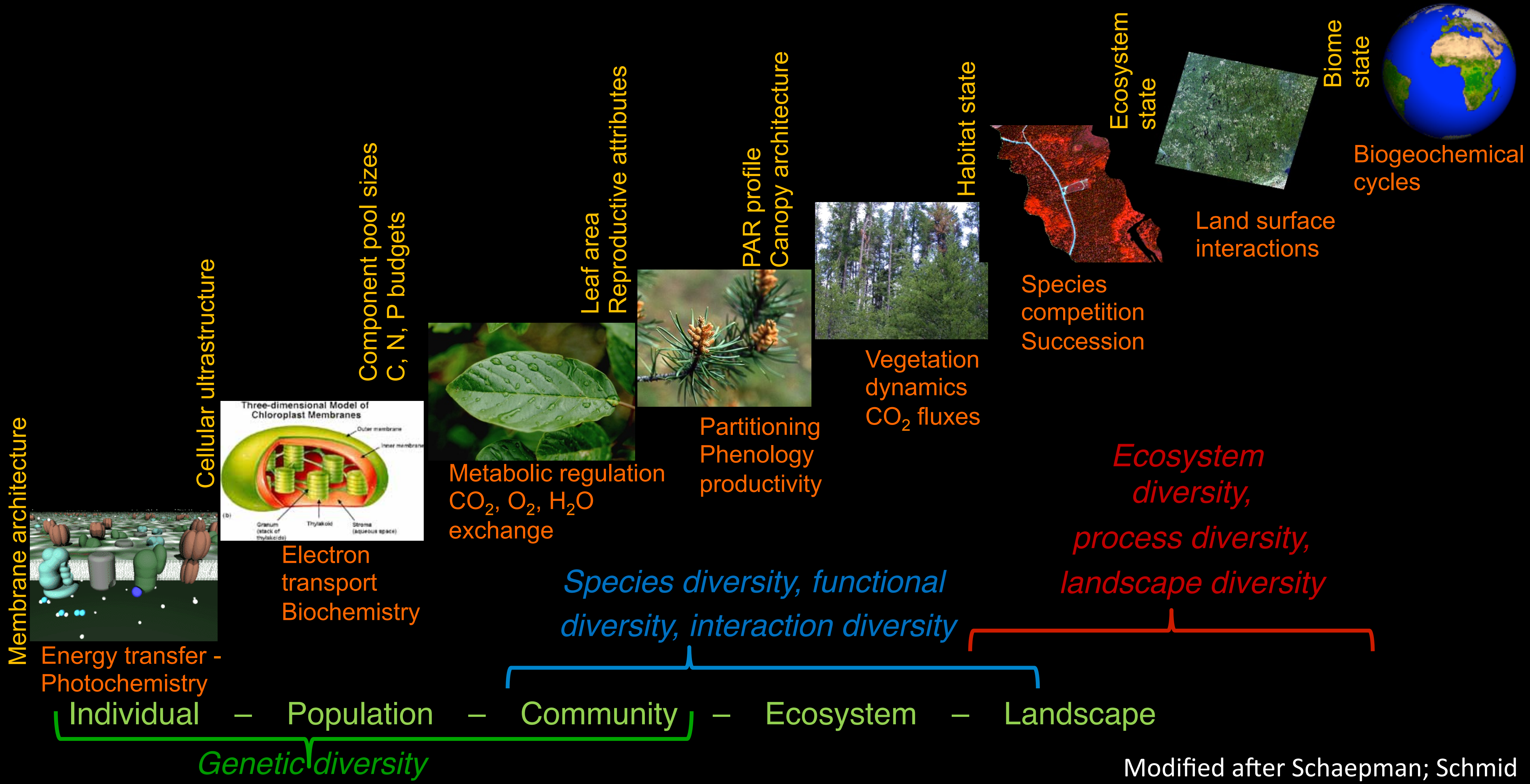
Max Planck Institute
for Biogeochemistry

Franziska Schrodt et al. 2016 NIMBioS Workshop, May 2016

University of Zurich[UZH]

URPP Global Change and Biodiversity

Scaling and Biodiversity



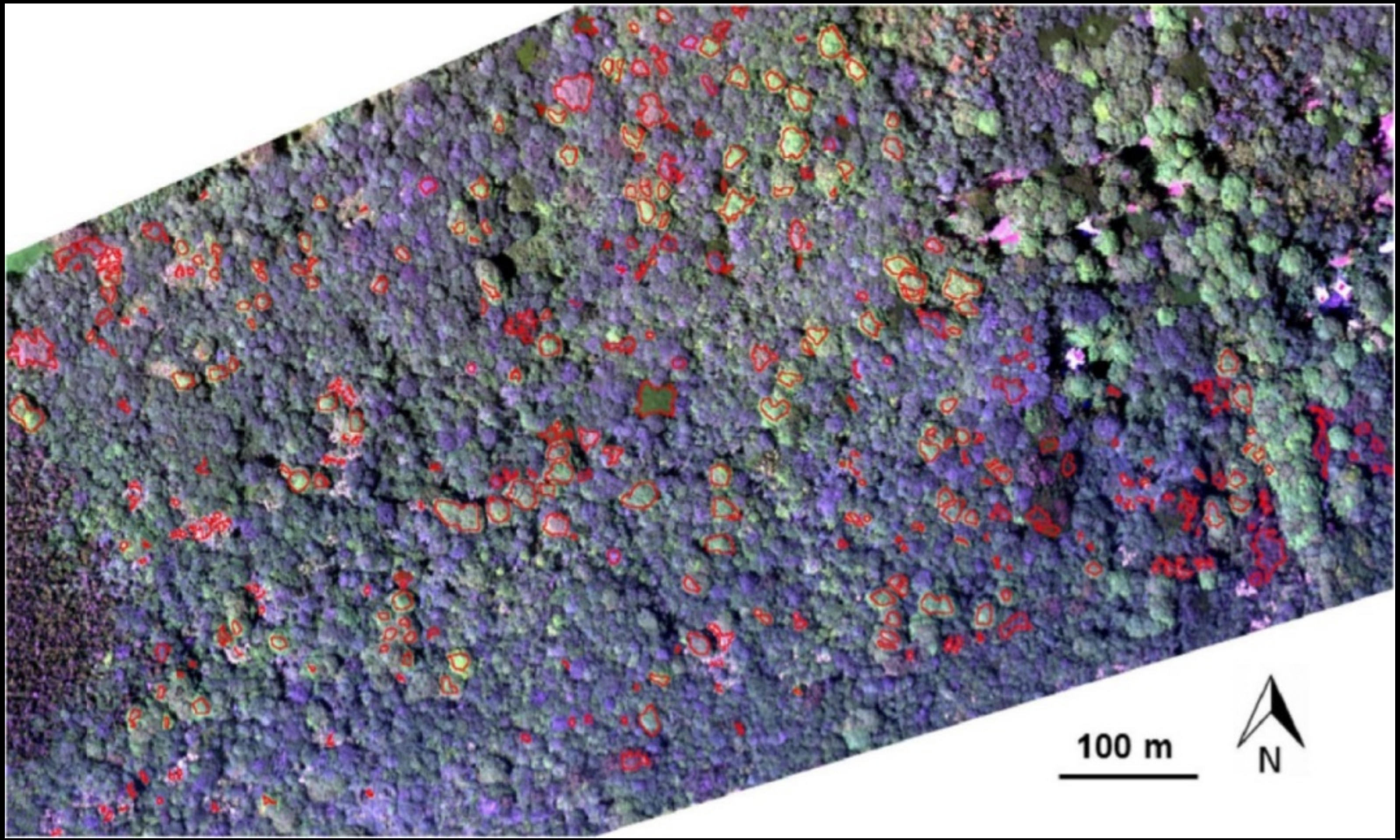
Modified after Schaepman; Schmid

Mapping species in a Lowland Tropical Forest

Nanawale Forest Reserve, HI:

9 tree species mapped

- SVM Classifier used CAO imaging spectrometer
- Adding lidar variables made incremental improvements

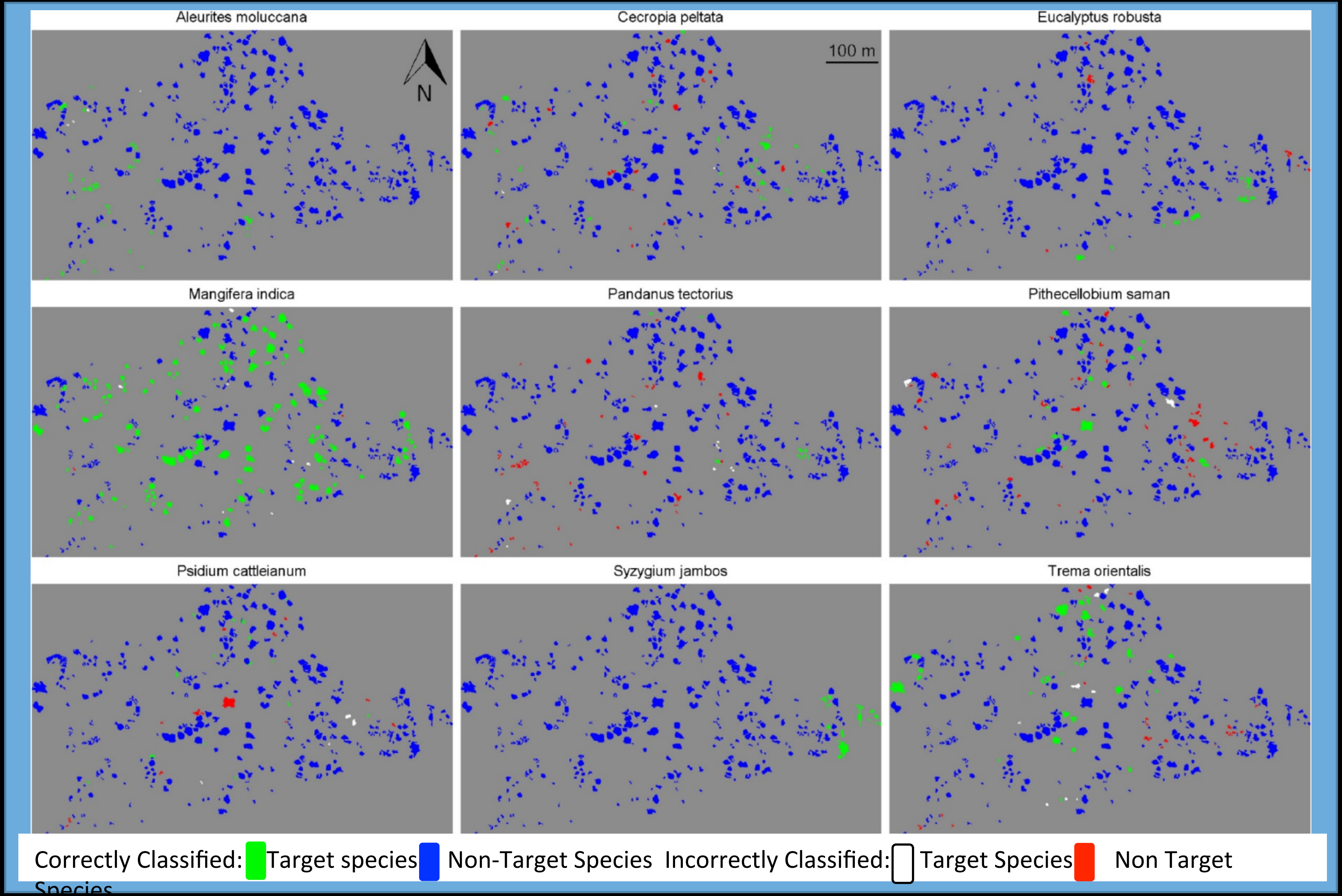


3 Color composite (646.0, 560.7, 447.0 nm) with field mapped crown delineations in red

1980 x 1240 pixels @0.56m resolution; 24 bands 390 to 1044 nm

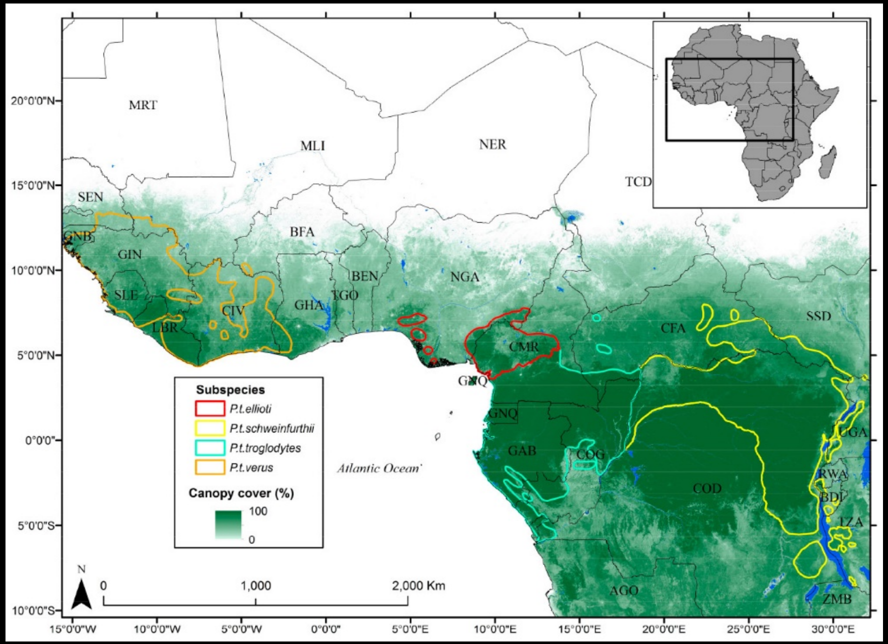
Jean-Baptiste Ferét and Greg Asner, Remote Sensing, 2012

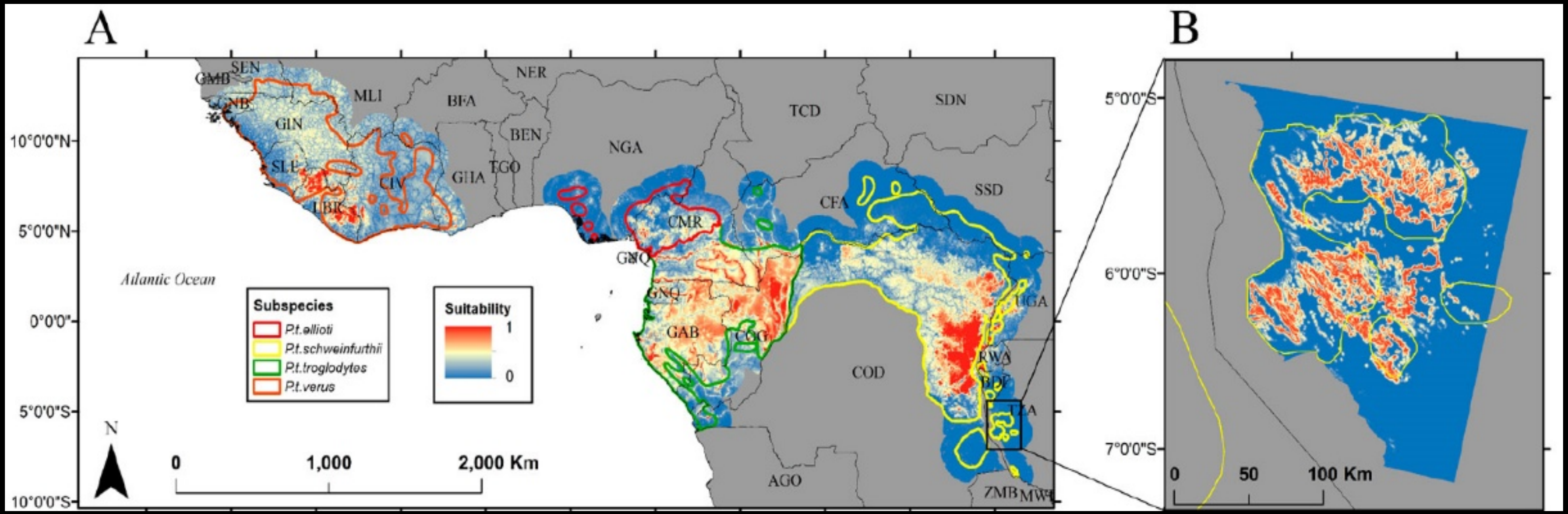
Nine Species Mapped across the Nanawale Forest Reserve



Jean-Baptiste Ferét and Greg Asner, Remote Sensing, 2012

Mapping Habitat Suitability for Endangered Chimpanzee Populations





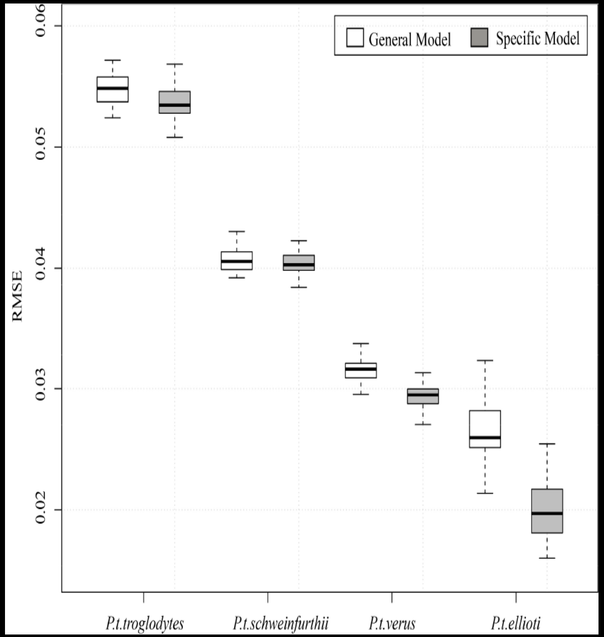
(A) Habitat suitability data used for Random Forest calibration. The map from the 2000s and (**B**) suitability map for 4 subspecies of Chimpanzee

Habitat map derived from AVHRR, MODIS, Landsat and SRTM

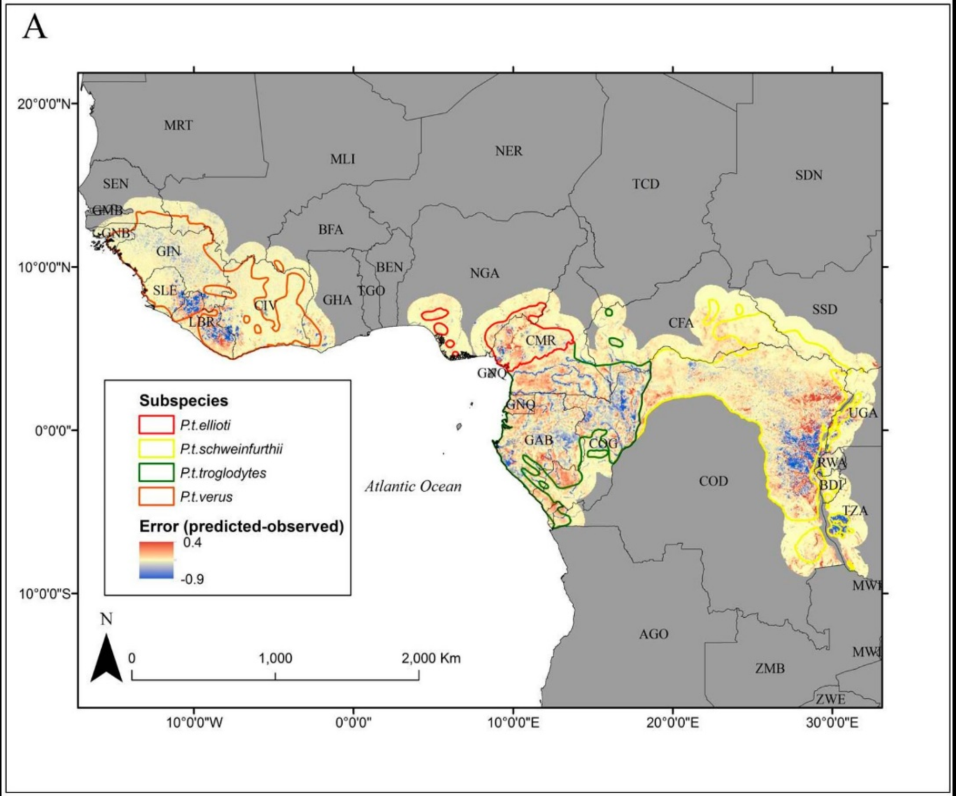
Junker, J.; Blake, S.; Boesch, C.; Campbell, G.; Toit, L.D.; Duvall, C.; Ekobo, A.; Etoga, G.; Galat-Luong, A.;Gamys, J.; et al. Recent decline in suitable environmental conditions for African great apes. Divers. Distrib. **2012**, 18, 1077–1091.

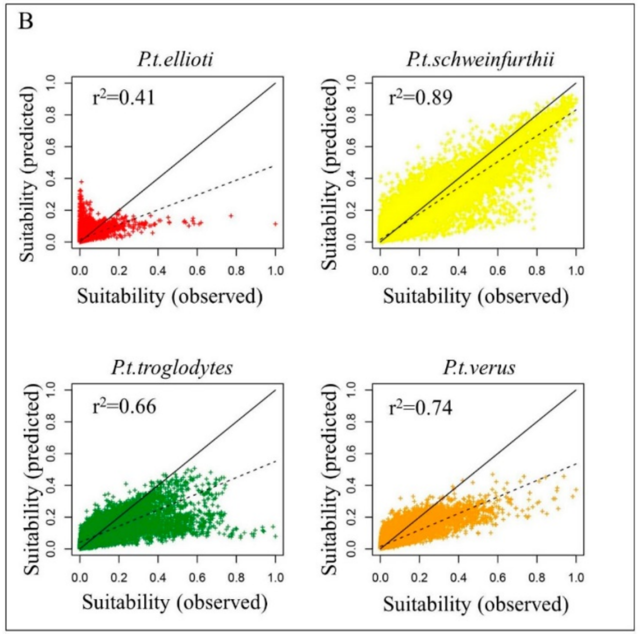
(Pintea, L.; Plumptre, A.J. Prediction of suitable habitat for chimpanzees using remote sensing and GIS. In Surveys of Chimpanzees and Other Biodiversity in Western Tanzania; Moyer)

Tested a generalized model for the entire area compared to quality to existing subspecies maps



New general model produces as good or better map than the 2000s



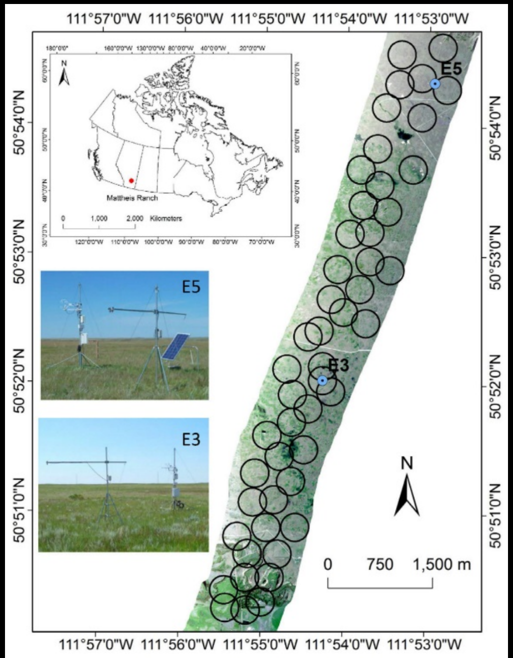


(**A**), distribution of suitability values of 5-km calibration map (x-axis) and coarsened 30-m map (y-axis) for each sub-species

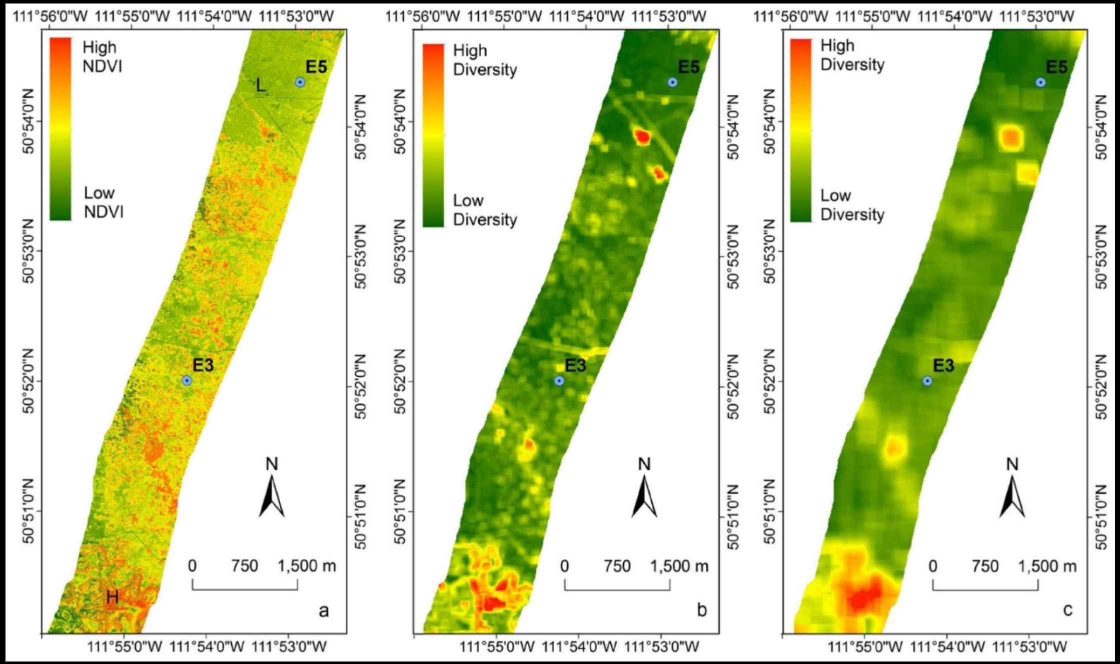
(**B**). The one-to-one line is shown in solid black and results of regressing values from the coarsened 30-m map onto values from the 5-km map for each sub-species are shown by the dashed black line

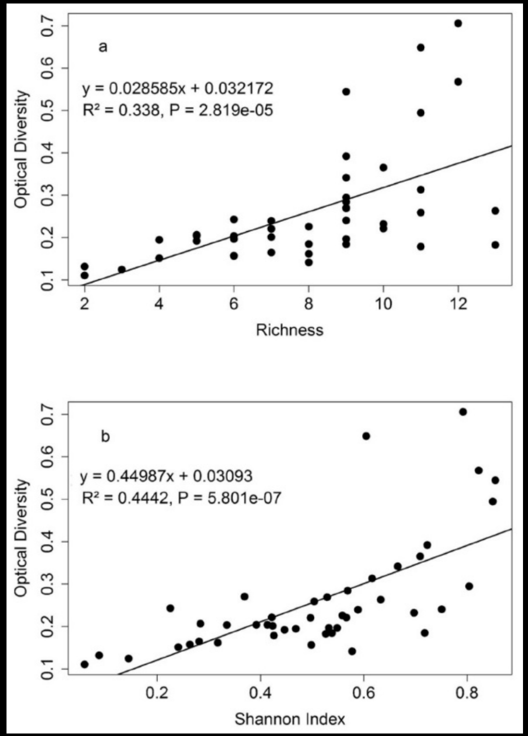
anz et al. Remote Sensing 2016

Predicting Biodiversity from Optical Variability



Mattheis Research Ranch, Alberta, Canada. Airborne true-color with 50 400-m diameter circles used to evaluate productivity-diversity relationship.





Headwall VNIR Imaging Spectrometer used to calculate calculate NEE and compared to flux tower data (E3 and E5).

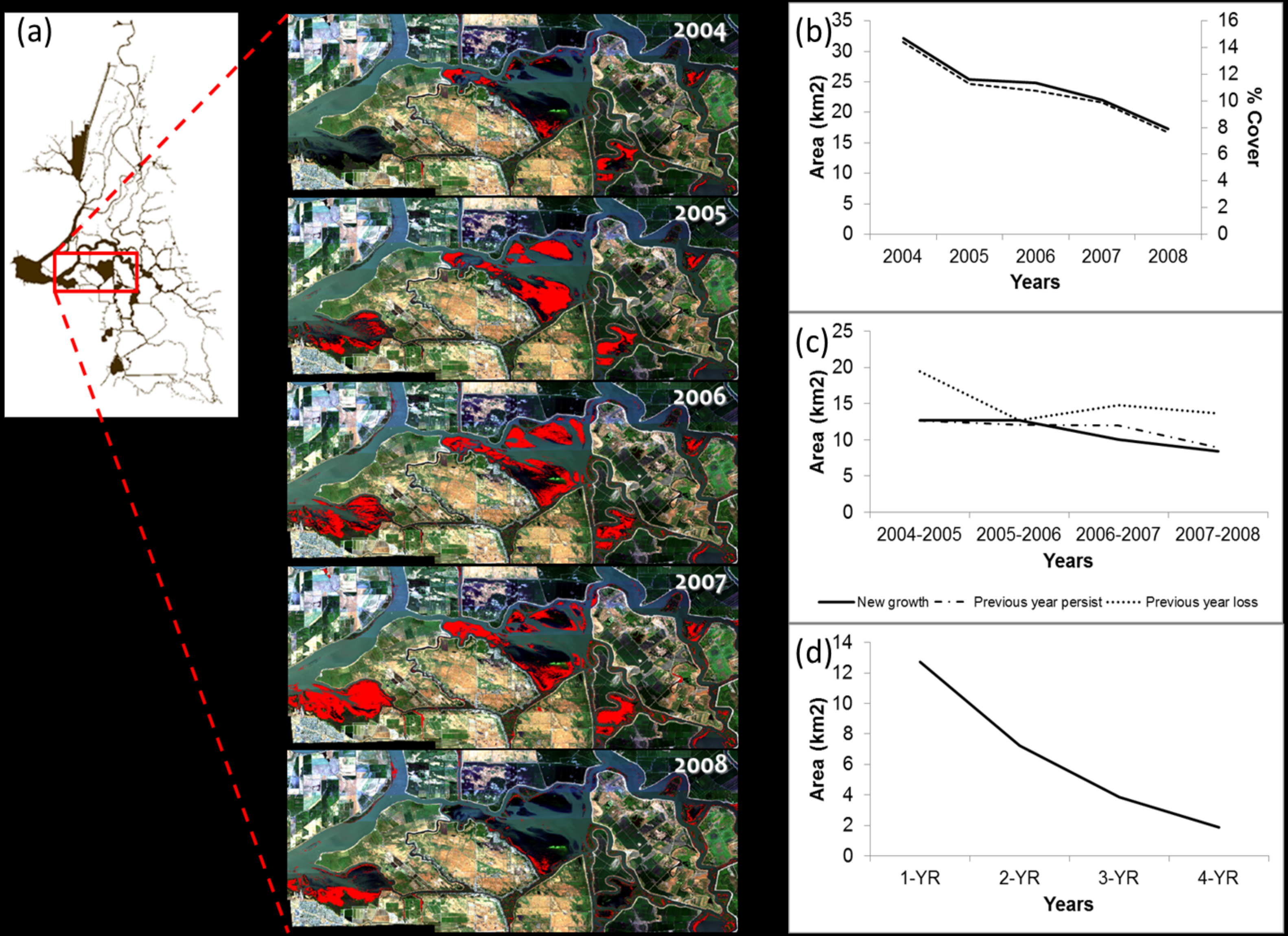
Optical diversity: Native resolution

Predicted species richness: 1 Ha 400m

Wang et al. 2016 Remote Sensing

Invasive Submerged Aquatic Macrophytes in the Sacramento Delta

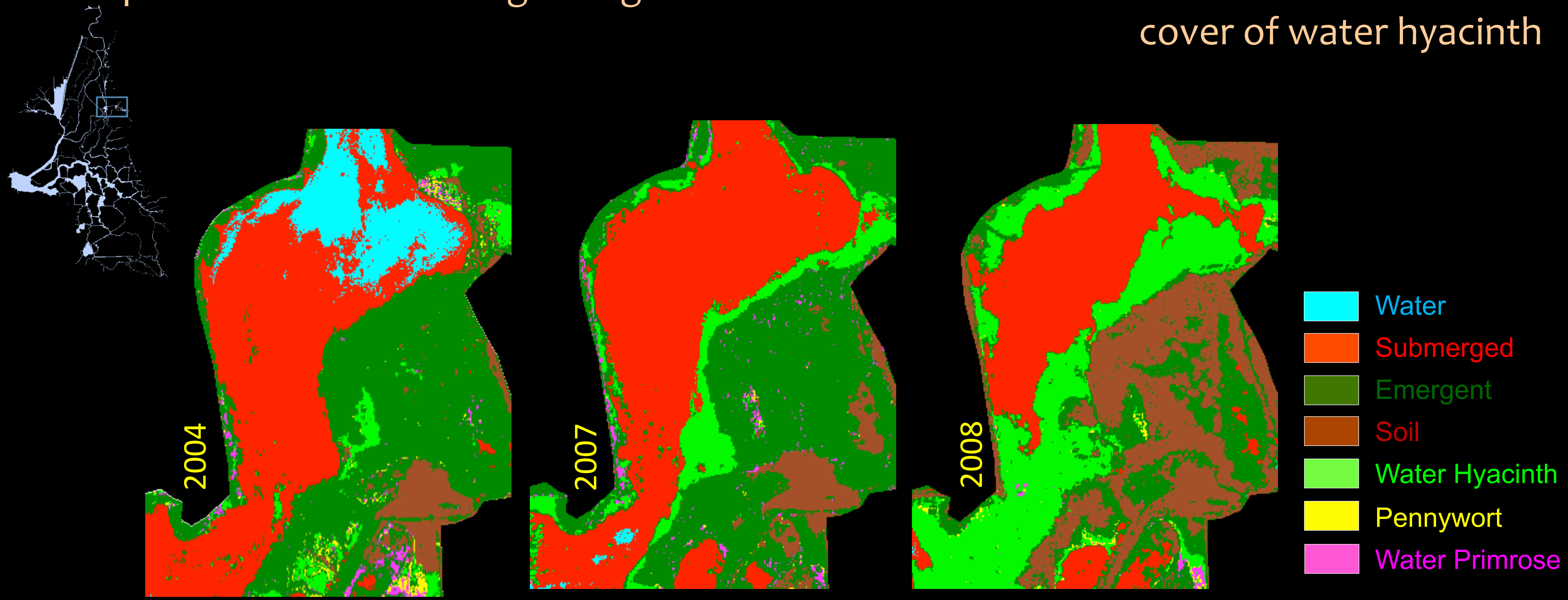
Sacramento-San Joaquin Delta:
2500 km^2 area
>1000 km waterways



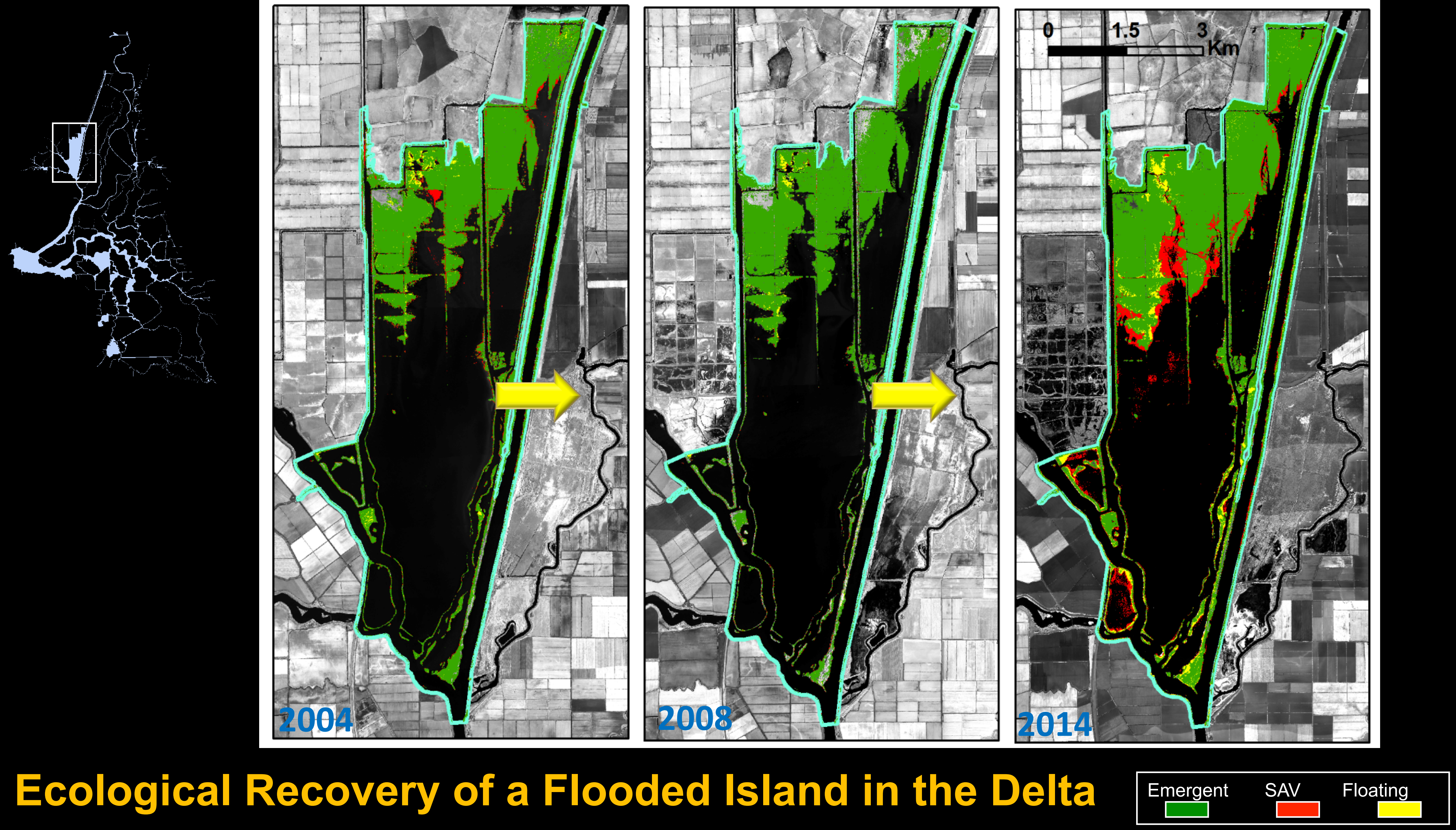
Maria Santos et al. 2016 Ecological applications

Dynamic Changes in Invasive Species Distribution in Stone Lake: 2004 – 2008

Open water and submerged vegetation cover decreased to accommodate increase in cover of water hyacinth

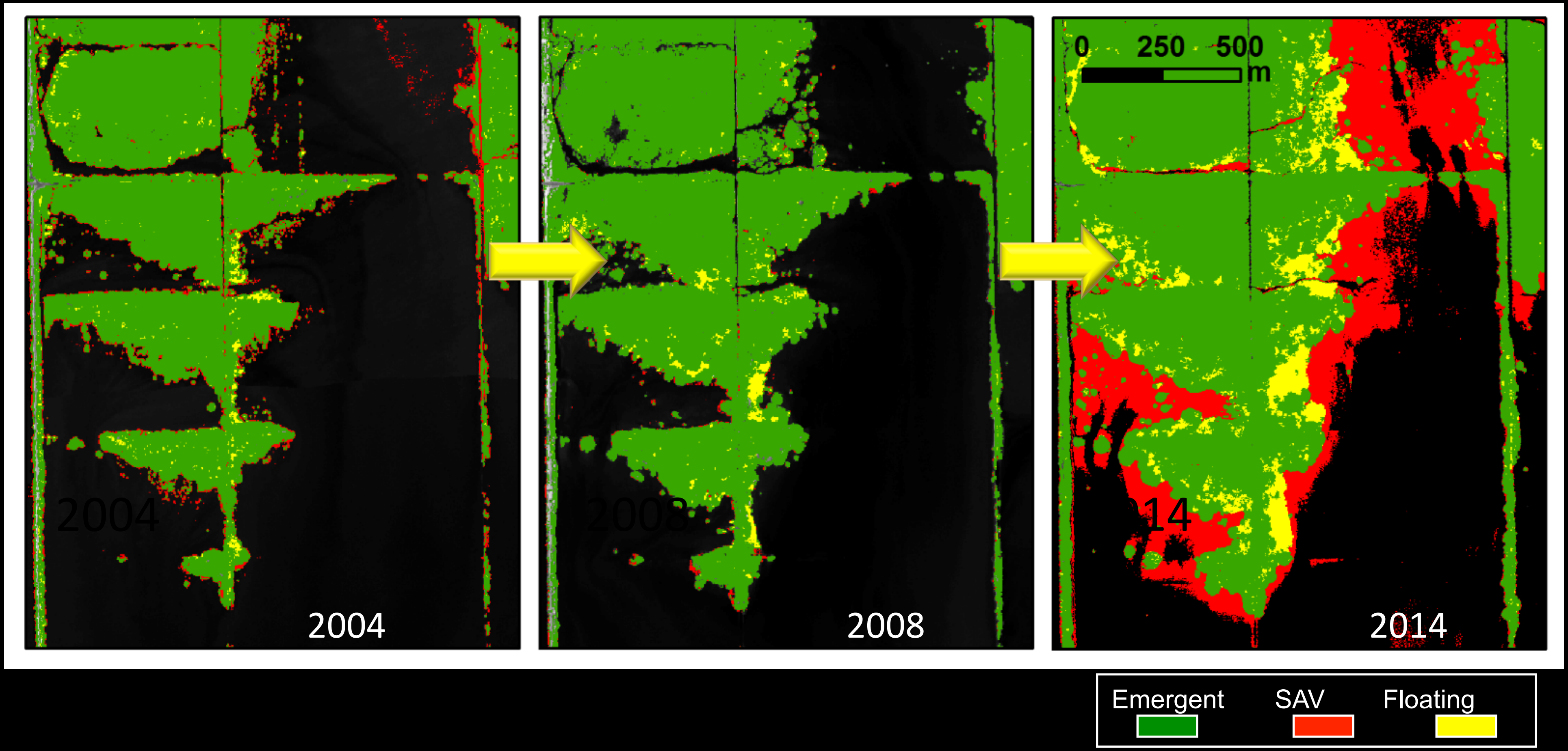


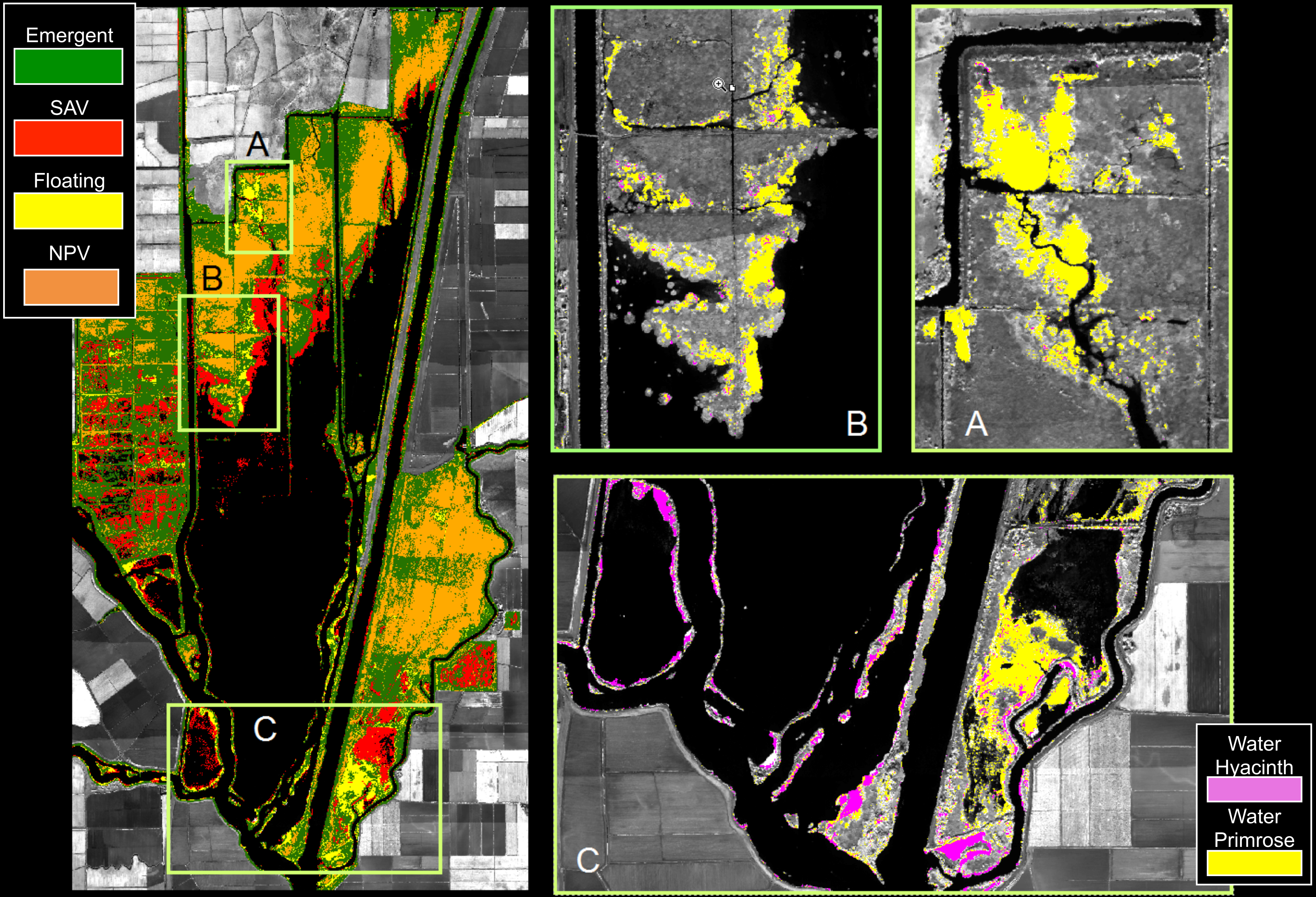
Mapped with HyMAP Imaging Spectrometer



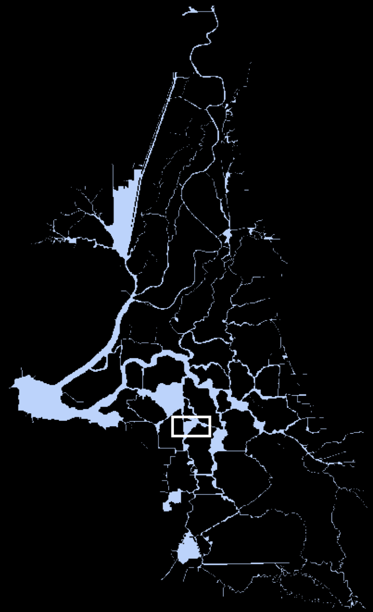
Ecological Recovery of a Flooded Island in the Delta

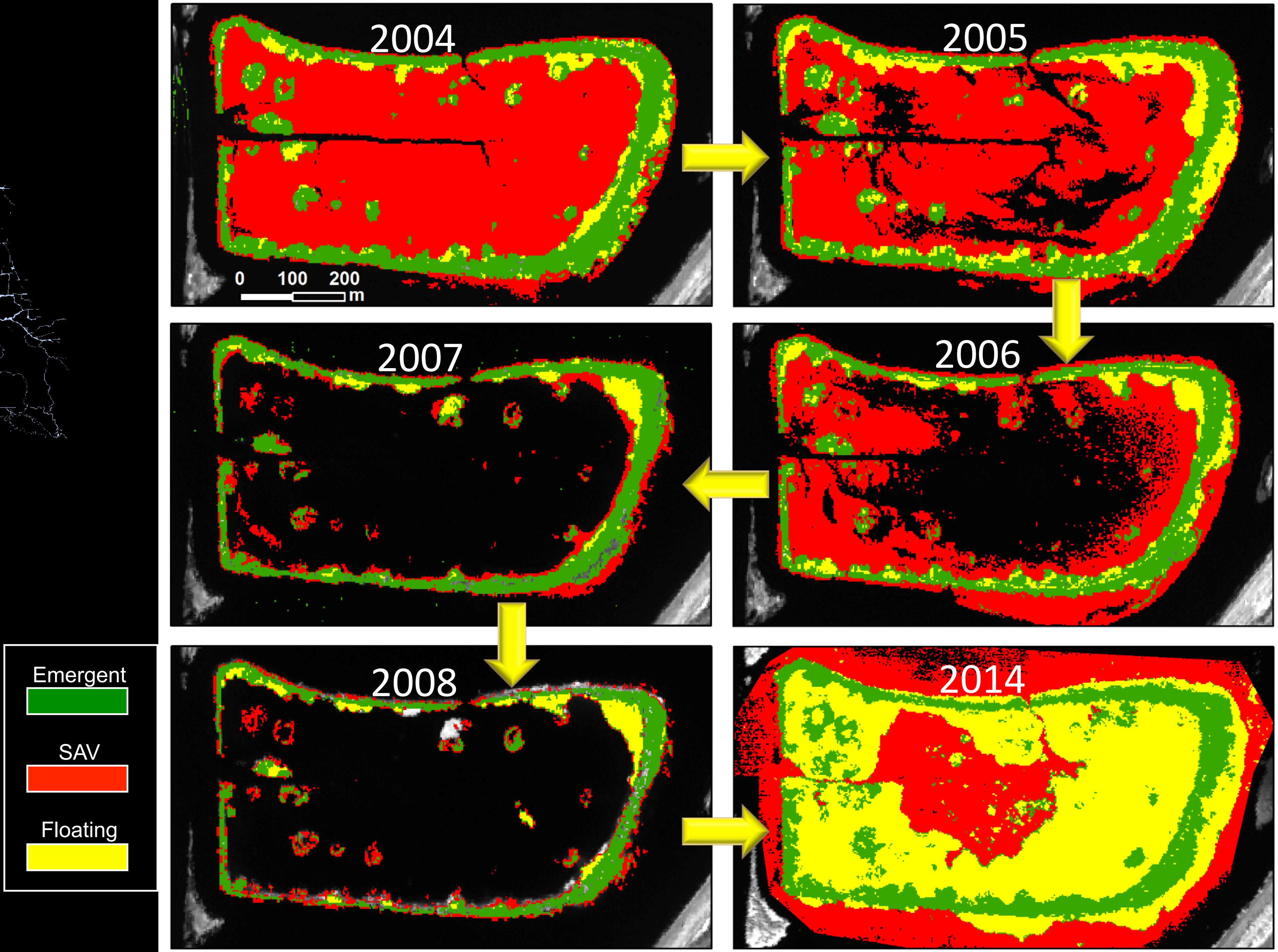
Liberty Island: Flooded Island in the Delta being reclaimed by emergent wetland species





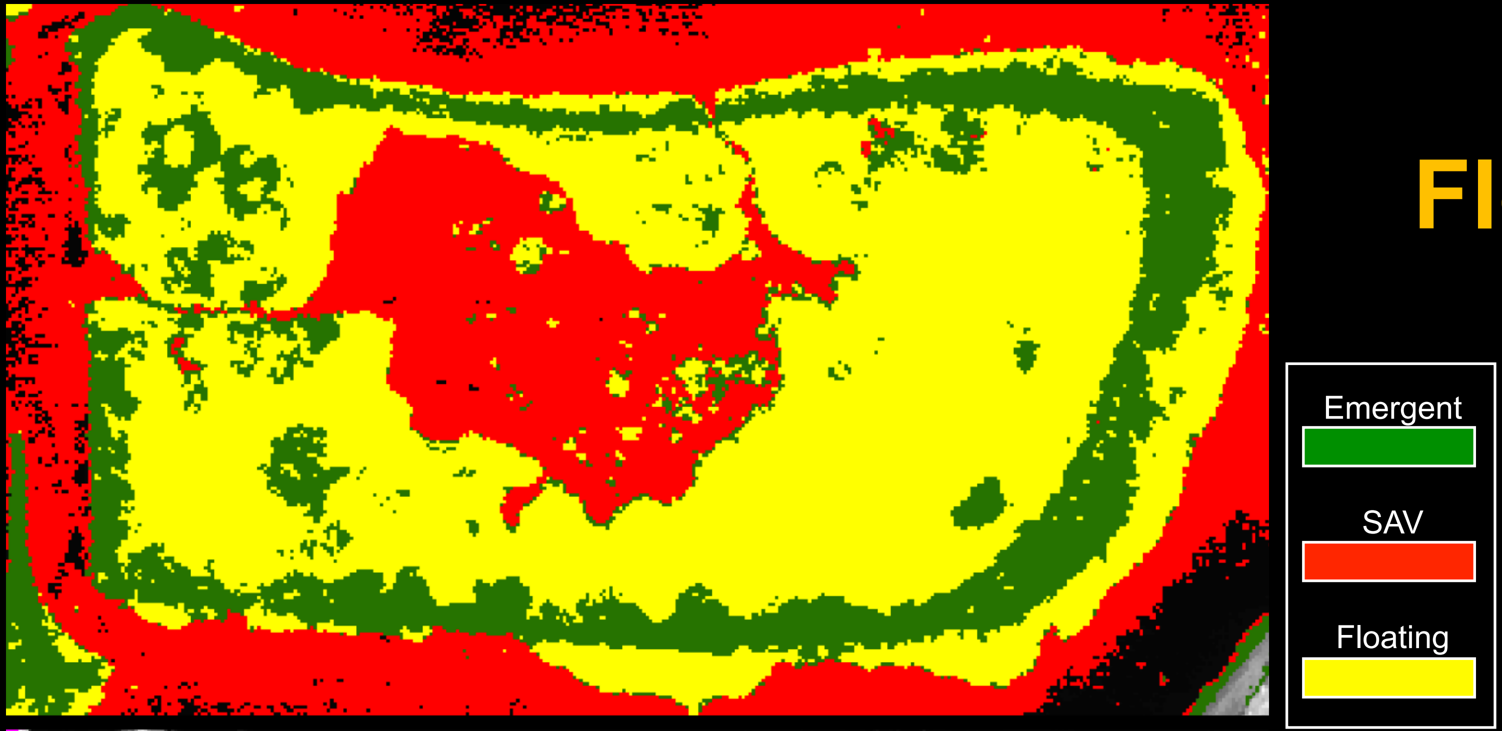
Emergent
SAV
Floating
NPV
A
B
C
B
A
C
Water Hyacinth
Water Primrose

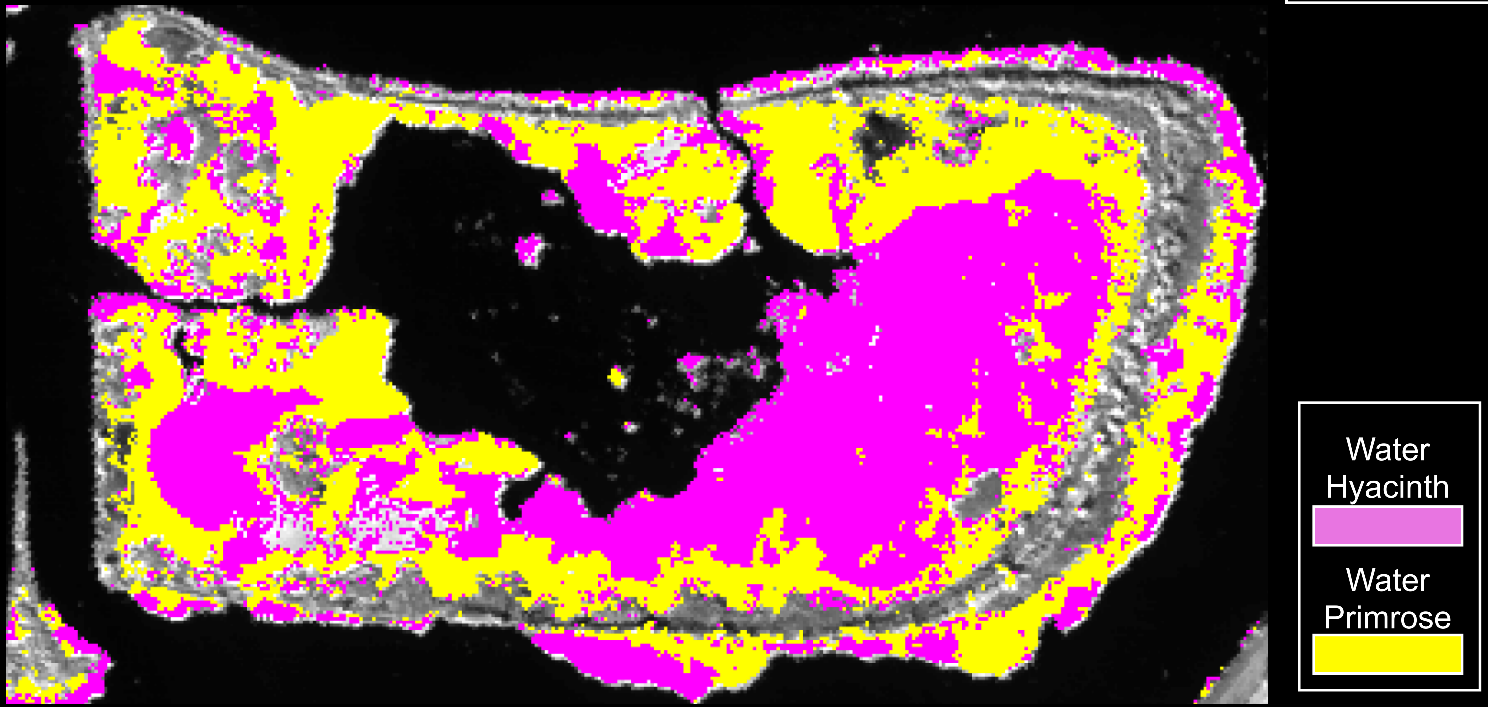




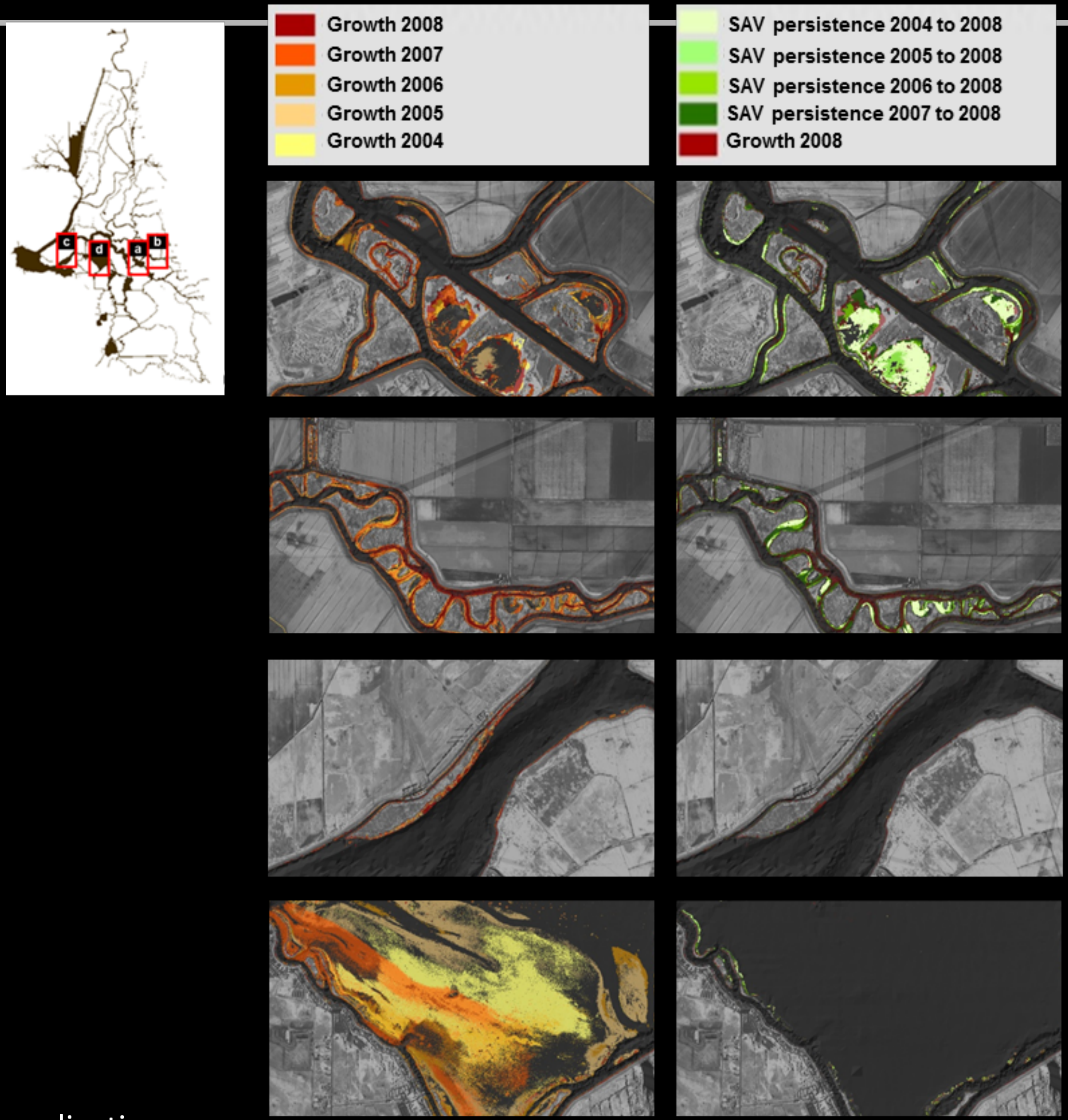
Rhode Island

Rhode Island Floating Species Fall, 2014





Annual Growth and Persistence over 5 years in the Sacramento-San Joaquin Delta



Small flooded Island

Small channels with low flows

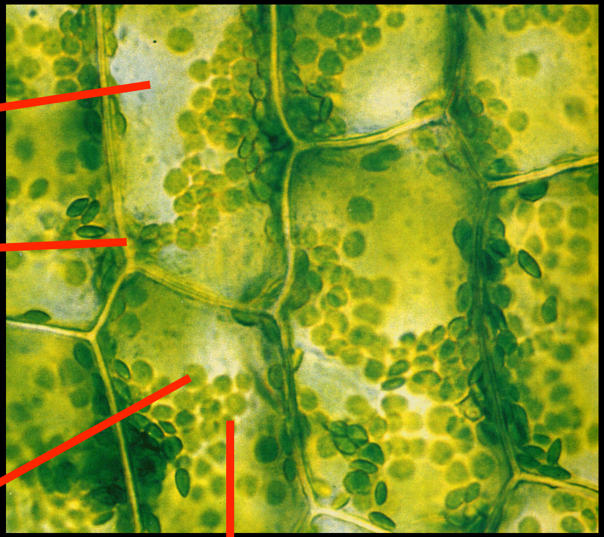
Deep channel with high velocity flows

Flooded Island with high tidal flows

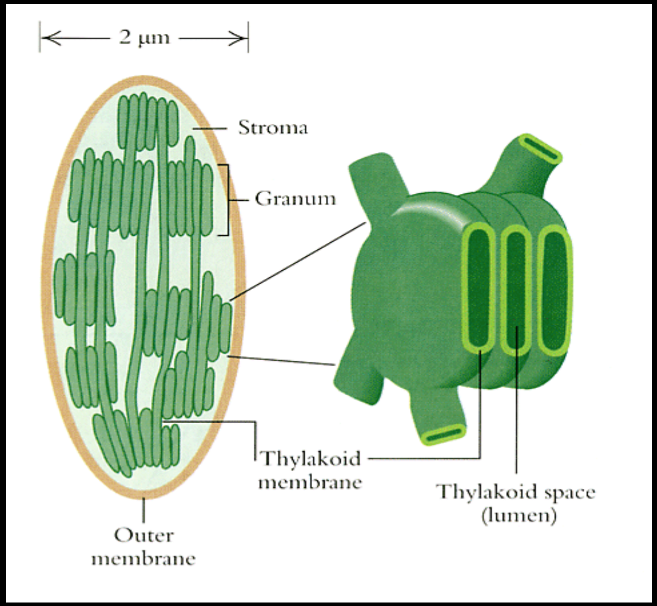
Maria Santos et al. 2016 Ecological applications

Leaf Biochemical Composition

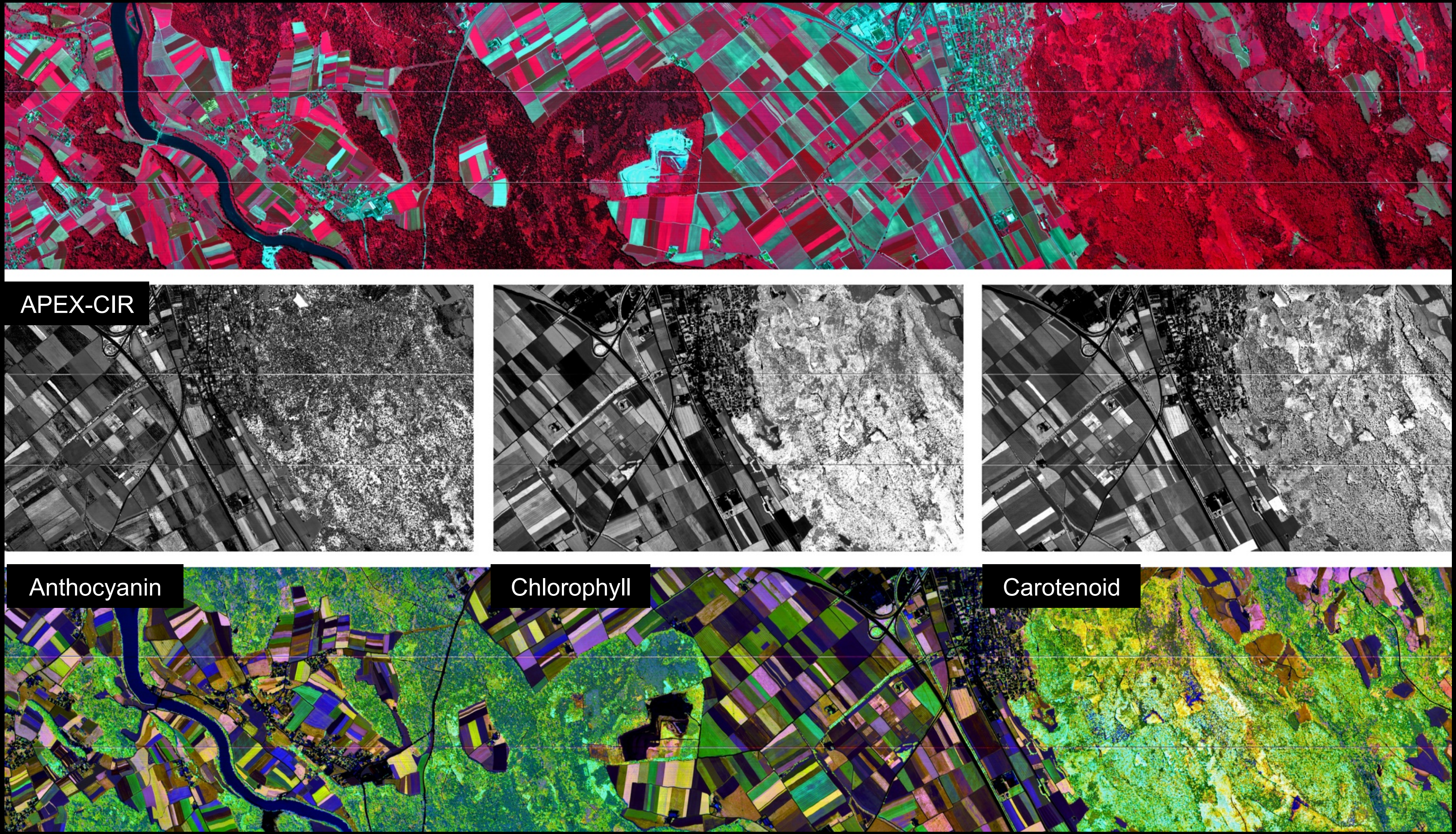
A typical fresh-green leaf contains:



- water (vacuole): 90-95%
- dry matter (cell walls): 5-10%
  - cellulose: 15-30%
  - hemicellulose: 10-30%
  - proteins: 10-20%
  - lignin: 5-15%
  - starch, sugar, etc. : 0.2-2.7%
- wax (cuticle)
- chlorophylls *a* and *b* (chloroplasts)
- carotenoids (chloroplasts)
- accessory pigments (cytoplasm)
  - anthocyanins
  - flavons
  - "brown pigments"
- carbon-based molecules
  - dry matter (cellulose, hemicellulose, lignin)
  - metabolism (sugars, starches, proteins, enzymes)

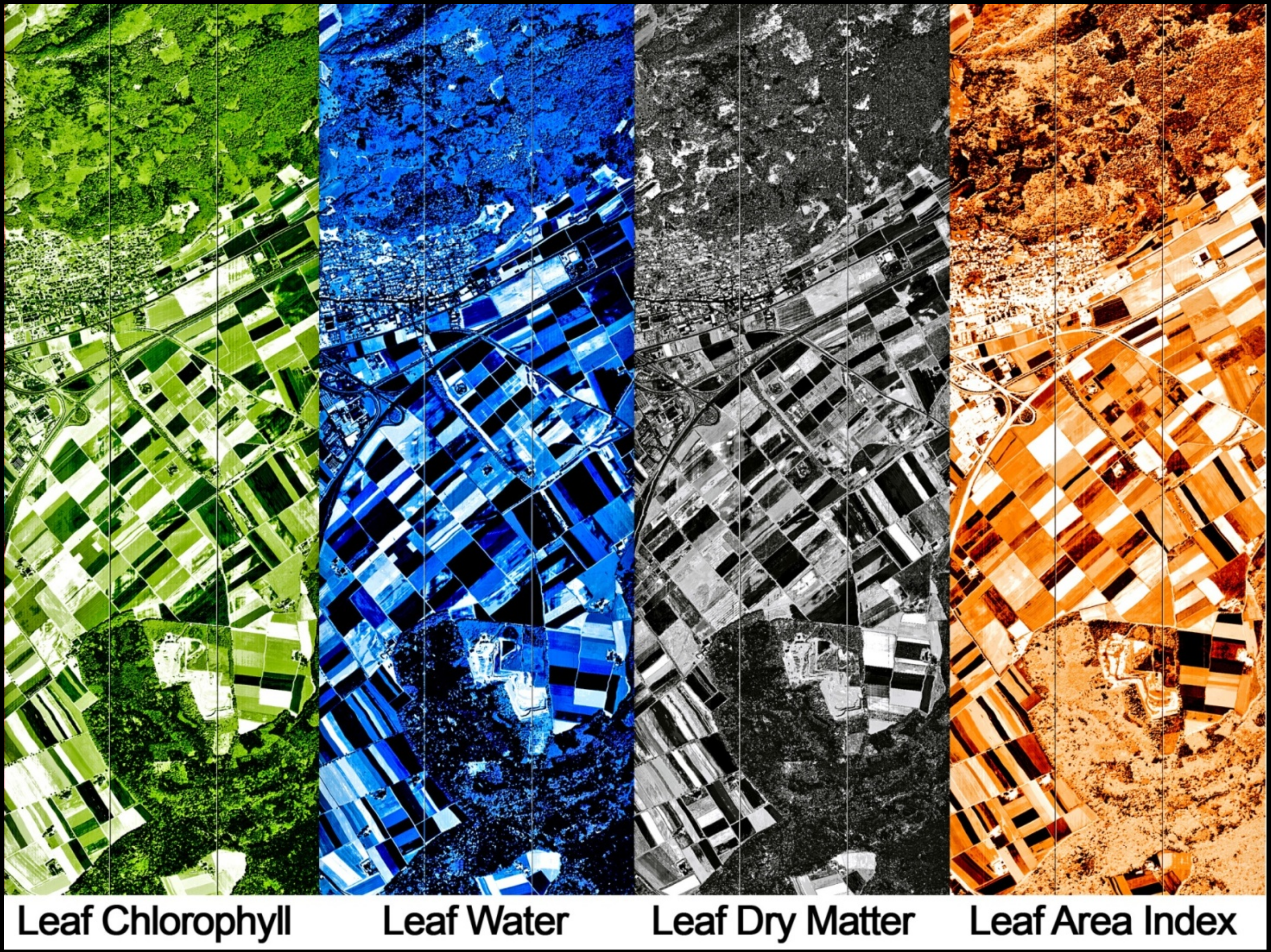


Pigment Retrieval



Pigment composition (Anthocyanin, Chlorophyll, and Carotenoid)

Conventional Inversion Scheme (PLS Optimization)



Chlorophyll

10 - 80 [μg cm^{-2}]

Water

0.01 - 0.03 [g cm^{-2}]

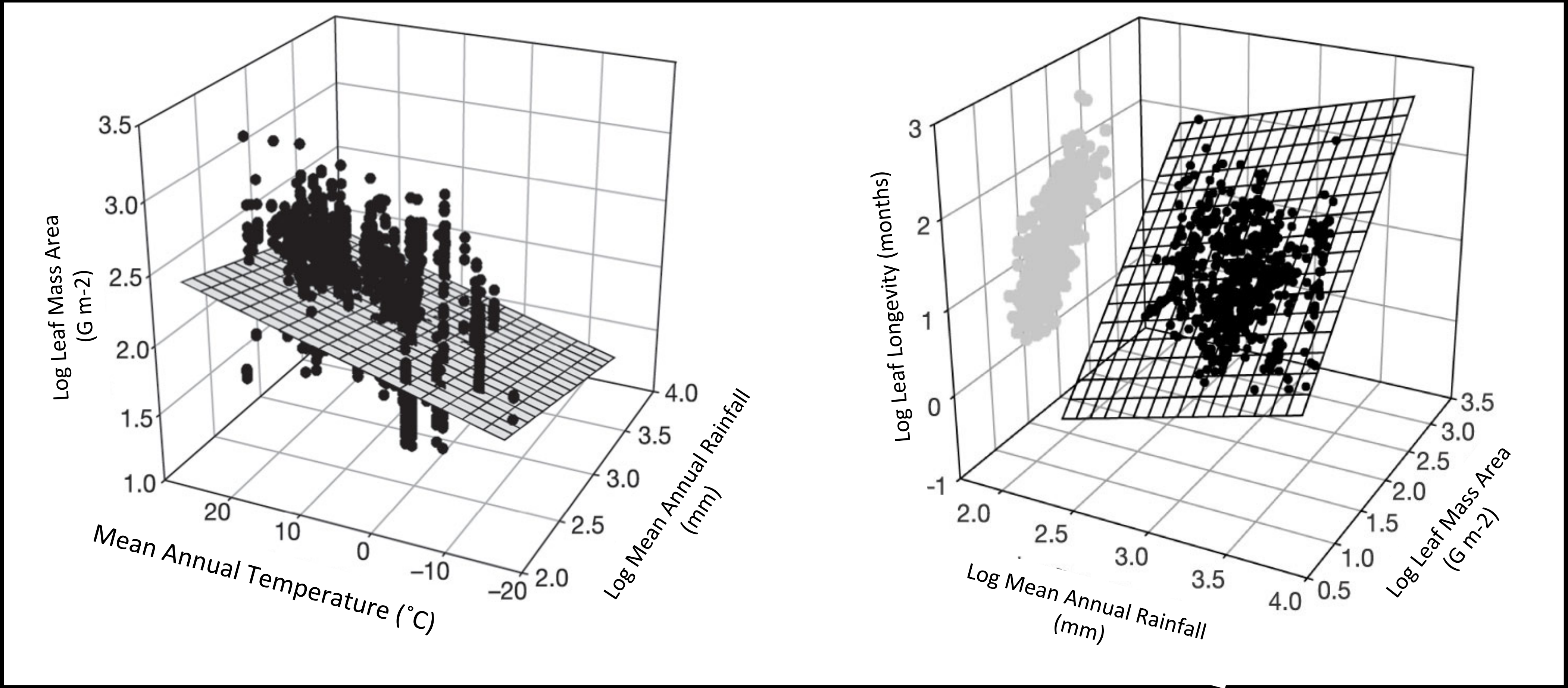
Dry Mater

0.001 - 0.01 [g cm^{-2}]

Leaf Area Index

0 – 7 [m^2 m^{-2}]

A Global Universal Spectrum of Leaf Economics: Key Co-Varying Structural and Physiological Properties

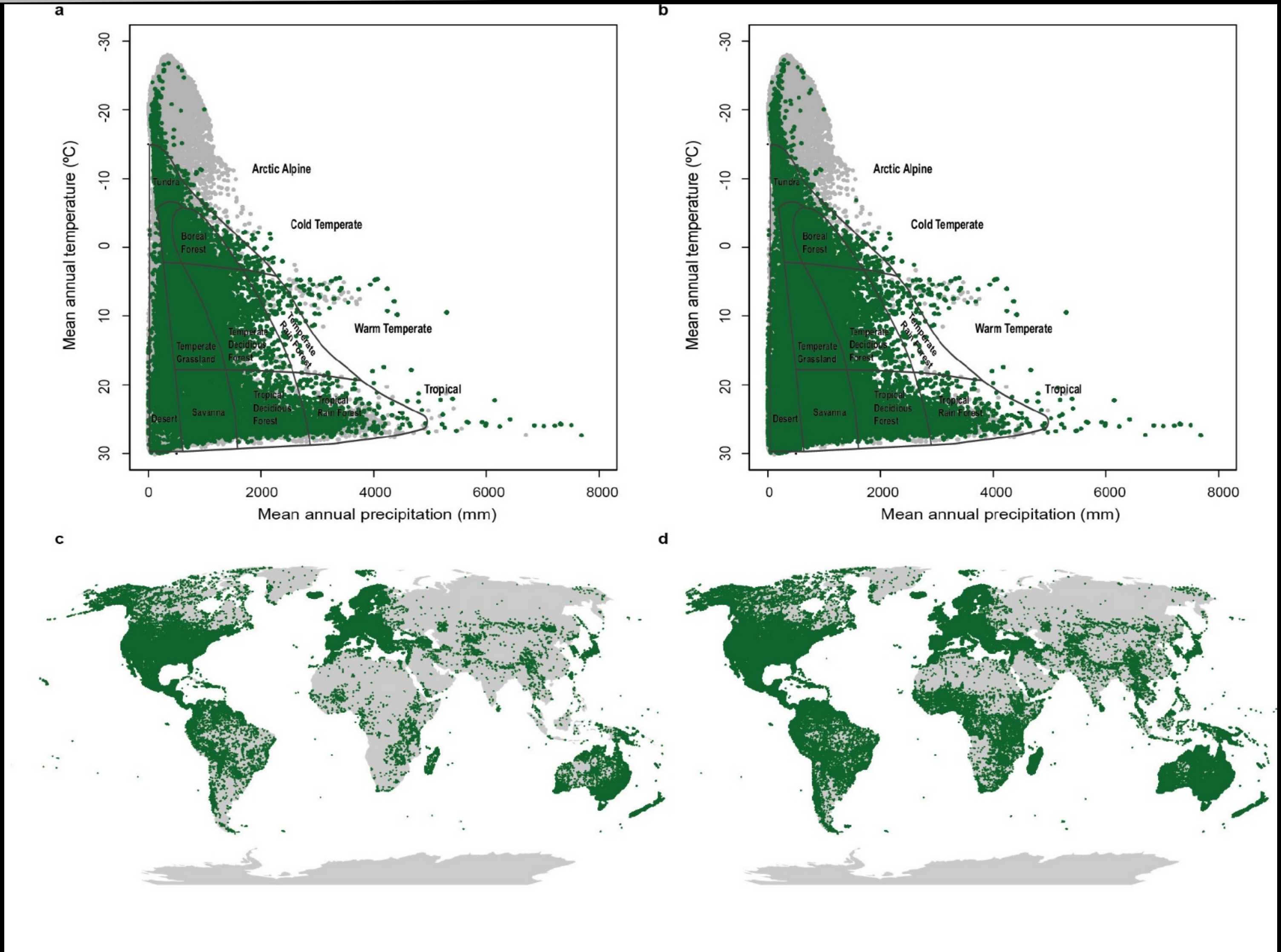


Traits vary from fast to slow return on investments in nutrients and dry mass in leaves, and operates largely independently of growth form, plant functional type or biome

I.J. Wright et al. 2004. Leaf Economics Spectrum. Nature

TRY Database of Plant Traits:

46,085 vascular plant species from 423 families; more than 100 trait fields in database

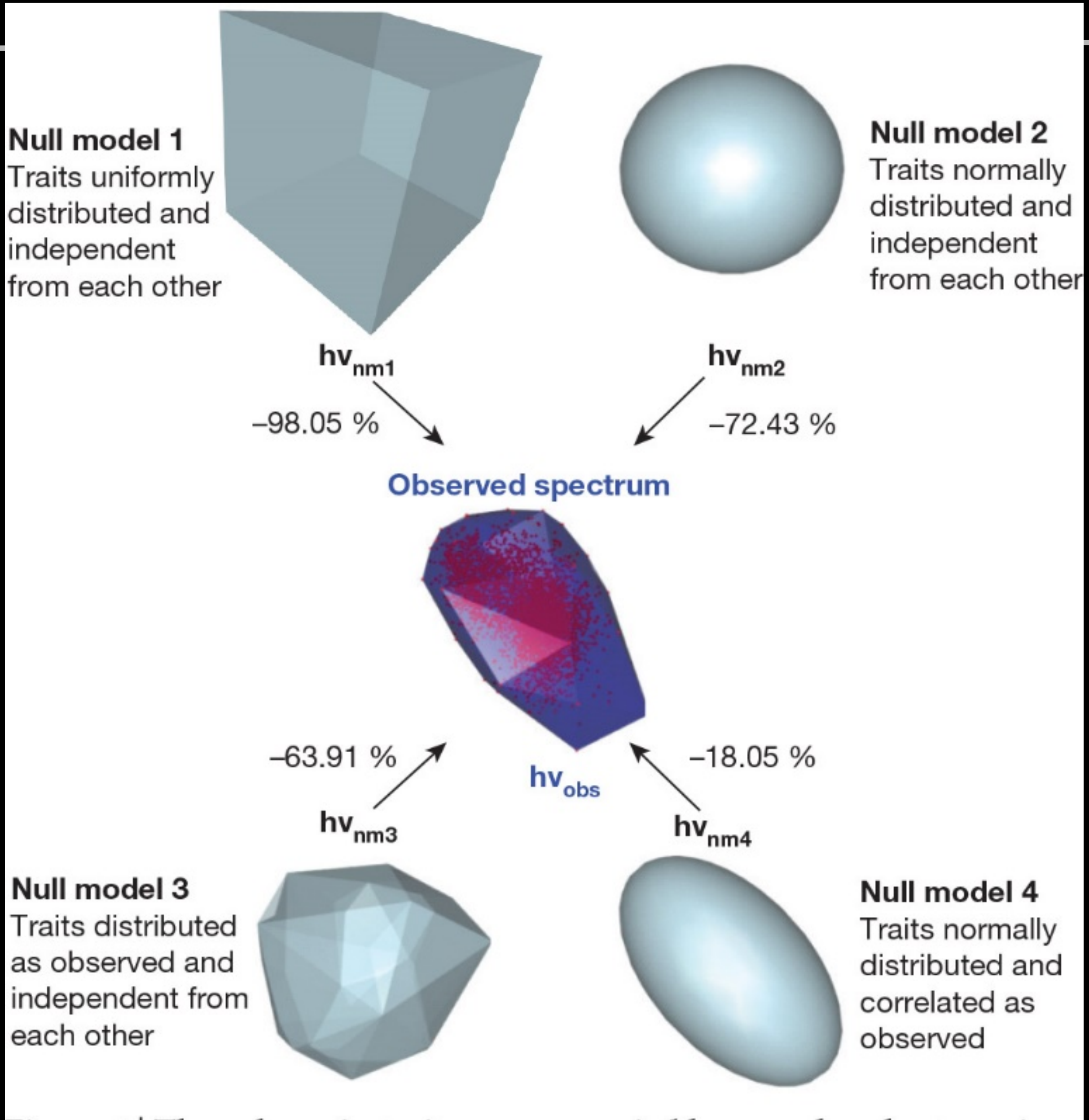


TRY Managed by Jan Kattge, Max Planck Institute for Biogeochemistry, Jena, Germany

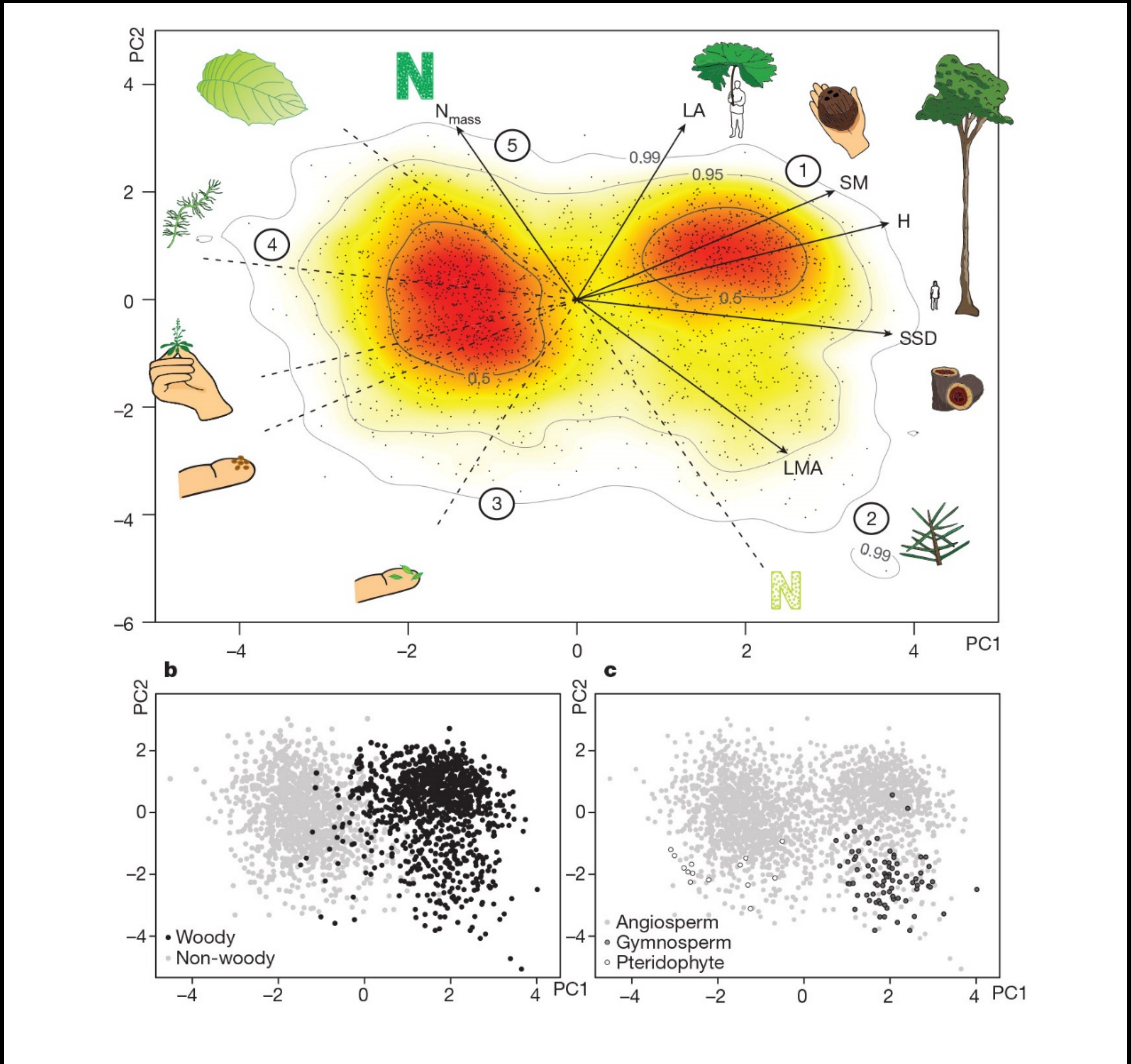
Diaz S, Kattge J, Cornelissen JHC, Wright IJ et al. 2016. The global spectrum of plant form and function. Nature doi: 10.1038/nature16489

Distribution of data in TRY database compared to 4 null models

Traits Examined:
Adult plant height
Stem specific density
Leaf area
Leaf mass/area
Leaf nitrogen content/mass
Diaspore mass



Diaz S, Kattge J, Cornelissen JHC, Wright IJ et al. 2016. The global spectrum of plant form and function. Nature doi: 10.1038/nature16489

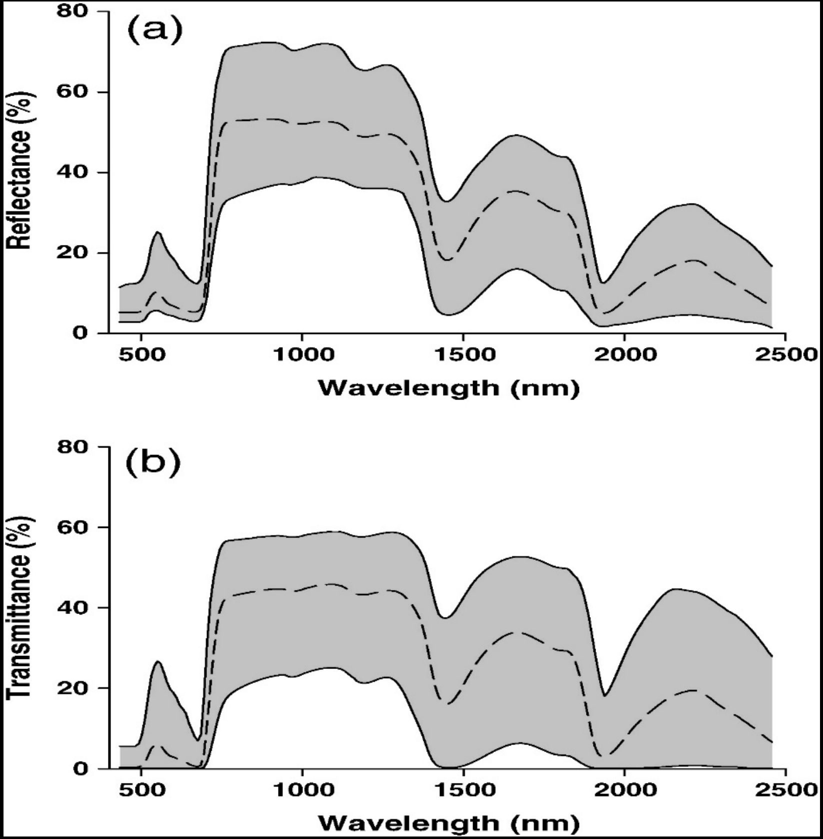


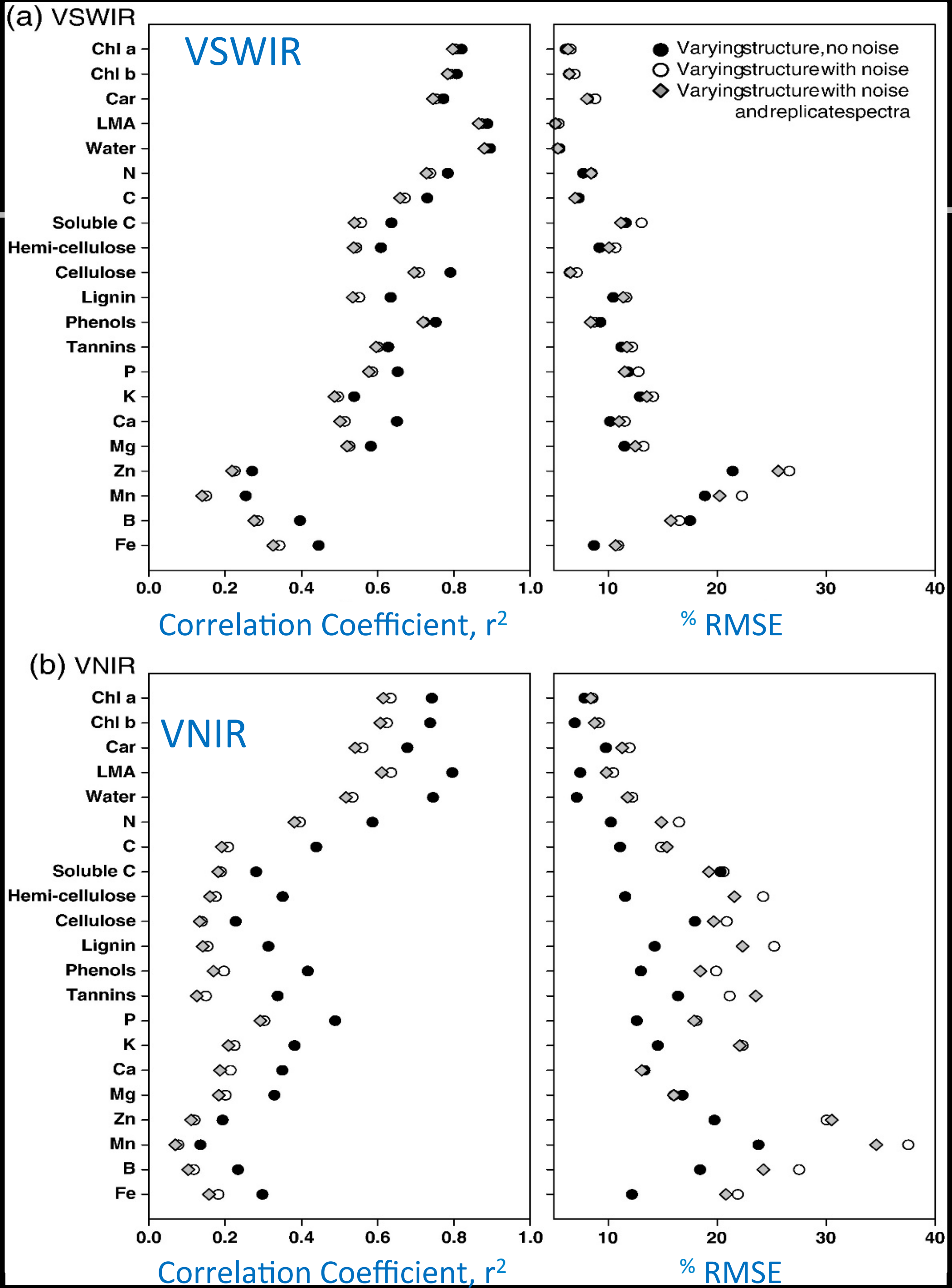
Strongest relationships are traits along woody to herbaceous axis

Diaz S, Kattge J, Cornelissen JHC, Wright IJ et al. 2016. The global spectrum of plant form and function. Nature doi: 10.1038/nature16489

Detailed Chemistry Retrieval from Canopy Reflectance

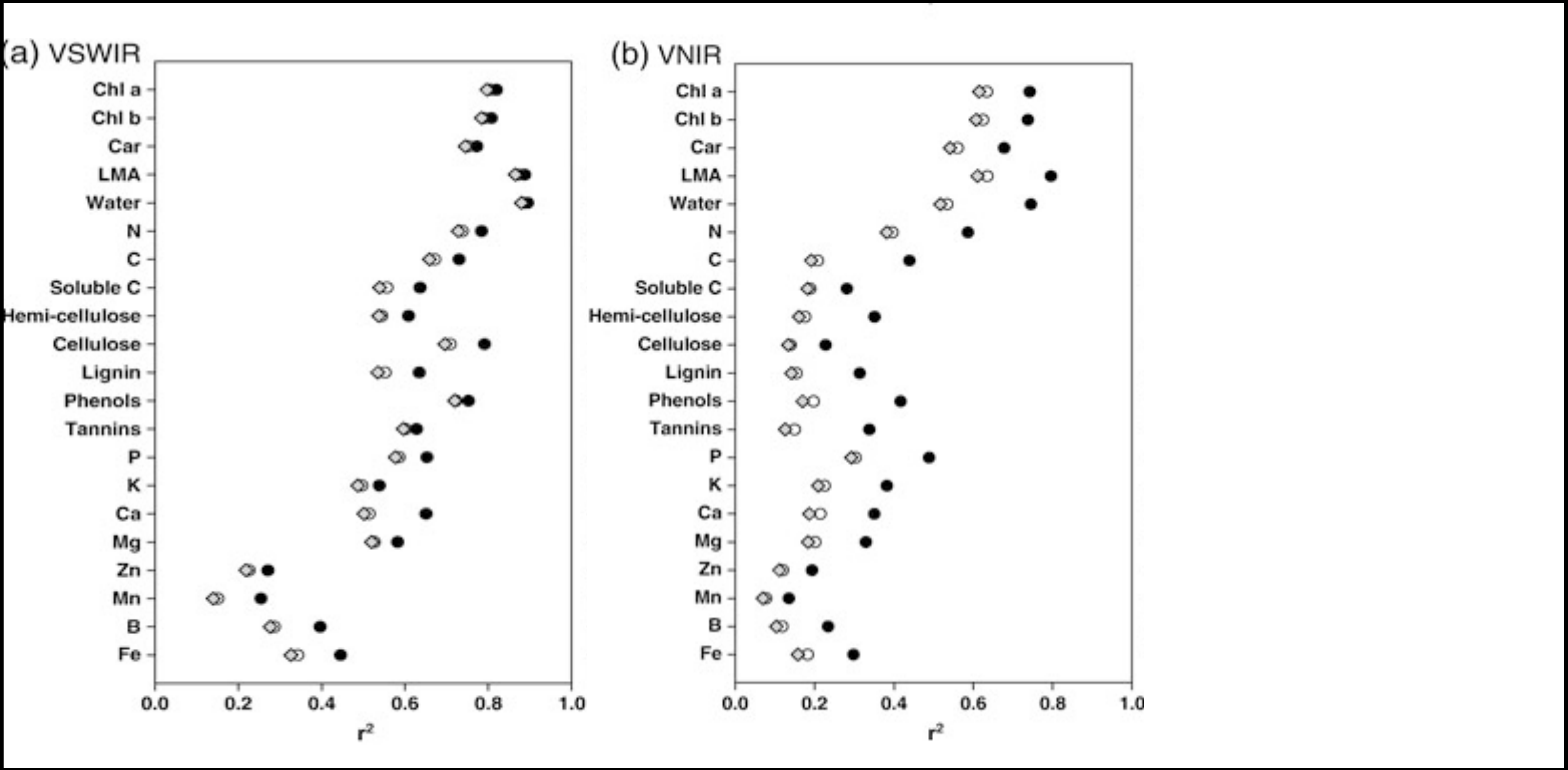
6136 Humid Tropical Forest Canopies





G.P. Asner et al. 2011 RSE

Detailed Chemistry Retrieval from Canopy Reflectance

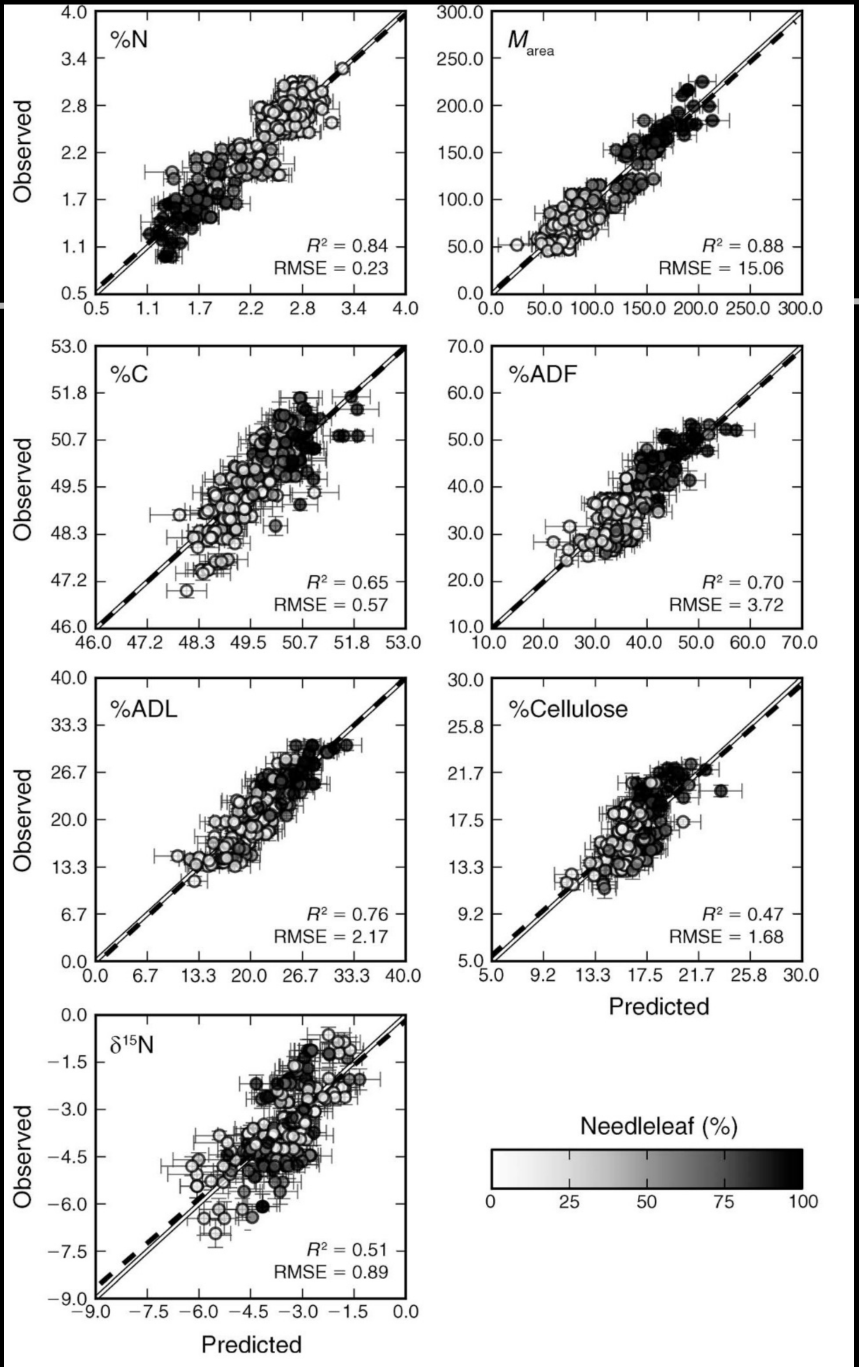


Asner et al. 2011 RSE

Quantifying Biochemical Traits from AVIRIS image

Maps of % nitrogen, % carbon, $\delta^{15}N$, leaf mass per area (M_{area}), fiber, lignin, and cellulose

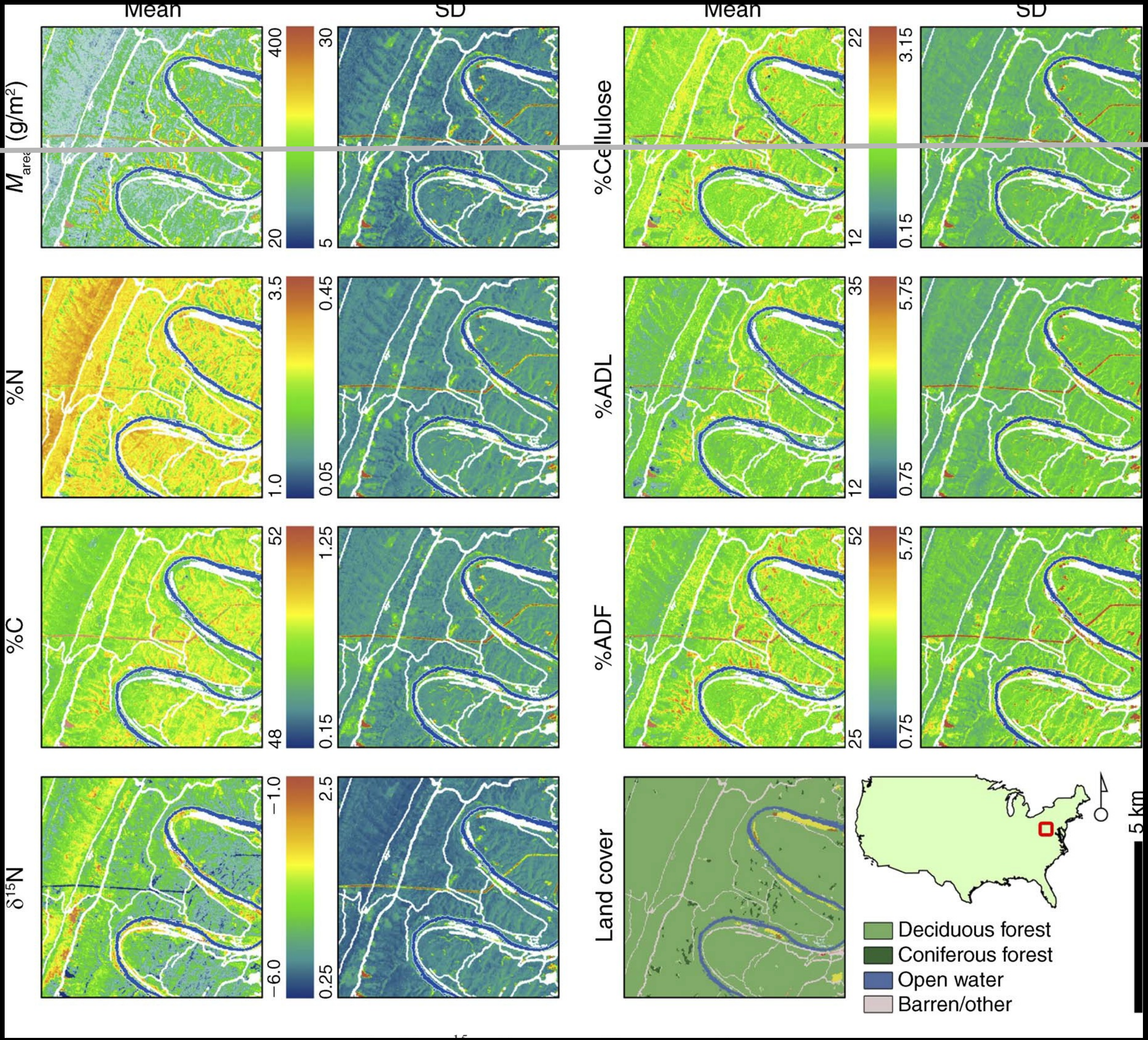
- PLSR Model developed for each 6 traits from data of 137 plots randomly resampled 500 x
- Provided range of predicted values plus uncertainties
- Developed PLSR model on 51 AVIRIS images, applied it to 145 images



A. Singh, S.P. Serbin, B.E. McNeil, C.C. Kingdon, and P.A. Townsend. 2015. Imaging spectroscopy algorithms for mapping canopy foliar chemical and morphological traits and their uncertainties. *Ecological Applications* 25:2180–2197. http://dx.doi.org/10.1890/142098.1 Fig. 6

Quantifying Biochemical Traits from AVIRIS images

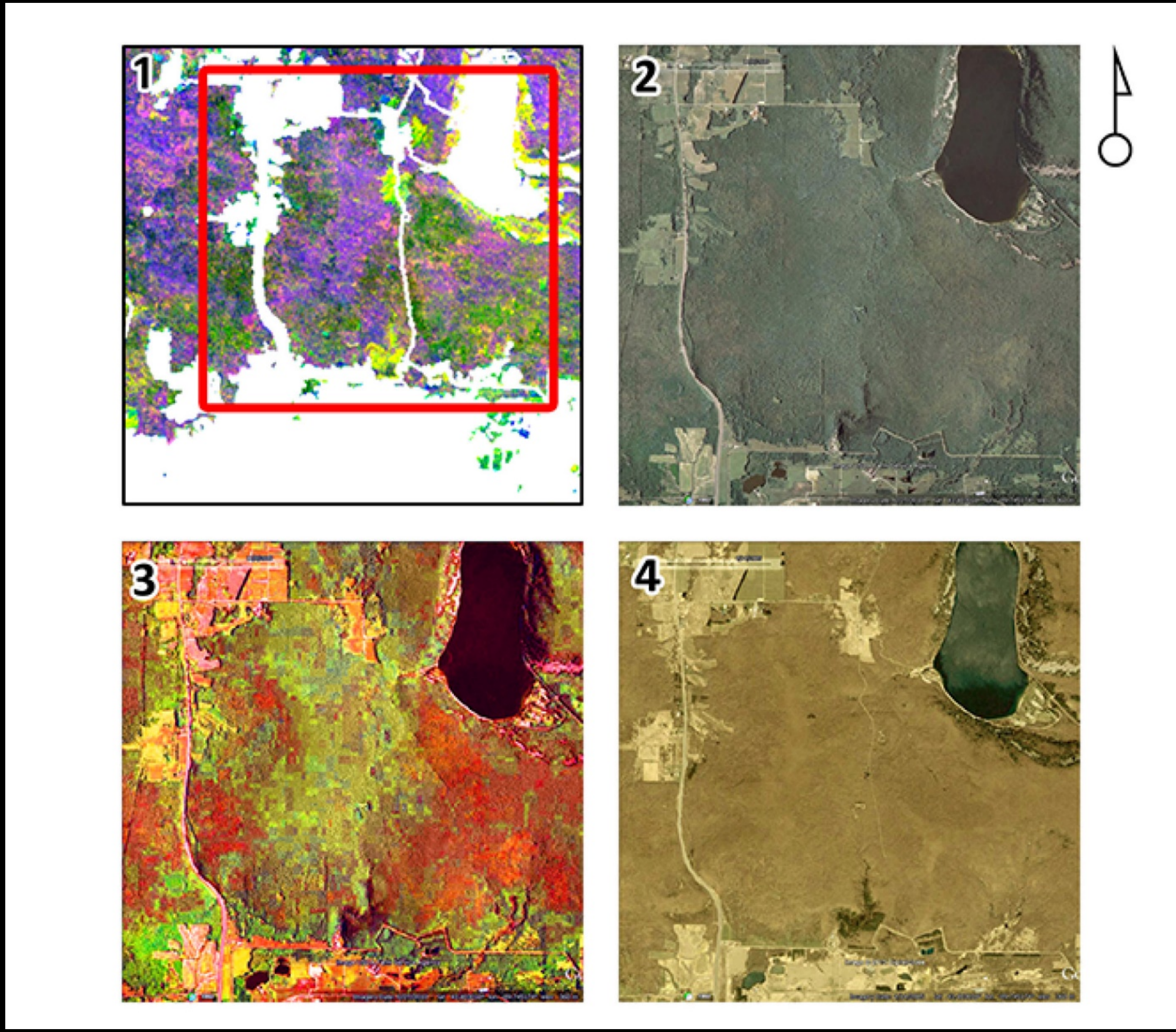
Green Ridge State Forest, Maryland

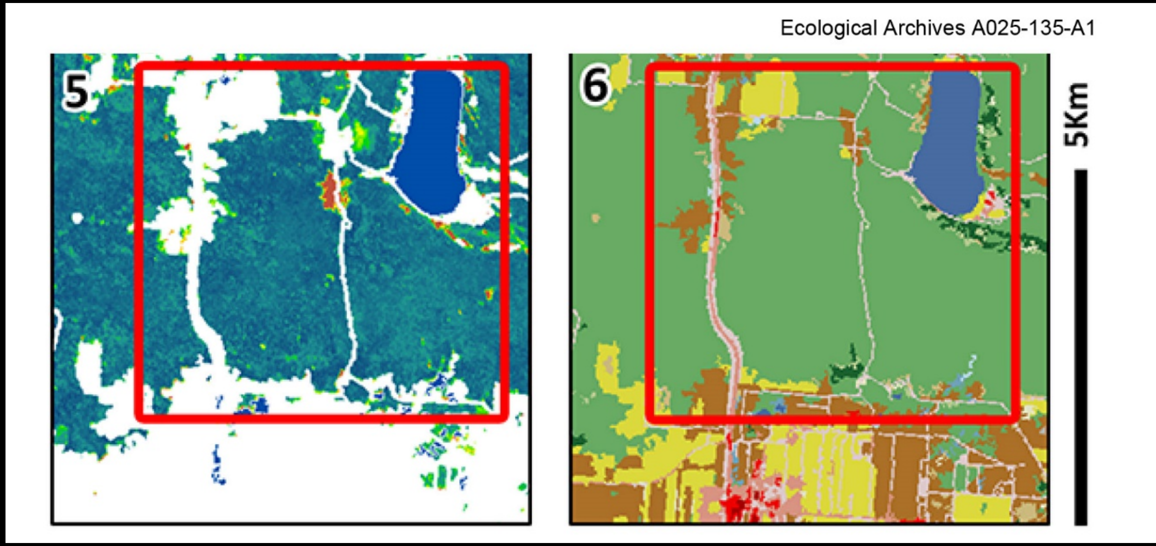


Maps of % nitrogen, % carbon, $\delta^{15}N$, leaf mass per area (M_{area}), fiber, lignin, and cellulose

Foliar trait association maps provide richer information on foliar traits across forest ecotones than discrete classes.

A. Singh, S.P. Serbin, B.E. McNeil, C.C. Kingdon, and P.A. Townsend. 2015. Imaging spectroscopy algorithms for mapping canopy foliar chemical and morphological traits and their uncertainties. *Ecological Applications* 25:2180–2197. http://dx.doi.org/10.1890/142098.1 Fig. 6





Subplot 1: false color composite R/G/B = %ADL/ M_{area}/ %Nitrogen provides richer detail than NLCD 2006 landcover classifications (Subplot 2), from fall aerial imagery.

Color enhancement of fall aerial imagery (subplot 3) shows phenological differences (subplot 4) between dominant deciduous species (*Quercus rubrum, Acer saccharum*) corresponding to spatial patterns of foliar traits.

Subplot 5 indicates high confidence in mapping traits (%N, S.D. shown) across deciduous forest landcover. High prediction uncertainties are only observed in edges or nonforest areas.

A. Singh, S.P. Serbin, B.E. McNeil, C.C. Kingdon, and P.A. Townsend. 2015. Imaging spectroscopy algorithms for mapping canopy foliar chemical and morphological traits and their uncertainties. *Ecological Applications* 25:2180–2197. http://dx.doi.org/10.1890/142098.1

Spectral Dimensionality of AVIRIS Scenes

510 AVIRIS Scenes Analyzed (1999 AVIRIS Archive)
1.14B spectra (478GB)

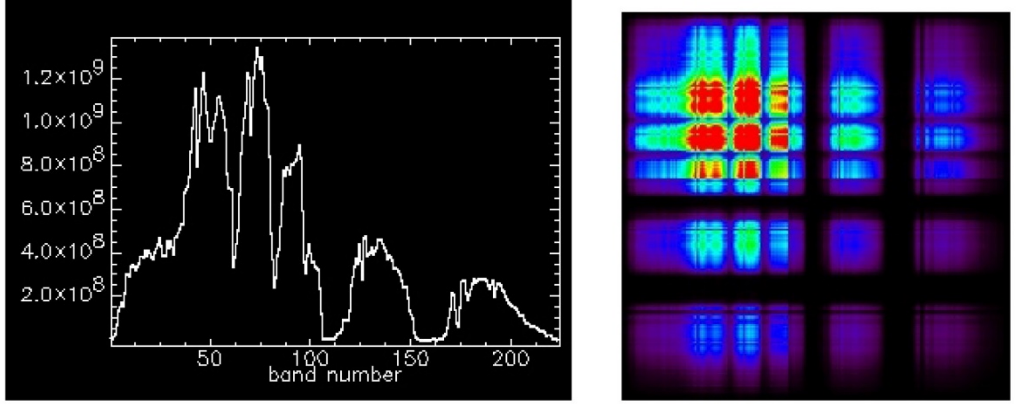


Figure 1. Example single-scene sums vector (left) and sums-of-squares matrix (right). Sums-of-squares matrix is color coded from high to low as red to black. Band 1 is in the upper left corner; band 224 is in the lower right.

Typical single scene vector and sum of squares matrix

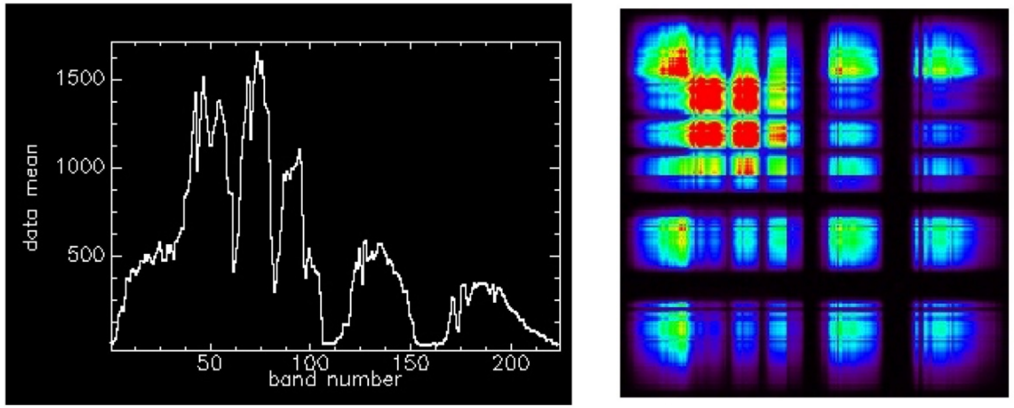


Figure 2. Example single-scene mean vector (left) and covariance matrix (right). Covariance matrix is color coded from high to low as red to black. Band 1 is in the upper left corner; band 224 is in the lower right.

Mean vector of scene and covariance matrix

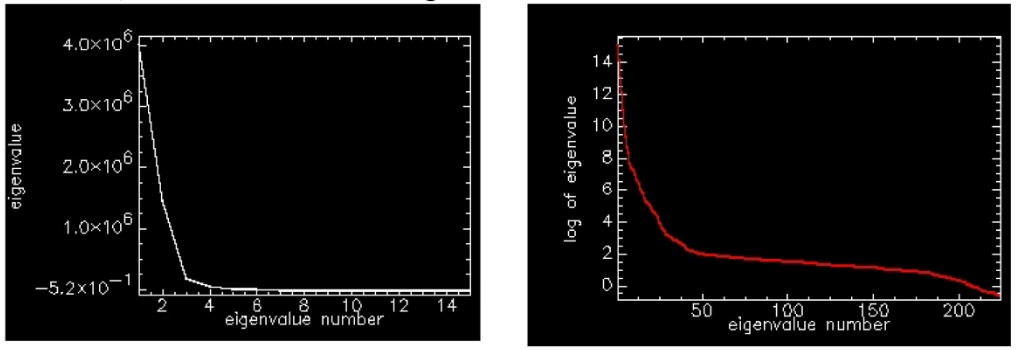


Figure 3. Example single-scene eigenvector plot, linear scale (left), log scale (right).

Single-scene eigenvector plot, linear scale (left), log scale (right).

Boardman J. and R.O. Green 2016. Exploring the Spectral Variability of the Earth as Measured by AVIRIS in 1999. Book chapter.

Scene Statistics from 510 AVIRIS Scenes from 1999

Scene eigenvector image, showing 224 eigenvectors, the first 40-50 contain signal

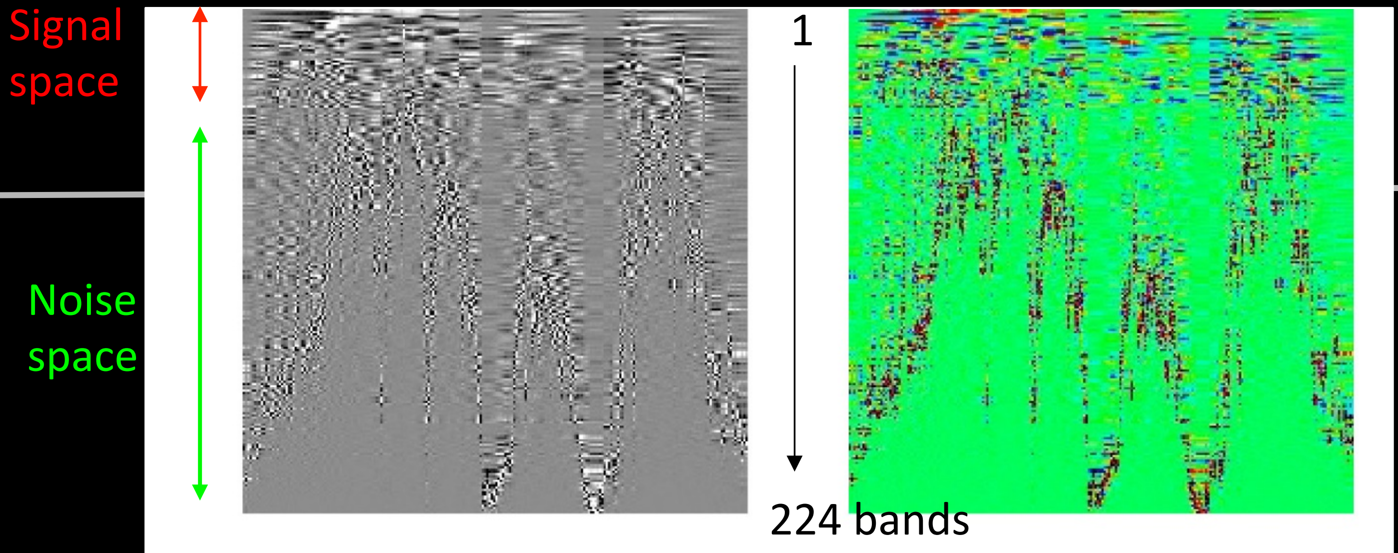
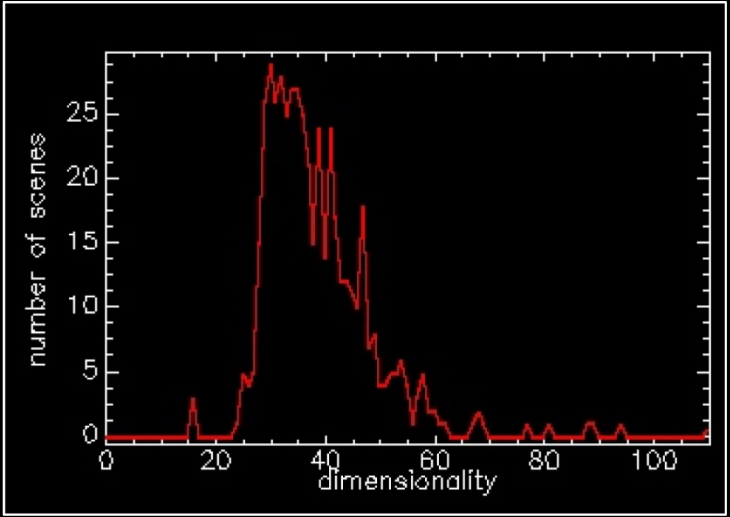
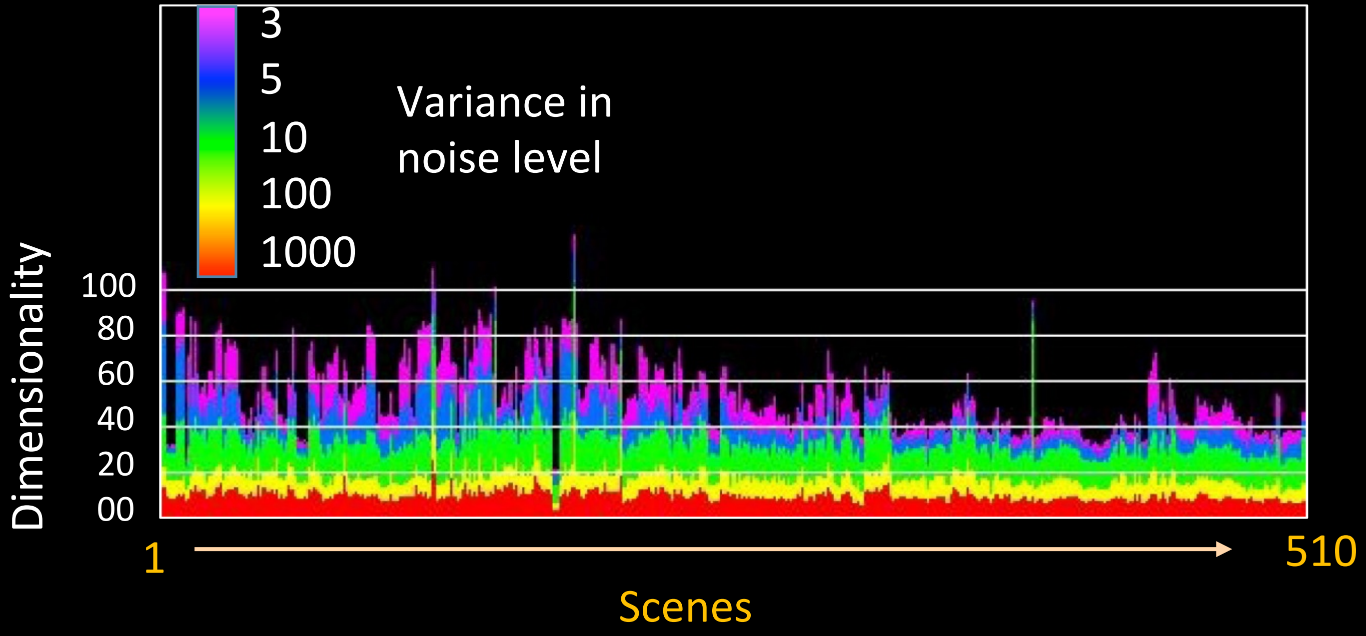


Figure 4. Gray scale (left) and pseudocolor (right) depictions of the eigenvectors for a single-scene example. Eigenvectors are rows in these images and are ordered top to bottom.



Distribution of Scenes with different Dimensionality



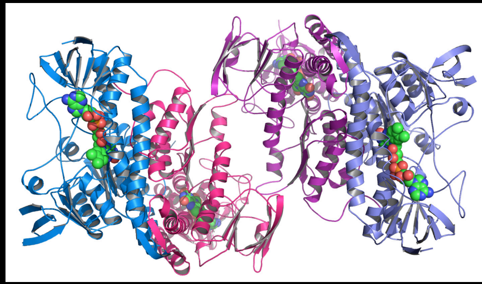
Boardman J. and R.O. Green 2016. Exploring the Spectral Variability of the Earth as Measured by AVIRIS

University of Zurich[UZH]

URPP Global Change and Biodiversity

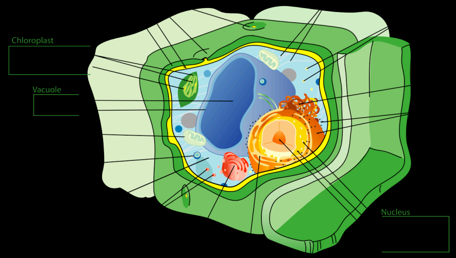
Mapping Diversity from Genomics, Phenomics and Spectranomics

Genomics → Increasing ecological value Ecological Genomics



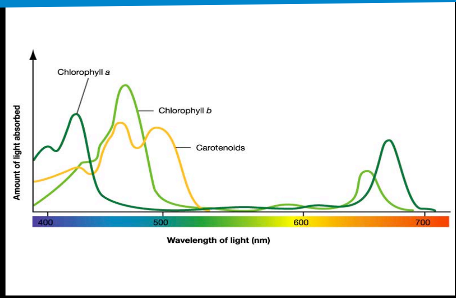
Increasing dimensionality due to increasing complexity of environmental conditions

Phenomics → Increasing organizational levels Imaging Phenomics

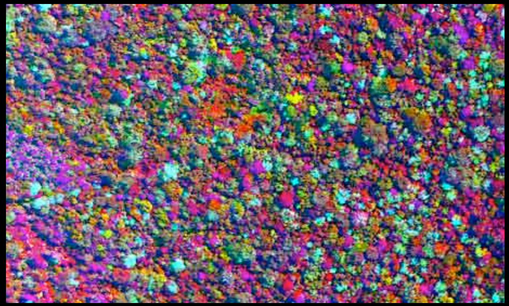


Increasing dimensionality due to organizational levels observed (eg phenotypic traits from cell to canopy level)

Spectranomics ← Increasing mechanistic value Imaging spectranomics

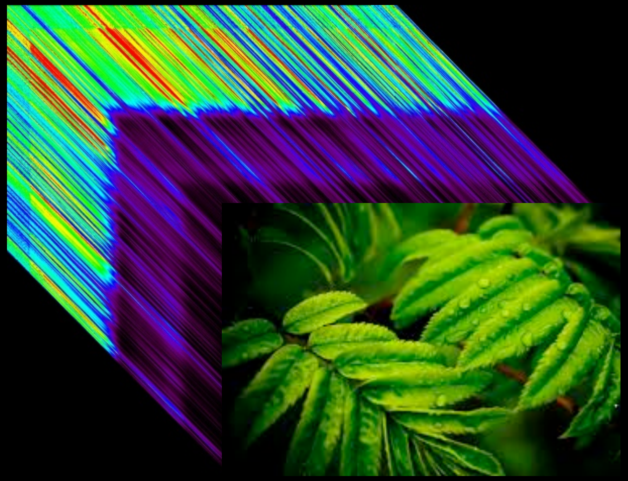


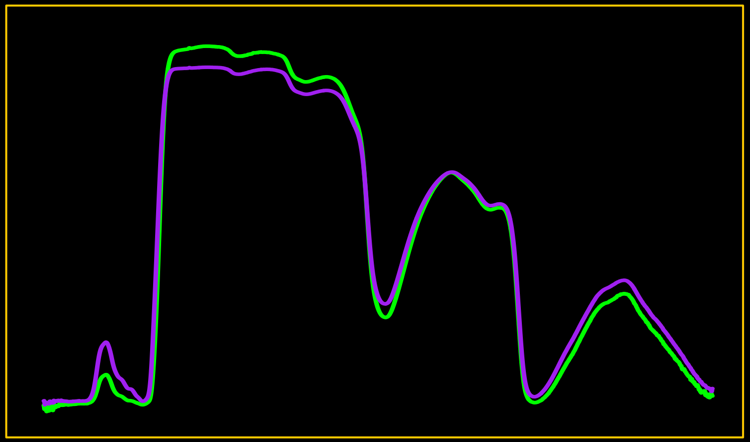
Increasing dimensionality due to structural and biochemical trait diversity observed



Schaepman & Shimizu, under discussion

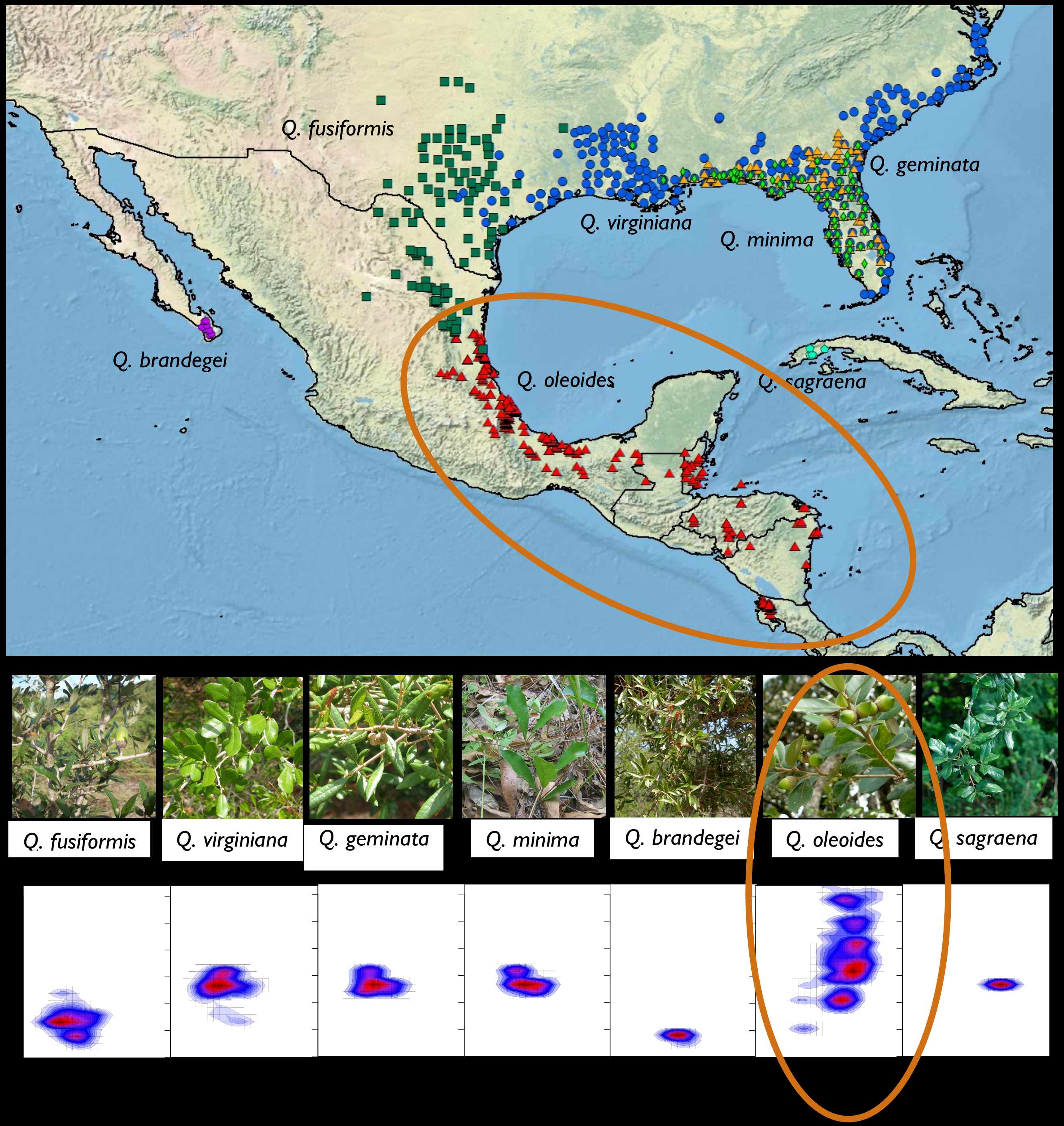
Can we detect the functional and phylogenetic diversity of plants on Earth?





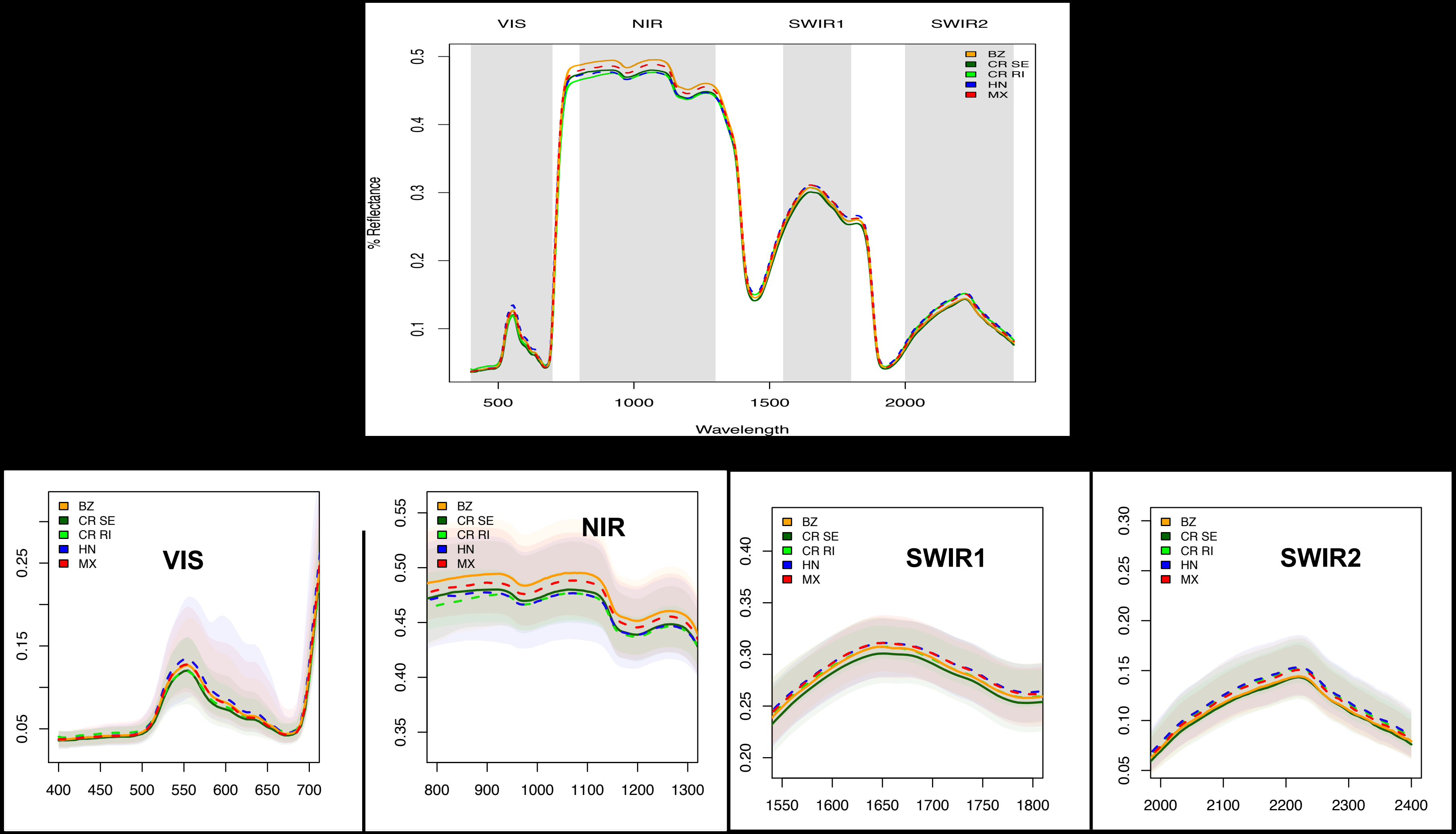
Jeannine Cavendar-Bares, NimBios Workshop

Variation within a single species of Oak (Quercus)



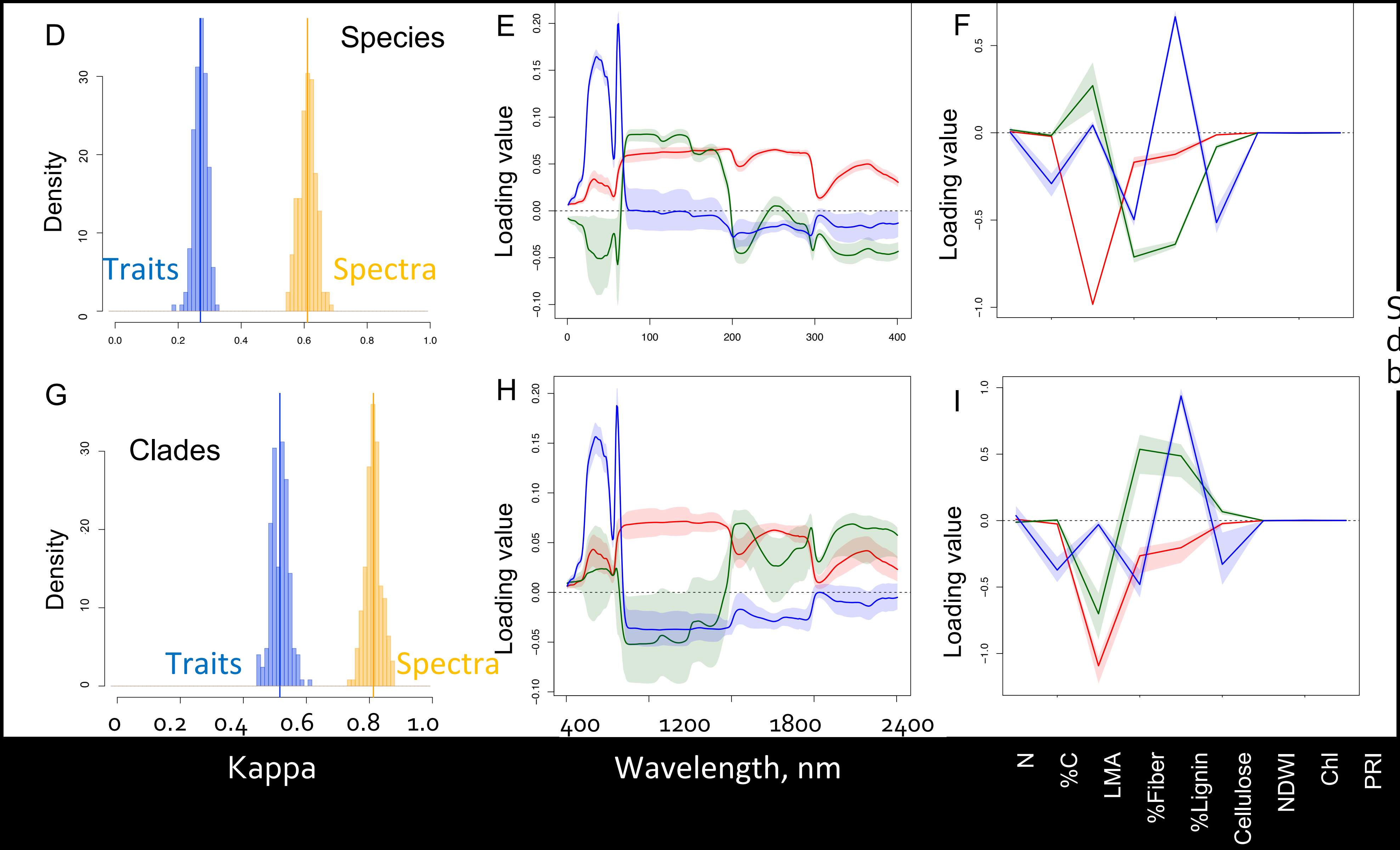
Cavender-Bares et al, *Molec. Ecol.* 2015

Leaf Level Spectra Averaged by Population



Cavender-Bares et al, *Molec. Ecol.* 2015

PLS-DA Loadings for First 3 Components



Some traits differentiate taxa better than others

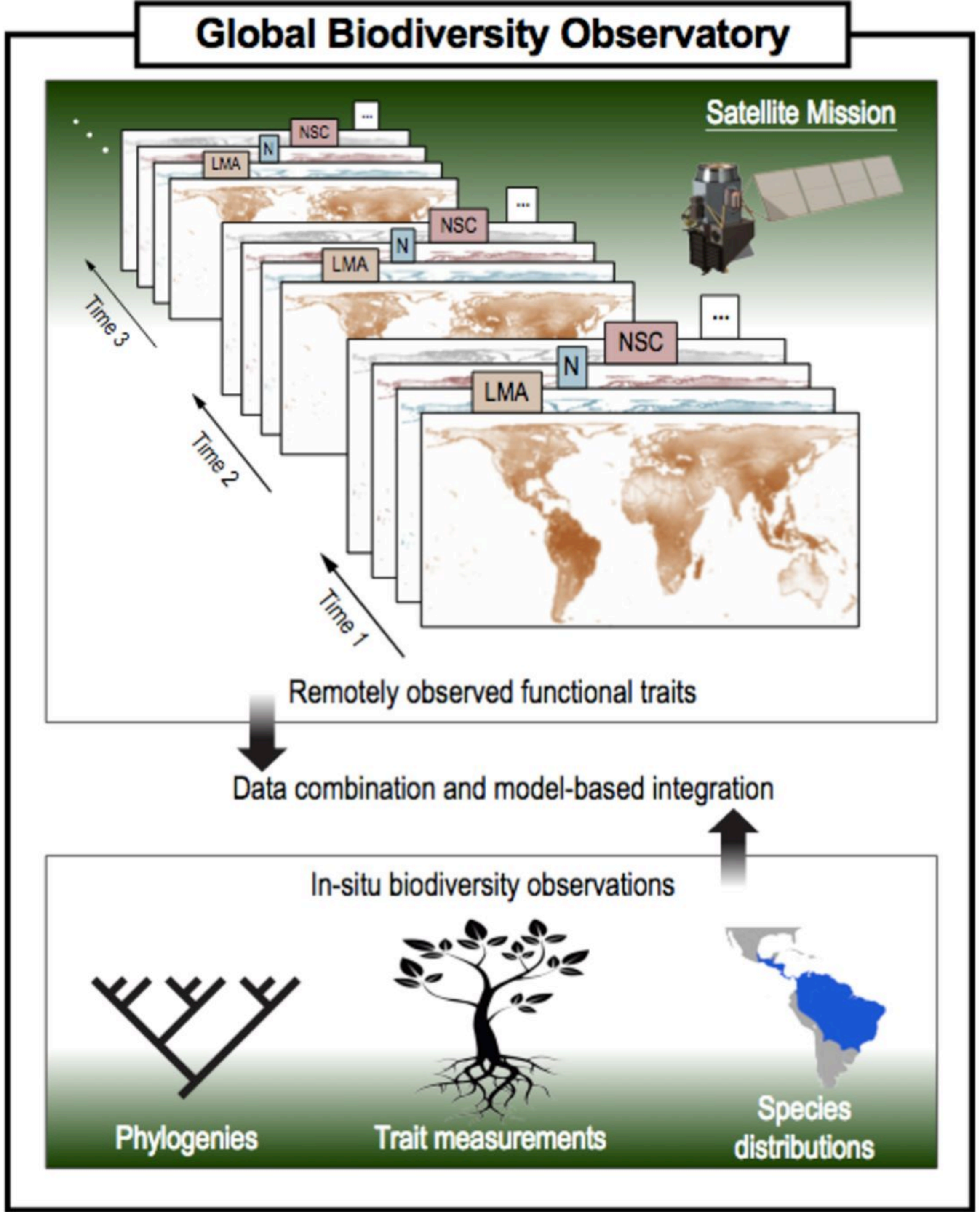
Cavender-Bares et al, *Molec. Ecol.* 2015

Table 1 | Key functional plant traits that are remotely observable from space.

Trait	Trait definition	Trait functions	Trait role (refs)	Remote observation (refs)
Leaf mass per area (LMA) ($g\,m^{-2}$)	The dry mass of a leaf divided by its one-sided area measured when fresh. The reciprocal is specific leaf area (SLA).	A primary axis of the global leaf economics spectrum[11].	49,66,67	34,35,68–70
Nitrogen (N) (%)	Concentration of elemental nitrogen in a leaf or canopy.	Important for photosynthesis and other metabolic processes as a constituent of plant enzymes.	67,71,72	34,35,73–75
Non-structural carbohydrates (NSC) (%)	Direct products of photosynthesis (sugars and starches), not yet incorporated into plant structural components and thus readily assimilable.	Indicator of tolerance to environment stress.	76	77
Chlorophyll ($mg\,g^{-1}$)	Green pigments.	Responsible for capturing light in the process of photosynthesis.	78,79	35,80,81
Carotenoids ($mg\,g^{-1}$)	Orange and yellow pigments.	Involved in the xanthophyll cycle for dissipating excess energy and avoiding oxygen radical damage under stress conditions (drought, chilling, low nutrients).	82,83	31,35
Lignin (%)	A complex organic polymer.	Provides mechanical support and a barrier against pests and pathogens; negatively correlated with tree growth rate and microbial decomposition.	84,85	32,35,73,86

See Supplementary Table 1 for more traits.

NCEAS Working group “Observing Biodiversity from Space” Jetz et al. Nature Plants 2016



NCEAS Working group "Observing Biodiversity from Space" Jetz et al. 2016