The Case for a Global Biodiversity Observatory

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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.
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

Published by AAAS
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
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).

## TRY Database: Subset Example Illustrating Incomplete Trait Data

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

### Dataset Statistics:

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td>78,300</td>
</tr>
<tr>
<td>Traits</td>
<td>13</td>
</tr>
<tr>
<td>Missing Value</td>
<td>79.9%</td>
</tr>
</tbody>
</table>
Scaling and Biodiversity

Membrane architecture
Cellular ultrastructure
Component pool sizes, C, N, P budgets
Leaf area, Reproductive attributes
PAR profile, Canopy architecture
Habitat state
Vegetation dynamics, CO_2 fluxes
Partitioning, Phenology, productivity
Species competition, Succession
Ecosystem state
Biome state
Biogeochemical cycles
Species diversity, functional diversity, interaction diversity
Ecosystem diversity, process diversity, landscape diversity

Individual – Population – Community – Ecosystem – Landscape

Genetic diversity

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
Nine Species Mapped across the Nanawale Forest Reserve

Correctly Classified: Target species | Non-Target Species  Incorrectly Classified: Target Species | Non Target Species

Jean-Baptiste Feret 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


(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
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 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 km² area >1000 km waterways

Maria Santos et al. 2016 Ecological applications

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
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
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
  - flavonoids
  - ”brown pigments”
- **carbon-based molecules**
  - dry matter (cellulose, hemicellulose, lignin)
  - metabolism (sugars, starches, proteins, enzymes)
Pigment composition (Anthocyanin, Chlorophyll, and Carotenoid)

APEX-CIR

Anthocyanin

Chlorophyll

Carotenoid
Chlorophyll: 10 - 80 [$\mu g$ $cm^{-2}$] 
Water: 0.01 - 0.03 [$g$ $cm^{-2}$] 
Dry Mater: 0.001 - 0.01 [$g$ $cm^{-2}$] 
Leaf Area Index: 0 – 7 [$m^2$ $m^{-2}$]

Conventional Inversion Scheme (PLS Optimization)
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

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

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

Strongest relationships are traits along woody to herbaceous axis

Detailed Chemistry Retrieval from Canopy Reflectance

6136 Humid Tropical Forest Canopies

G.P. Asner et al. 2011 RSE
Detailed Chemistry Retrieval from Canopy Reflectance

(a) VSWIR
(b) VNIR

Asner et al. 2011 RSE
Quantifying Biochemical Traits from AVIRIS image

Maps of % nitrogen, % carbon, δ^{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](http://dx.doi.org/10.1890/142098.1) Fig. 6
Quantifying Biochemical Traits from AVIRIS images

Maps of % nitrogen, % carbon, $\delta^{15}$N, leaf mass per area ($M_{\text{area}}$), 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](http://dx.doi.org/10.1890/142098.1) Fig. 6

Subplot 1: false color composite R/G/B = %ADL/\text{M}_\text{area}/%\text{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.
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.

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.

Figure 3. Example single-scene eigenvector plot, linear scale (left), log scale (right).
Scene Statistics from 510 AVIRIS Scenes from 1999

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

Distribution of Scenes with different Dimensionality

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.

Variance in noise level

Boardman J. and R.O. Green 2016. Exploring the Spectral Variability of the Earth as Measured by AVIRIS
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 (e.g., phenotypic traits from cell to canopy level)

Spectranomics ➠ Increasing mechanistic value  
Imaging spectranomics

Increasing dimensionality due to structural and biochemical trait diversity observed
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)

Leaf Level Spectra Averaged by Population

Cavender-Bares et al., *Molec. Ecol.* 2015
Some traits differentiate taxa better than others

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

See Supplementary Table 1 for more traits.

Global Biodiversity Observatory

Satellite Mission

Time 3

Time 2

Time 1

Remotely observed functional traits

Data combination and model-based integration

In-situ biodiversity observations

Phylogenies

Trait measurements

Species distributions

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