The Canadian Airborne Biodiversity Observatory

The challenge: changes in biodiversity outpace our monitoring ability

We have entered the "Anthropocene": an epoch characterised by the Earth's sixth major species extinction, driven by human activities[1]. Land-use change, climate change, biotic invasions and altered biogeochemical cycles are profoundly and rapidly transforming biodiversity across the globe[2]. Yet our ability to monitor, understand and predict changes in biodiversity at regional to continental scales is constrained by the small spatial extent at which high-resolution biodiversity data are acquired – often limited to single or a few snapshots in time. For example, the largest, coordinated global research effort to study tropical and temperate forest biodiversity, the Center for Tropical Forest Science and Forest Global Earth Observatories (http://www.forestgeo.si.edu), involves hundreds of researchers from around the globe who monitor every five years 60 forest plots together totalling ~2200 ha –only 0.00006% or 1/2,000,000 of the world's forested area. However as essential and invaluable such initiatives are, their narrow geographical scope and limited sampling frequency illustrate a grand challenge of biodiversity science in the Anthropocene: the broad extent and rapid rate at which biodiversity changes occur outpace our ability to study them through field-based sampling alone. As a consequence, immense portions of the biosphere are left entirely unstudied, despite being exposed to a range of threats. How can we conserve what we do not even know?

Spectranomics: a new paradigm for biodiversity science

Field surveys are and will remain the gold standard for acquiring high-resolution biodiversity data. However, once we accept that the overwhelming majority of the biosphere cannot possibly be sampled using field surveys, we must seek ways to scale up. At one extreme, satellite-based sensors can yield essential biodiversity indicators over broad regions at a high frequency[3,4], but ground resolution is too coarse (~5–30 m) for direct, detailed biodiversity monitoring except for the largest of trees (Fig. 1).

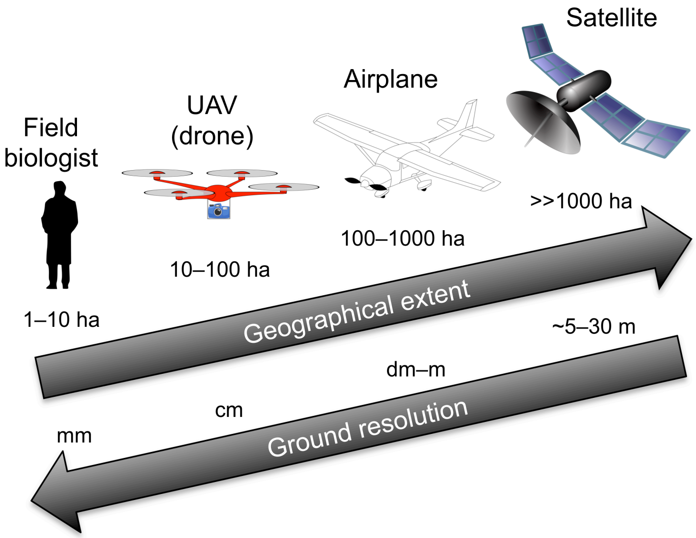

Figure 1. The four complementary approaches that will be used by The Canadian Airborne Biodiversity Observatory (CABO) to acquire biodiversity data, each representing a distinct spatial scale. Traditional field-based biodiversity surveys (left) enable high ground resolution but are labourious, costly and time-consuming, limiting sampling to a small geographical extent. At the other extreme, satellite imagery (right) can remotely survey vegetation over entire continents with a relatively high frequency, but ground resolution is too coarse for detailed biodiversity monitoring. Hyperspectral sensors mounted on unmanned aerial vehicles (UAVs, or 'drones') or airplanes (middle) bridge the gap between these two extremes, allowing relatively high-resolution biodiversity data to be acquired over significantly broader extents than what can be achieved via field work.

We are currently witnessing the emergence of an integrative, transformative, paradigm-shifting approach to biodiversity monitoring that bridges the gap between field-based surveys and satellite imagery (Fig. 1): 'airborne spectranomics'[5]. Spectranomics relies on aircraft-mounted hyperspectral sensors to capture high-resolution images of entire canopies, from which individual plants are identified to species by their unique foliar reflectance spectral signatures –or 'barcodes'– in the visible (VIS) to short-wave infrared

(SWIR) range (400–2500 nm)[6]. Spectranomics yields biodiversity data approaching the high resolution of ground-based approaches, but over considerably larger geographical extents (Fig. 1).

The enormous potential of spectranomics is demonstrated by its ability to accurately and semi-autonomously map canopy tree diversity in remote, difficult-to-access species-rich Amazonian tropical forests across entire landscapes[7]. Importantly, because spectral signatures express foliar chemical, morphological, and anatomical characteristics, spectranomics enables remote sensing of canopy functional biodiversity[8], providing a enticing way to link changes in biodiversity to their ecosystem-level and biosphere-level consequences[9], and to guide conservation decisions and actions[10].

We propose to establish The Canadian Airborne Biodiversity Observatory (CABO), a cross-scale (Fig. 1) initiative involving some of Canada's leading researchers in biodiversity and remote sensing. Our **overall objective** is to build on and extend the spectranomics approach[5] in Canada to improve our ability to forecast biosystem responses to environmental changes. In doing so, CABO will revolutionise the way biodiversity data are acquired across Canada and the world. CABO will link with and strengthen other international spectranomics initiatives[5,11] to position Canada as a global leader in biodiversity science and conservation.

CABO's foundation: a foliar spectral database of Canadian plant species

CABO will use high-fidelity field spectroscopy to measure foliar spectra using standardised protocols[12,13] across a wide range of plant species of various growth forms from ecosystems representing major Canadian ecozones. This will provide the foundational data on which CABO depends. Standardised field-collected foliar spectra will allow us to determine how spectral signatures map onto plant phylogeny and at their potential for remote species discrimination across Canadian ecosystems. In addition, we will quantify the extent to which foliar spectra enable us to remotely sense the major foliar chemicals that drive the biosphere (e.g. chlorophyll, nitrogen)[14].

A major asset of CABO's spectral database will be its reliability and traceability, both in terms of its geo-referenced, high-fidelity standardised spectral measurements[13] and the accurate plant species identification relying up-to-date taxonomy (using VASCAN). Each spectrum will be associated with a herbarium species deposited at the Marie-Victorin herbarium at the Centre sur la biodiversité of Université de Montréal, and entered into Canadensys (http://www.canadensys.net/). This freely accessible foliar spectral database will be of tremendous value for taxonomy, ecology, and remote sensing research, and will provide the foundation for all future applications of high-resolution canopy biodiversity censuses based on hyperspectral imagery.

1. Pimm, S. L., Russell, G. J., Gittleman, J. L. & Brooks, T. M. The future of biodiversity. *Science* **269,** 347–350 (1995).
2. Sala, O. E. *et al.* Global biodiversity scenarios for the year 2100. *Science* **287,** 1770–1774 (2000).
3. Duro, D. C., Coops, N. C., Wulder, M. A. & Han, T. Development of a large area biodiversity monitoring system driven by remote sensing. *Prog. Phys. Geogr.* **31,** 235–260 (2007).
4. Pereira, H. M. *et al.* Essential Biodiversity Variables. *Science* **339,** 277–278 (2013).
5. Asner, G. P. & Martin, R. E. Spectranomics: Emerging science and conservation opportunities at the interface of biodiversity and remote sensing. *Glob. Ecol. Conserv.* **8,** 212–219 (2016).
6. Fassnacht, F. E. *et al.* Review of studies on tree species classification from remotely sensed data. *Remote Sens. Environ.* **186,** 64–87 (2016).
7. Féret, J.-B. & Asner, G. P. Mapping tropical forest canopy diversity using high-fidelity imaging spectroscopy. *Ecol. Appl.* **24,** 1289–1296 (2014).
8. Asner, G. P. *et al.* Airborne laser-guided imaging spectroscopy to map forest trait diversity and guide conservation. *Science* **355,** 385–389 (2017).
9. Jetz, W. *et al.* Monitoring plant functional diversity from space. *Nat. Plants* 16039 (2016). doi:10.1038/nplants.2016.39
10. Kapos, V. Seeing the forest through the trees. *Science* **355,** 347–349 (2017).
11. Zeng, Y., Zhao, Y., Zhao, D. & Wu, B. Forest biodiversity mapping using airborne LiDAR and hyperspectral data. in *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)* 3561–3562 (2016). doi:10.1109/IGARSS.2016.7729922
12. Asner, G. P. *et al.* Functional and biological diversity of foliar spectra in tree canopies throughout the Andes to Amazon region. *New Phytol.* **204,** 127–139 (2014).
13. Pfitzner, K., Bartolo, R., Carr, G., Esparon, A. & Bollhöfer, A. *Standards for reflectance spectral measurement of temporal vegetation plots*. (Supervising Scientist, Australian Government, Department of Sustainability, Environment, Water, Population and Communities, 2011).
14. McManus, K. M. *et al.* Phylogenetic structure of foliar spectral traits in tropical forest canopies. *Remote Sens.* **8,** 196 (2016).