Estimating spatial and temporal beta-diversity of plant communities from spaceborne hyperspectral data

Simon Ferrier (CSIRO)

Pedro Leitão (Technische Universität Braunschweig)

With thanks to: Kerry Cawse-Nicholson, Chris Ware, Karel Mokany, Tom Harwood, Andrew Hoskins, Mike Harfoot

Biodiversity crisis is now attracting significant attention

Are you being lied to?

A guide for the age of dishonesty G2

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Humanity facing 'urgent threat' from loss of Earth's natural life

Landmark UN report says a million species at risk of extinction

Jonathan Watts
Global environment editor

Human society is in jeopardy from the accelerating decline of the Earth's natural life-support systems, the world's leading scientists have warned as they announced the results of the most thorough planetary health check ever undertaken.

From coral reefs flickering out beneath the oceans to rainforests desiccating into savannahs, nature is being destroyed at a rate tens to hundreds of times higher than the average over the past 10m years, according to the UN Global Assessment Report.

The biomass of wild mammals has fallen by 82%, natural ecosystems have lost about half their area and a million species are at risk of extinction – all largely as a result of human actions, said the study, compiled over three years by more than 450 scientists and diplomats.

Two in five amphibian species are at risk of extinction, as are about one-third of reef-forming corals and close to one-third of other marine species. The picture for insects – which are crucial to plant pollination – is less clear, but conservative estimates suggest at least one in 10 are threatened with extinction and, in some regions, populations have crashed. In economic terms, the losses are jaw-dropping. Pollinator loss has put as much as $577bn (£440bn) of crop output at risk, while land degradation has reduced the productivity of 23% of global land.

'We should have gone to the doctor sooner. We are in a bad way'
Prof Andy Purvis
An author of the report

The knock-on impacts on humankind, including freshwater shortages and climate instability, were already "ominous" and would worsen without drastic remedial action, the authors said. "The health of the ecosystems on which we and other species depend is deteriorating more rapidly than ever," said Robert Watson, the chair of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). "We are eroding the very foundations of economies, livelihoods, food security, health and quality of life worldwide. We have lost time. We must act now." The warning was 2 →

Outrage over Farage 'conspiracy theories'

Exclusive
Peter Walker

Nigel Farage is facing strong criticism from Jewish organisations and other groups after he repeatedly took part in interviews with a far-right US talk-show host, in which the Brexit party leader openly discussed conspiracy theories, some of them antisemitic.

Farage has appeared at least six times on the show presented by Alex Jones, a notorious figure who was sued by bereaved parents after claiming a US primary school massacre was faked,

Overjoyed royals welcome baby son

The Duke and Duchess of Sussex yesterday announced the birth of their baby boy, who will be seventh in line to the throne. At a hastily arranged press conference, Prince Harry said both mother and baby were doing well and that his new son was

Group on Earth Observations
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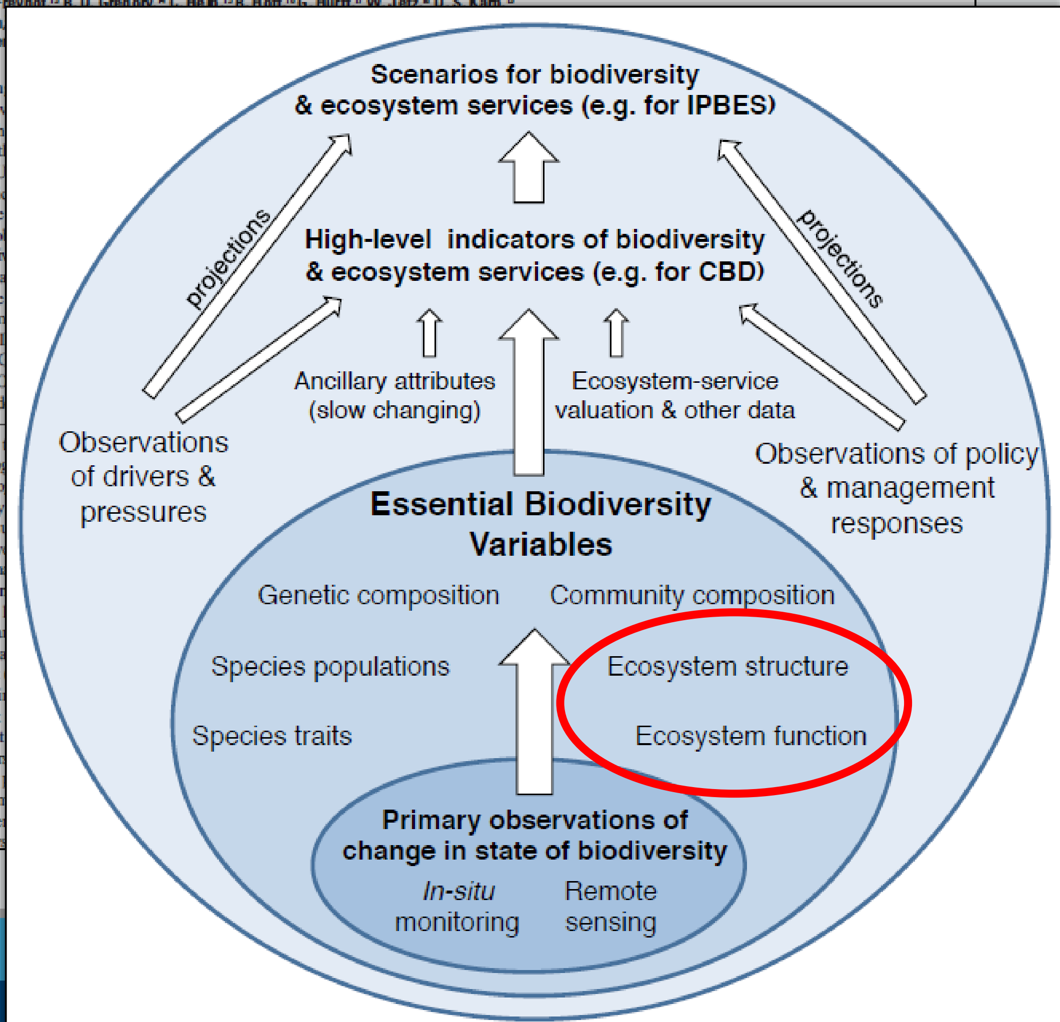
POLICYFORUM

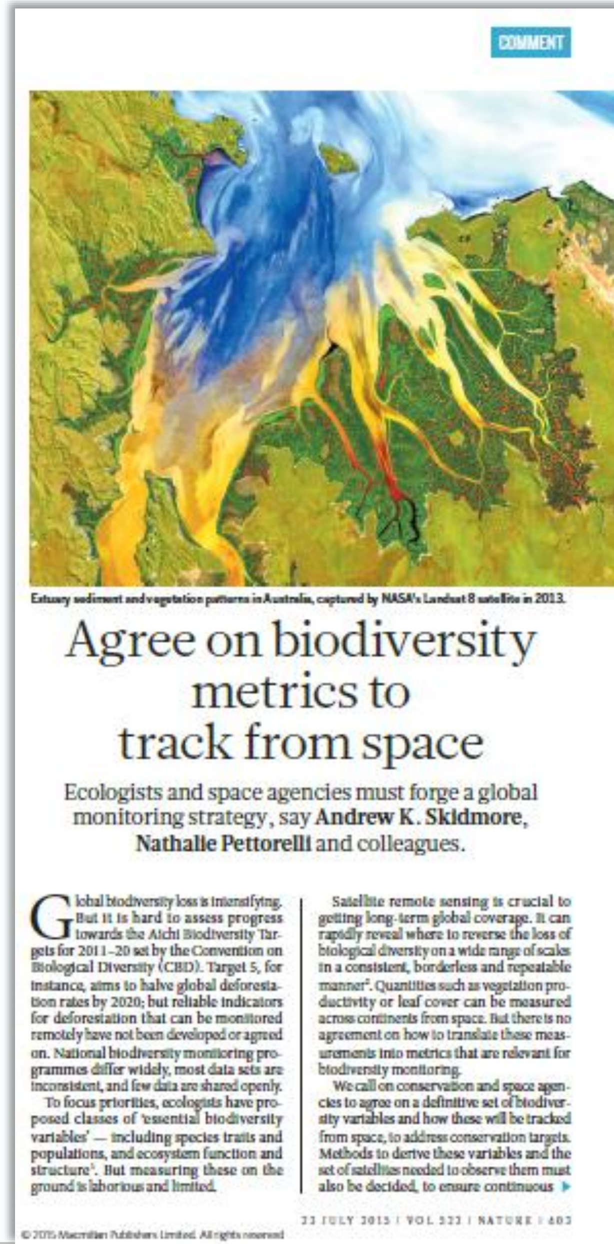
ECOLOGY

Essential Biodiversity Variables

A global system of harmonized observations is needed to inform scientists and policy-makers.

H. M. Pereira,[1*†] S. Ferrier,[2] M. Walters,[3] G. N. Geller,[4] R. H. G. Jongman,[5] R. J. Scholes,[3] M. W. Bruford,[6] N. Brummitt,[7] S. H. M. Butchart,[8] A. C. Cardoso,[9] N. C. Coops,[10] E. Dulloo,[11] D. P. Faith,[12] J. F...




COMMENT

Estuary sediment and vegetation patterns in Australia, captured by NASA's Landsat 8 satellite in 2013.

Agree on biodiversity metrics to track from space

Ecologists and space agencies must forge a global monitoring strategy, say **Andrew K. Skidmore, Nathalie Pettorelli** and colleagues.

Global biodiversity loss is intensifying. But it is hard to assess progress towards the Aichi Biodiversity Targets for 2011–20 set by the Convention on Biological Diversity (CBD). Target 5, for instance, aims to halve global deforestation rates by 2020; but reliable indicators for deforestation that can be monitored remotely have not been developed or agreed on. National biodiversity monitoring programmes differ widely, most data sets are inconsistent, and few data are shared openly.

To focus priorities, ecologists have proposed classes of 'essential biodiversity variables' — including species traits and populations, and ecosystem function and structure[1]. But measuring these on the ground is laborious and limited.

Satellite remote sensing is crucial to getting long-term global coverage. It can rapidly reveal where to reverse the loss of biological diversity on a wide range of scales in a consistent, borderless and repeatable manner[2]. Quantities such as vegetation productivity or leaf cover can be measured across continents from space. But there is no agreement on how to translate these measurements into metrics that are relevant for biodiversity monitoring.

We call on conservation and space agencies to agree on a definitive set of biodiversity variables and how these will be tracked from space, to address conservation targets. Methods to derive these variables and the set of satellites needed to observe them must also be decided, to ensure continuous ▸

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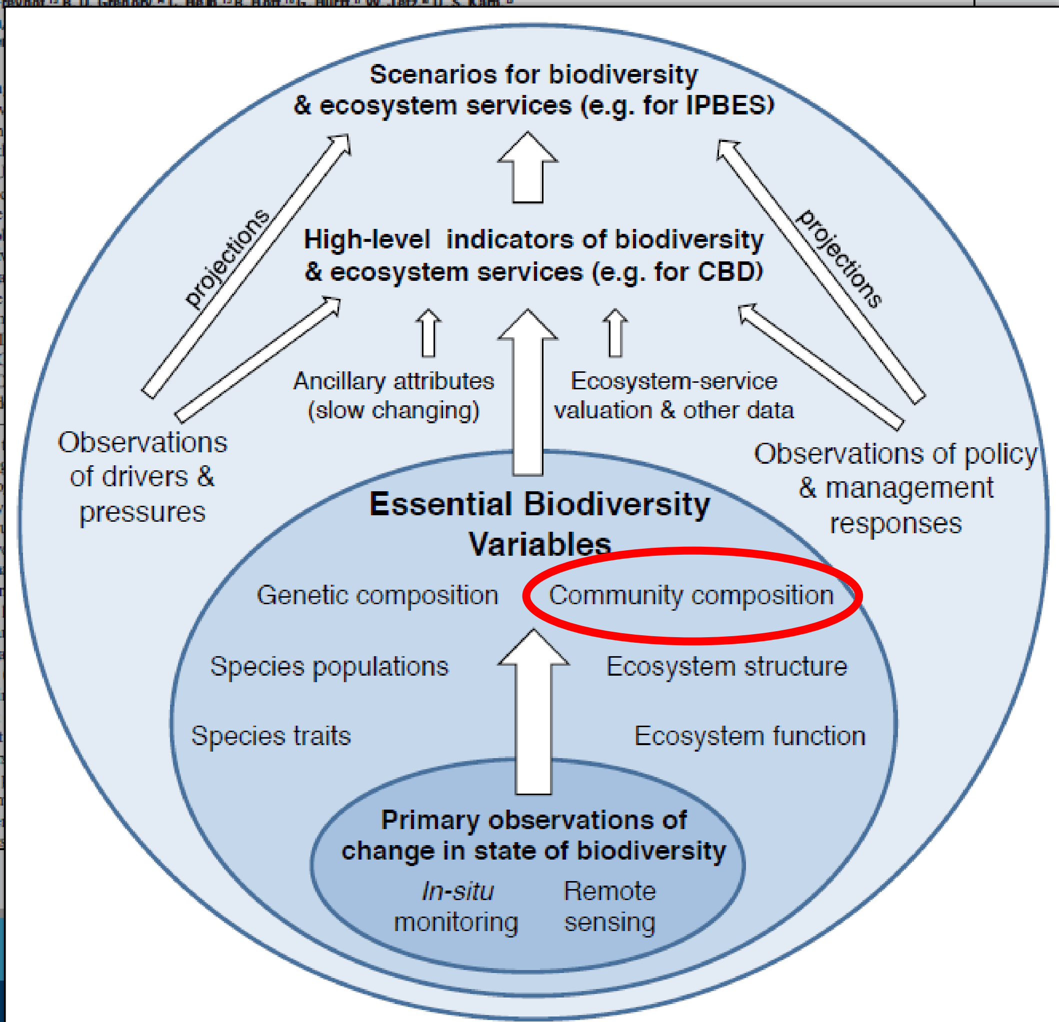

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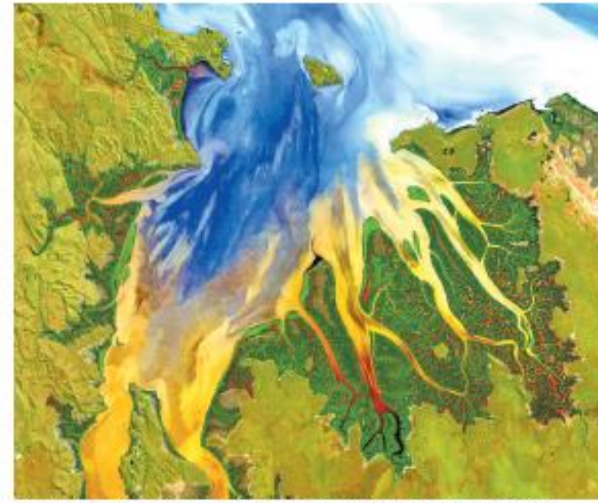

Estuary sediment and vegetation patterns in Australia, captured by NASA's Landsat 8 satellite in 2013.

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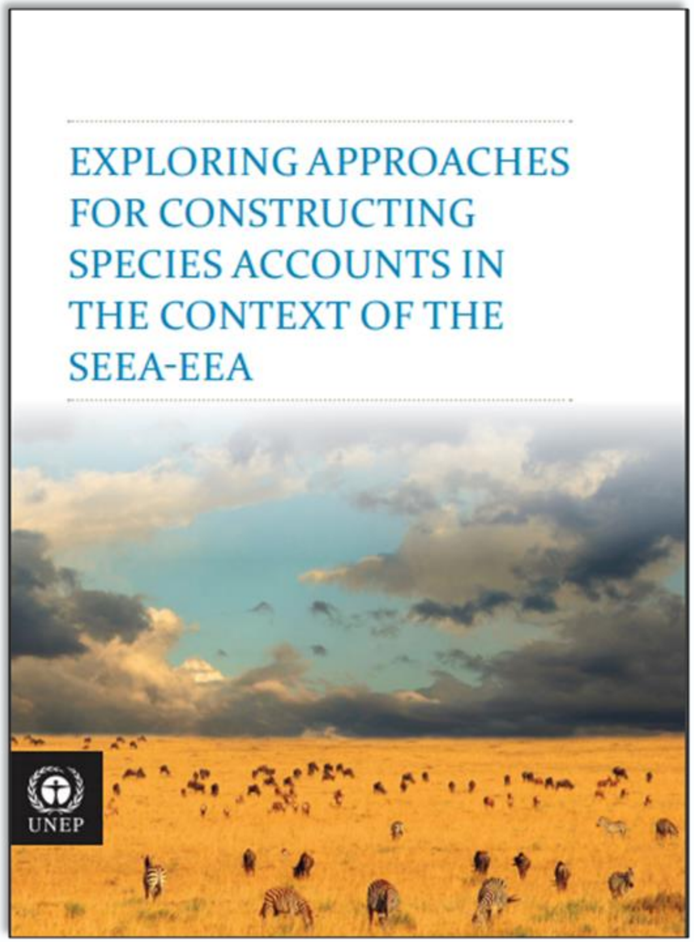
CSIRO

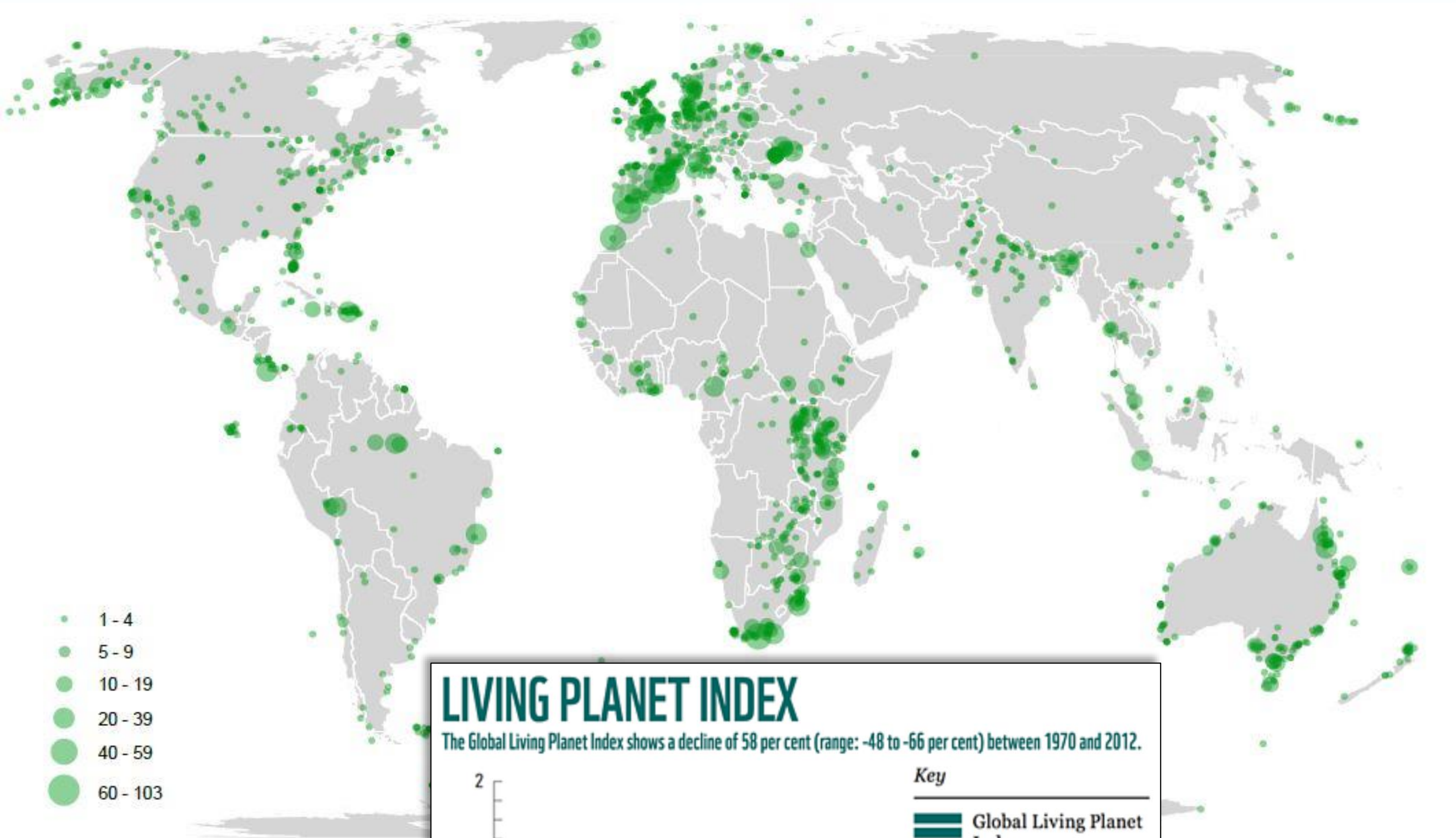
Broad approaches to monitoring biodiversity change



Data acquisition strategies

- **Direct observation of biological change**
- **Indirect habitat-based approaches**
  intersecting remotely observed change in habitat condition with mapping of…
  - Individual species distributions
  - Discrete community (or ecosystem) classes
  - Continuous variation in community composition

https://www.unep-wcmc.org/resources-and-data/towards-an-approach-for-species-accounting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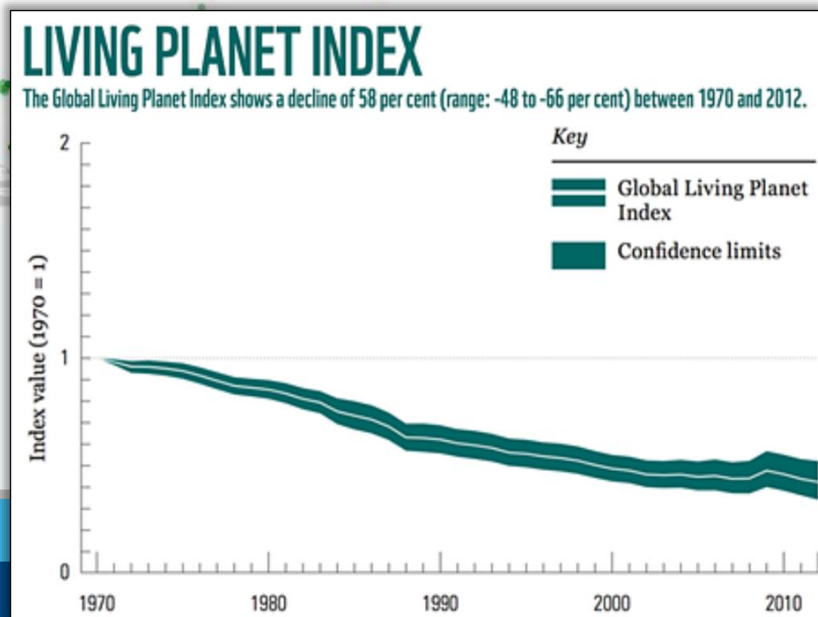
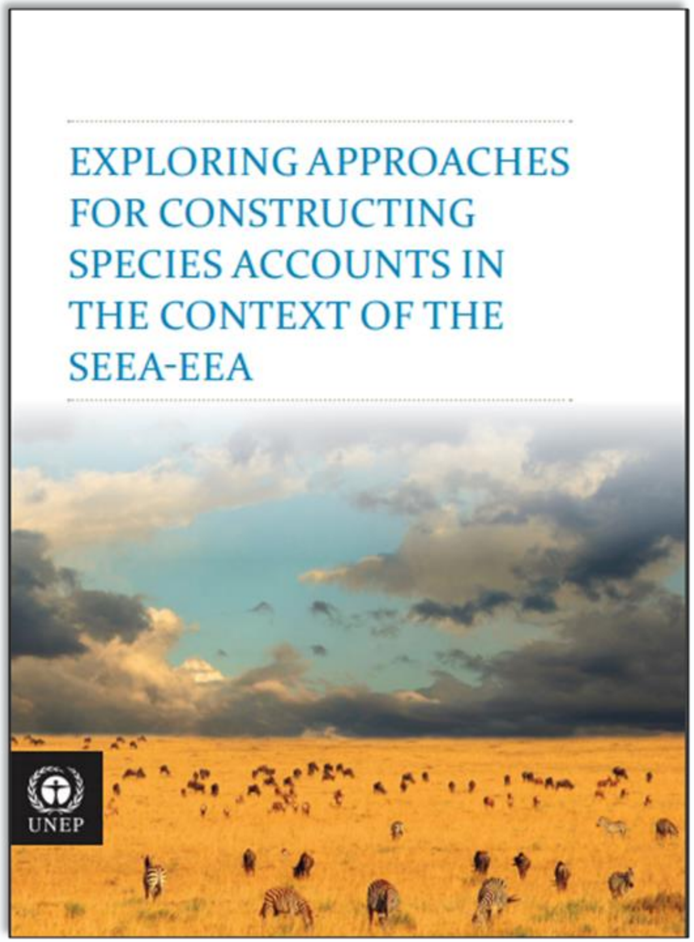
20 - 39
40 - 59
60 - 103


LIVING PLANET INDEX
The Global Living Planet Index shows a decline of 58 per cent (range: -48 to -66 per cent) between 1970 and 2012.
Key
Global Living Planet Index
Confidence limits
Index value (1970 = 1)
2
1
0
1970
1980
1990
2000
2010

Broad approaches to monitoring biodiversity change



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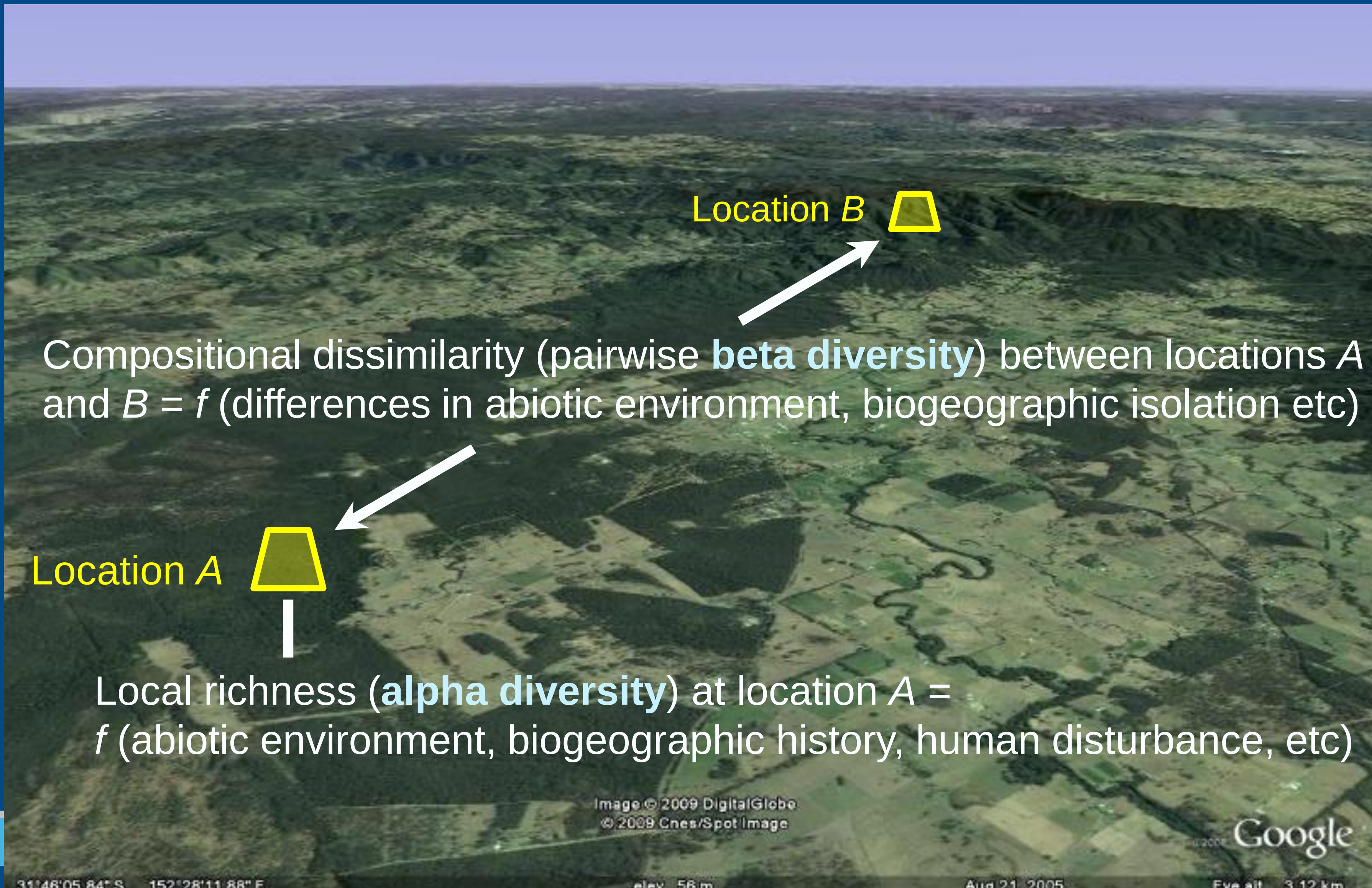
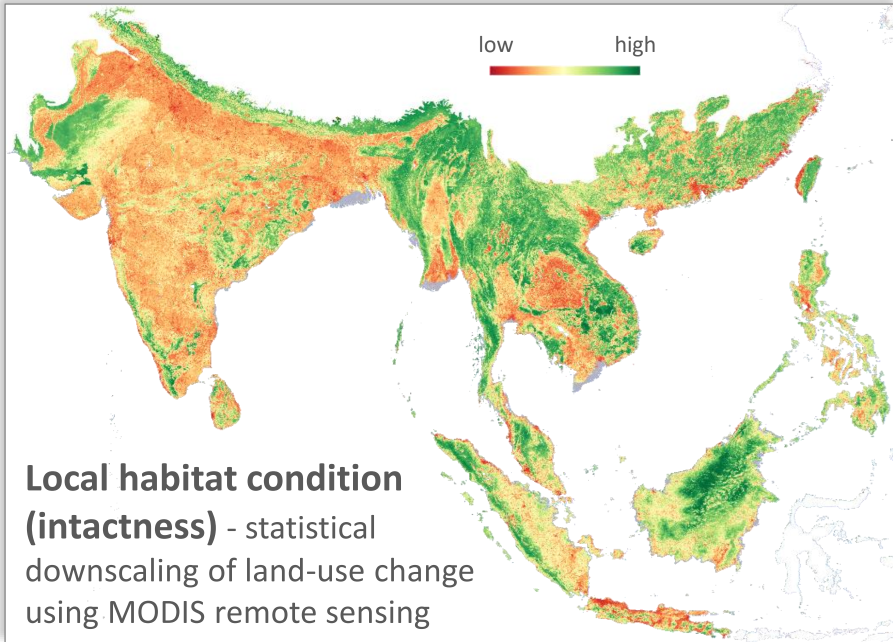
Modelling and mapping of continuous patterns in collective properties of biodiversity

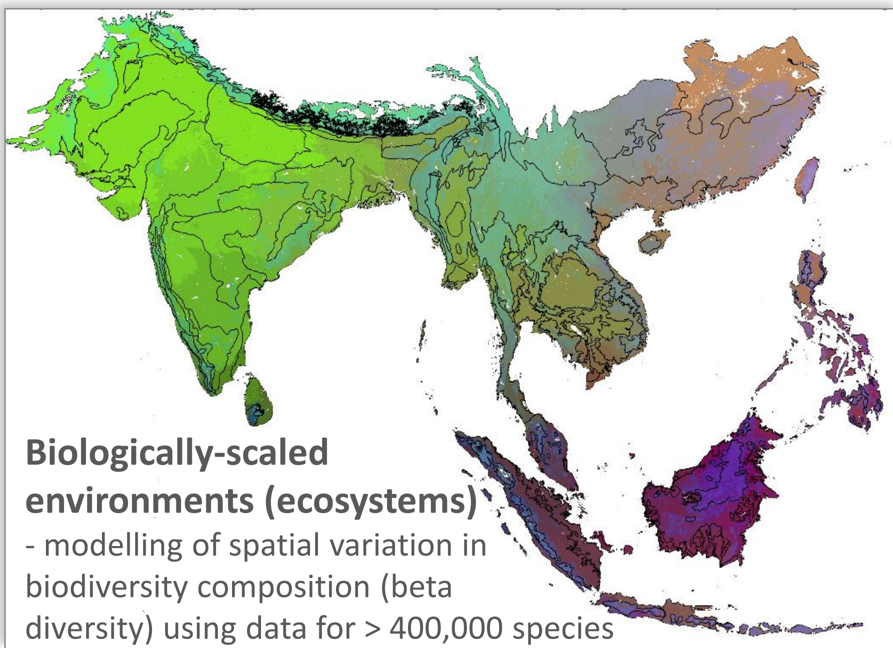


Biodiversity Habitat Index (BHI)

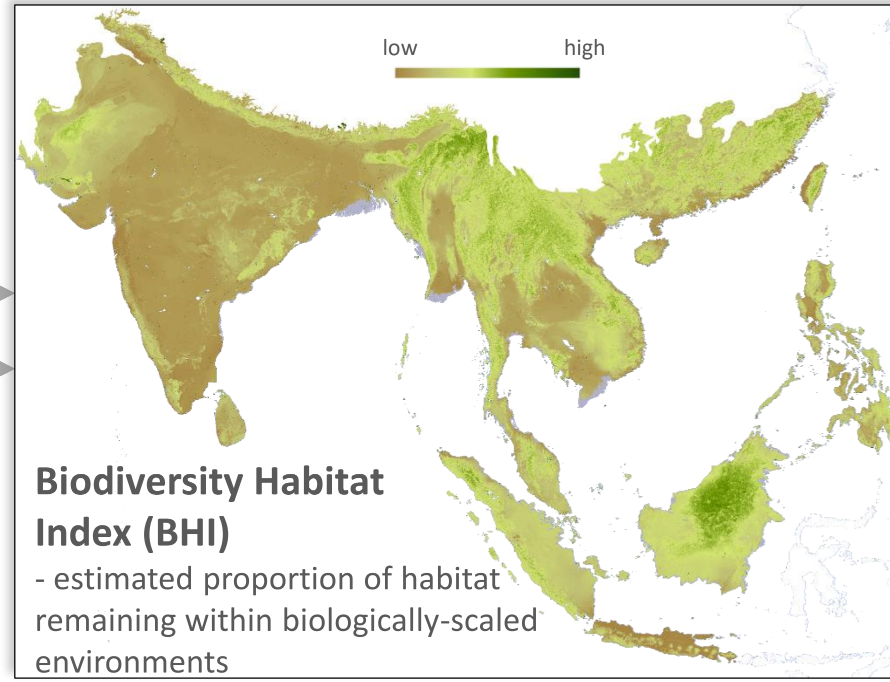
- **Combines remotely monitored habitat condition with modelled spatial variation in biodiversity composition**
- **Derived at 1km grid resolution across the entire land surface of the planet**



Local habitat condition (intactness) - statistical downscaling of land-use change using MODIS remote sensing



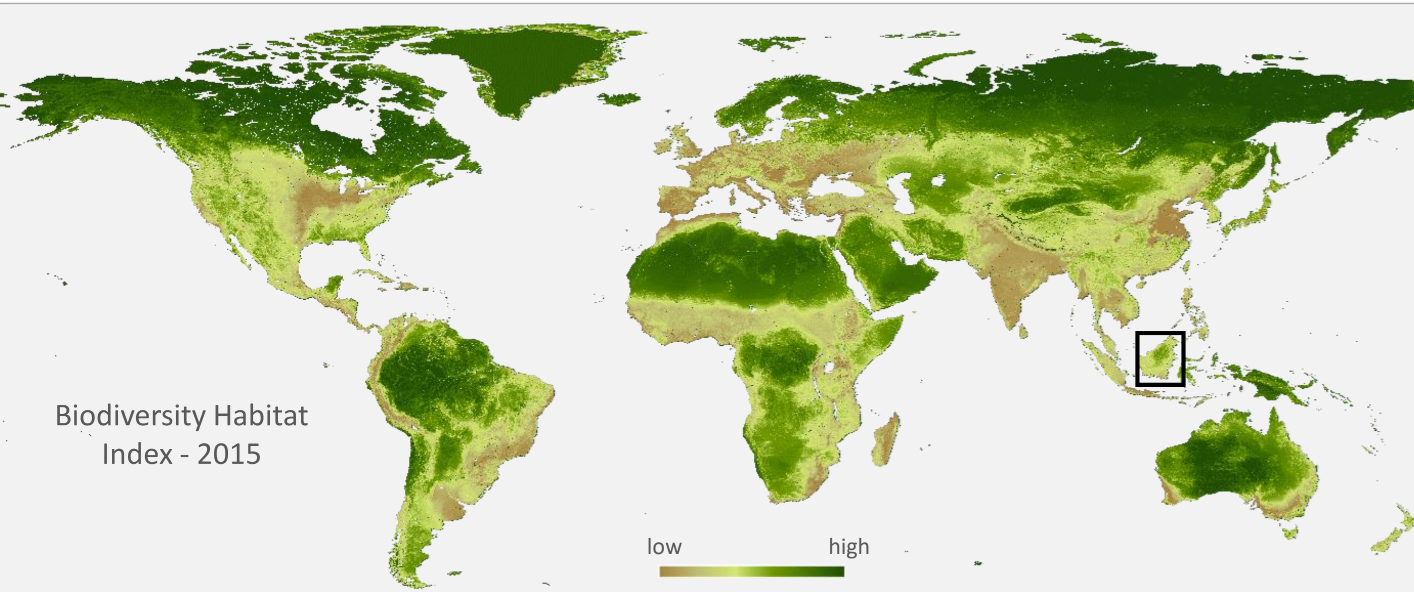
Biologically-scaled environments (ecosystems) - modelling of spatial variation in biodiversity composition (beta diversity) using data for > 400,000 species

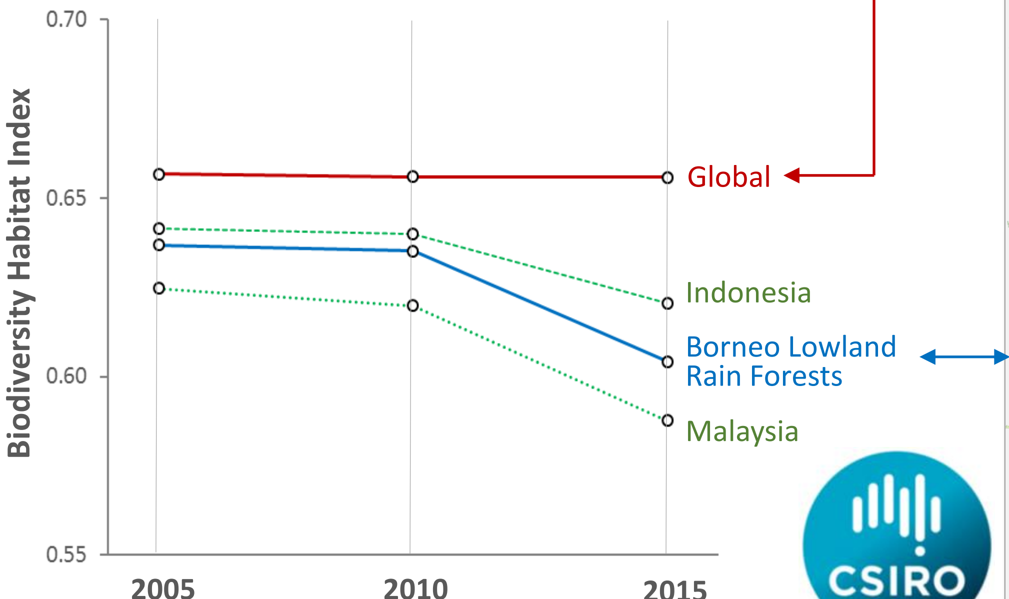


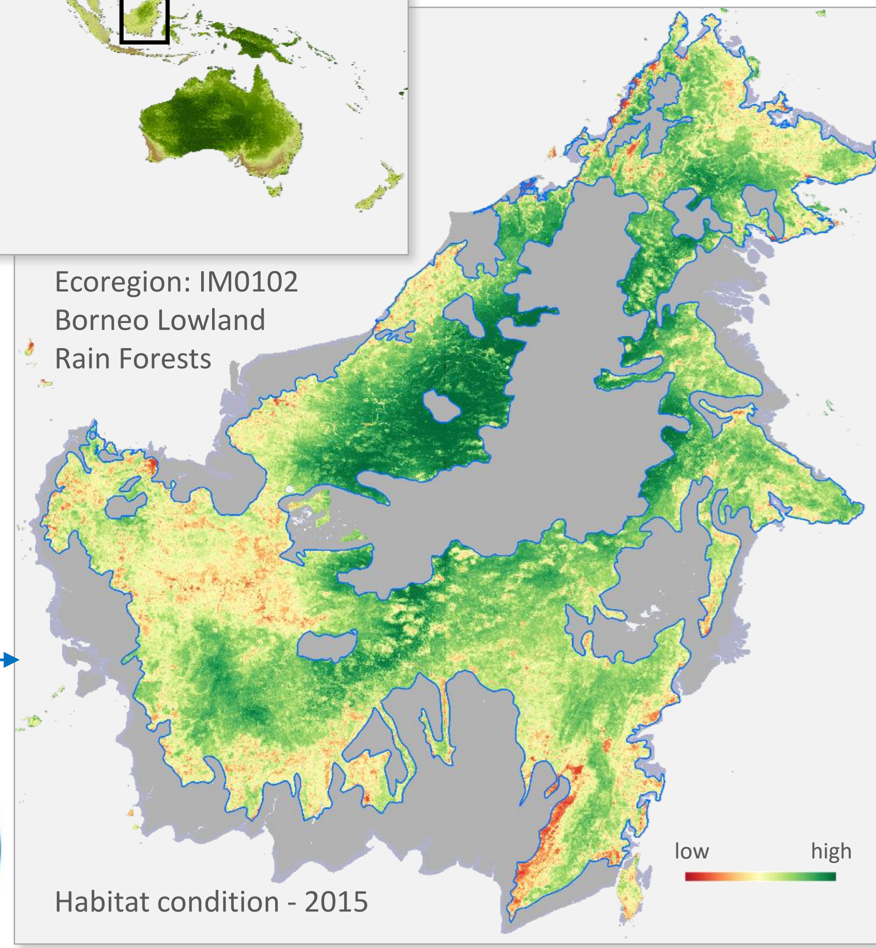
Biodiversity Habitat Index (BHI) - estimated proportion of habitat remaining within biologically-scaled environments

CSIRO GEO BON Biodiversity Indicators Partnership GBIF MOL MAP OF LIFE Predicts

The BHI is recalculated, using remote-sensing inputs from different years, to report change in habitat retention across all biologically-scaled environments occurring within any given spatial unit (e.g. country, ecoregion, the entire planet)

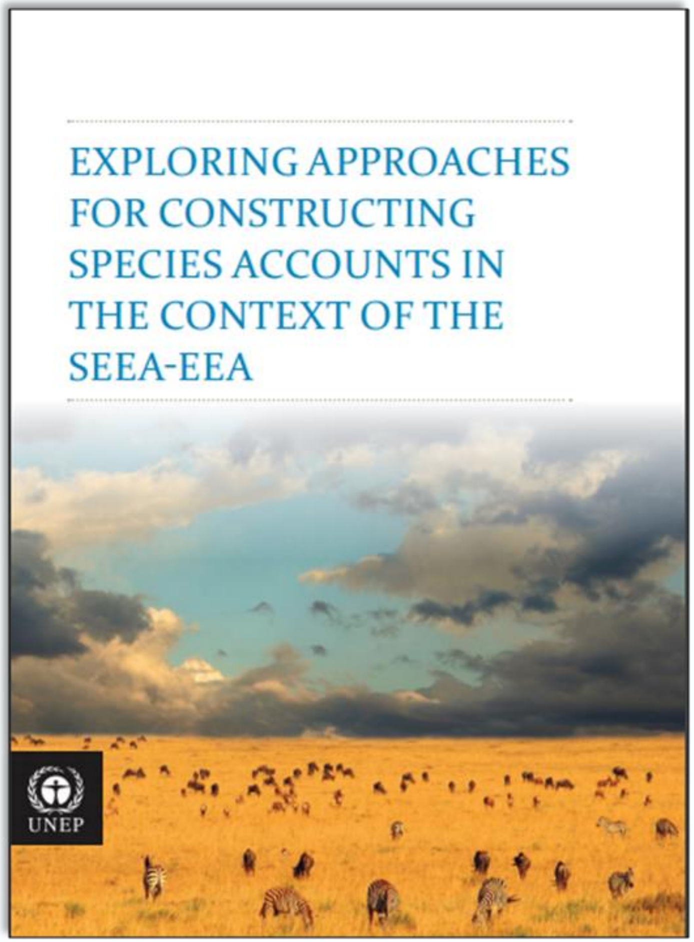


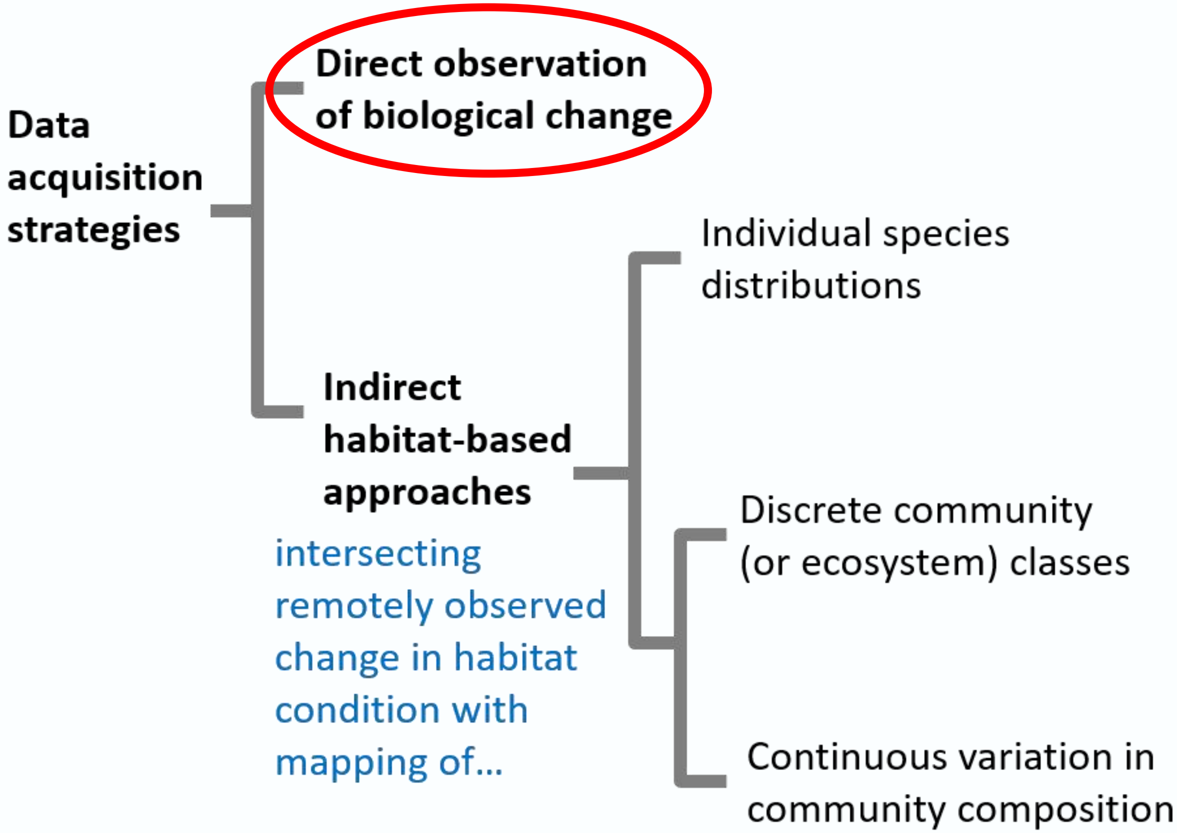




CSIRO

Broad approaches to monitoring biodiversity change



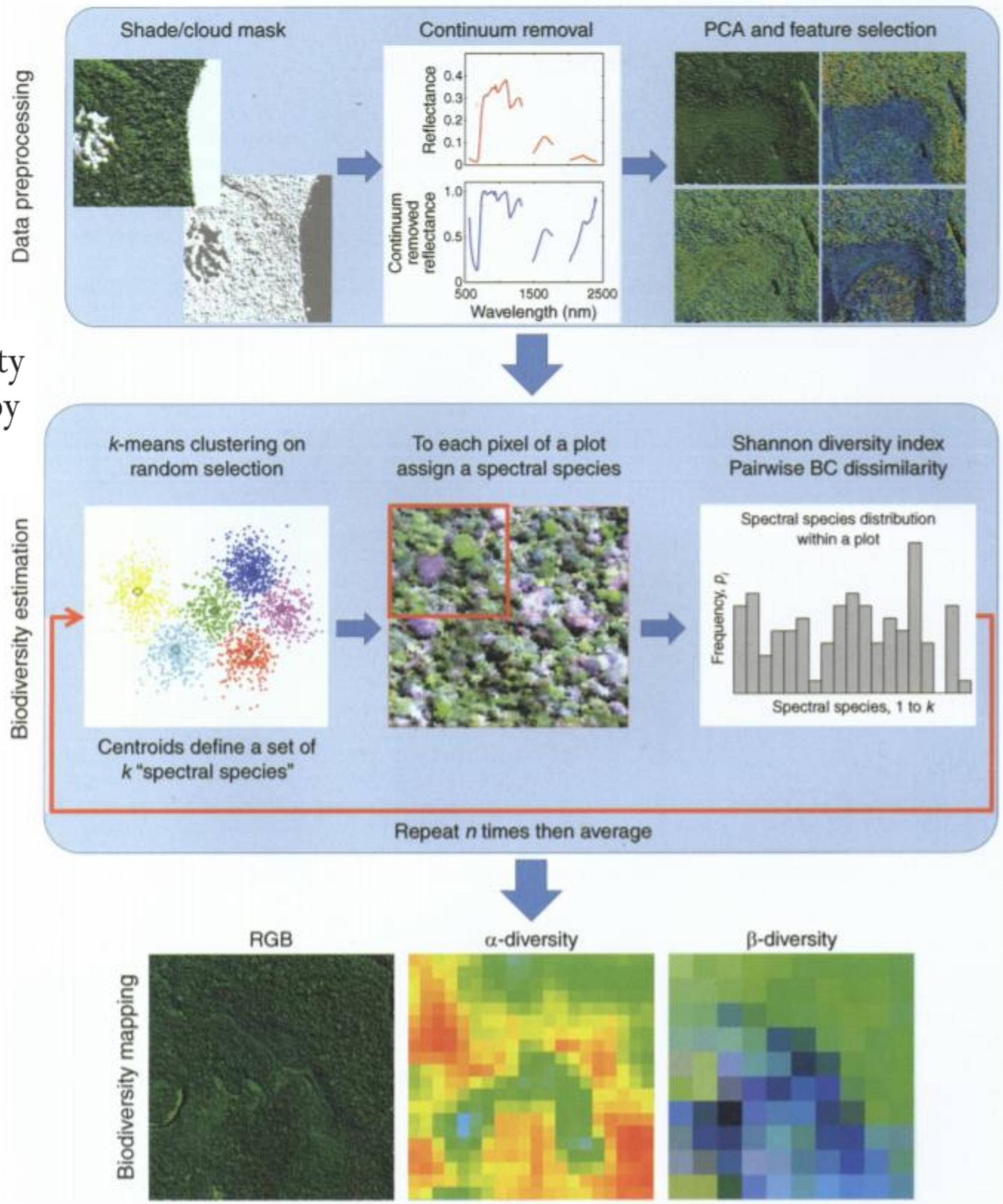


https://www.unep-wcmc.org/resources-and-data/towards-an-approach-for-species-accounting

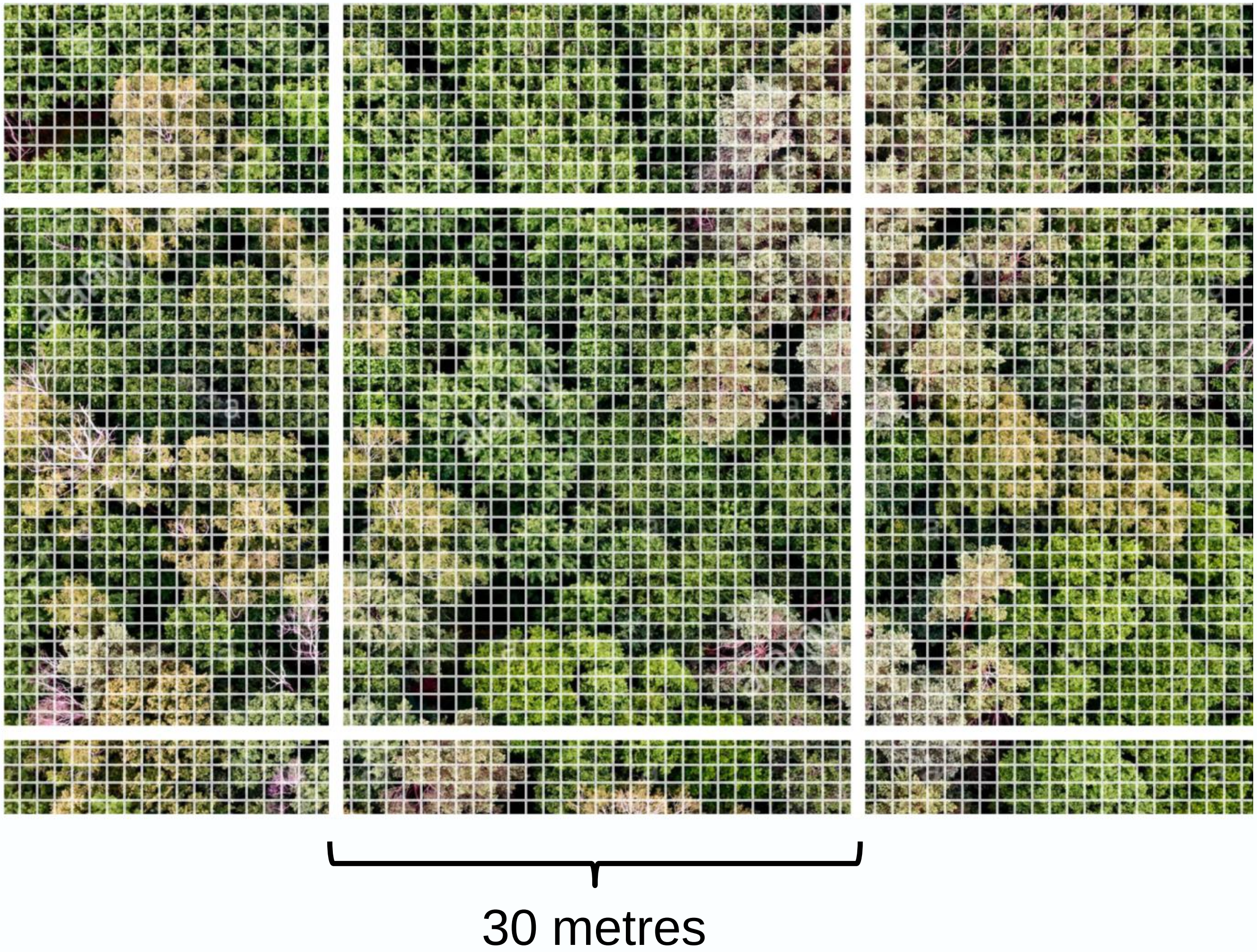
Ecological Applications, 24(6), 2014, pp. 1289–1296

Mapping tropical forest canopy diversity using high-fidelity imaging spectroscopy

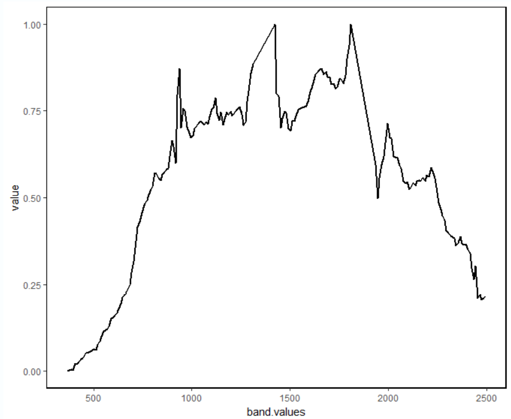
Jean-Baptiste Féret[1] and Gregory P. Asner

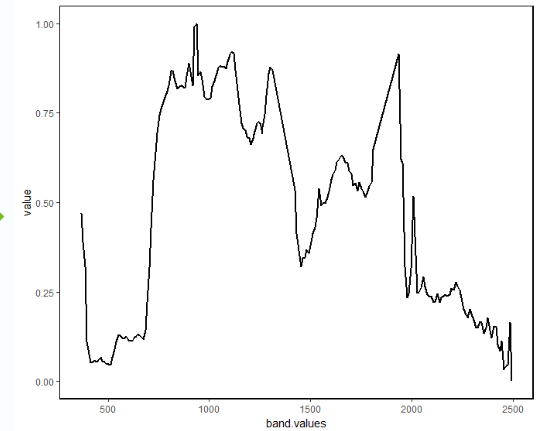


The coarser pixel resolution of spaceborne imaging spectroscopy presents a major challenge

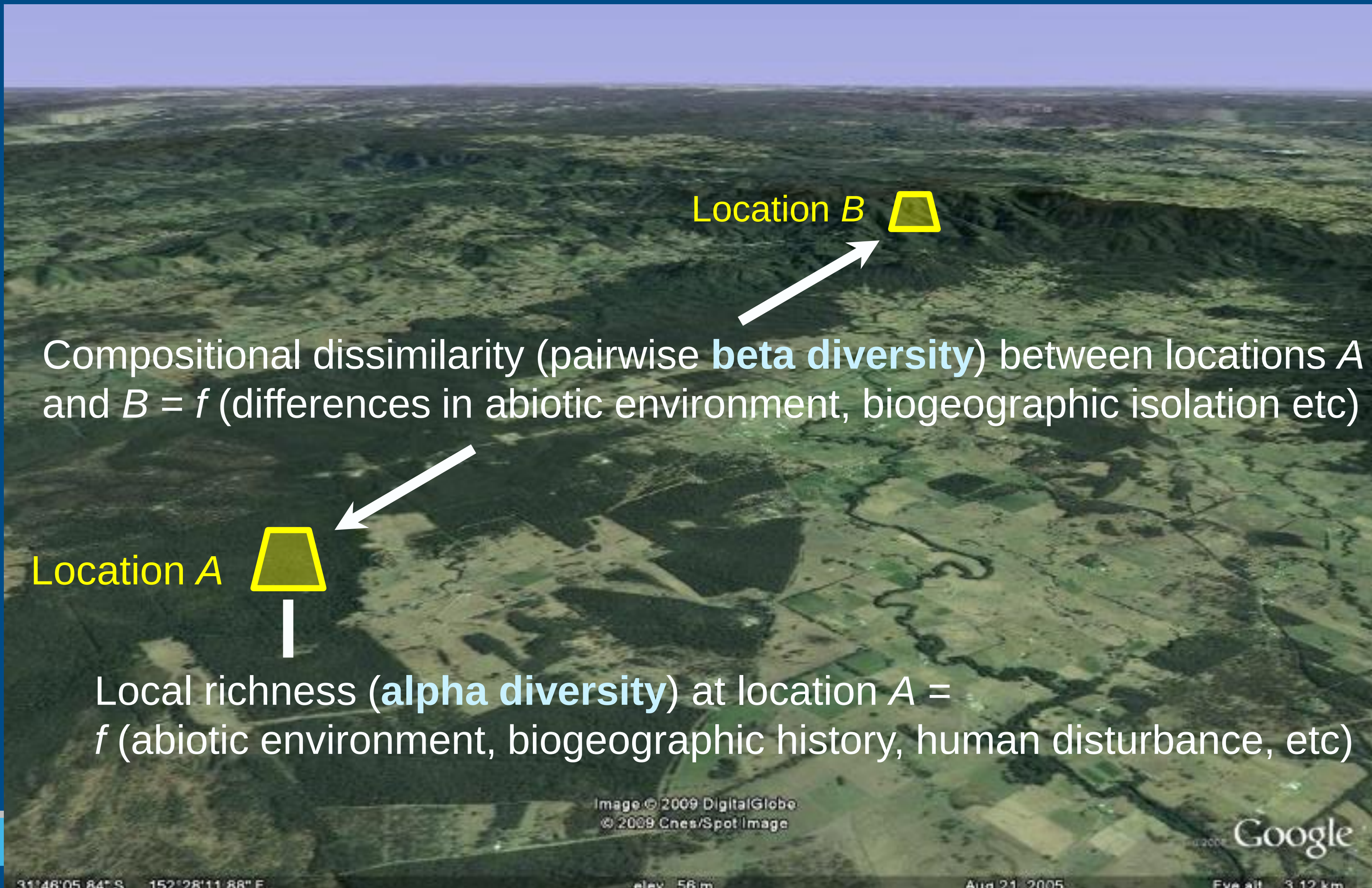


Can pairwise beta-diversity (across space and/or time) be estimated directly from composite spectral profiles?



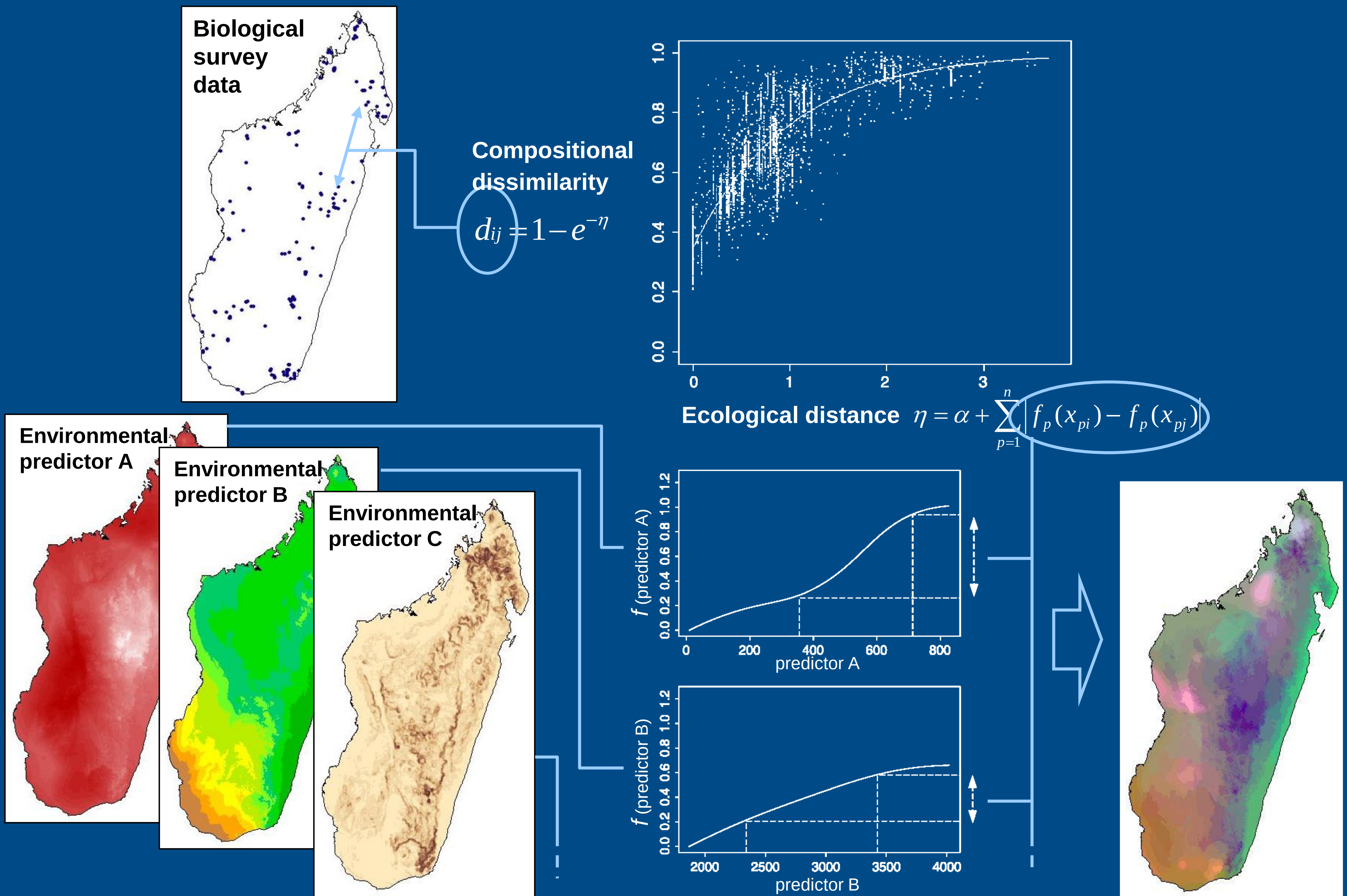


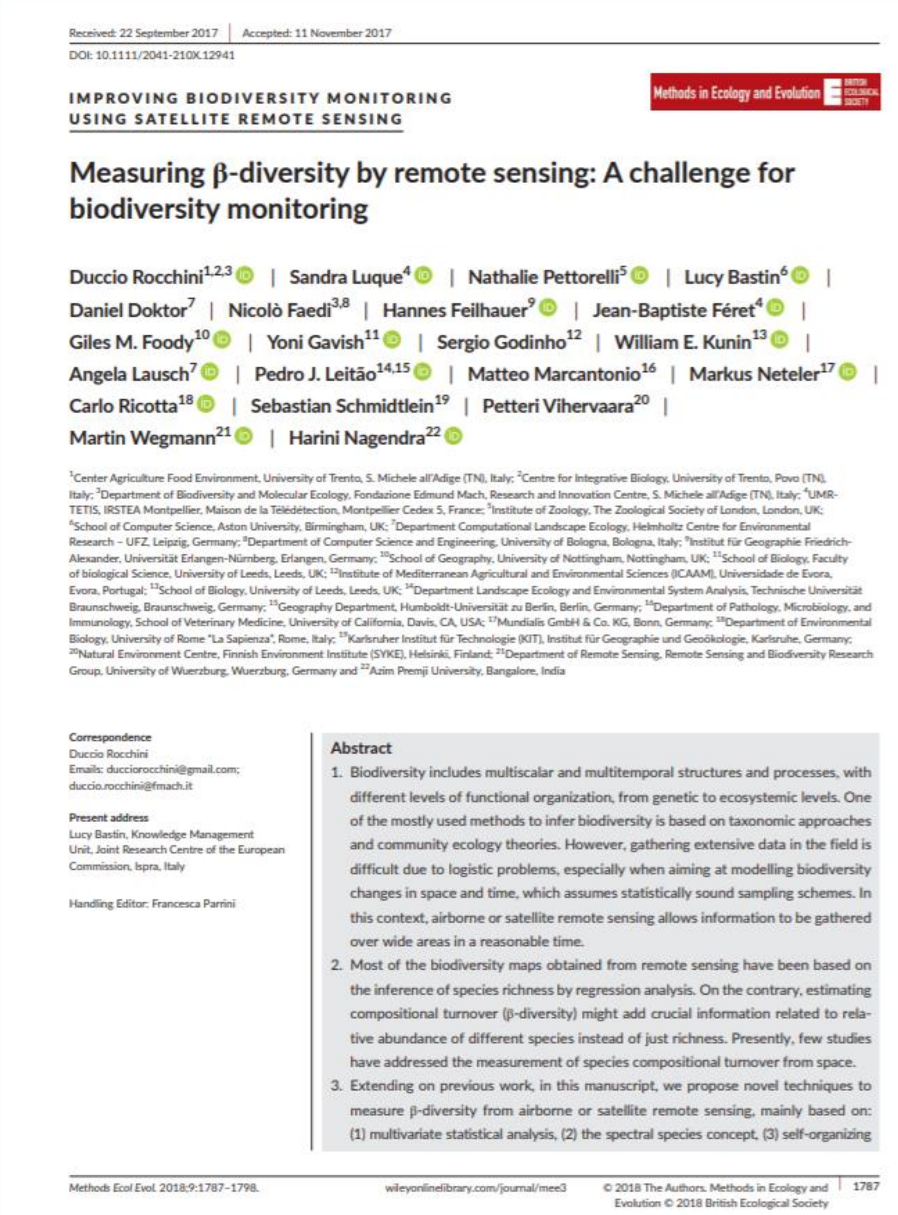
Modelling and mapping of continuous patterns in collective properties of biodiversity



Generalised dissimilarity modelling (GDM)

Ferrier, S et al (2007) *Diversity & Distributions*

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Methods in Ecology and Evolution

IMPROVING BIODIVERSITY MONITORING USING SATELLITE REMOTE SENSING

Measuring β-diversity by remote sensing: A challenge for biodiversity monitoring

Duccio Rocchini[1,2,3] | Sandra Luque[4] | Nathalie Pettorelli[5] | Lucy Bastin[6] | Daniel Doktor[7] | Nicolò Faedi[3,8] | Hannes Feilhauer[9] | Jean-Baptiste Féret[4] | Giles M. Foody[10] | Yoni Gavish[11] | Sergio Godinho[12] | William E. Kunin[13] | Angela Lausch[7] | Pedro J. Leitão[14,15] | Matteo Marcantonio[16] | Markus Neteler[17] | Carlo Ricotta[18] | Sebastian Schmidtlein[19] | Petteri Vihervaara[20] | Martin Wegmann[21] | Harini Nagendra[22]

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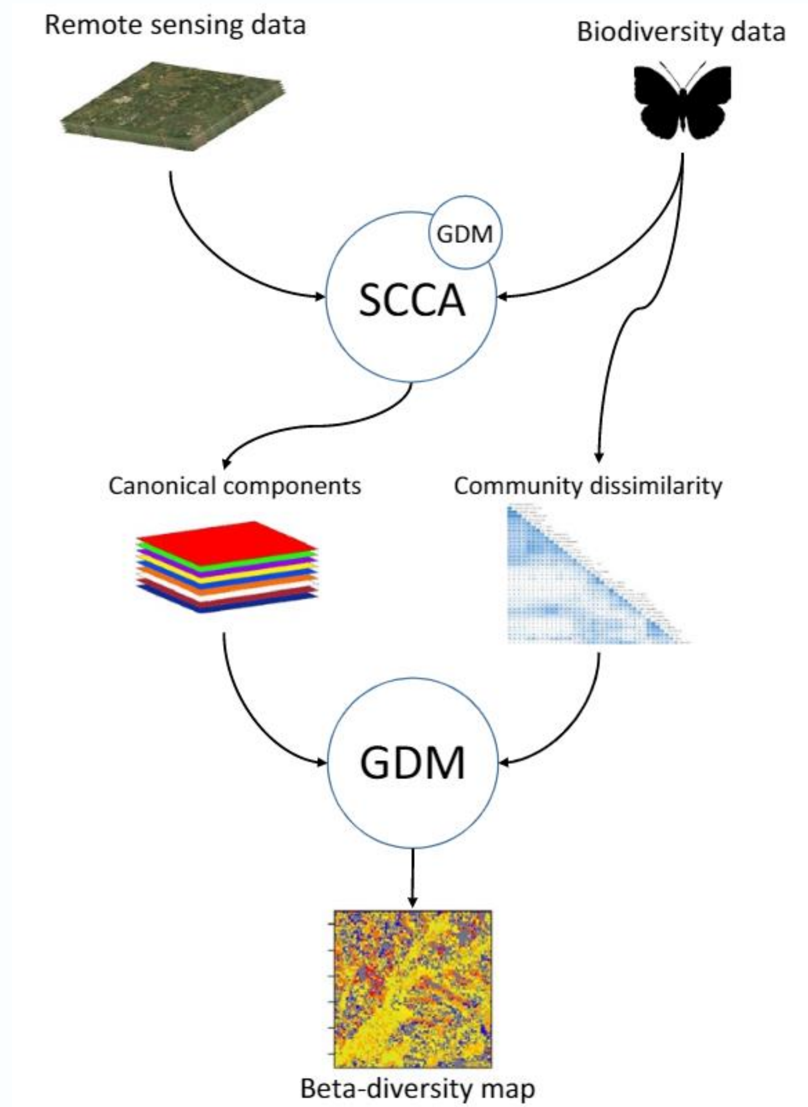
Handling Editor: Francesca Parrini

Abstract

1. Biodiversity includes multiscalar and multitemporal structures and processes, with different levels of functional organization, from genetic to ecosystemic levels. One of the mostly used methods to infer biodiversity is based on taxonomic approaches and community ecology theories. However, gathering extensive data in the field is difficult due to logistic problems, especially when aiming at modelling biodiversity changes in space and time, which assumes statistically sound sampling schemes. In this context, airborne or satellite remote sensing allows information to be gathered over wide areas in a reasonable time.
2. Most of the biodiversity maps obtained from remote sensing have been based on the inference of species richness by regression analysis. On the contrary, estimating compositional turnover (β-diversity) might add crucial information related to relative abundance of different species instead of just richness. Presently, few studies have addressed the measurement of species compositional turnover from space.
3. Extending on previous work, in this manuscript, we propose novel techniques to measure β-diversity from airborne or satellite remote sensing, mainly based on: (1) multivariate statistical analysis, (2) the spectral species concept, (3) self-organizing



Pedro Leitão's work

Methods in Ecology and Evolution

Methods in Ecology and Evolution 2015, **6**, 764–771 doi: 10.1111/2041-210X.12378

Mapping beta diversity from space: Sparse Generalised Dissimilarity Modelling (SGDM) for analysing high-dimensional data

Pedro J. Leitão[1,2]*, Marcel Schwieder[1], Stefan Suess[1], Inês Catry[2], Edward J. Milton[3], Francisco Moreira[2], Patrick E. Osborne[4], Manuel J. Pinto[5], Sebastian van der Linden[1] and Patrick Hostert[1]

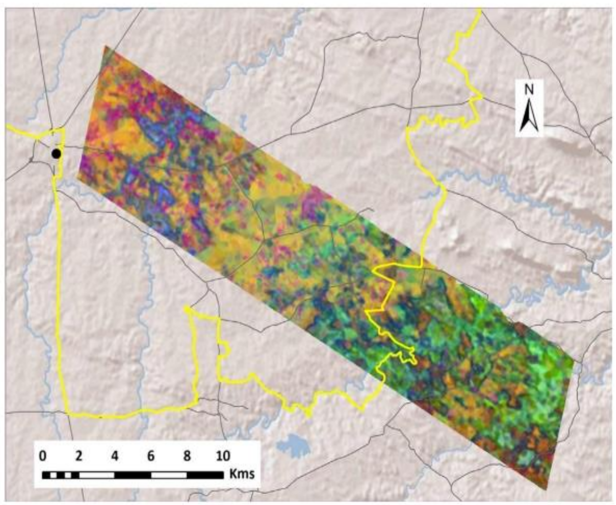


Fig. 3. Example of species compositional turnover mapping in the study area with Sparse Generalised Dissimilarity Modelling based on Landsat time series. The predicted dissimilarities between the sample plots were transformed with Non-metric Multi-Dimensional Scaling. The resulting three axes were applied to the image and visualised on the red, green and blue channels. Roads are represented by the grey lines, the limits of the Castro Verde Special Protection Area by the yellow line and the Castro Verde town by black circle.

Remote Sensing in Ecology and Conservation Open Access ZSL LET'S WORK FOR WILDLIFE

ORIGINAL RESEARCH

Mapping woody plant community turnover with space-borne hyperspectral data – a case study in the Cerrado

Pedro J. Leitão[1,2], Marcel Schwieder[1], Fernando Pedroni[3], Maryland Sanchez[3], José R. R. Pinto[4], Leandro Maracahipes[5], Mercedes Bustamante[6] & Patrick Hostert[1,7]

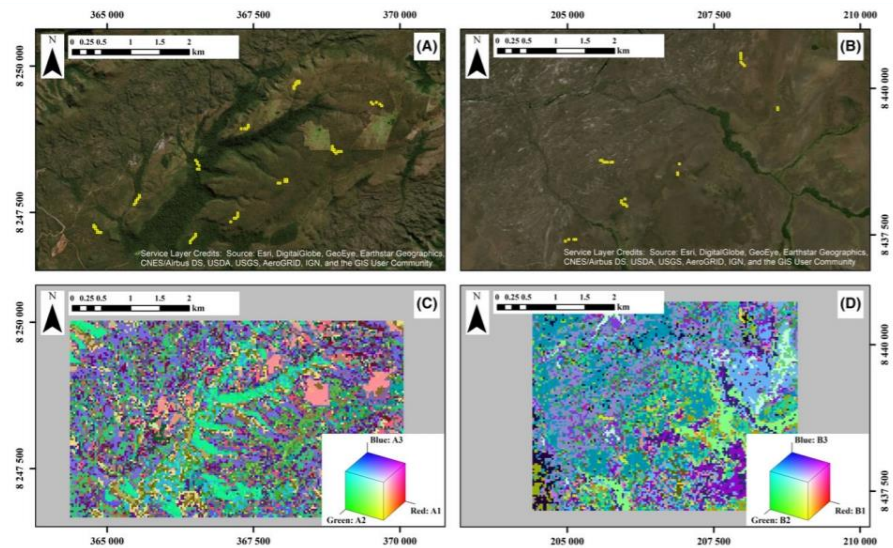


Figure 3. Above (in yellow) the location of the sampled pixels with a sample cover of at least 75% in PESA, Parque Estadual da Serra Azul (A) and PNCV, Parque Nacional da Chapada dos Veadeiros (B). Below, RGB maps of the main axes of variation in species turnover in PESA (C) and PNCV (D) woody plant communities. Each of the first three NMDS axes (A1 to A3 for PESA and B1 to B3 for PNCV) were, respectively, plotted in the R, G and B channels, so that, for example, a bright turquoise pixel would mean high loadings on axes 2 and 3 (high values on both the G and B channels).

Technische Universität Braunschweig

INSTITUT FÜR GEOÖKOLOGIE
Landschaftsökologie und Umweltsystemanalyse

Mapping Cerrado woody plant community turnover with spaceborne imaging spectroscopy data

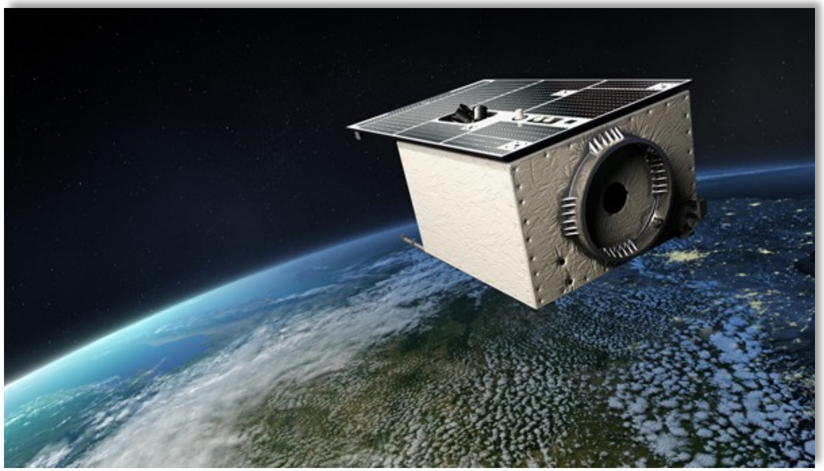
Pedro J. Leitão,

Marcel Schwieder, Fernando Pedroni, Maryland Sanchez, José R. R. Pinto, Mercedes Bustamante, Patrick Hostert

Motivation & Aims:

- Mapping and monitoring **spatial patterns** of **community composition** and **turnover** using **spaceborne imaging spectroscopy**

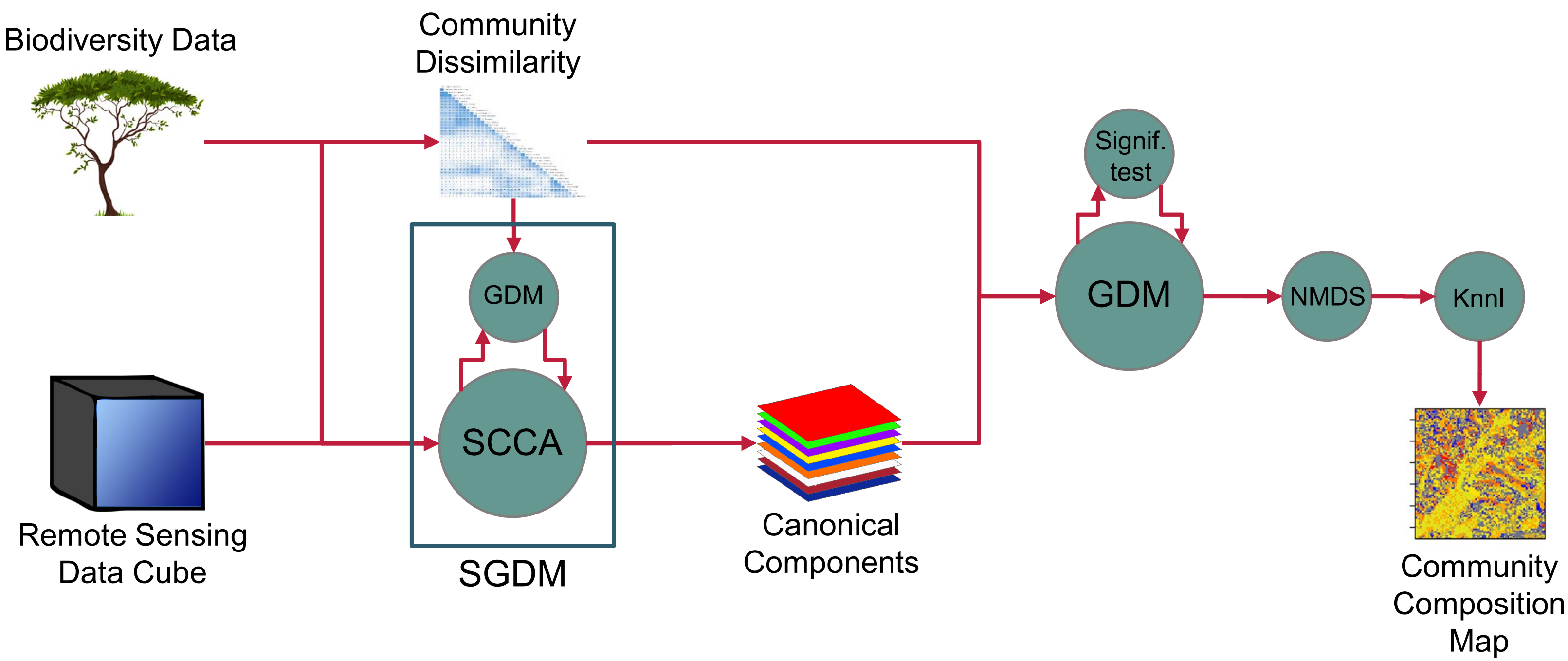
- Develop an **operational method** capable of dealing with high-dimensional and high-collinear remote sensing data



The EnMAP is one of several forthcoming spaceborne imaging spectroscopy missions

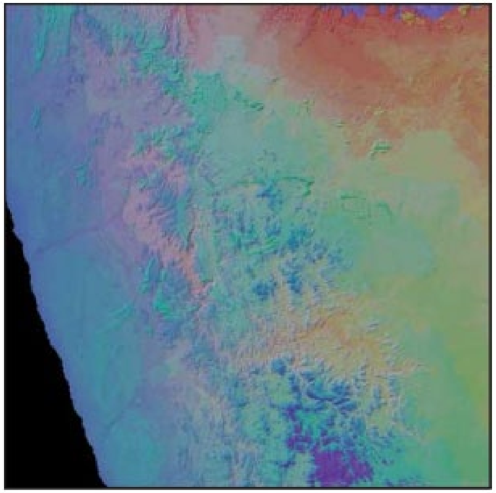
Methods:

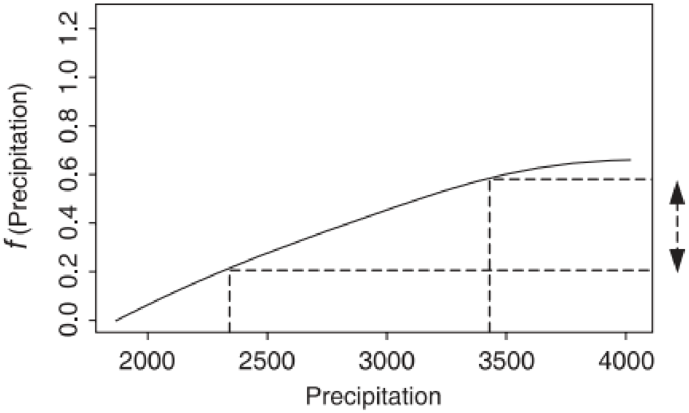
- Sparse Generalized Dissimilarity Modelling (SGDM)



Methods:

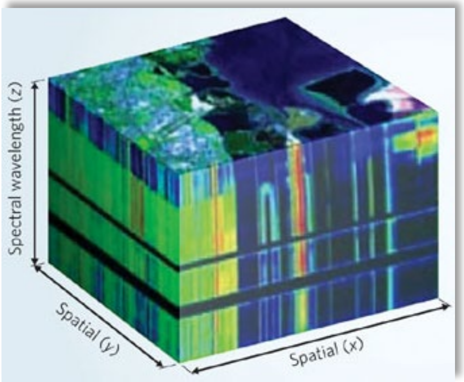
- Sparse Generalized Dissimilarity Modelling (SGDM)
  - Generalized Dissimilarity Modelling (GDM)
    - A statistical technique for analysing and predicting patterns of turnover in community composition
    - Fits non-linear functions on the environmental variables to predict compositional dissimilarity
    - Affected by data collinearity



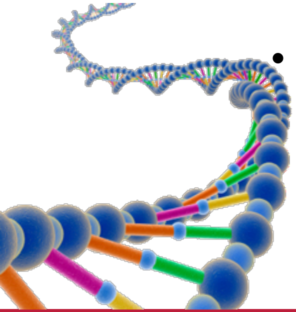


Methods:

- Sparse Generalized Dissimilarity Modelling (SGDM)
    - Sparse Canonical Correlation Analysis (SCCA)



- Supervised transformation approach
- Used in genetic research, where typically number of features is much greater than number of samples
- Transforms two matrices in order to maximise the correlation between them
- Based on penalised (Lasso) regression, thus downweighting redundant data
- Capable of (and designed for) dealing with high-dimensional and high-collinear datasets



Methods:

- Sparse Generalized Dissimilarity Modelling (SGDM)

sgdm Package

Methods in Ecology and Evolution

British Ecological Society

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Mapping beta diversity from space: Sparse Generalised Dissimilarity Modelling (SGDM) for analysing high-dimensional data

Pedro J. Leitão[1,2]*, Marcel Schwieder[1], Stefan Suess[1], Inês Catry[2], Edward J. Milton[3], Francisco Moreira[2], Patrick E. Osborne[4], Manuel J. Pinto[5], Sebastian van der Linden[1] and Patrick Hostert[1]

➢ 2015, Description of the SGDM method

isprs International Journal of *Geo-Information* MDPI

Communication

sgdm*: An R Package for Performing Sparse Generalized Dissimilarity Modelling with Tools for *gdm

Pedro J. Leitão *, Marcel Schwieder and Cornelius Senf

➢ 2017, Description of the *sgdm* R package

Remote Sensing in Ecology and Conservation Open Access ZSL LET'S WORK FOR WILDLIFE

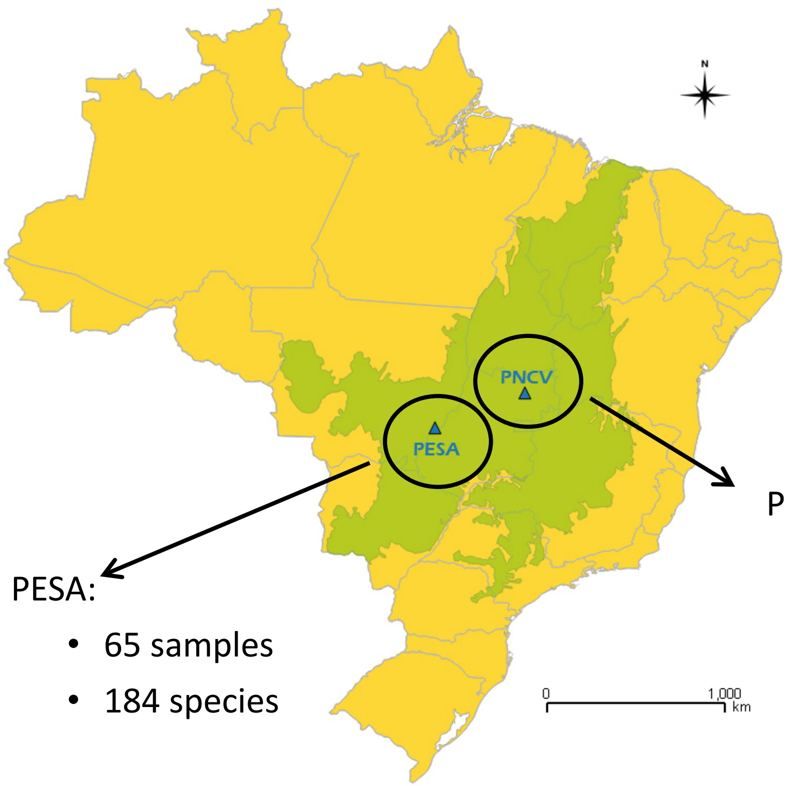
Mapping woody plant community turnover with spaceborne hyperspectral data – a case study in the Cerrado

Pedro J. Leitão[1,2]*, Marcel Schwieder[1], Fernando Pedroni[3], Maryland Sanchez[3], José Roberto R. Pinto[4], Leandro Maracahipes[5], Mercedes Bustamante[6] and Patrick Hostert[1,7]

➢ 2018, Mapping Cerrado woody plant communities

Data:

- Woody plant inventory data following a systematic sampling scheme (RAPELD adapted to the Cerrado)



PESA:

- 65 samples
- 184 species

PNCV:

- 29 samples
- 94 species

Floristic gradients

Data:

- Hyperion (hyperspectral) data

  - Pre-processing:
    - Radiometric correction
    - Correction for pixel shift, striping, keystone & smile
    - Atmospheric correction
    - Geometric correction
    - Spectral smoothing

  - Post-processing:
    - Data quality screening > 81 spectral bands remaining per image

esa ECOSPHERE

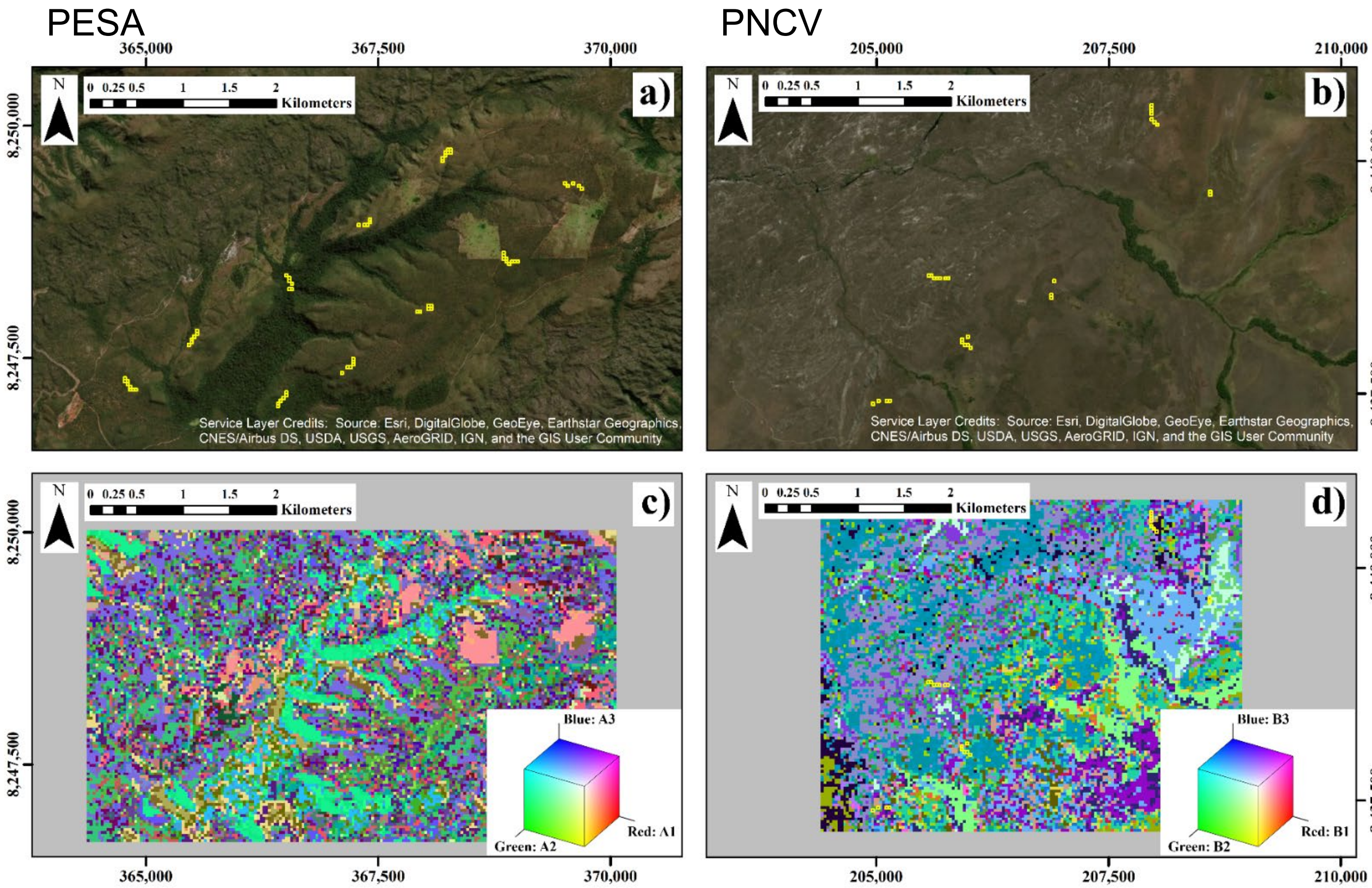
EMERGING TECHNOLOGIES

From sample to pixel: multi-scale remote sensing data for upscaling aboveground carbon data in heterogeneous landscapes

Pedro J. Leitão,[1,2,]† Marcel Schwieder,[1] Florian Pötzschner,[1] José R. R. Pinto,[3] Ana M. C. Teixeira,[4] Fernando Pedroni,[5] Maryland Sanchez,[5] Christian Rogass,[6] Sebastian van der Linden,[1,7] Mercedes M. Bustamante,[8] and Patrick Hostert[1,7]

Results:

- Woody plant community maps



$R^2 = 0.710$ $R^2 = 0.392$

Results:

- Spectral band contribution

PESA		PNCV	
Spectral band	Relative contribution	Spectral band	Relative contribution
620.15 (R)	4.229	569.27 (G)	4.039
701.55 (RE)	4.137	1517.83 (SWIR)	3.377
630.32 (R)	3.804	1507.73 (SWIR)	3.237
599.80 (G)	3.679	609.97 (R)	3.138
640.50 (R)	3.637	477.69 (B)	2.979
609.97 (G)	3.498	1568.22 (SWIR)	2.911
1285.76 (NIR)	3.442	1598.51 (SWIR)	2.821
732.07 (RE)	3.107	1235.27 (NIR)	2.711
650.67 (R)	2.939	579.45 (G)	2.664
589.62 (G)	2.642	467.52 (B)	2.629
1719.60 (SWIR)	2.544	1225.17 (NIR)	2.615
518.39 (G)	2.529	1003.30 (NIR)	2.570
498.04 (B)	2.503	1527.92 (SWIR)	2.509
579.45 (G)	2.376	589.62 (G)	2.042
1537.92 (SWIR)	2.343	874.53 (NIR)	1.928

Conclusions & Discussion

- Our method allowed for mapping species community turnover using spaceborne imaging spectroscopy

- Relevant considerations/challenges for the generalization of SGDM include:
  - The method is not suitable for data extrapolation (i.e. models need to include the full data space)
  - Input spectral data needs to be harmonized
  - It is sensitive to
    - Detection/correction of atmospheric effects
    - Topographic/shading effects
    - Phenological changes
  - Sensitivity to temporal or physiological changes needs to be tested

Thank you for your attention

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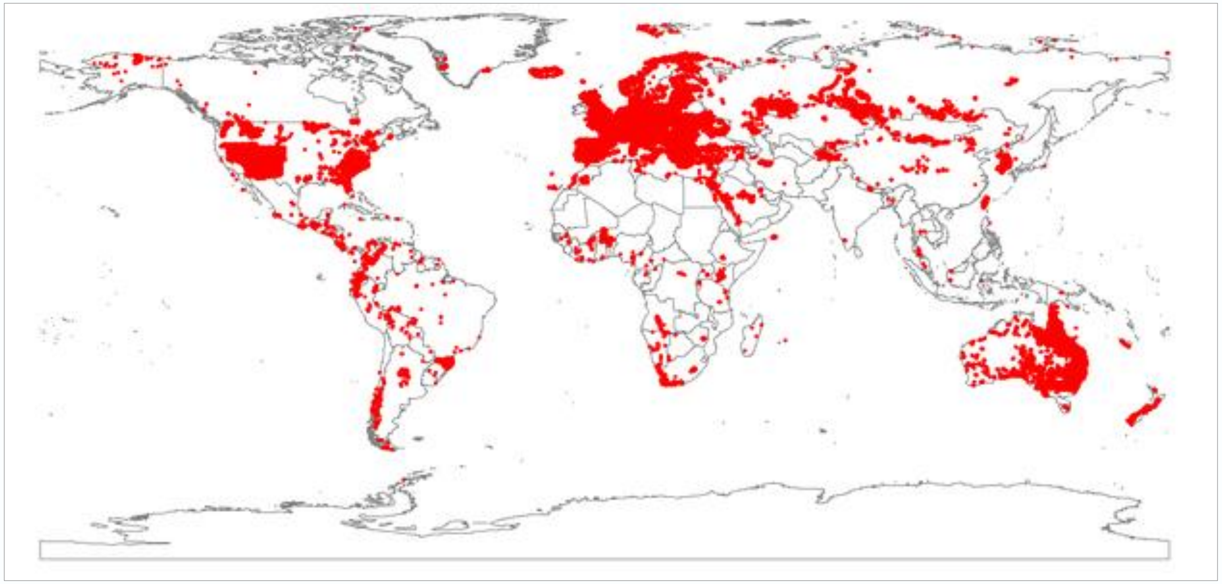
Where to from here? – strategies for accessing or generating data to further test and develop ideas

- Combine existing spaceborne hyperspectral data (e.g. Hyperion archive) and coincident existing vegetation plot data (e.g. sPlot database)
- Simulate spaceborne hyperspectral data by aggregating existing airborne data (e.g. AVIRIS) across areas with existing vegetation plot data
- Commission spaceborne data (e.g. DESIS) across areas with existing vegetation plot data
- Collect new vegetation plot data across areas with good spaceborne and/or airborne hyperspectral data coverage

Over 93,000 of the 1.12 million vegetation plots in the sPlot database fall within Hyperion scenes

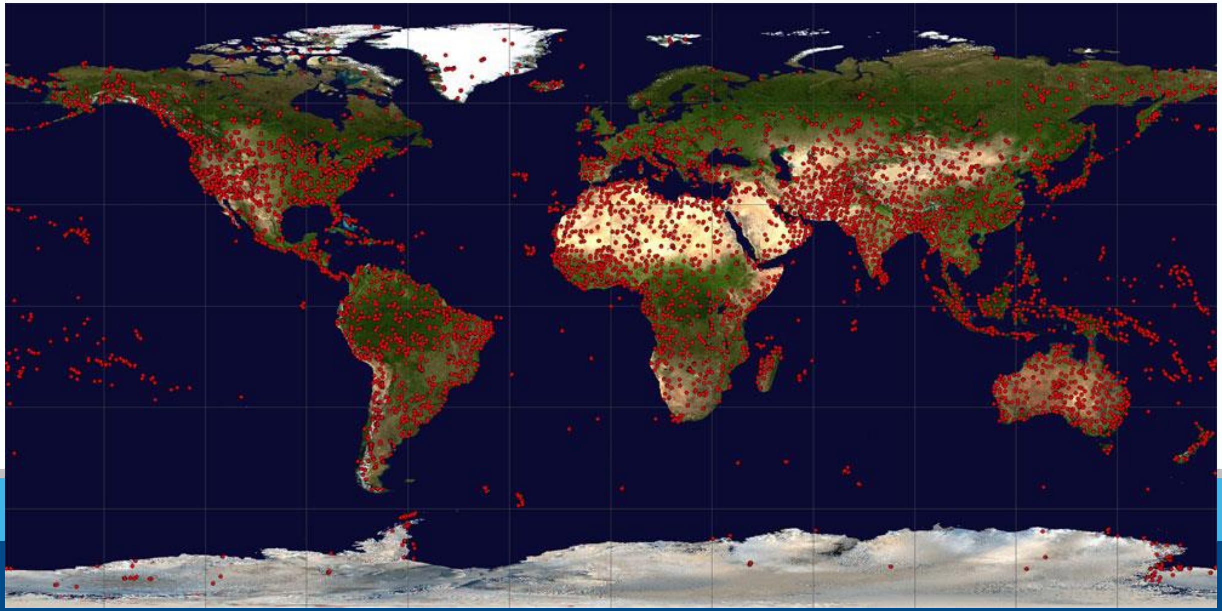


sPlot

Vegetation plots

iDiv

German Centre for Integrative Biodiversity Research (iDiv)
Halle-Jena-Leipzig



EO-1 Hyperion: archive scenes

CSIRO

Where to from here? – strategies for accessing or generating data to further test and develop ideas

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Where to from here? – numerous challenges in refining and extending the analytical approach – for example …

- Accommodating shorter-term temporal dynamics (seasonality, drought, fire etc)
- Disentangling natural and anthropogenic drivers of variation in community composition
- Coupling spaceborne imaging spectroscopy with other cutting-edge observation technologies – e.g. eDNA / metabarcoding / metagenomics

nature ecology & evolution

PERSPECTIVE

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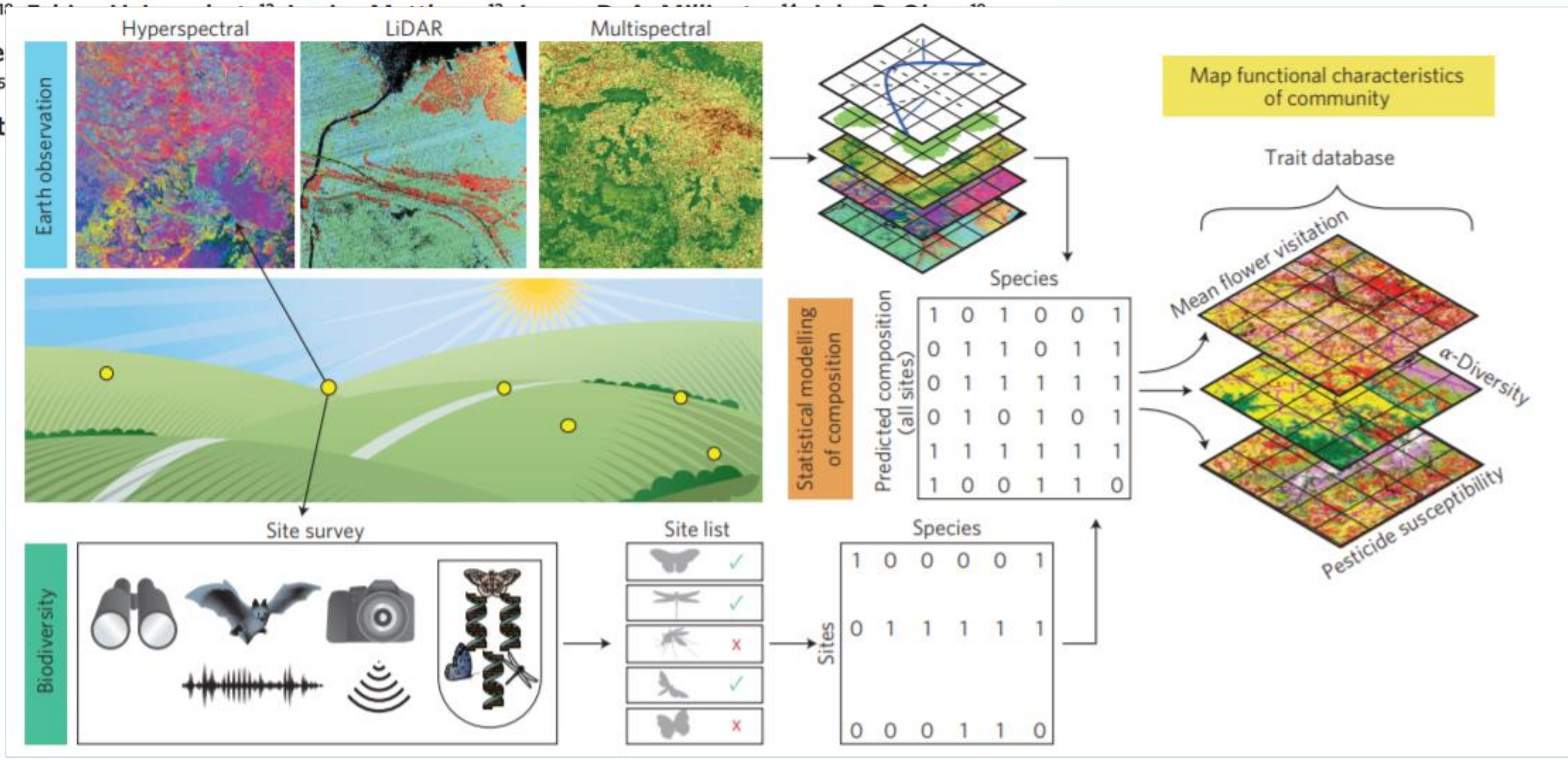
Connecting Earth observation to high-throughput biodiversity data

Alex Bush[1,2,3], Rahel Sollmann[4], Andreas Wilting[5], Kristine Bohmann[6,7], Beth Cole[8], Heiko Balzter[8,9], Christopher Martius[10], András Zlinszky[11], Sébastien Calvignac-Spencer[12], Christina A. Cobbold[13], Terence P. Dawson[14], Brent C. Emerson[15,7], Simon Ferrier[3], M. Thomas P. Gilbert[6,16], Martin Herold[17], Laurence Jones
Otso Ovaskaine
Stewart Snape[25]
Martin J. Woost



Drummond *et al. GigaScience* (2015) 4:46
DOI 10.1186/s13742-015-0086-1

(GIGA)^n SCIENCE

RESEARCH **Open Access**

Evaluating a multigene environmental DNA approach for biodiversity assessment

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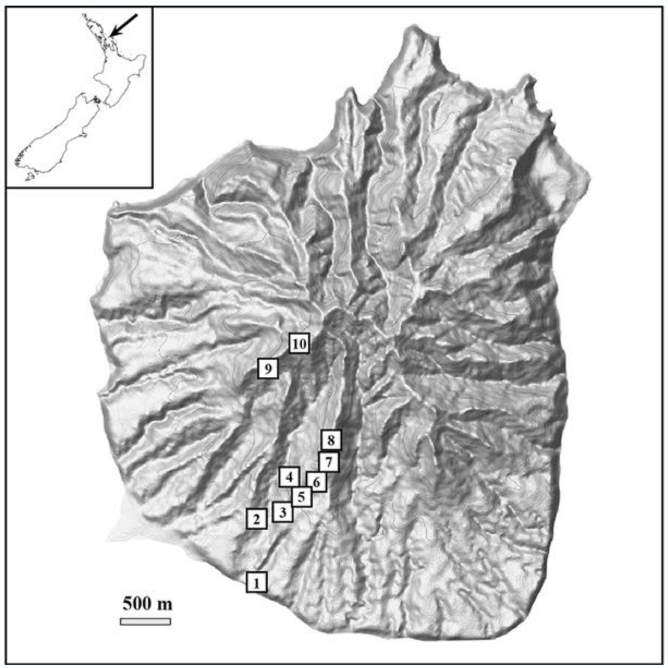


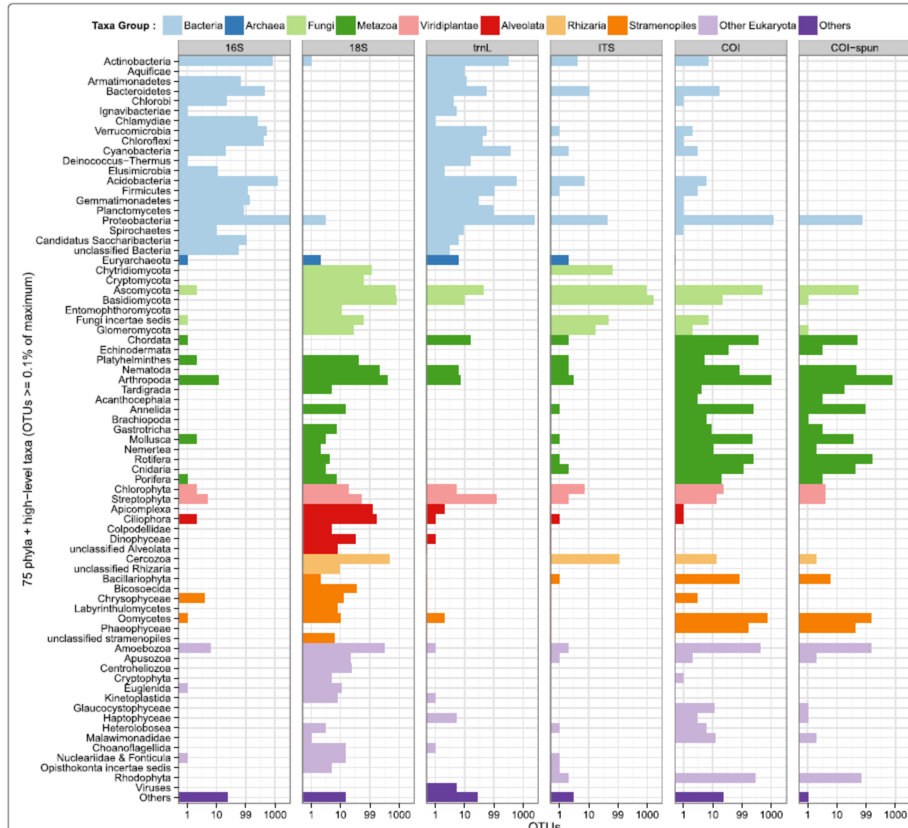
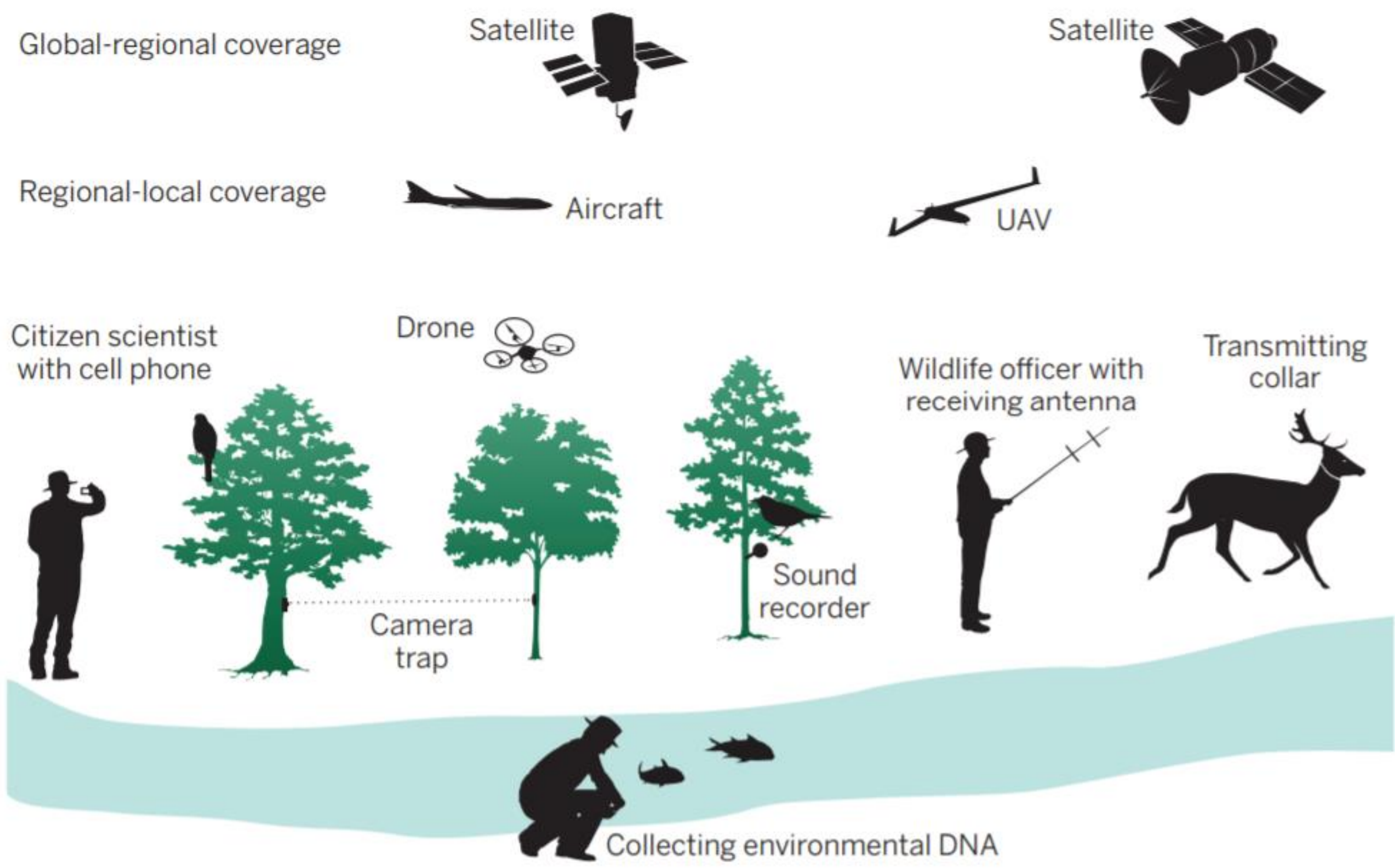


Fig. 3 The number of OTUs at the 97 % clustering threshold assigned to phyla. Unclassified OTUs and OTUs containing low-complexity sequences are not included, OTUs from phyla that are represented by less than 0.1 % of the OTUs are grouped into the 'Others' category

Sensing biodiversity

Sophisticated networks are required to make the best use of biodiversity data from satellites and in situ sensors

Turner, W (2014) *Science*



Thank you

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