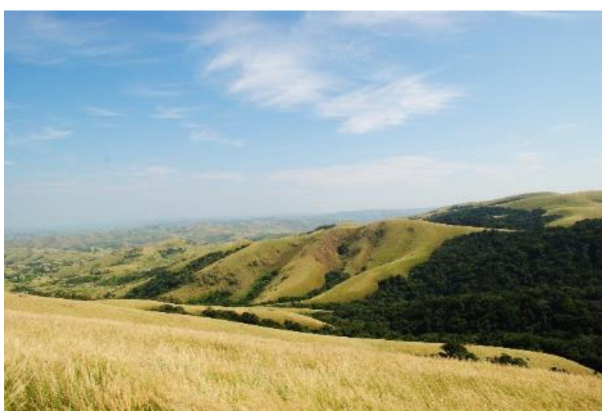
Mapping and predicting ecosystem functions and services under environmental changes

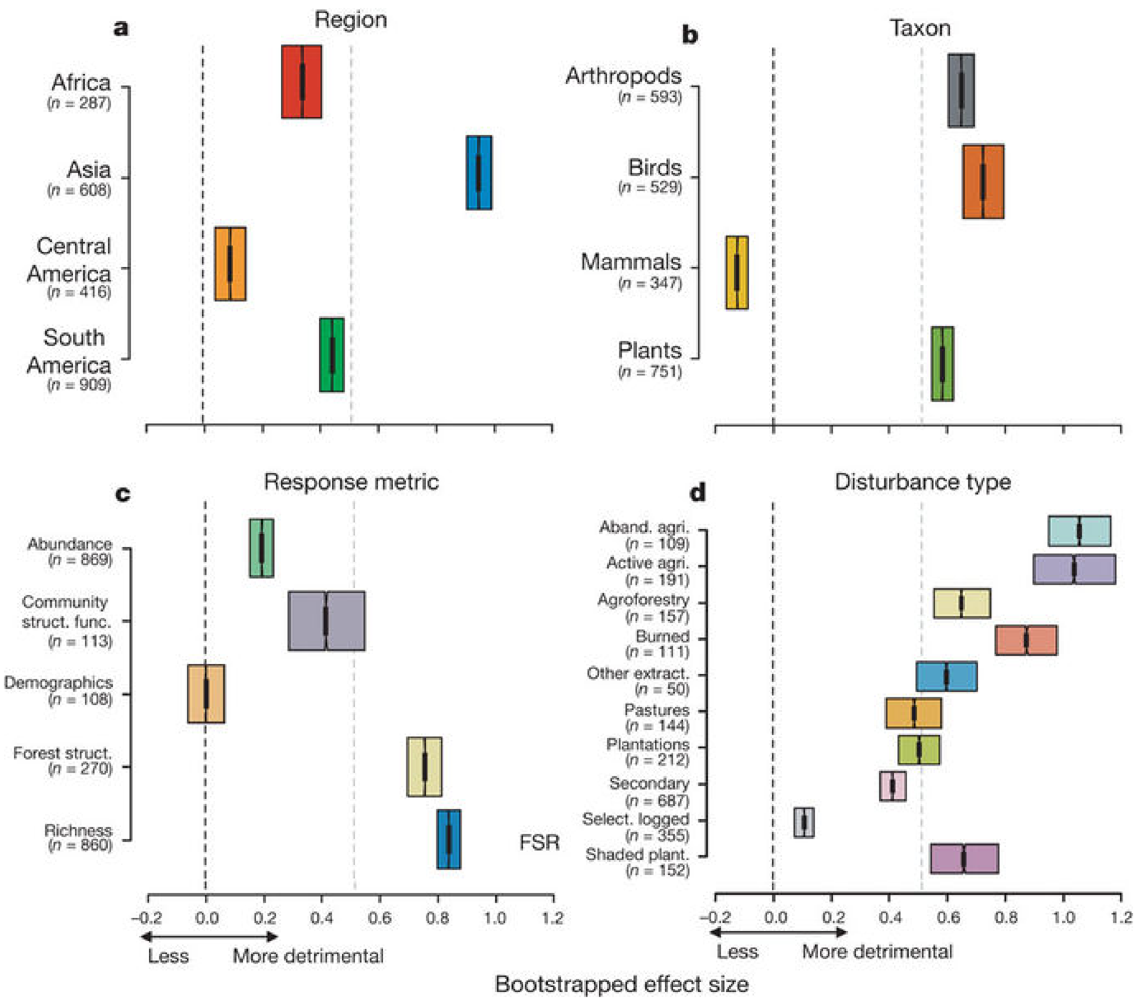
Dr Marion Pfeifer, SNES, Newcastle University. Talk @Zurich, May 2018

Human-modified landscapes in the tropics!



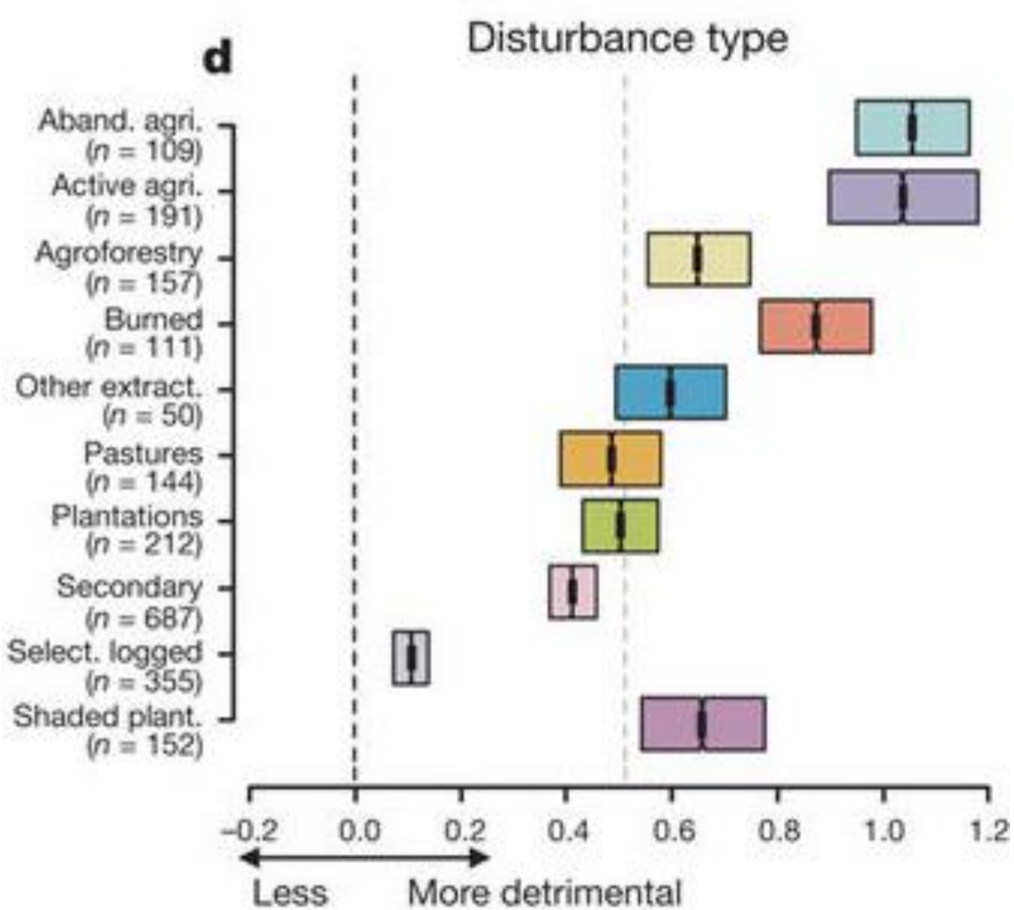
Where is the biodiversity?



Human activities reduce biodiversity, which is concentrated in tropical forests, with the effect size varying by region, taxonomic group, response metric and disturbance type

Gibson et al. 2011 ***Nature*** 478, 378-381

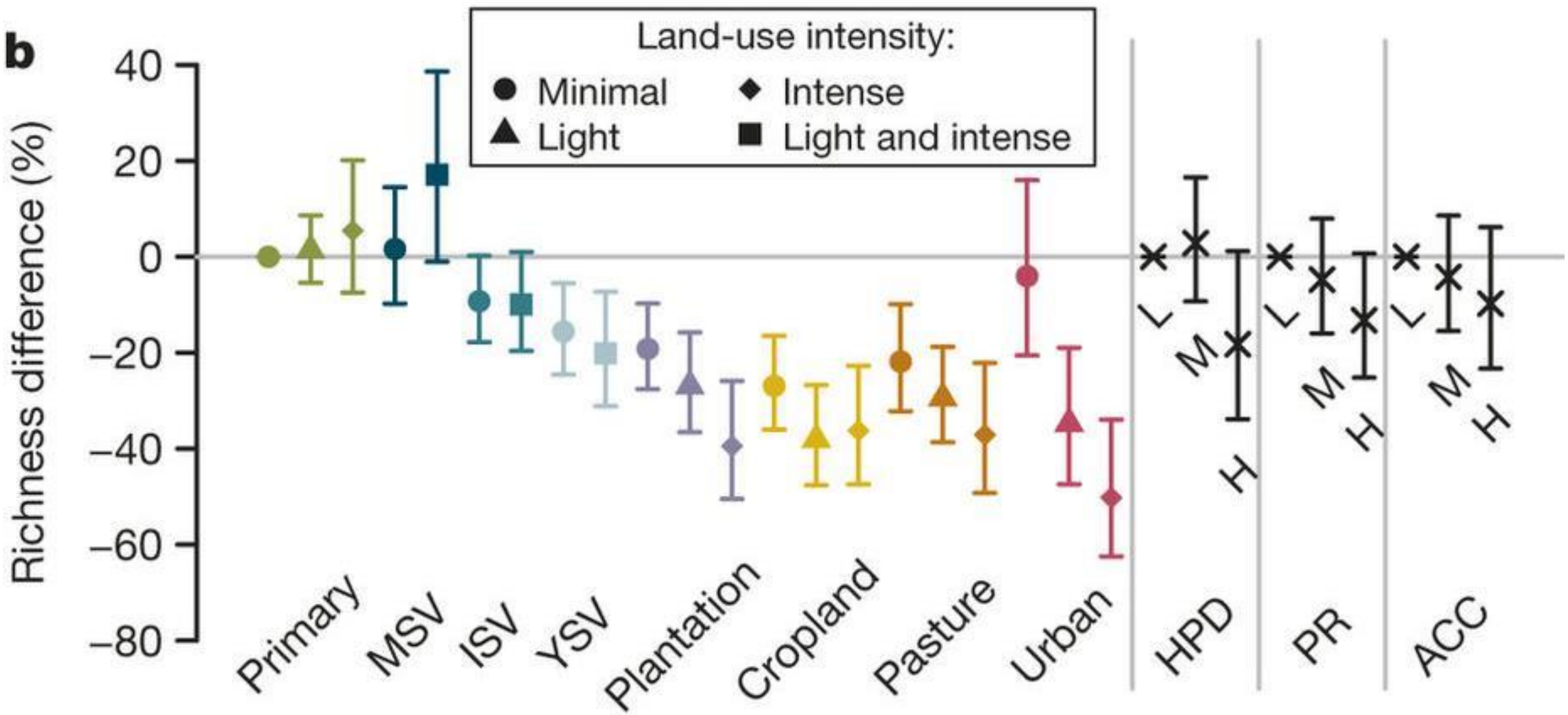
Tropical forests are biodiversity refugia



Agricultural land-use classes (abandoned and active agricultural sites) has a much greater impact than agroforestry systems and plantations (both shaded and unshaded)

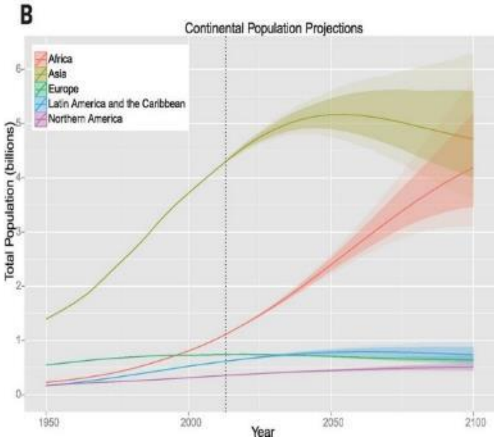
Gibson et al. 2011 ***Nature*** 478, 378-381

A similar study – with similar findings



Newbold et al. 2015 ***Nature*** 478, 378-381

Land use change drives biodiversity declines



There is an 80% probability that the world population will increase by 2100 to

9.6 billion - 12.3 billion

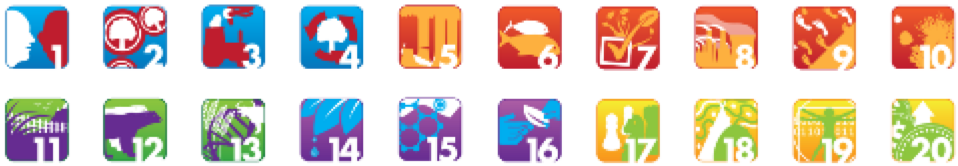
Gerland et al. 2014 ***Science*** 346, 234-237

Ecosystem loss to cropland & pasture in developing countries by 2050 would be:

half of all suitable remaining land

	2000	2050
N [MT]	$87 * 10^6$	$236 * 10^6$
P [MT]	$34.3 * 10^6$	$83.7 * 10^6$
Cropland [ha]	$1.54 * 10^9$	$1.89 * 10^9$
Pasture land [ha]	$3.47 * 10^9$	$4.01 * 10^6$
Irrigated land [ha]	$280 * 10^6$	$529 * 10^6$
Pesticide, produced [MT]	$3.75 * 10^6$	$10.1 * 10^6$

Tilman et al. 2001 ***Science*** 346, 234-237



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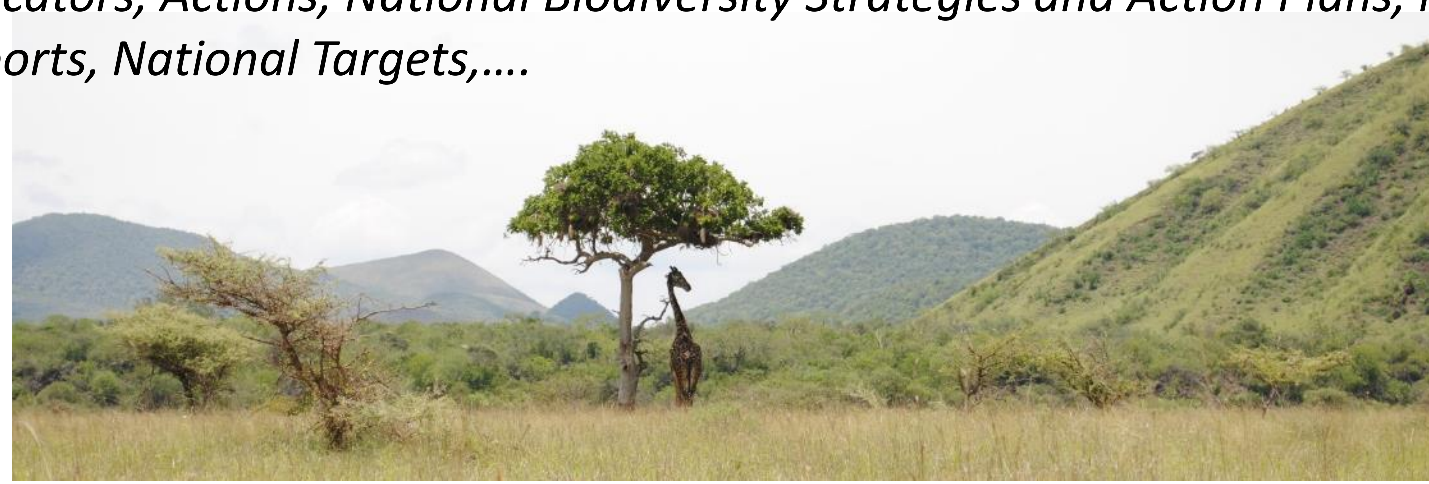
Aichi Biodiversity targets

Strategic Goals A – E (*shortened considerably* ☺): Address causes of biodiversity loss, reduce pressure and promote sustainable use, improve status of biodiversity, enhance benefits from biodiversity, enhance implementation through participation and capacity training

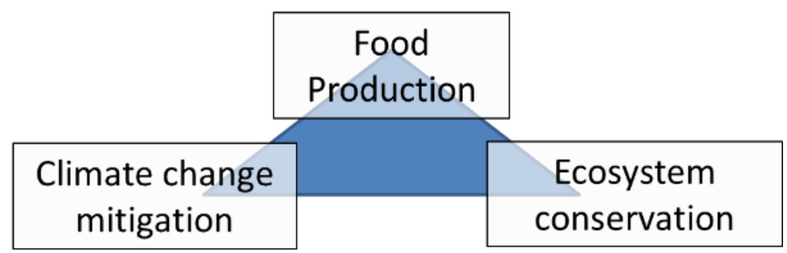
Indicators, Actions, National Biodiversity Strategies and Action Plans, National Reports, National Targets,….



Sustainable Development Goals

A set of 17 goals agreed in 2015 to end poverty, protect the planet and ensure prosperity for all as part of a new sustainable development agenda

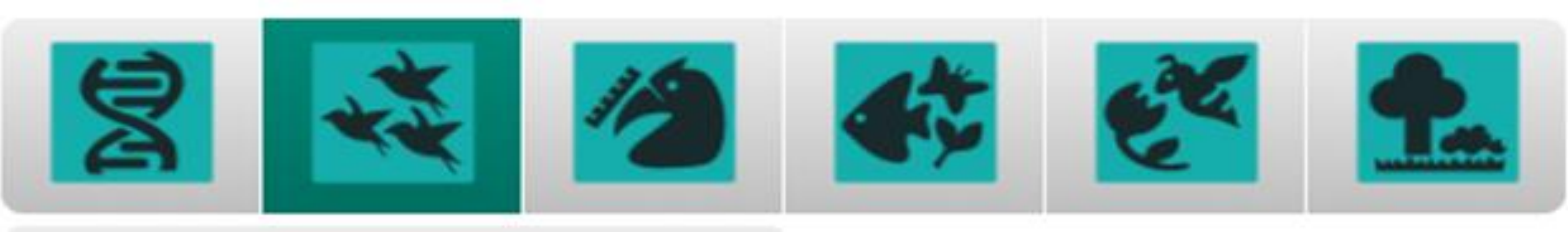
SDG Media Events to engage, Interviews, Panel Discussions, Policy Forum, Youth Leadership



The concept of Essential Biodiversity Variables

i.e. 'essential measurements to capture major dimensions of biodiversity change, complementary to one another and to other environmental change observation initiatives' (Pereira et al. 2013 ***Science*** 339, 277-278)

Genetic composition, Species traits, Abundance, Community composition, Ecosystem function, Ecosystem structure

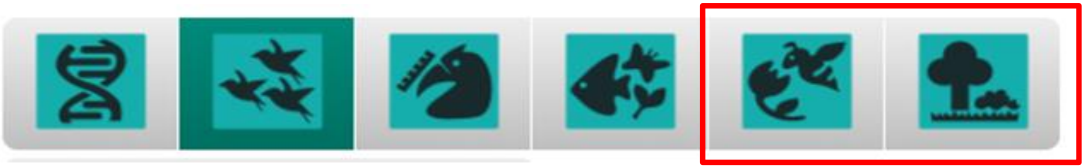


Criteria for Essential Biodiversity Variables

An ideal EBV should be

- able to capture critical scales and dimensions of biodiversity
- biological
- a state variable (in general)
- sensitive to change
- ecosystem agnostic (to the degree possible)
- technically feasible, economically viable and sustainable in time

Remote Sensing is listed as a key tool in the concept of Essential Biodiversity variables



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But where are we in the processing chain?

When sensing tropical human-modified landscapes remotely, how effectively can we (currently & realistically) monitor progress towards Aichi and SDG Targets

Genetic composition, Species traits, Abundance, Community composition, Ecosystem function, Ecosystem structure

Net Primary Productivity, Secondary productivity, Nutrient regimes & disturbance

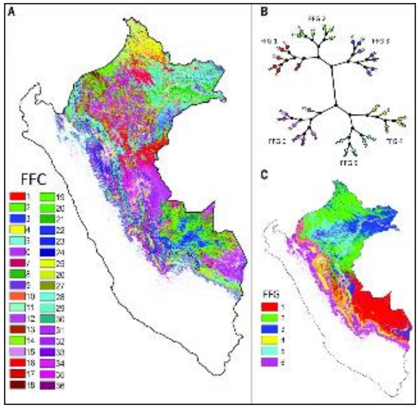
Habitat structure including in 3D, ecosystem extent & fragmentation, ecosystem functional types composition

What the literature suggests

Satellite remote sensing can play a crucial role in building EBV products including on species distributions & population abundances

- Accurate identification of large wildlife in open savannah habitats or penguins on ice (listed to support the argument by Kissling et al. 2017 ***Biological Reviews***)

- 'Spectranomics hype' (Asner lab): mapping forest biodiversity; or more precisely mapping canopy foliar chemical traits and especially Ca, P and Leaf Mass per Area (Asner et al. 2017 ***Biol Conservation***)



Yet, spectranomic maps are not

- Maps of tree species diversity or
- Maps of functions (instead of canopy chemical traits)

Yes, certainly:

- Biomass & structure mapping works beautifully & some studies show positive links between LIDAR & tree species richness (Laurin et al. 2016 **Int J Appl Earth Obs Geoinf**) or other diversity indices

Yet:

- Biomass is not a map of tree richness (Jucker et al. 2015 **J Ecol**)
- Maps of biomass are not necessarily maps of animal diversity (Beaudrot et al. 2015 **Ecol Appl**)

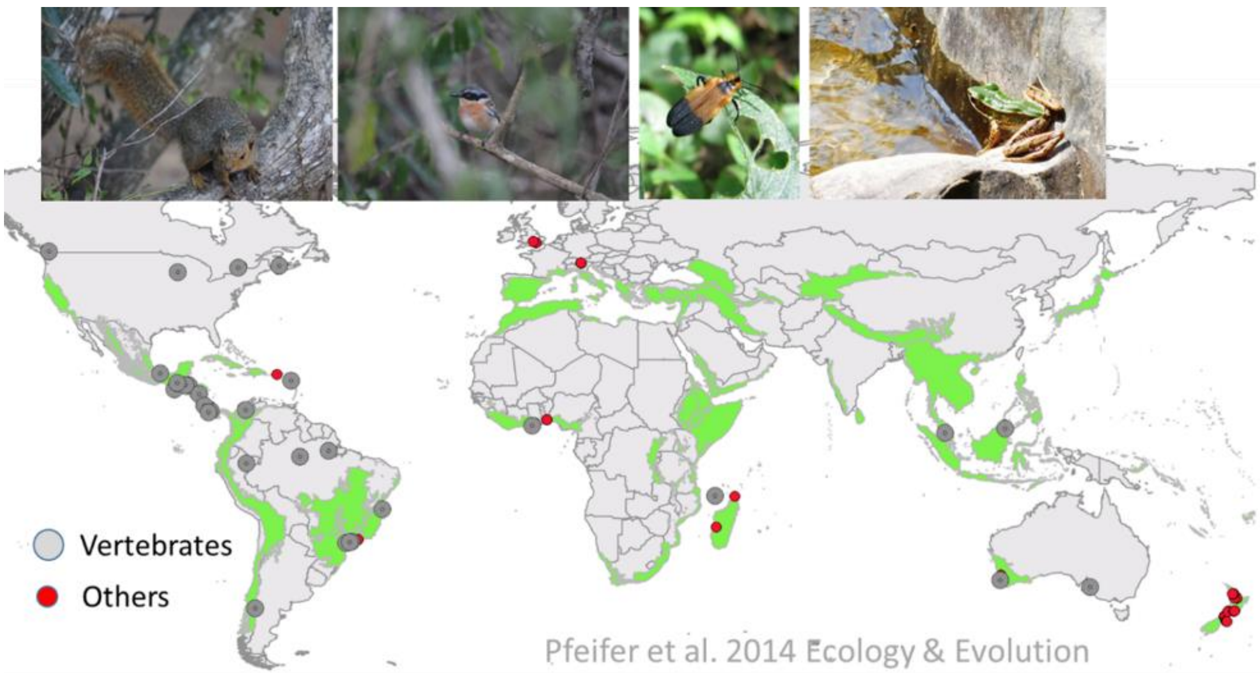
How much evidence is there for a link between structural metrics and species richness or species abundance metrics in tropical landscapes along ‘disturbance’ gradients?




Do local patterns hold at global scales?

Let's have a look at some global data first

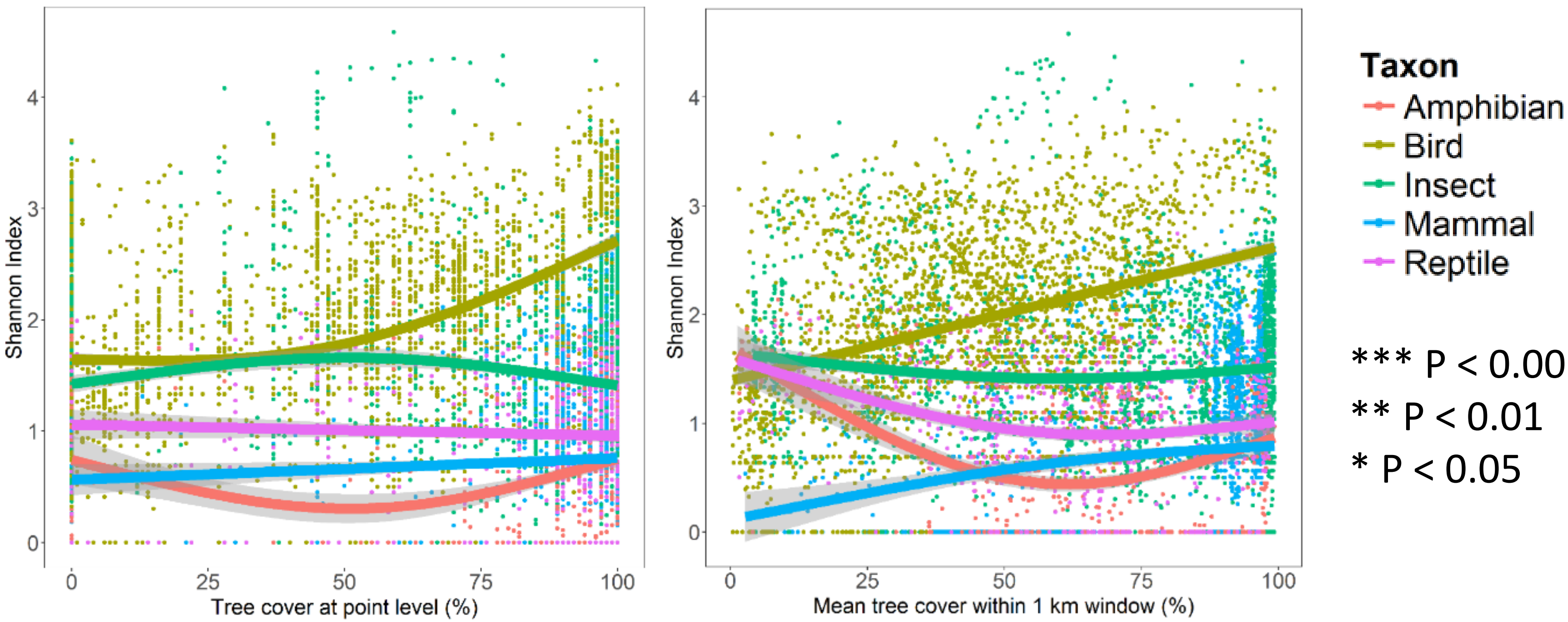
BIOFRAG datasets: https://biofrag.wordpress.com/



Hansen et al. 2013 tree cover maps:
https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html

Challenge 1: biodiversity – forest structure links

Species diversity not clearly linked to structure

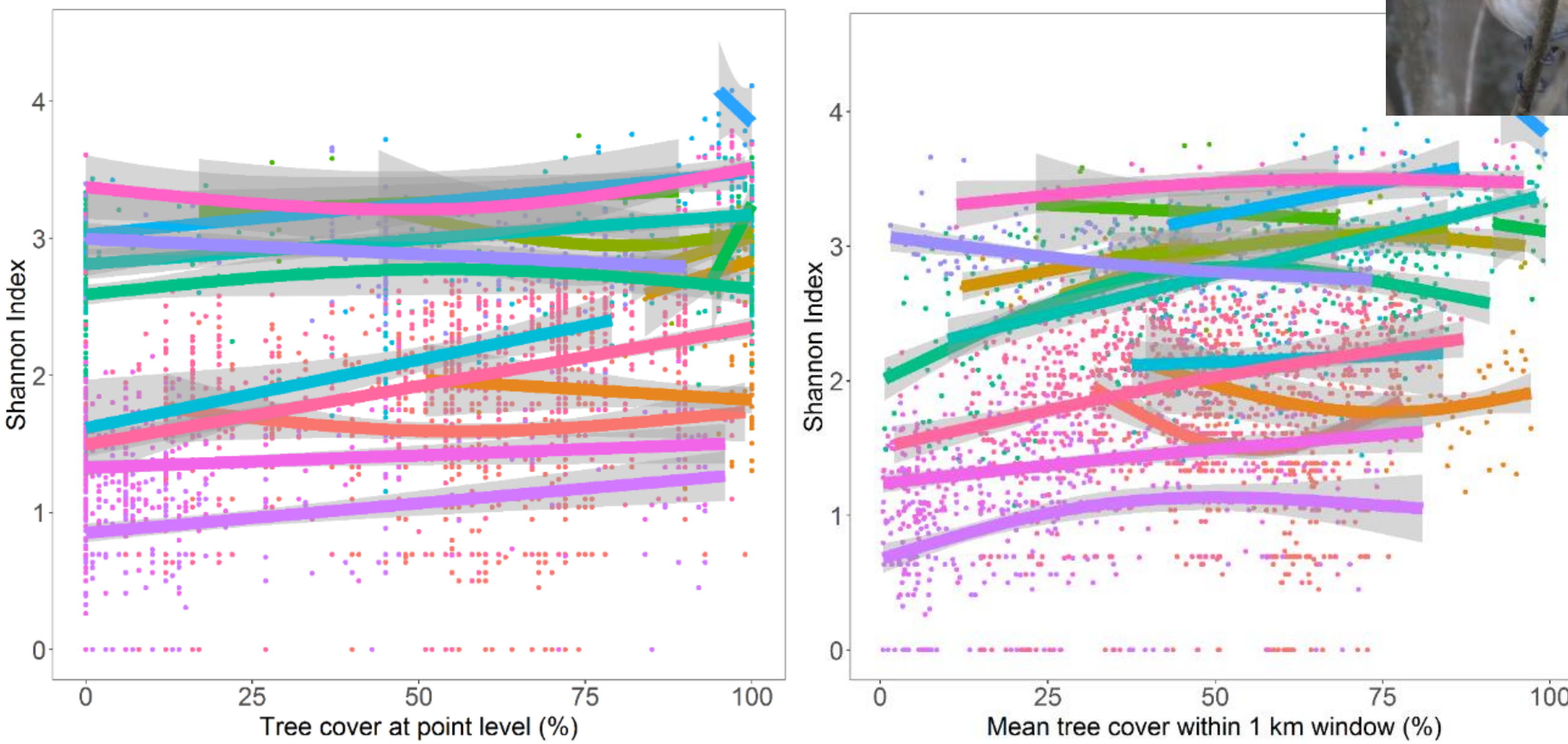


*** P < 0.001
** P < 0.01
* P < 0.05

	p	Coeff	D	D	p	Coeff	N
Amphibians	*	0.002	0.89	ns			492
Birds	***	0.009	14.3	12.4	***	0.012	2701
Mammals	*	0.002	0.27	1.84	***	0.005	2388
Reptiles	ns			2.11	***	-0.003	541

Huge variation at landscape scale

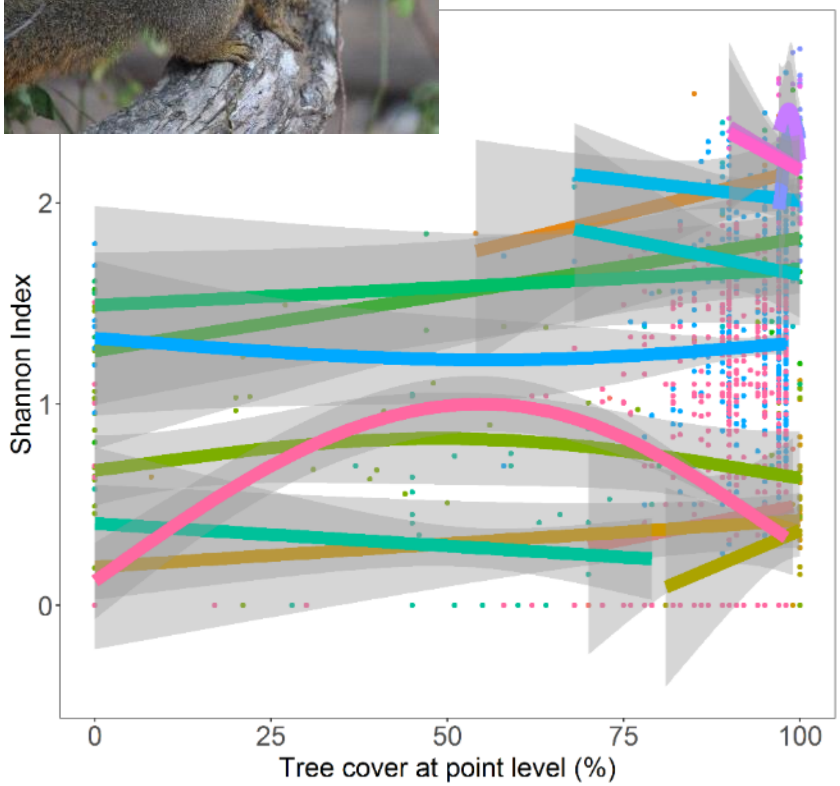
Birds: 17 landscapes

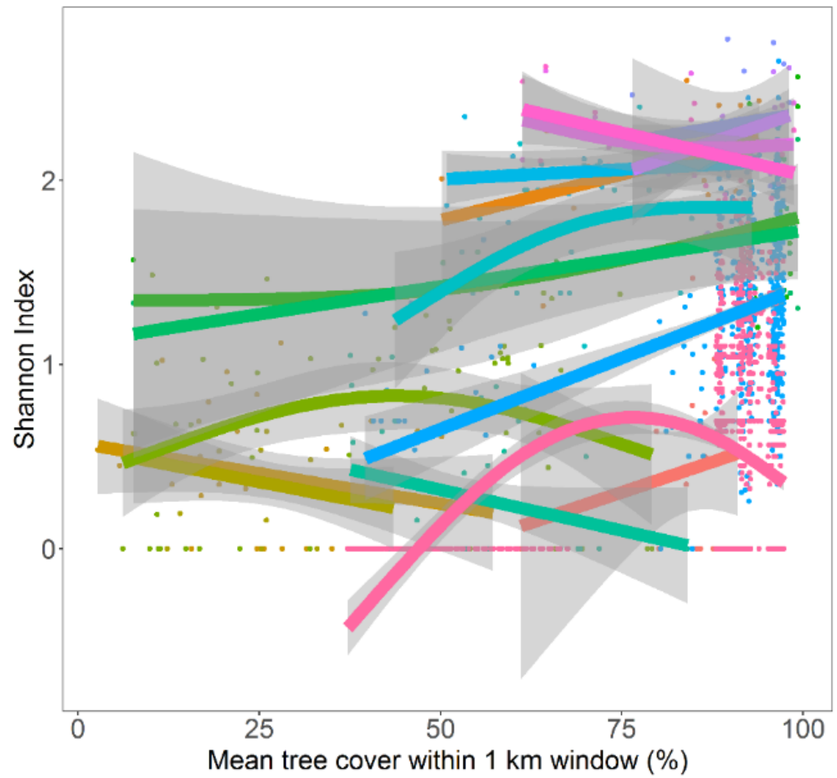


Challenge 1: biodiversity – forest structure links

Huge variation at landscape scale

Mammals: 16 landscapes





Challenge 2: habitat quality metrics

Tree cover (%) is perhaps not the best metric?

Habitat quality is an ubiquitous term. In terms of tropical forests, are we clear what we need to measure?:

- Canopy openness?
- 3D vegetation structure?
- Tree biomass?
- Tree density? …..
- Food plant availability (for plant-/nectar-eating animals)?

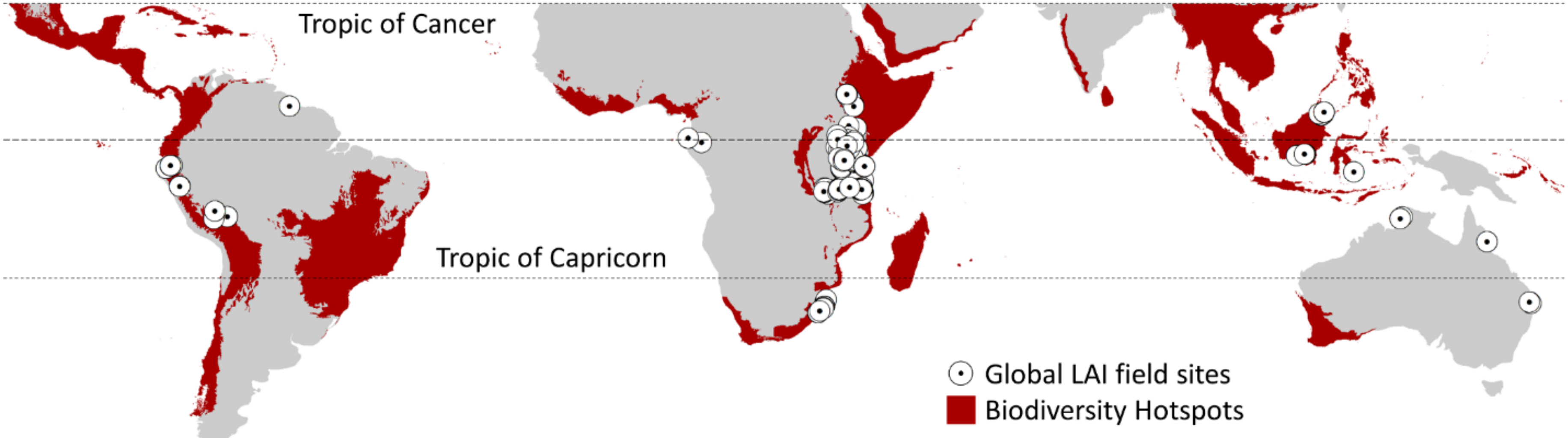
In terms of forest functions, it might be easier

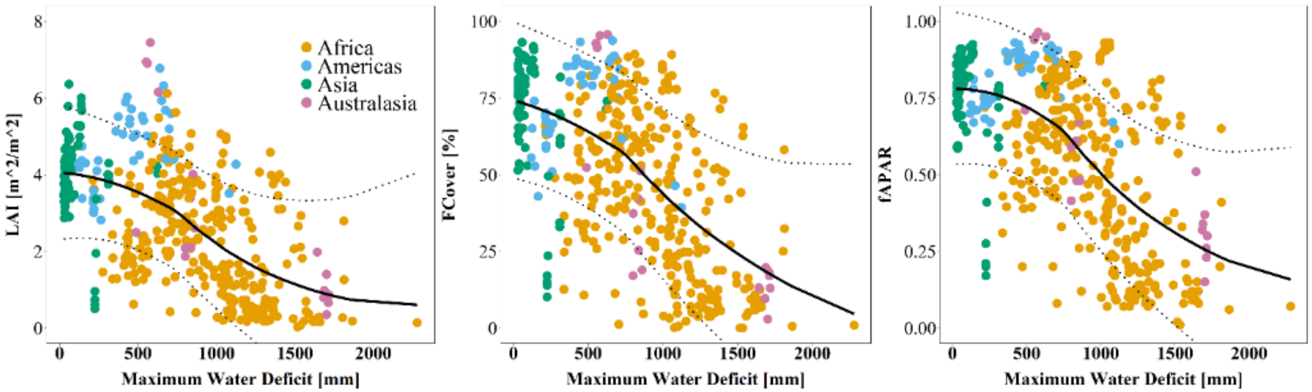
To measure essential forest functions regulated by canopies and in particular Essential Climate Variables LAI & fAPAR?!

- regulating: gas exchange, microclimate, hydrology ✓
- provisioning: food, biomass, habitats ?

Challenge 2: habitat quality metrics

The Global LAI project





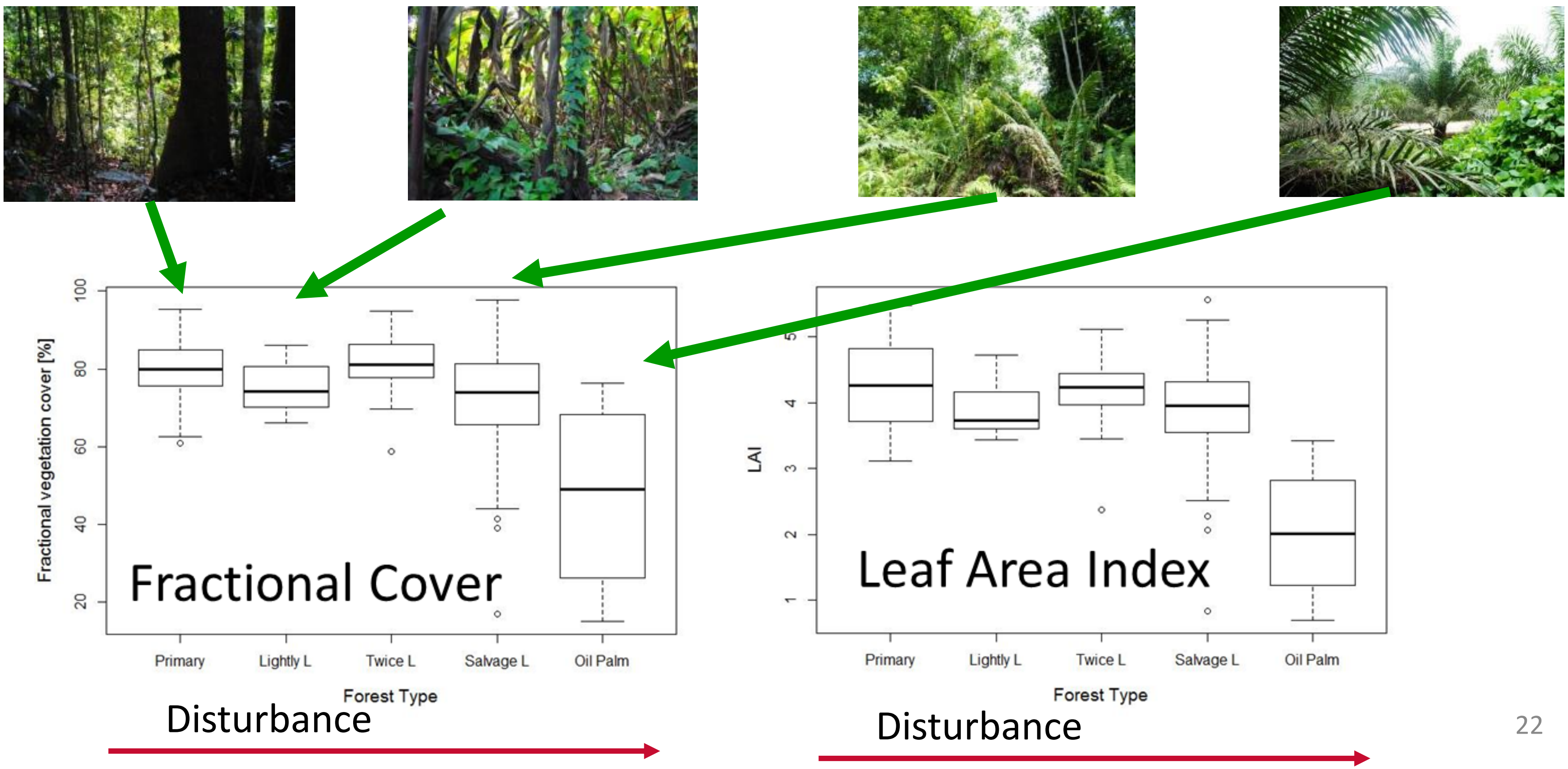
Pfeifer et al. 2018

Forest Ecosystems

Newcastle University

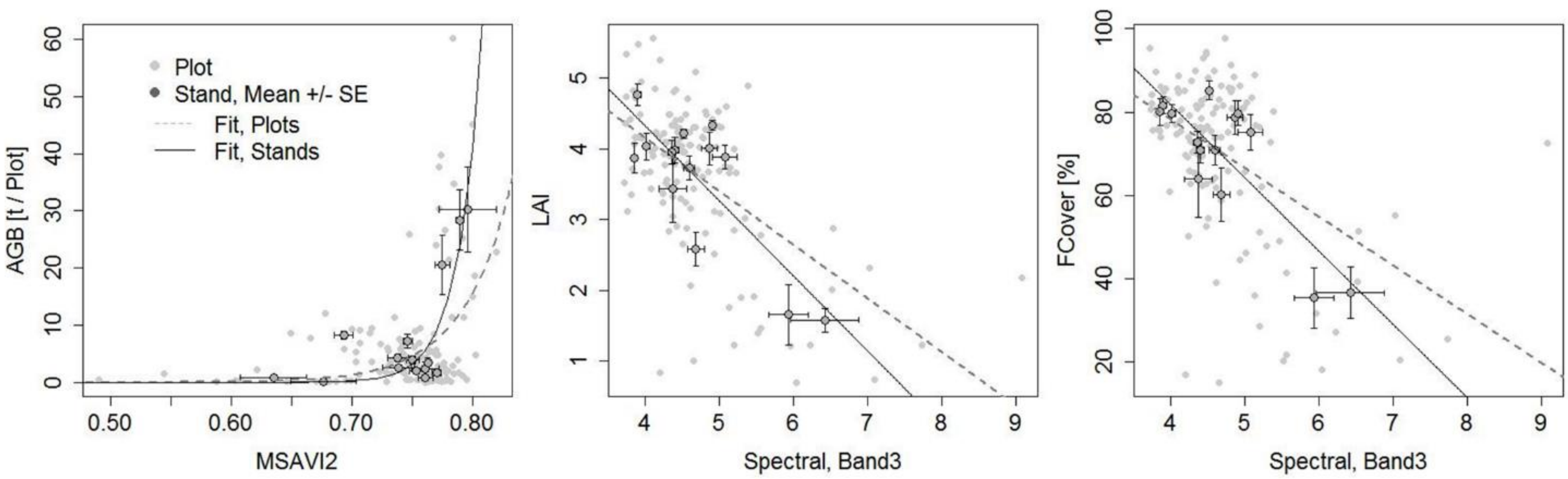
Canopy structure varies along disturbance gradients

However, it can also recover rapidly: Borneo, SAFE site (Pfeifer et al. 2016 ***Remote Sens Environment***)



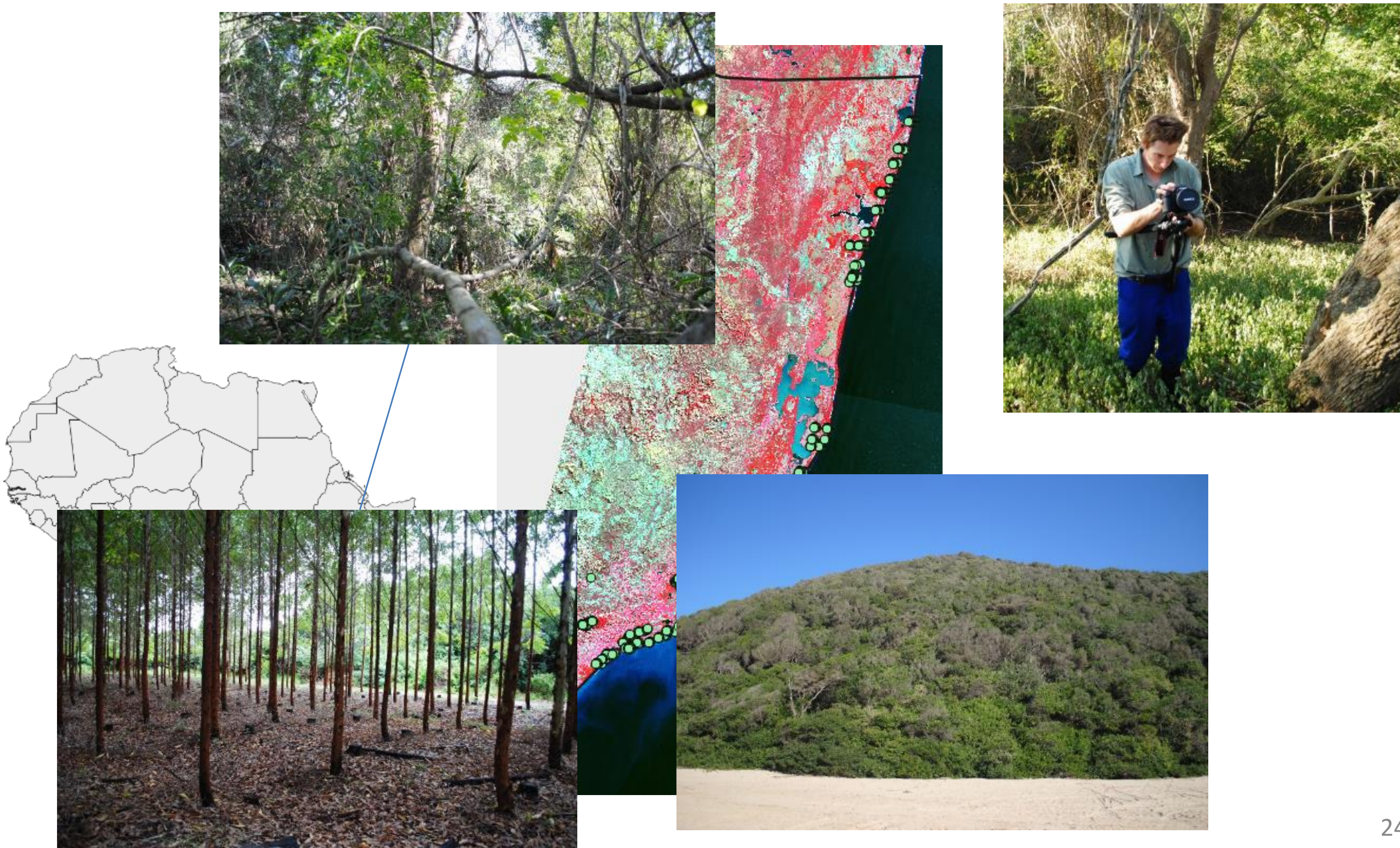
Upscaling forest functions using passive sensor data

RapidEye, 5 m pixel resolution, Blue/Green/Red/Red Edge/NIR



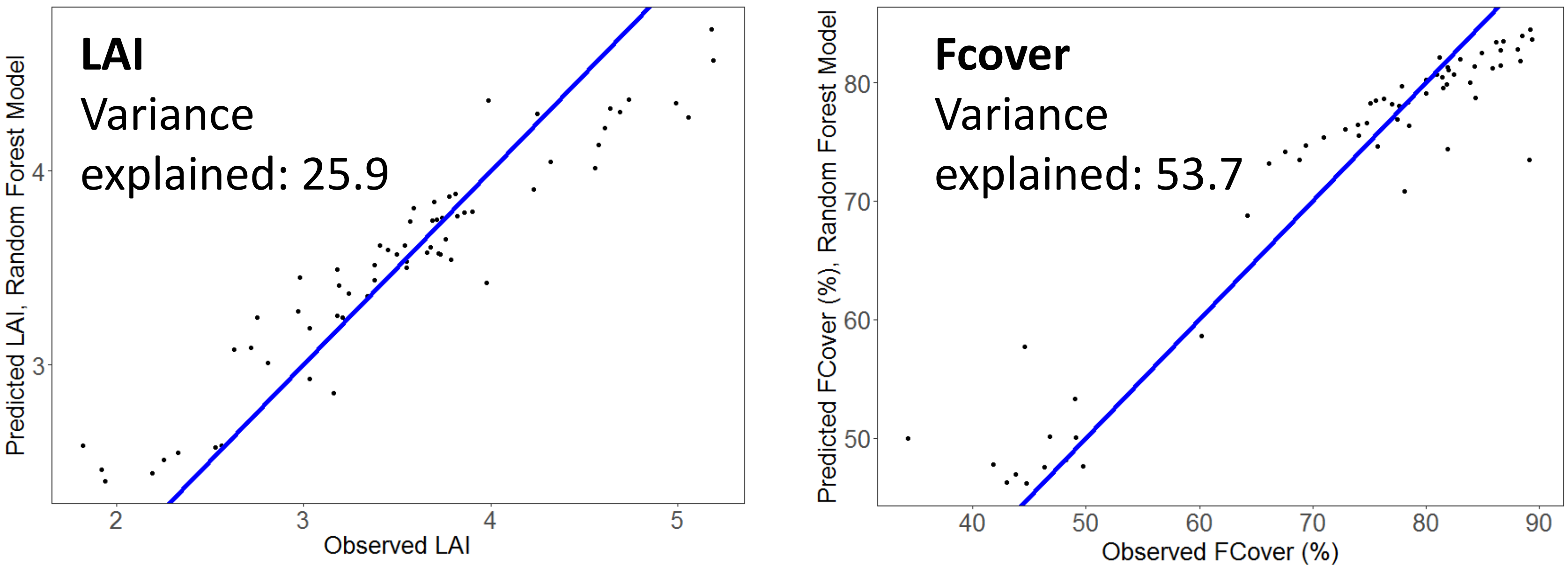
Final upscaling algorithms with spectral bands & texture data (grey level dissimilarities) (Pfeifer et al. 2016 ***Remote Sens Environ)*** explained from 38 % (Fcover) to 62 % (AGB) of variance in the data.

What about other landscapes?



Canopy structure mapping in South Africa

Landsat 8, 30 m pixel resolution



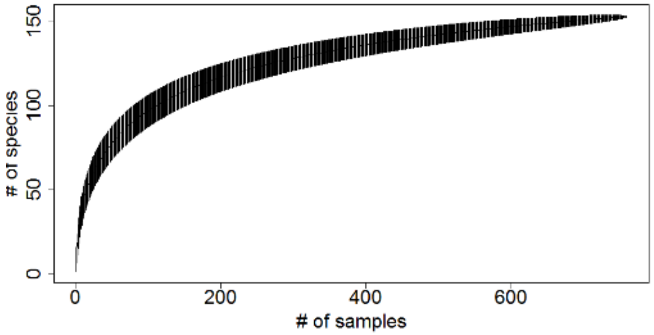
Final upscaling algorithms (random forest models) with spectral bands & texture data explained from 26 % (LAI) to 54 % (FCover) of variance in the data.

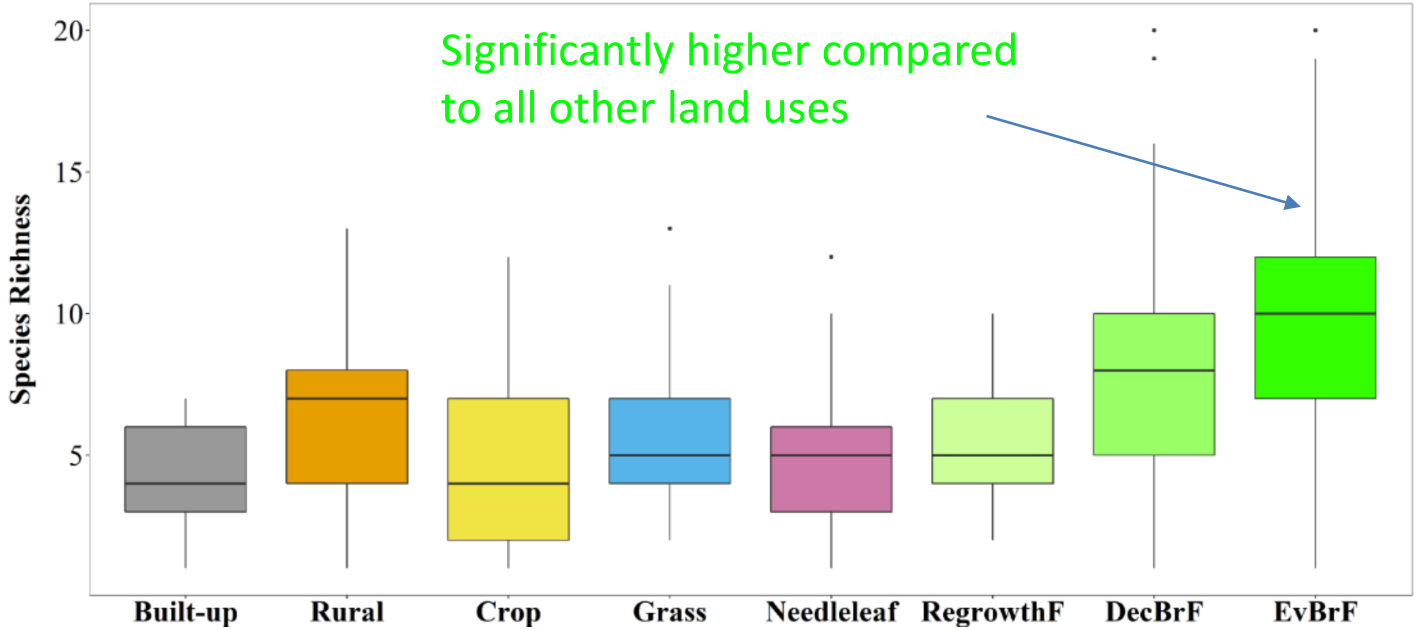
But can we link structure maps to diversity?

South Africa's coast

N = 760 plots

N – S: ~ 270 km



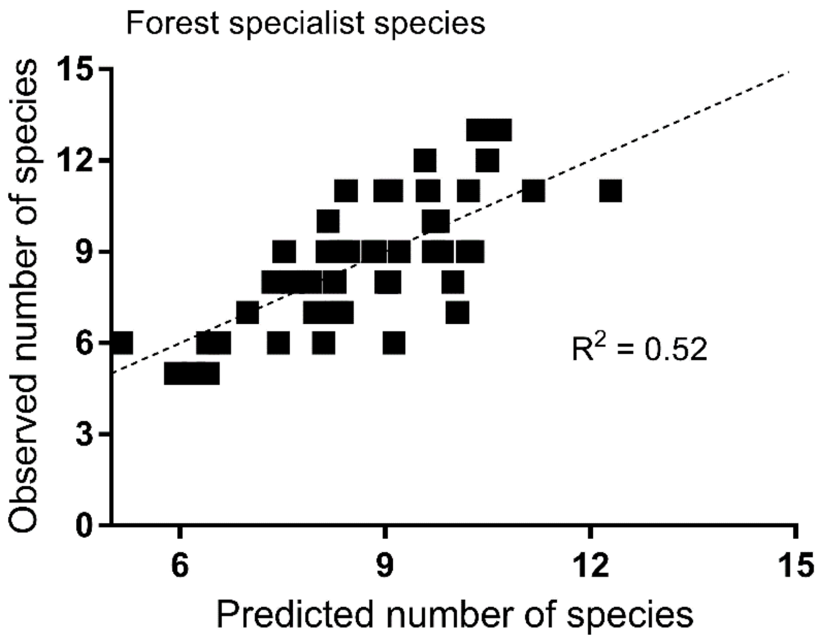


Challenge 2: habitat quality metrics

Next steps

Model using field inventory data: N = 50

Species richness ~ Remotely sensed variables



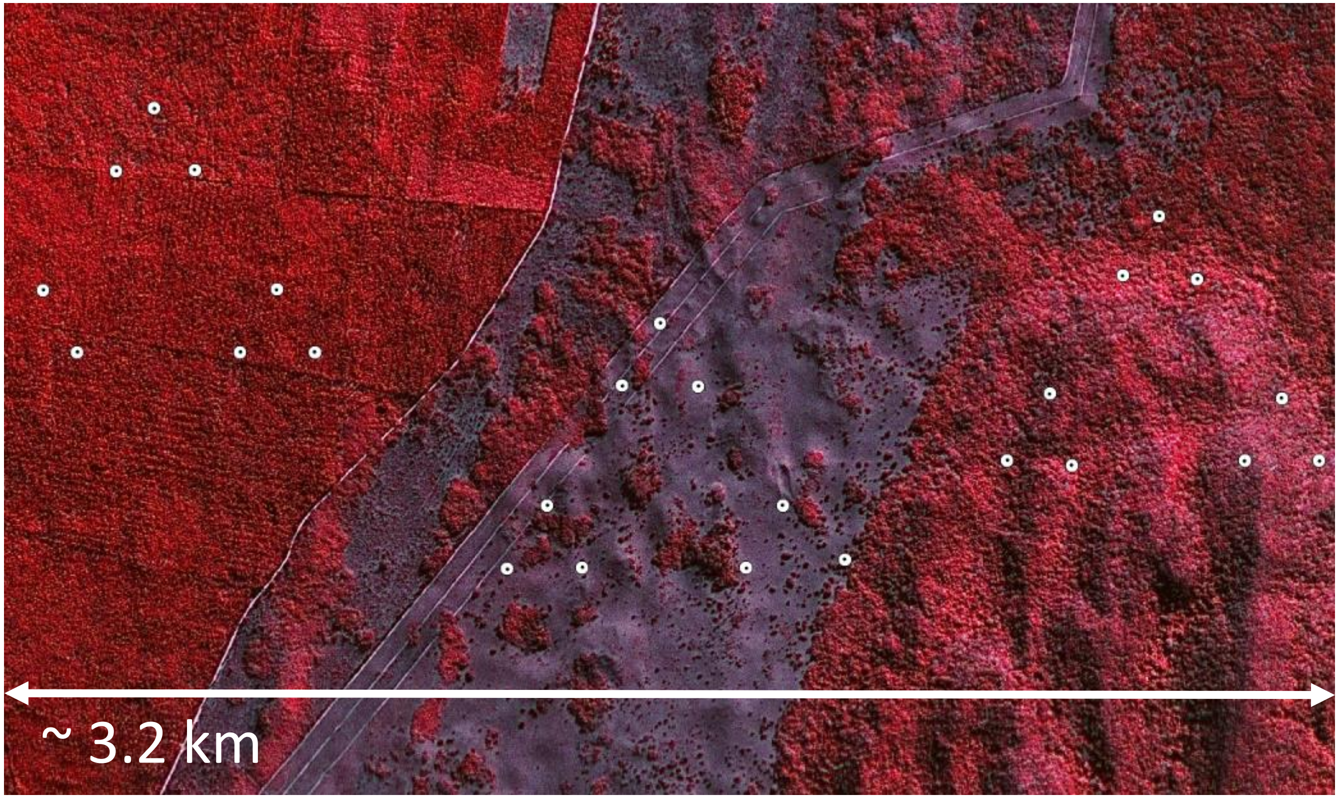
Pilot study in 2015

N = 34 species

Predictors: AGB + FCover

Next steps

Use different sensor data: SPOT 6, RapidEye, Pleiades

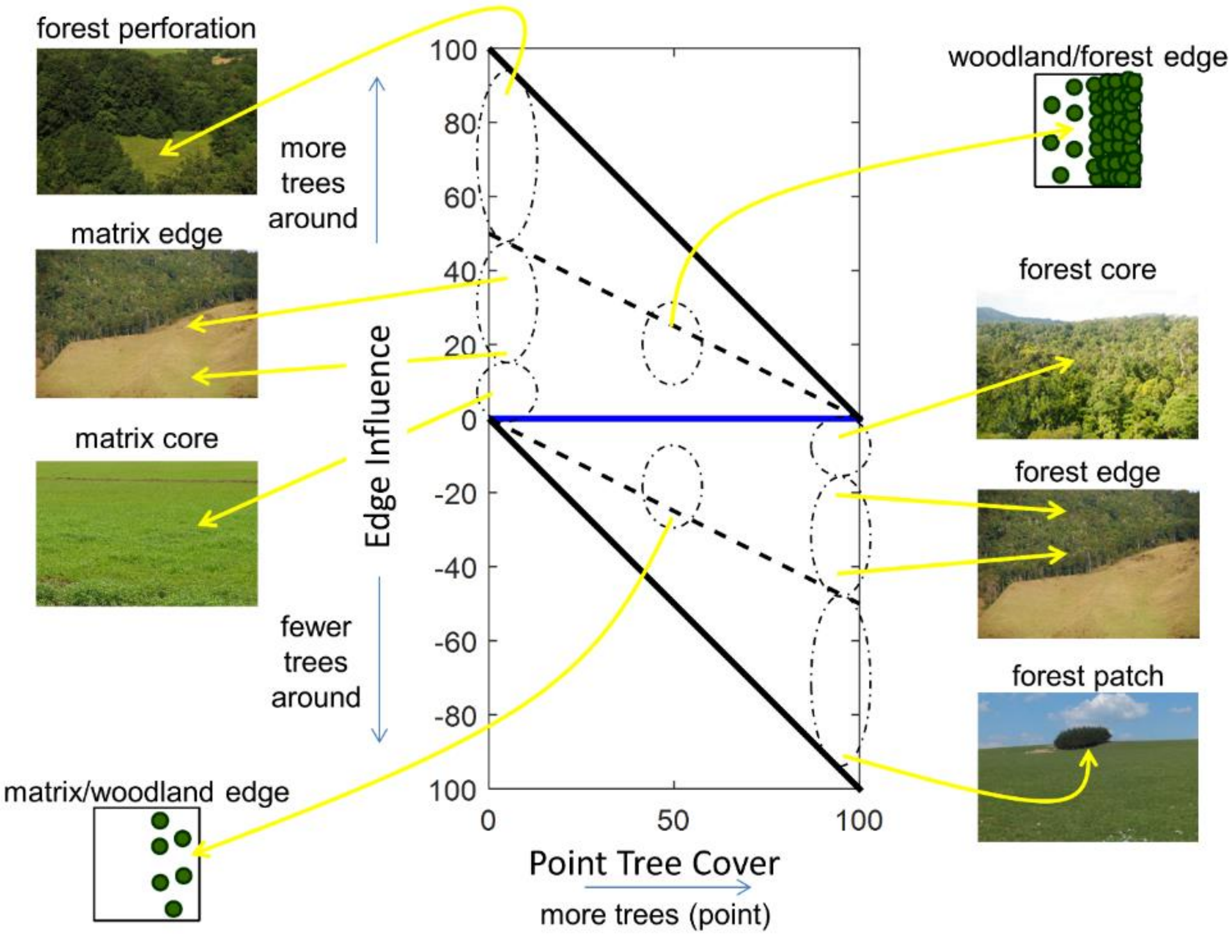


Look at transects across multitude of habitat quality edges.

Look at many more landscapes

Challenge 3: species-specific responses

Species perceive landscapes as habitat quality surface rather than categories of suitable habitats



Landscape-scale variation in habitat quality (e.g. tree cover, NDVI, LAI, Fcover, …..) **and edge effects can be used to predict species abundance (Pfeifer et al. 2017 Nature)**

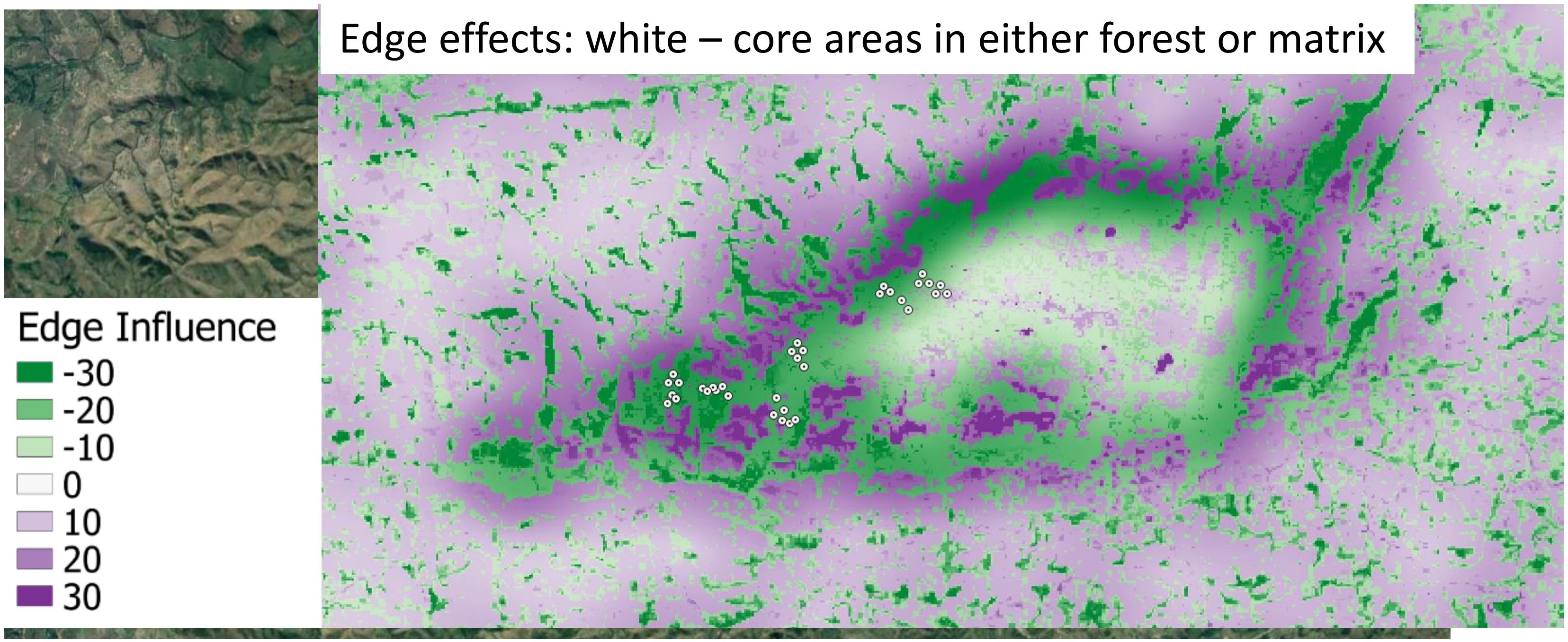
Challenge 3: species-specific responses

The landscape context matters

Species respond to habitat quality variation and in particular edge effects. Here: Ngoye Forest, South Africa.

Challenge 3: species-specific responses

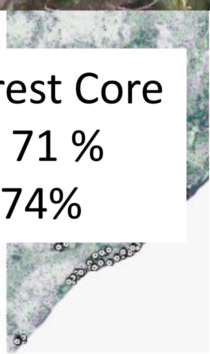
The landscape context matters



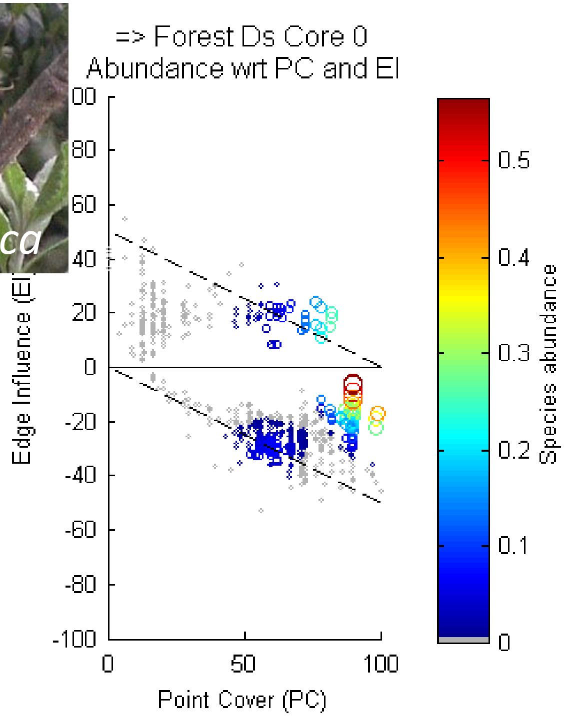
Species respond to habitat quality variation and in particular edge effects, shaped by habitat – matrix contrast and patch shape and size.

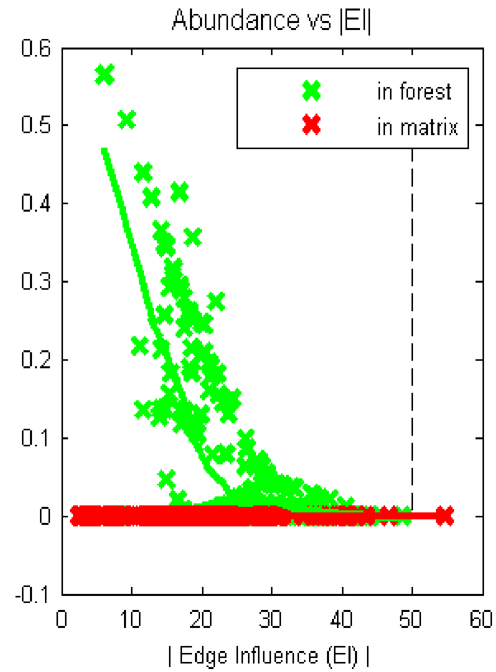
Challenge 3: species-specific responses

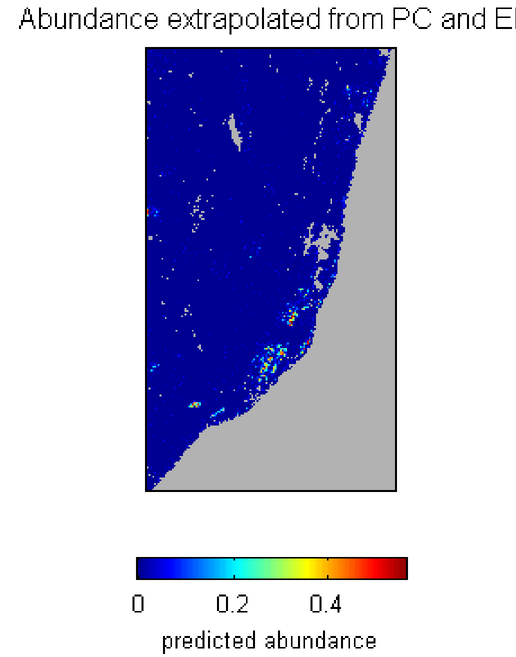
The landscape context matters



Forest Core
ES: 71 %
FI: 74%







Species respond to habitat quality variation and in particular edge effects, shaped by habitat – matrix contrast and patch shape and size.

Predicting species abundance in NDVI landscapes

South Africa – coastal forests

N = 153 bird species

High NDVI Core ('Forest core')	N = 23
High NDVI Edge ('Forest edge')	N = 10
Low NDVI Core ('Matrix core')	N = 8
Low NDVI Edge ('Matrix edge')	N = 2
High NDVI no preference	N = 8
Generalist	N = 17
Too rare	N = 80
Unknown:	N = 6

Batis capensis

High NDVI core

Zosterops pallidus

High NDVI edge

Challenges 2 & 3 are linked

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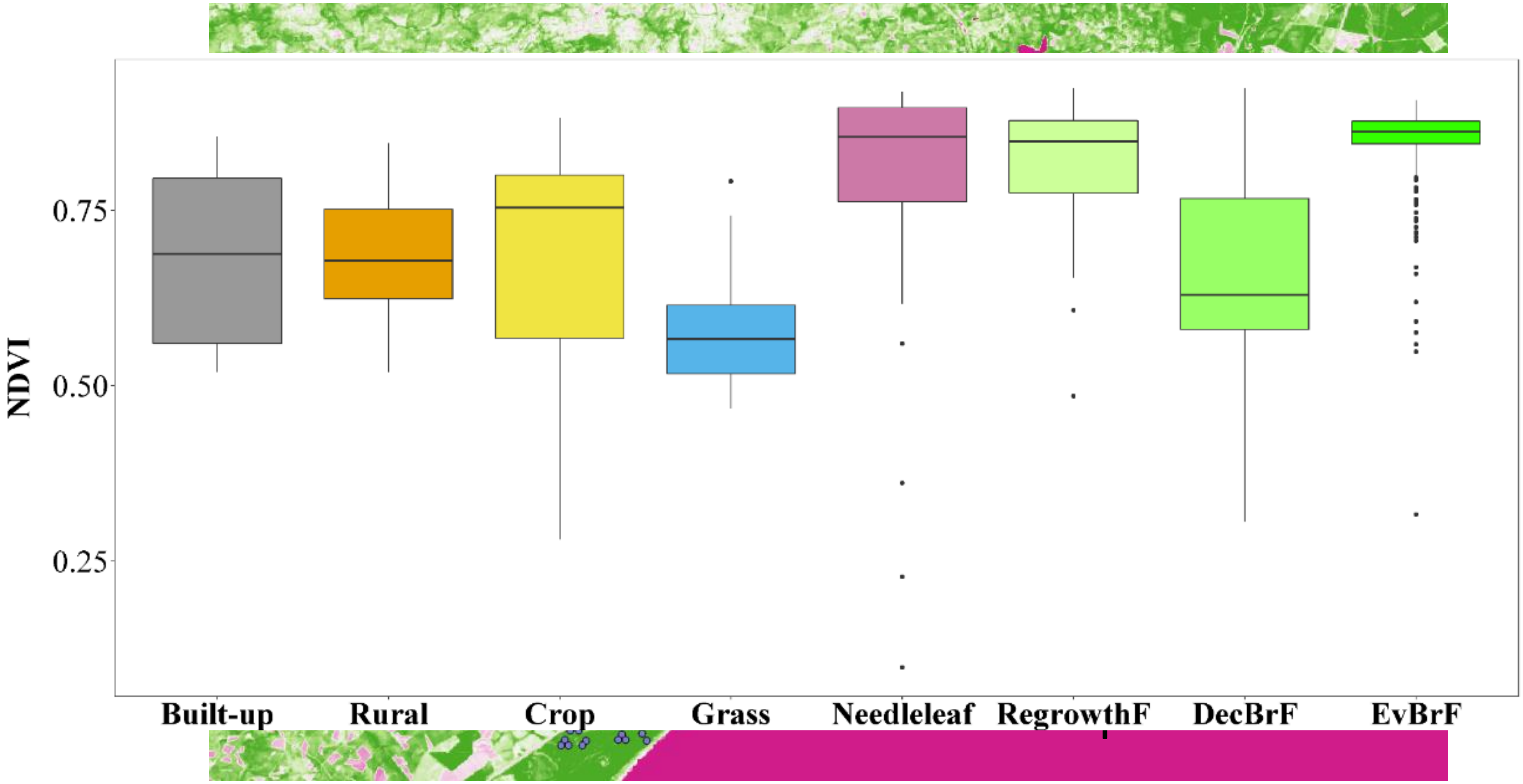
Plantations have a wonderfully high NDVI

Landsat 8 sensor data, False Colour Composite



~ 30 km

Challenges 2 & 3 are linked

Newcastle University

… yet high NDVI or tree cover does not mean high habitat quality

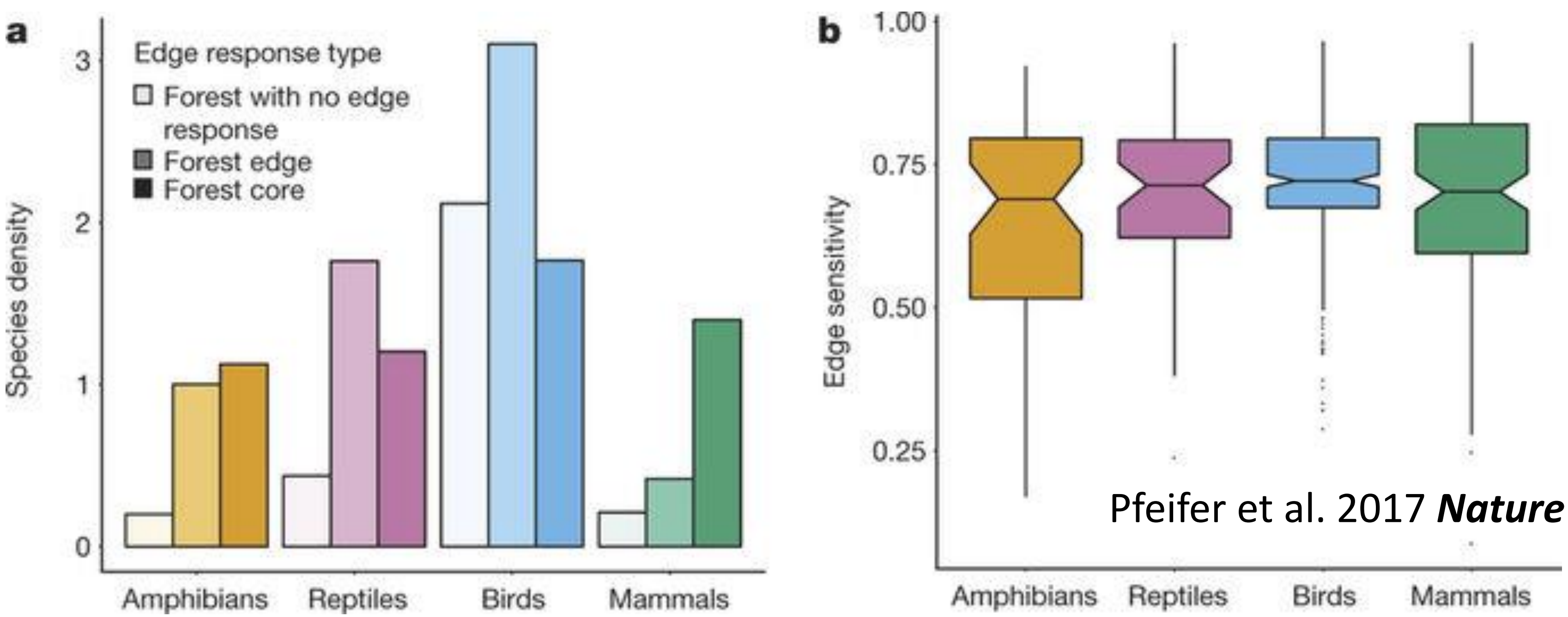
Challenge 3: species-specific responses

The higher the edge sensitivity, the less of the fragmented landscape the species can use

85% of species analysed (N = 1673) responded to forest edges (46% positively = edge species, 39% negatively = core species).

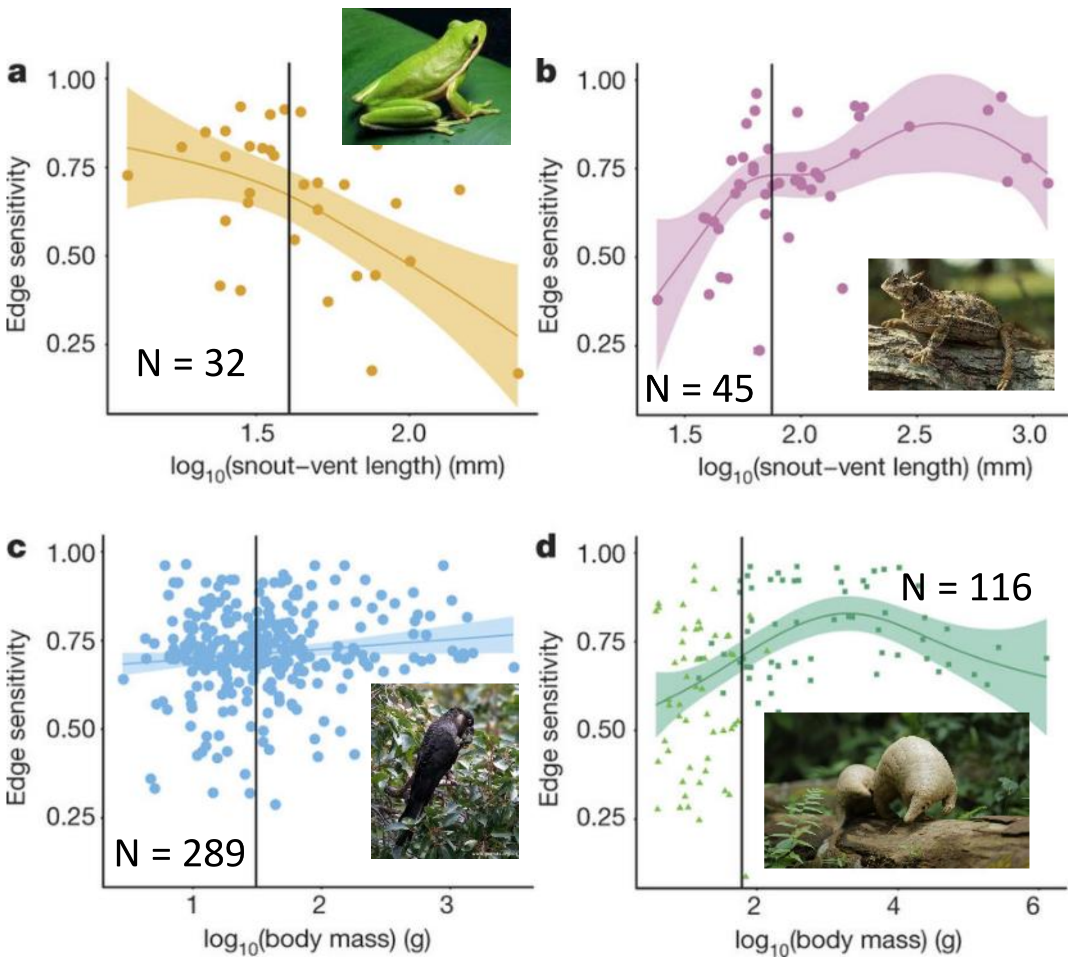
Forest occupancy

Edge sensitivities for forest-core species



Pfeifer et al. 2017 ***Nature***

Species differ in their responses



Pfeifer et al. 2017 ***Nature***

Edge sensitivity and body size in forest-core vertebrates are linked suggesting we might be able to predict forest species' sensitivities to forest fragmentation.

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?

If you accept my assertion that species respond to habitat quality variation rather than ‘habitat’ extents:

Question 1: Can we improve our maps of habitat quality?

Test a range of different sensors to capture ‘quality’ or ‘health’ of habitat types & link back to species abundance distributions:

- Vegetation greenness
- Light availability & its links to microclimate
- LAI, FCover, fAPAR: determine habitat differentiation along vertical gradients of light availability and control vegetation productivity
- Surface temperature: plant stress induced variations
- Leaf chlorophyll fluorescence: photosynthesis related

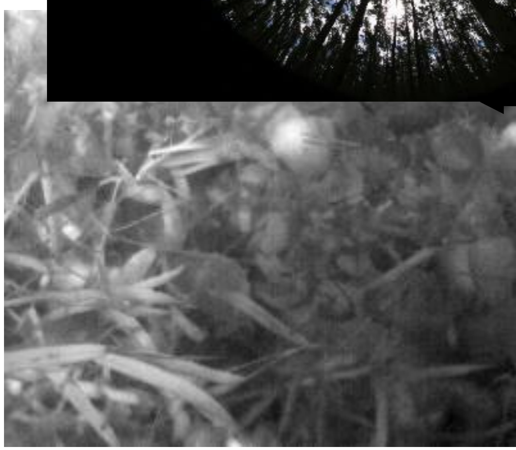
Given the three challenges

C … hap

P … non

h … topic

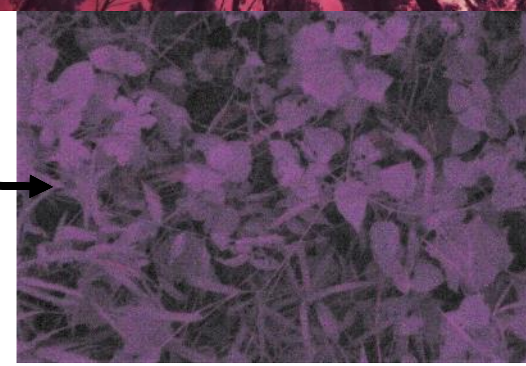
R … 018



ature

scan

NDVI scan →



Plantation floor

Further proposal submitted to UK Research Councils and ERC. Let me know if you can lend me suitable sensors to test some ideas ☺

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?

If you accept my assertion that species respond to habitat quality variation and in particular edge effects, shaped by habitat – matrix contrast and patch shape and size.

Question 2: Can we link species abundance and habitat quality needs?

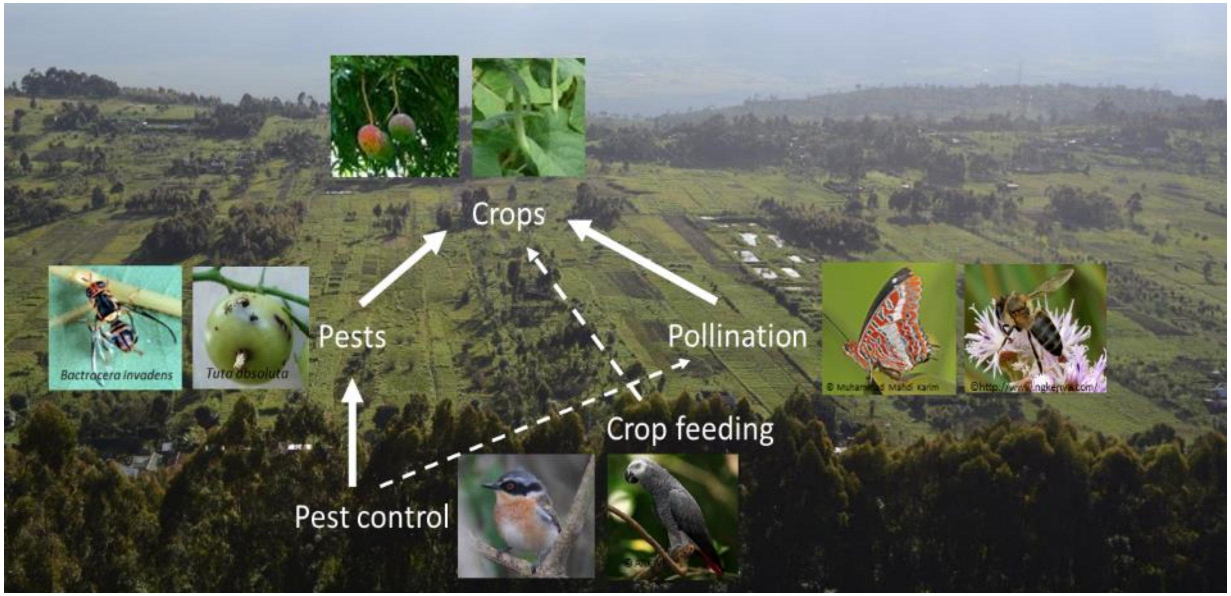
es … s in response to habitat … align

Given the three challenges

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?

If you accept my assertion that biodiversity is not a measure of ecosystem services:

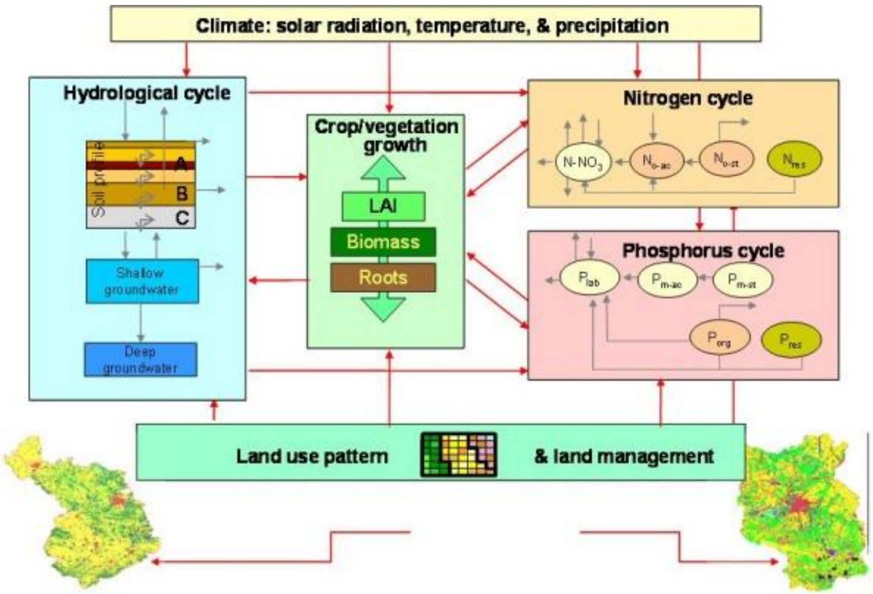
Question 3: Can we link species abundance and habitat quality needs to ecosystem services?



Conservation agriculture – where does it work and where not? Proposals submitted to ~~BBSRC SASSA~~ & ERC.

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?

Mind you, linking habitat quality maps to ecosystem services such as ‘clean water’, ‘carbon sequestration’ and ‘microclimate regulation’ is far more straightforward.



Soil and Water Integrated Model: SWIM (PIK)

http://econs.pik-potsdam.de/index.php?a=data_models

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?

Accepting that habitat quality surfaces can be linked to ecosystem services rooted in biophysics & assuming they can be linked to biodiversity dependent ecosystem services

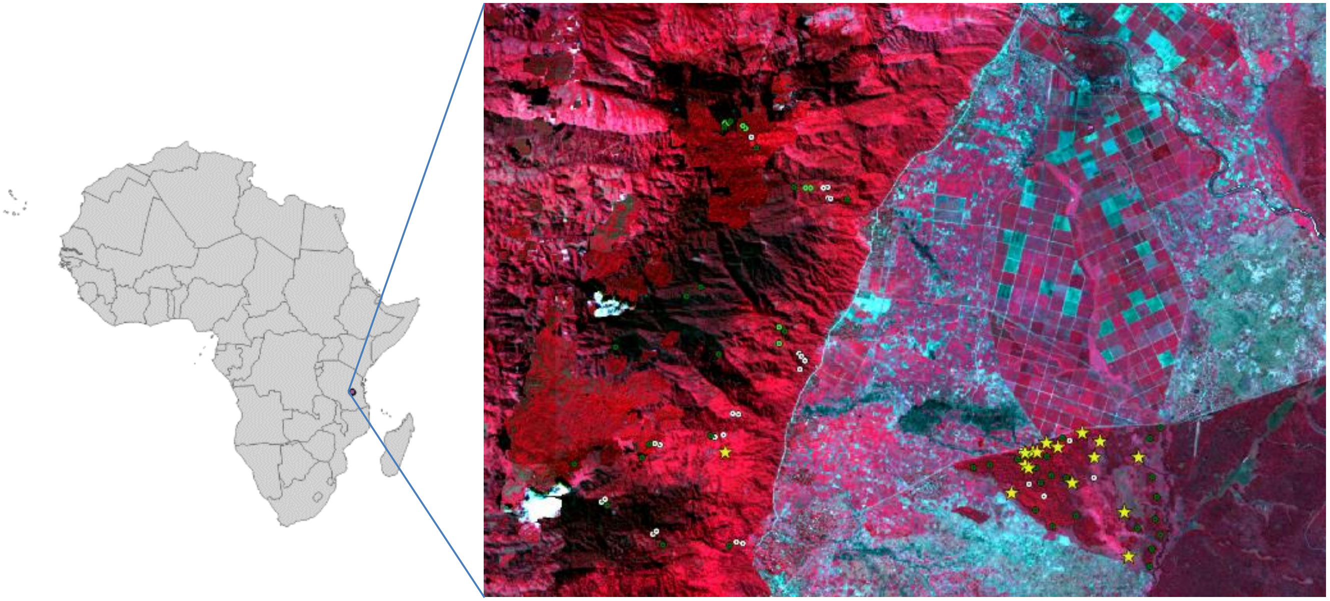
Question 4: How can we manage (human-modified tropical' landscapes to improve habitat quality surfaces?

Focus groups, stakeholder analysis, participatory mapping, governance actors, scenario modelling, systems modelling (Bayesian Belief Networks), UN policy forum, ……

Given the three challenges

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?

http://force-experiment.com/ Forest Restoration & Climate Experiment



ARC funded project (2018 – 2021): Understanding the importance of liana dominance for tropical forest health, value & management

Can we sense biodiversity & ecosystem services from space?

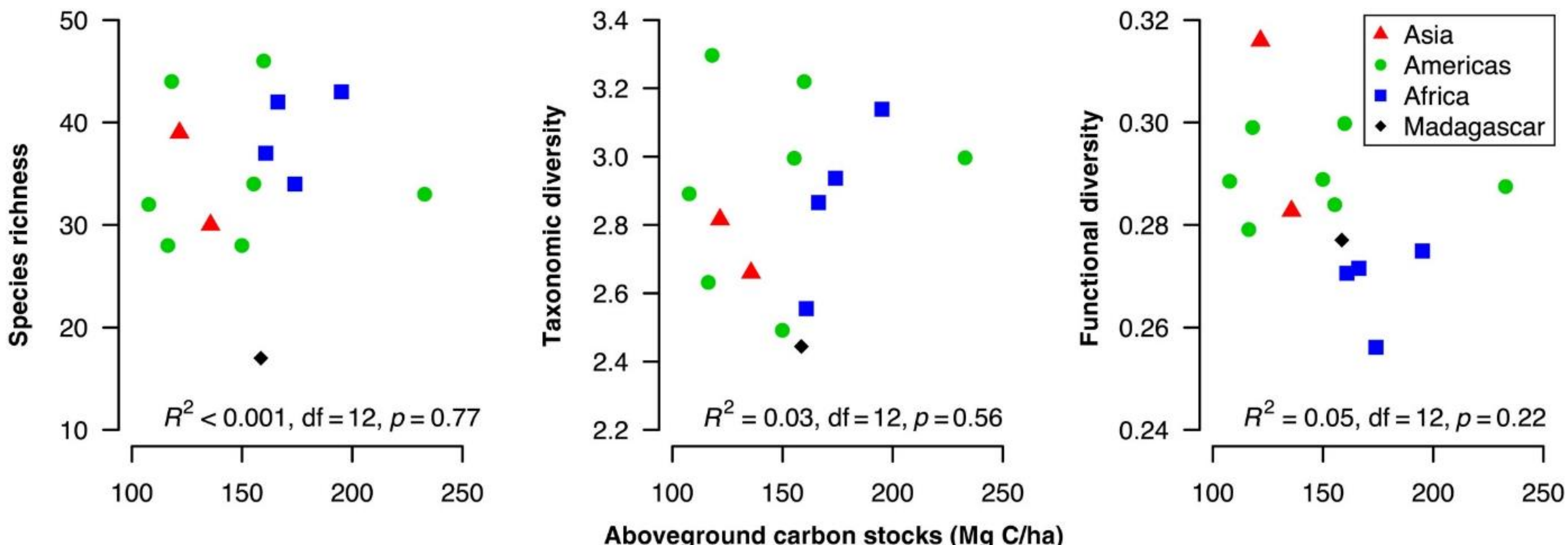
Not yet, but:

- We can identify suitable **metrics of habitat quality** in landscapes
- We can analyse species responses to habitat quality in the landscape (BIOFRAG tools), provided we **improve our sampling**
- We can predict species responses to changes in quality of habitats
- We can **link predictions of species abundance changes including local extinctions) to predictions of species traits**: functional diversity, plant – pollinator & plant – pest – pest control interactions

[1]Newcastle University, UK [2]https://biofrag.wordpress.com/ [3]https://globallai.wordpress.com/

Yet, spectranomic maps are not

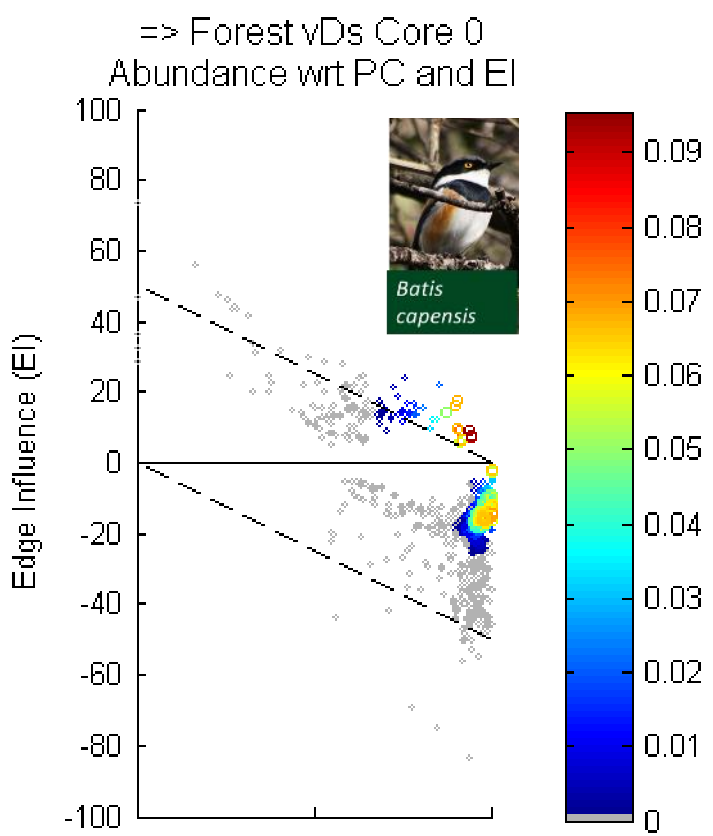
Beaudrot et al. 2015 **Ecol Appl analysed** medium to large bodied ground-dwelling mammals and birds in tropical forest plots:
No significant relationships between carbon density and species richness/taxonomic diversity/trait diversity.



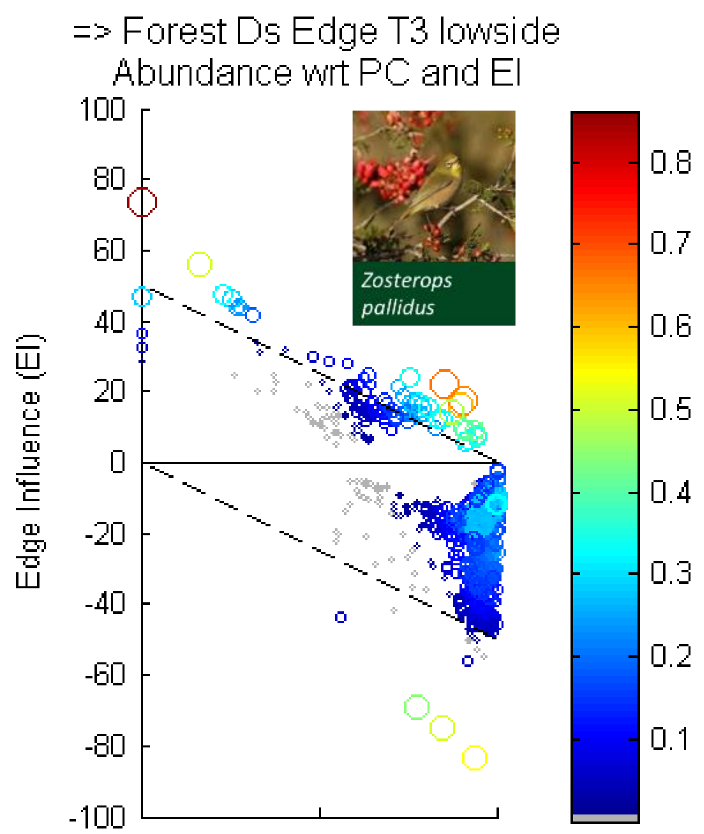
The landscape context matters

BIOFRAG software
https://github.com/VeroL/BioFrag/releases

Analysing species abundance in NDVI landscapes



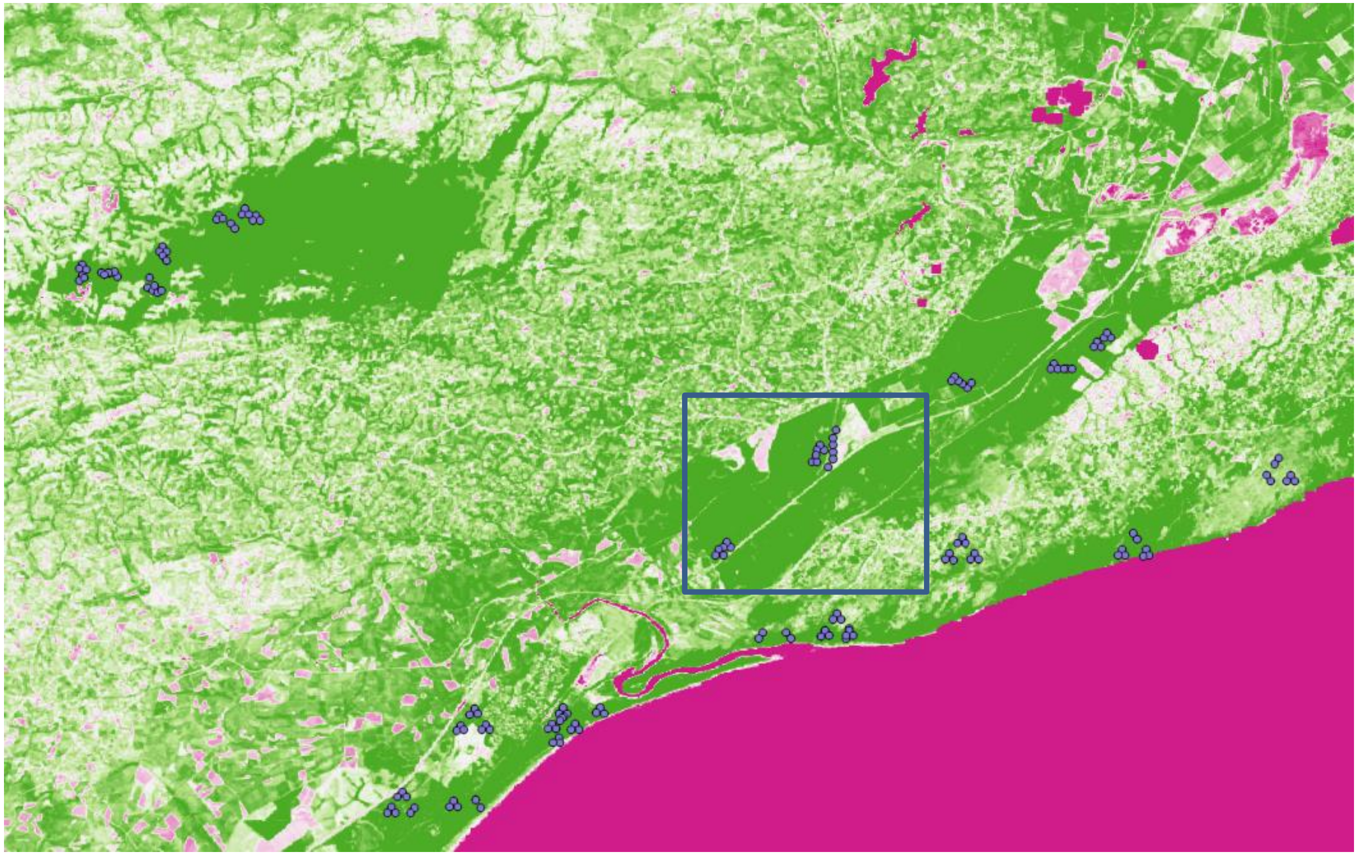
Batis capensis



Zosterops pallidus

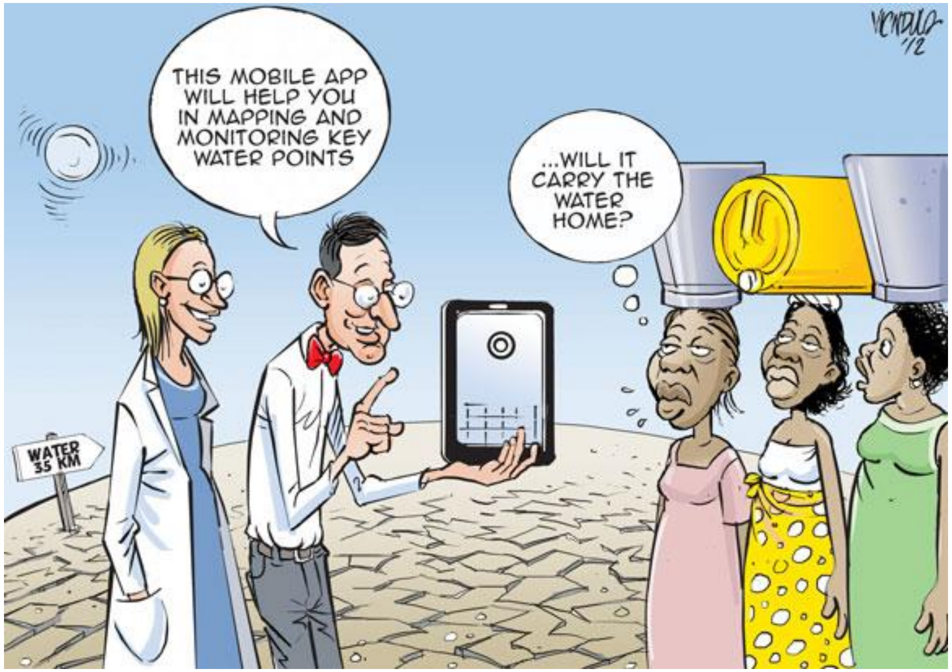
Plantations have a wonderfully high NDVI

And yet they harbour much less biodiversity when the coastal forests



~ 30 km

Where do we go from here towards monitoring for Aichi and SDGs using remote sensing?



Responding to the needs identified by the communities affected