SynCER: Synthesising post-disturbance Carbon Emissions and Removals across Brazil’s forest biomes

Day 2: Quantifying secondary forest regrowth rates: a synthesis

São José dos Campos, 30 Oct 2025

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Session 2.1 (Part 1): Biomass Datasets and Missions

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Biomass maps used in inventory

Jean Ometto

Session 2.1 (Part 1): Biomass datasets and missions

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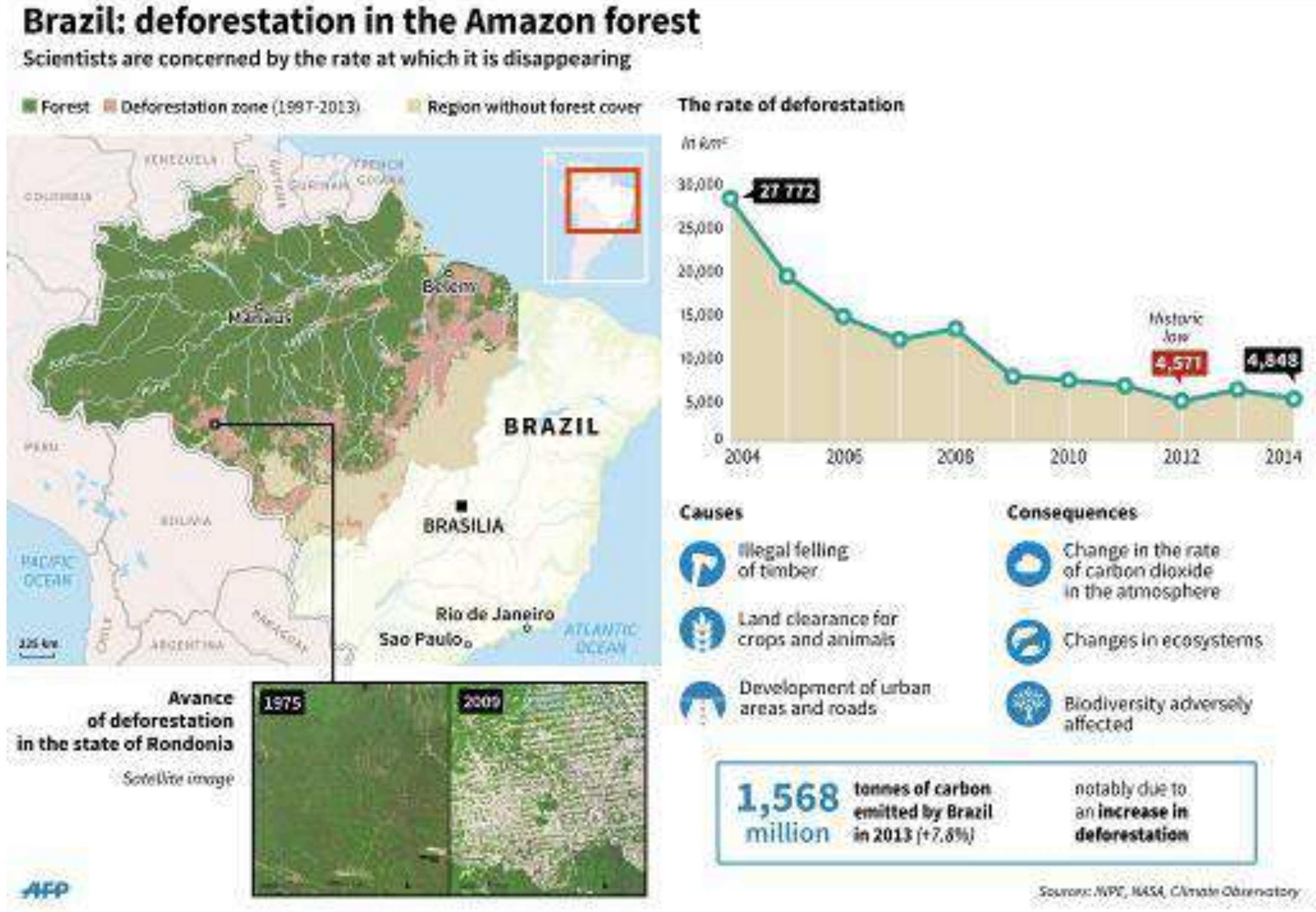
Biomass estimation in the Amazon basin and GHG emissions inventories

Jean Ometto
jean.Ometto@inpe.br

EBA
Estimativa de biomassa na Amazônia

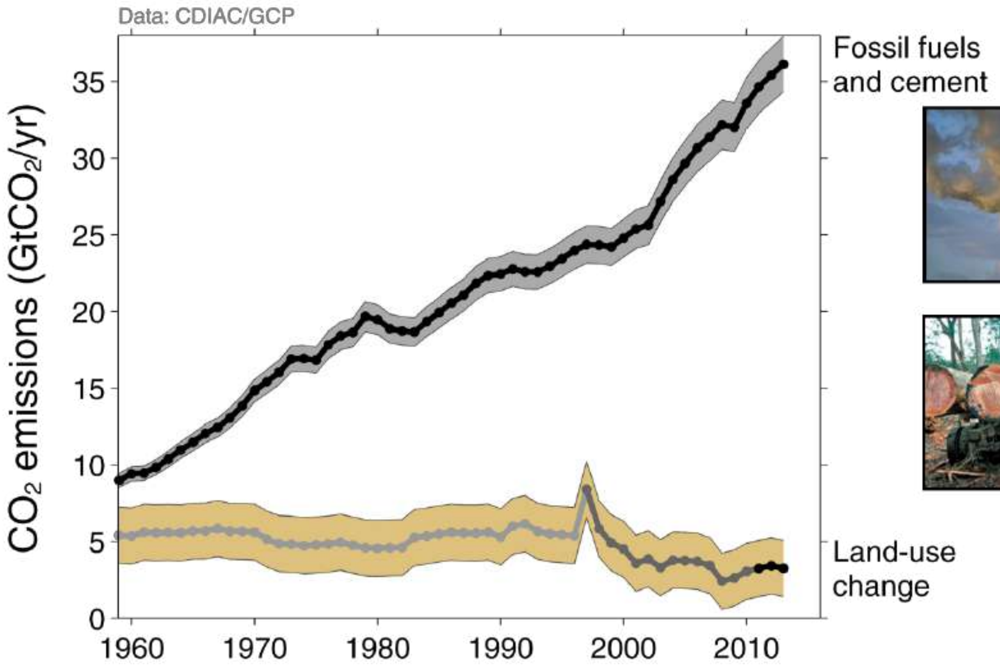
AMAZÔNIA REVELADA

Some of the Carbon world in 2014



Total Global Emissions

Total global emissions: 39.4 ± 3.4 $GtCO_2$ in 2013, 42% over 1990
Percentage land-use change: 36% in 1960, 19% in 1990, 8% in 2013



Three different methods have been used to estimate land-use change emissions, indicated here by different shades of grey
Source: CDIAC; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

The Guardian

2014 set to be world's hottest year ever

Record average temperatures highlight the urgent need to agree a deal on emissions at the UN climate change talks in Lima

The hottest year on record - in pictures

Vehicles drive by a 134ft-high thermometer in Baker, California. Average land and sea surface temperatures have reached record levels in 2014. Photograph: Ethan Miller/Getty Images

The world is on course for the hottest year ever in 2014, the United Nations weather agency said on Wednesday, heightening the sense of urgency around climate change negotiations underway in Lima.

WORLD METEOROLOGICAL ORGANIZATION
Weather Climate Water

European Commission

NEWS ARTICLE | 14 April 2014 | Directorate-General for Climate Action | 4 min read

IPCC report highlights need for collective and significant action to keep warming below 2°C

WMO: Global Climate in 2014 marked by extreme heat and flooding

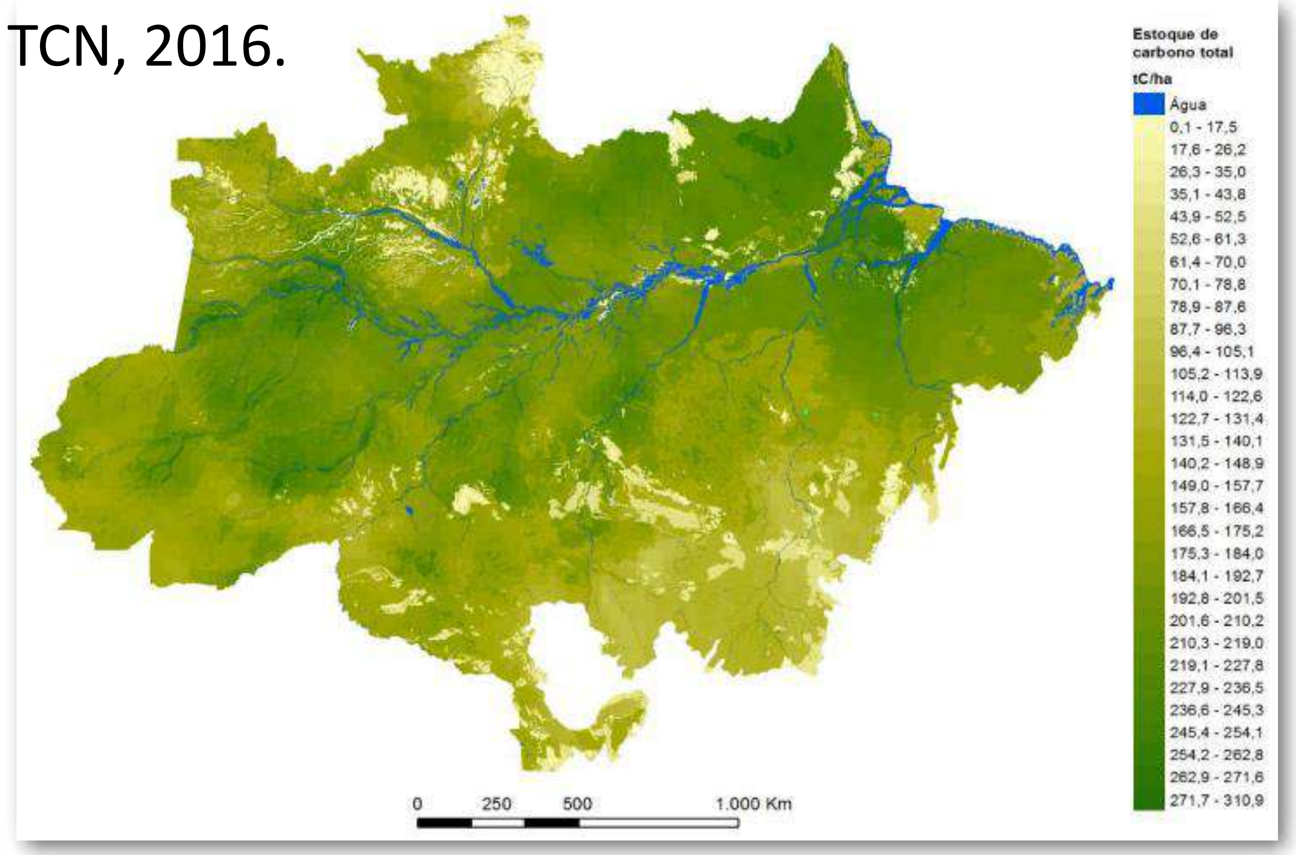
NEWS

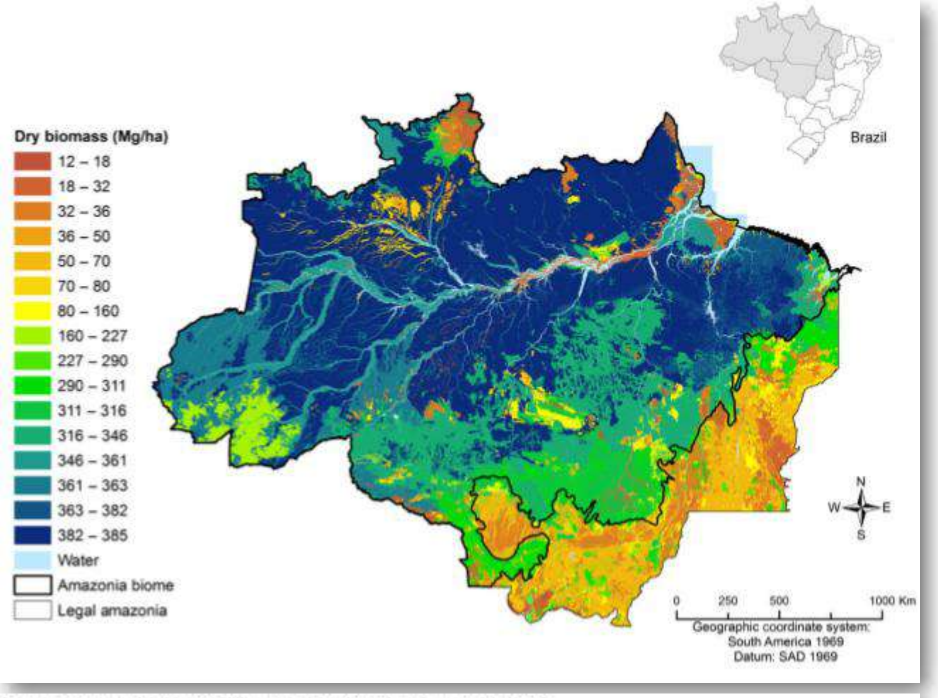
23 March 2015

Report Released for World Meteorological Day: Climate Knowledge for Climate Action
Record ocean heat, high land-surface temperatures and devastating flooding were some of the defining characteristics of the global climate in 2014, which was...

Forest Biomass Maps

MCTI, TCN, 2016.

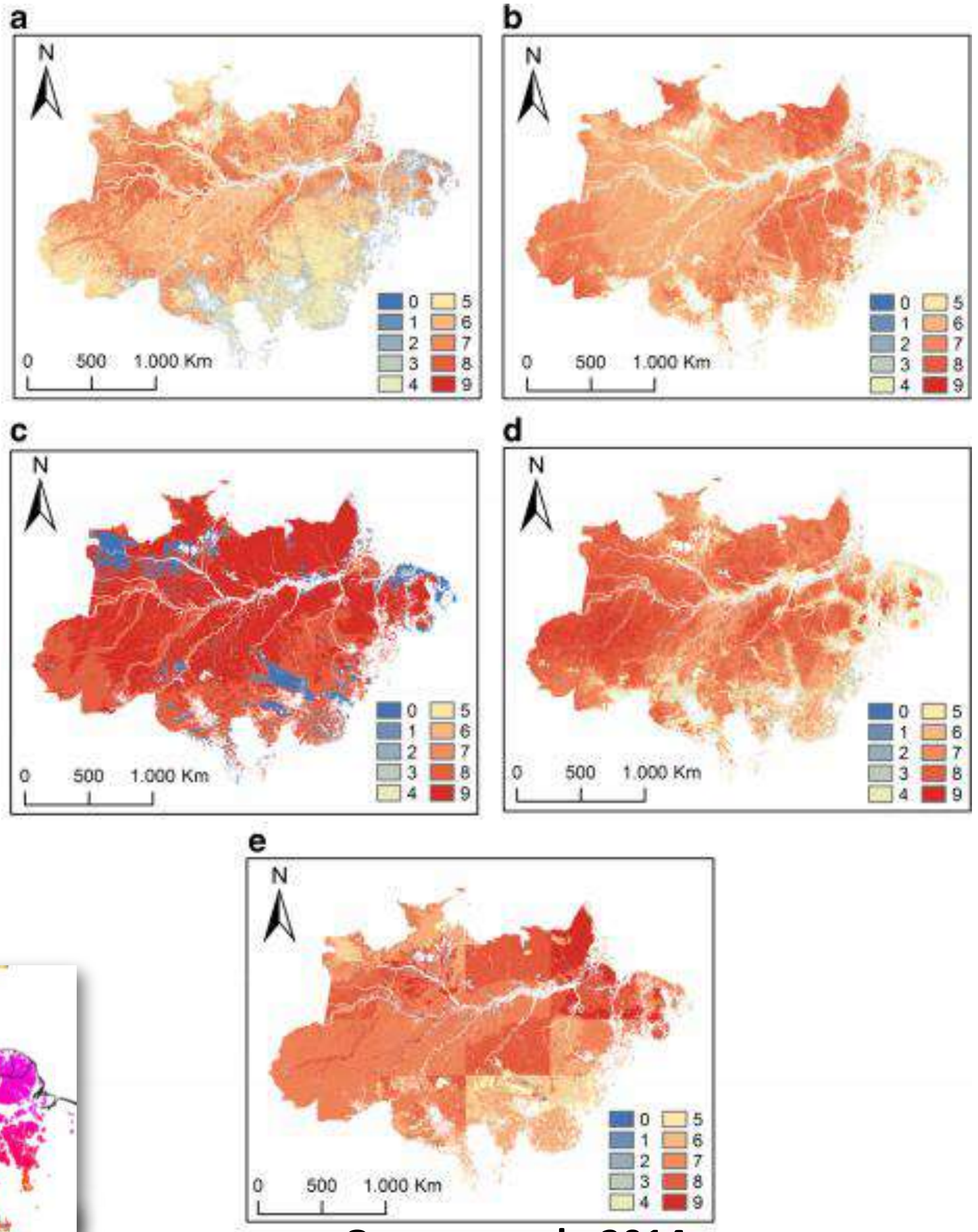




Global Change Biology (2015) 21, 1271–1292, doi: 10.1111/gcb.12798

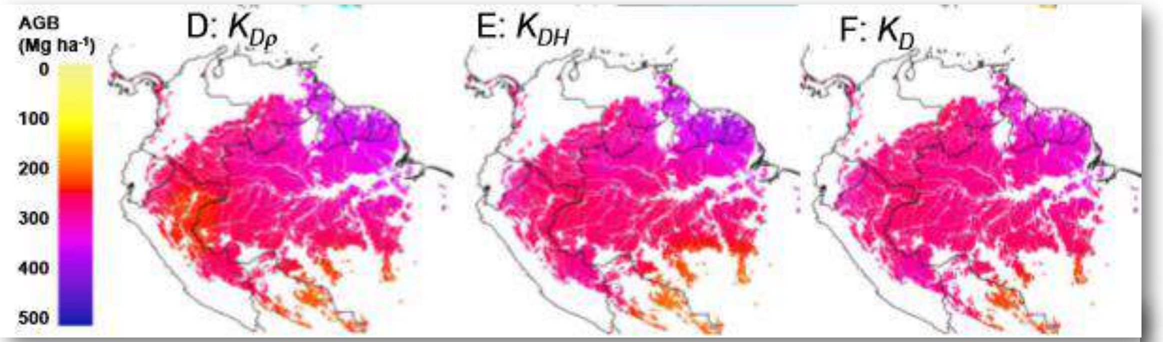
Carbon stock loss from deforestation through 2013 in Brazilian Amazonia

EULER MELO NOGUEIRA, AURORA M YANAI, FREDERICO O R FONSECA and PHILIP MARTIN FEARNSIDE
Department of Environmental Dynamics, National Institute for Research in Amazonia (INPA), Av. André Araújo no 2936, Manaus, Amazonas, CEP 69 067-375, Brazil



Ometto et al., 2014

Climatic Change
DOI 10.1007/s10584-014-1058-7



RESEARCH PAPER

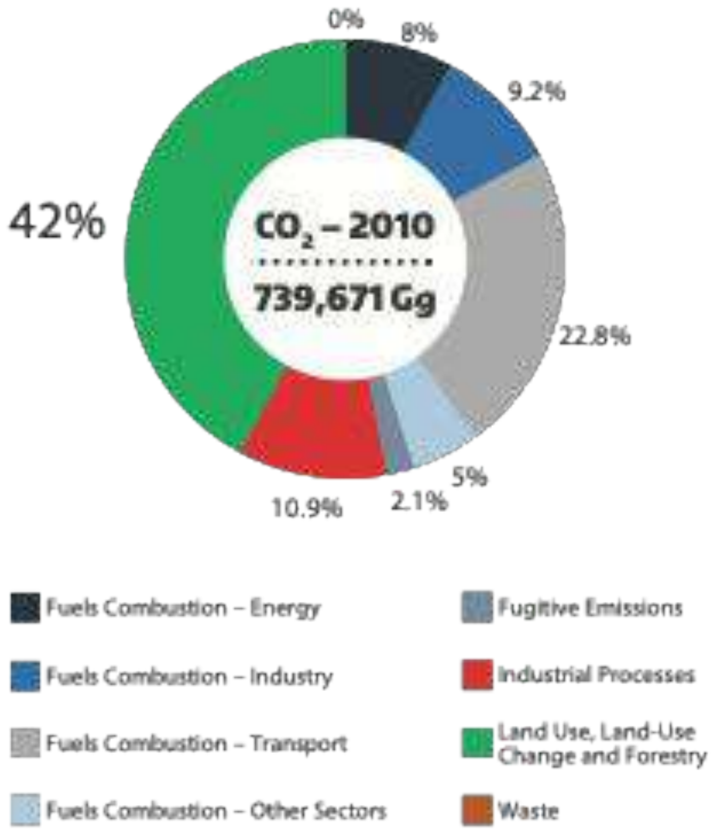
Markedly divergent estimates of Amazon forest carbon density from ground plots and satellites

Edward T. A. Mitchard[1*], Ted R. Feldpausch[2,3], Roel J. W. Brienen[2], Gabriela Lopez-Gonzalez[2], Abel Monteagudo[4], Timothy R. Baker[2], Simon L. Lewis[2,5], Jon Lloyd[6], Carlos A. Quesada[7], Manuel Gloor[2], Hans ter Steege[8,9], Patrick Meir[1,10], Esteban Alvarez[11], Alejandro Araujo-Murakami[12], Luiz E. O. C. Aragão[3,13], Luzmila Arroyo[12], Gerardo Aymard[14],

EMISSIONS OF THE MAIN GREENHOUSE GASES

FIGURE II

Sectors and sub-sectors shares of net CO_2 emissions in 2010

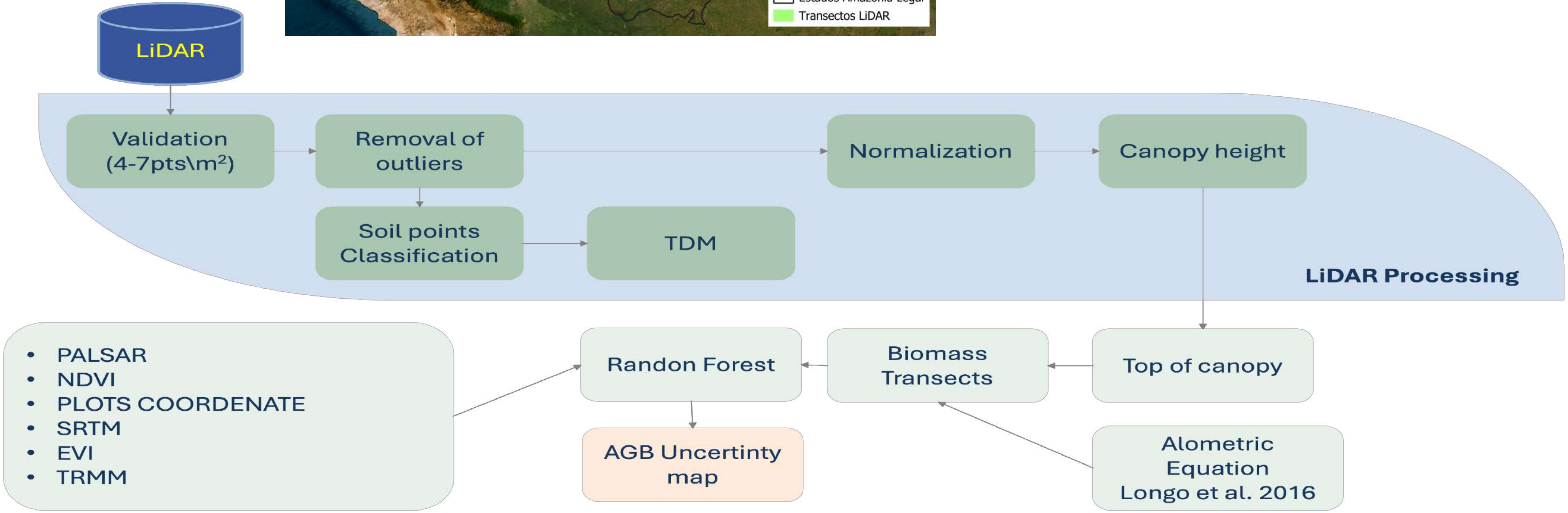


Transect: 3,75 km^2

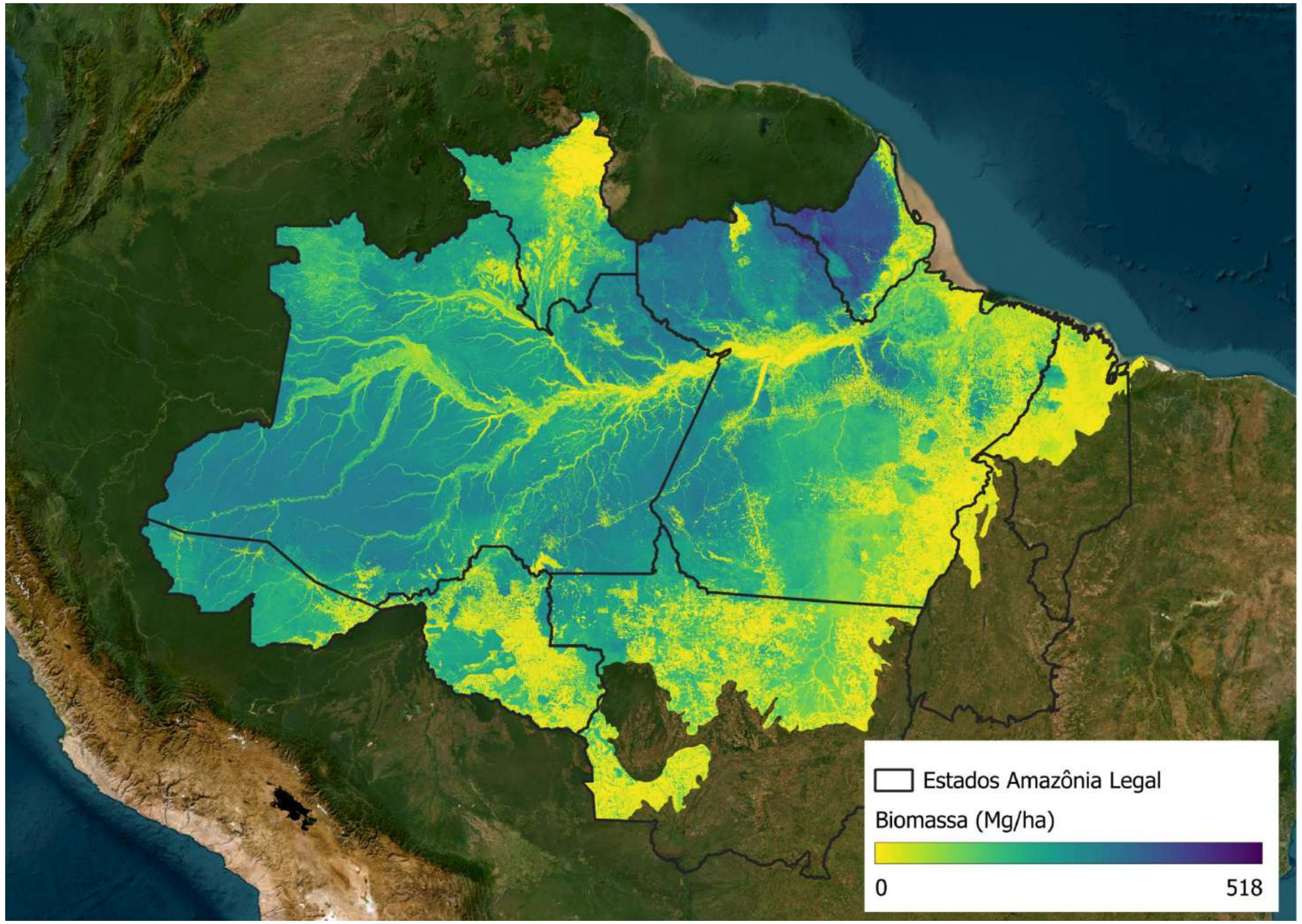
Total area: 3.750 km^2

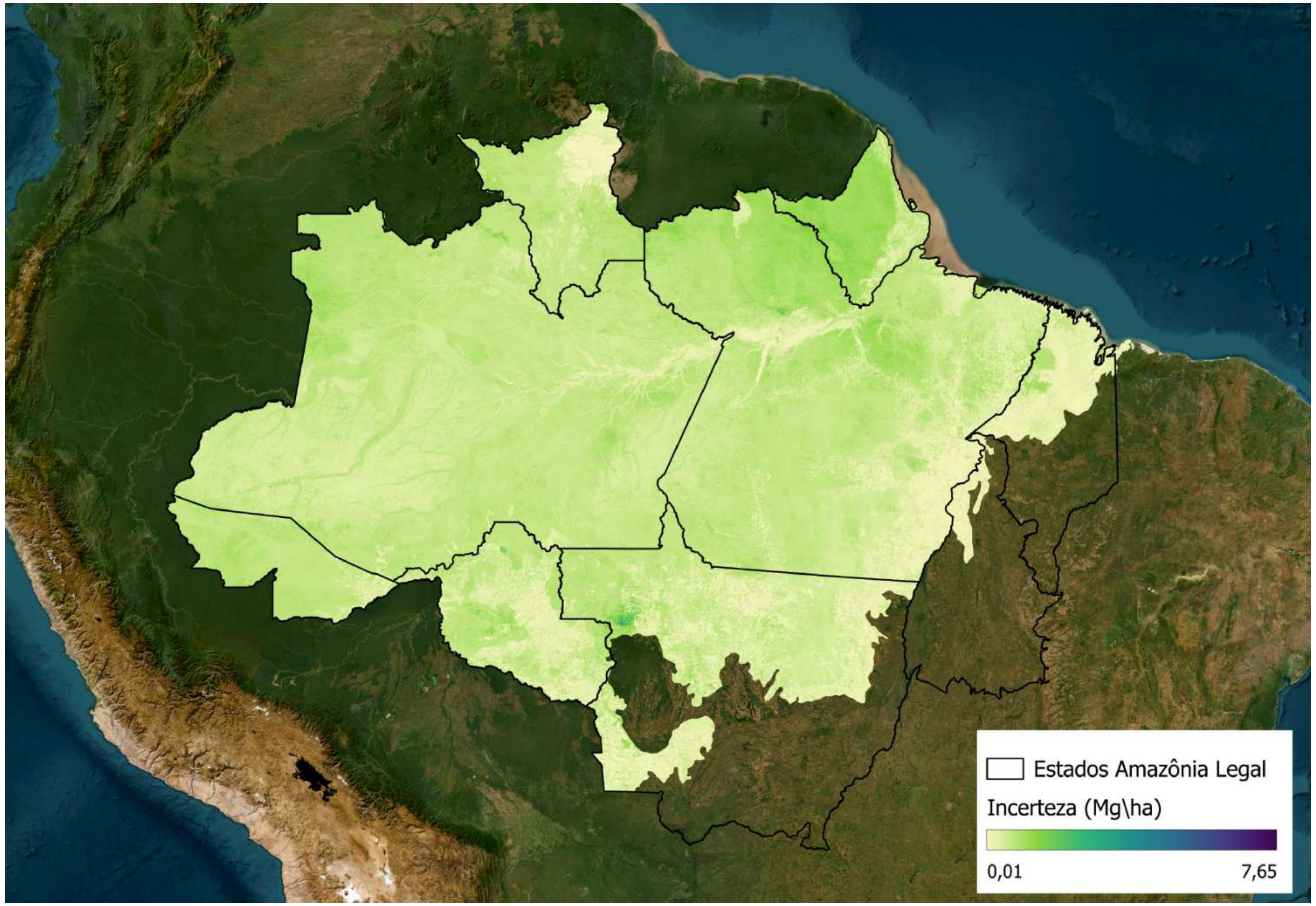
Randomly distributed considering :

- PRODES mask
- TerraClass
- Flooded areas



AGB (Mg/ha)





Uncertainty Map (Mg/ha)

Mapa de Incertezas

Nível 1 | Nível 2 | Nível 3

Parcelas de Campo

- Calcula a AGB das parcelas de campo – equações alométricas
- Extrai do LiDAR as métricas de altura do Topo da Vegetação – das mesmas áreas das parcelas

LiDAR 50 m

- Ajusta um modelo:

LiDAR x Campo

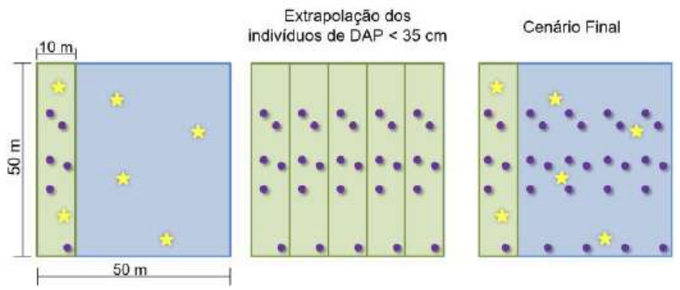
Longo et al. 2016

LiDAR 250 m

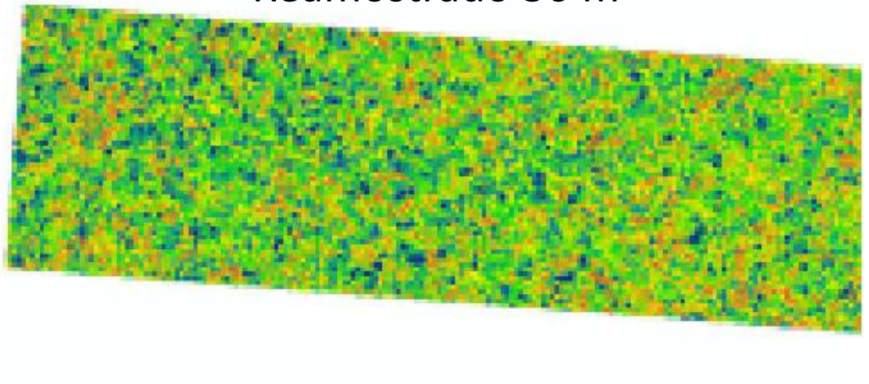
- AGB e incerteza de 50 m são reamostradas para 250 m (compatível com os dados de satélite).
- Resultado: AGB e incerteza de 250 m para todos os pixels de dados LiDAR

AGB\Incerteza 250 m

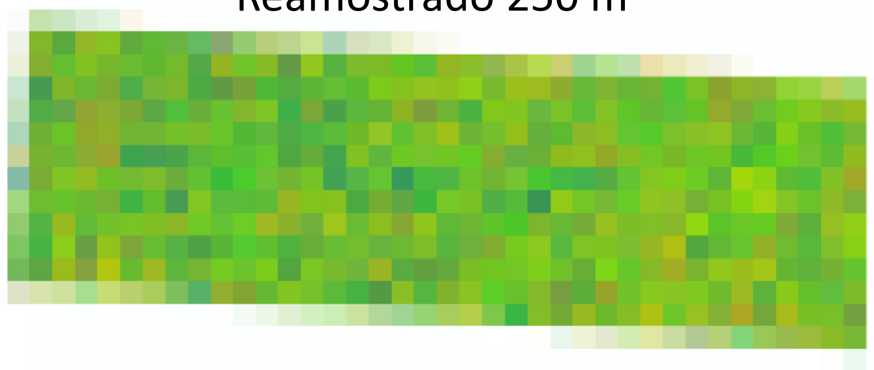
- Para a Amazônia: modelo Random Forest prever AGB a partir de camadas de satélite (índices de veg., terreno, precipitação)
- O modelo gera AGB para todos os pixels (inclusive onde não temos LiDAR)



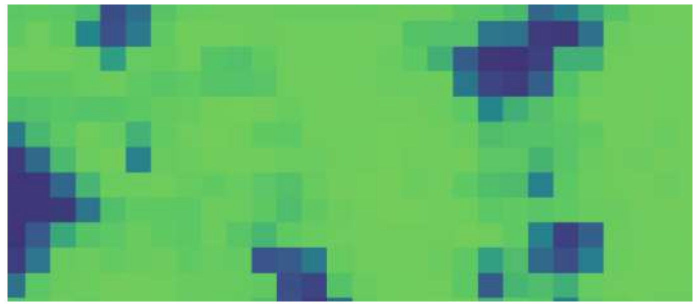
Reamostrado 50 m



Reamostrado 250 m



AGB\Incerteza 250 m



Outras Análises

National Communication to the Climate Convention and as support for the Forest Reference Level (FREL)

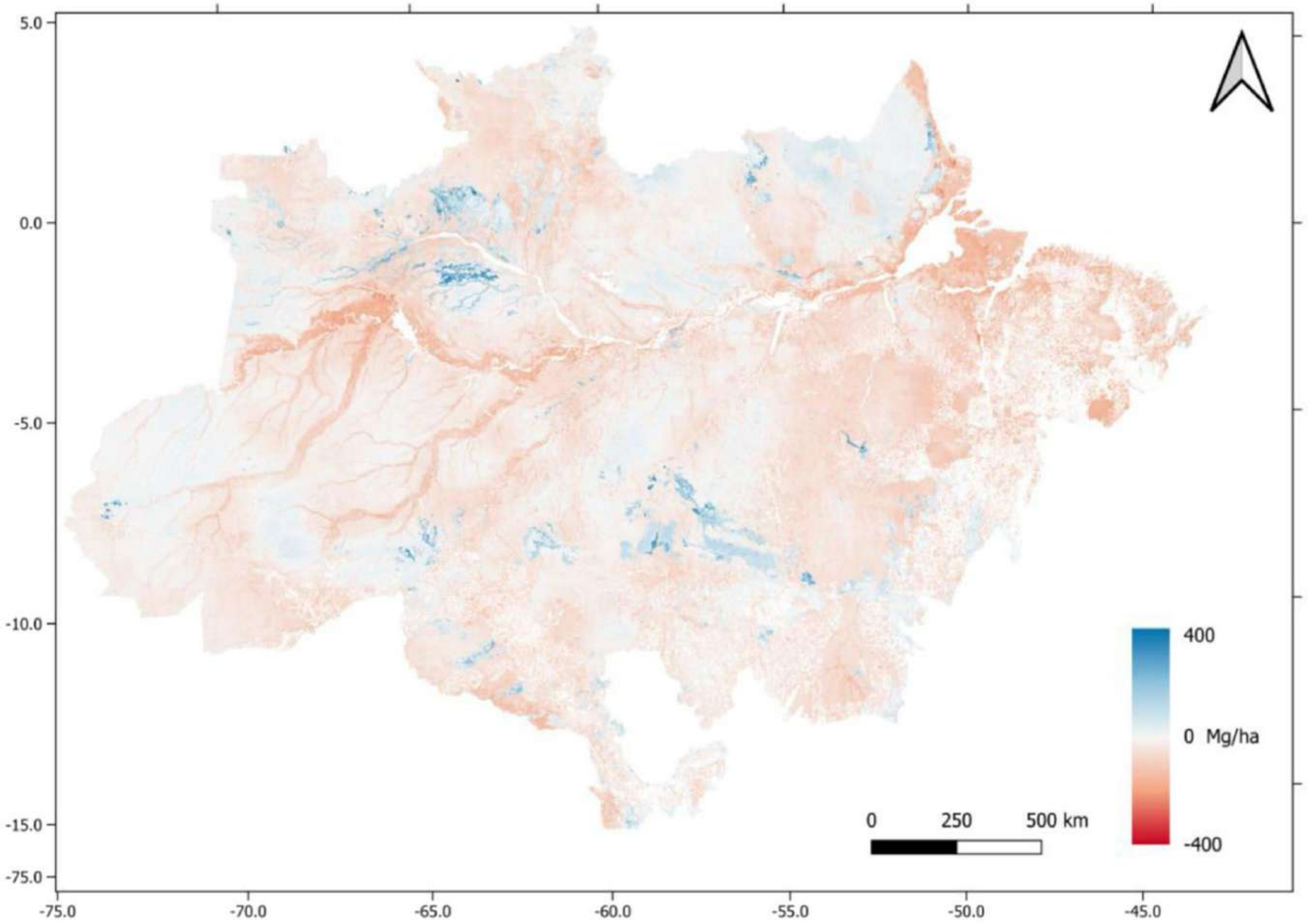
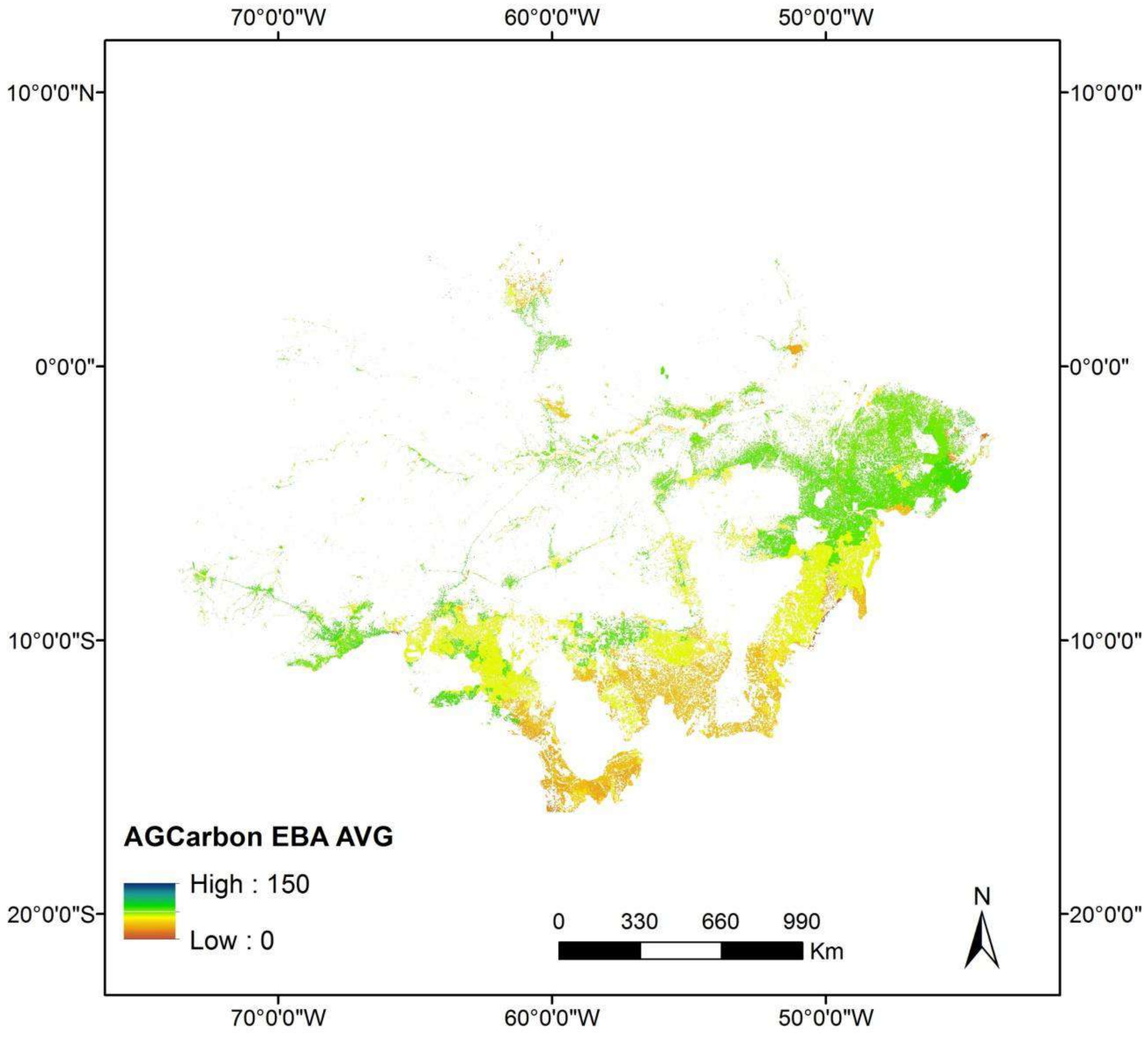


Fig. 6 Comparison with the 3rd Brazilian National Communication. Negative values (red) indicate lower values to 3rd National Communication. Positive values (blue) indicate higher values to the new estimations.

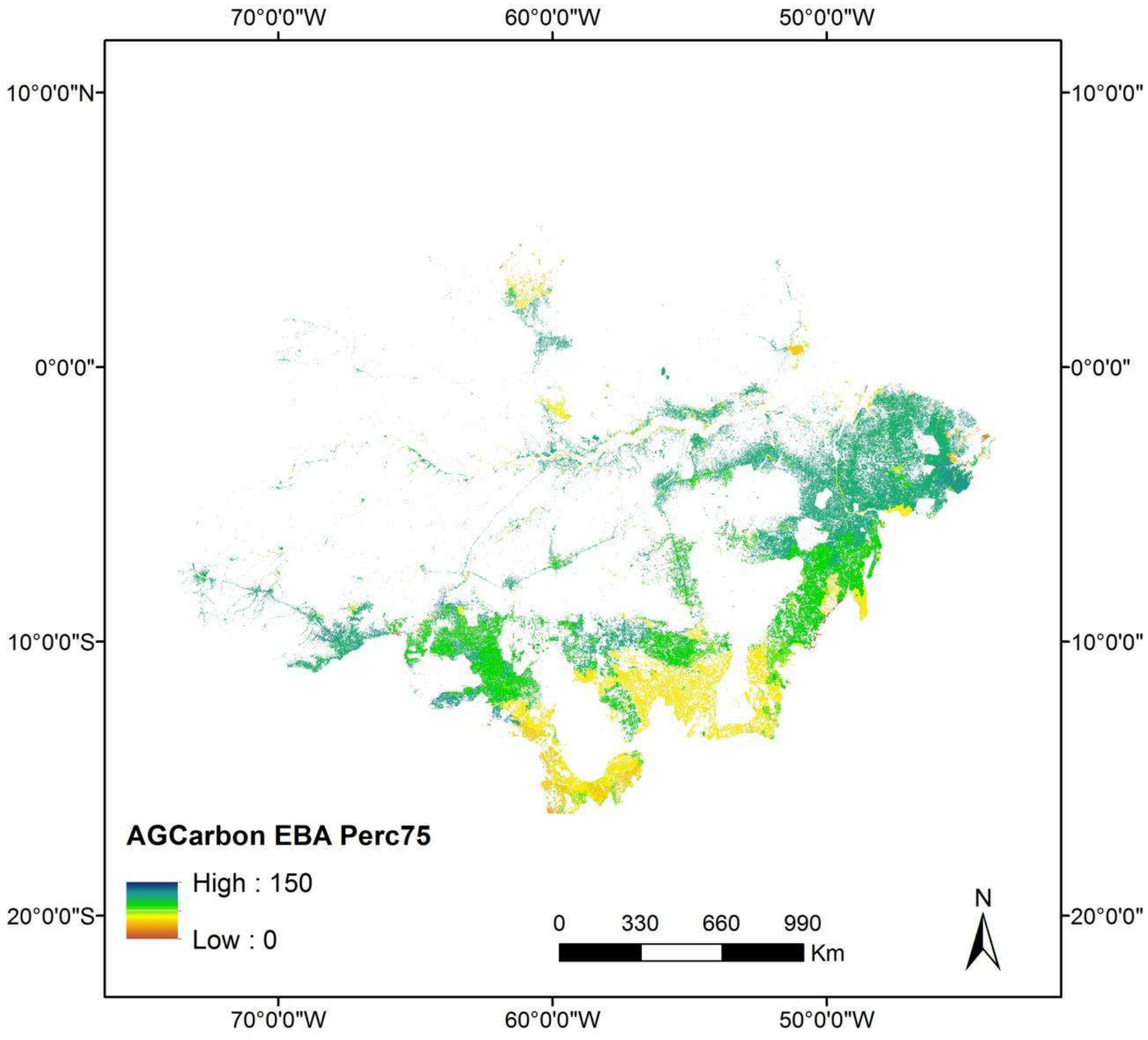
Rede Clima
Mudanças Climáticas
Globais no Brasil

Áreas antropizadas até 2016

AGCarbon EBA considering the average content from vegetation classes



AGCarbon EBA considering the Percentil 75 content from vegetation classes



A few other contributions

scientific reports

Check for updates

OPEN **Large-scale variations in the dynamics of Amazon forest canopy gaps from airborne lidar data and opportunities for tree mortality estimates**

Ricardo Dalagnol[1], Fabien H. Wagner[1,2], Lênio S. Galvão[1], Annia S. Streher[1], Oliver L. Phillips[3], Emanuel Gloor[3], Thomas A. M. Pugh[4,5], Jean P. H. B. Ometto[6] & Luiz E. O. C. Aragão[1,7]

remote sensing MDPI

Article

Characterizing Canopy Structure Variability in Amazonian Secondary Successions with Full-Waveform Airborne LiDAR

Aline D. Jacon [1], Lênio Soares Galvão [1], Rorai Pereira Martins-Neto [2], Pablo Crespo-Peremarch [3,4], Luiz E. O. C. Aragão [1], Jean P. Ometto [5], Liana O. Anderson [6], Laura Barbosa Vedovato [7], Celso H. L. Silva-Junior [8], Aline Pontes Lopes [1], Vinícius Peripato [1], Mauro Assis [1], Francisca R. S. Pereira [1], Isadora Haddad [1], Catherine Torres de Almeida [9], Henrique L. G. Cassol [1,10] and Ricardo Dalagnol [11,12,*]

Science of Remote Sensing 6 (2022) 100067

ELSEVIER

Contents lists available at ScienceDirect

Science of Remote Sensing

journal homepage: www.sciencedirect.com/journal/science-of-remote-sensing

Assessment of terrain elevation estimates from ICESat-2 and GEDI spaceborne LiDAR missions across different land cover and forest types

Mikhail Urbazaev [a,*], Laura L. Hess [b], Steven Hancock [c], Luciane Yumie Sato [d], Jean Pierre Ometto [d], Christian Thiel [e], Clémence Dubois [a], Kai Heckel [a], Marcel Urban [a], Markus Adam [a], Christiane Schmullius [a]

PNAS RESEARCH ARTICLE | ECOLOGY SUSTAINABILITY SCIENCE OPEN ACCESS

A large net carbon loss attributed to anthropogenic and natural disturbances in the Amazon Arc of Deforestation

Ovidiu Csillik[a,1,2], Michael Keller[a,b], Marcos Longo[c], Antonio Ferraz[a], Ekena Rangel Pinagé[d], Eric Bastos Görgens[e], Jean P. Ometto[f], Vinicius Silgueiro[g], David Brown[h], Paul Duffy[h], K. C. Cushman[i], and Sassan Saatchi[a]

nature communications

Article https://doi.org/10.1038/s41467-025-61856-1

Human influence on Amazon's aboveground carbon dynamics intensified over the last decade

Received: 23 August 2024

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Published online: 21 July 2025

Arthur Fendrich[1,2], Yu Feng[1,3], Jean-Pierre Wigneron[4], Jerôme Chave[5], Arnan Araza[6], Zheyuan Li[7], Martin Herold[8,9], Jean Ometto[10], Luiz E. O. C. Aragão[11,12], Isabel Martinez Cano[1], Lei Zhu[1,13], Yidi Xu[1] & Philippe Ciais[1]

Environ. Res. Lett. 20 (2025) 054024 https://doi.org/10.1088/1748-9326/adc58c

ENVIRONMENTAL RESEARCH LETTERS

LETTER

Degradation and deforestation increase the sensitivity of the Amazon Forest to climate extremes

Marcos Longo[1,2,*], Michael Keller[2,3], Lara M Kueppers[1,4], Kevin W Bowman[2], Ovidiu Csillik[2,5], António Ferraz[2], Paul R Moorcroft[6], Jean Pierre Ometto[7], Britaldo S Soares-Filho[8], Xiangtao Xu[9], Mauro L R de Assis[7], Eric B Görgens[10], Erik J L Larson[6], Jessica F Needham[1], Elsa M Ordway[11,12], Francisca R S Pereira[7], Ekena Rangel Pinagé[13], Luciane Sato[7], Liang Xu[2,14] and Sassan Saatchi[2,11]

More than 10,000 pre-Columbian earthworks are still hidden throughout Amazonia

VINICIUS PERIPATO, CAROLINA LEVIS, GUIDO A. MOREIRA, DANI GAMERMAN, HANS TER STEEGE, NIGEL C. A. PITMAN, JONAS G. DE SOUZA, JOSÉ IRIARTE, MARK ROBINSON, [...], AND LUIZ E. O. C. ARAGÃO +220 authors Authors Info & Affiliations

Science 382, 103–109 (2023)

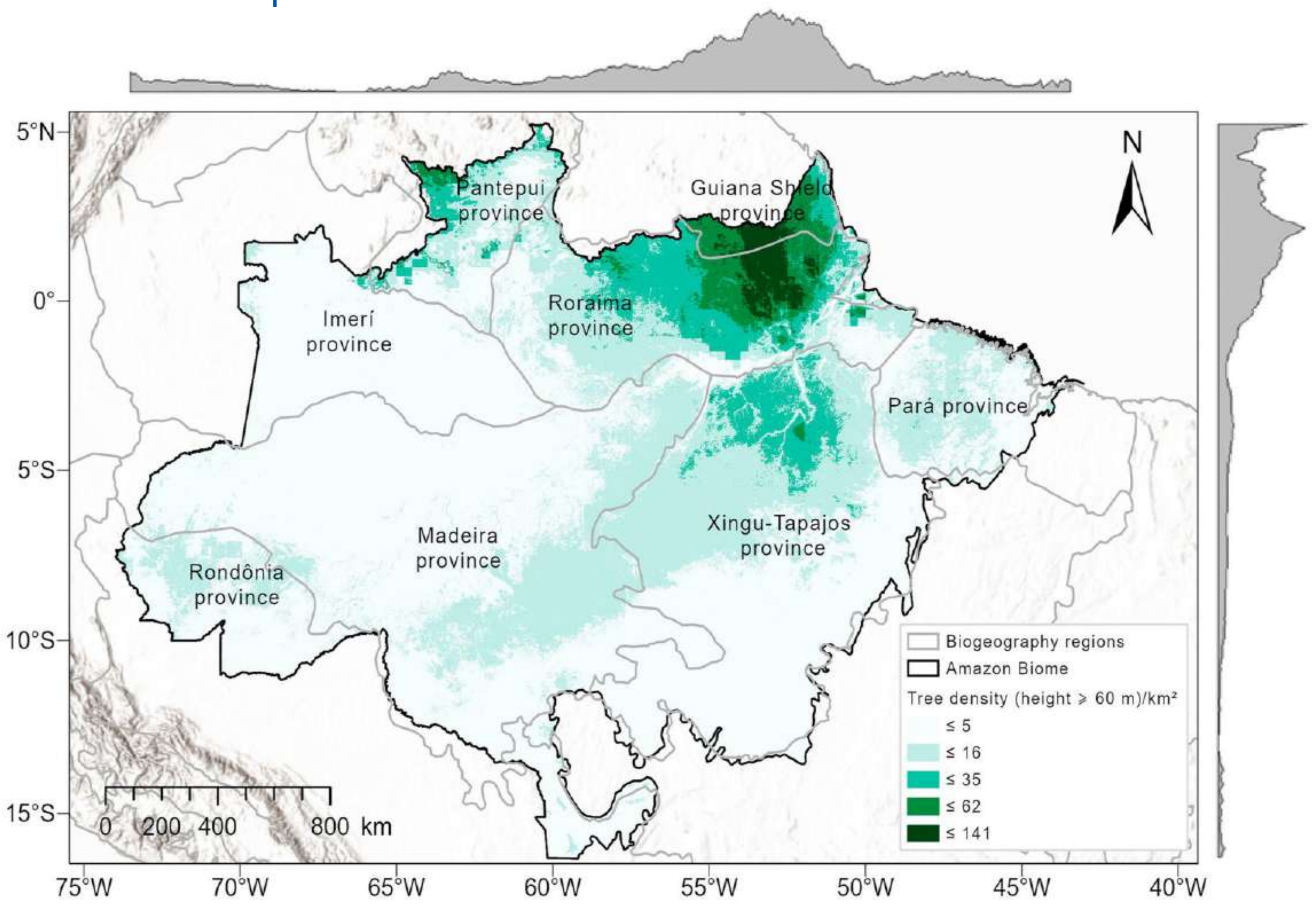
[...]

New Phytologist Resea

Mapping the density of giant trees in the Amazon

Robson Borges de Lima[1], Diego Armando Silva da Silva[2], Matheus Henrique Nunes[3], Paulo R. de Lima Bittencourt[4], Peter Groenendyk[5], Cinthia Pereira de Oliveira[1], Daniela Granato-Souza[6], Rinaldo L. Caraciolo Ferreira[7], José A. Aleixo da Silva[7], Jesús Aguirre-Gutiérrez[8], Toby Jackson[9], João R. de Matos Filho[10], Perseu da Silva Aparício[1], Joselane P. Gomes da Silva[1], José Julio de Toledo[11], Marcelino Carneiro Guedes[12], Danilo R. Alves de Almeida[13], Niro Higuchi[14], Fabien H. Wagner[15], Jean Pierre Ometto[16] and Eric Bastos Görgens[17]

DOI: 10.1111/nph.70634



Potential map generated by the random forest spatial model to define ideal zones for the occurrence of high density of giant trees in the Amazon.

Resolution Tree Height Mapping of the1 Amazon forest using Planet NICFI and2 LiDAR-Informed U-Net Model3

Wagner et al (Remote Sensing in Ecology and Conservation)

model successfully estimated canopy heights up to 40–50 m without much saturation, outperforming existing canopy height products from global models in this region. We determined that the Amazon forest has an average canopy height of~22 m.
Events such as logging or deforestation could be detected from changes in tree height, and encouraging results were obtained to monitor the height of regenerating forests.

Very high resolution map of the Amazon canopy height

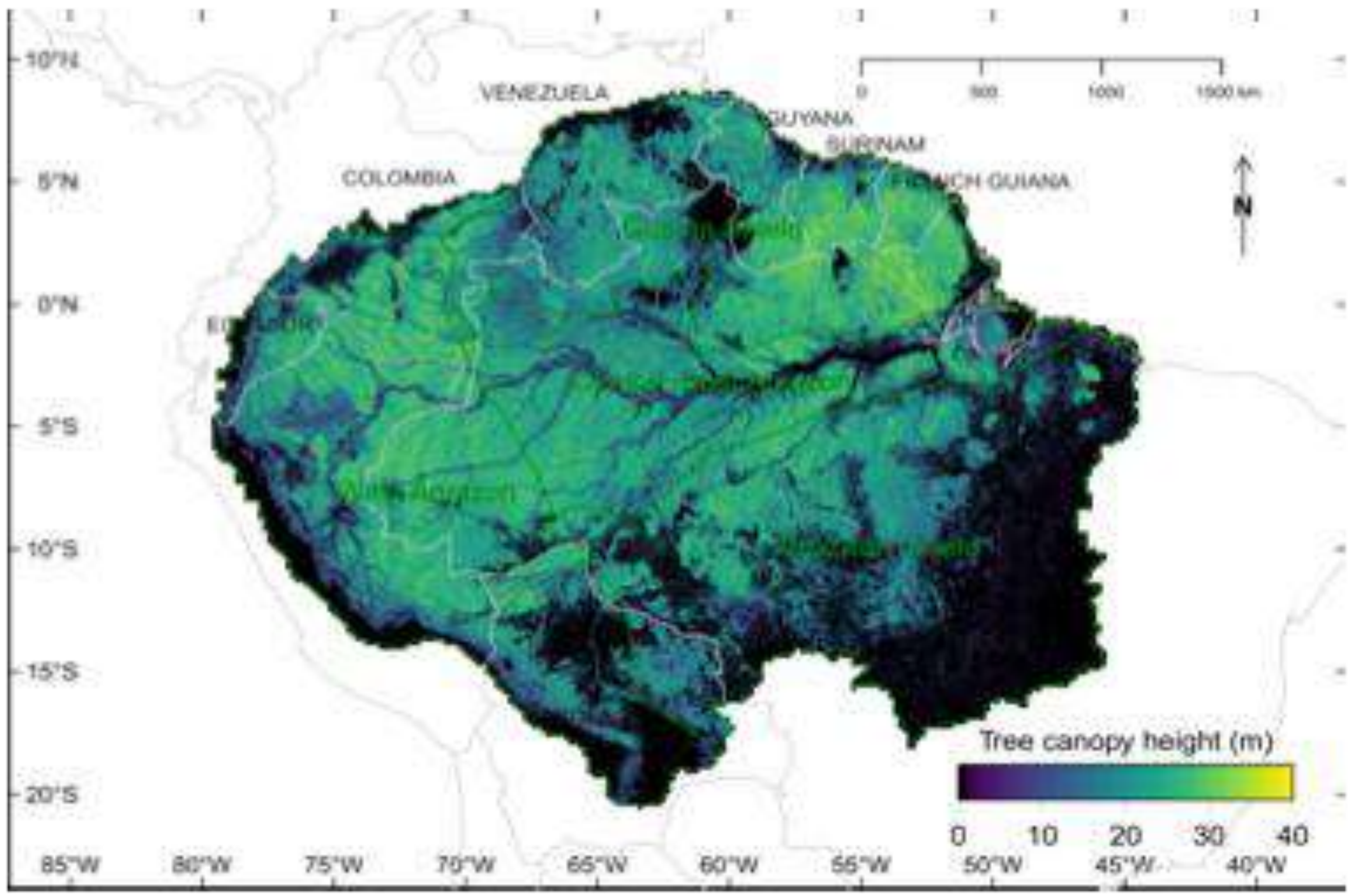
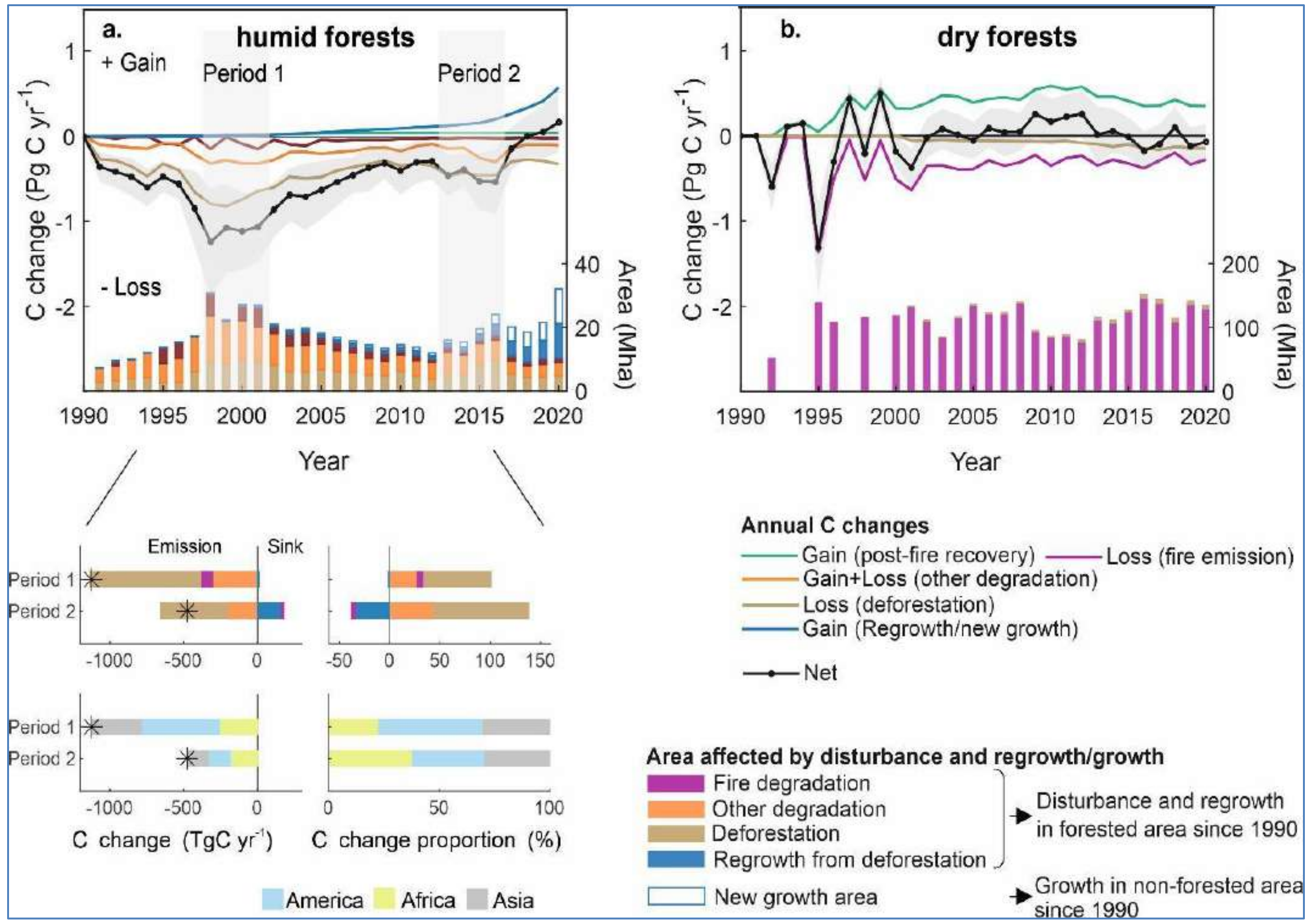


Figure 14. Canopy height of the Amazon forest (m). To facilitate visualization at very high resolution, the colors represent the estimates from our model, aggregated to an 80 m spatial resolution using the median.

A few other contributions (in review)

Small persistent humid forest clearings drive tropical forest biomass losses
Xu et al (in review)



Beyond forest height and biomass: characterizing the vertical structure of forests in the Brazilian Amazon
Valle et al (in review)

[…] secondary forests fully recover or even exceed reference areas at the 1-10 m height stratum after 5 to 10 years but that full recovery for the 20-30 m height stratum has not been achieved even after 35 years

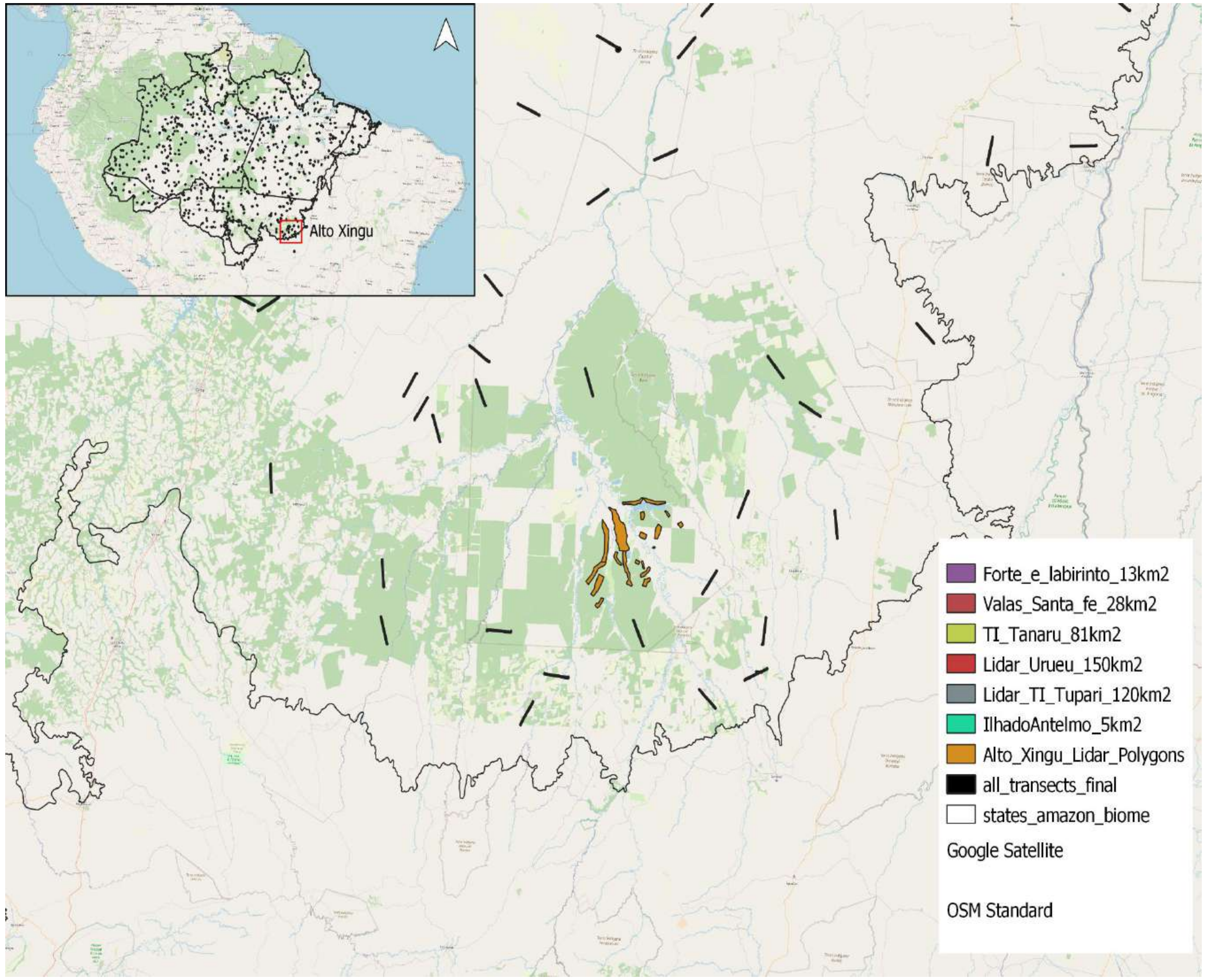
The Global Canopy Atlas: analysis-ready maps of 3D structure for the world's woody ecosystems
Fischer et all (in review)

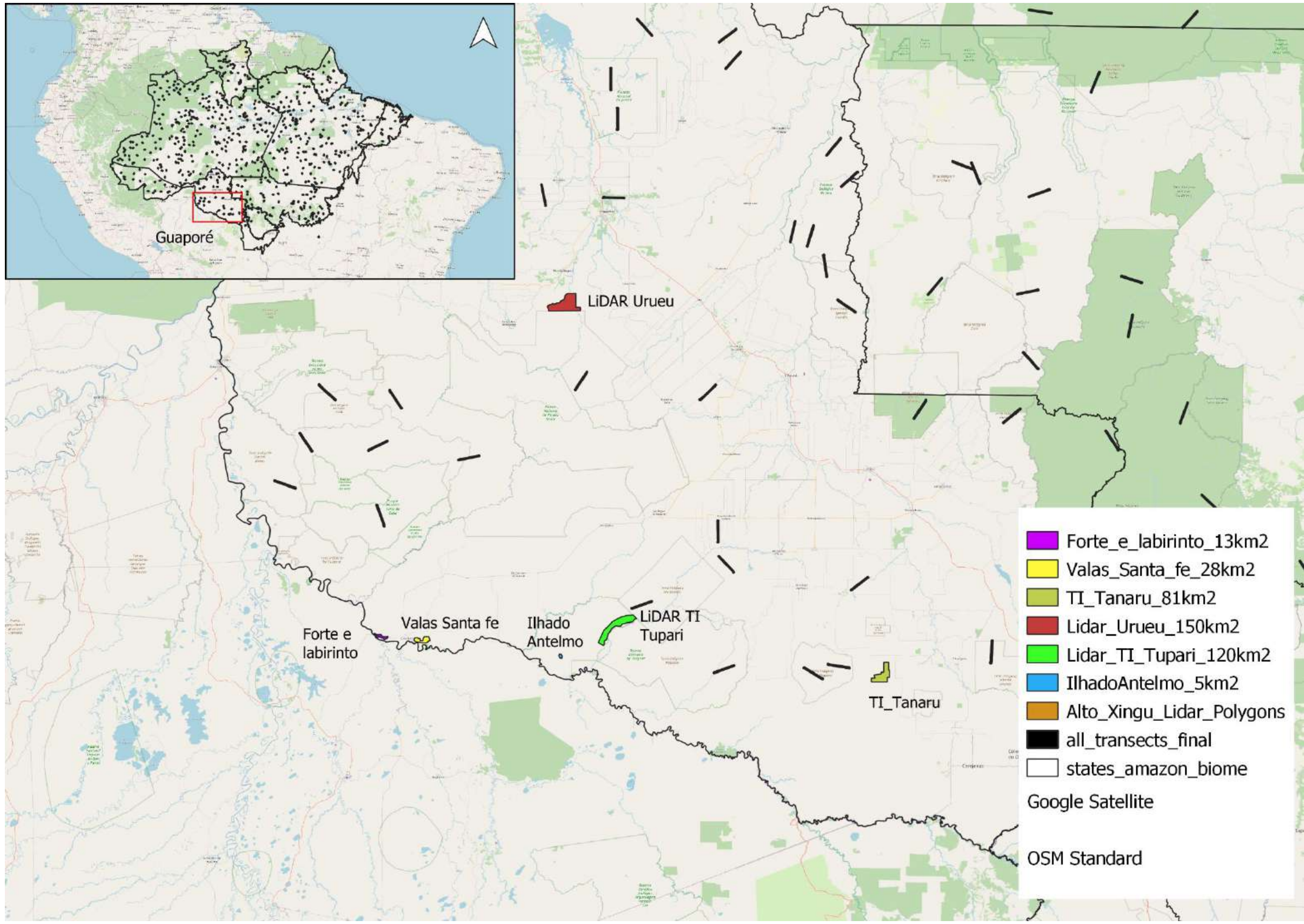
[…] Global Canopy Atlas (GCA): 3,458 ALS acquisitions transformed into standardized and analysis-ready maps of canopy height and elevation at 1 m2 resolution. The GCA covers 56,554 km2 across all major biomes.

Fire in a Central Amazon forest: Lingering top canopy loss and initial understory regrowth revealed by repeated LiDAR
Pontes-Lopes et al (in review)

[… results revealed initial incipient recovery occurring simultaneously to delayed large tree mortality—where a prior field study did not because of sample scale dependent detection—highlighting pervasive impacts of fire that may contribute to a greater sensitivity of rainforests to climate change."

[…]





Alto Xingu

Guaporé

AMAZÔNIA REVELADA

Obrigado

Estimation of Aboveground Biomass in Old-Growth Forests and Classification of Forests Across Successional Stages

Polyanna Bispo

Session 2.1 (Part 1): Biomass datasets and missions

São José dos Campos, 30 Oct 2025

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MANCHESTER 1824
The University of Manchester

Estimation of Aboveground Biomass in Old-Growth Forests and Classification of Forests Across Successional Stages

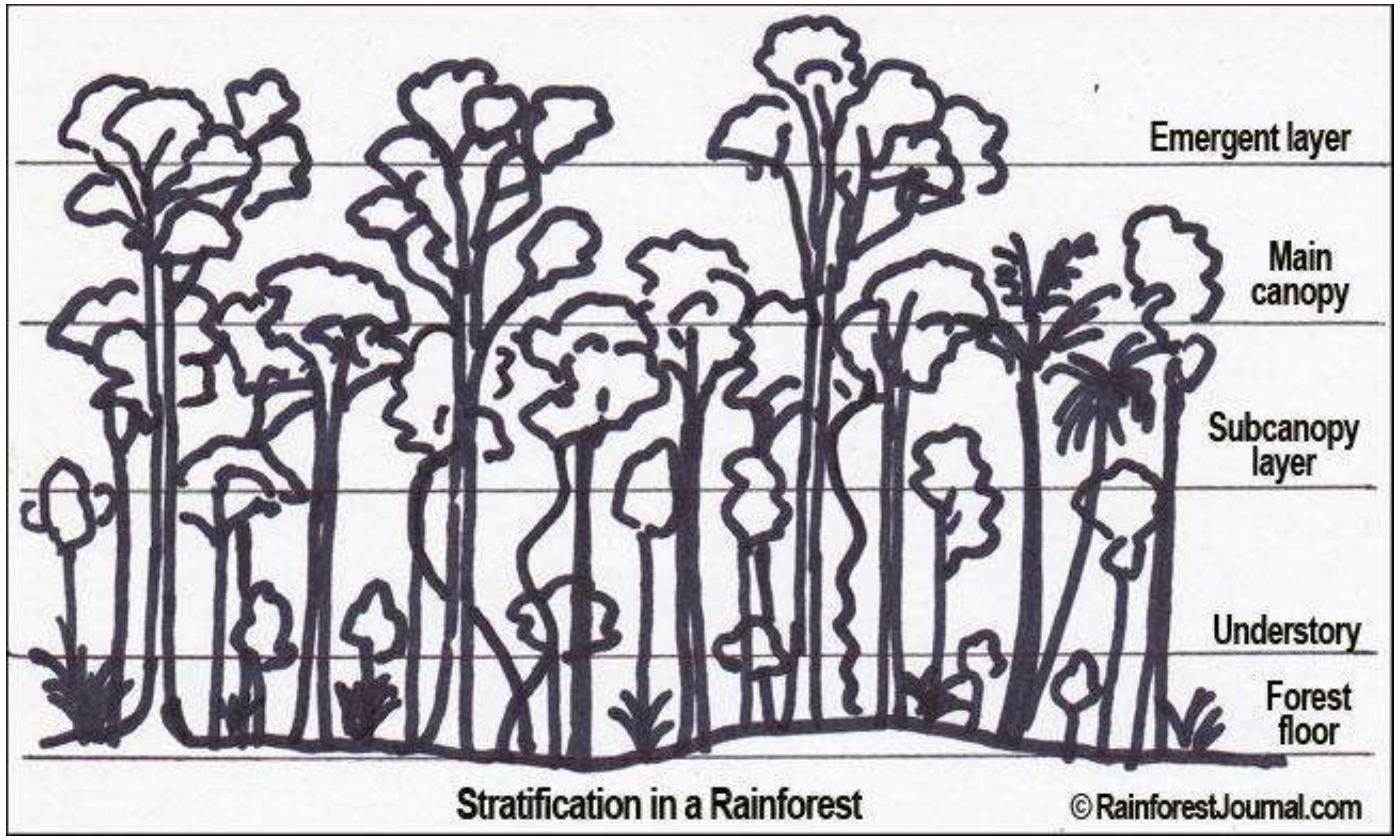
Dr. Polyanna da Conceição Bispo

Senior Lecturer (Associate Professor) in Physical Geography
Department of Geography, University of Manchester (UK)

Co-Lead of Land and Resources research theme of MERI (Manchester Environmental Institute)

Internal Reviewer Editor of IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services)

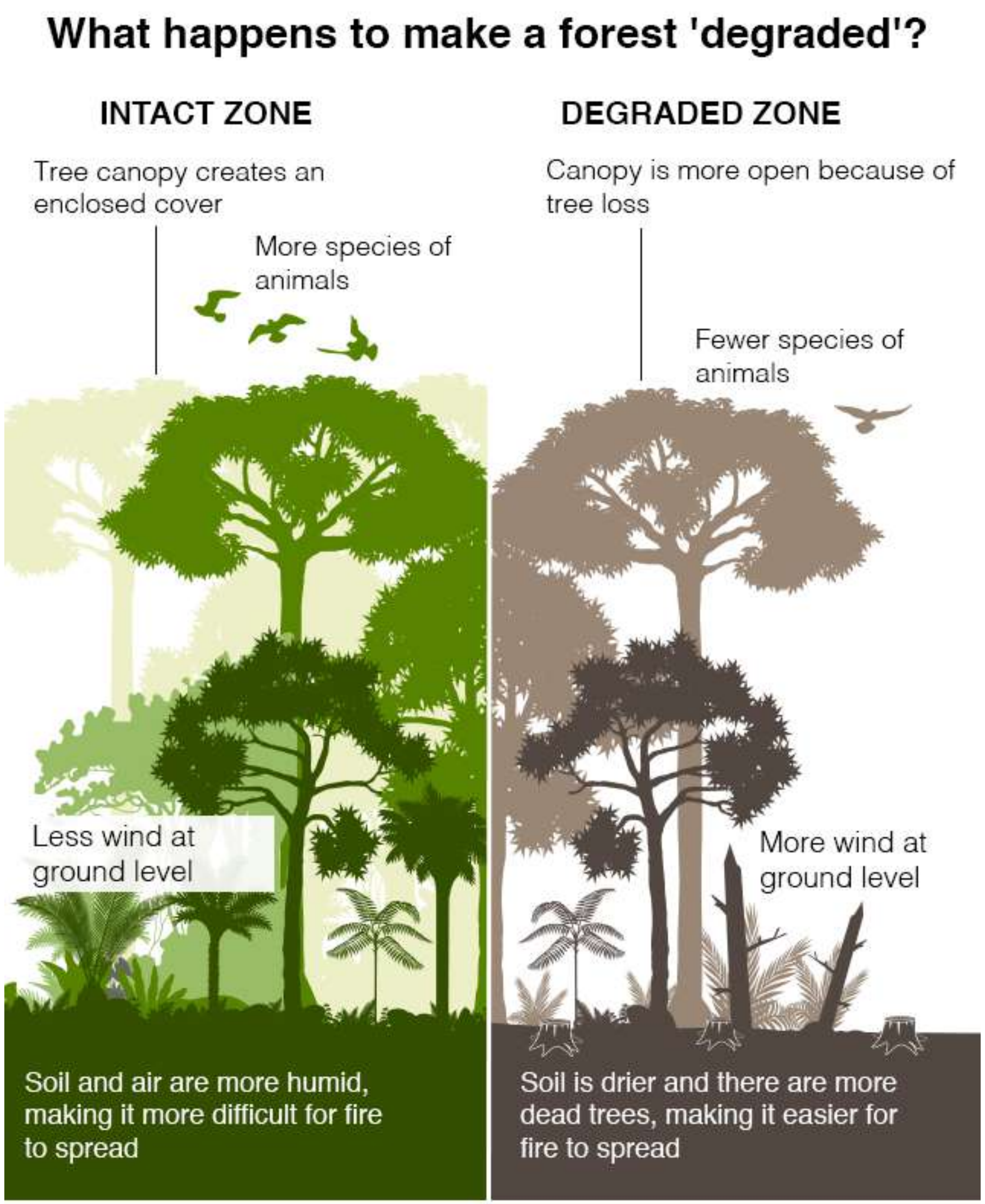
Email: polyanna.bispo@manchester.ac.uk
Linkedin: Polyanna Bispo



Estimation: 1,053 species account for half of the planet's 800 billion tropical forest trees. The other half are comprised of 46,000 tree species. The number of rare species is extreme, with the rarest 39,500 species accounting for just 10% of trees (Slik et al 2015).

Deforestation/ Clear Cut

A degraded forest is the result of a process of degradation which negatively affects the structural and functional characteristics of that forest



https://www.bbc.co.uk/news/science-environment-51300515

Above Ground Biomass

Taylor & Francis
Taylor & Francis Group

Canadian Journal of Remote Sensing
Journal Canadien de Télédétection

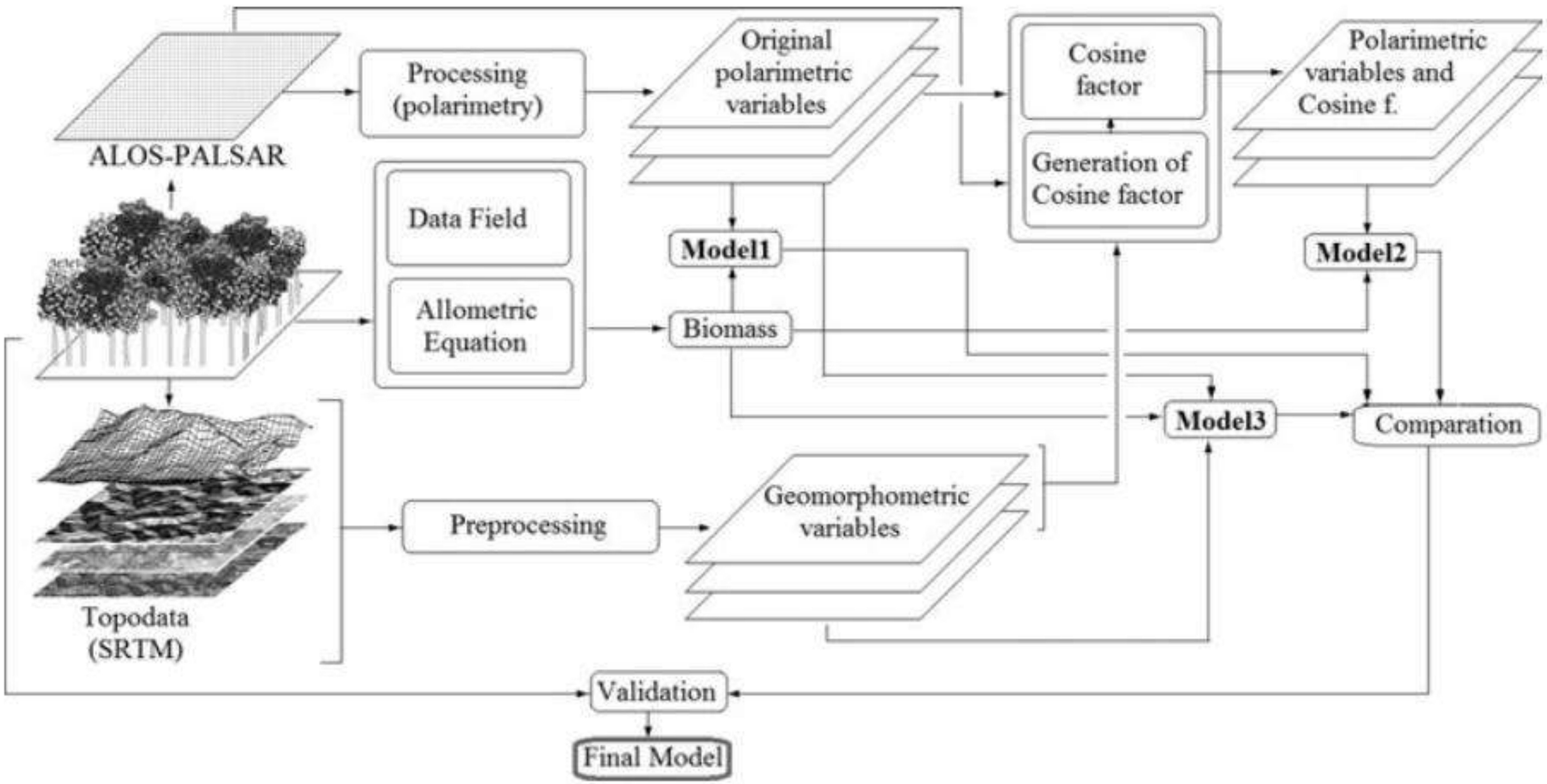
ISSN: 0703-8992 (Print) 1712-7971 (Online) Journal homepage: www.tandfonline.com/journals/ujrs20

Integration of Polarimetric PALSAR Attributes and Local Geomorphometric Variables Derived from SRTM for Forest Biomass Modeling in Central Amazonia

P. C. Bispo, J. R. Santos, M. M. Valeriano, R. Touzi & F. M. Seifert

To cite this article: P. C. Bispo, J. R. Santos, M. M. Valeriano, R. Touzi & F. M. Seifert (2014) Integration of Polarimetric PALSAR Attributes and Local Geomorphometric Variables Derived from SRTM for Forest Biomass Modeling in Central Amazonia, Canadian Journal of Remote Sensing, 40:1, 26-42, DOI: 10.1080/07038992.2014.913477

To link to this article: https://doi.org/10.1080/07038992.2014.913477



Analyses and generation of biomass estimation models with SRTM and PALSAR/ALOS data.

Modeling of forest biomass

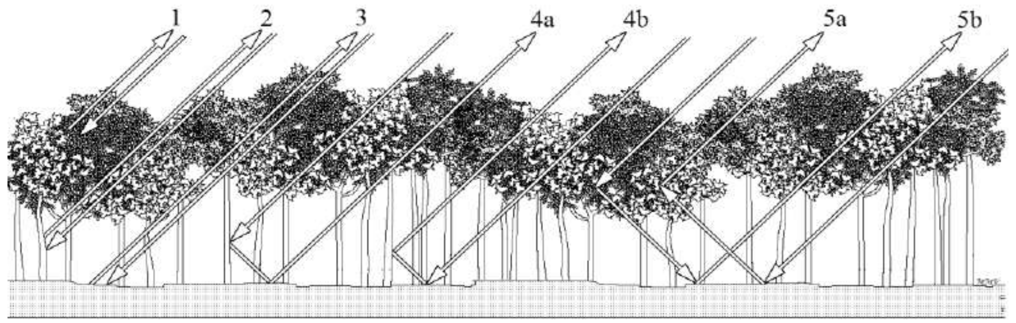
Estimated biomass from polarimetric variables (SAR):

$BM = -191{,}8 - 10{,}595\ \tau\_m1 - 11{,}562\ \alpha\_s1 + 634{,}6\ H - 463{,}9\ An$

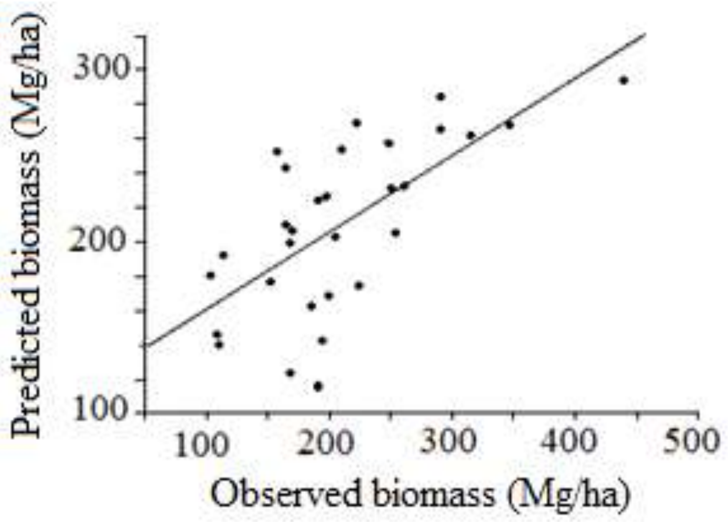
r^2=0,35, *p=0,004*

error=54,32 Mg/ha

(26% from biomass mean)



τ_m1: first component of the Touzi helicity; α_s1: first component of the Touzi magnitude; H: entropy; An: anisotropy;



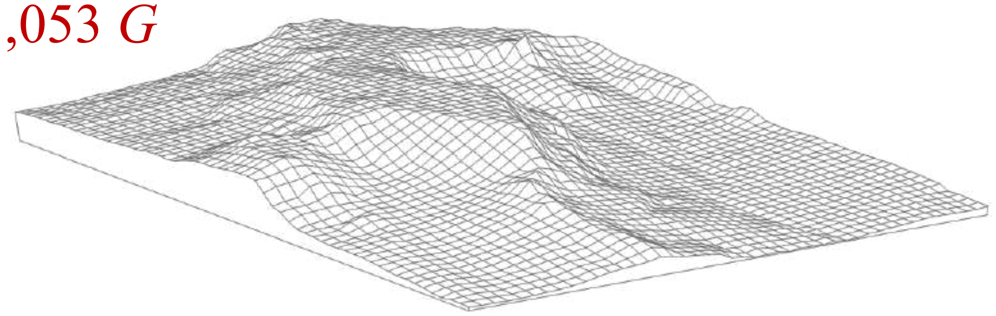
Estimated biomass from geomorphometric variables:

$BM = -19{,}67 + 1{,}3467\ h + 3{,}053\ G$

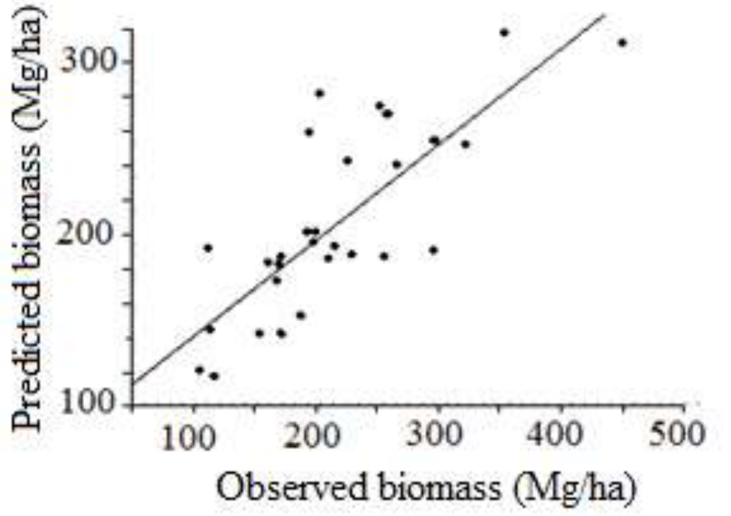
r^2=0,58, *p=0,000*

error= 45,80 Mg/ha

(22% from biomass mean)



h: elevation; G: slope



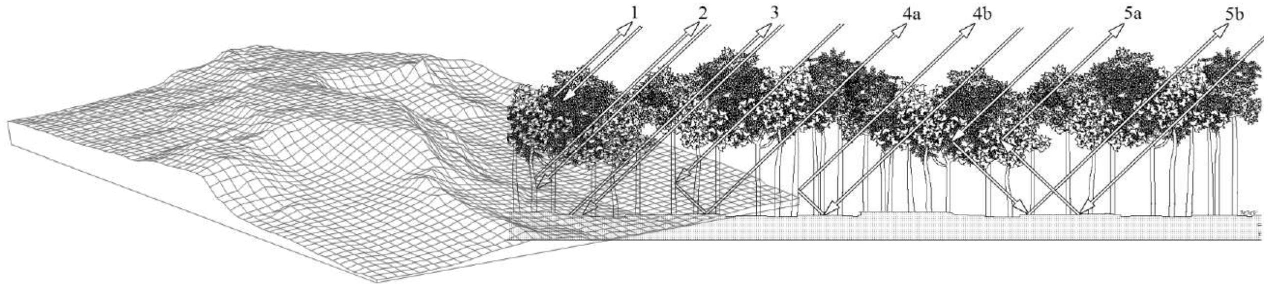
Estimated biomass from composite model:

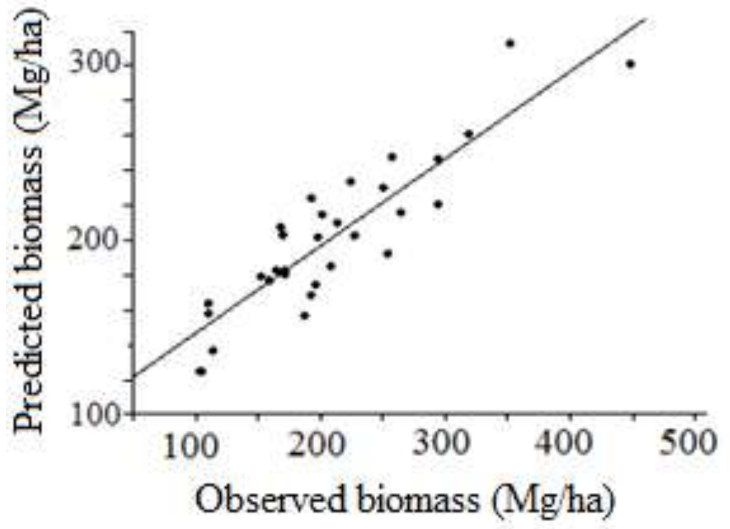
$BM = 31{,}11 + 142{,}01\ Pv - 598{,}3\ An + 1{,}465\ h + 3{,}35\ G + 0{,}4288\ \tau\_m3 - 9{,}478\ \tau\_m1$

r^2=0,74, *p=0,000*

erro= 33.15 Mg/ha

(15% from biomass mean)





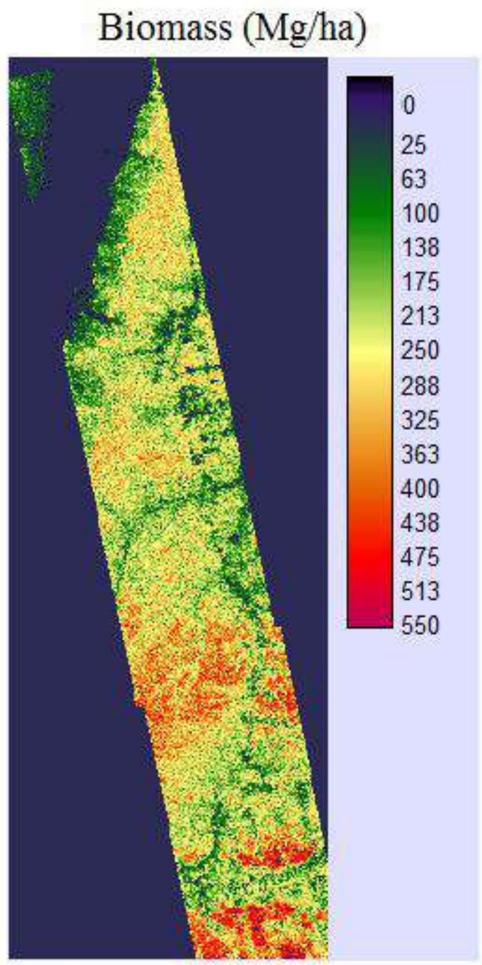
Estimated biomass from composite model:

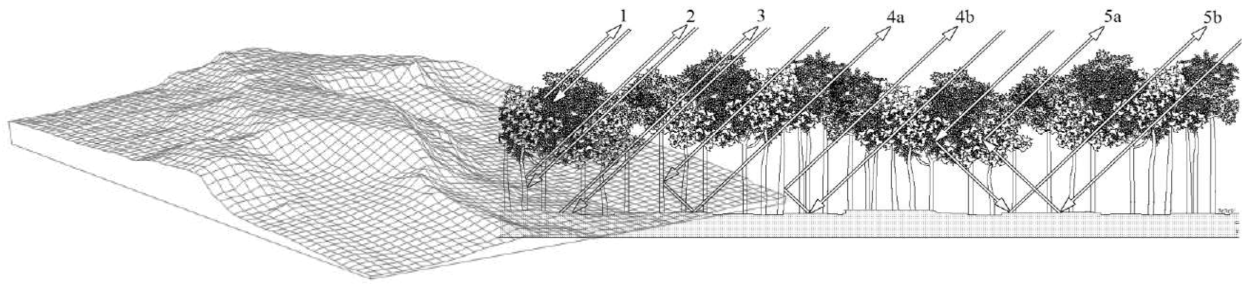
$BM = 31{,}11 + 142{,}01\,Pv - 598{,}3\,An + 1{,}465\,h + 3{,}35\,G + 0{,}4288\,\tau\_m3 - 9{,}478\,\tau\_m1$

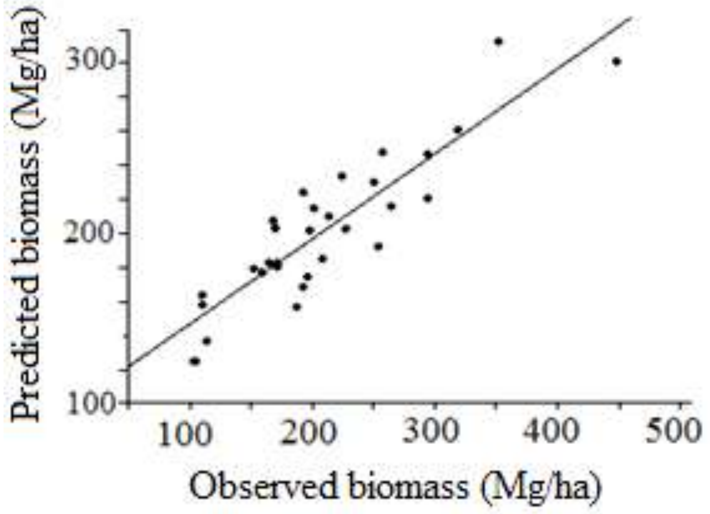
***r^2=0,74**, p=0,000*

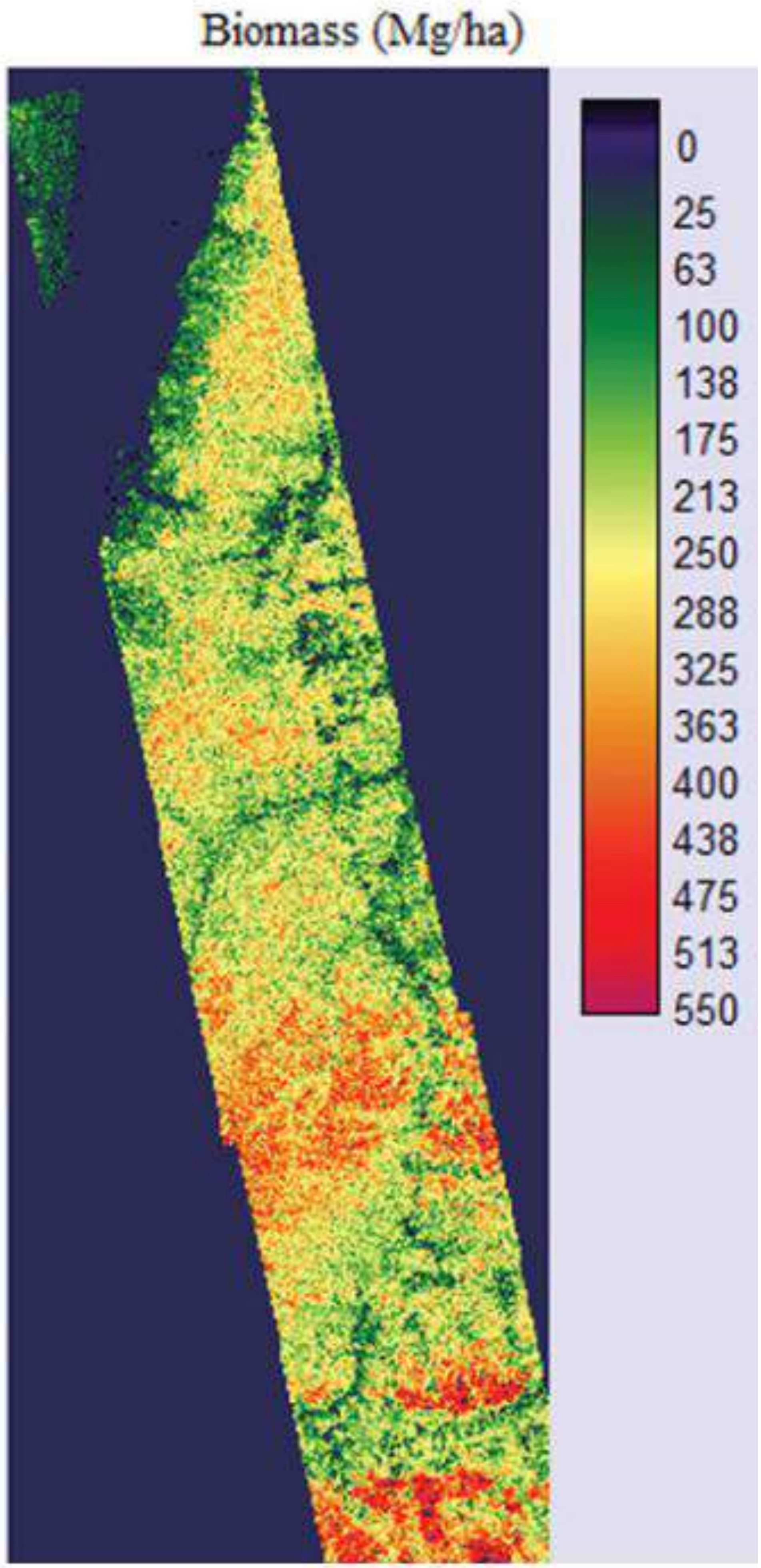
erro= 33.15 Mg/ha
(15% from biomass mean)

BM: Biomass; *Pv:* Volumetric Scaterring Freeman; *An:* Anisotropy; *h:* Altitude; *G:* Slope; *τ_m3:* Third Component of Touzi Helicity; *τ_m1:* First Component of Touzi Helicity

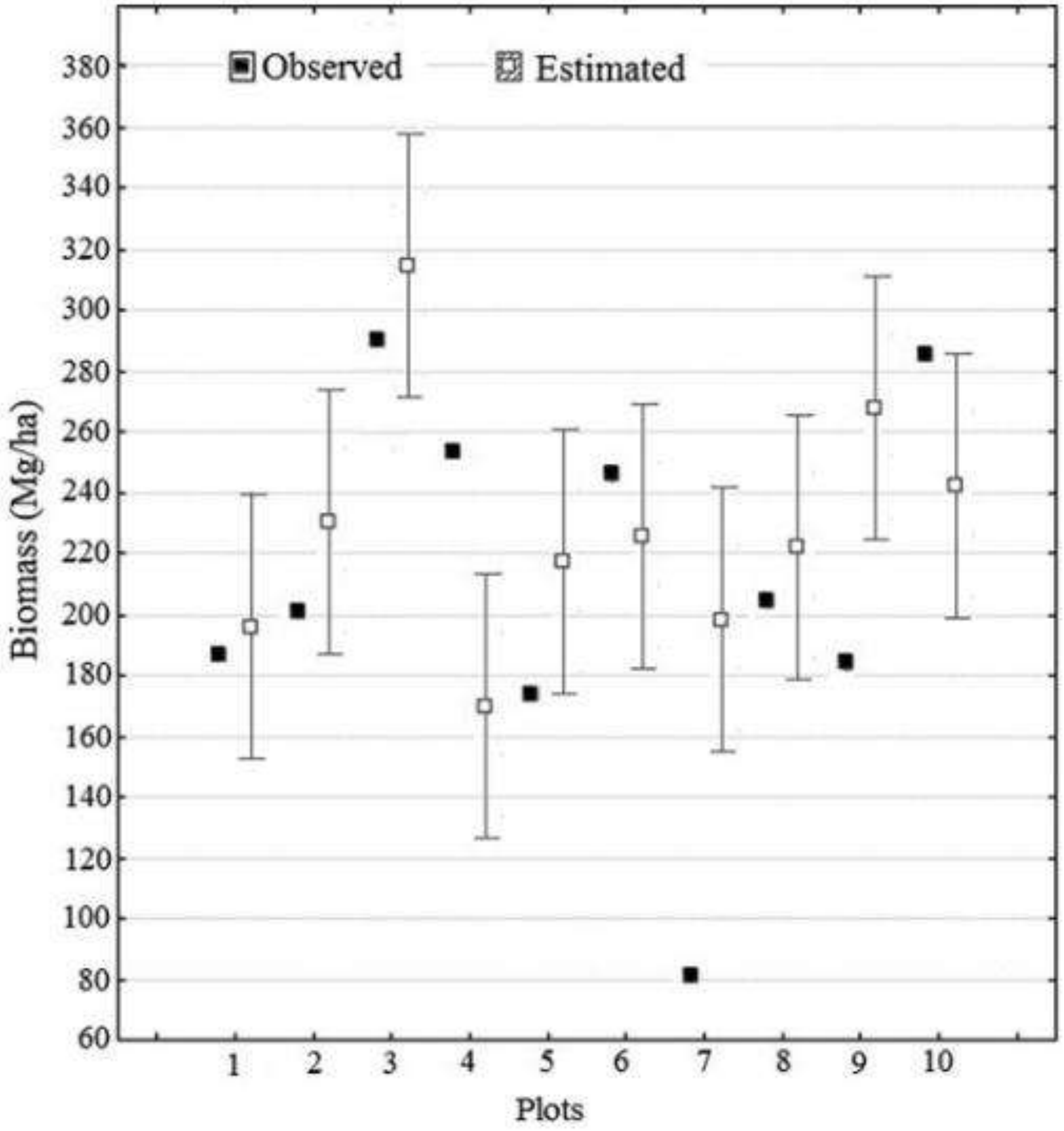








Biomass model image.



Observed and estimated values of biomass data for the 10 sample parcels of the forest inventory. The vertical bars correspond to prediction intervals computed with a 95% confidence level.

The validation of was conducted utilizing the biomass values of 10 independent samples from the 56. The mean biomass value of these 10 parcels was 210.68 ± 40.09 Mg/ha. The RMSE was approximately 42.96 Mg/ha. Comparing the values derived from the model and those measured in the field (graph on the left), there is a mean error of 20.31%, a value considered adequate for biomass inventory estimation conducted by traditional methods that employ allometric equations.

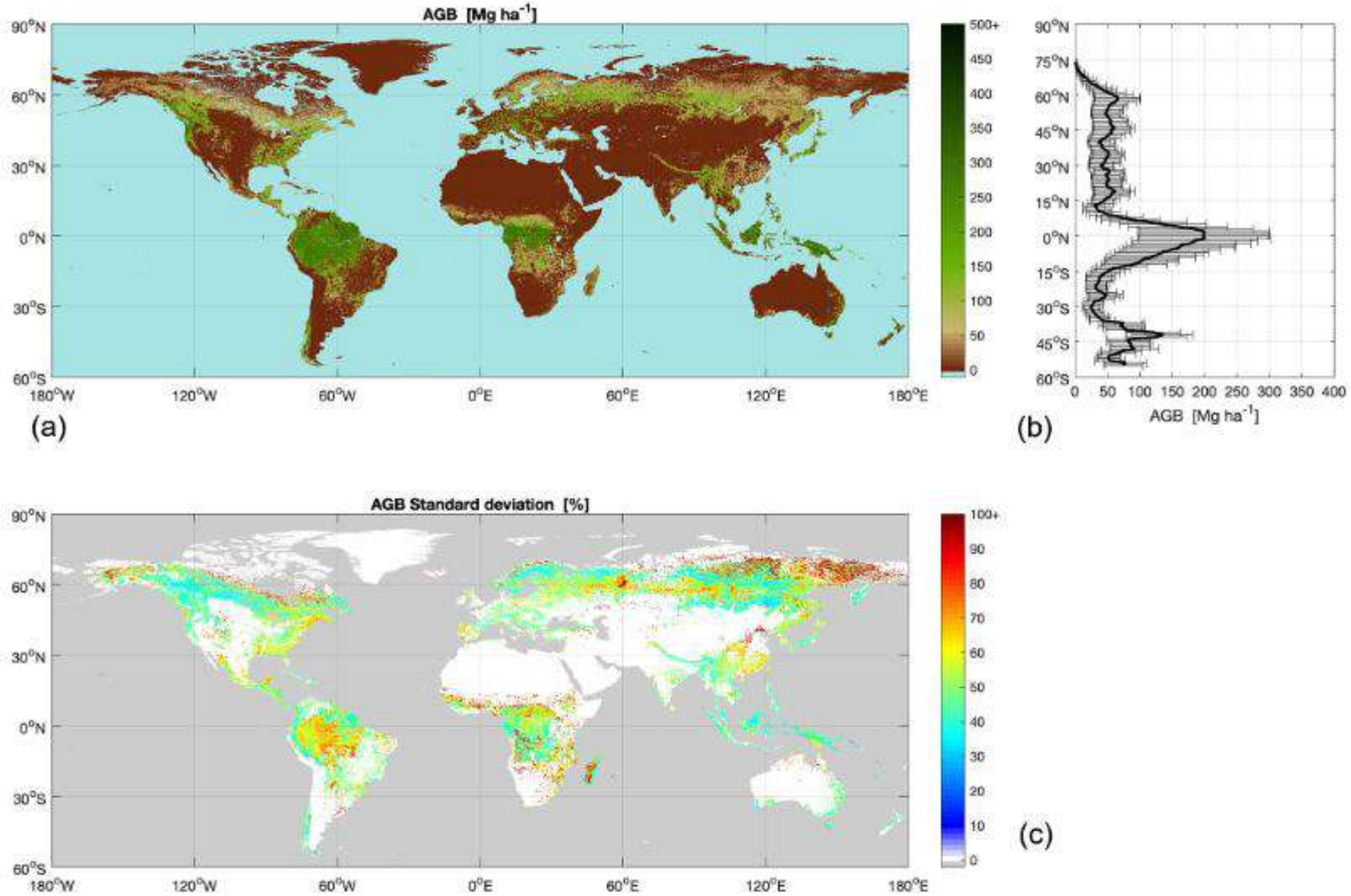


Figure 2. Map estimates of AGB (**a**) and AGB standard deviation expressed relative to the AGB (**b**). The colour bar of the AGB map has been truncated at 500 Mg ha^{-1} to increase contrast. Similarly, the colour bar of the AGB relative standard deviation has been truncated at 100 %. The right-hand panel shows the profile of average AGB along latitude (thick solid line) and the two-sided average standard deviation of AGB at a given latitude (horizontal bars).

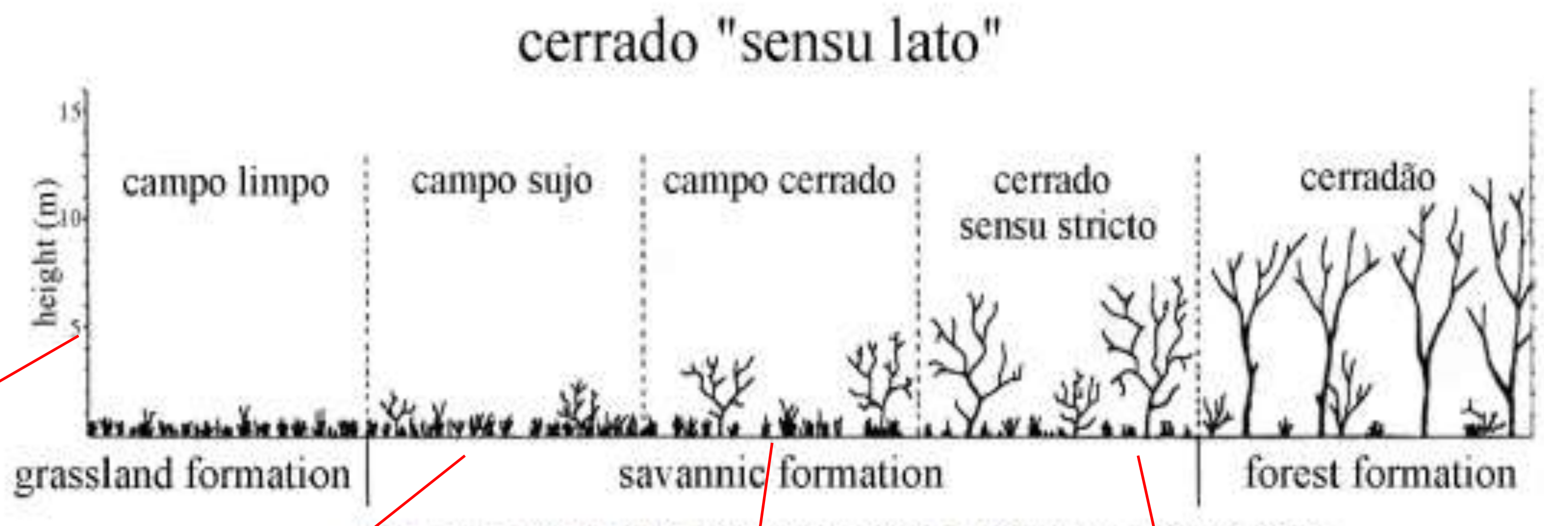
Santoro, et al. 2021, Earth System Science Data https://doi.org/10.5194/essd-13-3927-2021

Woody aboveground biomass mapping of the Brazilian savanna (Cerrado) with a multi-sensor and machine learning approach

The Brazilian Savanna, known as Cerrado (*Cerrado sensu lato* (s.l.)), is the second largest biome in South America.

Bispo, et al. 2020, Remote Sensing https://doi.org/10.3390/rs12172685

- The Cerrado Biome comprises different physiognomies due to variations of soil, topography and human impacts.
- The gradients of tree density, tree height, above ground biomass (AGB) and wood species cover vary according to the Cerrado formation, ranging from different grassland formations (*Campo limpo)*, savannah intermediary formations *(Campo sujo*, *Campo cerrado, and Cerrado sensu stricto* - s.s) and forest formations (*Cerradão*).



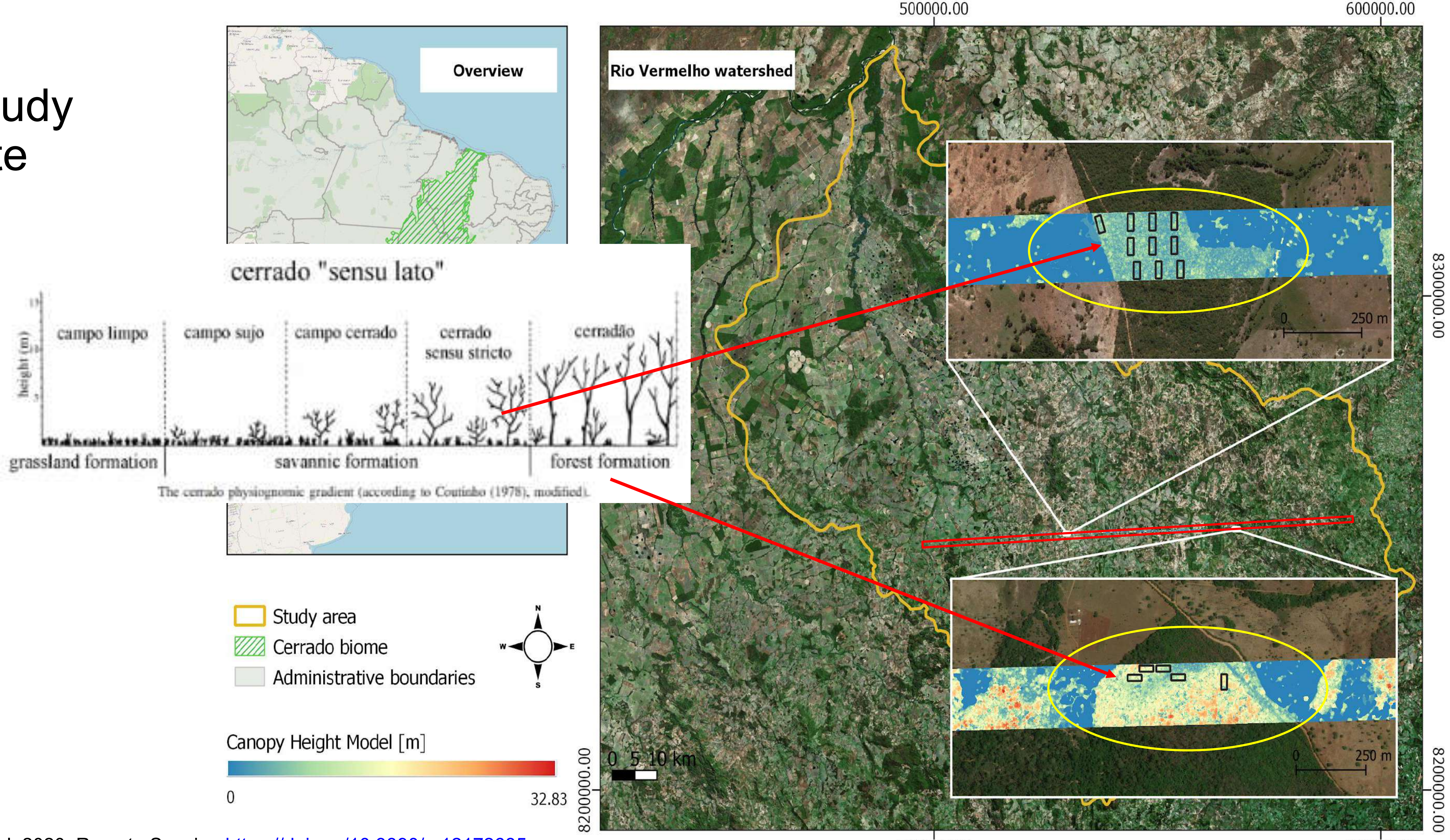
The cerrado physiognomic gradient (according to Coutinho (1978), modified).





Bispo, et al. 2020, Remote Sensing https://doi.org/10.3390/rs12172685

Study site



Bispo, et al. 2020, Remote Sensing https://doi.org/10.3390/rs12172685

Floristic and structural characterisation of the plots located in fragments of native Cerrado vegetation in the Rio Vermelho watershed, Goiás State, Brazil. **WS-FS = savanna-cerradão transition zone, TFS = cerradão, FS-SF = cerradão-seasonal forest transition zone**; S = species richness, DBH =diameter at breast height.

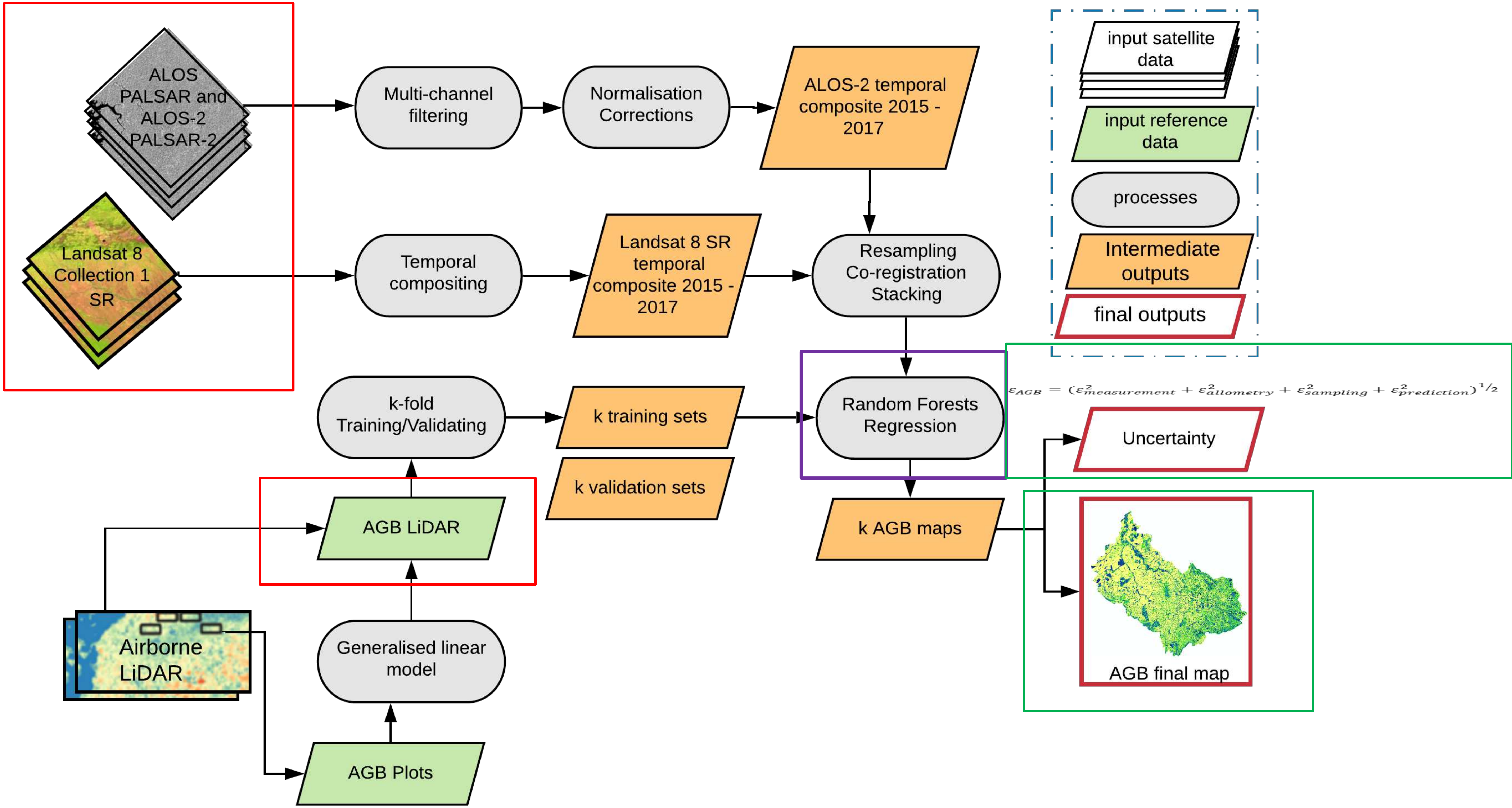
Plot ID	Vegetation Type	S (Species)	TD (Ind. ha^{-1})	DBH Range (cm) (Mean/CV%)	H (m) (Mean/CV%)	TBA (m^2/ha)	AGB (Mg ha^{-1})
Itapirapuã 1	WS-FS	38	990	5.0–36.7 (9.1/56.9)	1.7–11.2 (5.8/26.9)	13.5	19.3
Itapirapuã 2	WS-FS	32	920	5.0–45.5 (9.5/54.7)	1.6–13.4 (5.6/35.5)	10.8	21.2
Itapirapuã 3	WS-FS	45	1030	5.0–29.4 (10.4/54.5)	2.1–14.0 (5.8/35.9)	15.0	24.5
Itapirapuã 4	WS-FS	41	1040	5.3–52.0 (9.8/58.4)	1.3–12.6 (5.5/33.4)	14.4	28.2
Itapirapuã 5	TFS	36	1140	5.0–41.4 (10.3/60.4)	2.0–12.8 (6.0/31.9)	16.4	32.2
Itapirapuã 6	TFS	45	1570	5.0–34.7 (10.5/47.0)	1.5–12.9 (6.5/31.6)	22.6	35.3
Itapirapuã 7	TFS	50	1990	5.0–43.7 (9.1/52.9)	1.8–13.2 (6.5/33.6)	21.9	36.8
Itapirapuã 8	TFS	60	1440	5.0–48.0 (10.4/61.2)	2.6–13.2 (6.1/31.8)	20.1	40.2
Itapirapuã 9	TFS	35	1210	5.0–53.3 (10.1/62.9)	1.8–13.1 (6.5/30.8)	17.0	40.9
Goiás 10	TFS	41	1260	5.0–35.3 (10.9/57.3)	3.6–19.6 (8.7/38.6)	20.5	52.8
Itapirapuã 11	TFS	39	1260	5.0–42.3 (11.2/65.9)	1.7–14.9 (6.3/36.3)	24.3	54.3
Goiás 12	FS-SF	38	1310	5.0–49.3 (11.3/61.5)	2.5–19.3 (9.3/33.3)	24.6	70.4
Goiás 13	FS-SF	26	690	5.0–49.0 (13.0/73.6)	3.4–22.0 (10.2/43.5)	18.3	77.0
Goiás 14	FS-SF	27	820	5.0–44.2 (13.2/63.5)	3.0–38.0 (12.5/48.7)	22.0	98.3
Goiás 15	FS-SF	24	760	5.0–41.7 (14.0/67.3)	2.5–26 (10.9/52.5)	24.4	103.9

Bispo, et al. 2020, Remote Sensing https://doi.org/10.3390/rs12172685

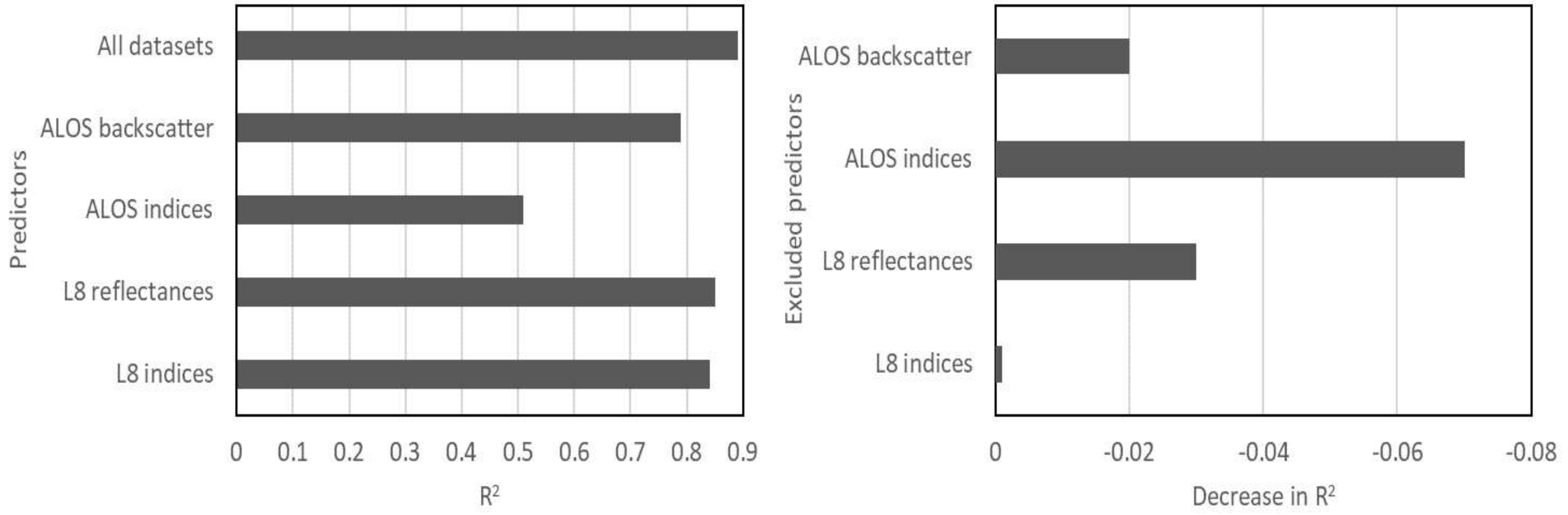
WS-FS

TFS

FS-SF

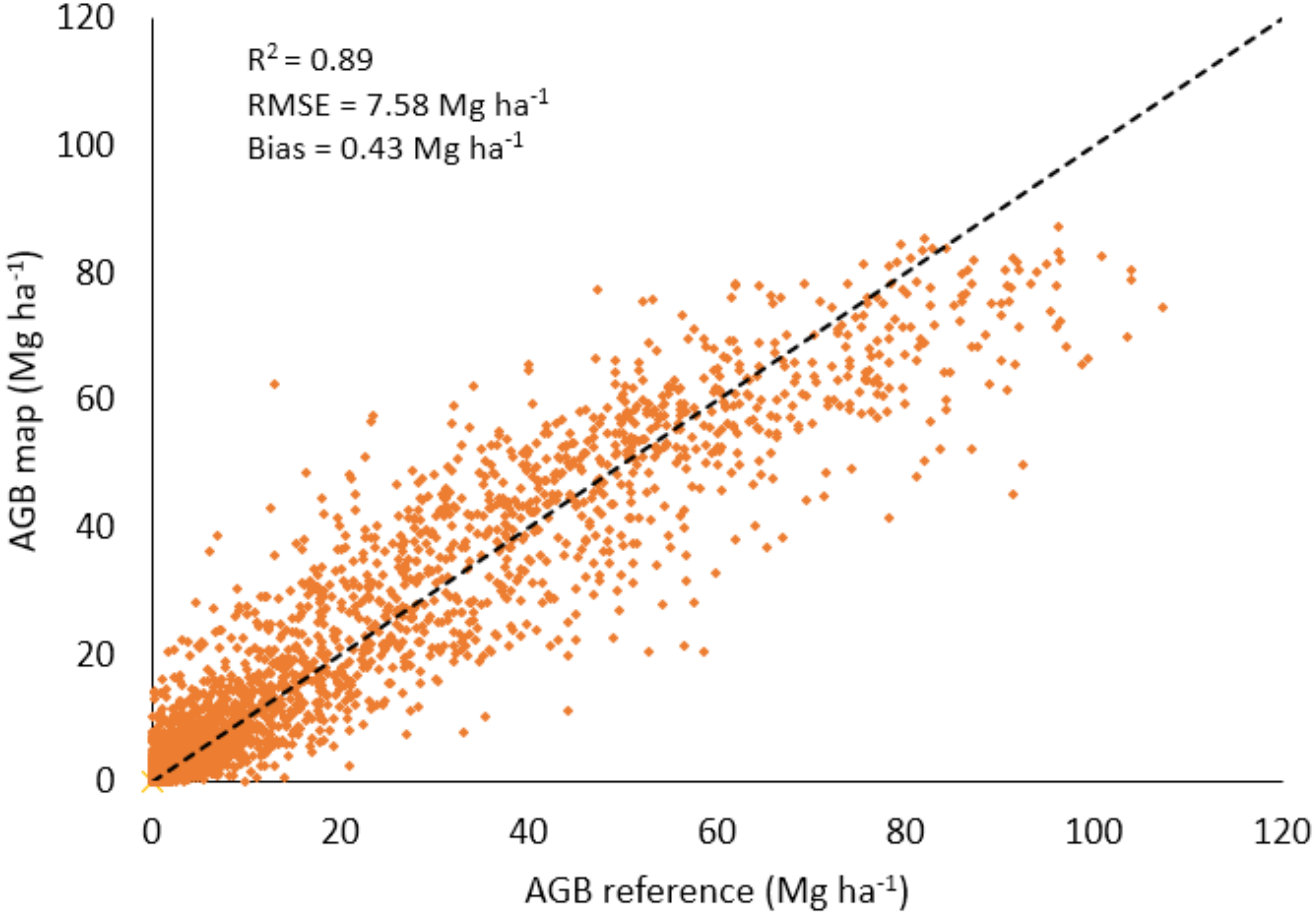

ALOS PALSAR and ALOS-2 PALSAR-2
Landsat 8 Collection 1 SR
Multi-channel filtering
Normalisation Corrections
ALOS-2 temporal composite 2015 - 2017
Temporal compositing
Landsat 8 SR temporal composite 2015 - 2017
Resampling Co-registration Stacking
k-fold Training/Validating
k training sets
k validation sets
Random Forests Regression
$\varepsilon_{AGB} = (\varepsilon^2_{measurement} + \varepsilon^2_{allometry} + \varepsilon^2_{sampling} + \varepsilon^2_{prediction})^{1/2}$
Uncertainty
AGB LiDAR
k AGB maps
AGB final map
Airborne LiDAR
Generalised linear model
AGB Plots
input satellite data
input reference data
processes
Intermediate outputs
final outputs

Variable importance analysis



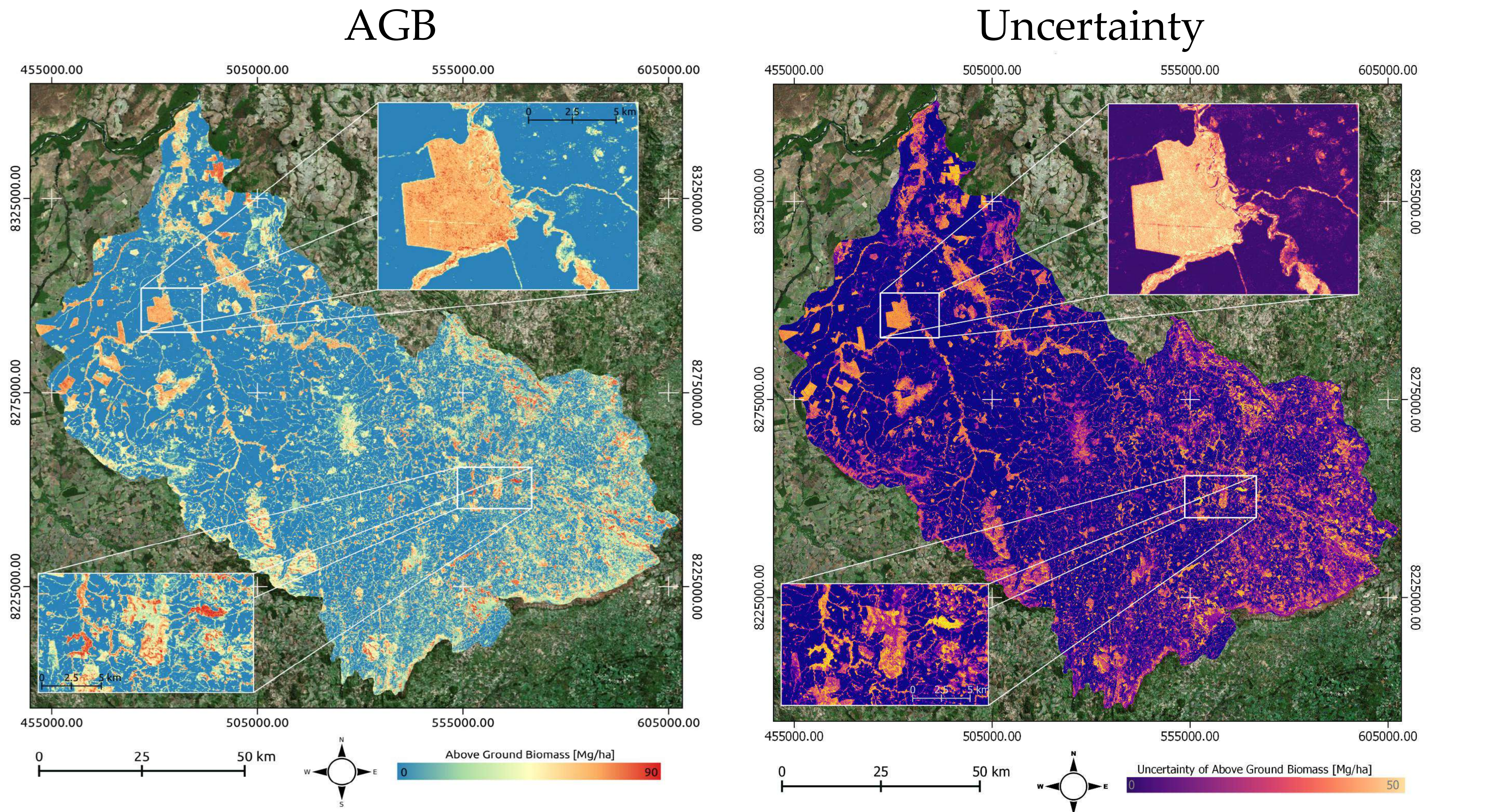
Averaged variable importance analysis across the k-fold procedure for each set of variables derived from Landsat 8 (L8) and ALOS-2/PALSAR-2 (ALOS) included in the RF model. The R^2 for each single set of variables and all variables together (left), and decrease in R^2 for models excluding a single set of variables (right). ALOS backscatter: γ^0_{HV}, γ^0_{HH}. ALOS indices: RFDI, CpR. L8 reflectances: blue, green, red, near infrared, shortwave infrared-1, shortwave infrared-2. L8 indices: NDVI, NBR, NBR2, NDMI, and SAVI.

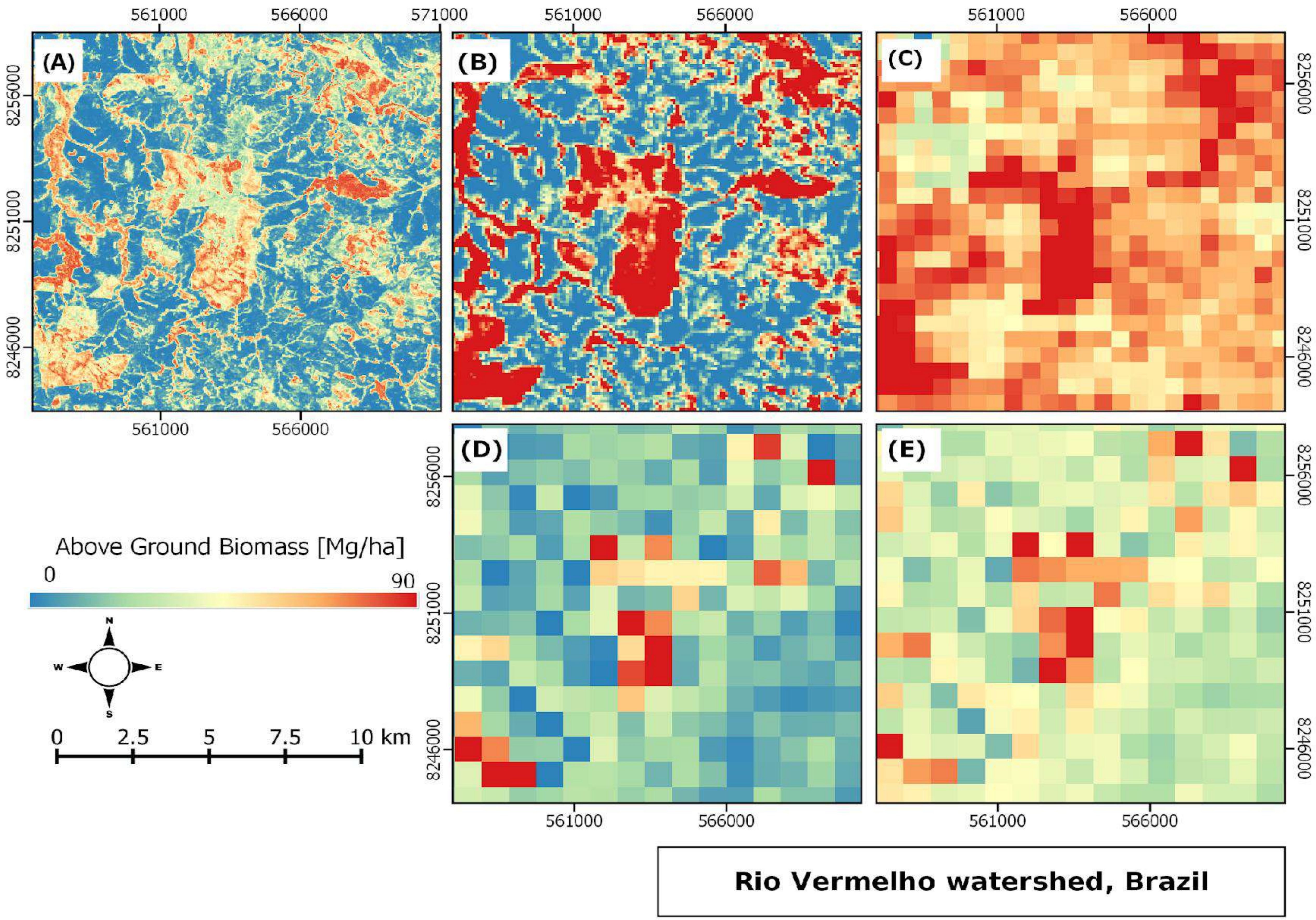
Cross-validation



Cross-validation between the AGB map predictions and AGB reference data derived from the LiDAR point clouds. The black dash line corresponds to the y = x line.

Bispo, et al. 2020, Remote Sensing https://doi.org/10.3390/rs12172685


AGB
Uncertainty
455000.00
505000.00
555000.00
605000.00
8325000.00
8275000.00
8225000.00
0
2.5
5 km
0
25
50 km
N
S
W
E
Above Ground Biomass [Mg/ha]
0
90
Uncertainty of Above Ground Biomass [Mg/ha]
0
50

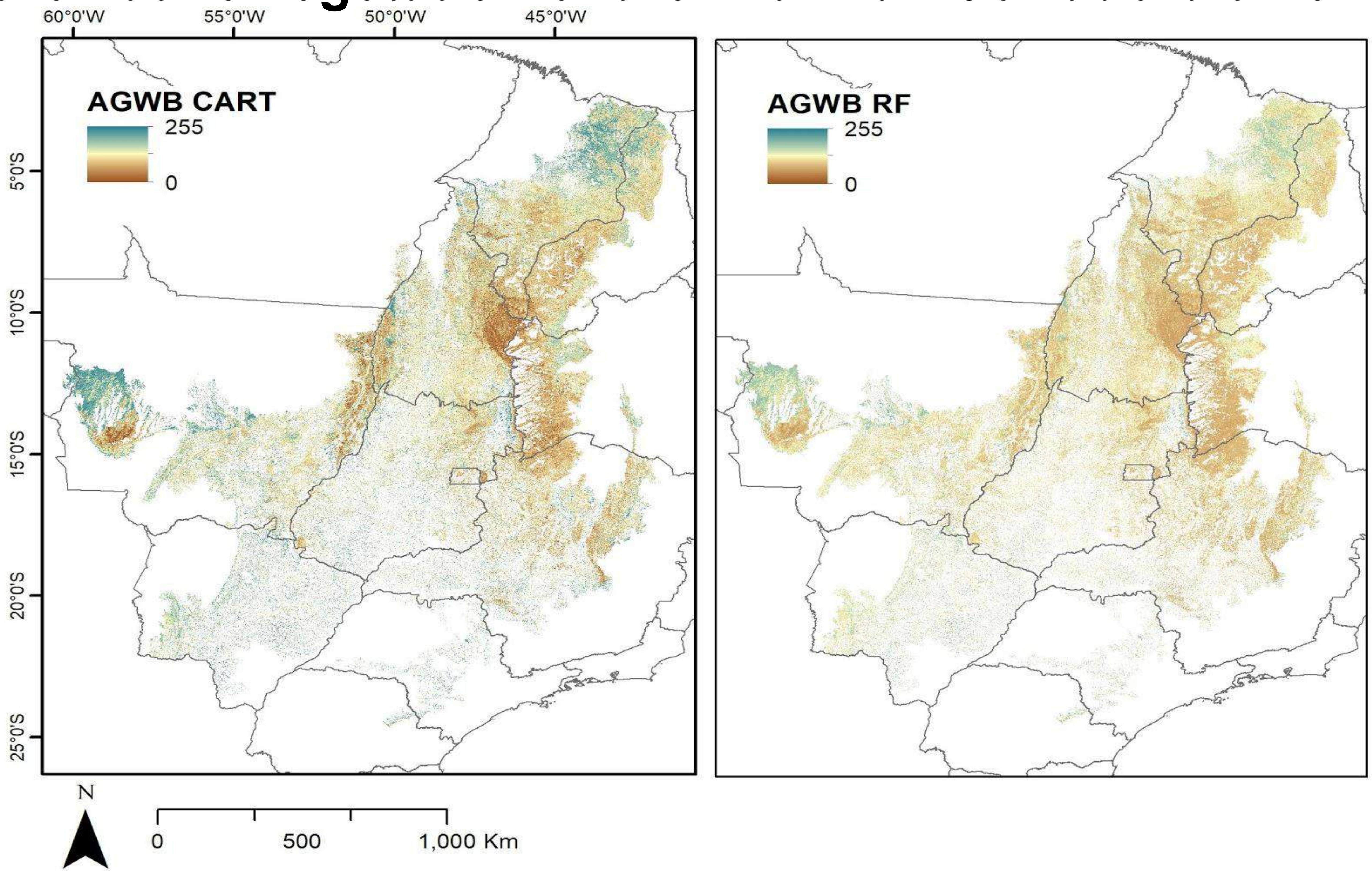


AGB maps over part of the Rio Vermelho watershed, Goiás State, Brazil, produced by this study (30 m) (A) and by Santoro *et al. 2018* (100 m) (B); Baccini *et al.* 2012 (500m) (C); Avitable *et al*. 2016 (1 km) (D); and Saatchi *et al.* 2011(1 km) (E).

Conclusion

- One of is the most accurate AGB map (R^2 = 0.89%, RMSE = 7.58 Mg/ha) over the Brazilian Savannah
- The AGB map showed similar performance for the different vegetation types in Rio Vermelho watershed
- Our methodology characterises the spatial distribution of aboveground biomass over Brazilian Cerrado using **two stage estimates**: from the field to LiDAR, and LIDAR to EO data in order to upscale the AGB estimations
- The method was applied later on over the whole Brazilian Cerrado biome
- Our results represent an important contribution as a method to monitoring the carbon emissions in Brazilian Cerrado within the framework of REDD+ under the United Nations Framework Convention on Climate Change

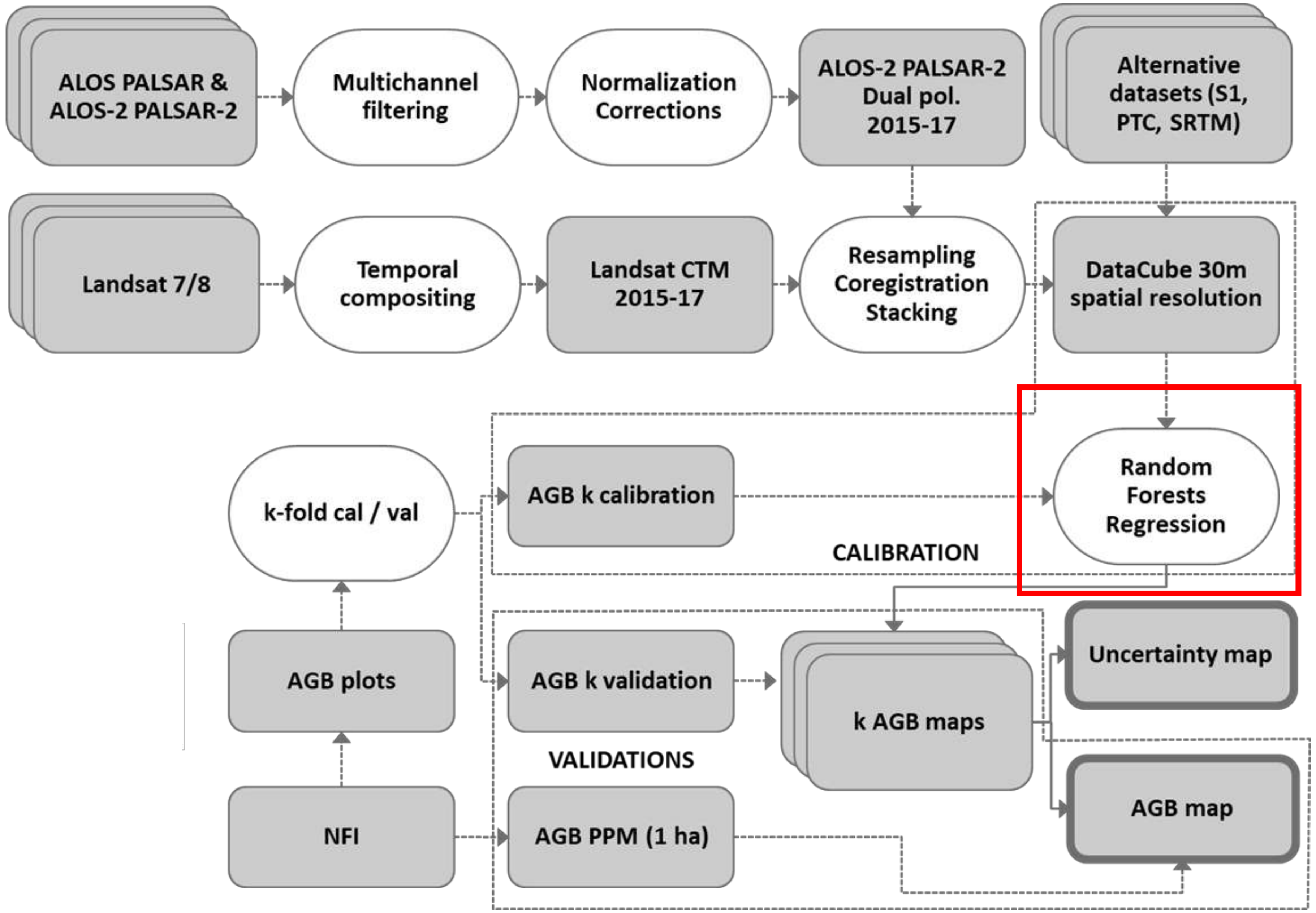
Mapping the stock and spatial distribution of aboveground woody biomass in the native vegetation of the Brazilian Cerrado biome



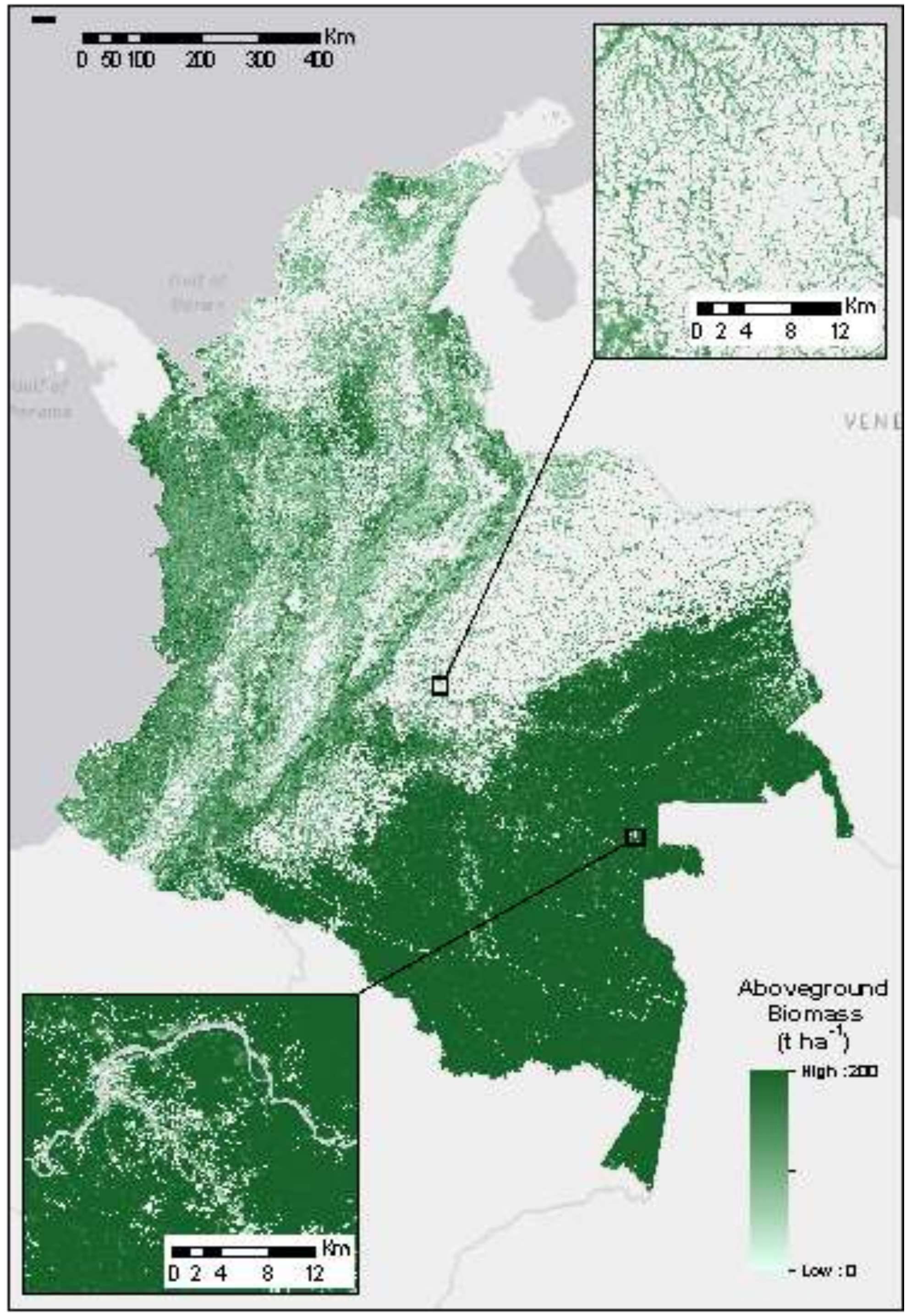
Aboveground woody biomass (AGWB, in $t.ha^{-1}$) maps at 30-m resolution for the Cerrado biome, based on two machine learning algorithms tested (CART, left panel, and RFRandom Forest, right panel). Predictions are mapped over the native vegetation pixels, classified by the MapBiomas Project Collection 5.0 (forest, savanna, and grasslands).

Zimbres, *et al.* 2021, Forest Ecology and Management, https://doi.org/10.1016/j.foreco.2021.119615

Aboveground biomass and multisensory approach



AGB Colombian Amazon



Forest in different successional stages

Remote Sensing of Environment 232 (2019) 111194

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Mapping forest successional stages in the Brazilian Amazon using forest heights derived from TanDEM-X SAR interferometry

Check for updates

Polyanna Da Conceição Bispo[a,b,*], Matteo Pardini[c], Konstantinos P. Papathanassiou[c], Florian Kugler[c], Heiko Balzter[a,b], Dominik Rains[d,e], João Roberto dos Santos[f], Igor G. Rizaev[g], Kevin Tansey[a], Maiza Nara dos Santos[h], Luciana Spinelli Araujo[i]

[a] *Leicester Institute for Space and Earth Observation, Centre for Landscape and Climate Research, School of Geography, Geology and Environment, University of Leicester, Leicester, United Kingdom*

[b] *NERC, National Centre for Earth Observation at the University of Leicester, Leicester, United Kingdom*

[c] *German Aerospace Center (DLR), Microwave and Radar Institute, Oberpfaffenhofen, Wessling, Germany*

[d] *Department of Environment, Ghent University, Ghent, Belgium*

[e] *Earth Observation Science, Department of Physics & Astronomy, University of Leicester, Leicester, United Kingdom*

[f] *Remote Sensing Division, National Institute for Space Research (INPE), São José dos Campos, Brazil*

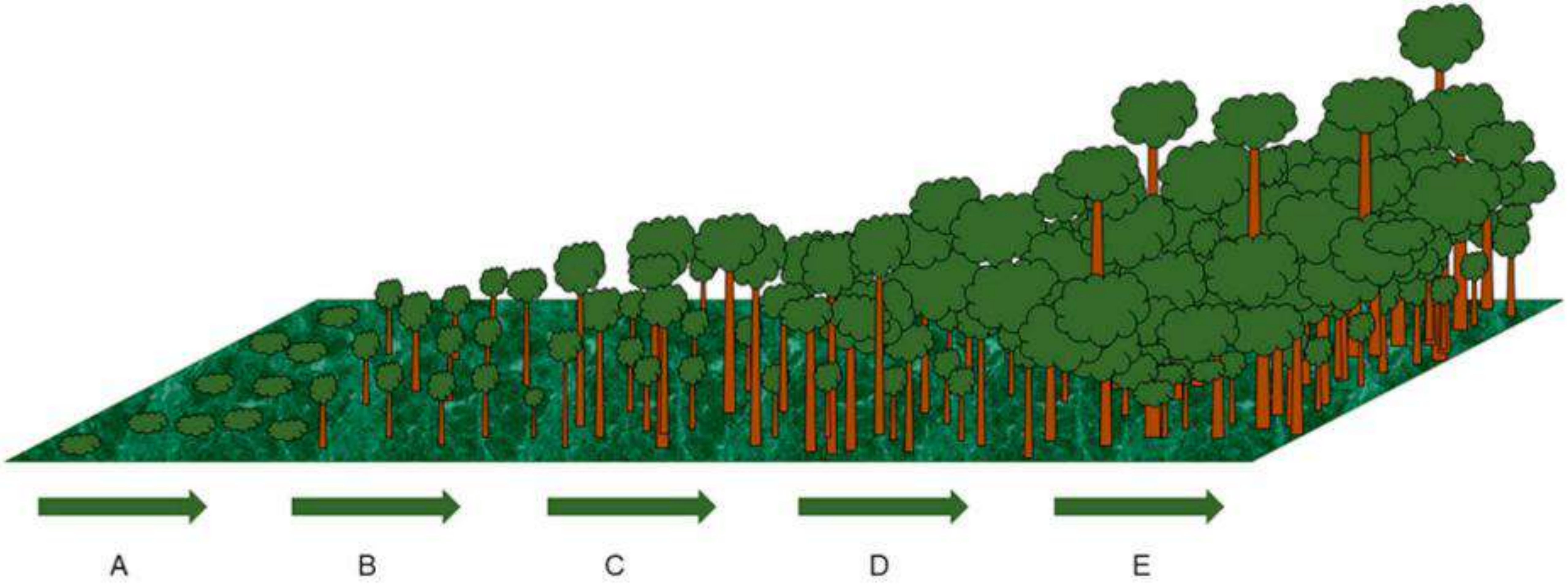
[g] *Visual Information Laboratory, University of Bristol, Bristol, United Kingdom*

[h] *Embrapa Agricultural Informatics, Brazilian Agricultural Research Corporation (Embrapa), Campinas, SP, Brazil*

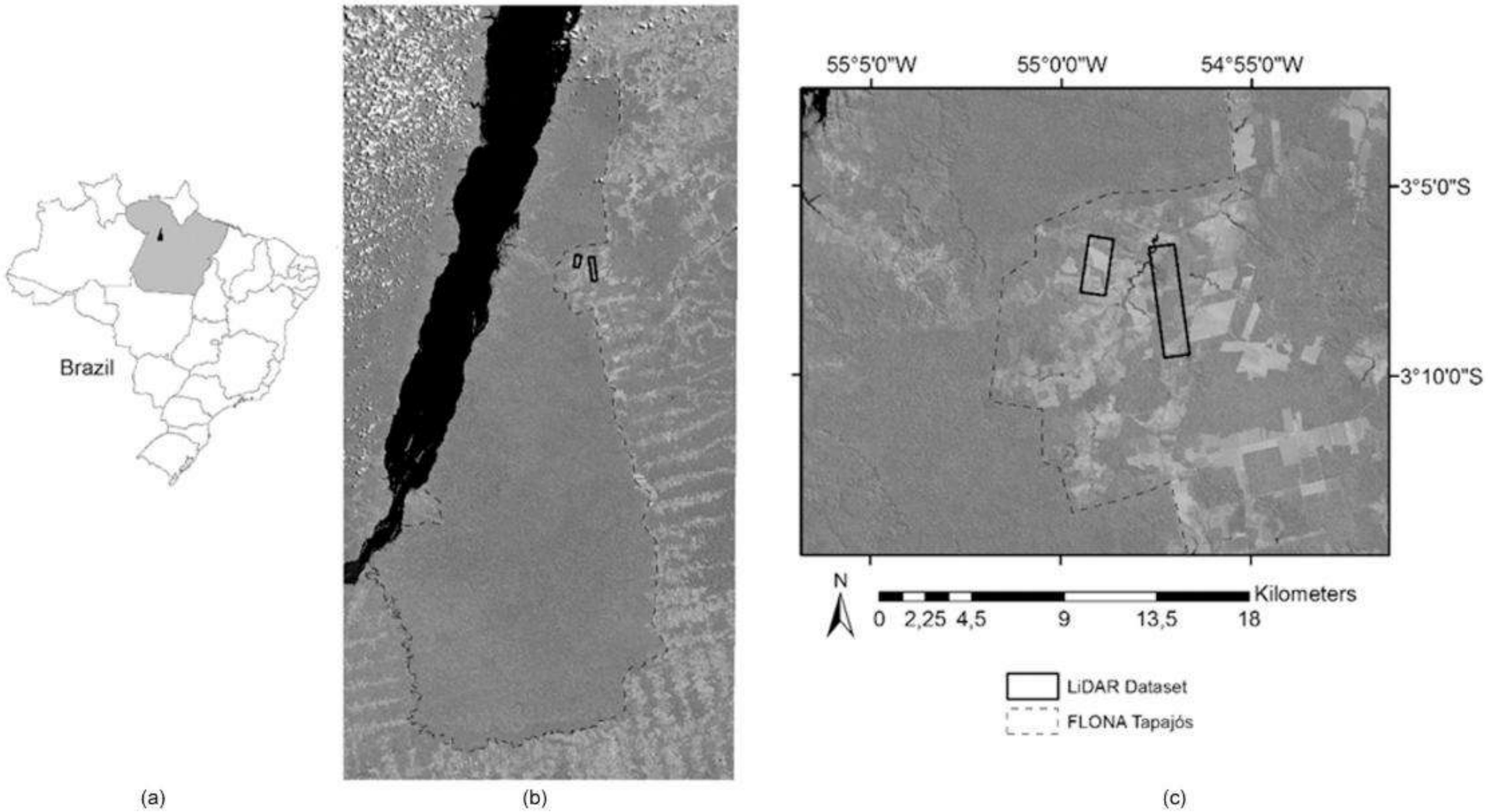
[i] *Embrapa Environment, Brazilian Agricultural Research Corporation (Embrapa), Jaguariúna, SP, Brazil*

Forest in different successional stages

P.C. Bispo, et al. *Remote Sensing of Environment 232 (2019) 111194*



Schematic representation of a tropical forest with different successional stages: A (non-forest); B (secondary forest in initial stage - SFIni); C (secondary forest in intermediated stage - SFInt); D (secondary forest in advanced stage - SFAdv): E (old growth forest or primary forest - OF).



(a) Location of the TNF in the Brazilian territory. (b) Zoom on the TNF, enclosed by the dashed line (TNF limits from 2013). The two small rectangles delimit the area covered by the LiDAR acquisition. (c) Zoom on the LiDAR coverage. The whole area inside and outside of the two LiDAR rectangles is covered by each TanDEM-X acquisition used in this study (2012, 2013 and 2016). Background image: Landsat 8 (14/08/2015).

General characteristics of forests types representative for the area of the TNF (which is part of eastern Amazon region) collected by Lu (2005). DBH, H, AGB and Age represent the interval of the means of stand diameter (cm), stand height (m), aboveground biomass (kg/m^2) and age (years) respectively.

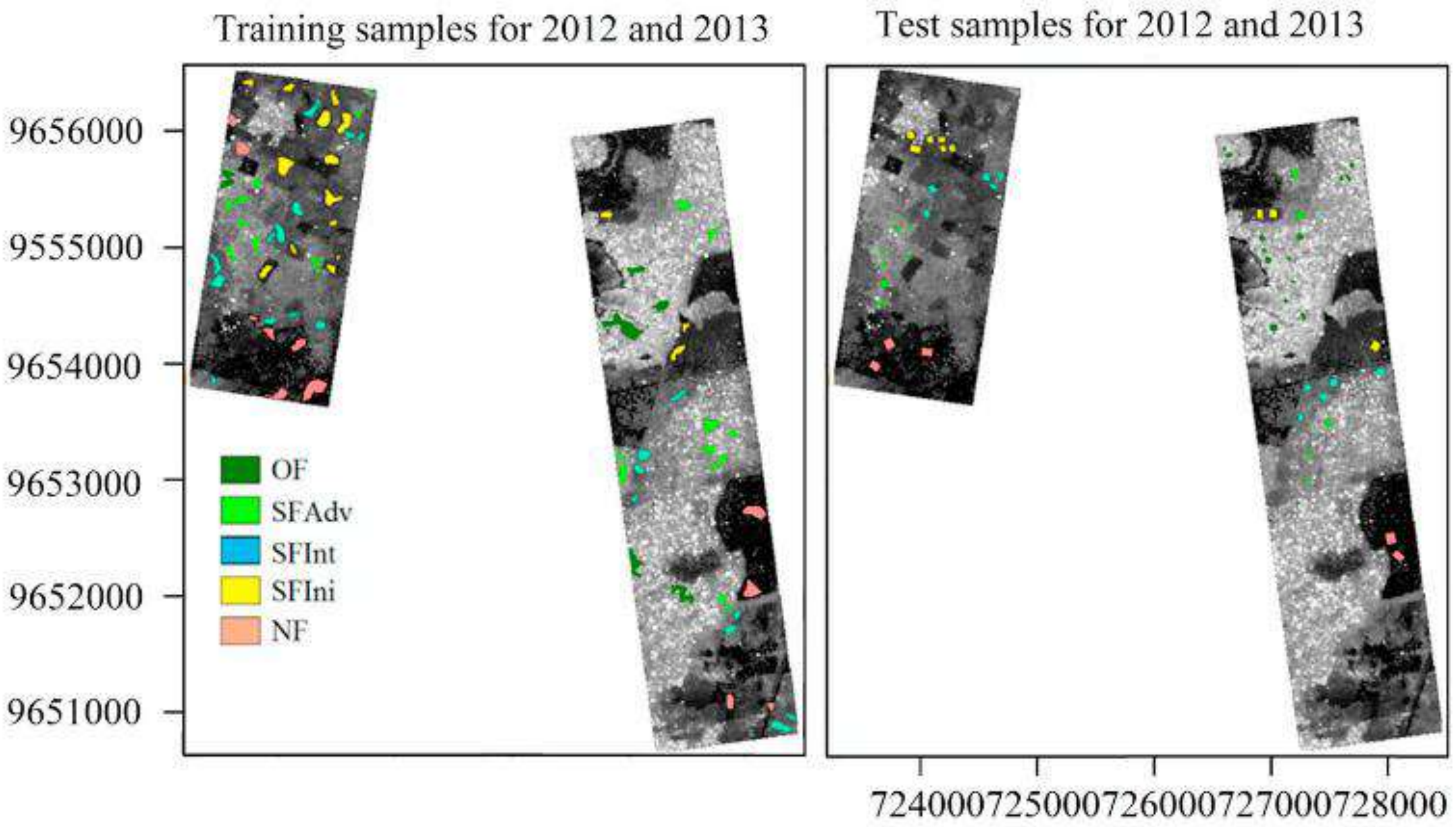
Forest types	Characteristics	DBH (cm)	H (m)	AGB (kg/m^2)	Age (years)
SFIni	Herbaceous plants, seedlings, and saplings together are responsible for > 90% of total biomass. The vertical structure is characterized by a full profile of saplings and herbaceous plants. Saplings are the main structure element and represent the majority of the aboveground biomass.	2–5	2–6	0.5–5	1–5
SFInt	Saplings still account for most of the biomass in SFInt. Vegetation structure provides a mix of dense ground cover of saplings and young trees with higher canopy than SFIni. There is very small internal difference between canopy and understory individuals. SFInt is characterized by a lack of stratification between canopy and understory.	5–15	6–12	4–10	4–15
SFAdv	Trees occupy the canopy and present obvious stratification of forest stand structure in SFAdv. In this stage, there is a major shift in structure that differentiates understory from canopy individuals; that is, the presence of saplings is less significant than that of trees. One can find differences between the canopy and understory in terms of height and density of individuals at both levels.	10–25	9–17	8–25	10–50
OF or PF	In the mature forest, aboveground biomass and vegetation density can be considerably different depending on soil conditions, species composition, and topography at the site. In a typical mature forest, trees account for the majority of aboveground biomass, reaching > 90%. Many tree individuals are taller than 17 m, and some are between 25 m and 30 m, followed by a few scattered individuals over 35 m tall or emergent.	13–30 or more	11–25 or more	12–50	–

Acquisition parameters of TanDEM-X. HoA indicates the InSAR height of ambiguity (see Section 3.1).

Date	Mode	Polarization	Orbit	Incidence Angle (°)	Effective Baseline (m)	HoA (m)
05/12/2012	Bistatic/StripMap	Dual (HH, VV)	Ascending	40.60	110.44	60.65
30/05/2013	Bistatic/StripMap	Dual (HH, VV)	Ascending	40.56	83.38	80.67
23/01/2016	Bistatic/StripMap	Dual (HH, VV)	Ascending	40.56	102.00	65.41

Field data from forest plots (0.25 ha) used as reference data. For H, DBH, Age and AGB the mean and the standard deviation (SD) is given with H being the stand height, DBH the diameter at breast height and AGB the aboveground biomass.

N. of Plots	Forest Types	H (m)		DBH (cm)		Age (years)		AGB (kg/m^2)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	SFIni	5	1.2	5	1.8	5	2	0.5	0.1
2	SFInt	9	0.8	10	3.0	15	1	4	0.8
3	SFAdv	14	2.1	19	2.0	30	1	17	1.2
1	OF	19	3.6	21	2.2	> 50	–	29	1.4



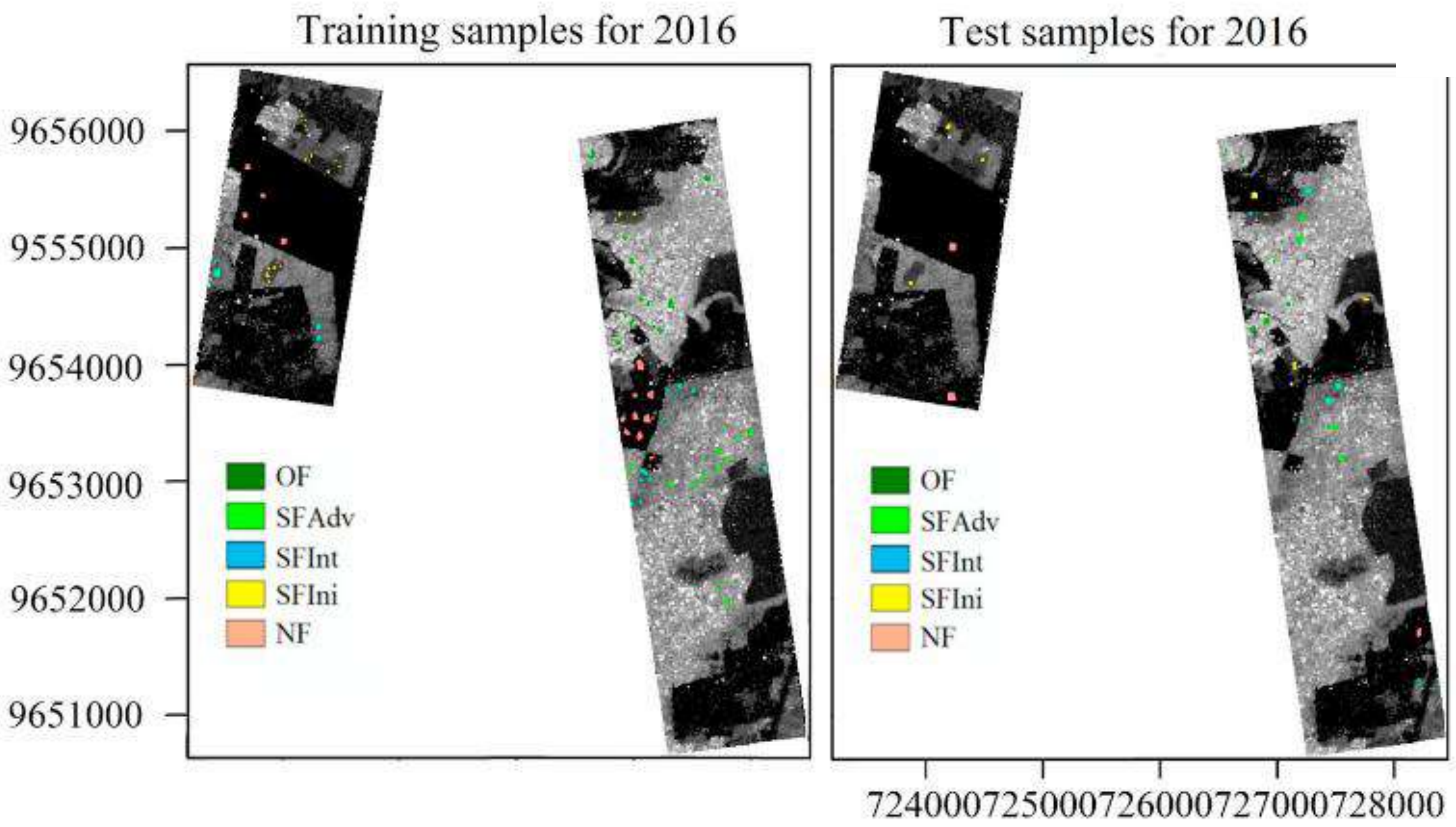


Fig. 6. Interferometric heights derived from TanDEM-X (top panel) and H100 (bottom panel) derived from LiDAR CHM, for 2012, 2013 and 2016. For each year and sensor, the two rectangles correspond to the LiDAR coverage.

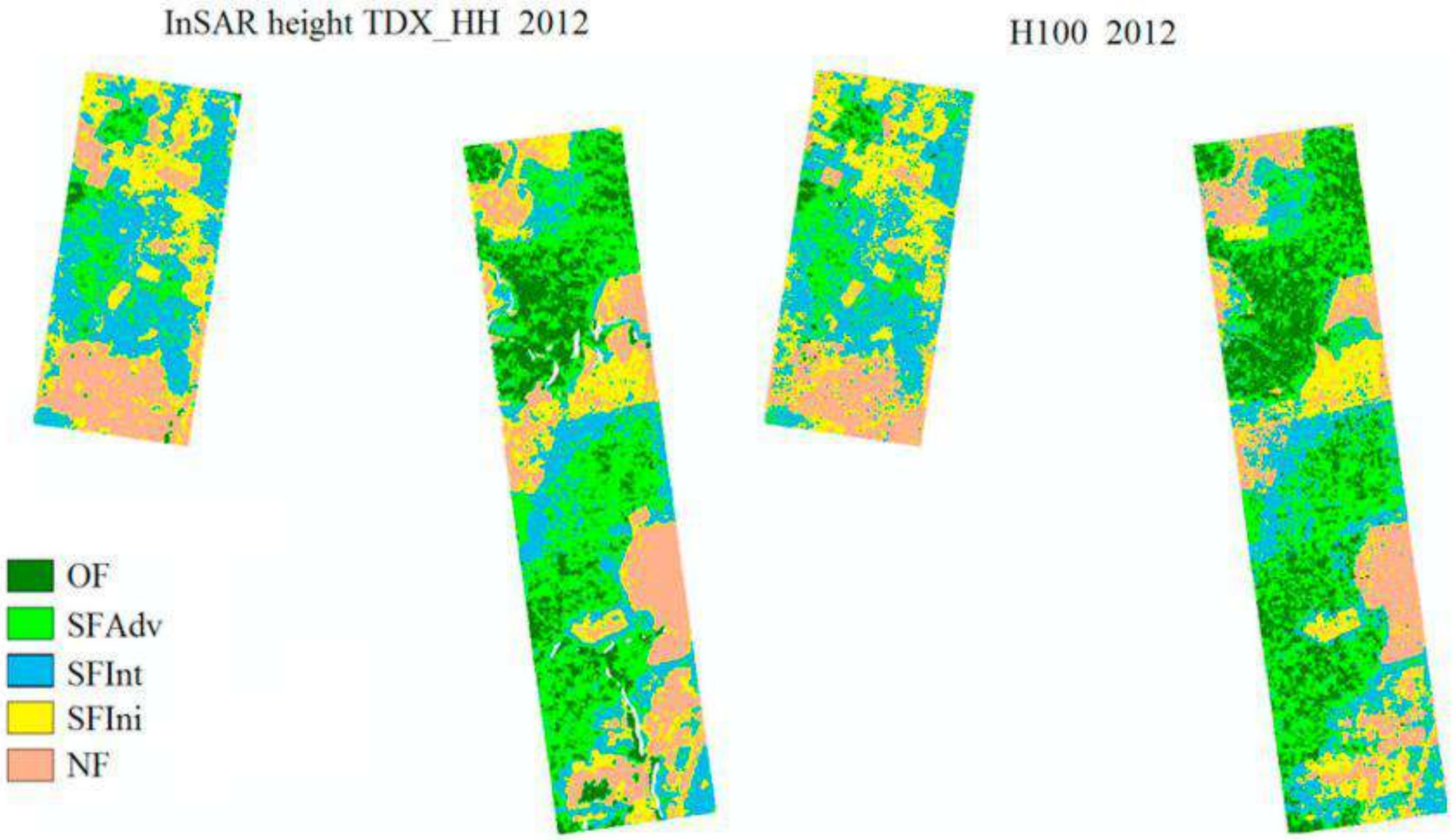


Fig. 9. Supervised classification of interferometric heights from TanDEM-X HH (05/12/2012) and LiDAR H100 (31/07/2012). The selected classes were old growth forest (OF), secondary forest in advanced stage (SFAdv), secondary forest in intermediary stage (SFInt), secondary forest in initial stage (SFIni) and non-forest (NF). The two rectangles correspond to the LiDAR coverage.

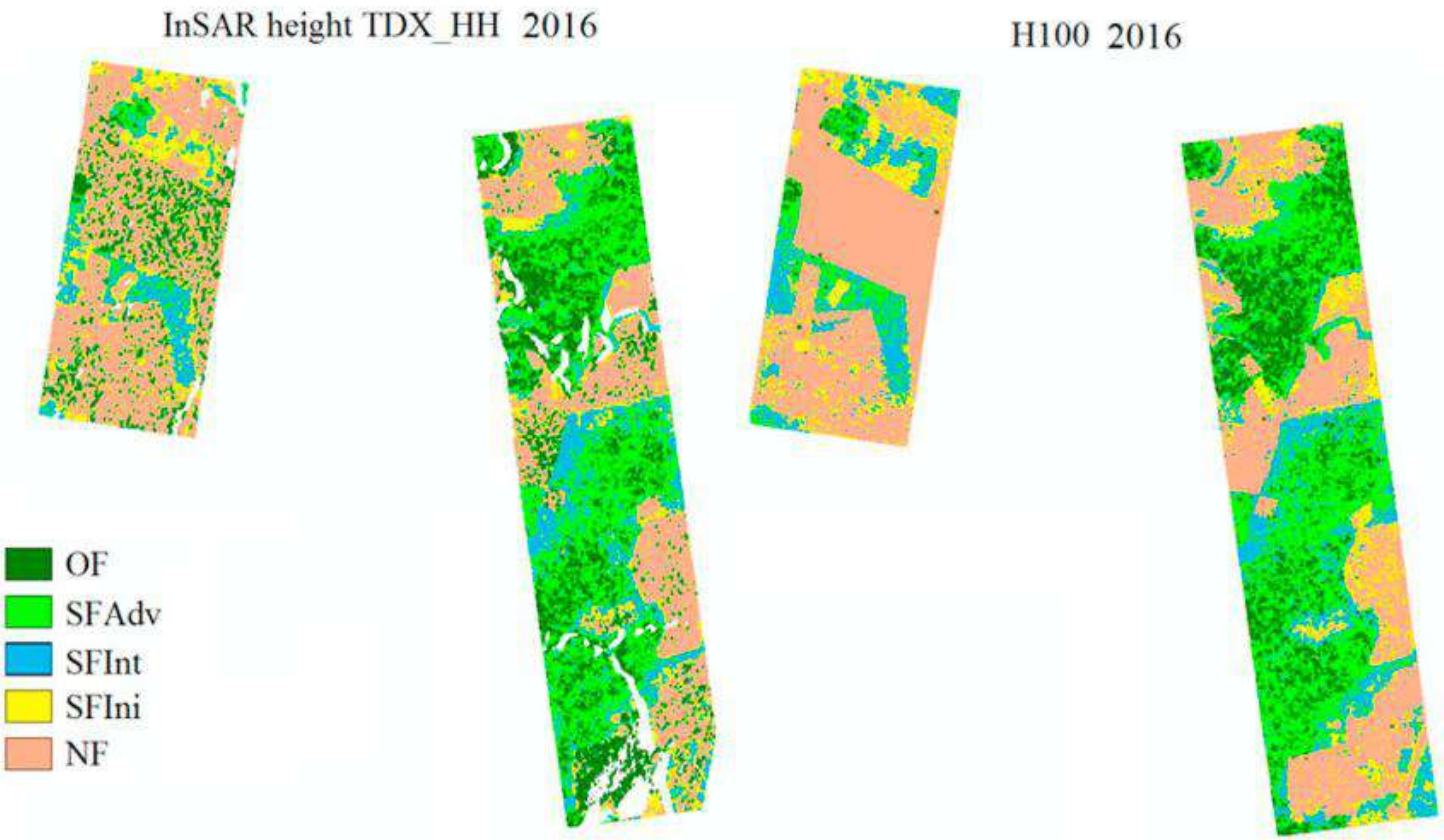
Table 12
Confusion matrix and cross-validation of TanDEM-X and H100 for 2012.

Classes	Ref. OF	Ref. SFAdv	Ref. SFInt	Ref. SFIni	Ref. NF
H100%					
OF	96	3	0	0	0
SFAdv	4	87	8	0	1
SFInt	0	10	83	1	0
SFIni	0	0	9	98	4
NF	0	0	0	1	95
	100	100	100	100	100
Overall Accuracy = 0.92; Kappa = 0.90					
TDX HH%					
OF	93	2	0	0	0
SFAdv	7	84	9	0	0
SFInt	0	14	79	6	0
SFIni	0	0	12	85	1
NF	0	0	0	9	99
	100	100	100	100	100
Overall Accuracy = 0.87; Kappa = 0.84					

Supervised classification of interferometric height from TanDEM-X HH (30/05/2013) and H100 (10/09/2013). The selected classes were old growth forest (OF), secondary forest in advanced stage (SFAdv), secondary forest in intermediary stage (SFInt), secondary forest in initial stage (SFIni) and non-forest (NF). The two rectangles correspond to the LiDAR coverage.

Table 13
Confusion matrix and cross-validation of TanDEM-X and H100 for 2013.

Classes	Ref. OF	Ref. SFAdv	Ref. SFInt	Ref. SFIni	Ref NF
H100%					
OF	95	4	0	0	0
SFAdv	5	88	8	0	0
SFInt	0	8	84	1	0
SFIni	0	0	8	99	0
NF	0	0	0	0	100
100	100	100	100	100	100
Overall Accuracy = 0.93; Kappa = 0.91					
TDX HH%					
OF	93	5	0	0	0
SFAdv	7	82	8	0	0
SFInt	0	13	80	13	0
SFIni	0	0	12	80	0
NF	0	0	0	7	100
	100	100	100	100	100
Overall Accuracy = 0.87; Kappa = 0.84					



Supervised classification of interferometric height from TanDEM-X HH (23/01/2016) and H100 (23/03/2016). The selected classes were old growth forest (OF), secondary forest in advanced stage (SFAdv), secondary forest in intermediary stage (SFInt), secondary forest in initial stage (SFIni) and non-forest (NF). The two rectangles correspond to the LiDAR coverage.

Confusion matrix and cross-validation of TanDEM-X and H100 for 2016.

Classes	Ref. OF	Ref. SFAdv	Ref. SFInt	Ref. SFIni	Ref. NF
H100%					
OF	84	16	0	0	0
SFAdv	8	74	23	0	0
SFInt	7	10	64	3	0
SFIni	1	0	13	70	0
NF	0	0	0	27	100
	100	100	100	100	100
Overall Accuracy = 0.80; Kappa = 0.75					
TDX HH %					
OF	82	15	0	21	0
SFAdv	15	79	28	11	0
SFInt	3	6	46	11	0
SFIni	0	0	25	18	50
NF	0	0	1	39	50
	100	100	100	100	100
Overall Accuracy = 0.55; Kappa = 0.43					

Conclusions

- Our results suggest that the approach described here allows to monitor the successional forest stages

- More investigations are needed to confirm these capabilities in different tropical forest test sites, and to further assess the robustness of the methodology.

- The availability of an external (LiDAR) DTM, which often is not the case in other tropical regions, limits the use of this approach with TanDEM-X data and the coverage of the resulting classification maps.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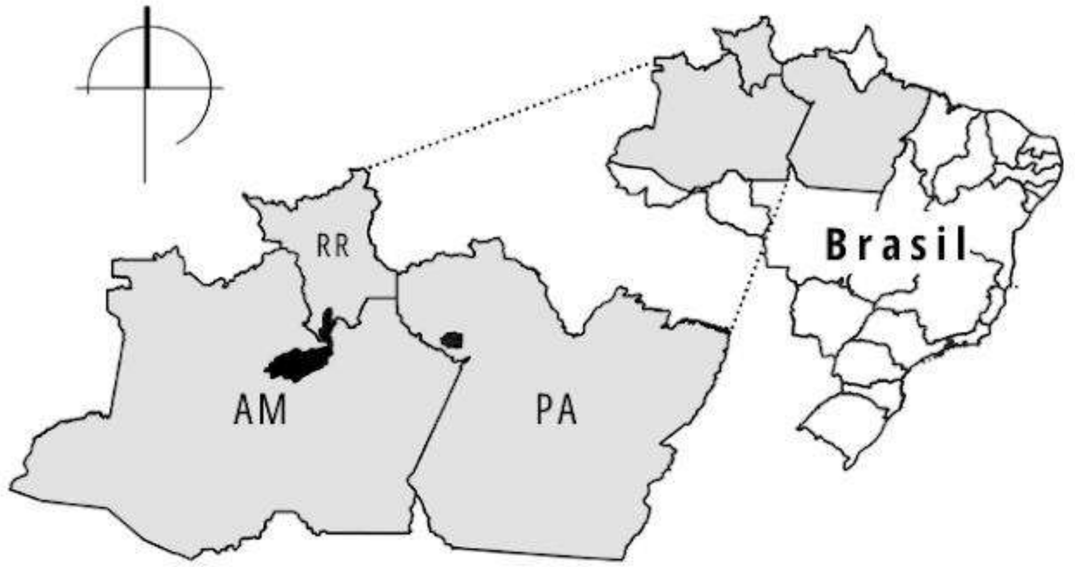
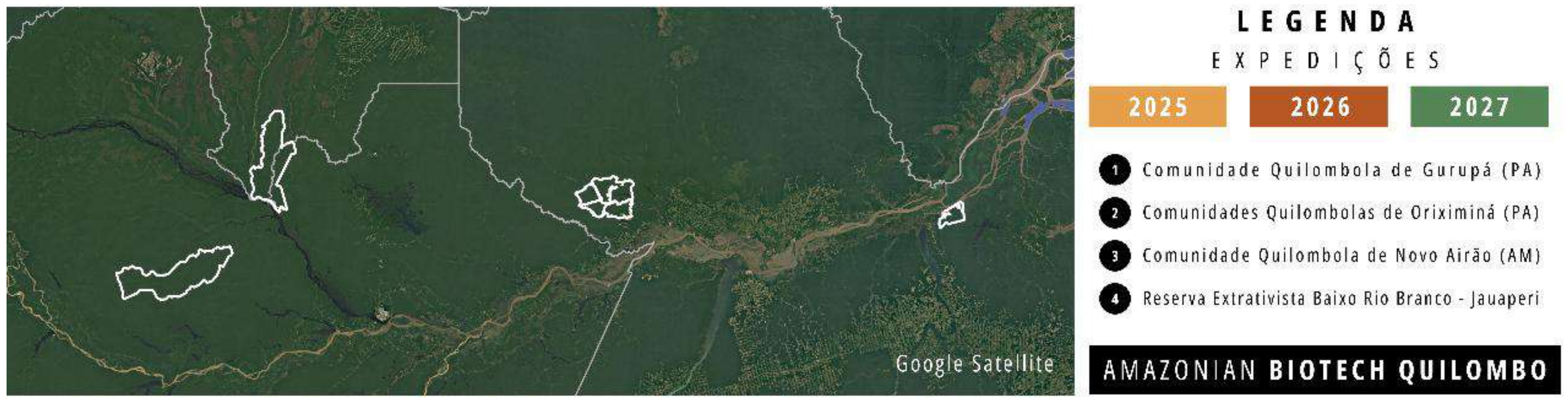
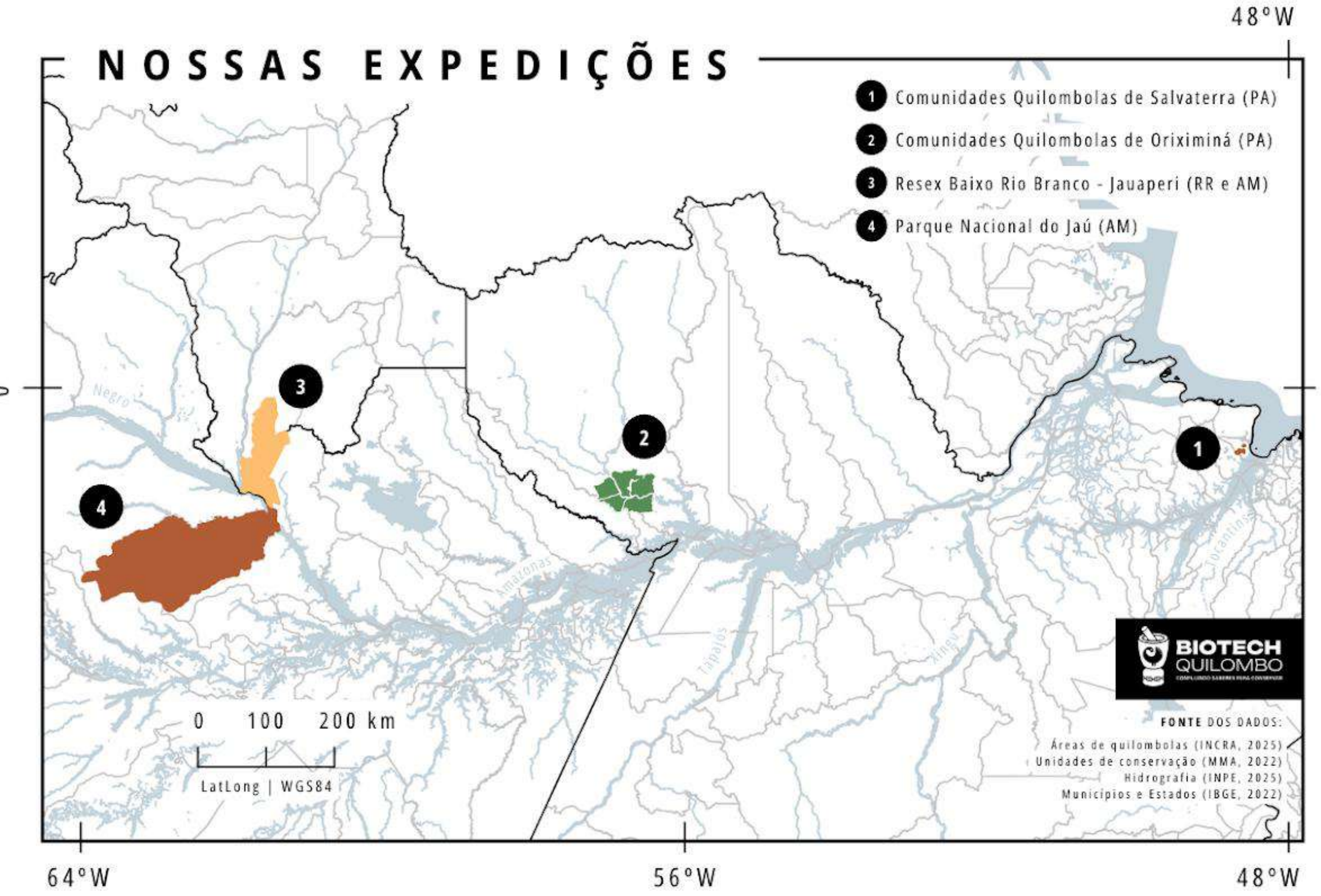
"Amazon +10 Initiative: Research Expeditions to the Amazon" The project involves the funding agencies UKRI (UK), SNSF (Switzerland), FAPESP (Brazil), FAPESPA (Brazil), FAPEAM (Brazil), FAPERR (Brazil), and CNPq (Brazil). More than 40 scientists and 10 Quilombola leaders (**Project started in Feb 2025**)

Total funding: ***£1,972,651.43*** ***~ €2,320,503.31*** ***~R$14,862,722.69***







O mapa apresenta as áreas previstas para expedições de campo. As coletas de dados serão realizadas em comunidades quilombolas da Amazônia, entre os anos de 2026 e 2028. *Fonte: BiotechQuilombo/ TERAQ-G projects.*

PP0106231 **- BioMassQuilombo-Amazon: Participatory Calibration and Validation of ESA BIOMASS SAR**

Links

- **BioTechQuilombo: Pioneering Community-Led Biodiversity Monitoring in the Amazon**

https://www.manchester.ac.uk/about/news/biotechquilombo-pioneering-community-led-biodiversity-monitoring-in-the-amazon/

- **Initiative brings together quilombola knowledge and technology for the benefit of biodiversity**

https://ipam.org.br/initiative-brings-together-quilombola-knowledge-and-technology-for-the-benefit-of-biodiversity/

- **Amazonia +10 Initiative**

https://www.amazoniamaisdez.org.br/en/iniciativa

BIOTECH
QUILOMBO
MERGING KNOWLEDGE FOR CONSERVATION

https://www.instagram.com/projetobiotechquilombo/

Some challenges

- Persistent uncertainties in biomass estimation and in detecting biomass changes over time.
- Inconsistent classification of secondary forests.
- Limited understanding of vegetation recovery dynamics under different disturbance regimes—both anthropogenic and natural—and how these affect forest regrowth and resilience.
- The need to standardize and harmonize datasets—including field measurements, LiDAR, and satellite imagery—to ensure long-term comparability, consistency, and interoperability across spatial and temporal scales.
- Lack of field plots specifically designed to validate remote sensing data and capture the complexity of tropical forest regeneration processes.

Future investigations

- Integrate other variables such as: microclimate, geomorphometric variables (e.g., slope, elevation, curvature, topographic position index) to capture terrain-driven variations influencing vegetation patterns
- Incorporate structural metrics such as canopy height, canopy density, and vertical complexity derived from LiDAR or radar data.
- Use contextual variables (e.g., proximity to mature forest, land-use history, disturbance type and frequency, trends) to better characterize regeneration environments.
- Analyse temporal trends in spectral and structural indicators to distinguish stages of forest recovery and succession dynamics.
- Combine field data (forest inventory) multisource remote sensing data (optical, radar, LiDAR) to enhance separability between successional stages.
- Apply machine learning or deep learning approaches to integrate diverse features and improve classification accuracy.
- Validate classifications using well-designed field plots representing different successional stages and disturbance histories.

Thank you!

Dr. Polyanna da Conceição Bispo
Senior Lecturer in Physical Geography
Department of Geography, University of Manchester

Email: polyanna.bispo@manchester.ac.uk

Twitter:@polybispo
Twitter: @rsategroup
Linkedin: Polyanna Bispo

Synthesis of regrowth rates in secondary forests

Mikhail Urbazaev, Viola Heinrich, Maurizio Santoro, Martin Herold

Session 2.1: Biomass datasets + missions

São José dos Campos, 30 Oct 2025

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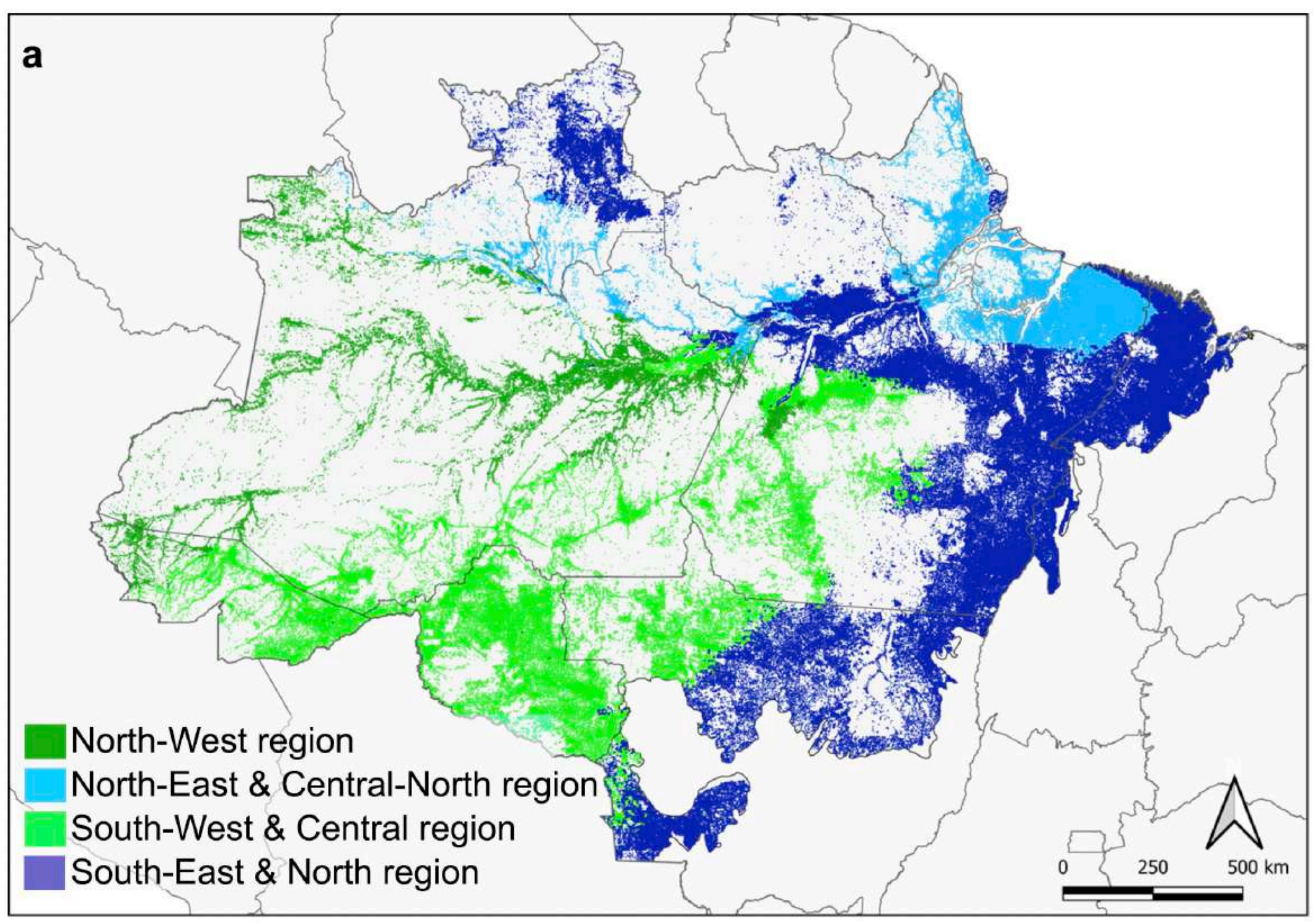
Regrowth rates from different sources

- ESA CCI Biomass regrowth rates
  - slope from time series maps
  - overlaid with MapBiomas Age
- INPE-ALS space-for-time approach

Literature

- Heinrich et al. 2021
  - CCI Biomass v3 space-for-time
- Holcomb et al. 2023*
  - GEDI space-for-time

    *different forest age map
- Robinson et al. 2025
  - based on field estimates and modeling



Regions for estimating regrowth rates
(Heinrich et al. 2021)

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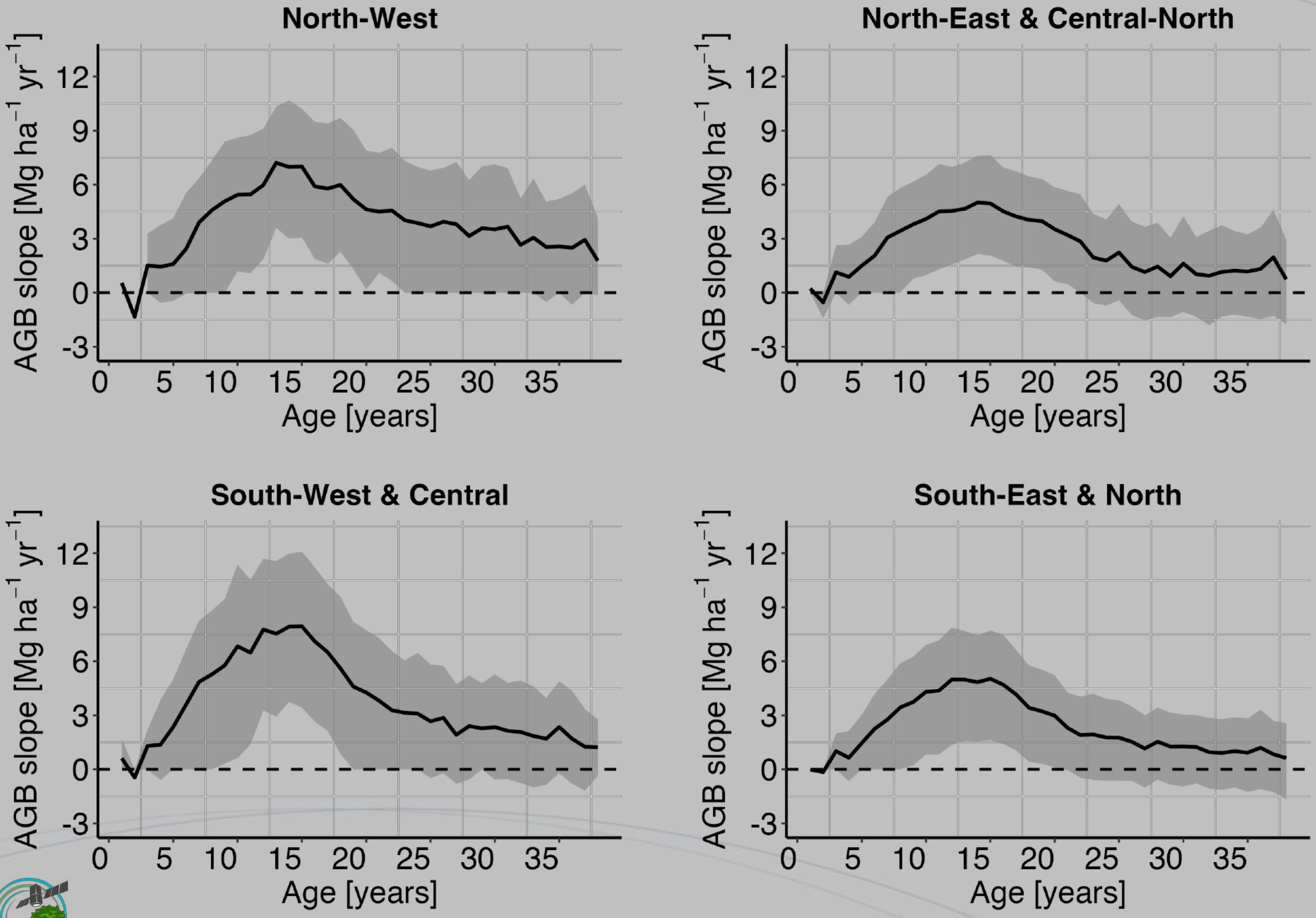
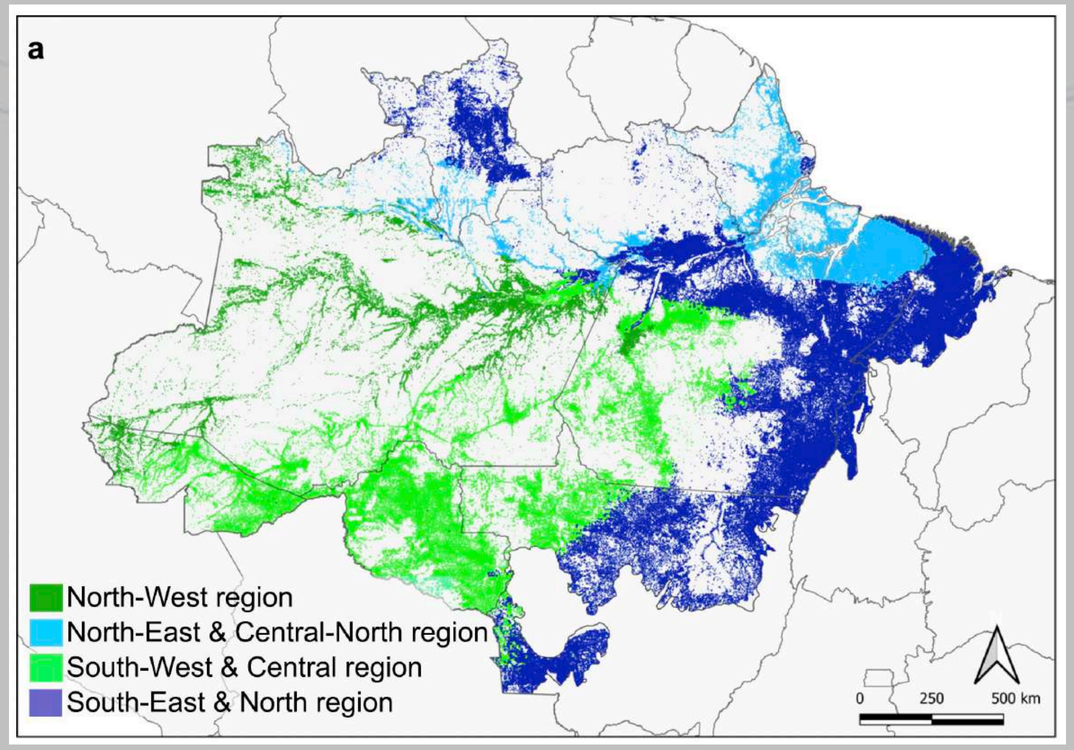
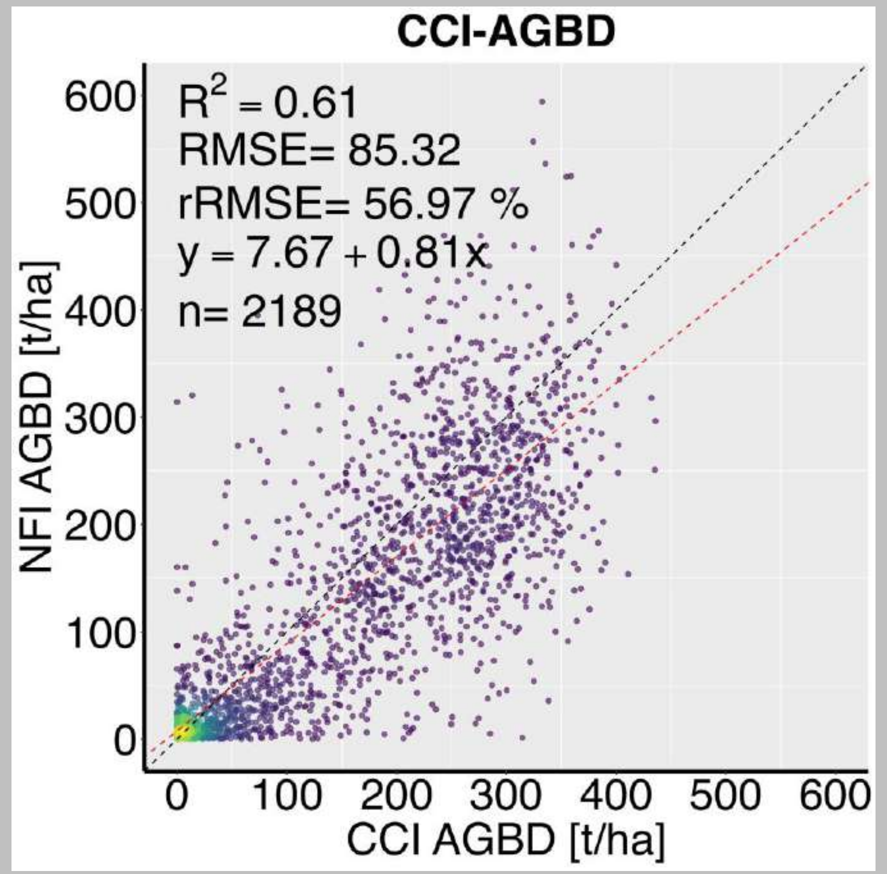
Regrowth rates from ESA CCI Biomass







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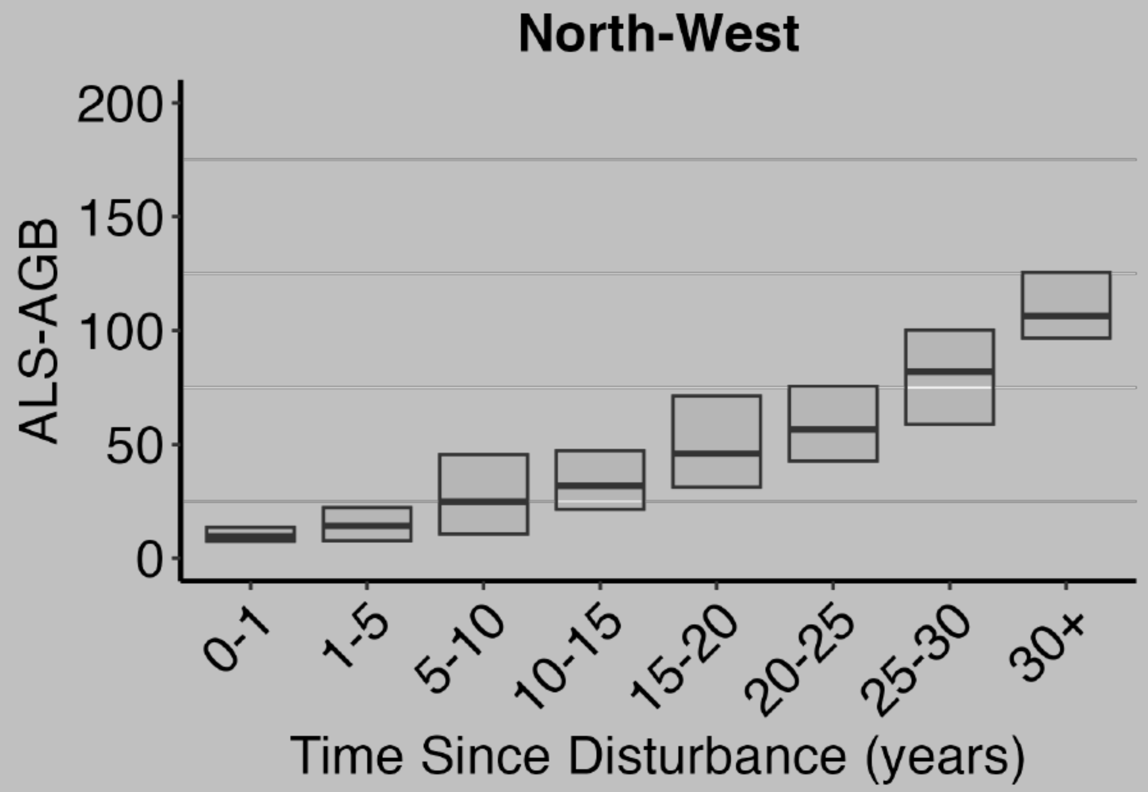
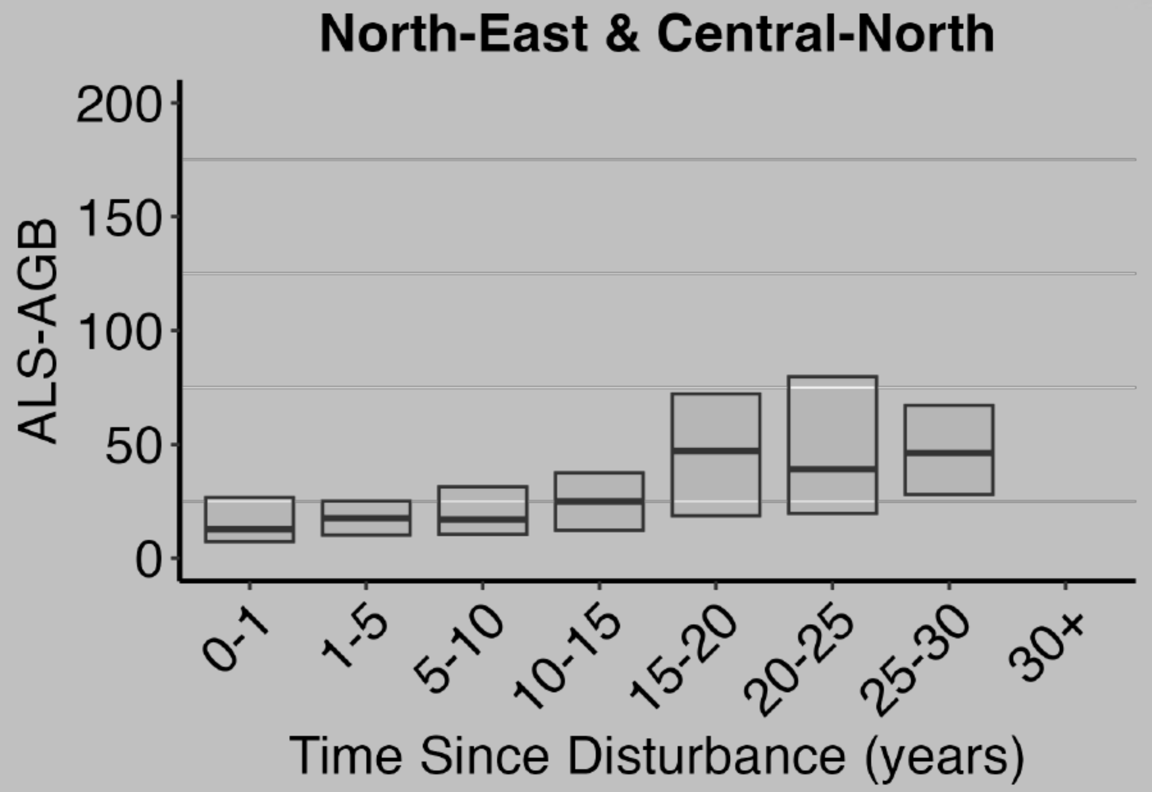
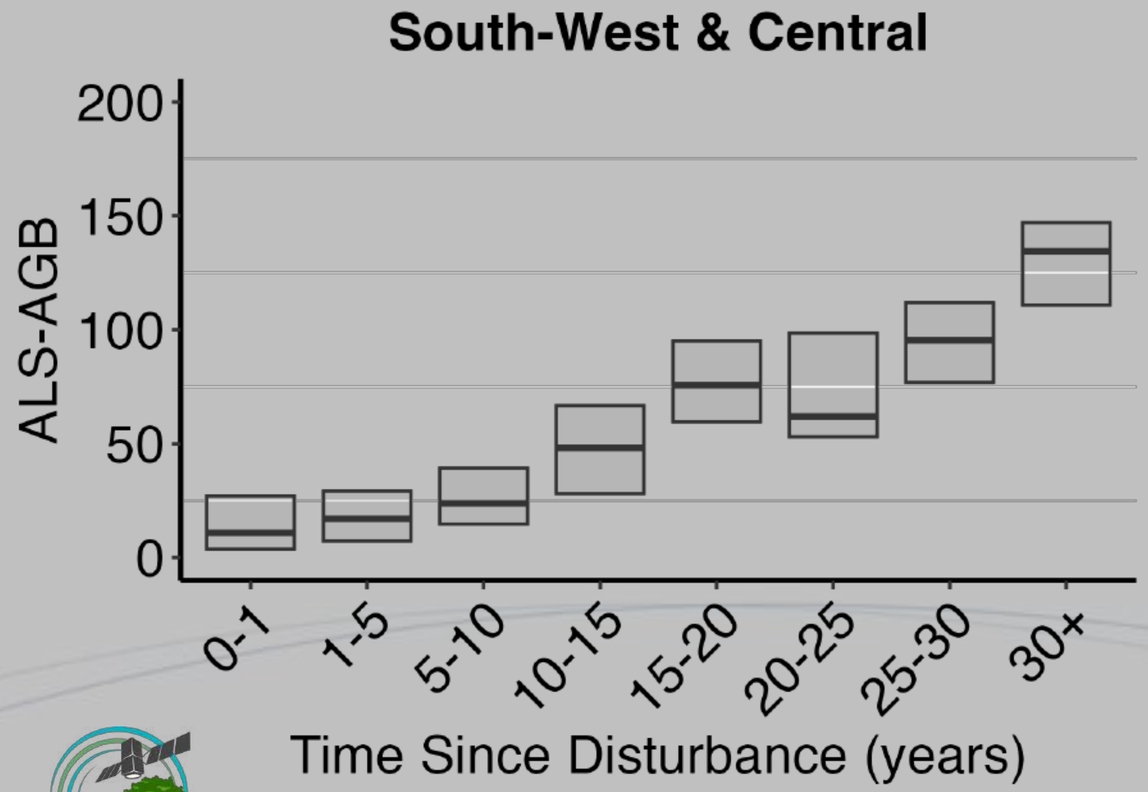
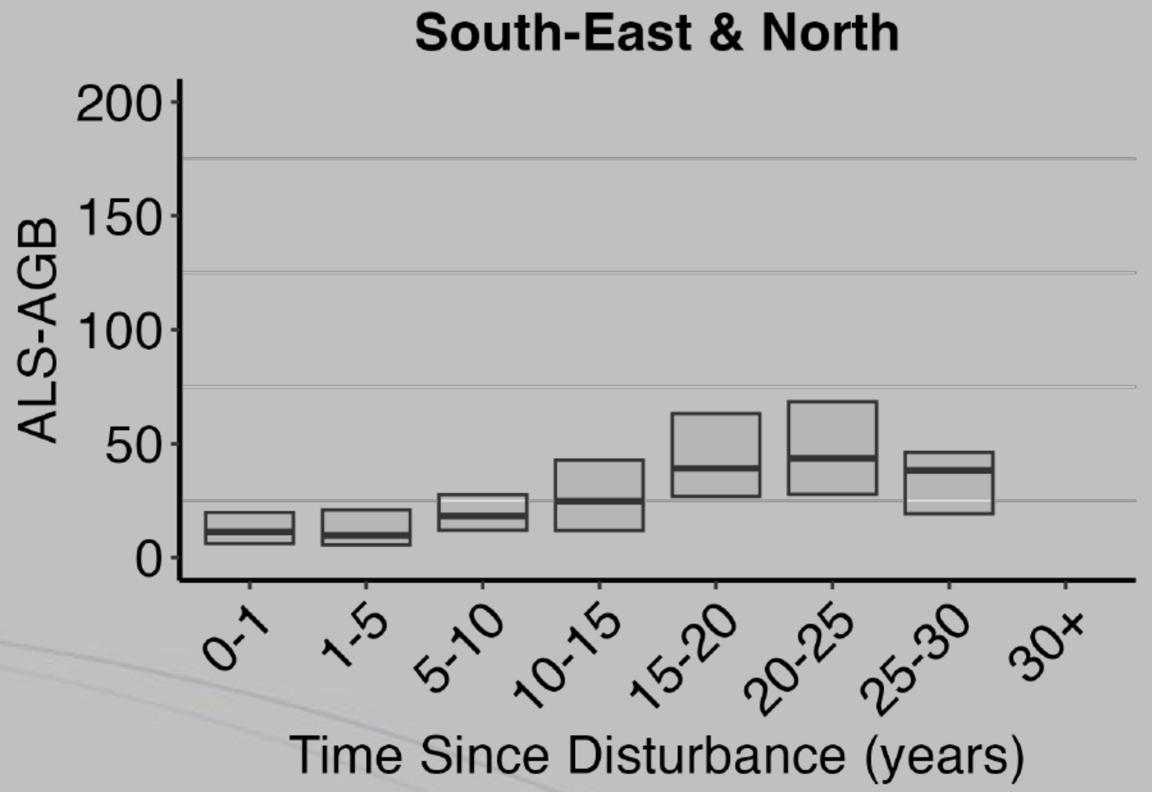
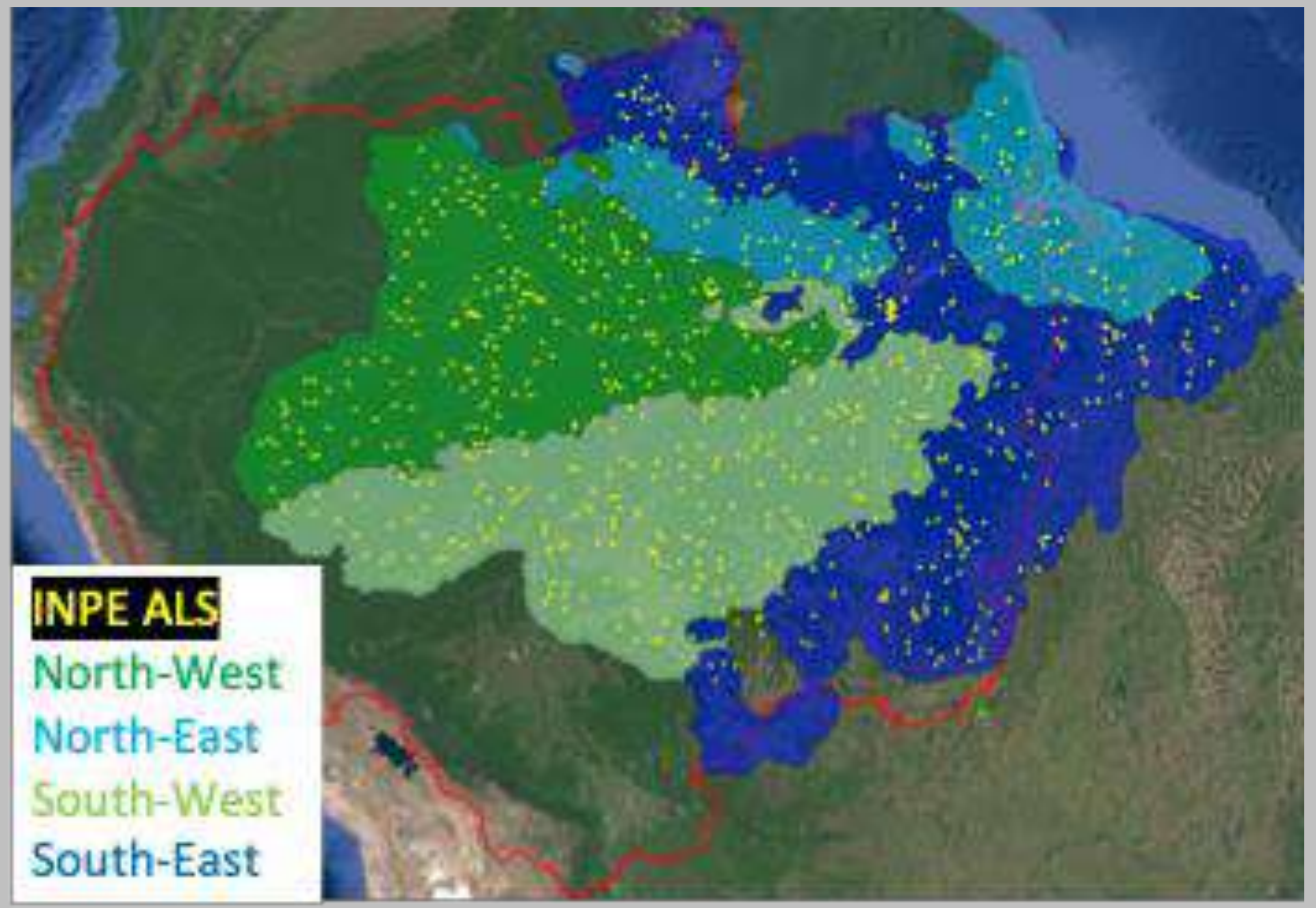
Regrowth rates from INPE-ALS











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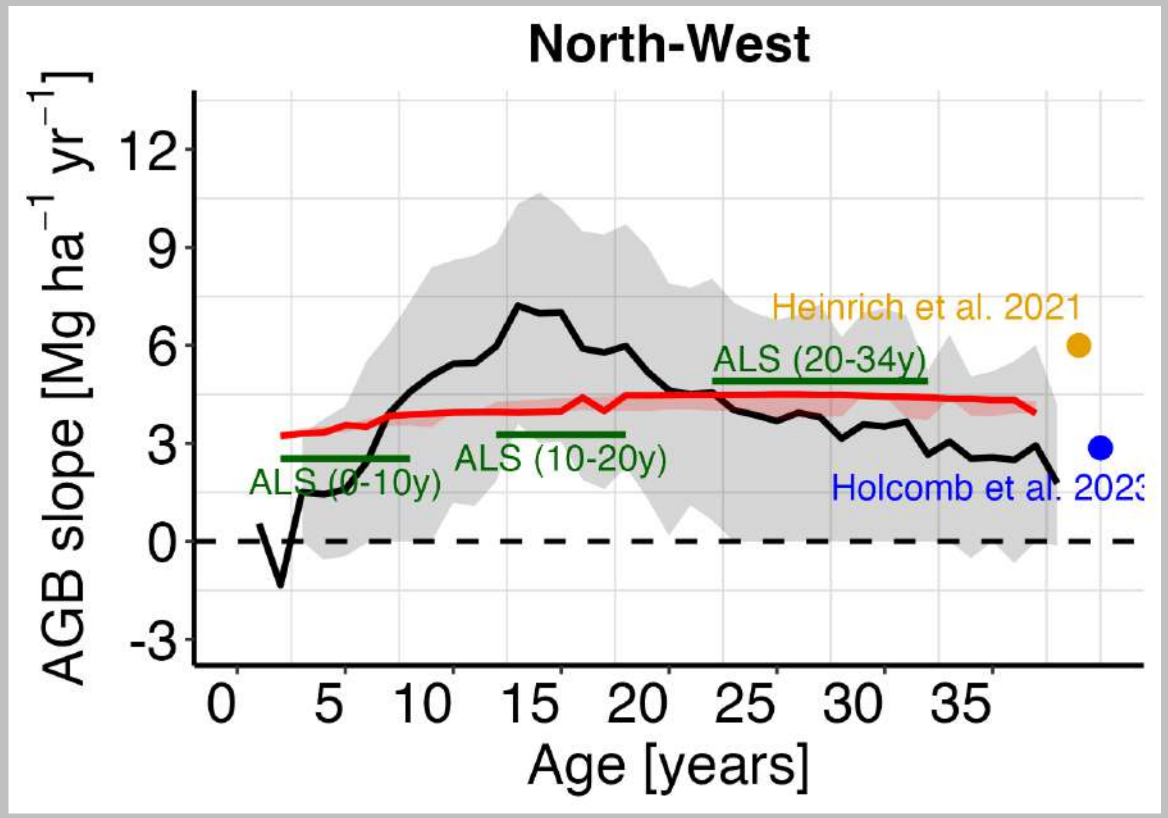
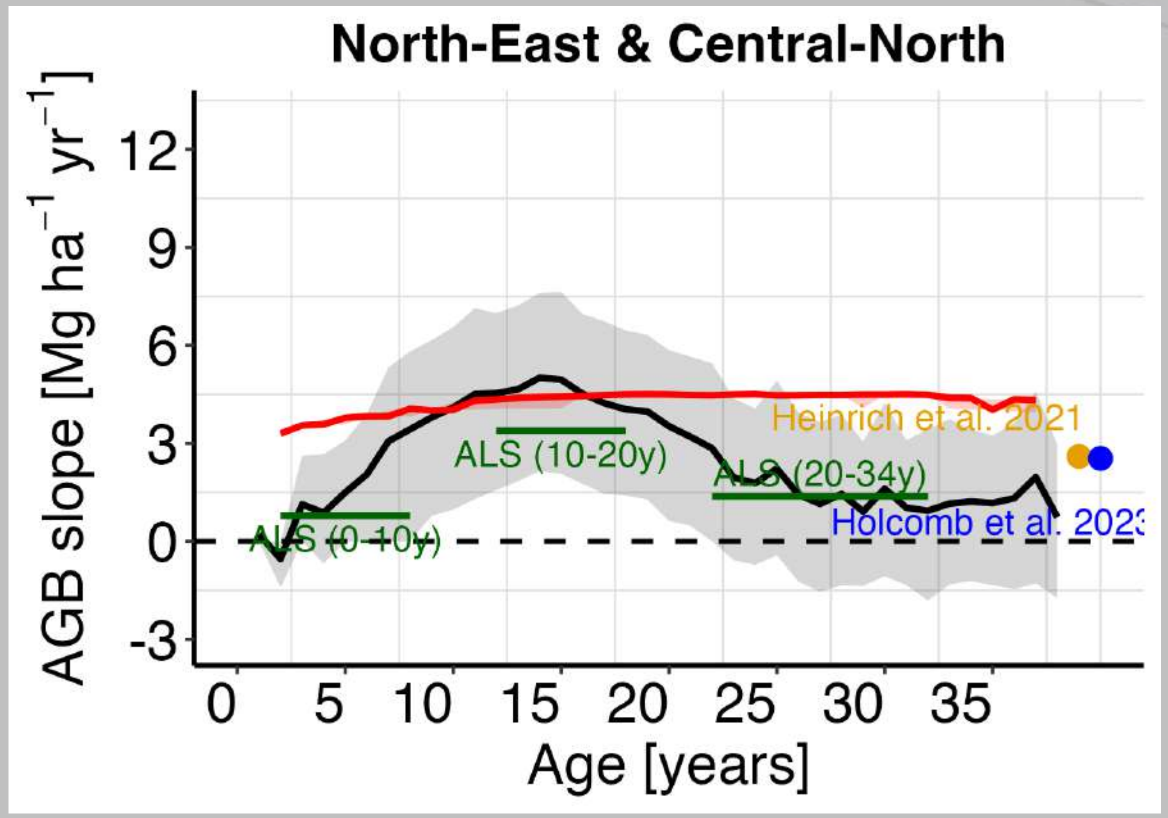
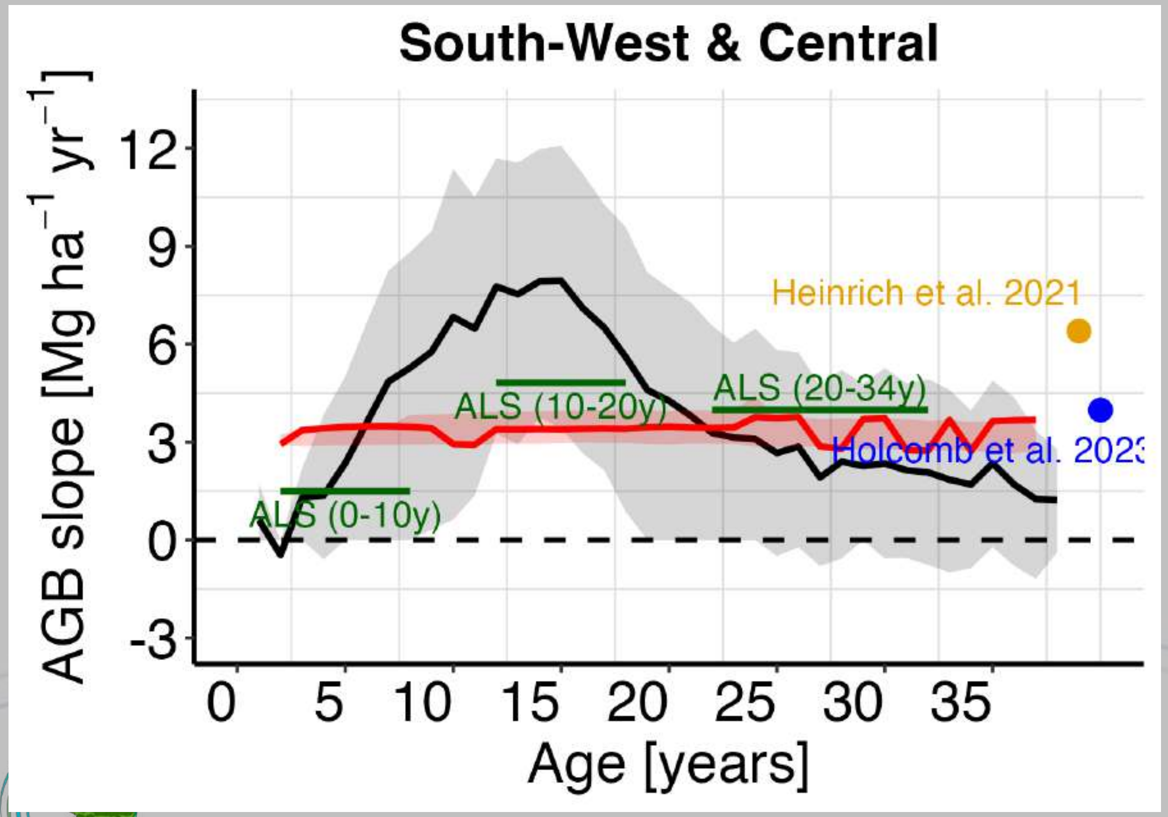
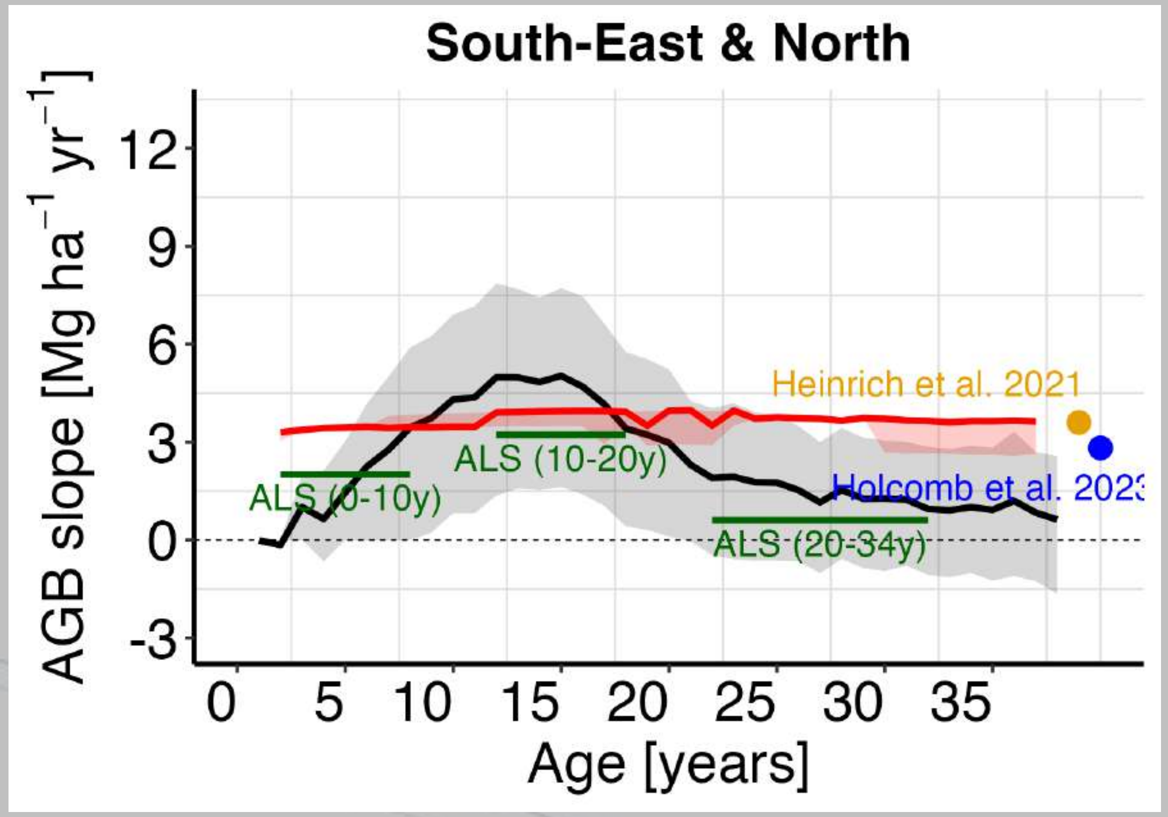
Regrowth rates from different sources

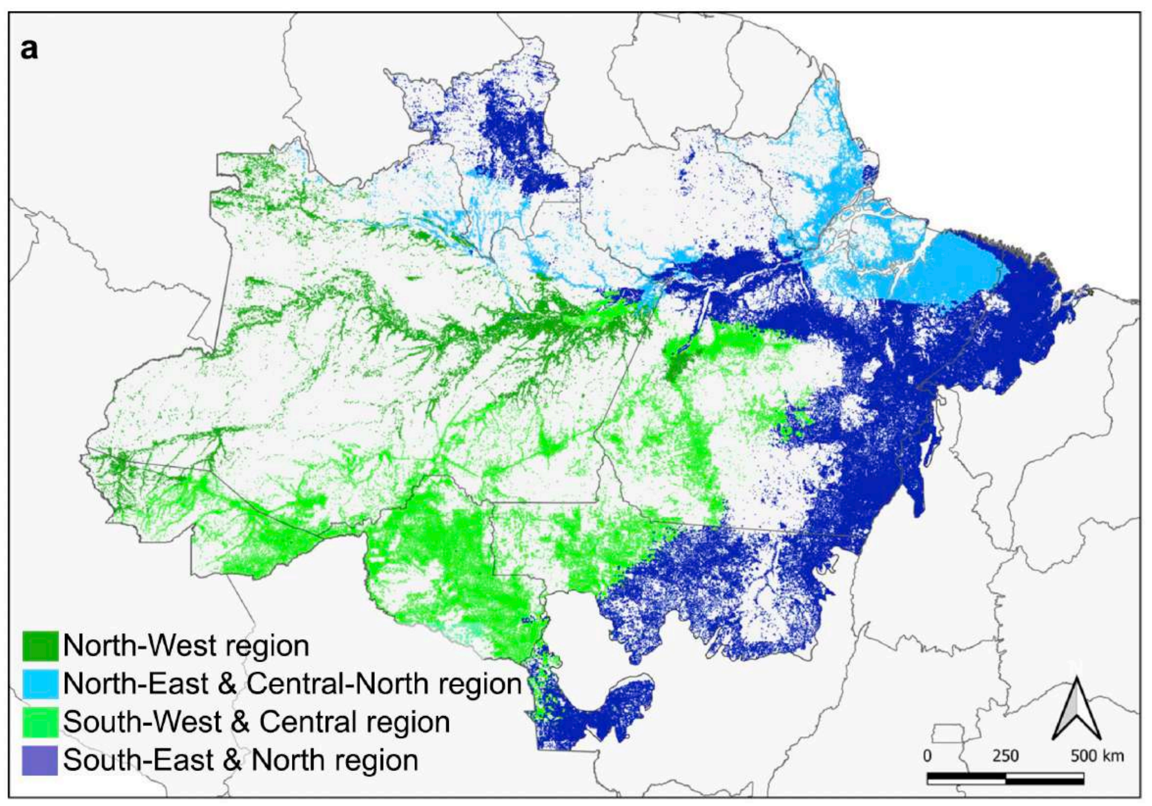








ESA CCI Biomass (10 annual maps)
INPE ALS-AGB (2016)
Heinrich et al. 2021
Holcomb et al. 2023
Robinson et al. 2025



Regions for estimating regrowth rates (Heinrich et al. 2021)

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Summary

- ESA CCI Biomass time-series products allow the estimation of regrowth rates for individual secondary forest age classes
- Regrowth rates from INPE-ALS show a similar pattern to the CCI in the Eastern Brazilian Amazon, with the highest rates at around 10-20 years
- Since INPE-ALS represents sampled AGB, its estimated regrowth rates are influenced by the MapBiomas product and its definition of secondary forest
- Robinson et al. 2025 report relatively little variation in regrowth rates across the age classes

First results from the ESA BIOMASS Mission in Brazilian Forests

Mikhail Urbazaev, Viola Heinrich, Martin Herold

Session 2.1: Biomass datasets + missions

São José dos Campos, 30 Oct 2025

work conducted under ESA BIOMASS DISC
as part of the BIOMASS In-Orbit Commissioning Programme

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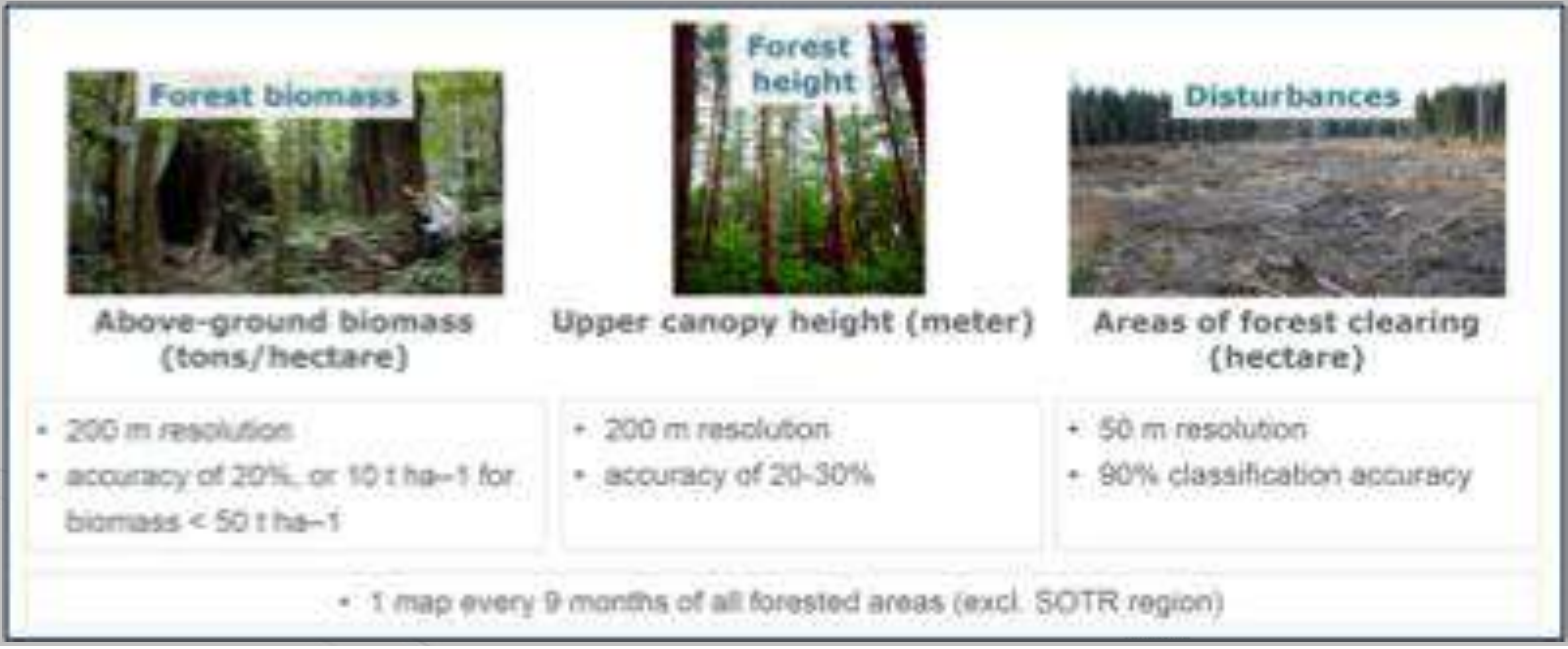
The BIOMASS mission: ESA‘s forest mission

Key facts

- ESA's 7th Earth Explorer
- Designed to observe forest height and biomass
- Launch date: April 29, 2025
- First civilian full polarimetric P-band SAR (Synthetic Aperture Radar)
- Two mission phases:
  - TomoSAR (18 months: one global coverage at the beginning of the mission)
  - PolInSAR (3.5 years: five repeated global coverages)
- 5 years lifetime

- Swath width is 51.1 km
- Spatial resolution (SLC): ~59 m (range) x 8 m (azimuth)

Primary science objectives



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Signature analysis of BIOMASS L1B amplitude (commissioning data) across secondary forests and their ages

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Summary

- First comparison of BIOMASS L1B IOC products with reference data (Brazilian NFI and INPE-ALS)
- The data are not yet radiometrically or polarimetrically calibrated, nor terrain normalized
- BIOMASS amplitude correlates with NFI-AGBD and ALS canopy height at cross-pol
- BIOMASS amplitude shows a stronger correlation with forest age as ALOS-2 PALSAR-2
- Further improvements (geolocation, calibration, terrain normalization) are expected to improve the correlation with the reference data
- Ground notched data (i.e., excluding the signal from ground) are expected to provide a significant improvement

work conducted under ESA BIOMASS DISC
as part of the BIOMASS In-Orbit Commissioning Programme

Acknowledgments

SERVIÇO FLORESTAL BRASILEIRO

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SynCER: Synthesising post-disturbance Carbon Emissions and Removals across Brazil’s forest biomes

(10:35-11:00) Break

São José dos Campos, 30 Oct 2025

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Temporal trajectories of biomass in Brazil from the ESA CCI Biomass dataset

Maurizio Santoro (Online)

Session 2.1 (Part 1): Biomass datasets and missions

São José dos Campos, 30 Oct 2025

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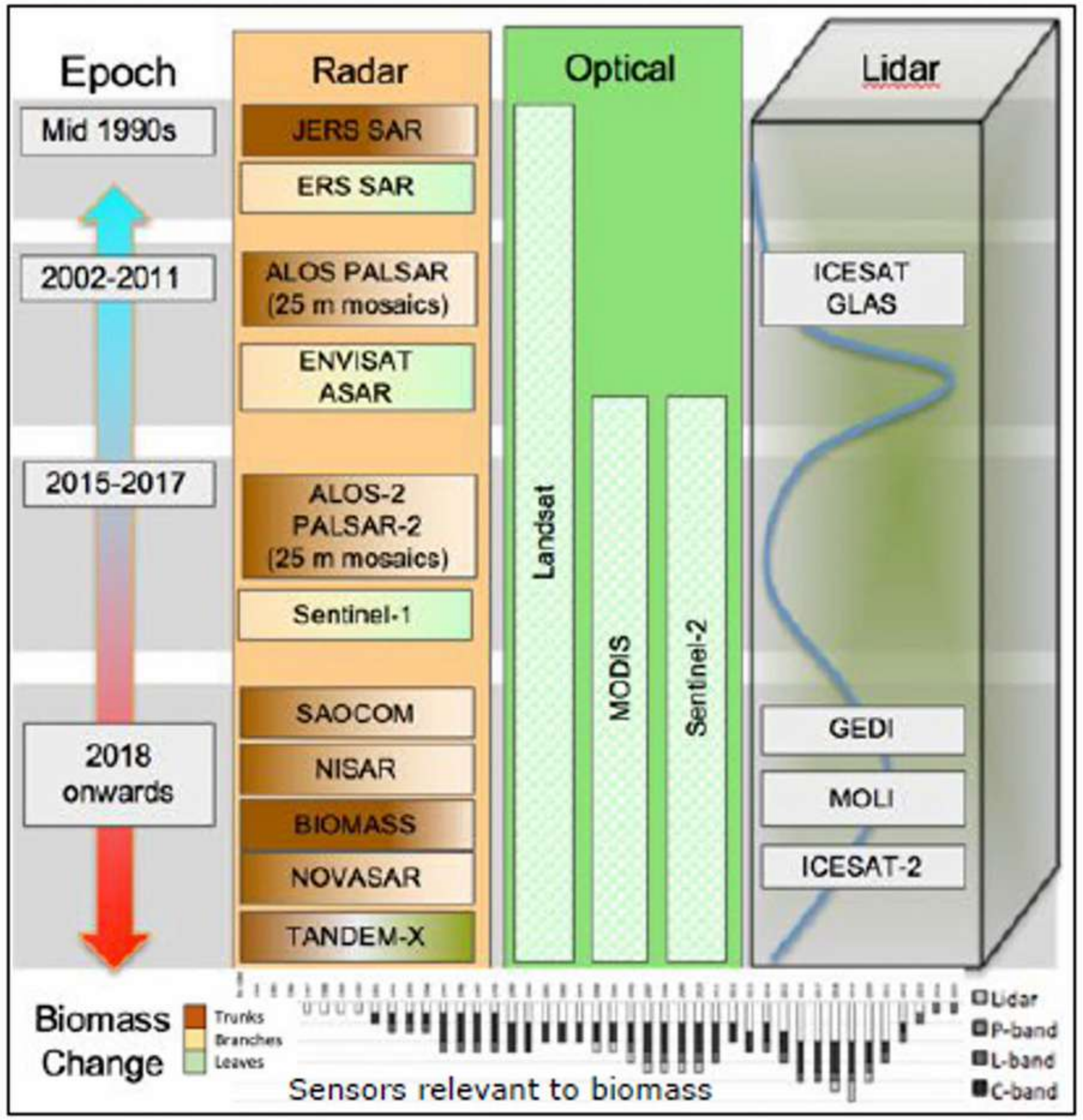
The CCI Biomass project - background

- Above-ground biomass (AGB) is an Essential Climate Variable (ECV) within the Global Climate Observing System (GCOS).

- One of the objectives of the CCI Biomass project is to generate global maps of AGB using a variety of Earth Observation (EO) datasets and state-of-the-art models for several epochs spanning two decades and assess biomass changes

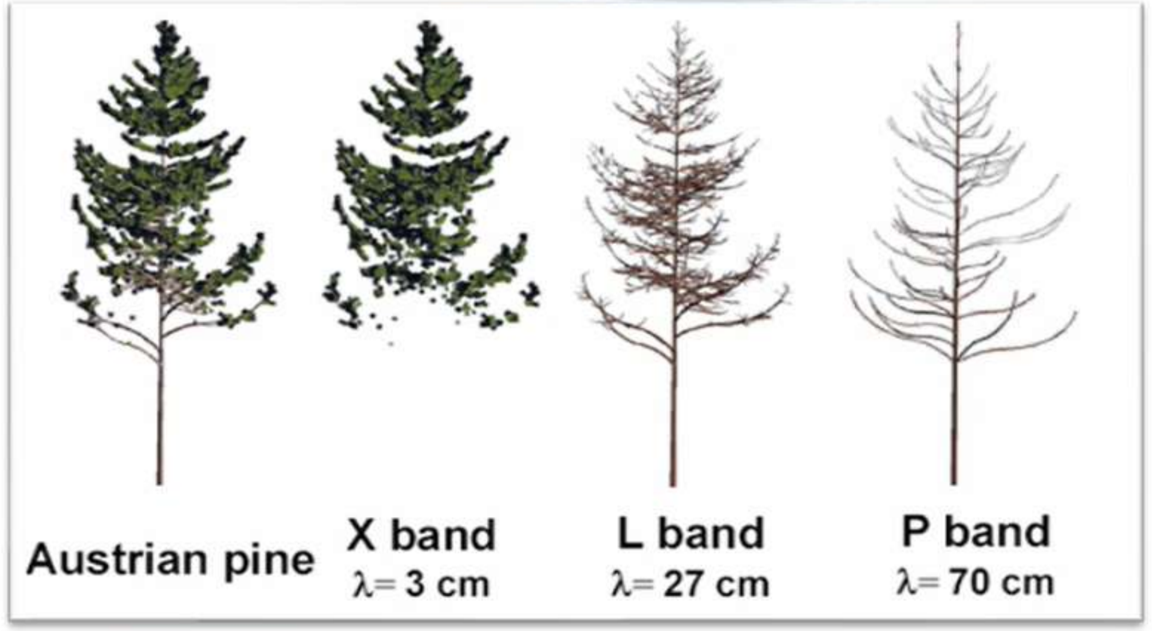
- Specs of the data products were shaped by requirements from the climate and carbon modelling community (GCOS) as well as from other communities including climate policy

Satellite observations of forests



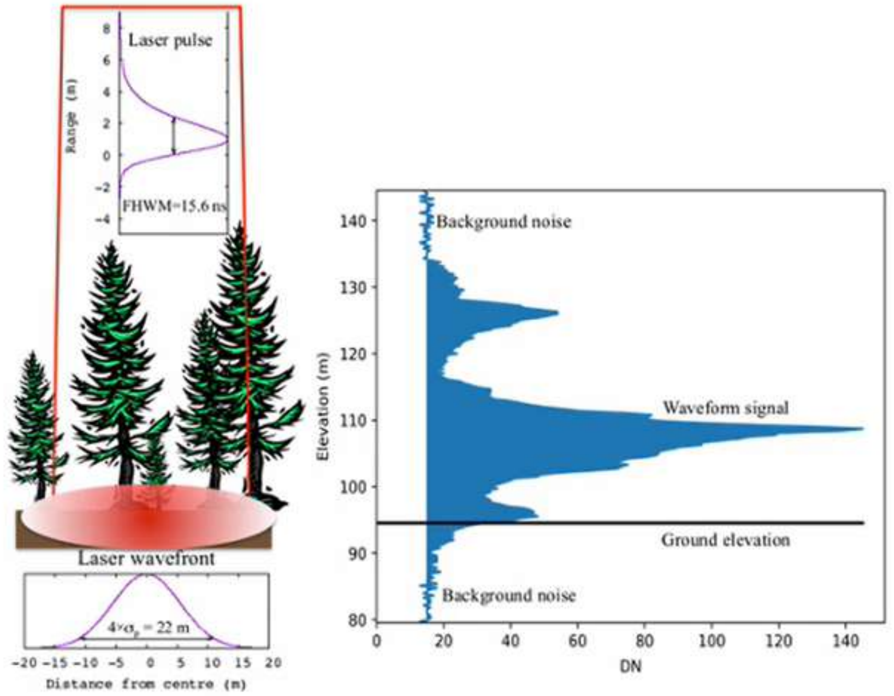
Radar

(Courtesy T. Le Toan)



LiDAR

(Hancock et al., RSE, 2019)



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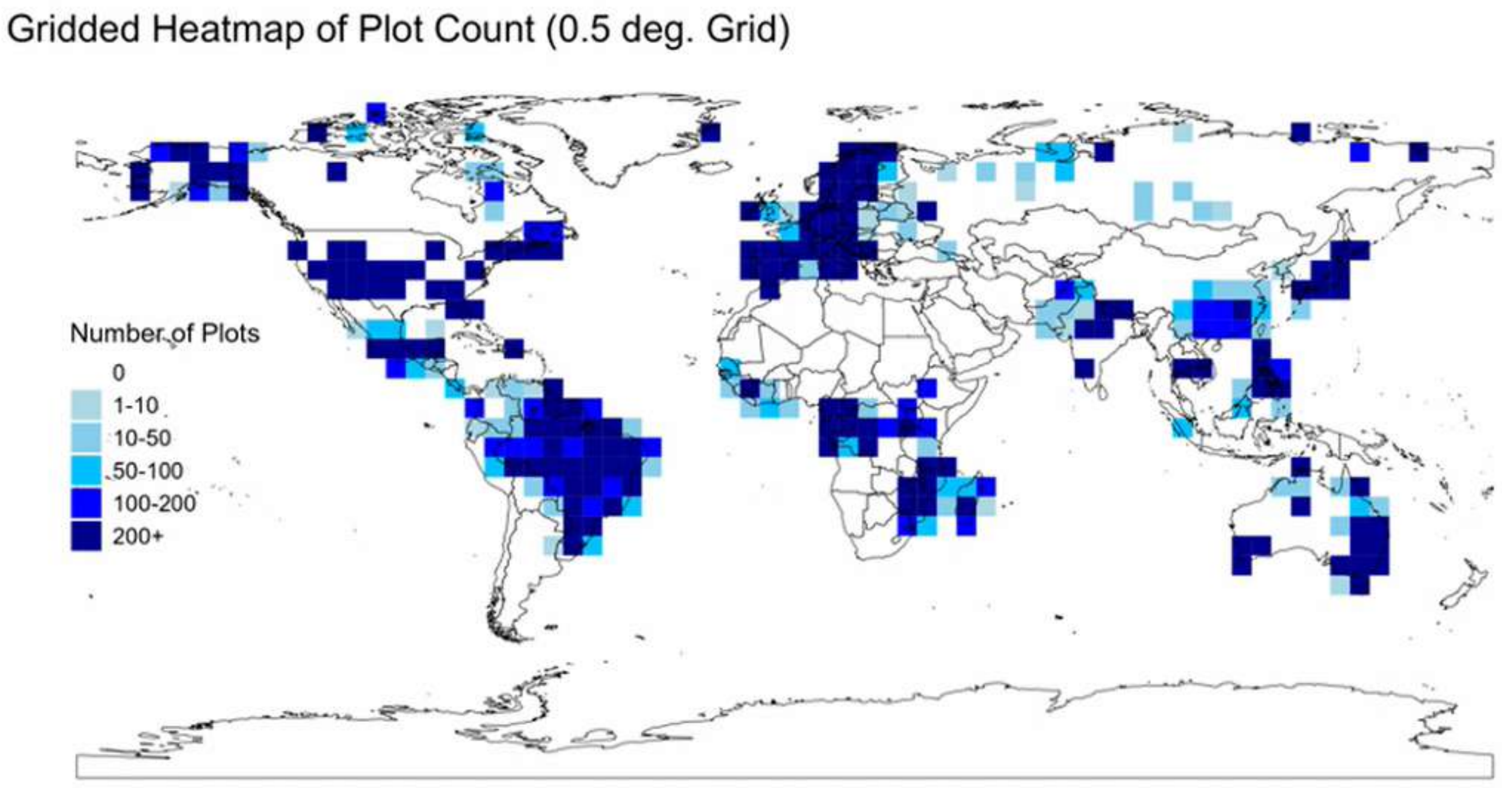
Field measurements of biomass

- Measurements from on ground surveys typically form the backbone of a biomass retrieval algorithm
- In practice, access to such data is cumbersome resulting in an uneven geographic distribution
- This constraint also decimates the amount of retrieval models relating space data to biomass



- In CCI Biomass, biomass is estimated without reference plot measurements

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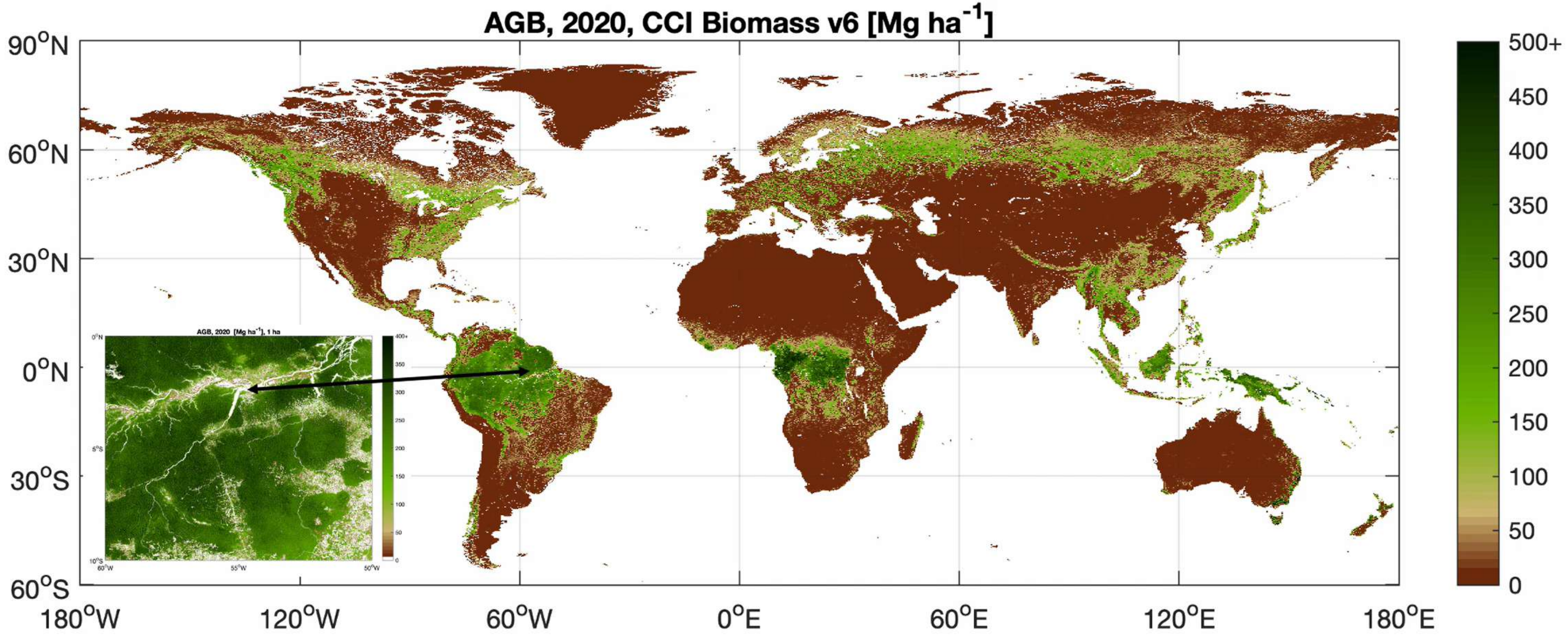
The CCI Biomass AGB product



Current release: v6 / Pixel size: 1 ha /

Temporal coverage: 2007, 2010 and 2015-2022

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The CCI Biomass AGB change product

- AGB change = AGB difference between two years
- AGB change is accompanied by the AGB change SD & quality flag layer

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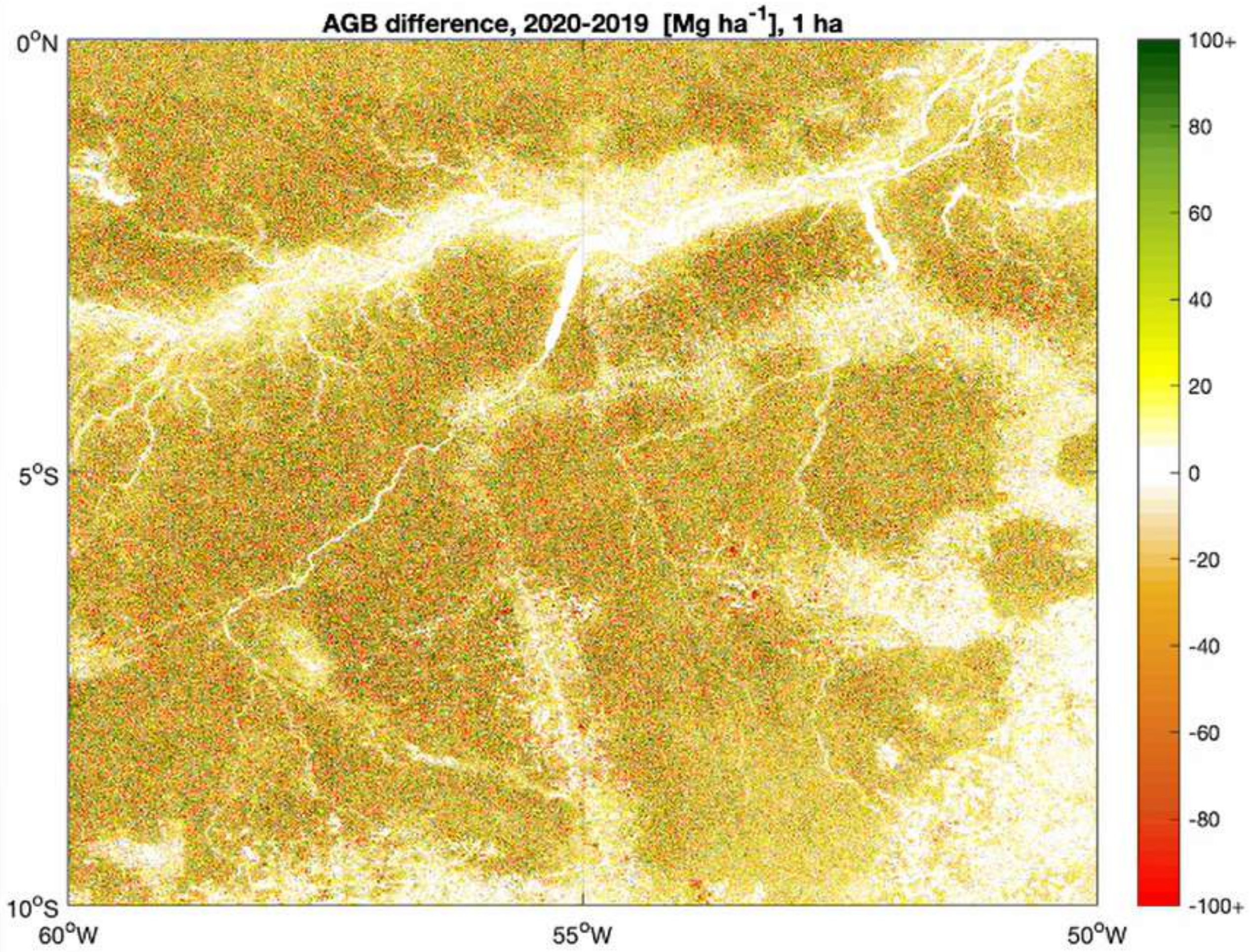
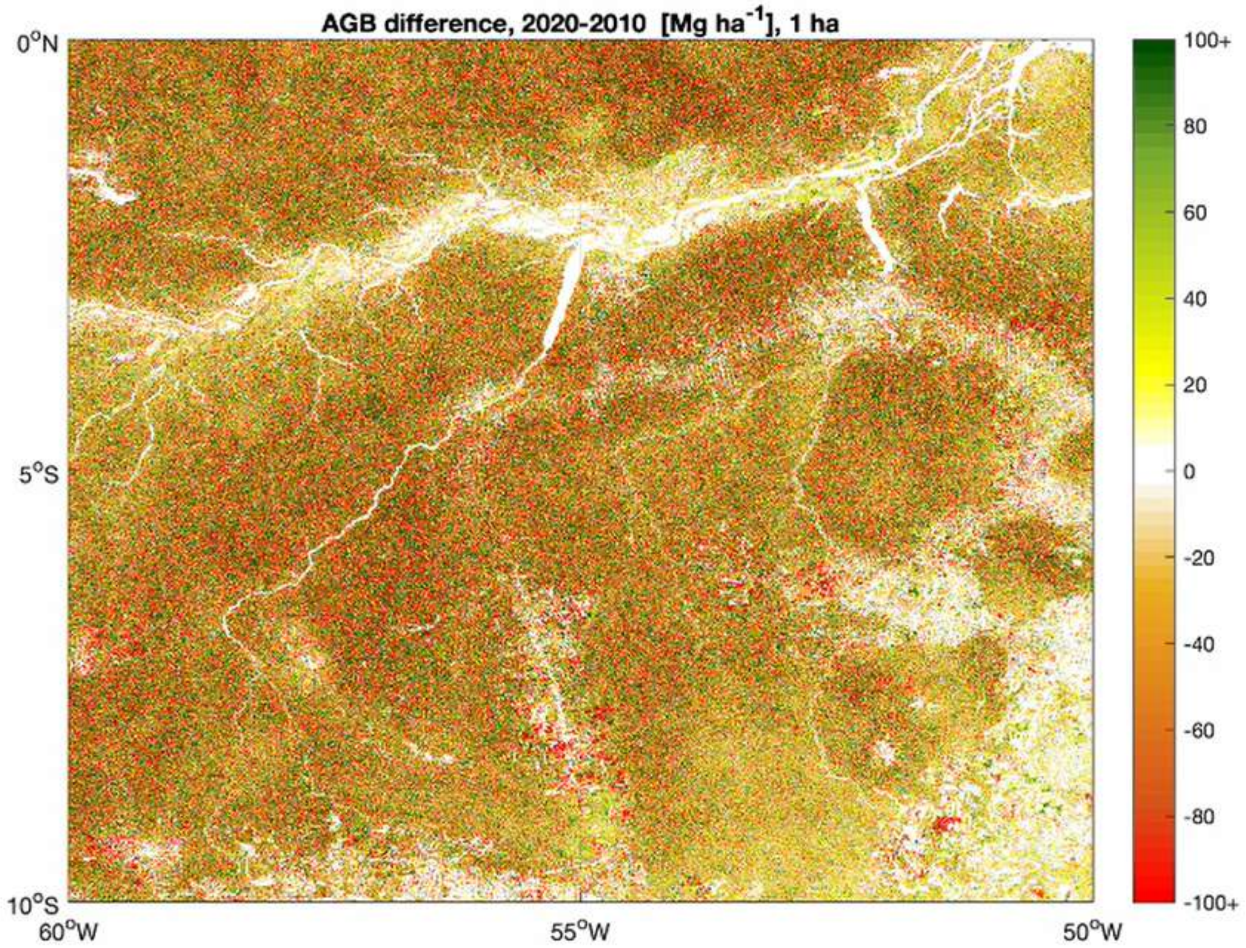
The CCI Biomass AGB change product

- AGB change = AGB difference between two years
- AGB change is accompanied by the AGB change SD & quality flag layer





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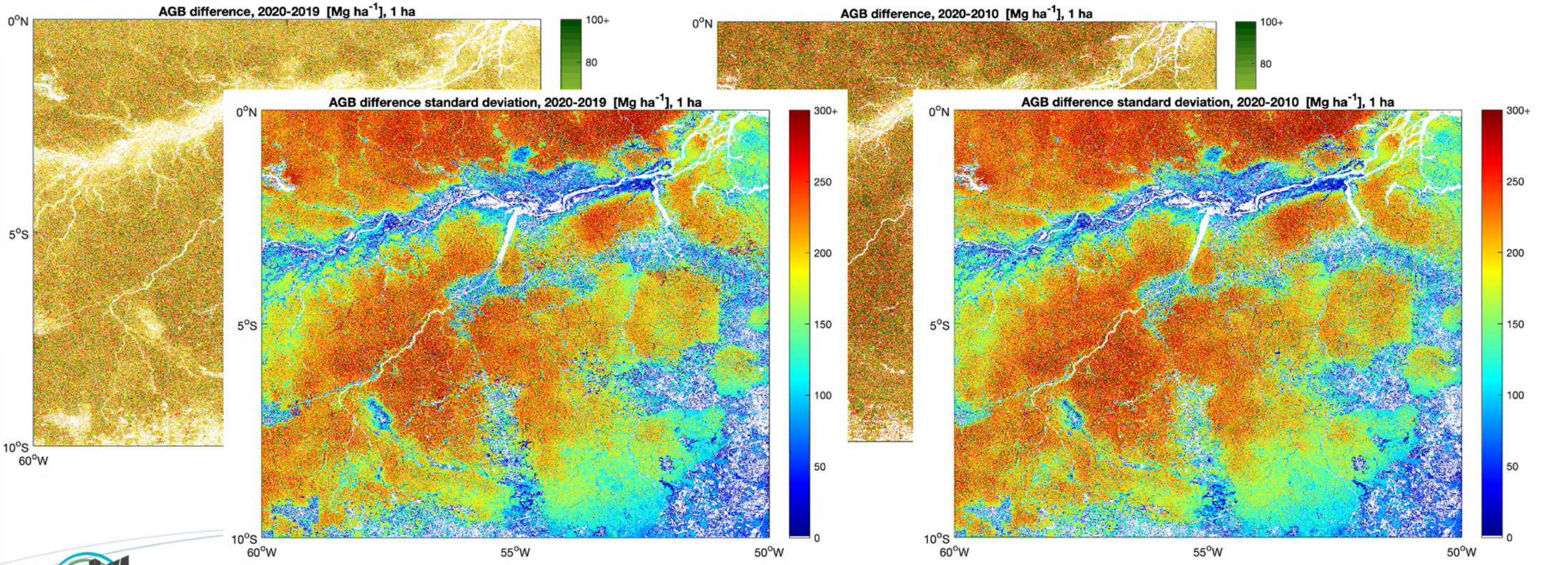
The CCI Biomass AGB change product

- AGB change = AGB difference between two years
- AGB change is accompanied by the AGB change SD & quality flag layer



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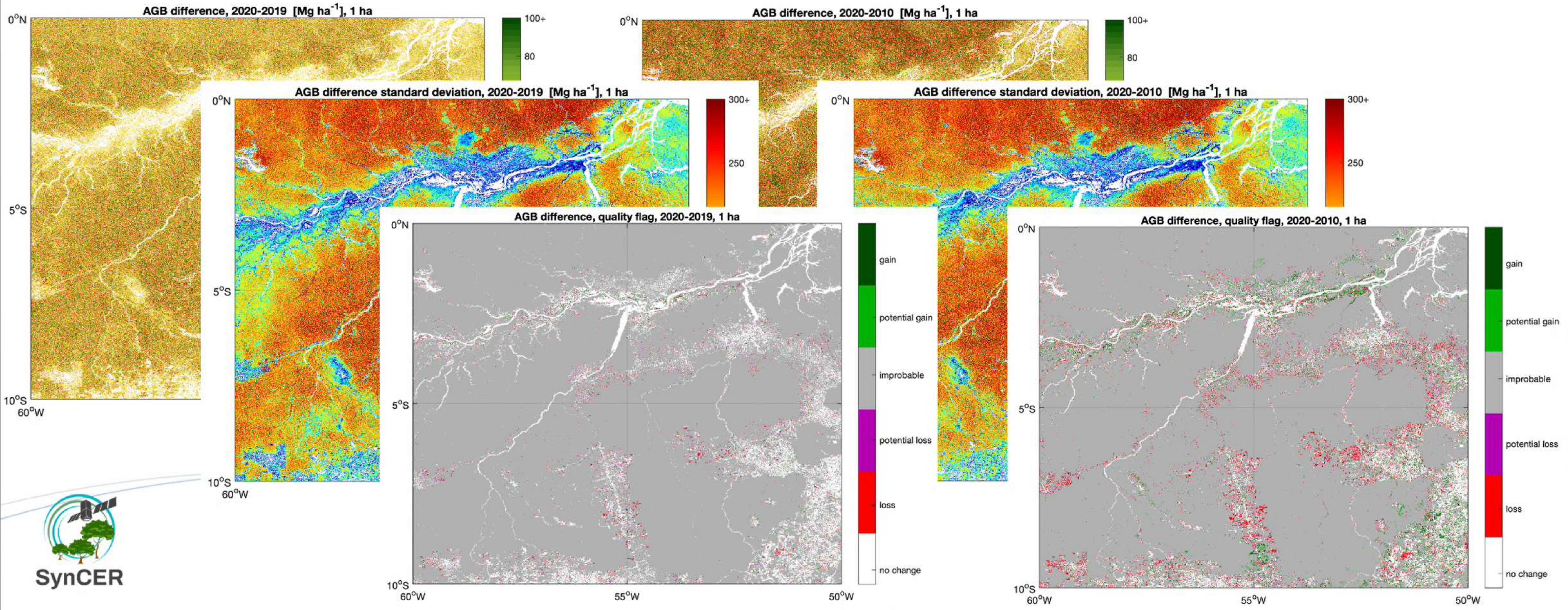
The CCI Biomass AGB change product

- AGB change = AGB difference between two years
- AGB change is accompanied by the AGB change SD & quality flag layer



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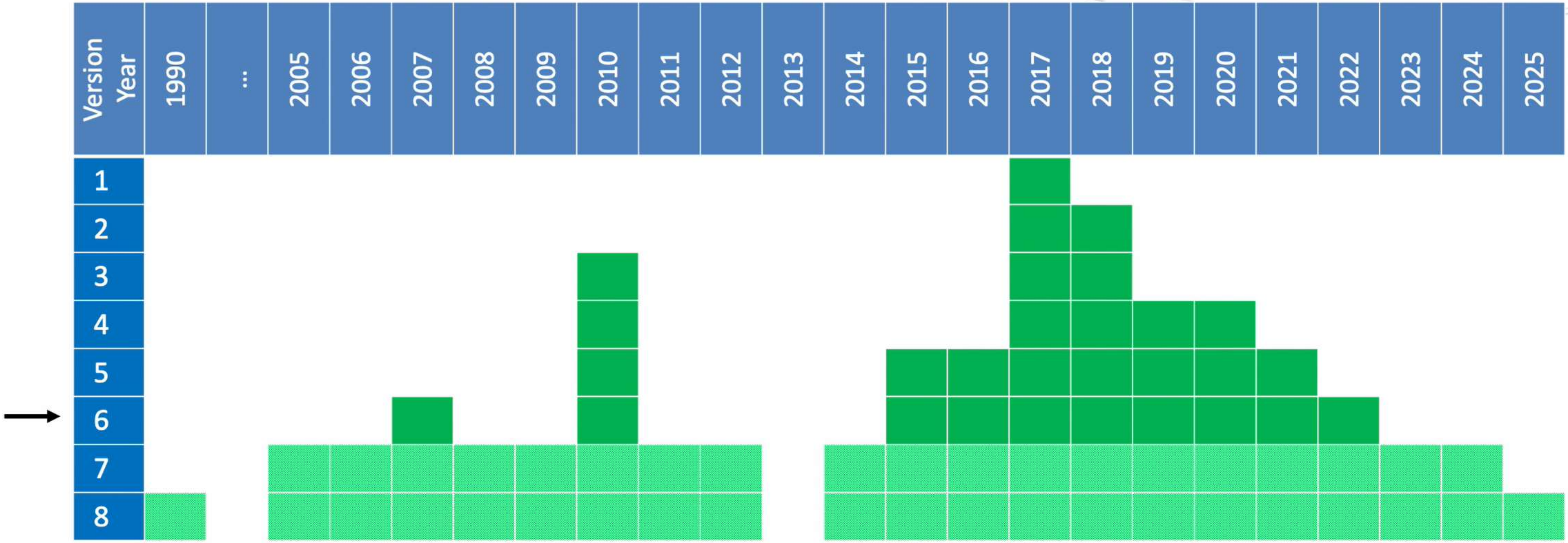
Timeline of the CCI Biomass dataset



→ v6 is the current release (May 2025)

v7: Release in spring 2026

v8: Release in spring 2027

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Biomass accumulation from CCI Biomass

1. For each CCI pixels, we computed the slope coefficient of a linear regression between year of the CCI AGB maps and the AGB values
2. Stratification of slope values (based on MapBiomas datasets)
   - Primary forest / Secondary forest / Plantation / Agroforestry (reference: MapBiomas)
   - Undisturbed forest (once detected as such) (reference: MapBiomas)
   - 10x10 deg latitude/longitude blocks
   - Ecoregion (reference Dinerstein et al., 2017)
3. For each secondary forest pixel (based on MapBiomas) we extracted the age
4. For each primary forest pixel (based on MapBiomas), we computed the average map-based AGB

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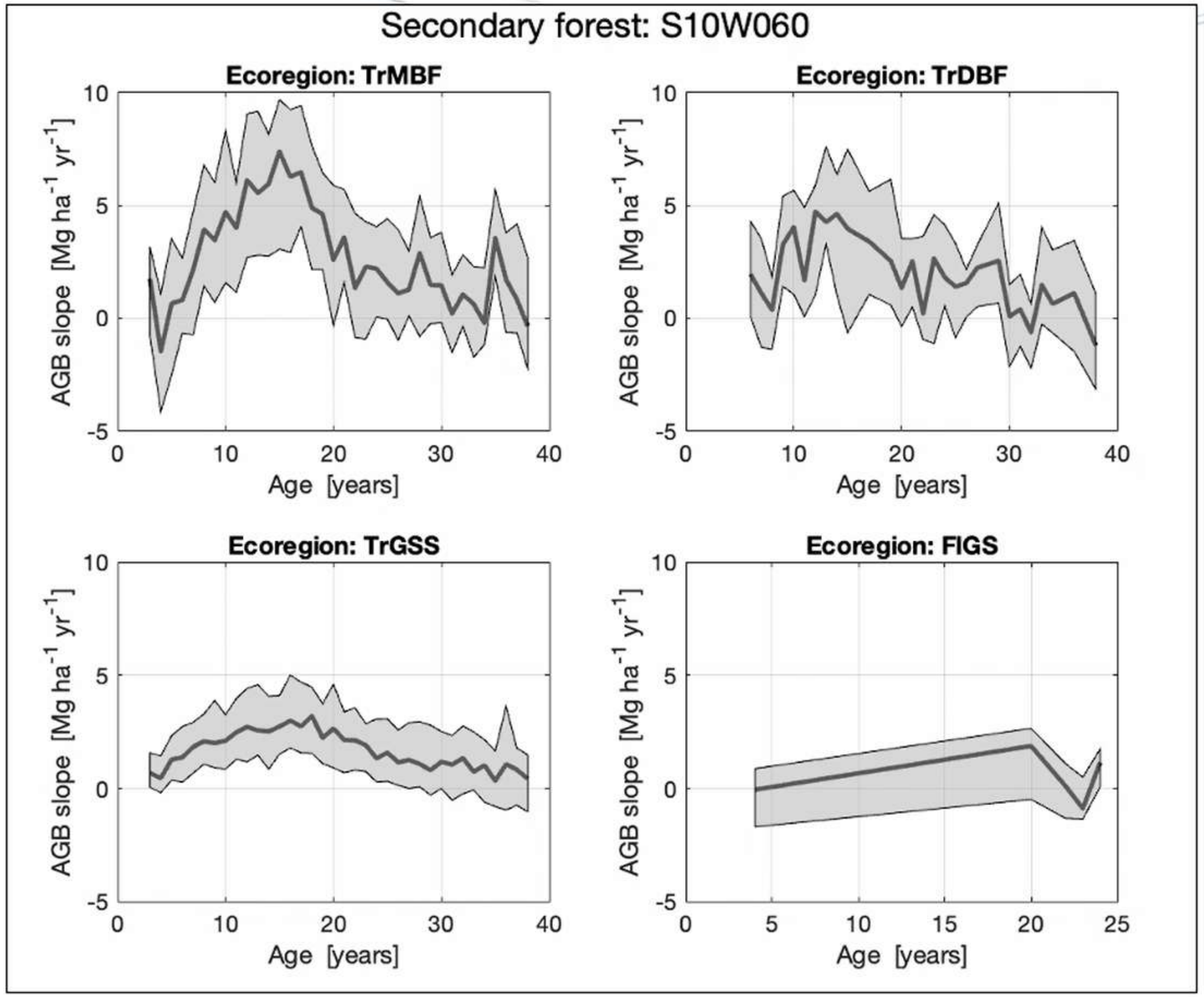
Regrowth rates from CCI Biomass

- Displaying mean and interquartile range of slope values per age of secondary forest
- The parabolic shape is consistent across Brazil but the peak differs, being higher in the NW than in the SE.



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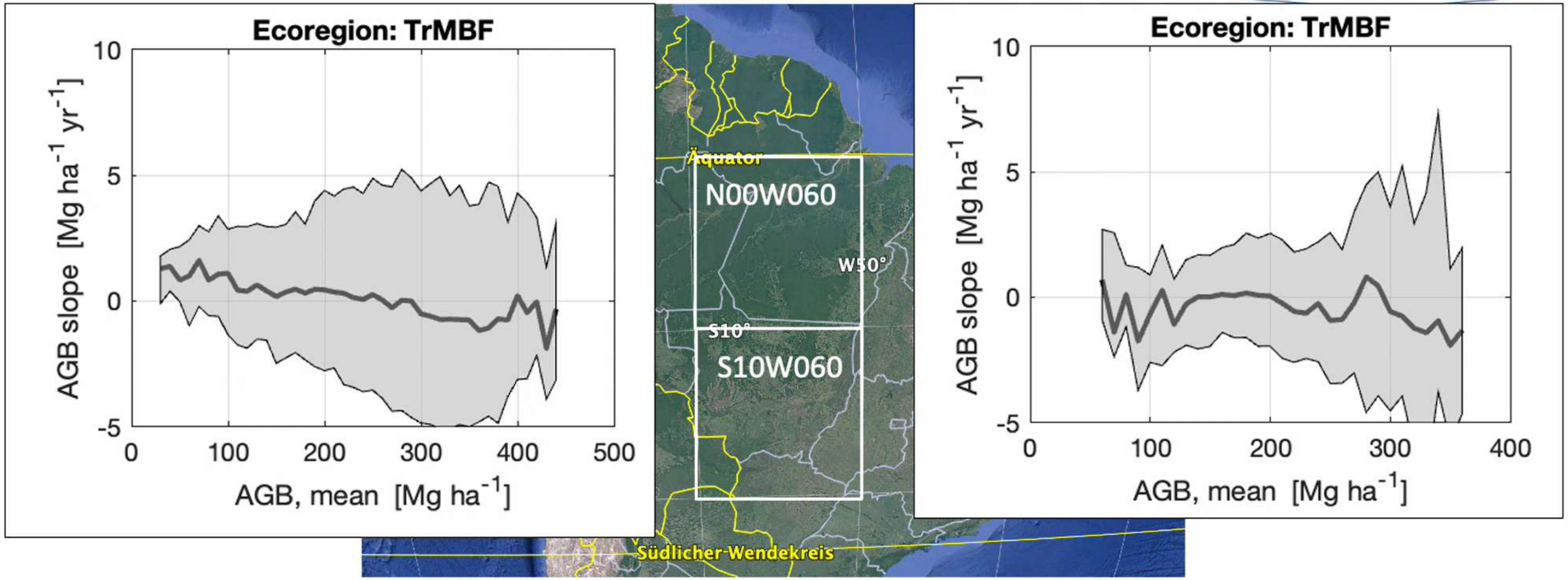
What happens in primary forests?



Is this real or is it an artefact of the CCI Biomass maps?

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Conclusions

1. The CCI Biomass dataset is valuable to identify spatial and temporal patterns
2. The dataset should not be used at the pixel level!!
3. The AGB changes between two years make sense only for fast losses or fast growth (young forest, plantation)
4. The regrowth rates in secondary forests appear to be realistic (see also talk by M. Urbazaev)
5. The trends detected in primary forests need to be taken with care!!
6. Future versions of CCI Biomass will reinforce our initial interpretation of the biomass trajectories

Access to the CCI Biomass datasets

CEDA Archive

About News Search Catalogue Get Data Deposit Tools

esa
View XML

ESA Biomass Climate Change Initiative (Biomass_cci): Global datasets of forest above-ground biomass for the years 2007, 2010, 2015, 2016, 2017, 2018, 2019, 2020, 2021 and 2022, v6.0

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Abstract

This dataset comprises estimates of forest above-ground biomass (AGB) for the years 2007, 2010, 2015, 2016, 2017, 2018, 2019, 2020, 2021 and 2022. They are derived from a combination of Earth observation data, depending on the year, from the Copernicus Sentinel-1 mission, Envisat's ASAR (Advanced Synthetic Aperture Radar) instrument and JAXA's (Japan Aerospace Exploration Agency) Advanced Land Observing Satellite (ALOS-1 and ALOS-2), along with additional information from Earth observation sources. The data has been produced as part of the European Space Agency's (ESA's) Climate Change Initiative (CCI) programme by the Biomass CCI team.

This release of the data is version 6. Compared to version 5, version 6 consists of an update of the maps of AGB for the years 2010, 2015, 2016, 2017, 2018, 2019, 2020, 2021 and new AGB maps for 2007 and 2022. AGB change maps have been created for consecutive years (e.g., 2020-2019), for a decadal interval (2020-2010) as well as for the interval 2010-2007. The pool of remote sensing data includes multi-temporal observations at L-band for all biomes and for all years and extended ICESat-2 observations to calibrate retrieval models. A cost function that preserves the temporal features as expressed in the remote sensing data

Citable as: Santoro, M.; Cartus, O. (2025): ESA Biomass Climate Change Initiative (Biomass_cci): Global datasets of forest above-ground biomass for the years 2007, 2010, 2015, 2016, 2017, 2018, 2019, 2020, 2021 and 2022, v6.0. NERC EDS Centre for Environmental Data Analysis, *17 April 2025*. doi:10.5285/95913ffb6467447ca72c4e9d8cf30501.
https://dx.doi.org/10.5285/95913ffb6467447ca72c4e9d8cf30501

EO-based forest carbon removals and emissions in Amazon

Yidi Xu (Online)

Session 2.2: Other metrics for identifying secondary forest success

São José dos Campos, 30 Oct 2025

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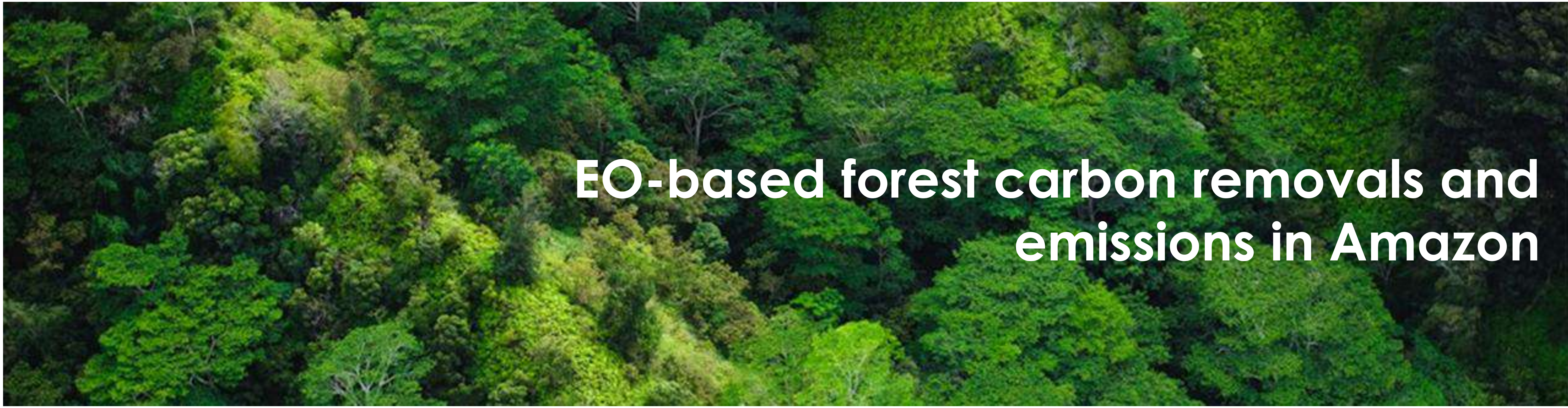


EO-based forest carbon removals and emissions in Amazon

Yidi Xu, Liang Wan, Philippe Ciais

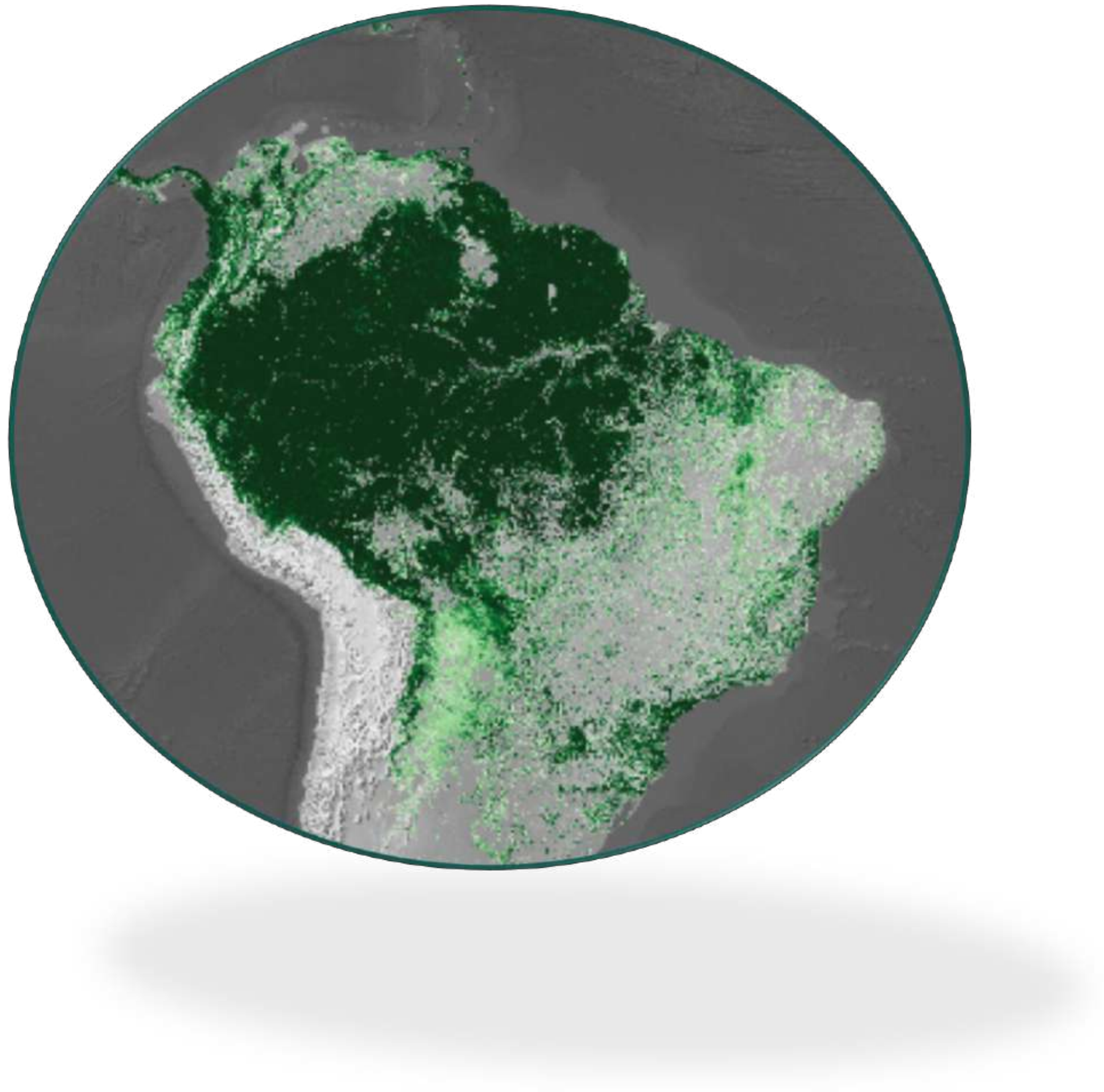
Laboratory for Climate and Environmental Sciences, France

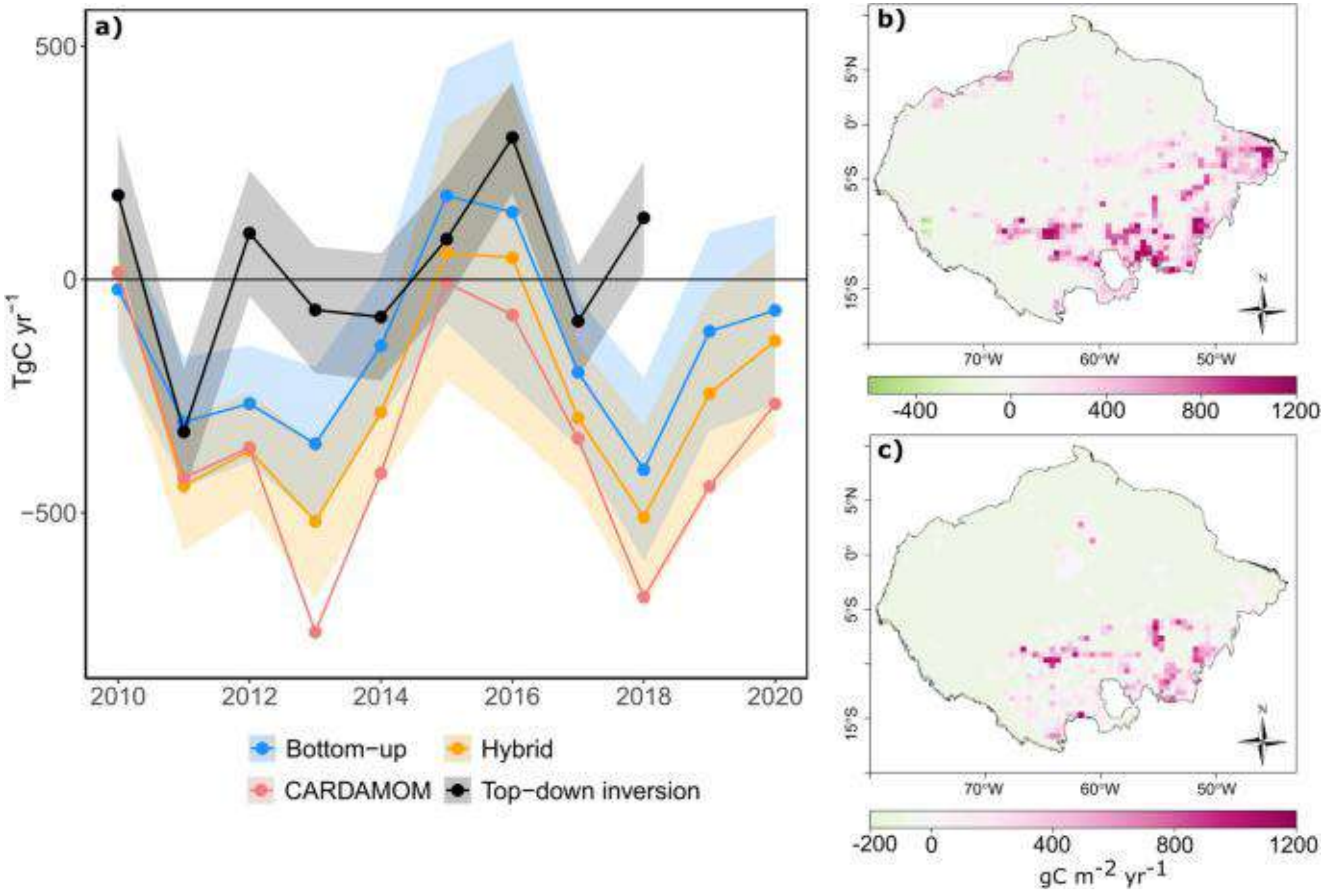
2025.10.29

Background

Amazon: globally important carbon stocks

C sink? C sources ?

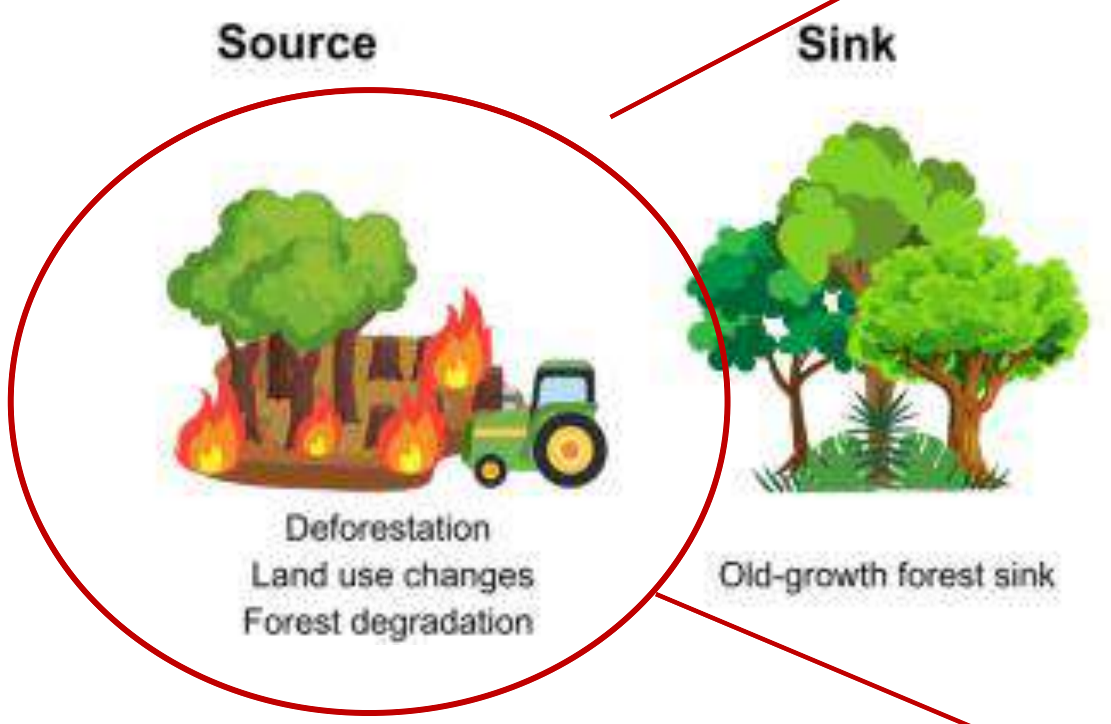




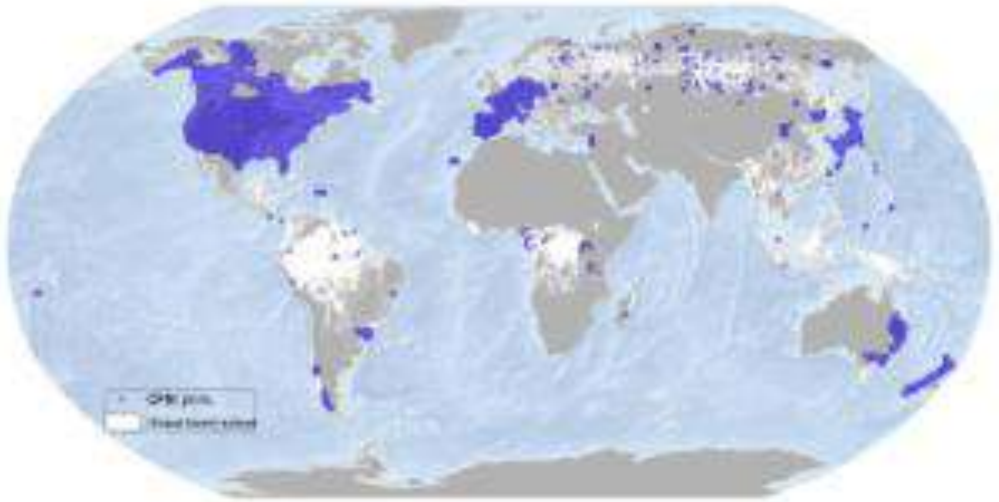
Rosan et al., 2024

Background

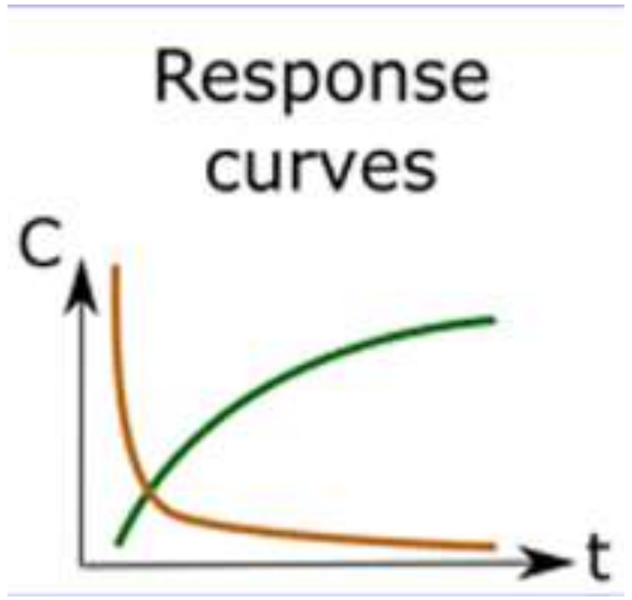
Bottom-up BK model DGVM simulation



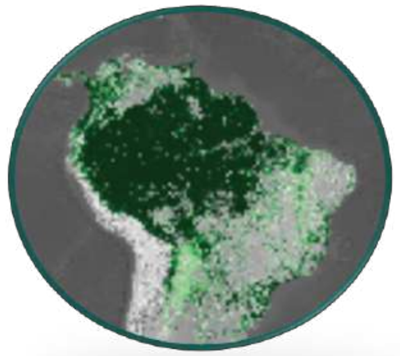
Rosan et al., 2024

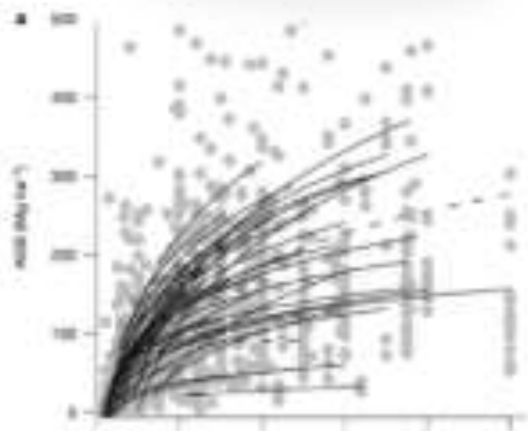


Sparse Inventory plot in tropics



Regional response curves used in BK models





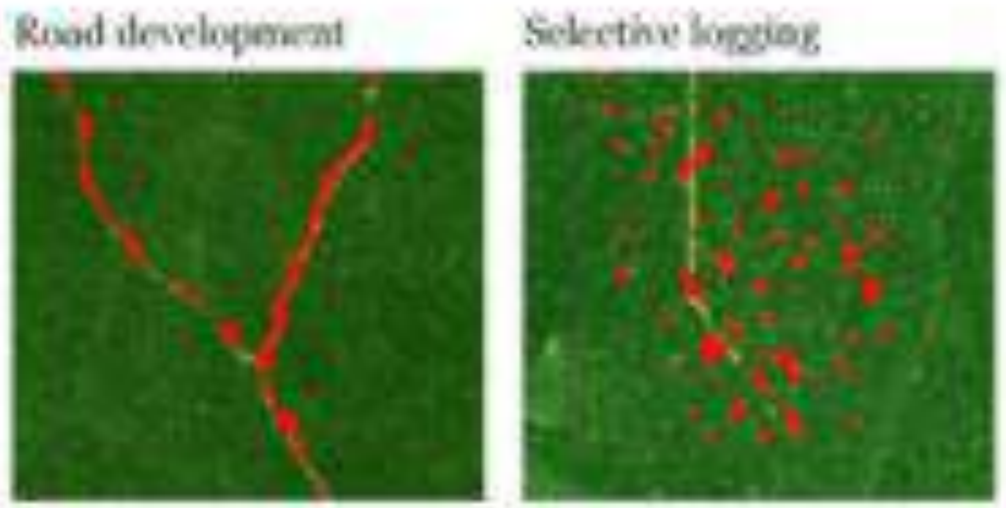
(Poorter et al., 2016)

Background

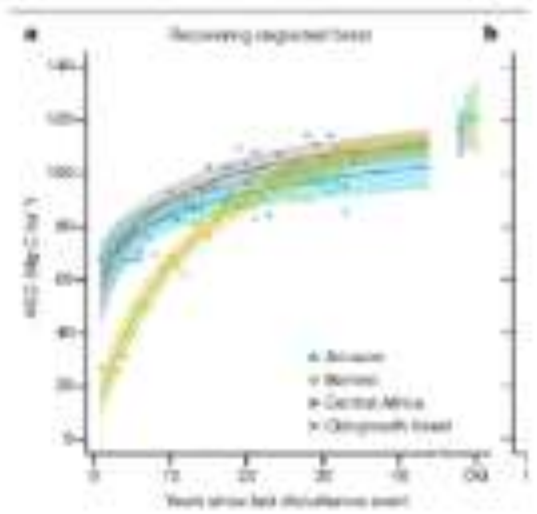
1) Improve the BK model with spatially-explicit regrowth curves

2) Annual canopy height and biomass mapping

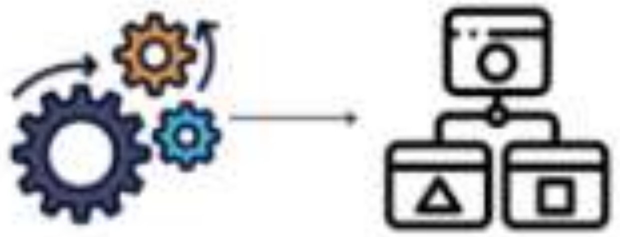
Satellite approach



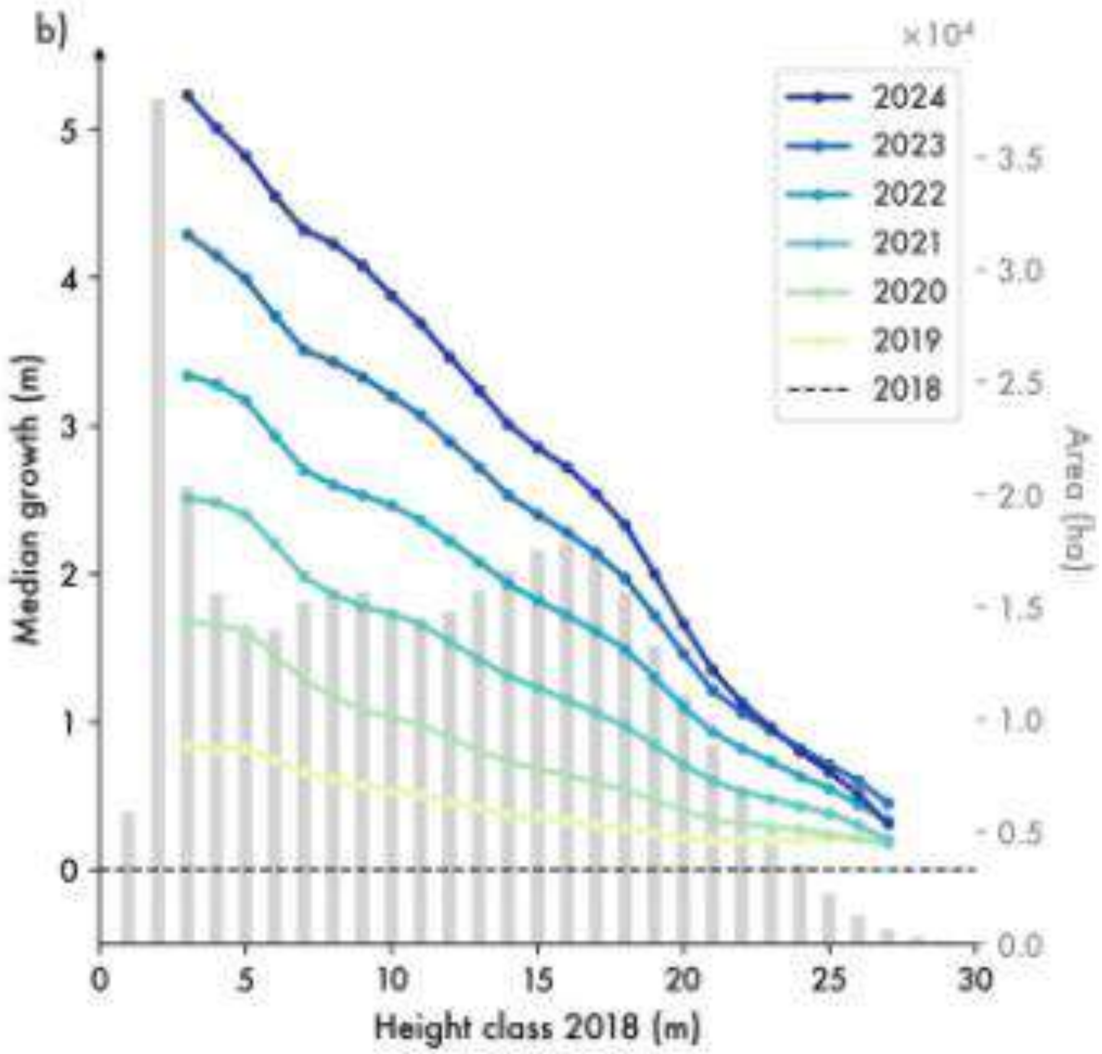
Slagter et al., 2024



(Heinrich et al., 2023; Holcomb et al., 2024)



(Cook-patton, 2020; Nathinial et al., 2025)



(Schwarz et al., 2025)

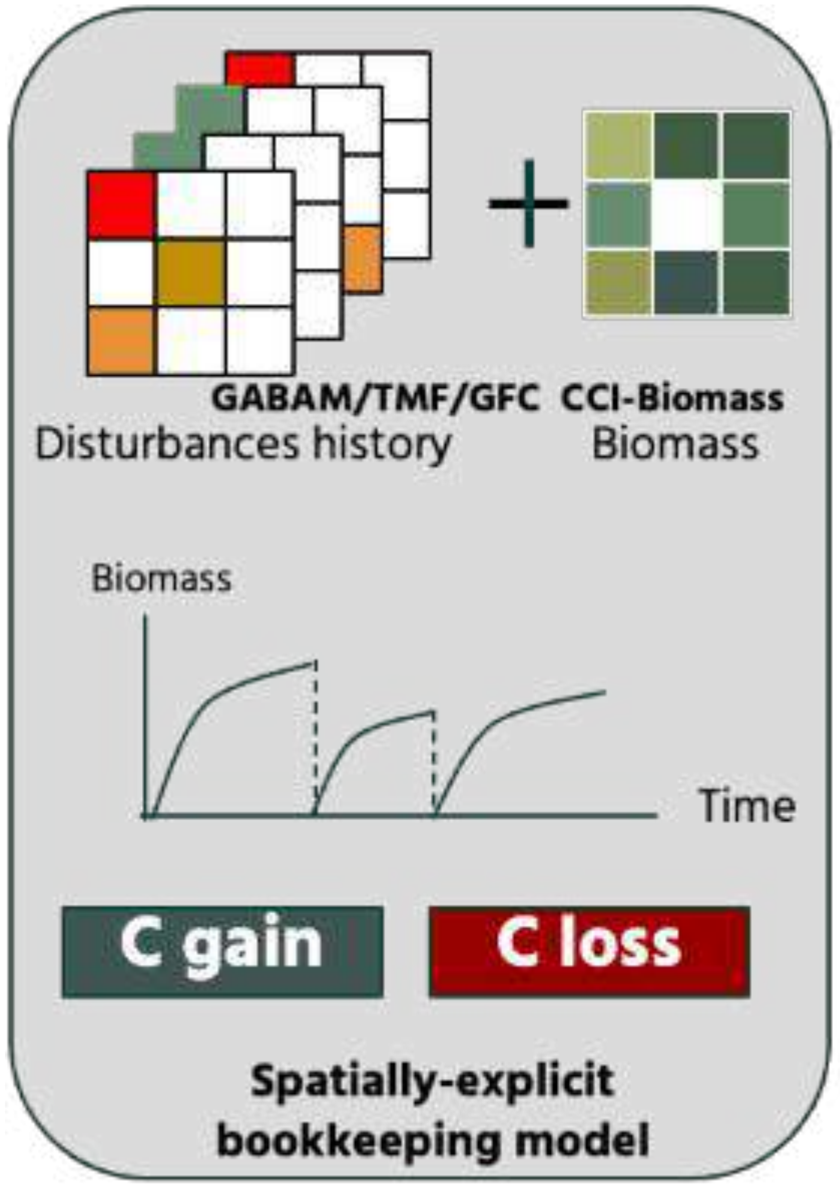
Small size disturbance

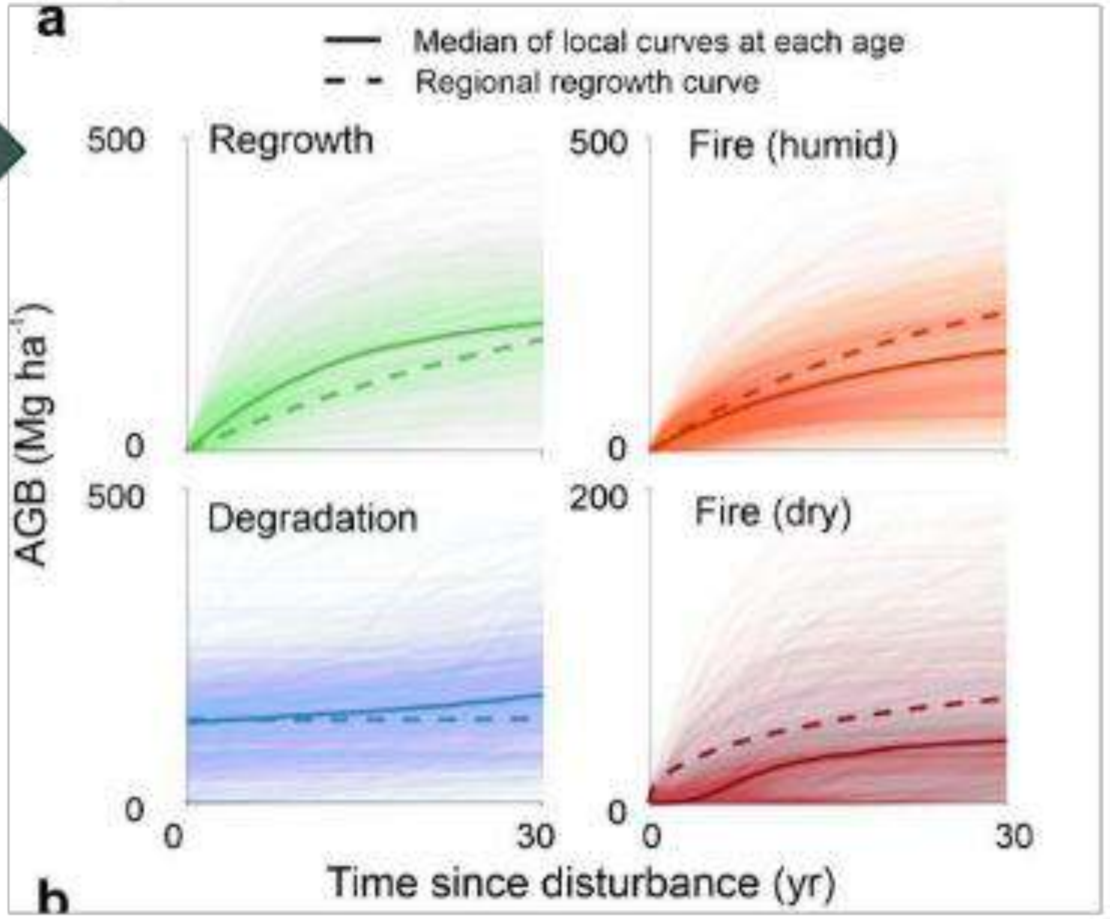
Satellite-based regrowth curve

Yearly CH growth of French forest

1. Gain-loss method: A spatially-explicit BK model

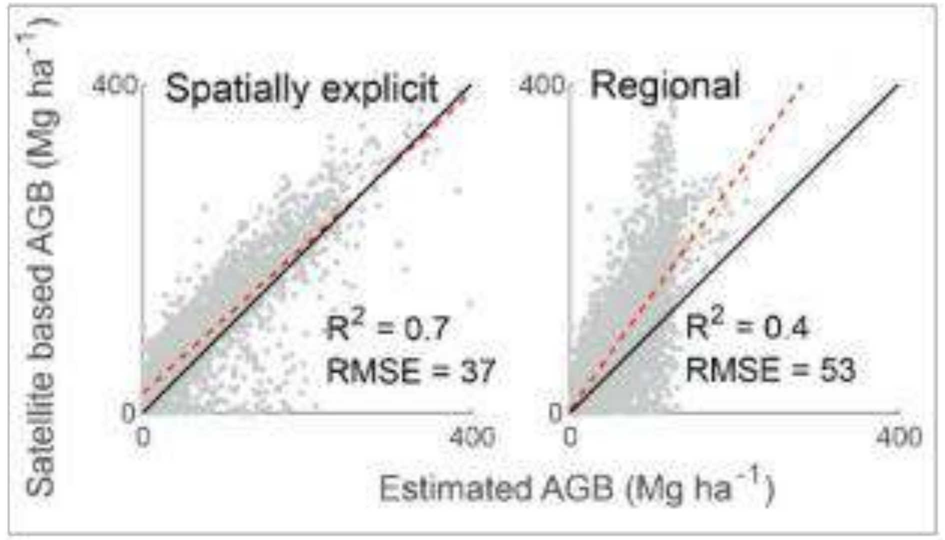
- Tropical disturbances + ESA CCI Biomass + space-for-time (1990-2020)
- Spatially-explicit BK model performs better than the model based on a continental-average curve





Performance

$$AGB_{2020} = \sum_{t=1990}^{2020} \left(\sum_{ti=0}^{p} \left[GR_{ti+1} - GR_{ti} \right] - \Delta AGB(t) \right)$$



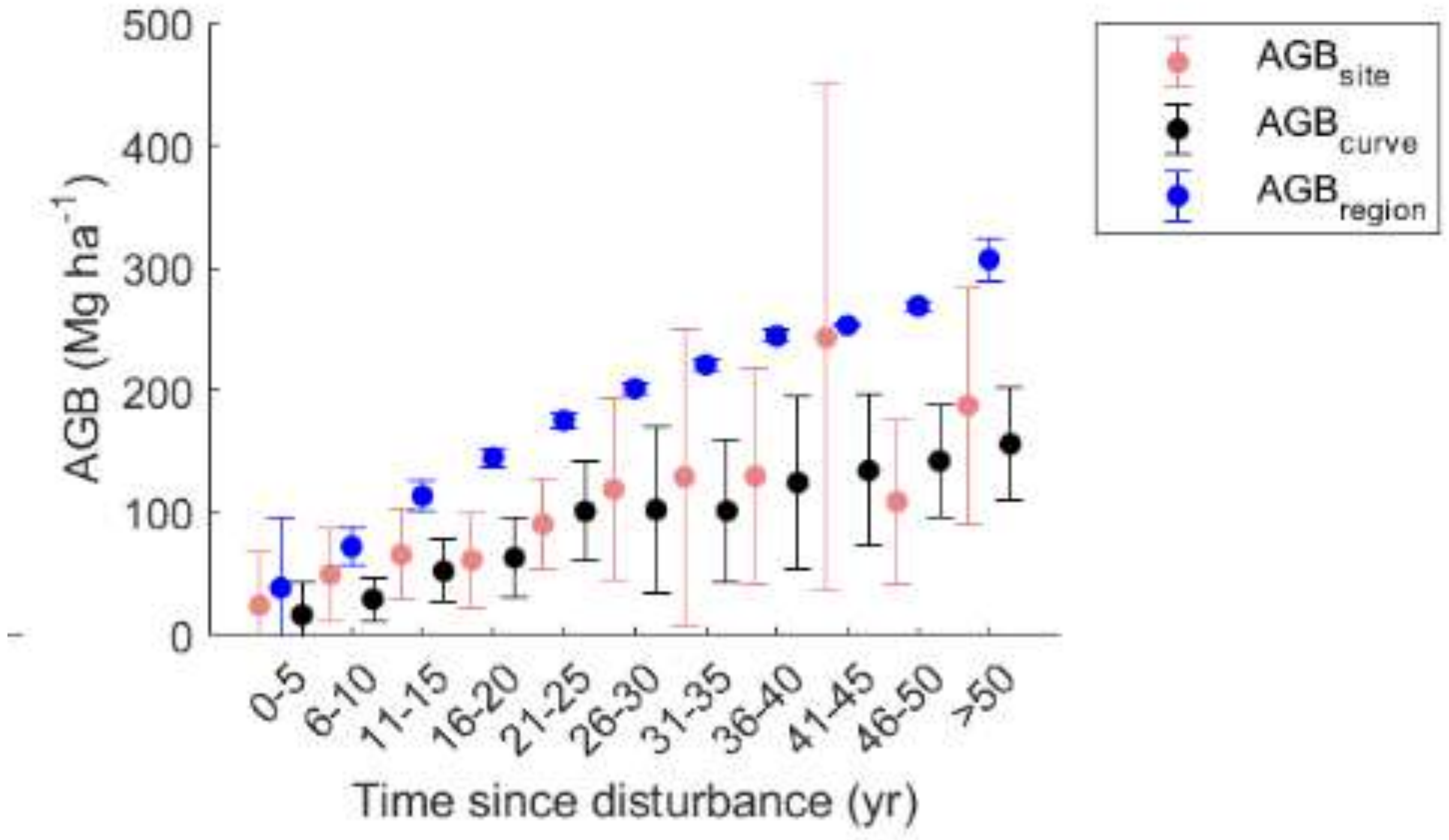
- Xu et al., in review

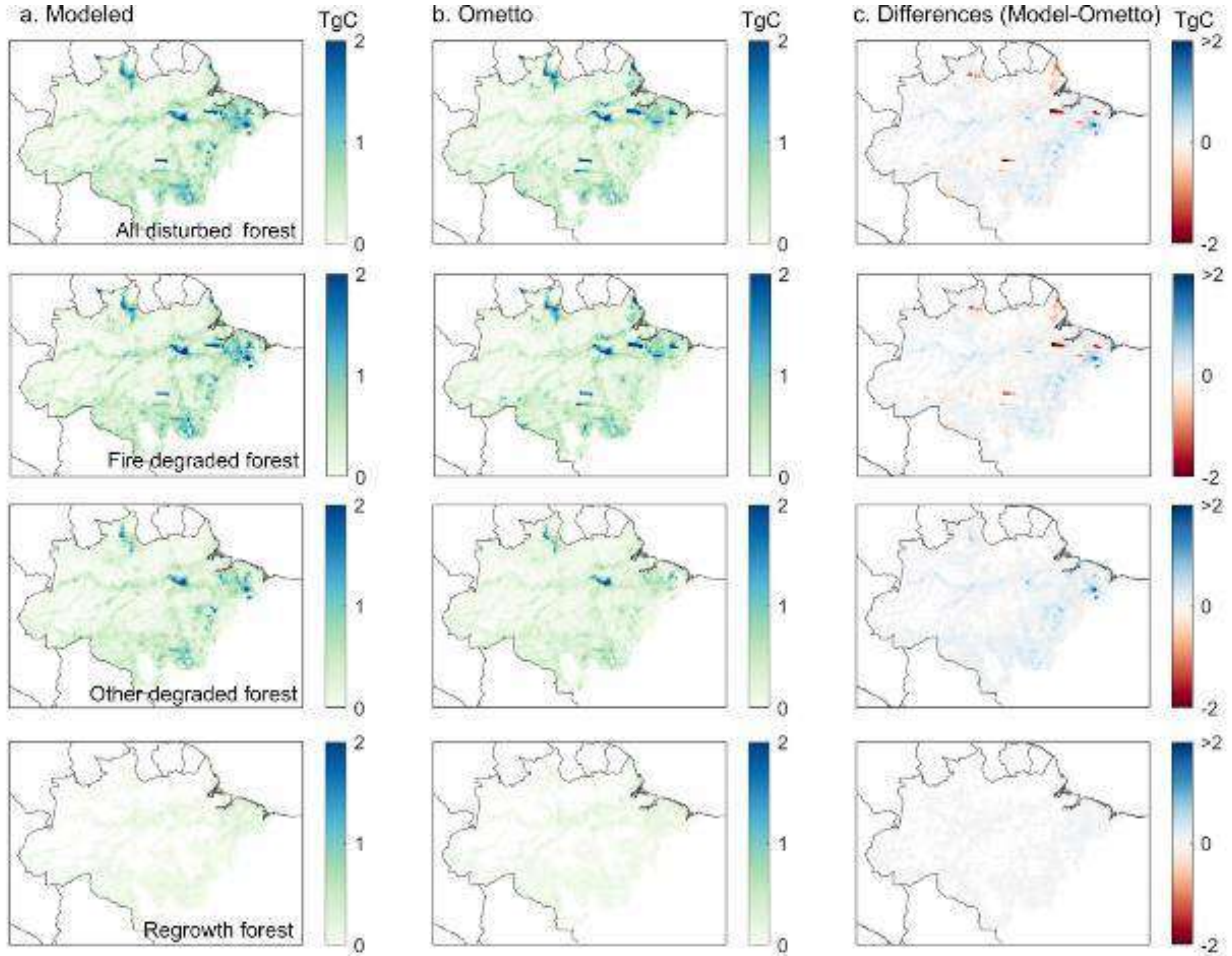
1. Gain-loss method: A spatially-explicit BK model

Ours modeled AGC for disturbed pixels

Independent Lidar based Biomass (Ometto et al)

Outperforms the continental curves



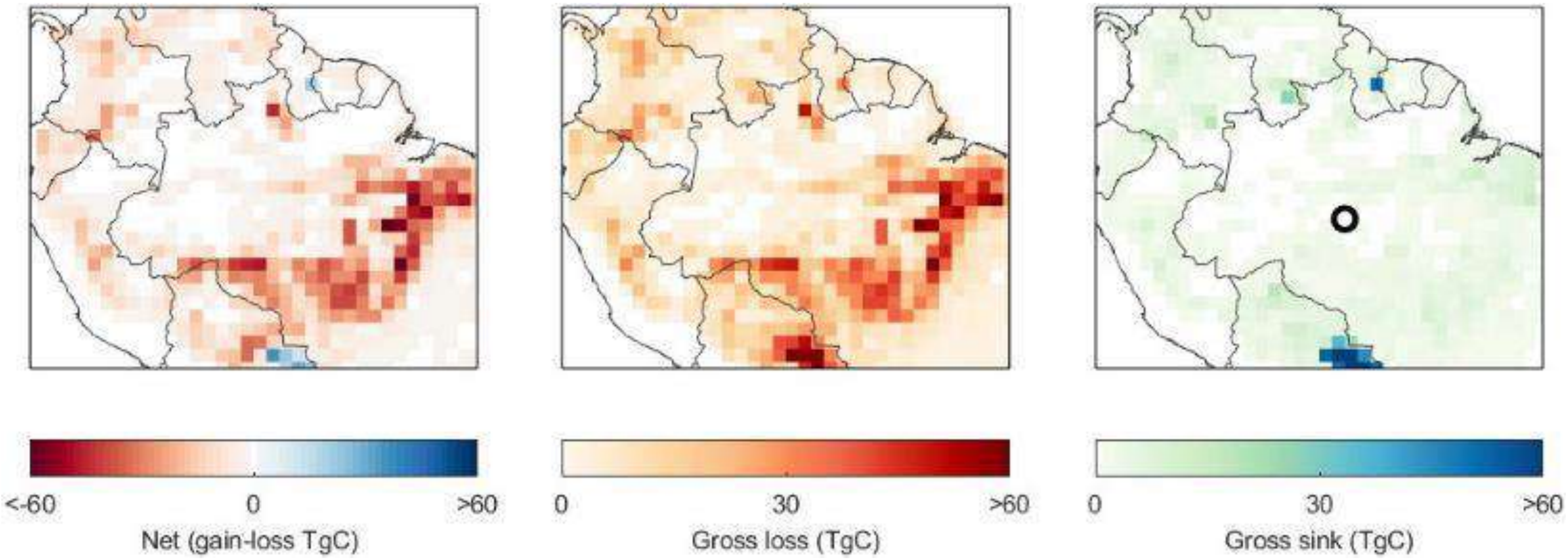


The Spatially-explicit BK model can reproduce the biomass for disturbed forests following different disturbances

- Xu et al., in review

1. Gain-loss method: A spatially-explicit BK model

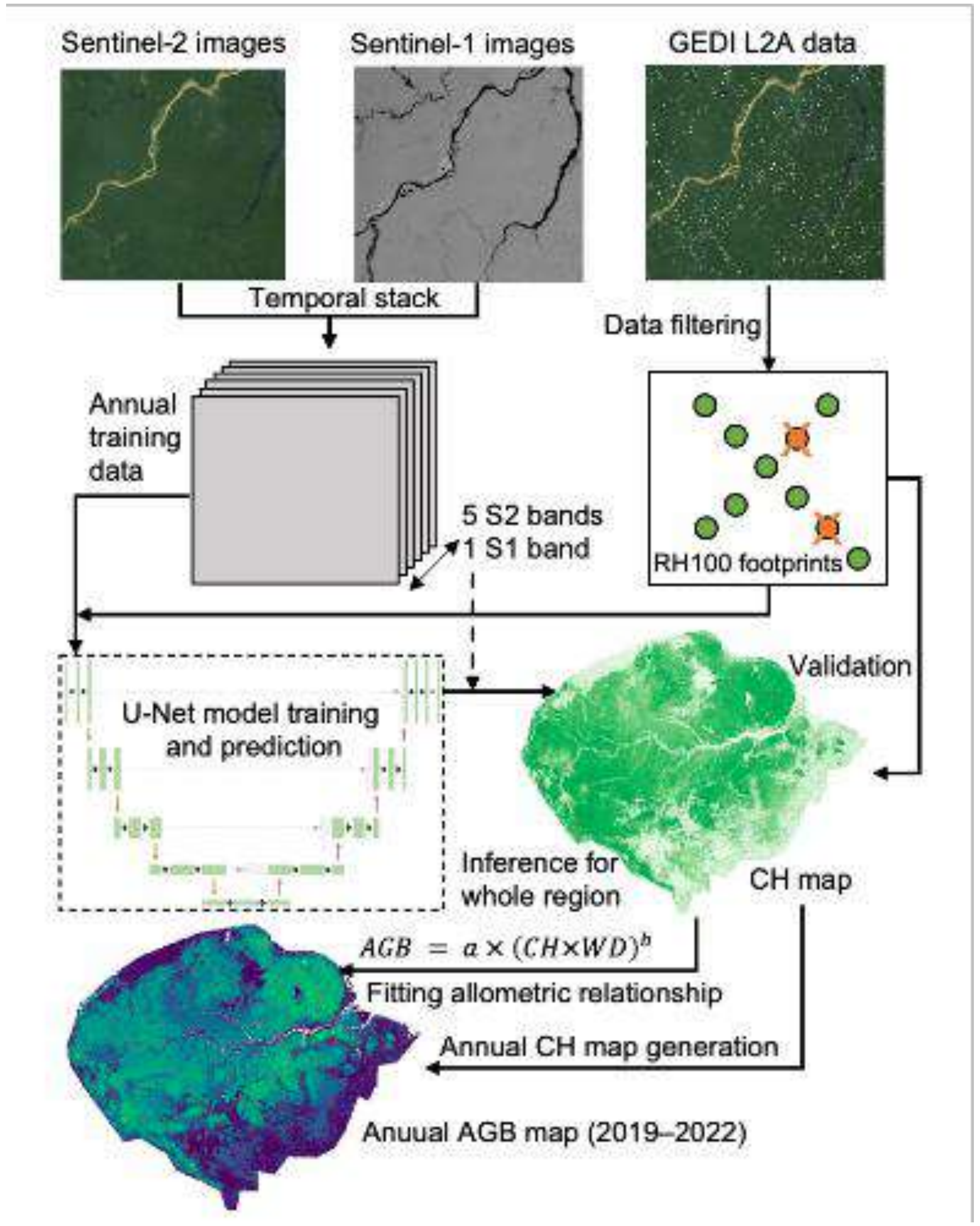
Carbon budgets from 1990-2020:
Biogeographical Amazon
Gross gain: 1.4 Pg C ; **Gross loss:** −6.2 Pg C ;**Net: -**4.9 Pg C (161.8 TgC/yr)



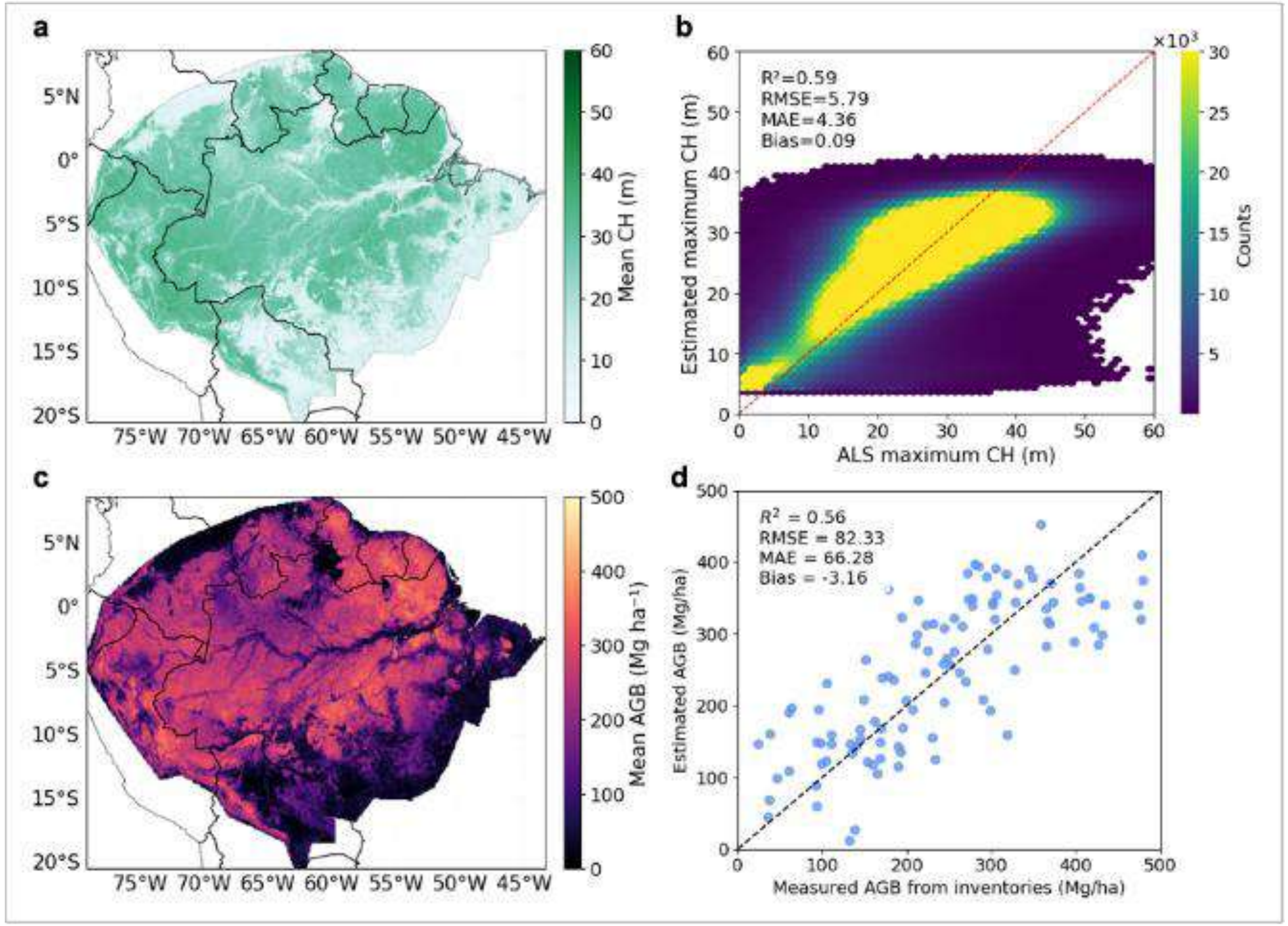
- Xu et al., in review

2. High-resolution mapping of forest height and biomass

Mapping framework for forest height and biomass mapping from 2019-2022



Mapping framework

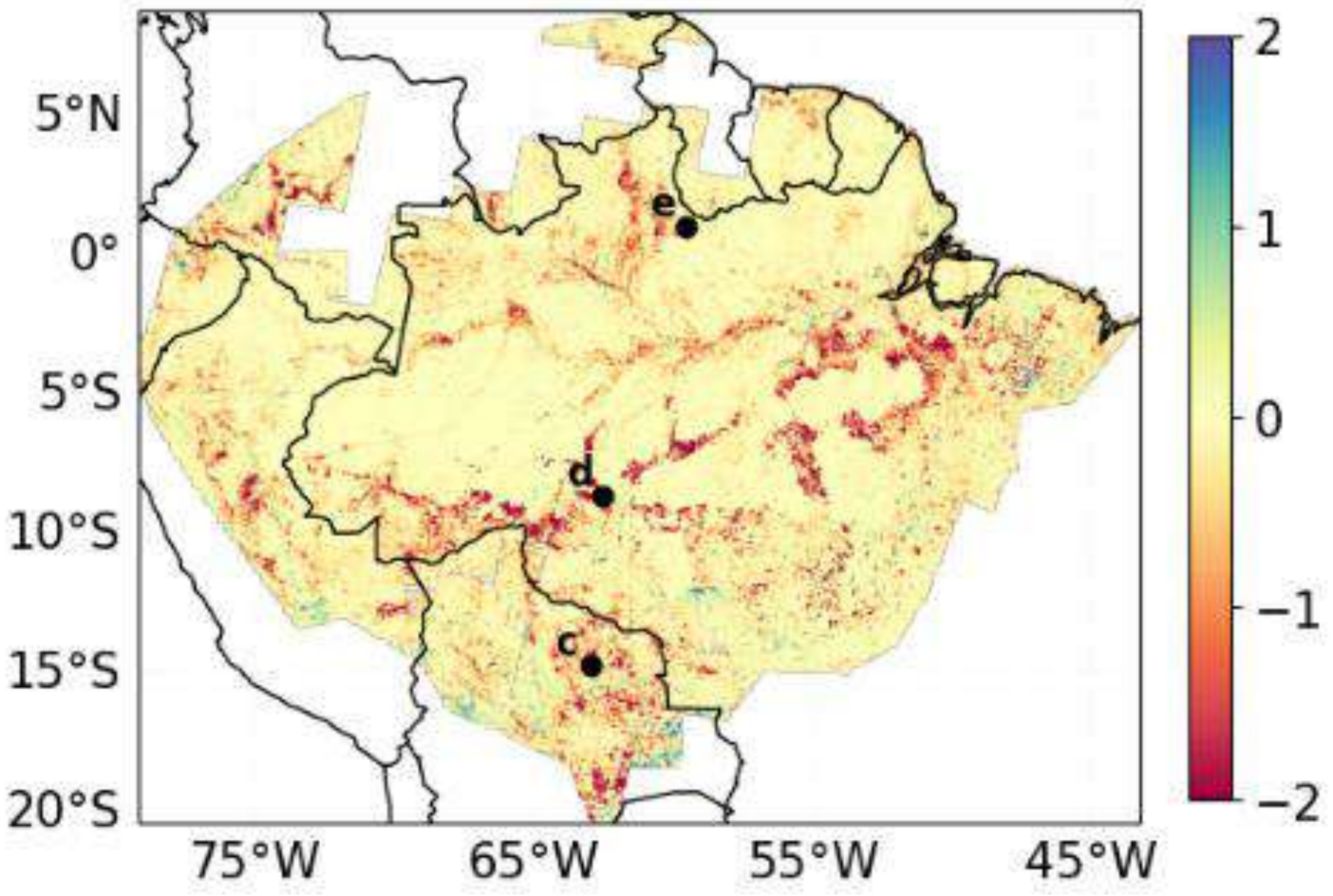


Validation of canopy height (10 m) and biomass (30 m) maps

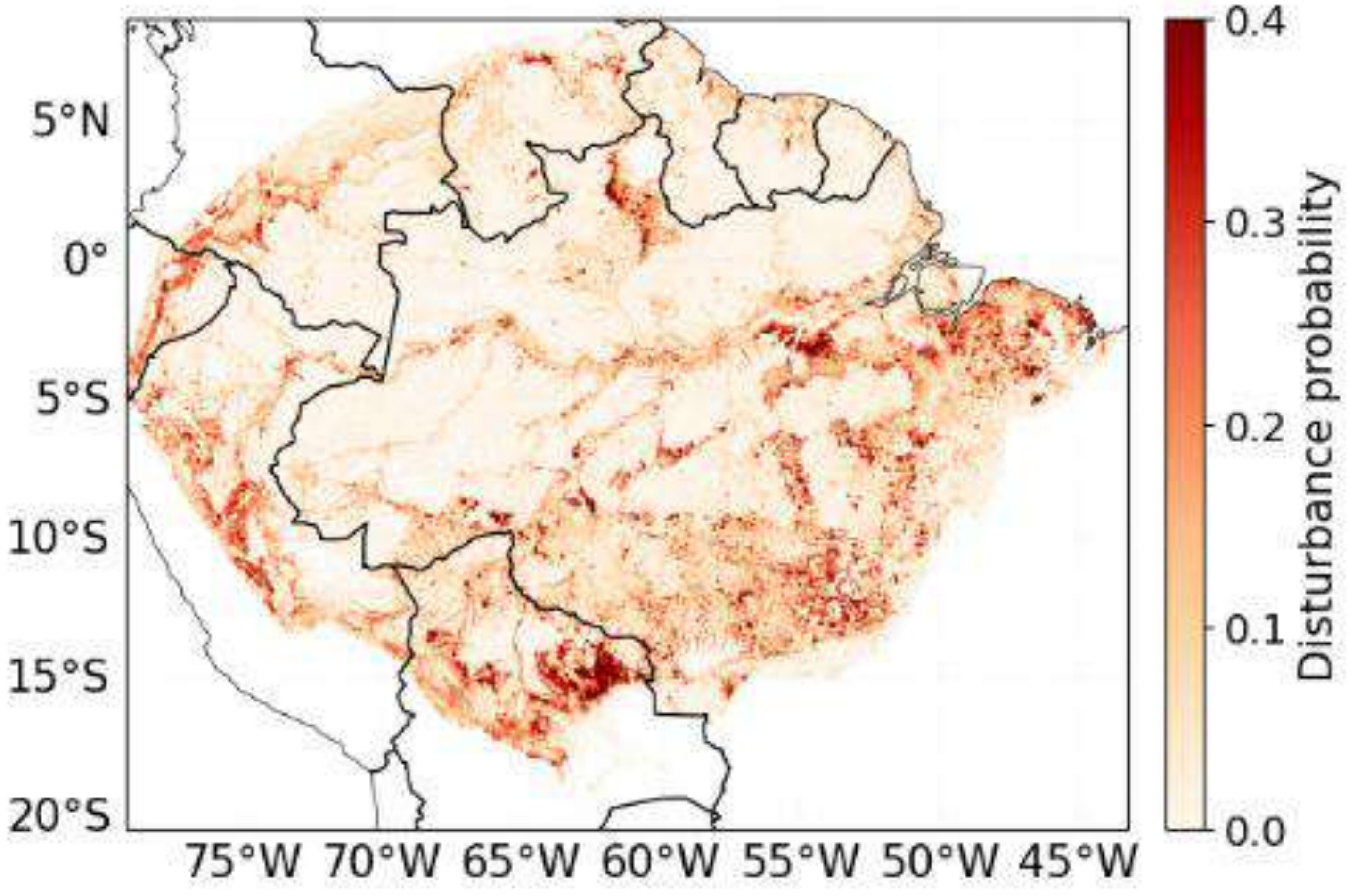
Wan et al., in preparation

Height changes mapping and the comparison with other products

New height change map (10 m) from 2019 to 2022



Our Height change maps (10m)



TMF disturbance

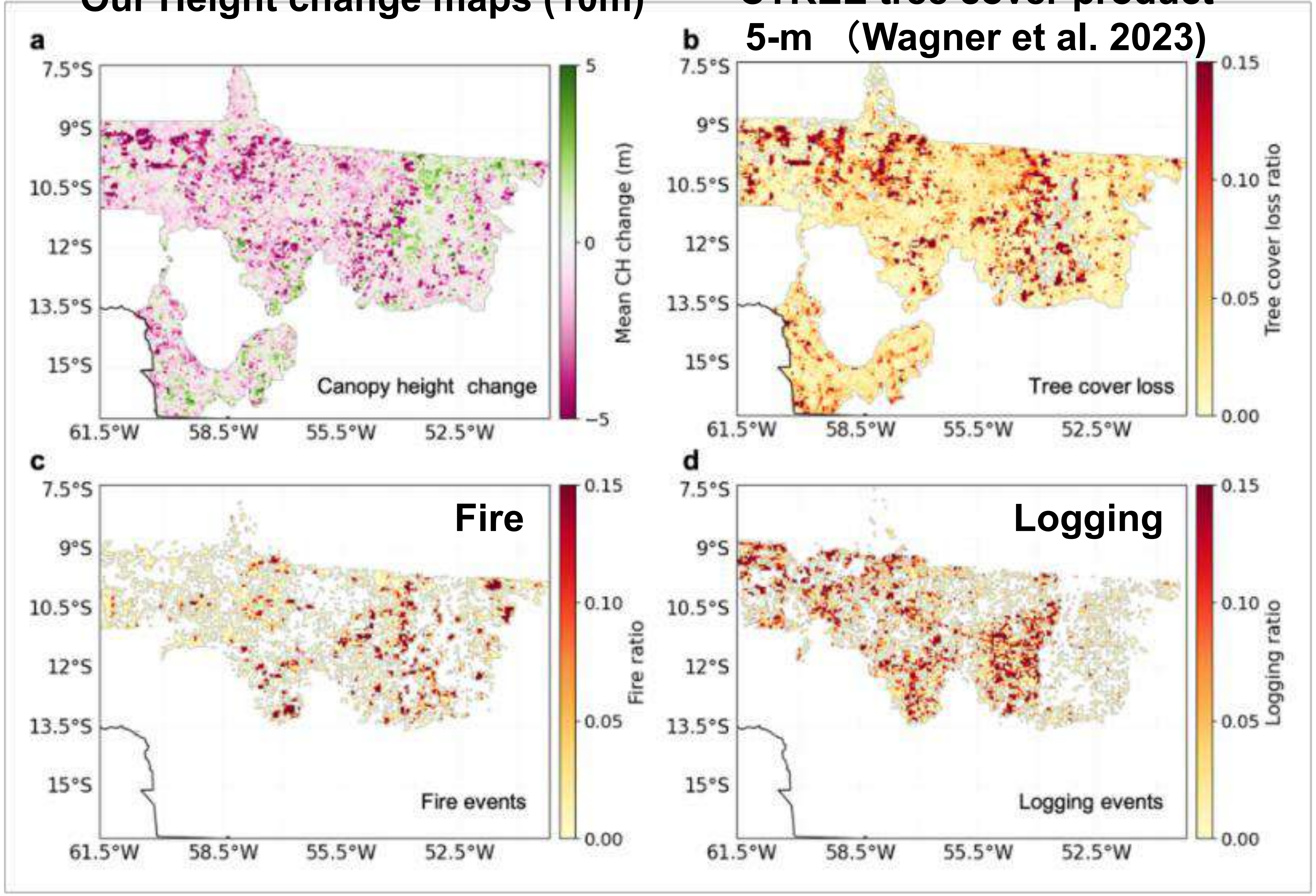
Wan et al., in preparation

Height changes mapping and the comparison with other products

Mato Grosso

Our Height change maps (10m)

CTREE tree cover product 5-m （Wagner et al. 2023)



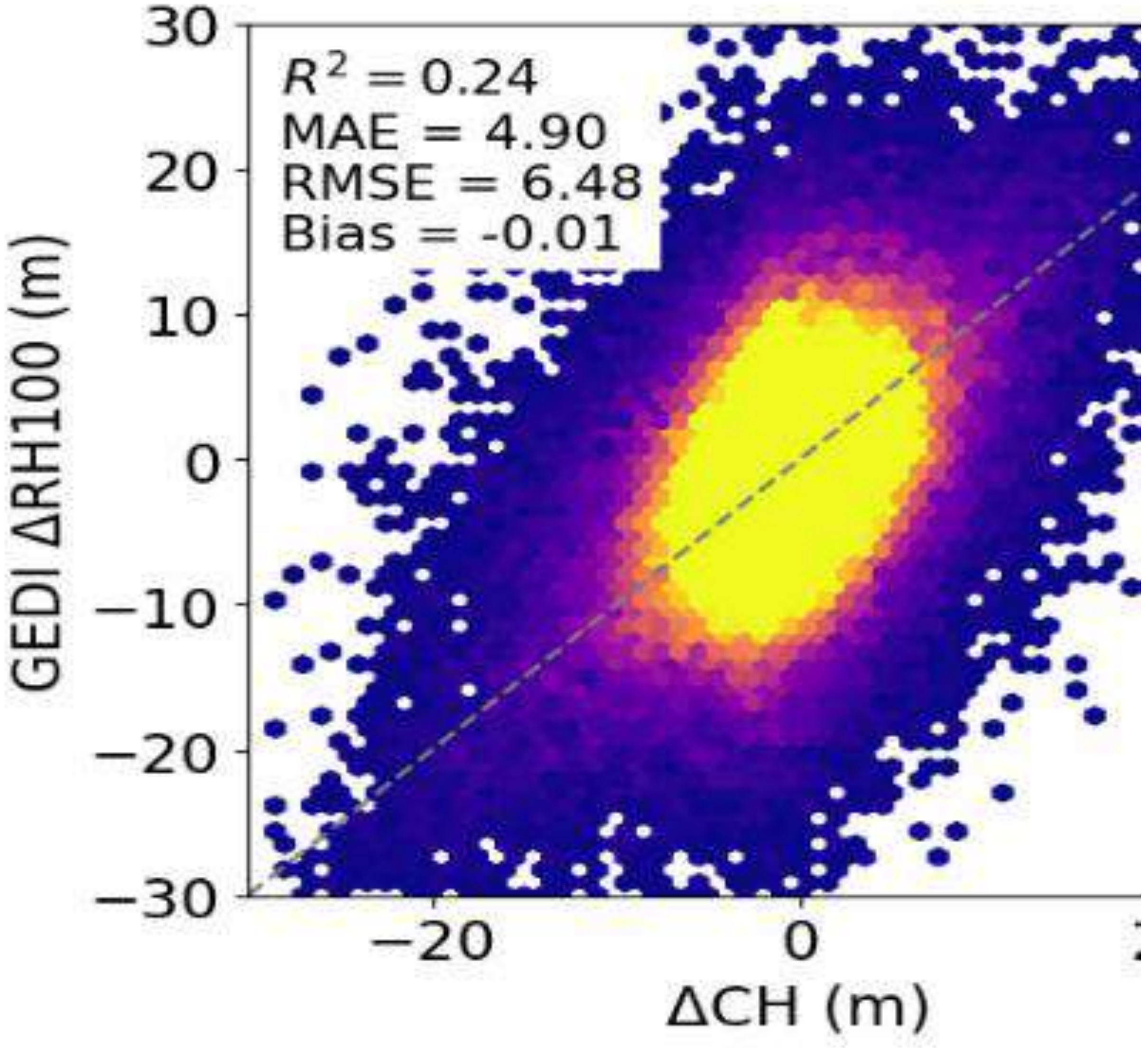
CTREE planet-based disturbance (Dalagnol et al., 2023)

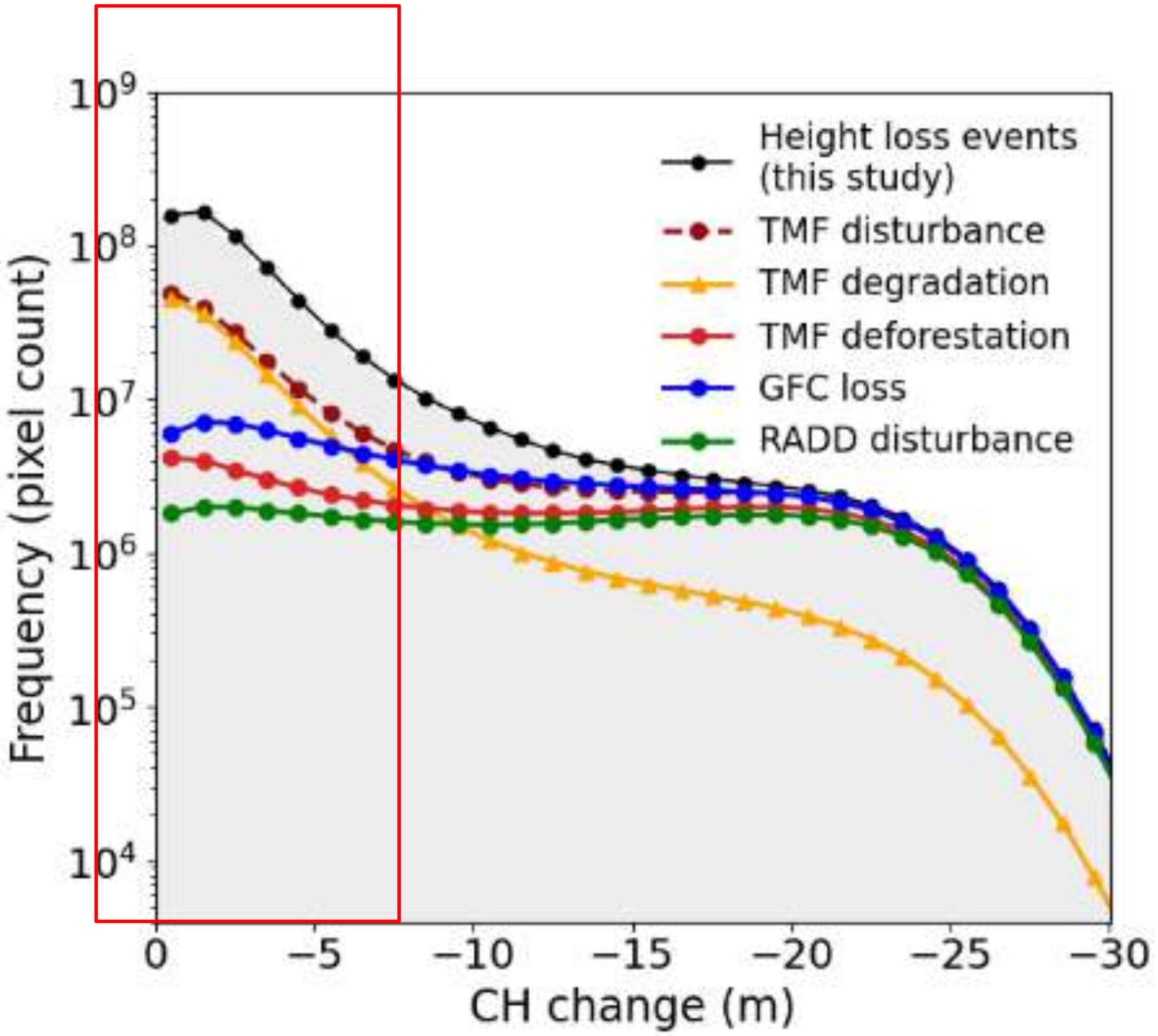
Wan et al., in preparation

Evaluation of the canopy height change maps

Evaluation: GEDI RH100, Landsat TMF disturbance, GFC tree cover loss, and radar alter

Our CH change is consistent with GEDI RH100 change but can detect more small disturbances than Landsat disturbance data



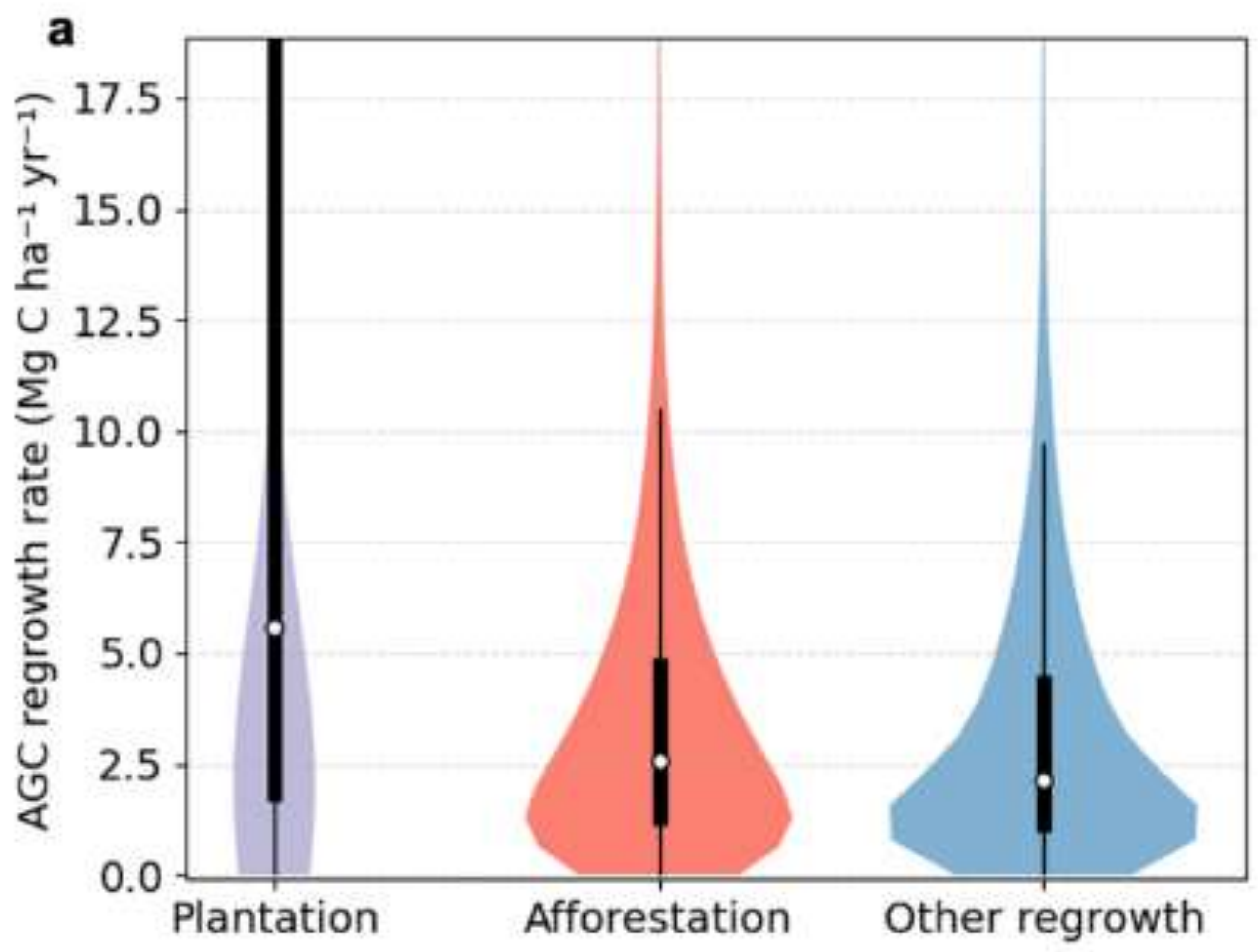


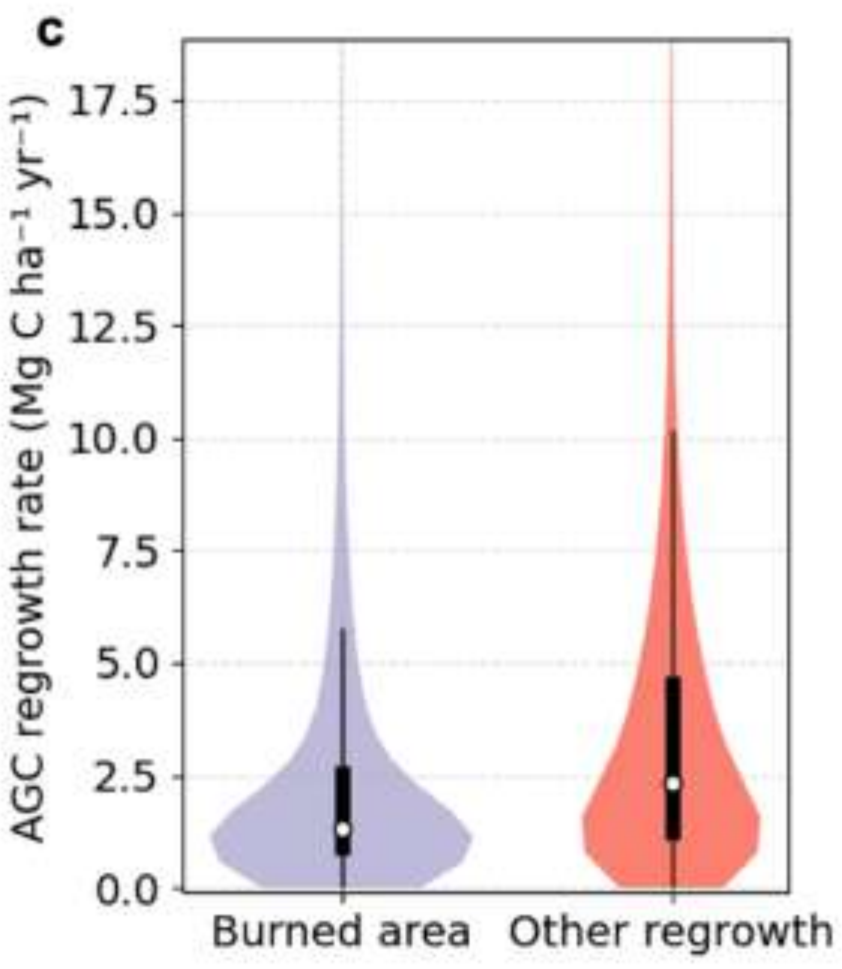
Wan et al., in preparation

Regrowth rates based on the annual AGC estimation

Method:

- **Overlap TMF plantation/Afforestation(new growth) /regrowth from deforestation (other regrowth)**
- **AGC rate: CH change and the allometry function.**





Growth rate from plantation if higher than the natural regenerated forest
AGC Recovery rate from fire is lower than the regrowth from deforestation

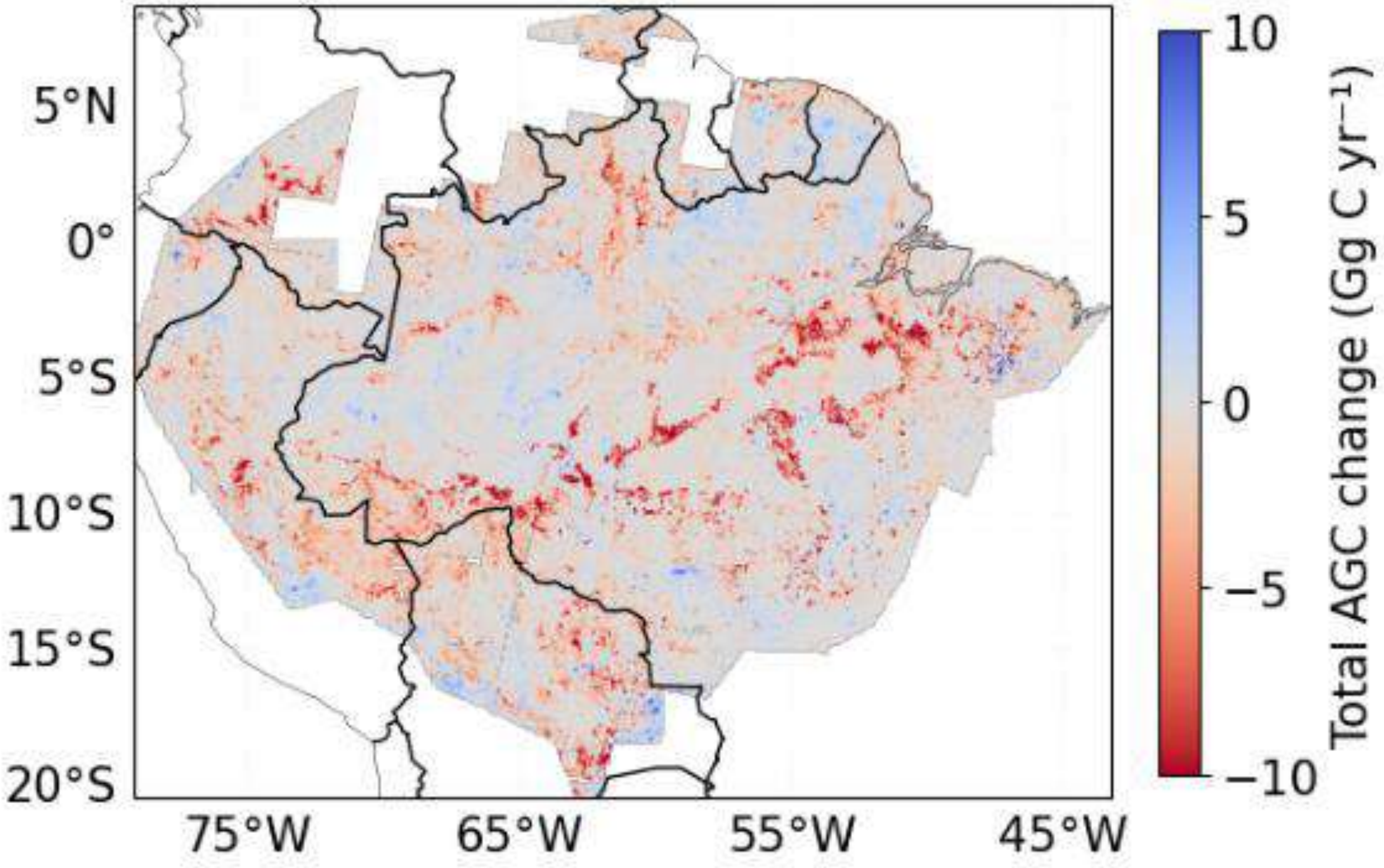
Wan et al., in preparation

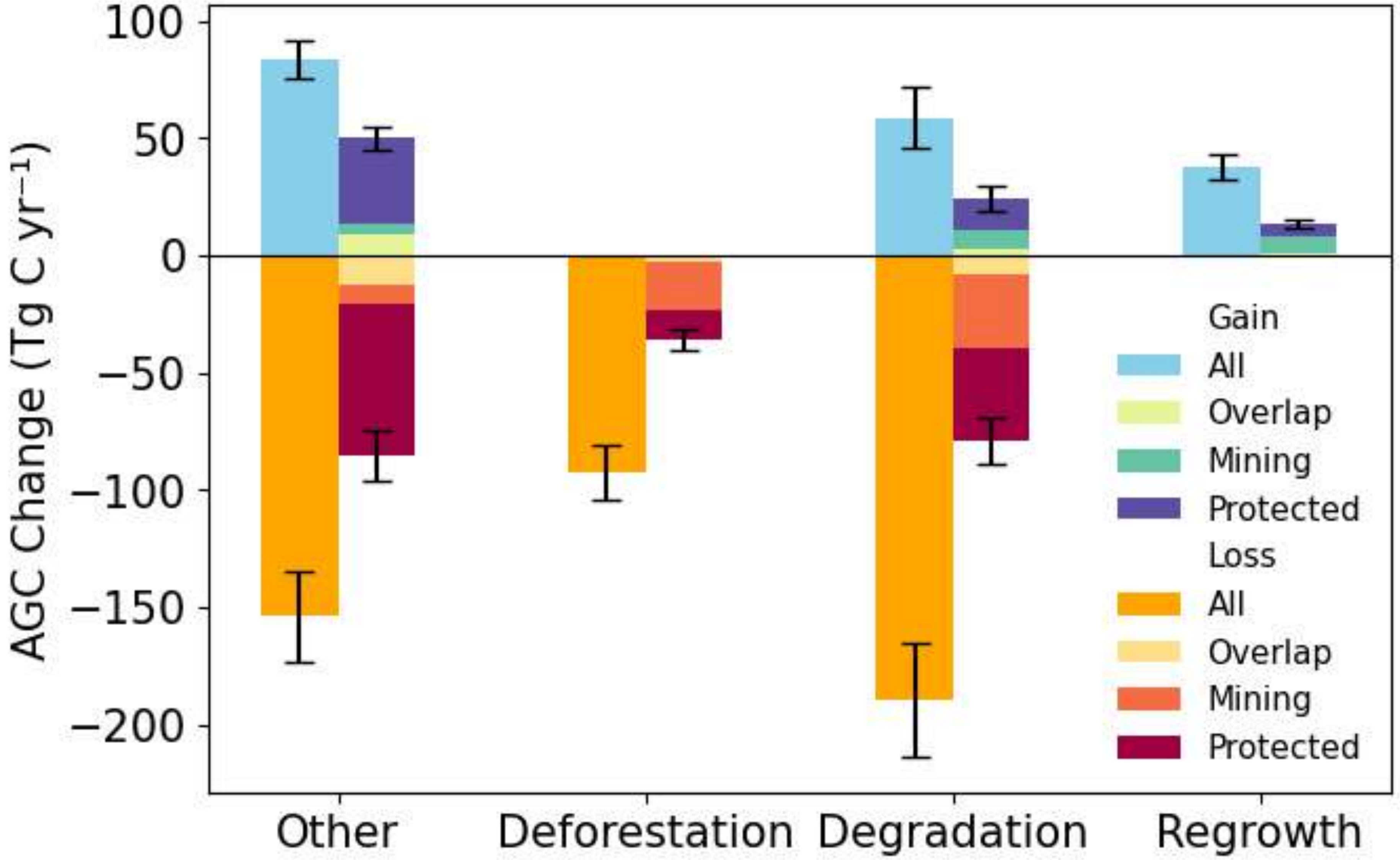
Direct estimation of AGB change

Method:

- **Combine height change and Landsat data to classify C loss and gain from degradation, deforestation, Regrowth, Other (undisturbed forests).**
- **AGC map and change maps : CH map + allometry function.**

Carbon budgets from 2019 to 2022:
Gross gain: 179.8 ± 16.4 Tg C/y ; **Gross loss:** −436.6 ± 33.3 Tg C/y ;**Net:** −256.7 ± 37.1 Tg C/y





Wan et al., in preparation

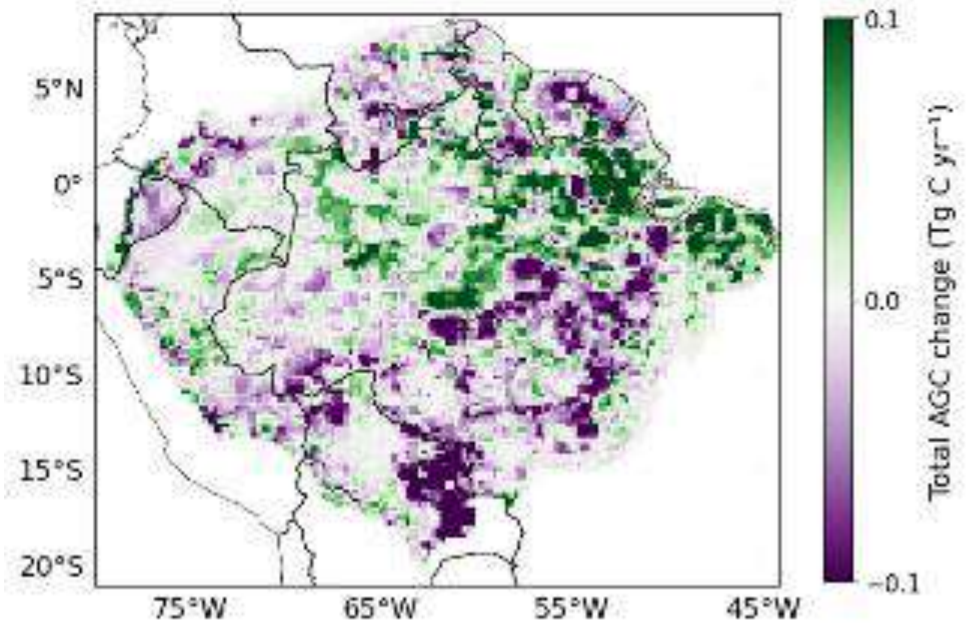
Summary

- Our EO-based approach
  - Provide the spatially-explicit bk model with outperforms the previous BK model by intergrating regional response curves
  - Offering new insights into fine-scale (10m) carbon dynamics overlooked by moderate 30m satellite products

Next step: Synthesis of the different satellite approach

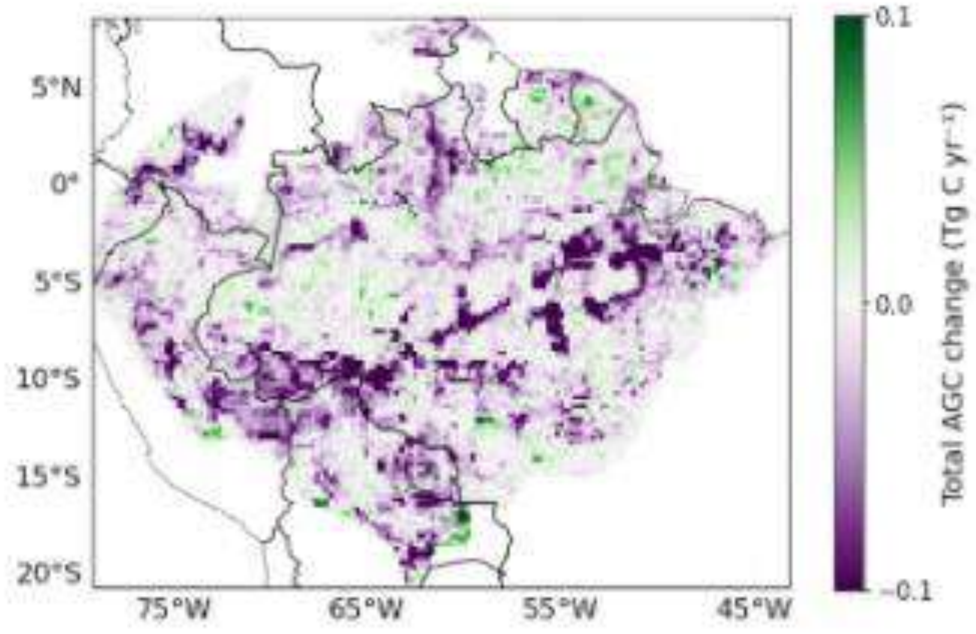
Very preliminary!!!!

All forest



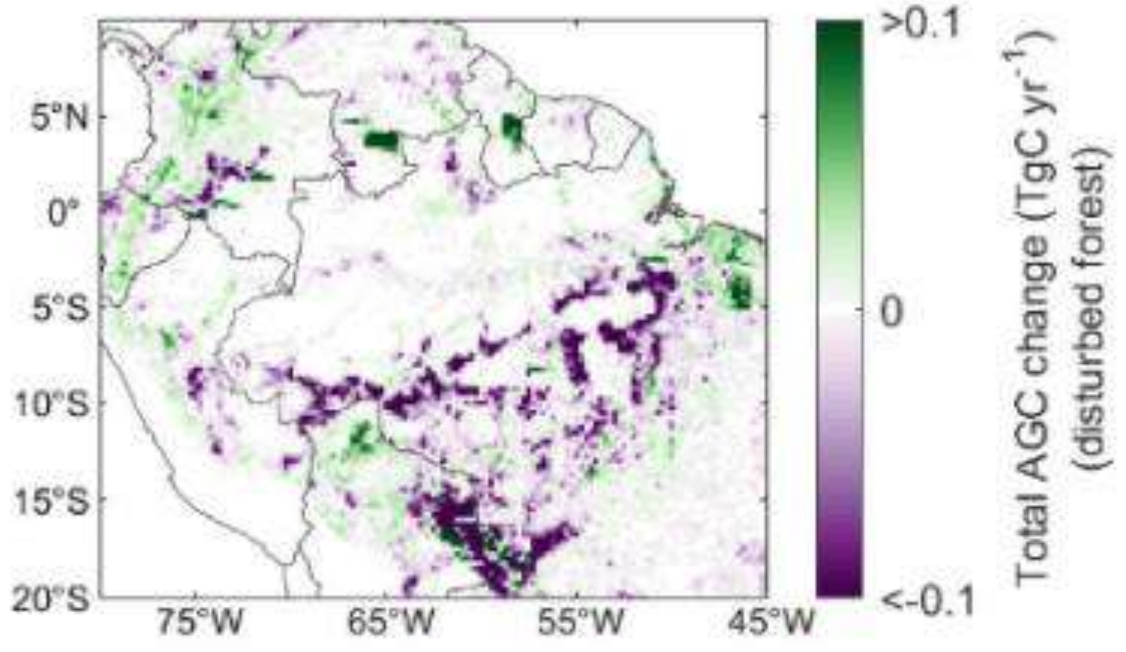
L-VOD AGC
Fendrich 2025

All forest



Direct AGC mapping
2019-2022

TMF Disturbed forest only



BK model
(2011-2020)


Thanks!
Yidi.xu@lsce.ipsl.fr

Mapping *Cecropia* distribution to adjust biomass estimates in the Amazon [RECCAP2-CS]

Scott Barningham, UNEXE

Session 2.1: Estimates of carbon accumulation from various approaches

São José dos Campos, 30th Oct 2025

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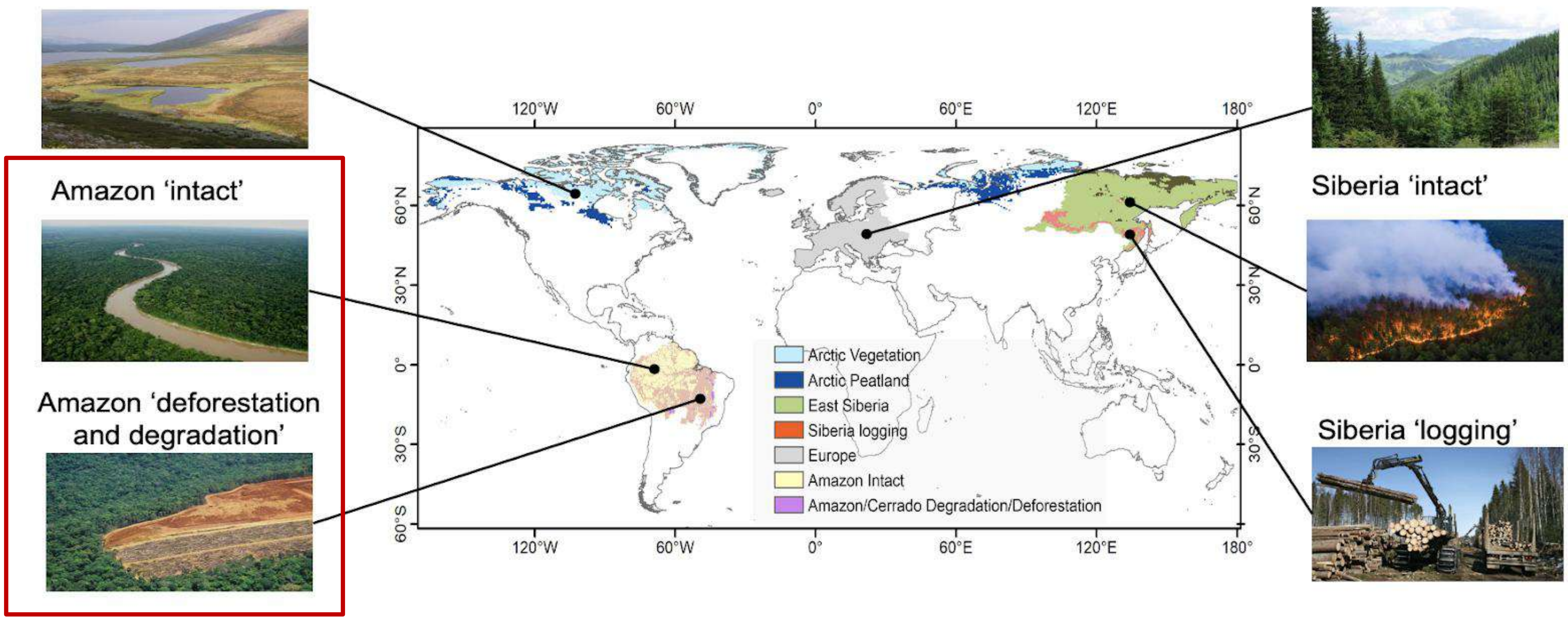
Harness satellite based ECV to make a giant leap for **reducing the uncertainty on the emissions and sinks of CO_2,** and CH_4 over key land regions, and attributing them to anthropogenic and global change drivers



Mapping key species to **improve wood density and biomass mapping**

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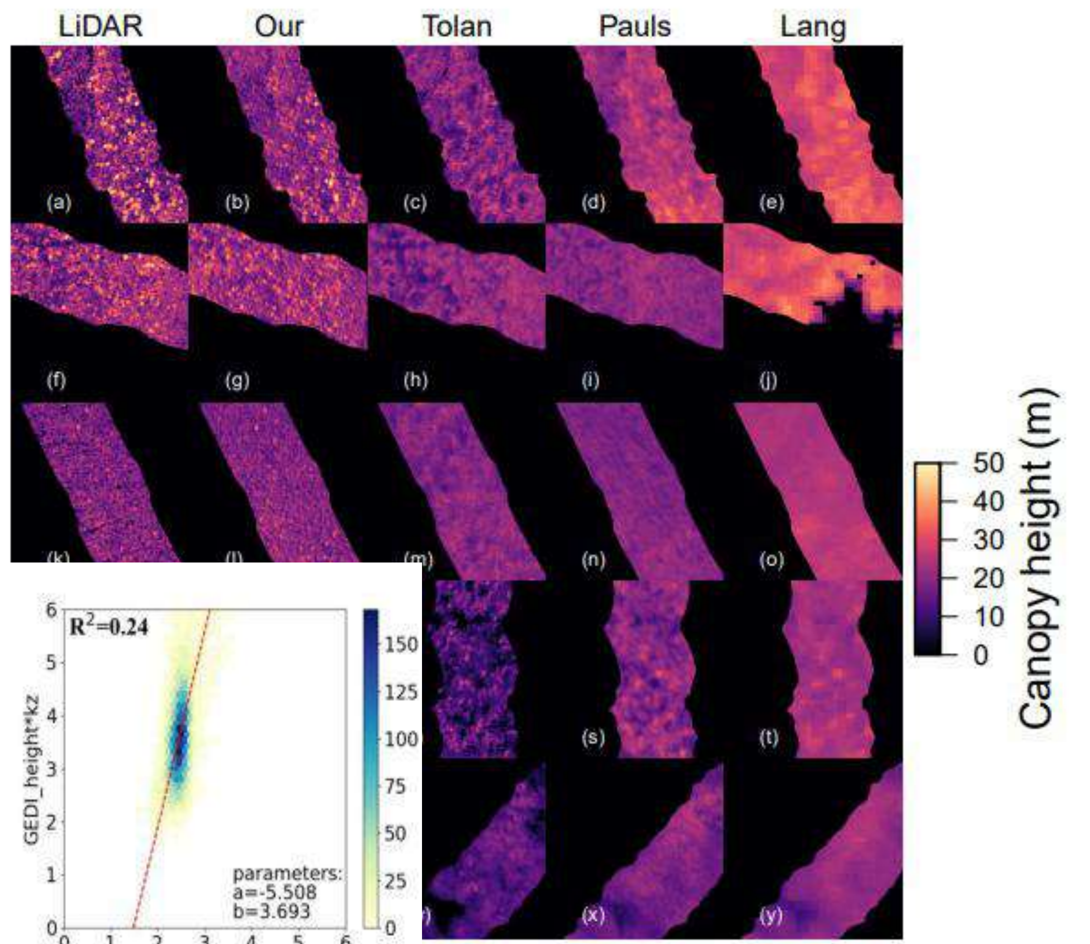
Existing AGB/ CH estimates

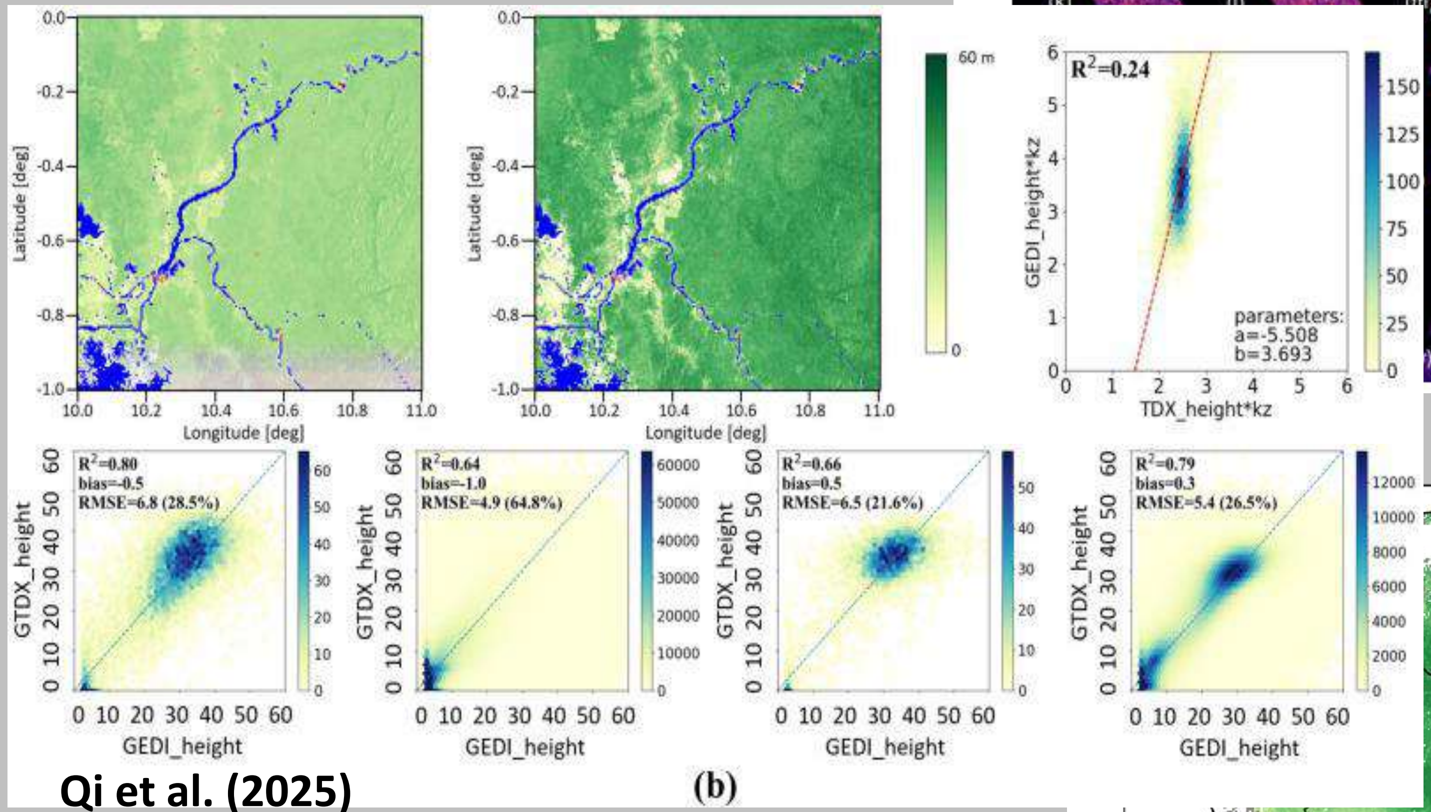
Recent advancements

- Trained on LiDAR using optical/ SAR through deep learning
- Canopy height spatial resolutions 1-30 m
- Small disturbances captured

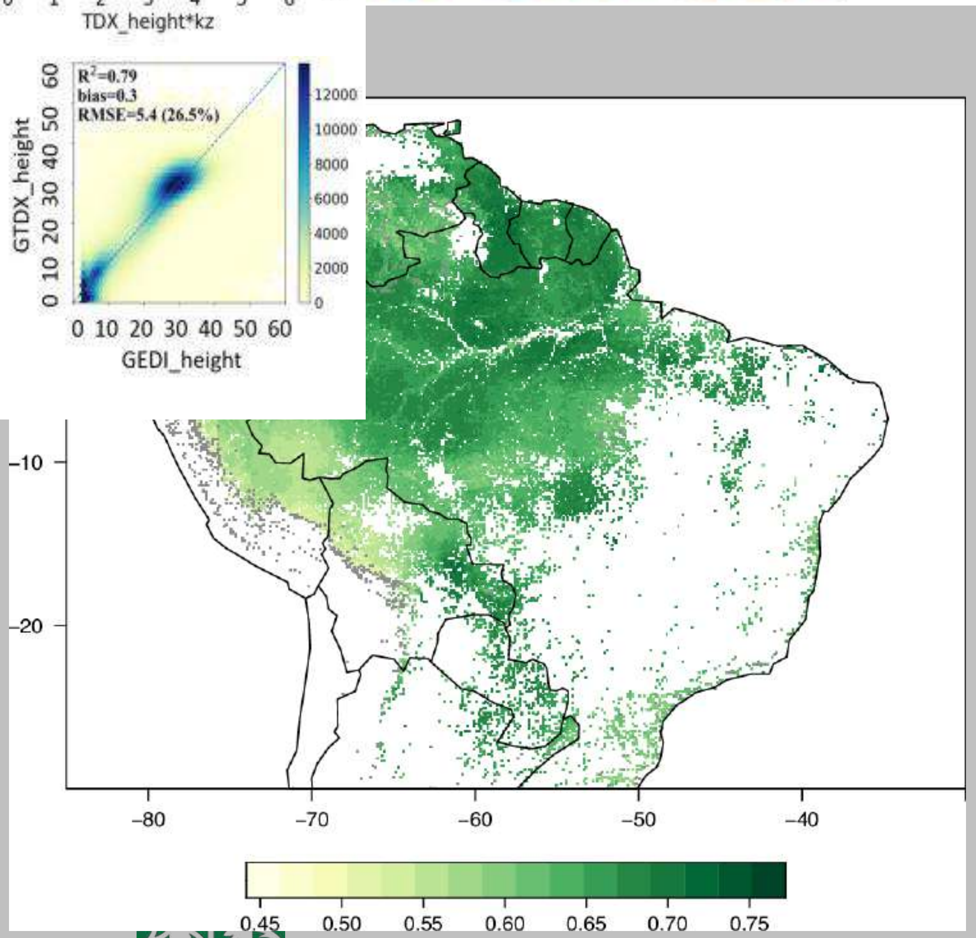
$$\boxed{AGB = f(CH \cdot WD)}$$



Wagner et al. (2025)
5m Canopy Height
U-Net
Planet + airbourne LiDAR



Qi et al. (2025)
25 m Canopy Height
TanDEM-X + GEDI



Sullivan et al. (2025)
1 km wood denisty
GAM

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Inconsistent specificity

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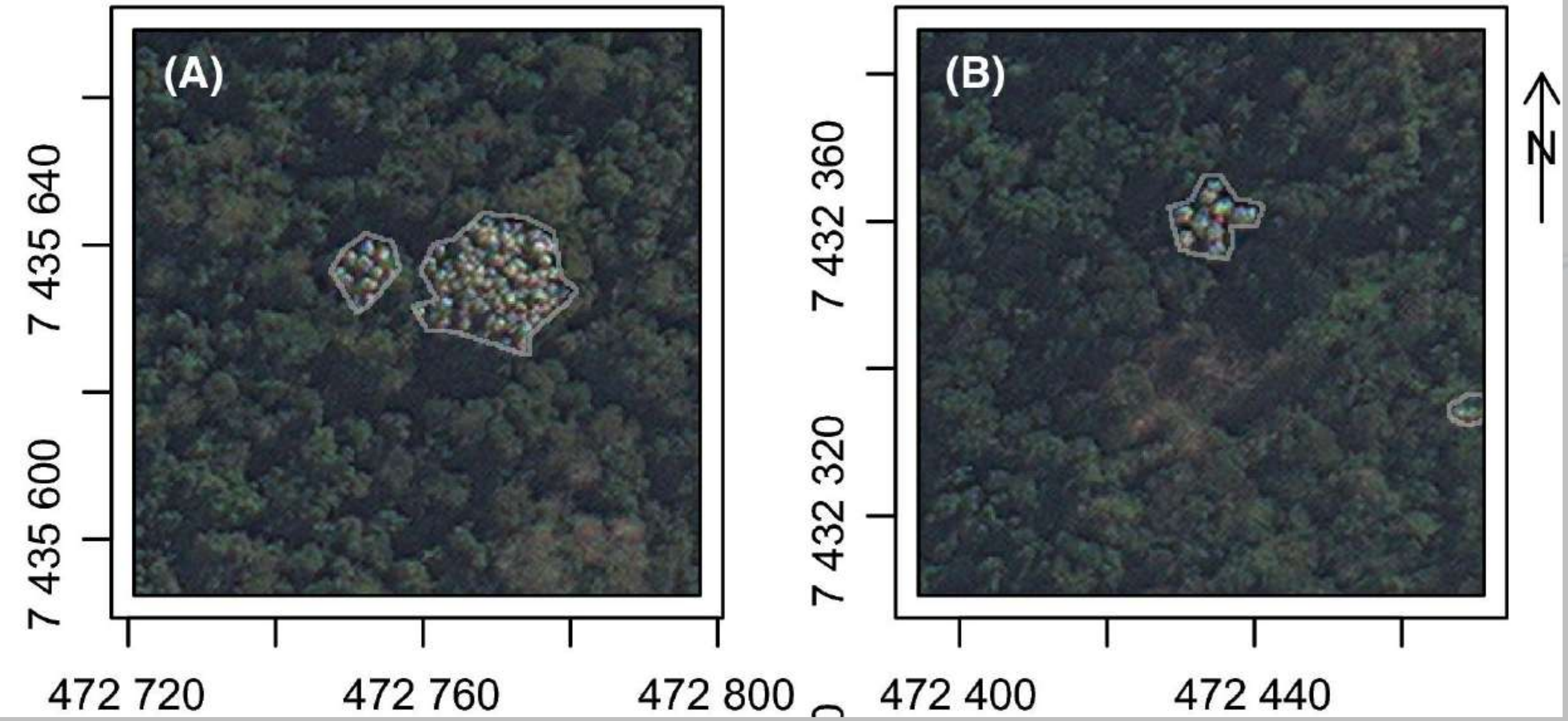
Estimating wood density

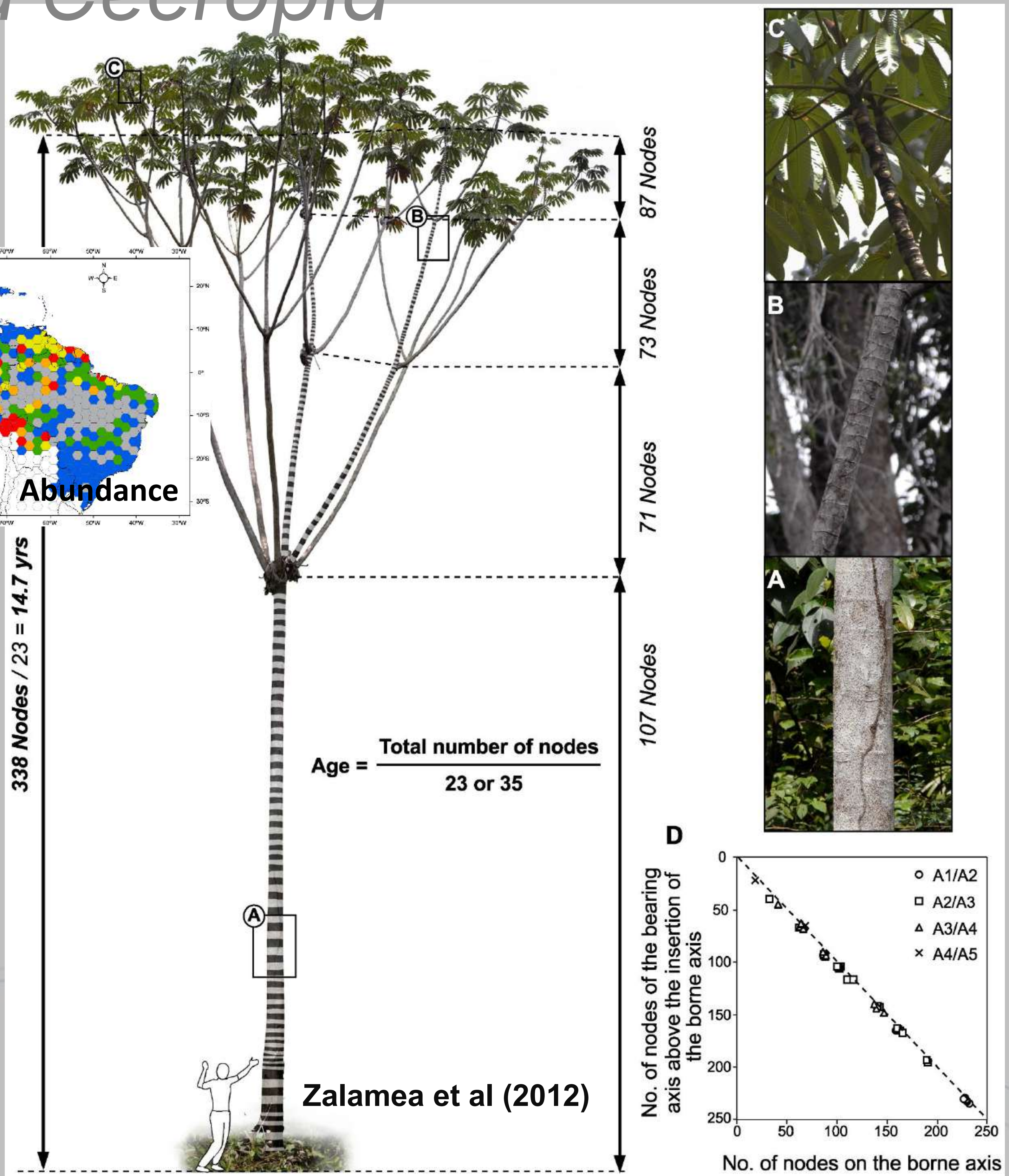
Via Cecropia

Wagner et al (2019)

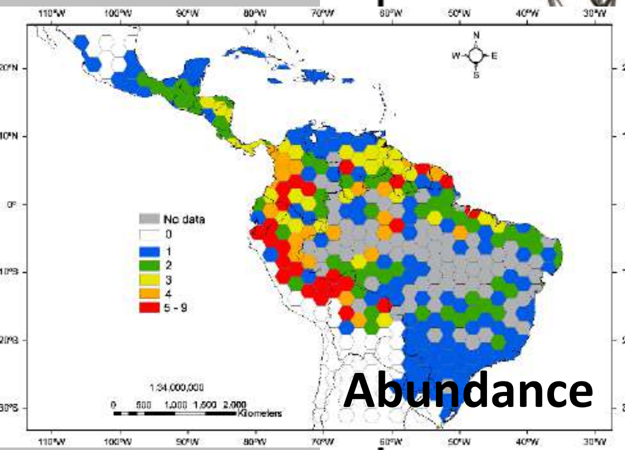
0.3 m spatial resolution 4 band WV-3



- Pioneer genus
- Low wood density
- Indicator of disturbance
- **+ve AGB bias in disturbed regions**



Zalamea et al (2012)



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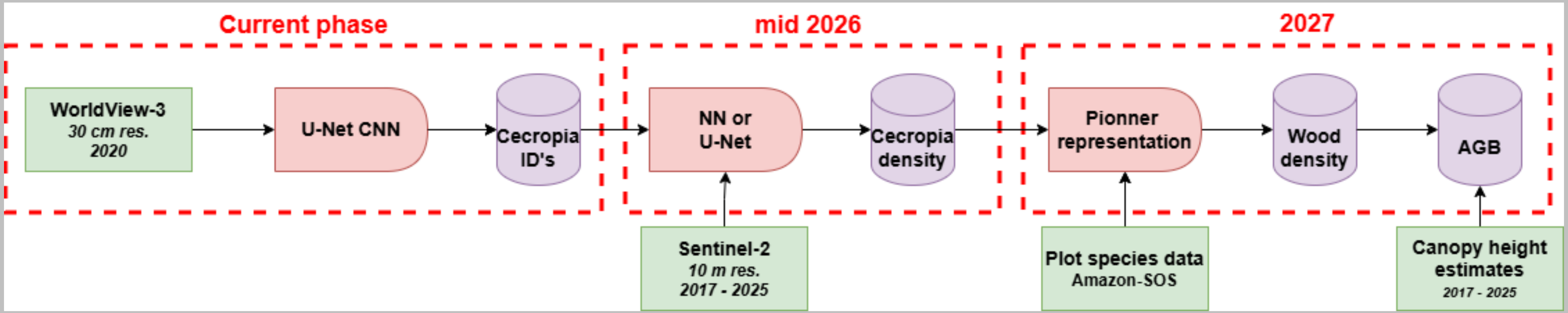
Estimating wood density and AGB
Simplified workflow



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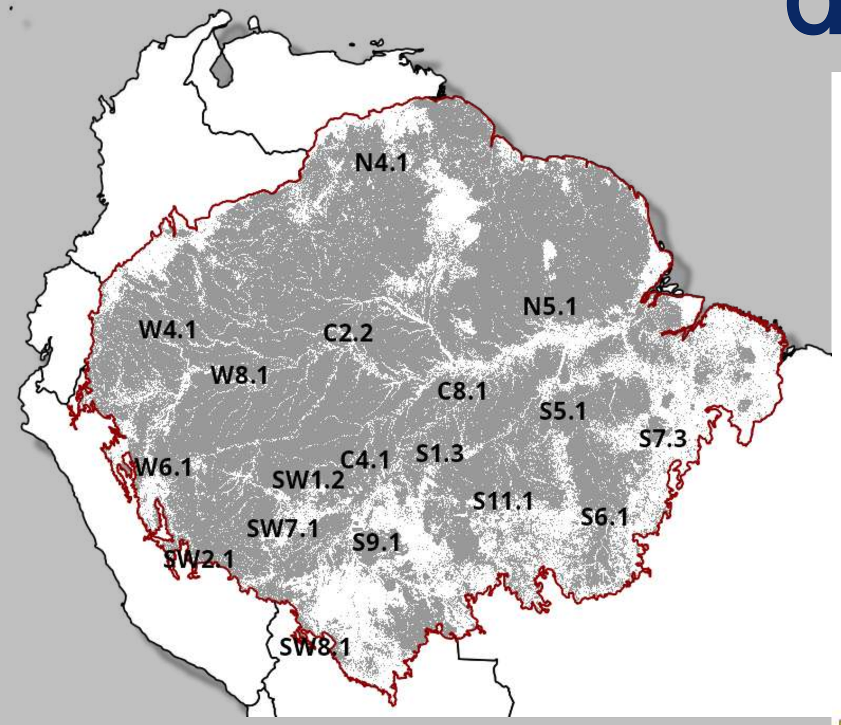
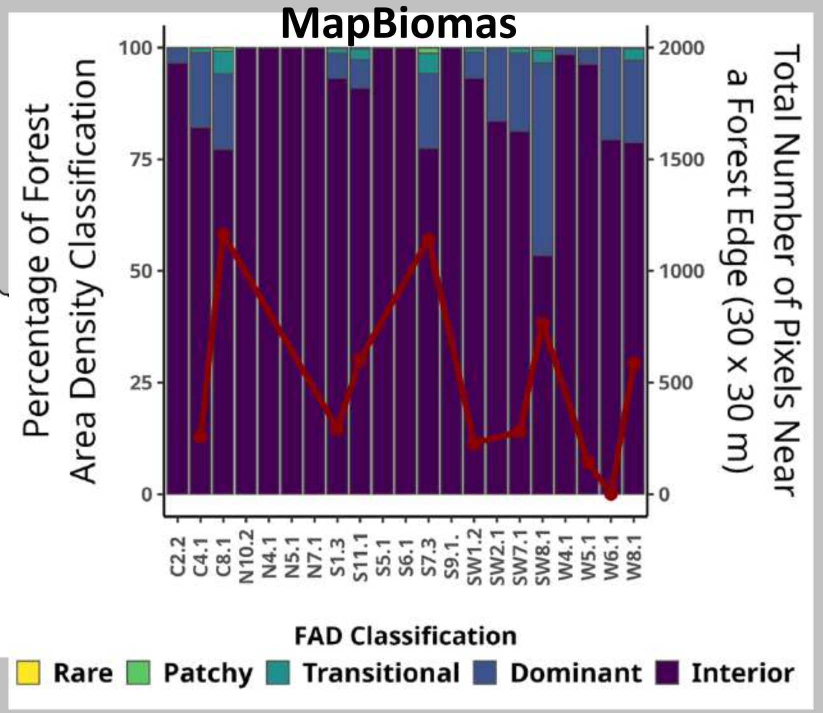
Cecropia Identification

WorldView-3 data (ESA 3rd Part Mission)

Objective: Cover environmental gradients across Amazonia disturbance, climatic + edaphic

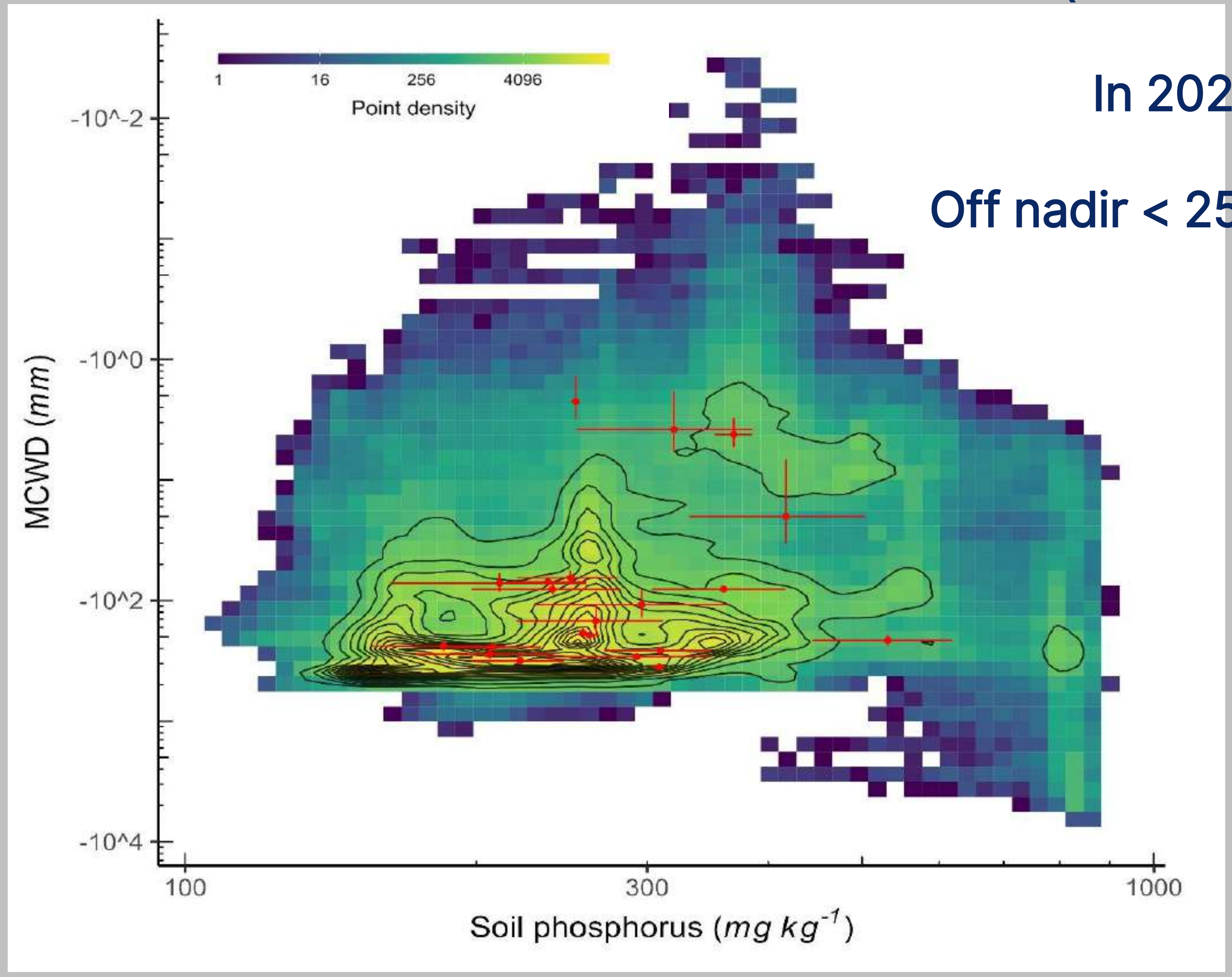


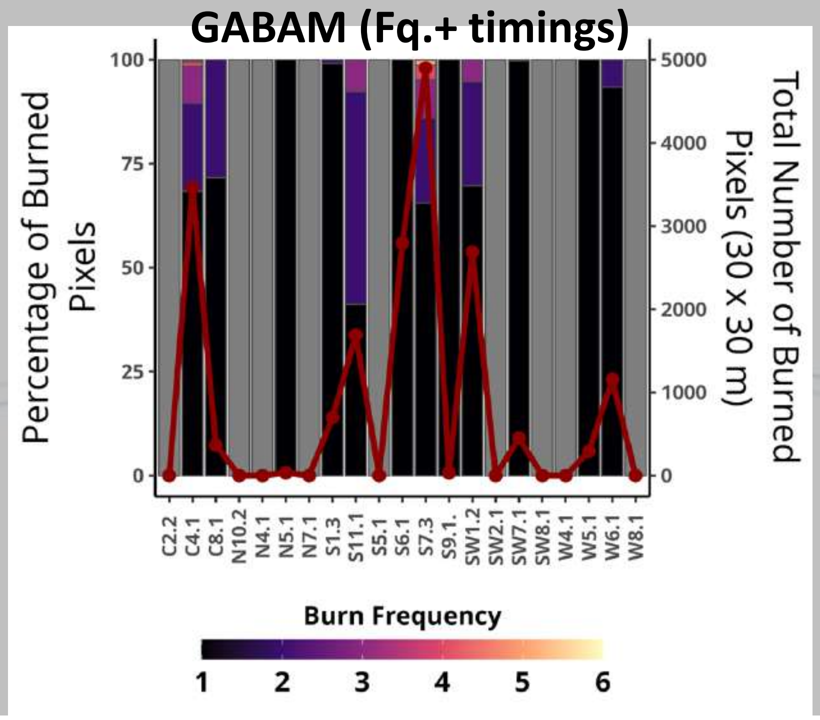


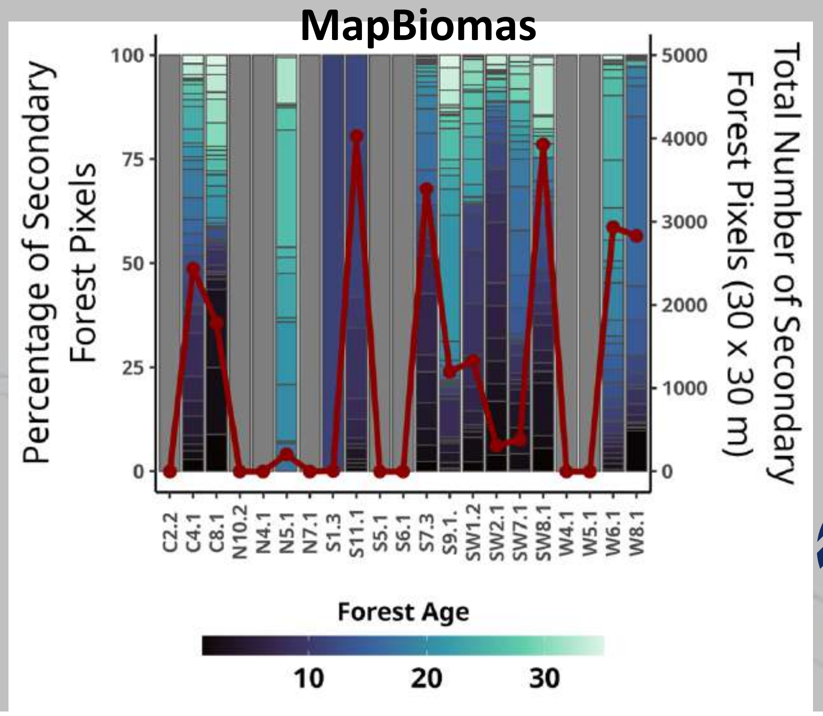
Total area = 450 km^2 (18 sites)

In 2020

Off nadir < 25°







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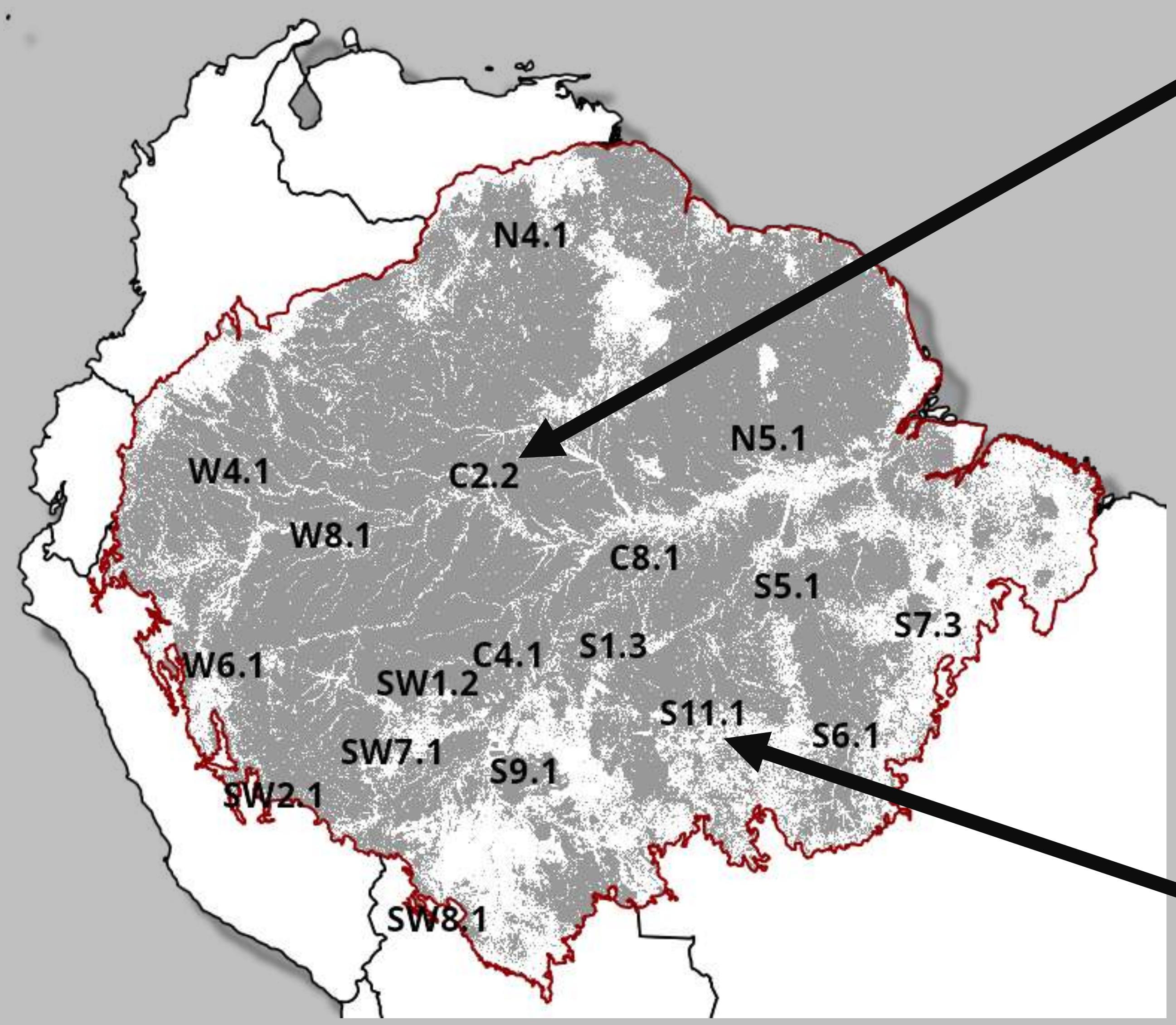
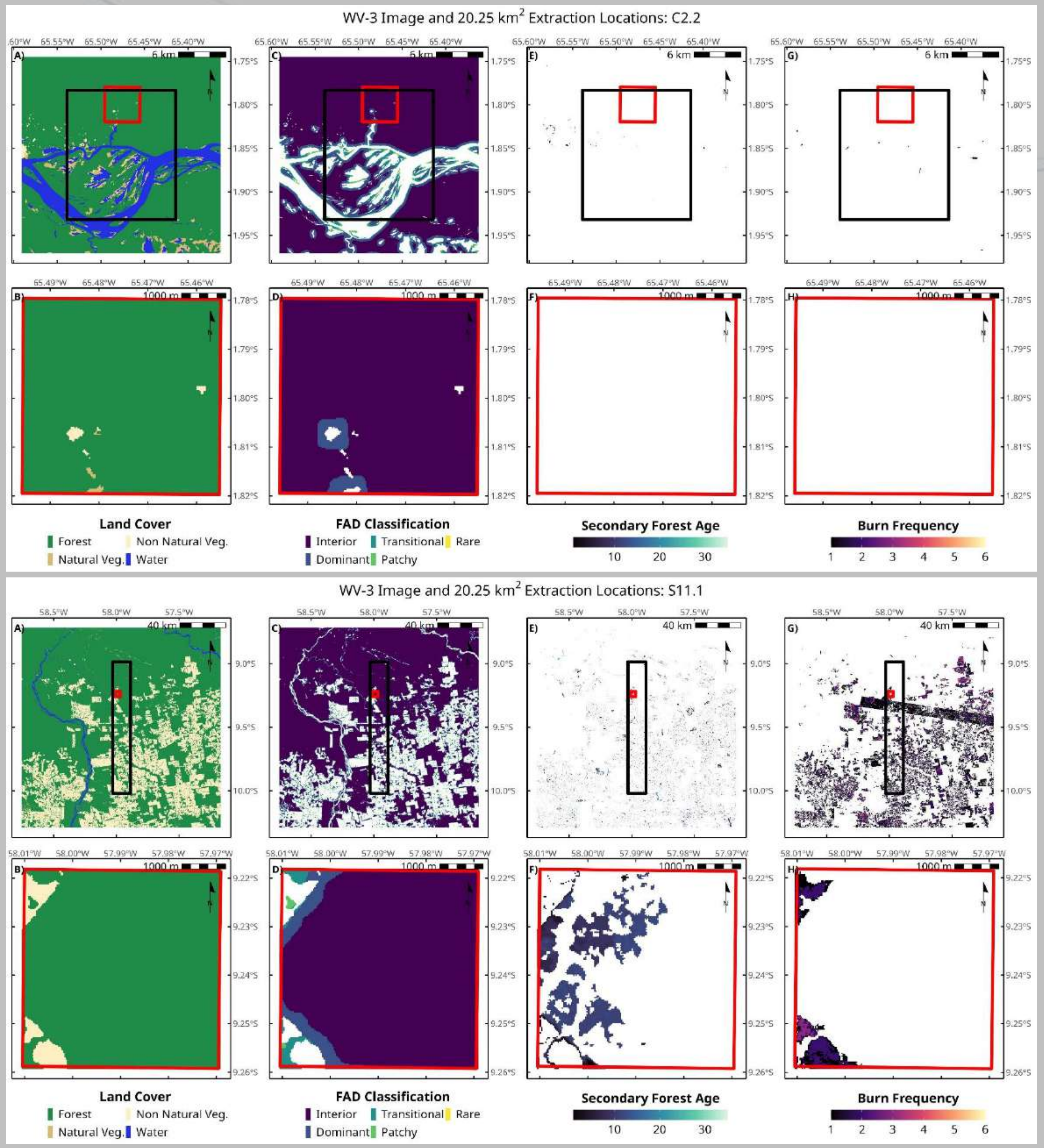
Cecropia Identification

WorldView-3 data
(ESA 3rd Part Mission)





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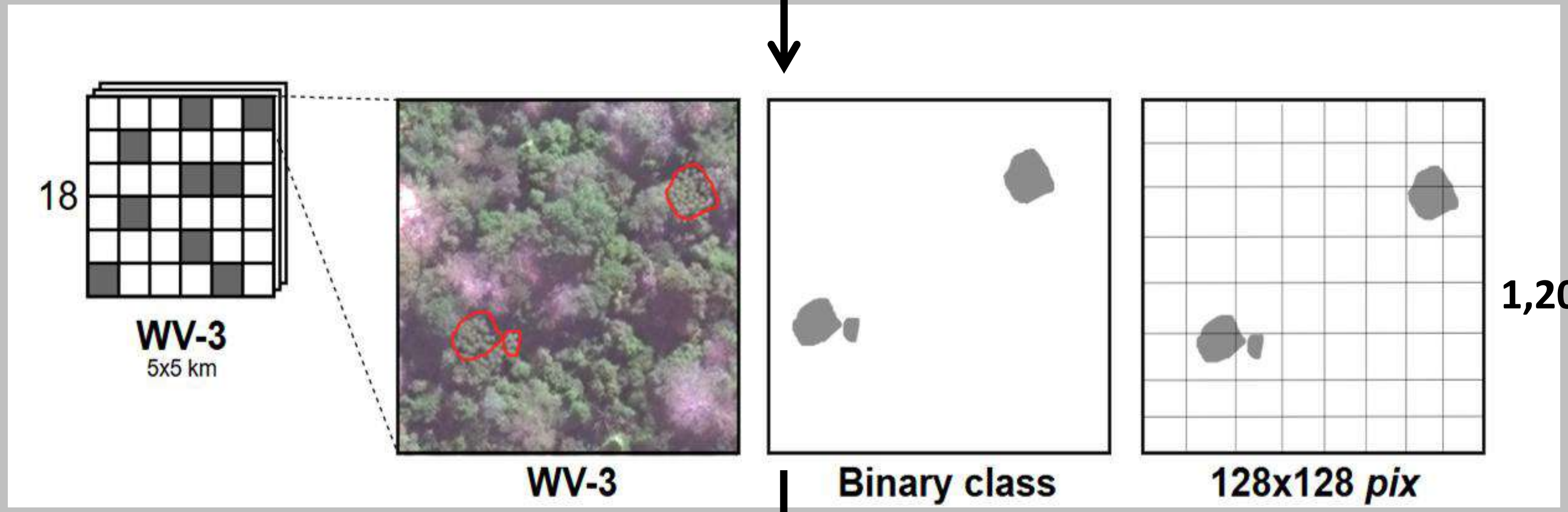
Cecropia Identification

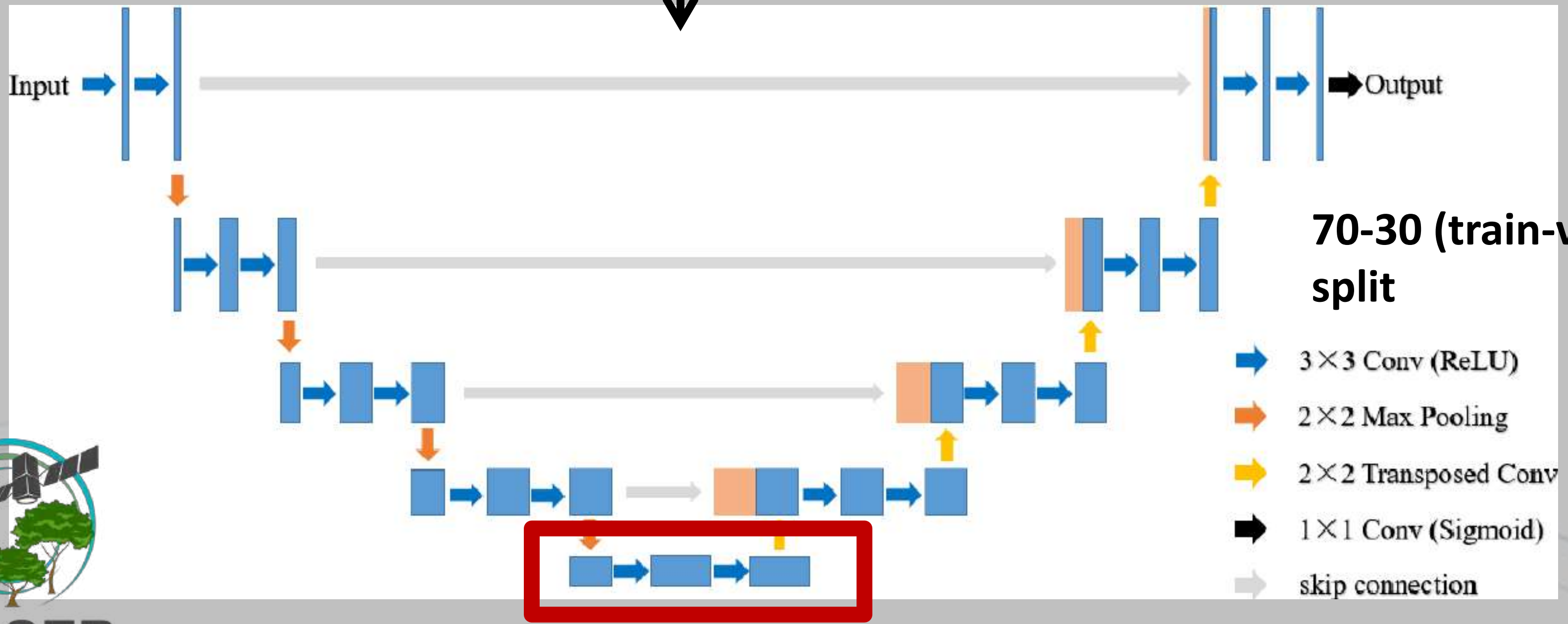
U-Net modelling

Manual delineation of Cecropia

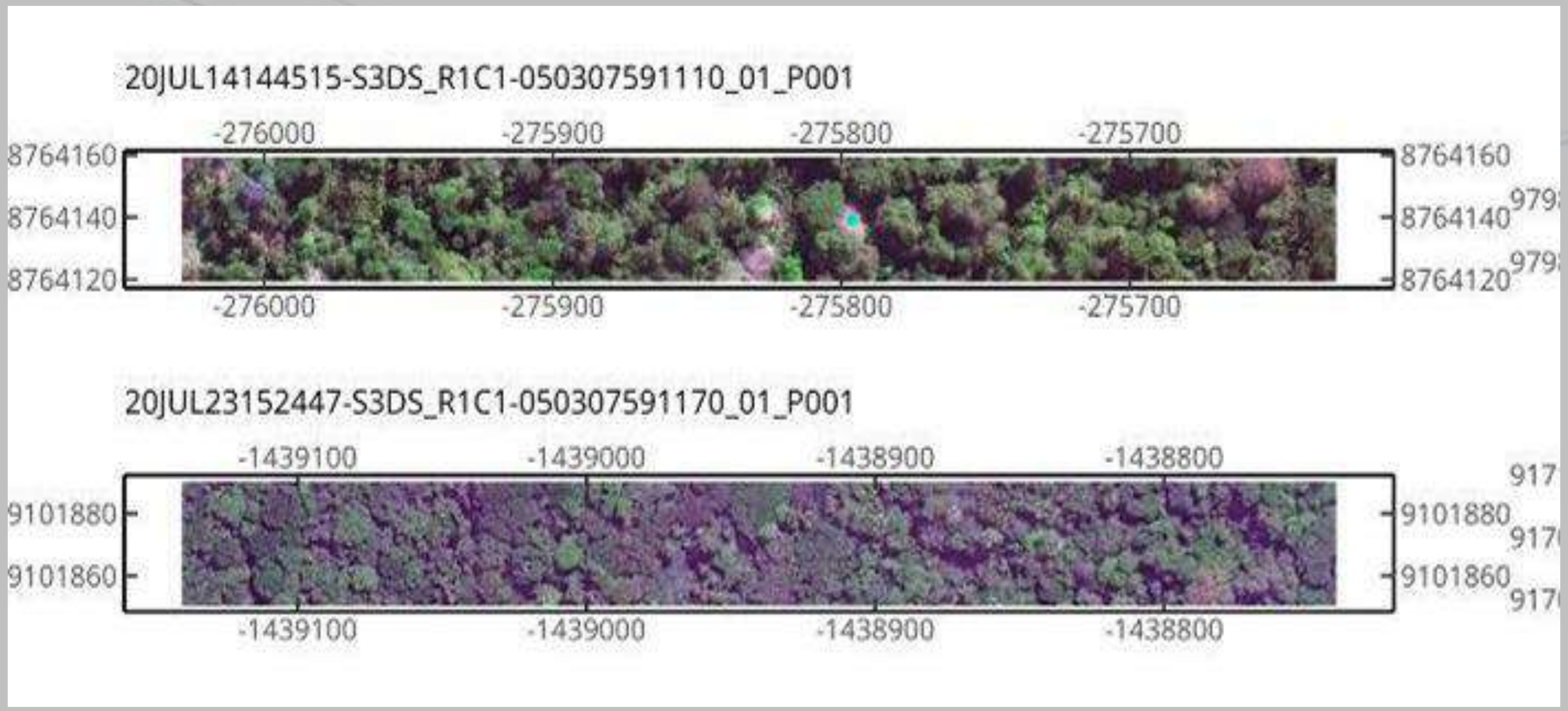
700 crown delineated



1,200 patches



70-30 (train-valid.) split



- Changing domains hinders performance i.e., shadowing and ρ()
- Heavy training augmentation applied
- Down sampled scene (5x5 km) **subnetwork embedded at bottleneck describing global variability (automatic correction)**

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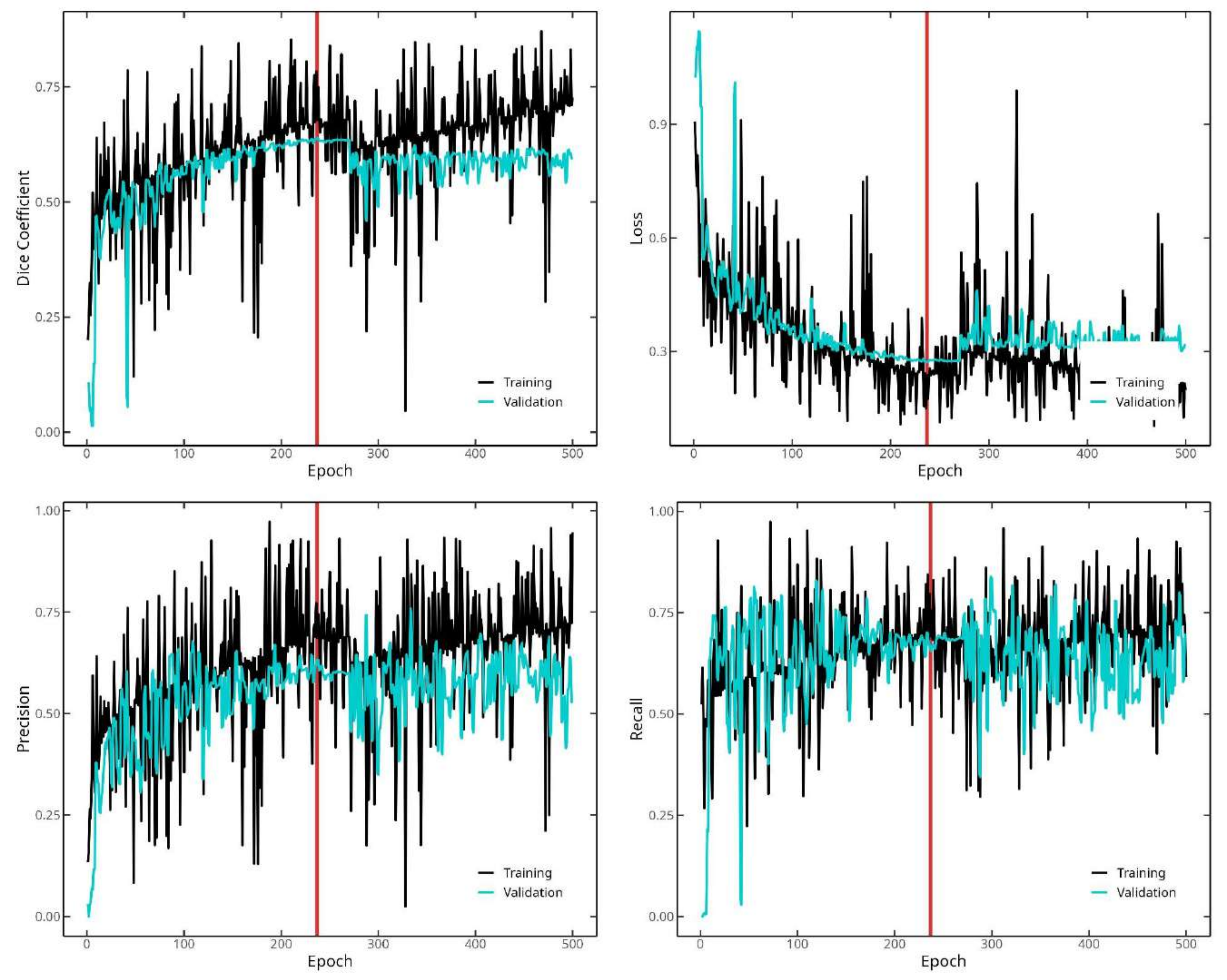
Cecropia Identification

U-Net modelling



Validation dice coefficient = 0.638
(epoch 237)
Good but still unsatisfactory…

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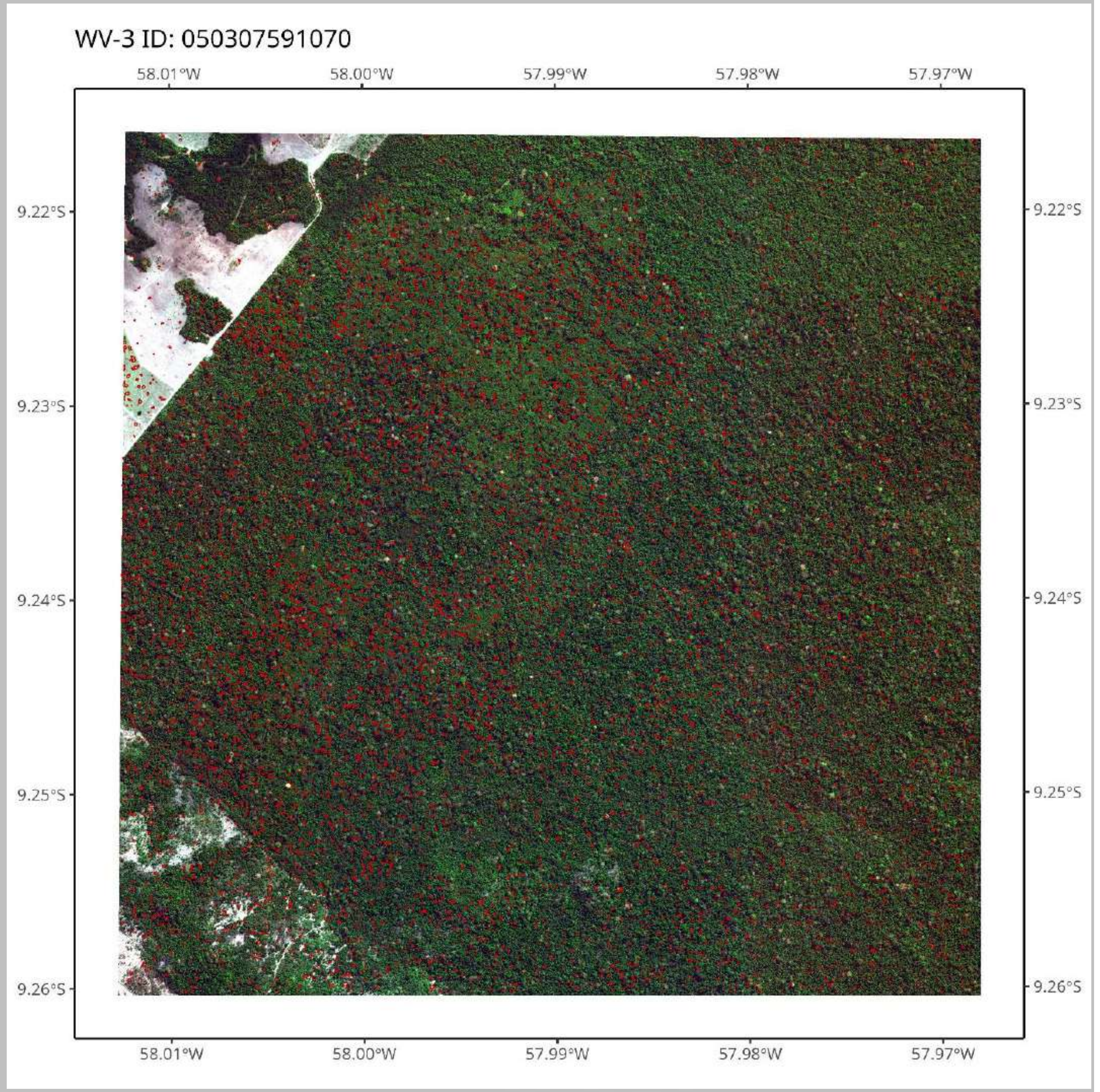
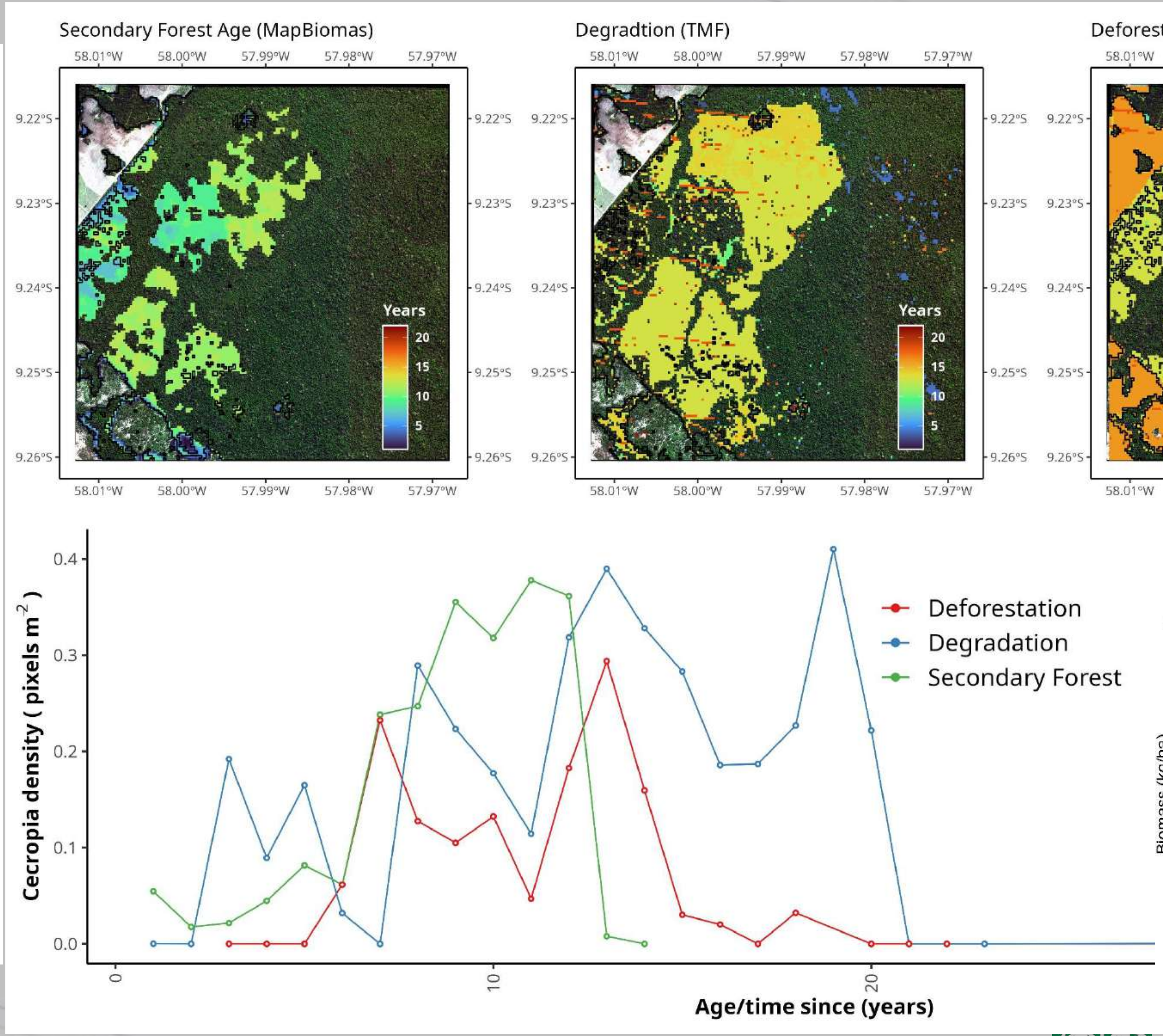
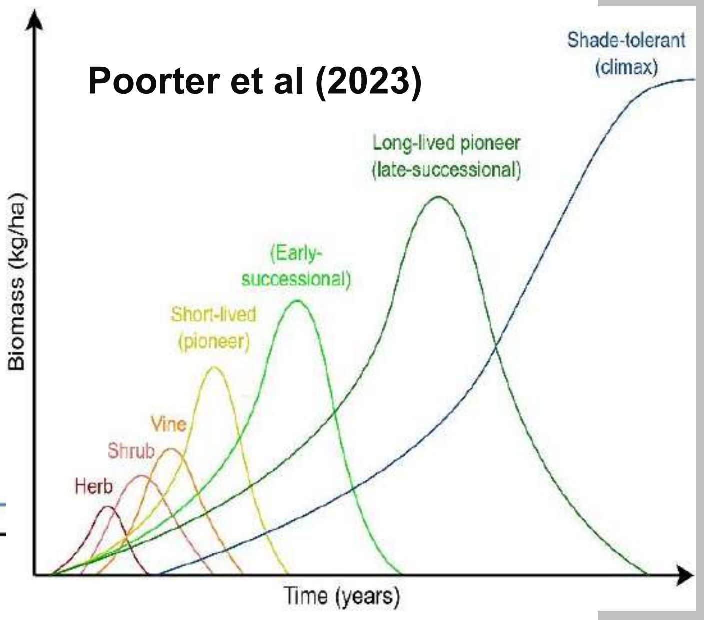
Cecropia Predictions
Disturbance gradients (30m)

Successional dynamics of pioneer functional species observed though Cecropia…



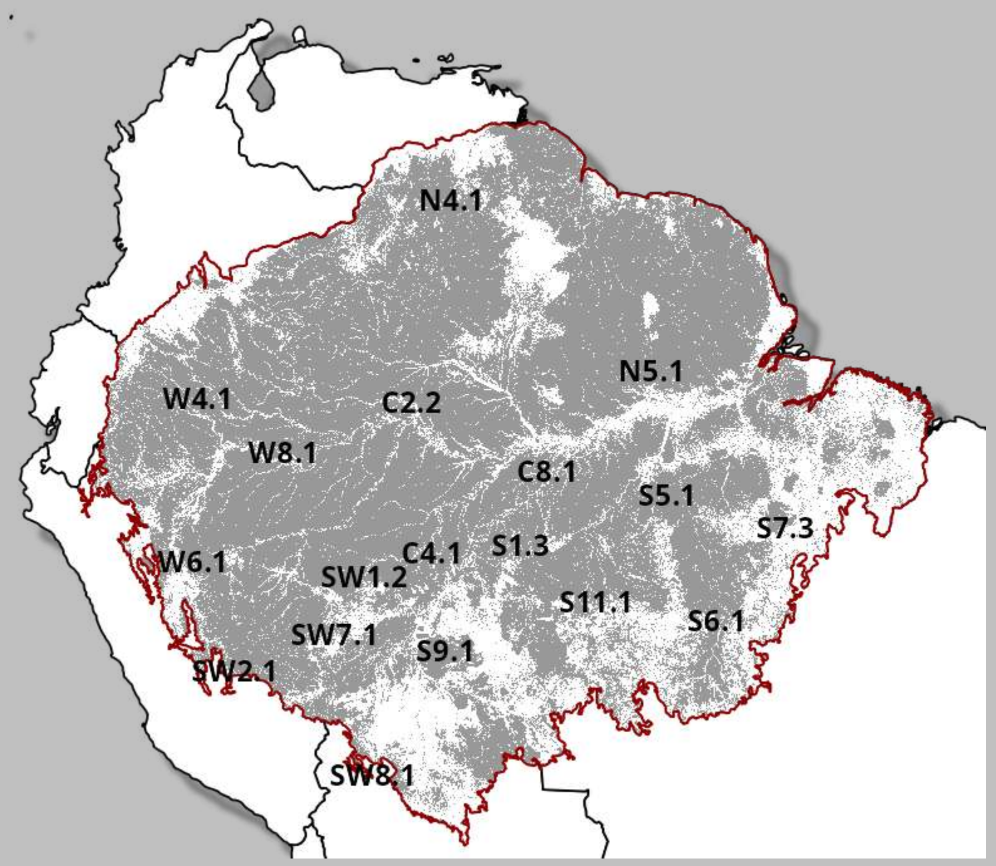




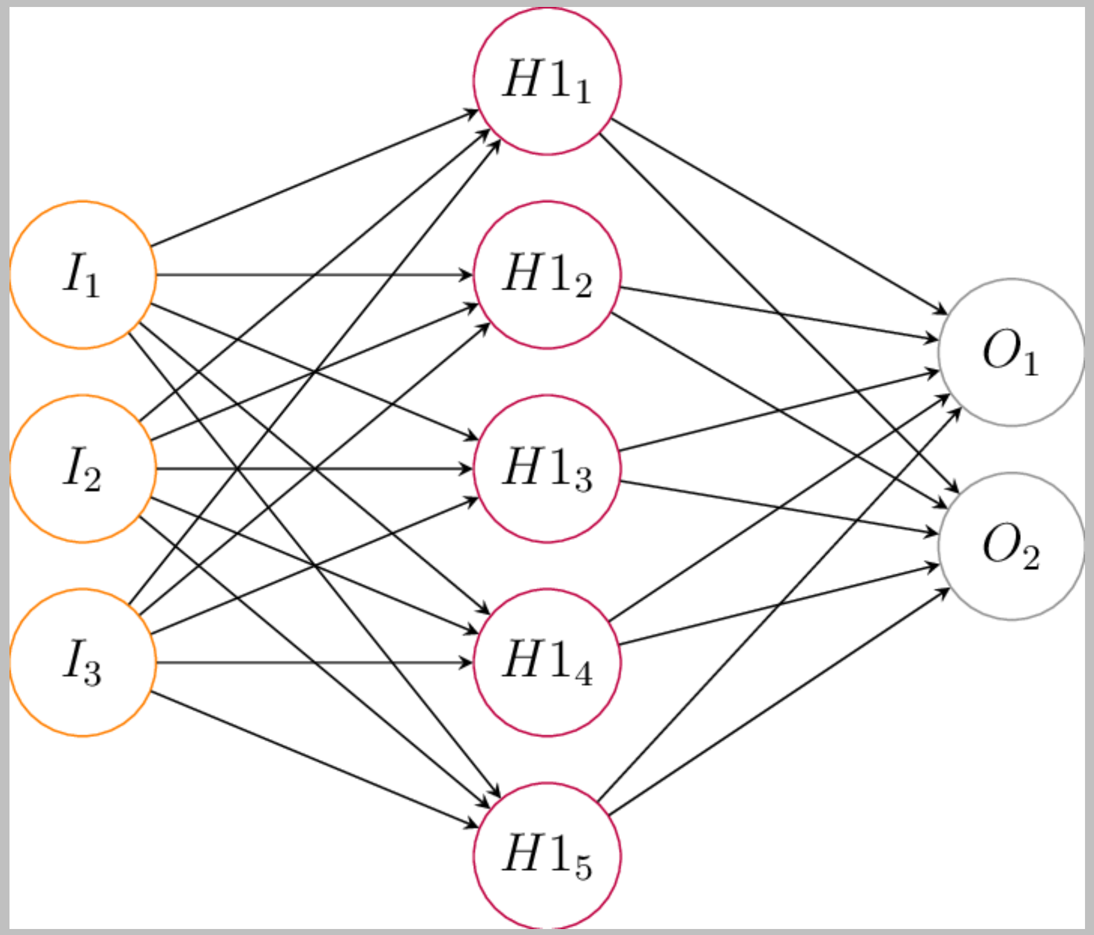
Expanding Cecropia predictions

Cecropia density (Amazon)

10 m *Cecropia* density
(aggregated U-Net output)
18 scenes of 25 km^2



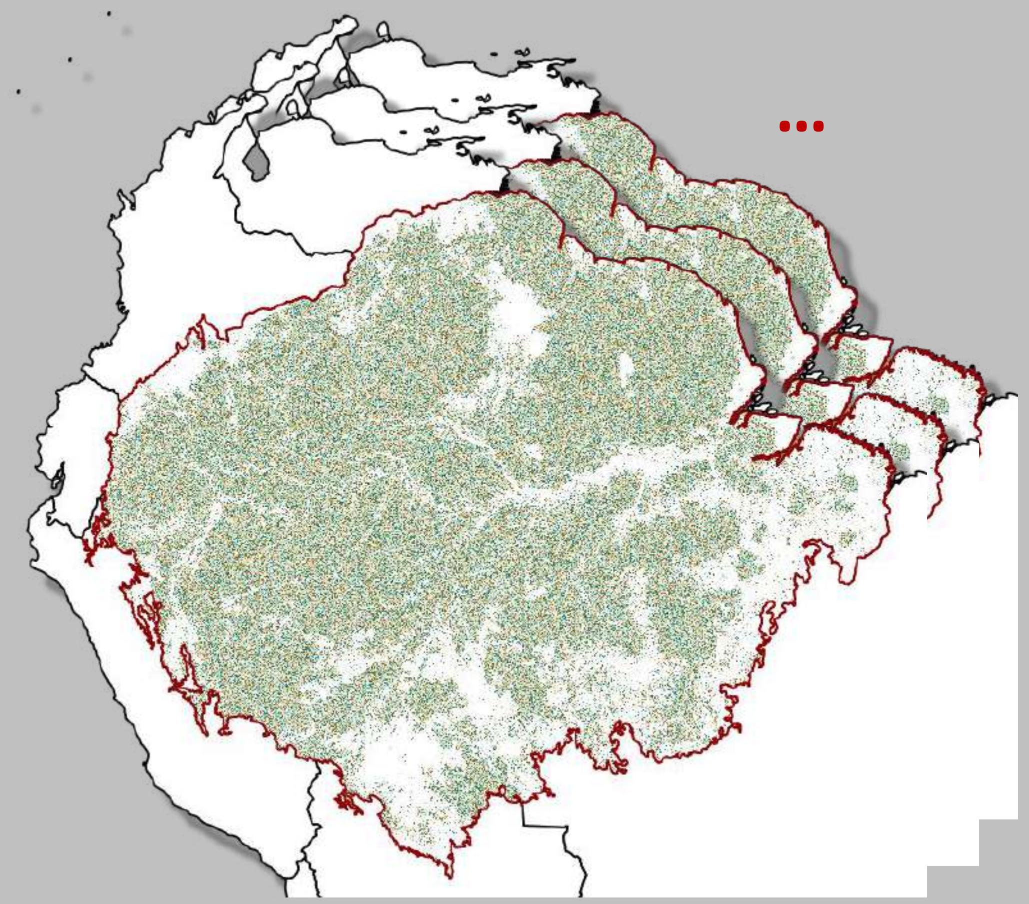
Train + validate NN/DL model
18 scenes of 25 km^2



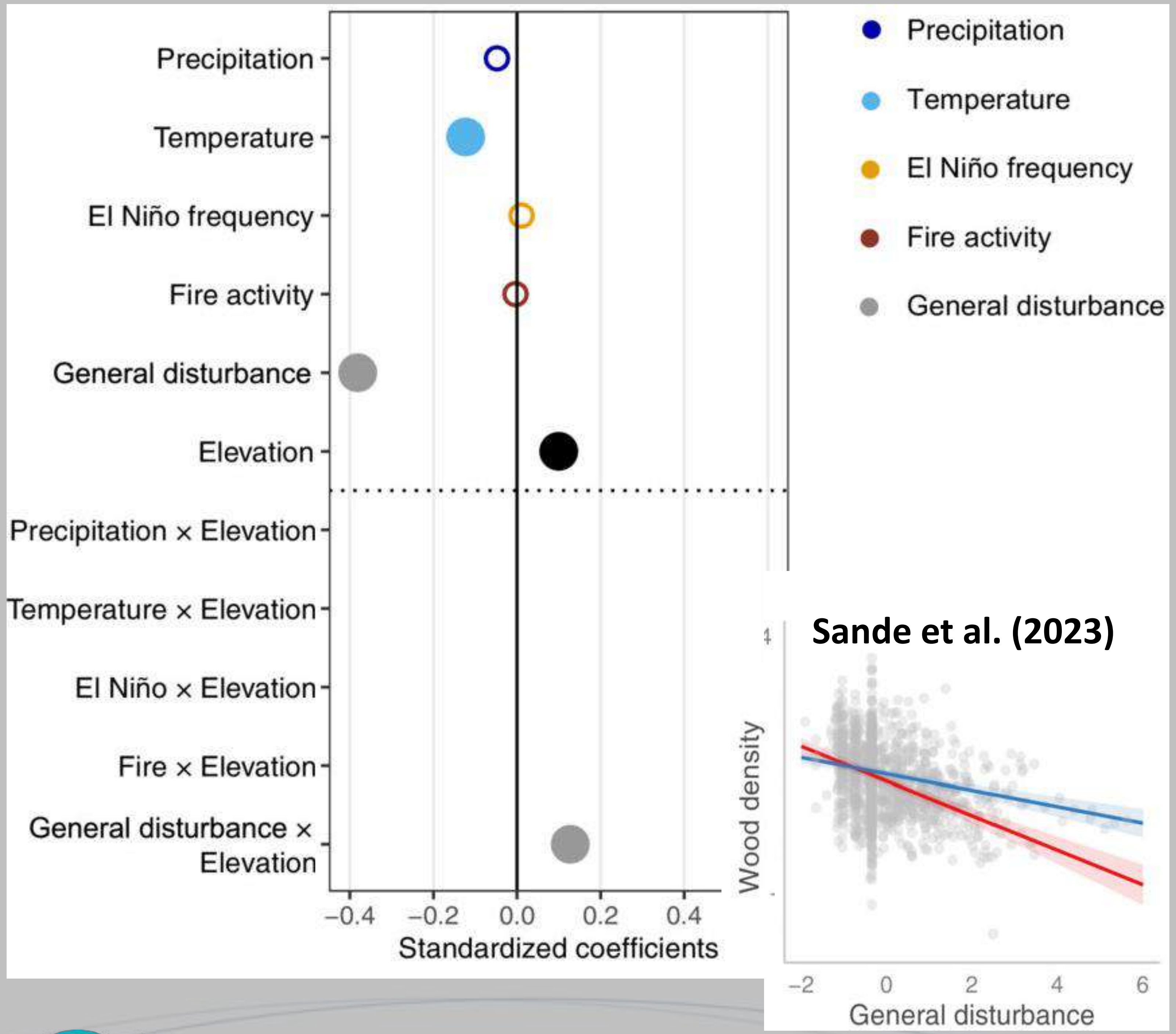
WV-3 predictions

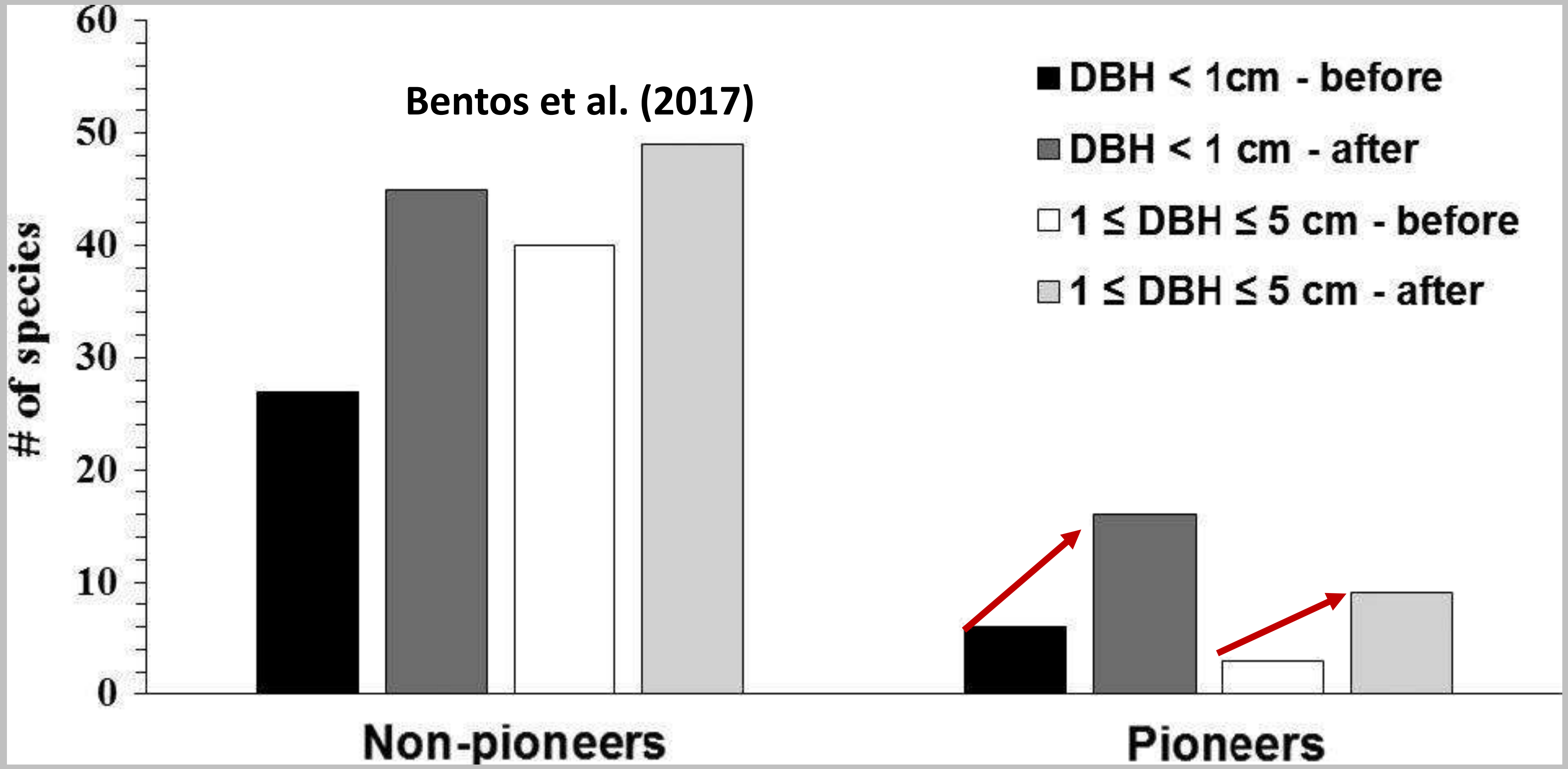
Sentinel-1/2 predictions

Application across the Amazon
10 m annual maps 2017 – 2025
6.7 Mkm^2



Estimating wood density
Community composition





"*Vismia*, *Bellucia*, *Miconi*a and *Cecropia*, comprised 90% of the emerging seedlings that established"

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Estimating AGB

Final product specification and utility

- New annual 10 m wood density and AGB maps between 2017-2025
- Insight into community composition at ecosystem scale
- Successional dynamics from disturbance explicitly incorporated into earth observation C stocks

$$\boxed{AGB = f(CH \cdot WD)}$$

Consistent specificity

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Scott Barningham
sdb221@exeter.ac.uk

UNIVERSITY OF EXETER

Special thanks to:
Stephen Sitch
Lina Mercado
Luiz Aragão

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Fire triples the recovery time of carbon stocks in easter Amazonian secondary forests

Isadora Haddad

Session 2.1 (Part 2): Estimates of carbon accumulation from various approaches

São José dos Campos, 30 Oct 2025

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Landscape Analysis of Brazilian Forest Regeneration: A Novel National Database of Secondary Vegetation

Débora Giancola

Session 2.2: Other metrics for identifying secondary forest success.

São José dos Campos, 30 Oct 2025

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Objectives

National Vegetation Recovery Plan

Recover of 12 million hectares of native vegetation by 2030

Kunming-Montreal Global Biodiversity Framework

Commitment at COP15 to restore at least 30% of degraded areas of terrestrial, inland, coastal and marine ecosystems

2020 UN BIODIVERSITY CONFERENCE
COP 15 - CP/MOP10-NP/MOP4
Ecological Civilization-Building a Shared Future for All Life on Earth
KUNMING – MONTREAL

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Objectives

National Vegetation Recovery Plan

PLANAVEG

STRATEGIES	
RECOVERY PRODUCTION CHAIN	SPATIAL INTELLIGENCE AND MONITORING
RECOVERY FINANCING	RESEARCH, DEVELOPMENT AND INNOVATION

Guidelines:

(III) ...consolidation of spatial intelligence and a monitoring system that qualifies decision-making processes and publicizes progress in achieving the goal and the final impacts resulting from monitoring these goals.

Objectives

National Vegetation Recovery Plan

PLANAVEG

STRATEGIES	
RECOVERY PRODUCTION CHAIN	SPATIAL INTELLIGENCE AND MONITORING
RECOVERY FINANCING	RESEARCH, DEVELOPMENT AND INNOVATION

Guidelines:

(III) *...consolidation of spatial intelligence and a monitoring system that qualifies decision-making processes and <u>publicizes progress in achieving the goal and the final impacts resulting from monitoring these goals.</u>*

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Objectives

National Vegetation Recovery Plan

PLANAVEG

STRATEGIES

RECOVERY PRODUCTION CHAIN

SPATIAL INTELLIGENCE AND MONITORING

RECOVERY FINANCING

RESEARCH, DEVELOPMENT AND INNOVATION

To improve the understanding of the **dynamics** of SV areas in Brazil

- **Persistence**
- **Connectivity**
- **Land tenure category**

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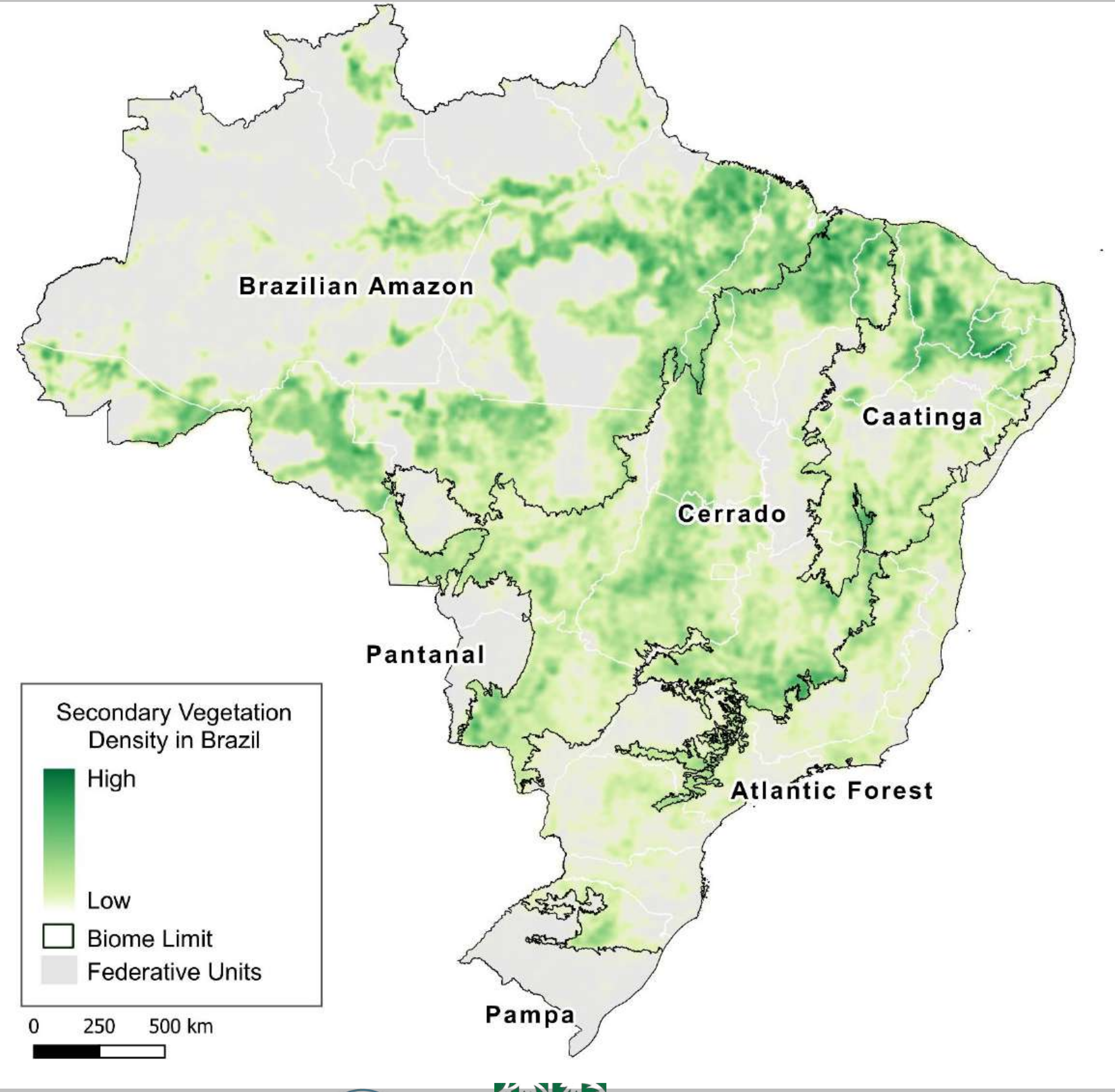
Secondary Vegetation

Definitions

"Areas that have been deforested and are in an advanced stage of regeneration, with the presence of trees and shrubs."



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Data Source

Data base for qualification

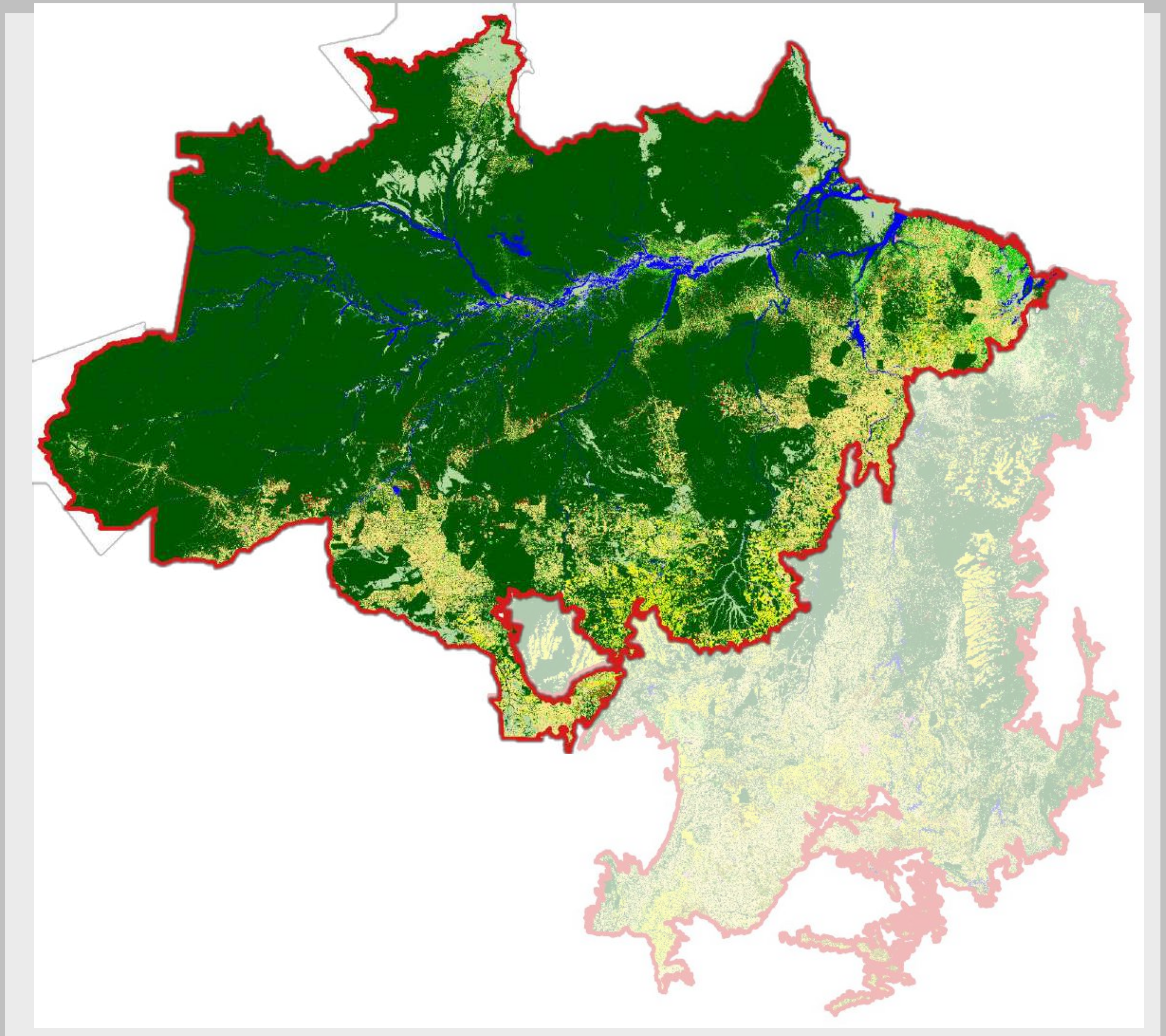
TerraClass

Amazon

2008

2022

- Mapped each 2 years



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Data Source

Data base for qualification

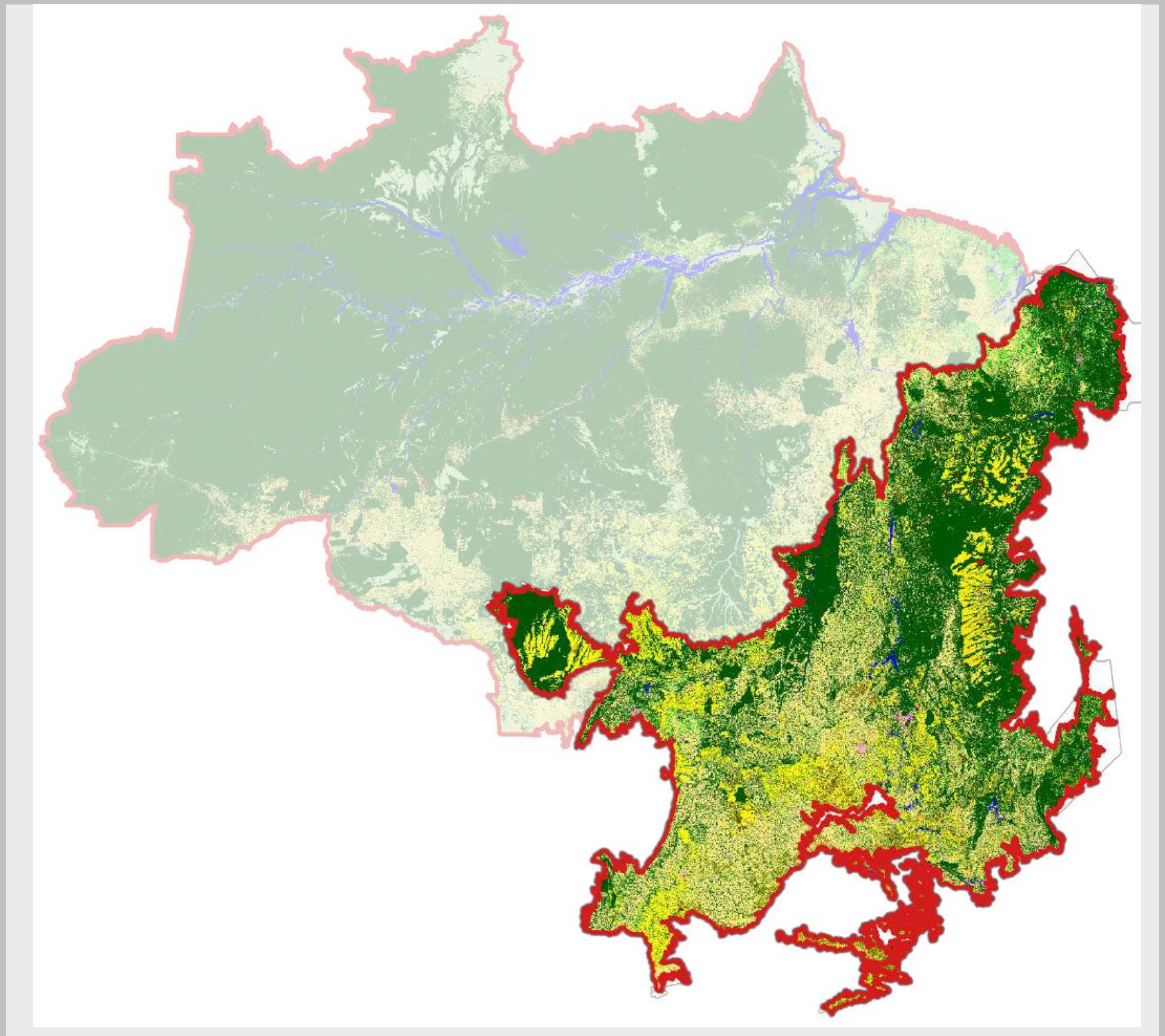
TerraClass

Amazon

2008 2022

Cerrado

2018 2024



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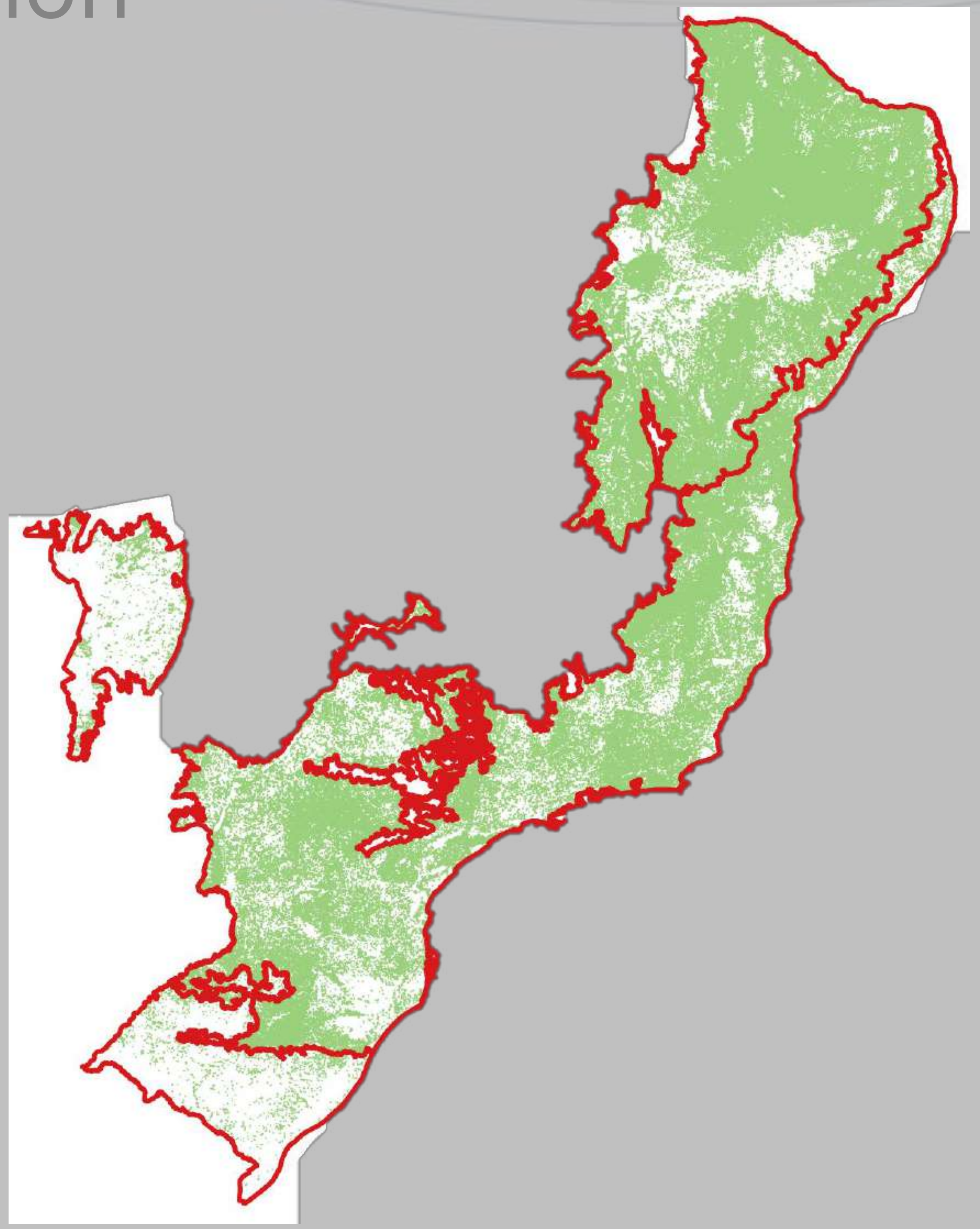
Data Source

Data base for qualification

FUNCATE
Fundação de Ciência, Aplicações e Tecnologia Espaciais

Atlantic Forest, Caatinga, Pantanal and Pampa

2018 2022



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Data Source

Land Tenure

- Indigenous Land
- Integral Protection Conservation Units
- Sustainable Use Conservation Units (excluding APA);
- Quilombola Territories
- Rural Settlements
- Environmental Protection Areas (APA)
- Private Properties
- Undesignated Public Forests
- Areas without Land Registration

TerraBrasilis

FUNAI, ICMBio and INCRA

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Landscape Ecology

Methodology

Landscape Metrics:

- Area (ha)
- Core area (ha) – 30, 60, 90 e 120 m
- Fractal dimension index
- Euclidean distance to the nearest neighbor (m)
- Type of nearest neighboring vegetation

Landscape Ecology

Methodology

Landscape Metrics:

- Area (ha)
- Core area (ha) – 30, 60, 90 e 120 m
- Fractal dimension index
- Euclidean distance to the nearest neighbor (m)
- Type of nearest neighboring vegetation

- Weighted age (years)
- Area (ha) of the fragment according to land tenure parcels in the region

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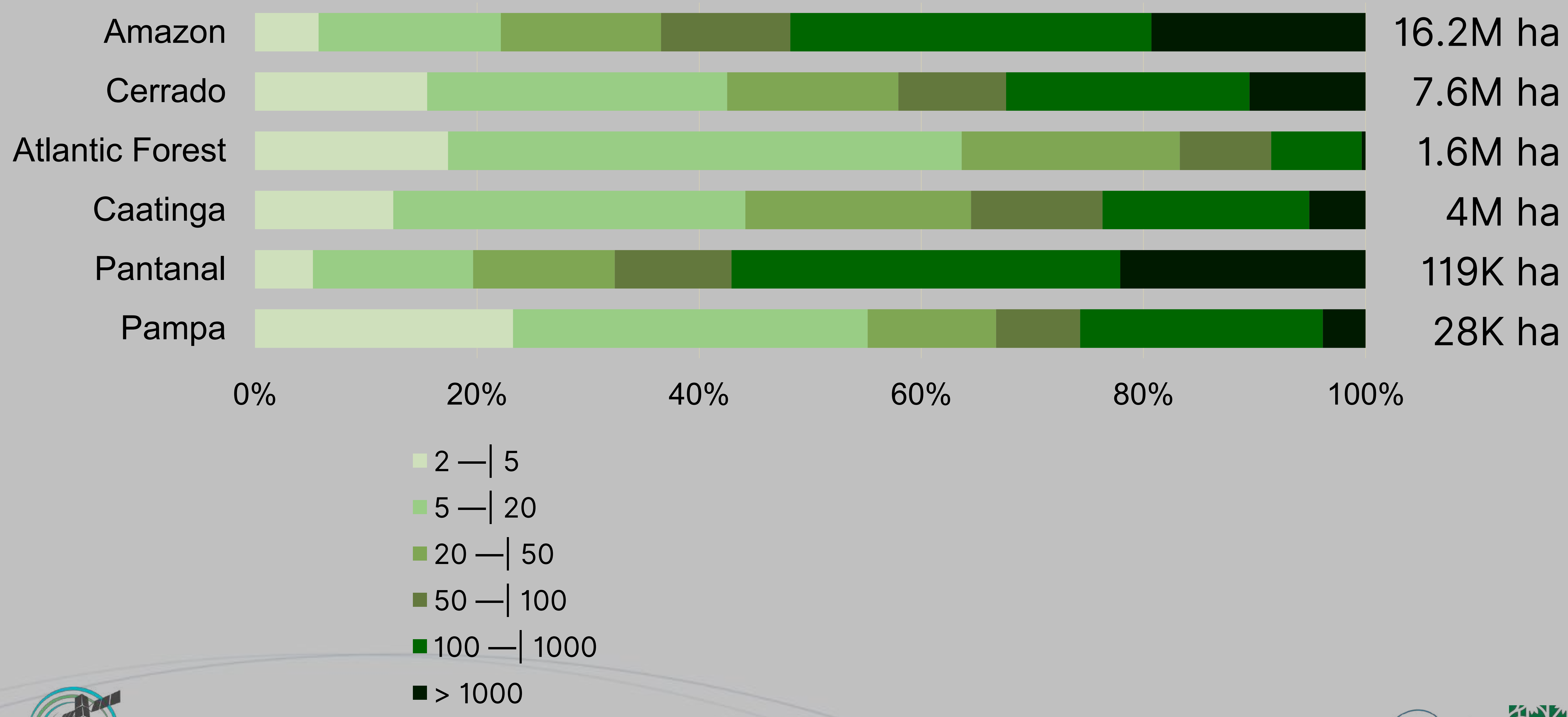
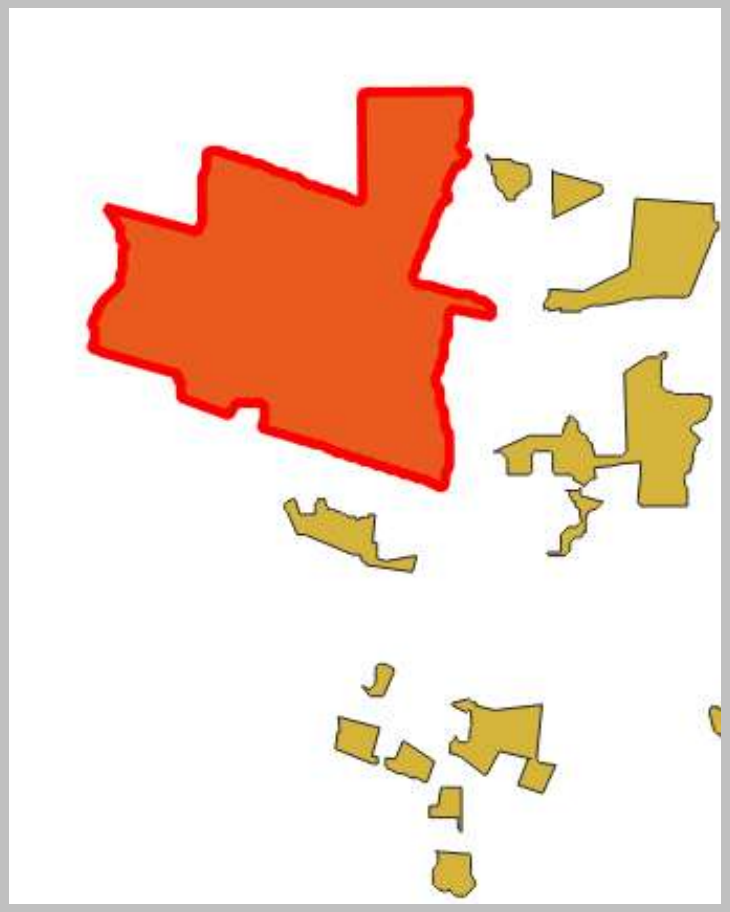
Area (ha)

Total area





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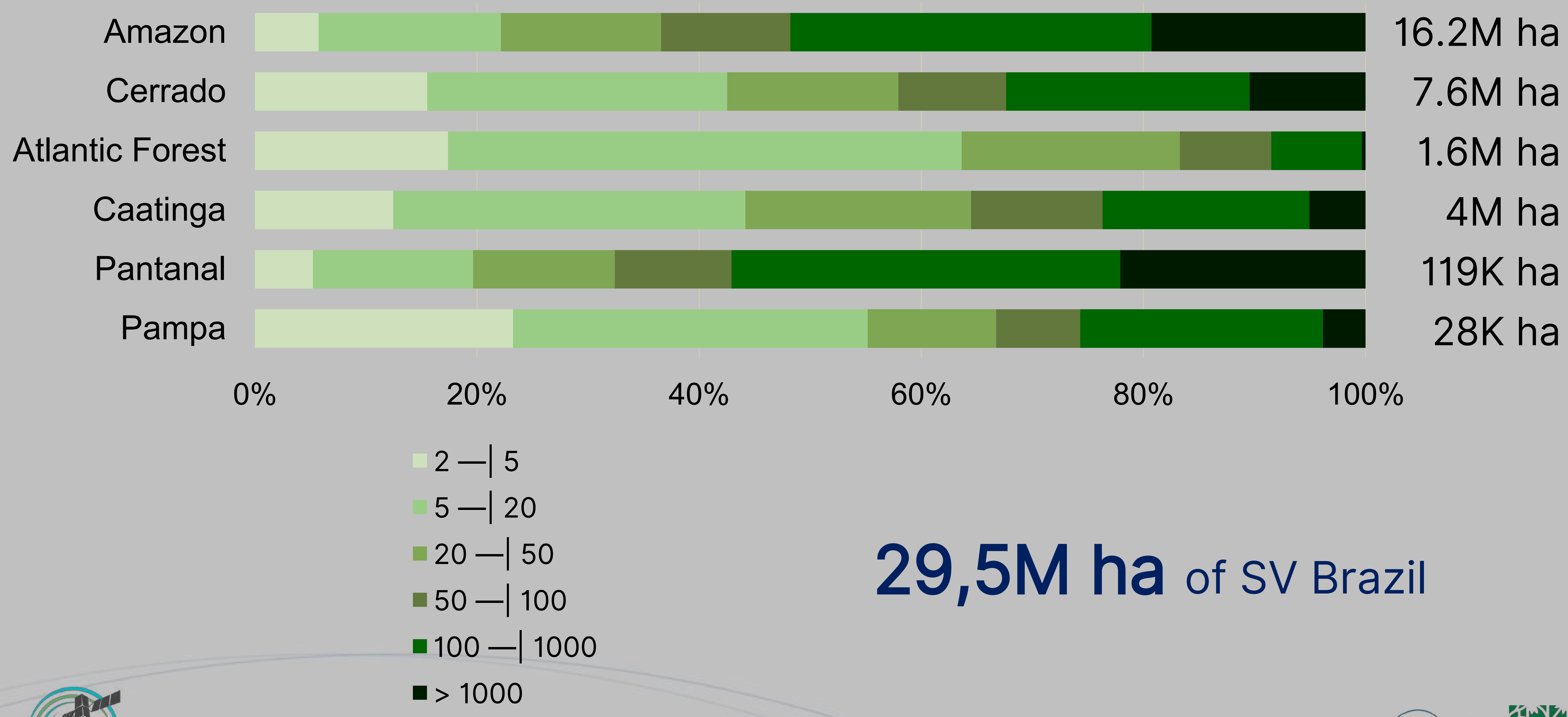
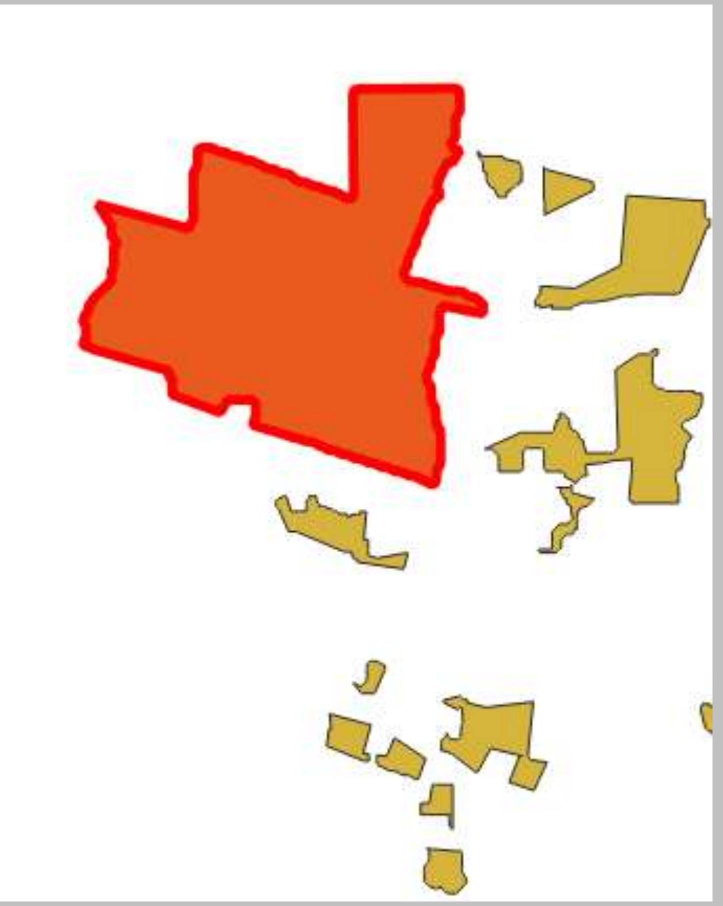
Area (ha)

Total area





29,5M ha of SV Brazil

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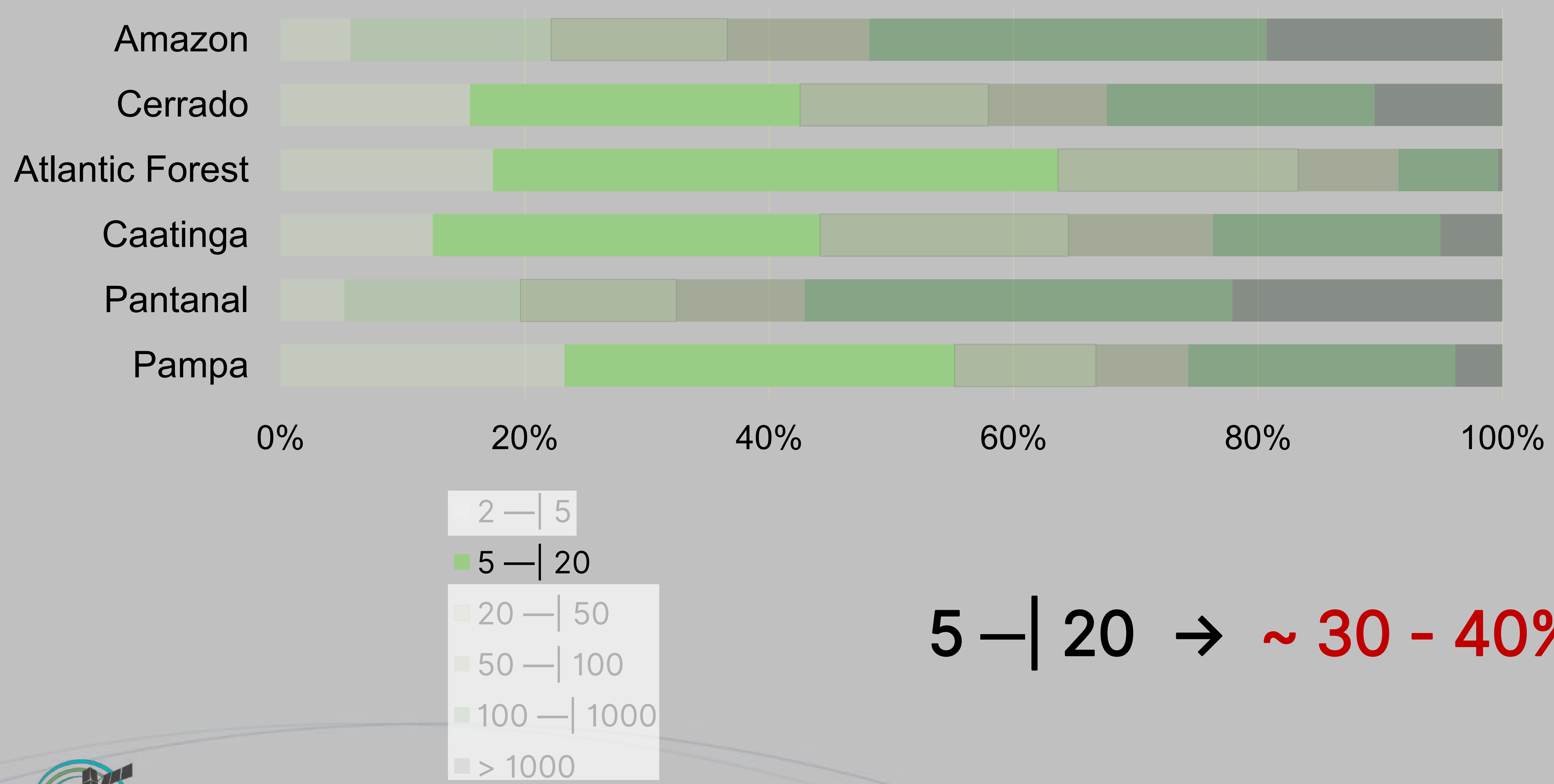
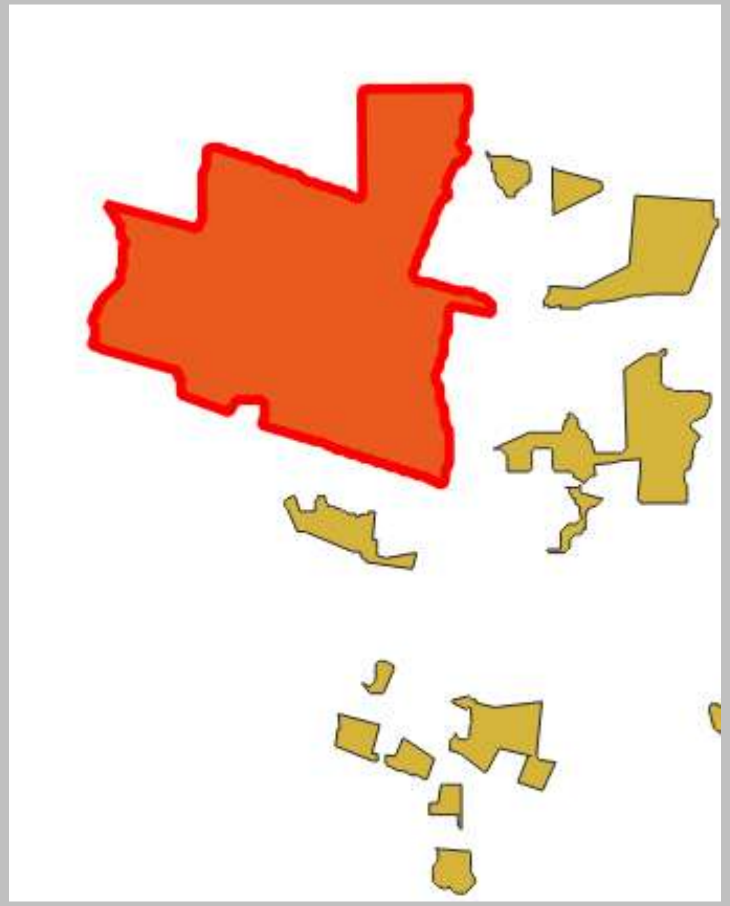
Area (ha)

Total area





5 —| 20 → ~ 30 - 40%

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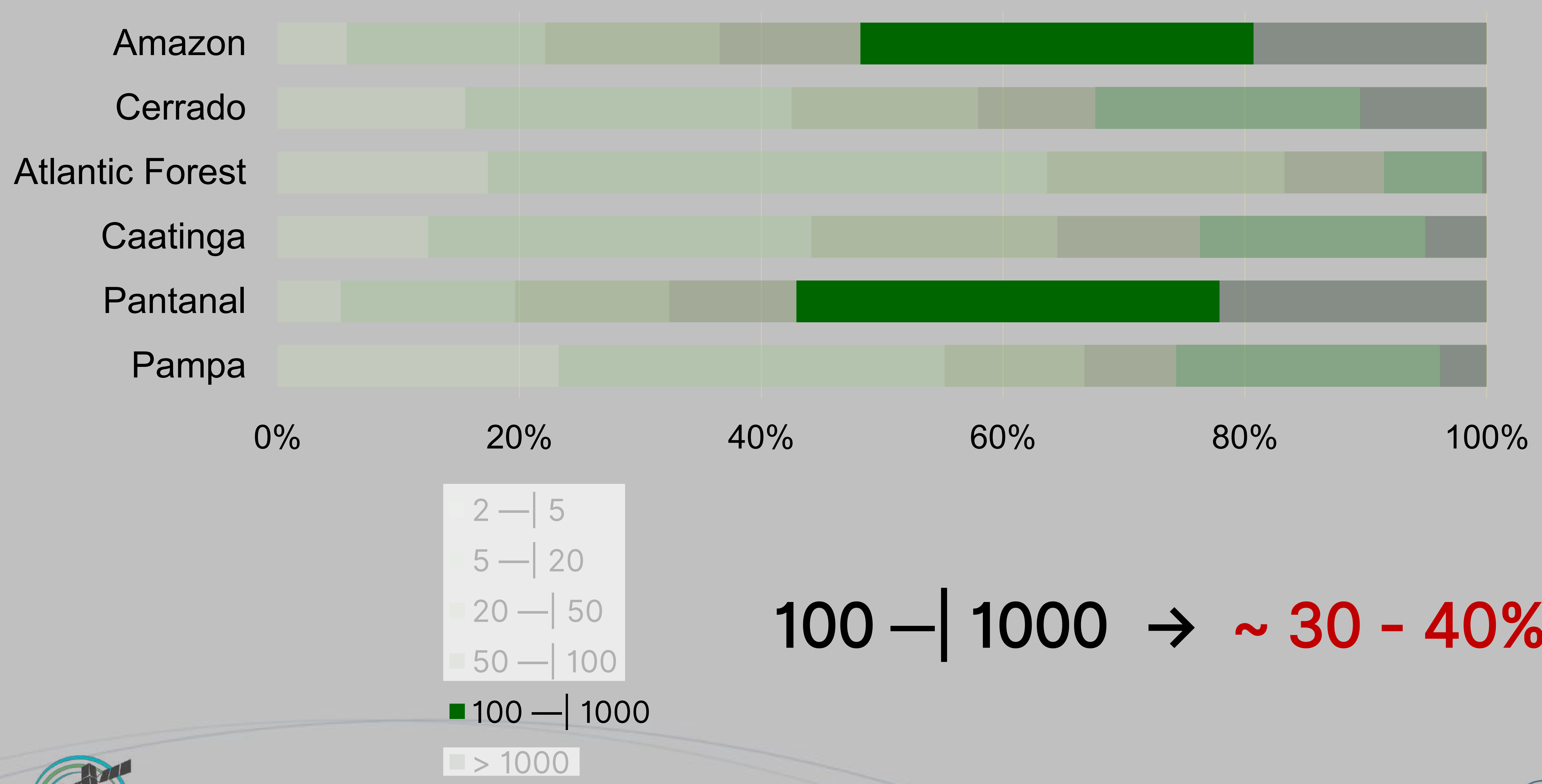
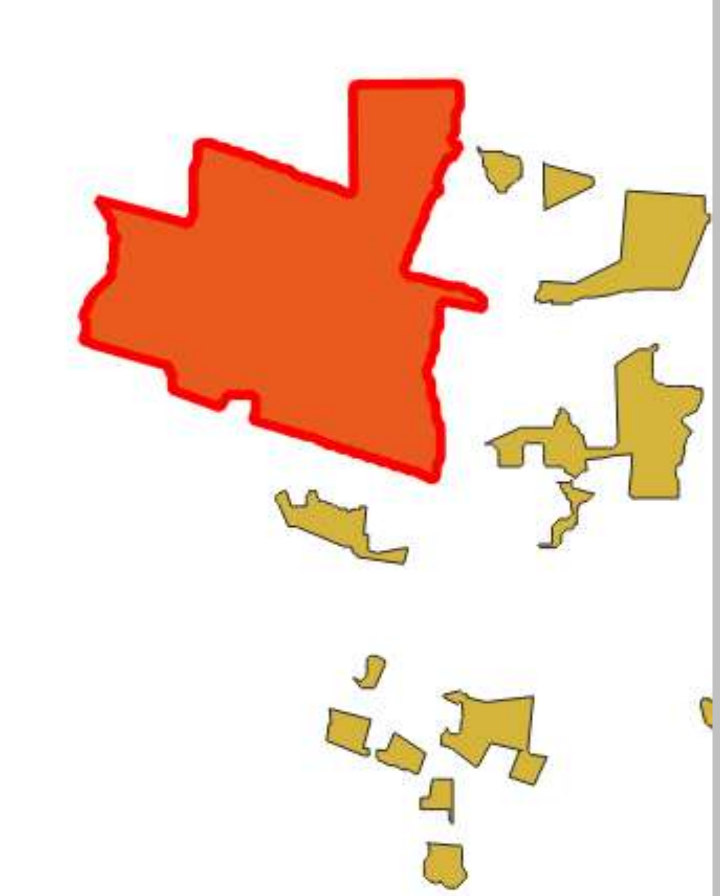
Area (ha)

Total area



100 —| 1000 → ~ 30 - 40%



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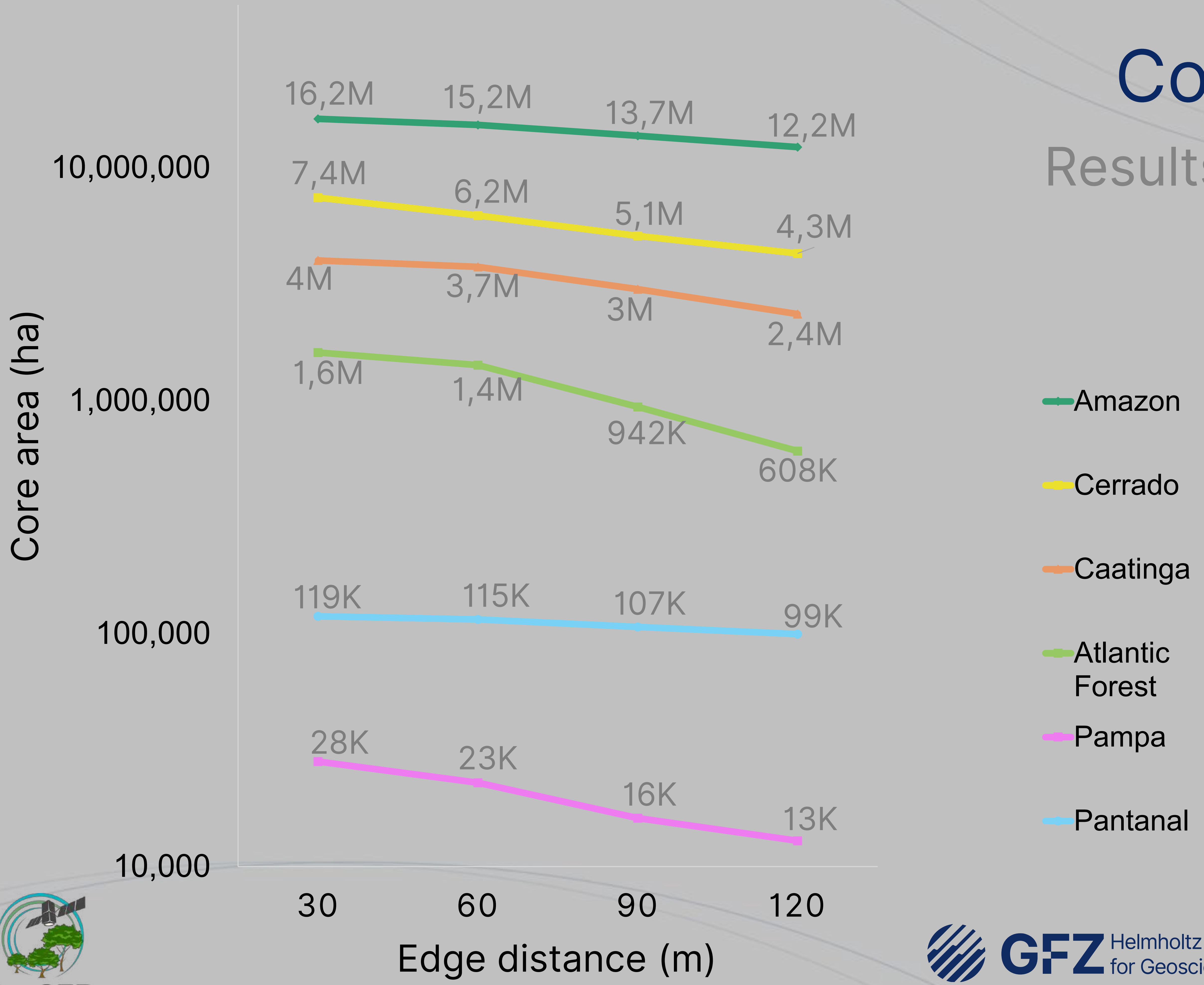
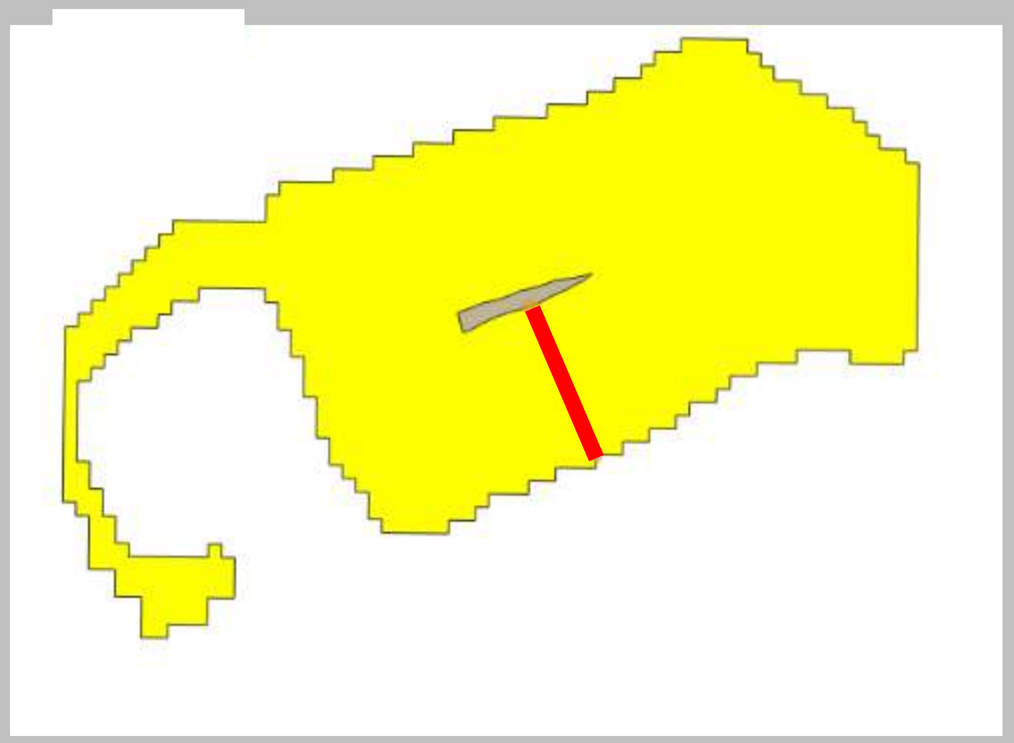
Core area (ha)

Results by edge distance





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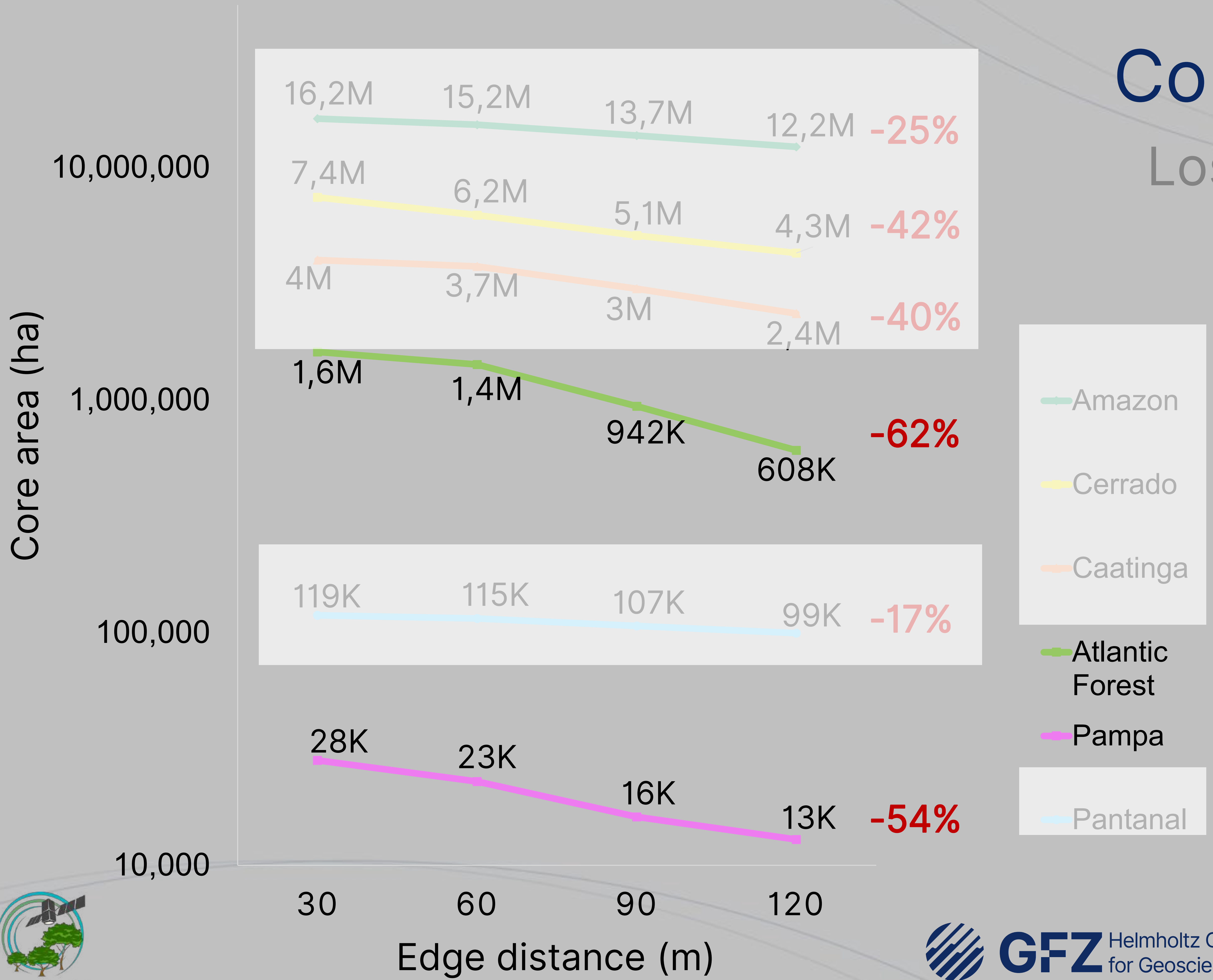
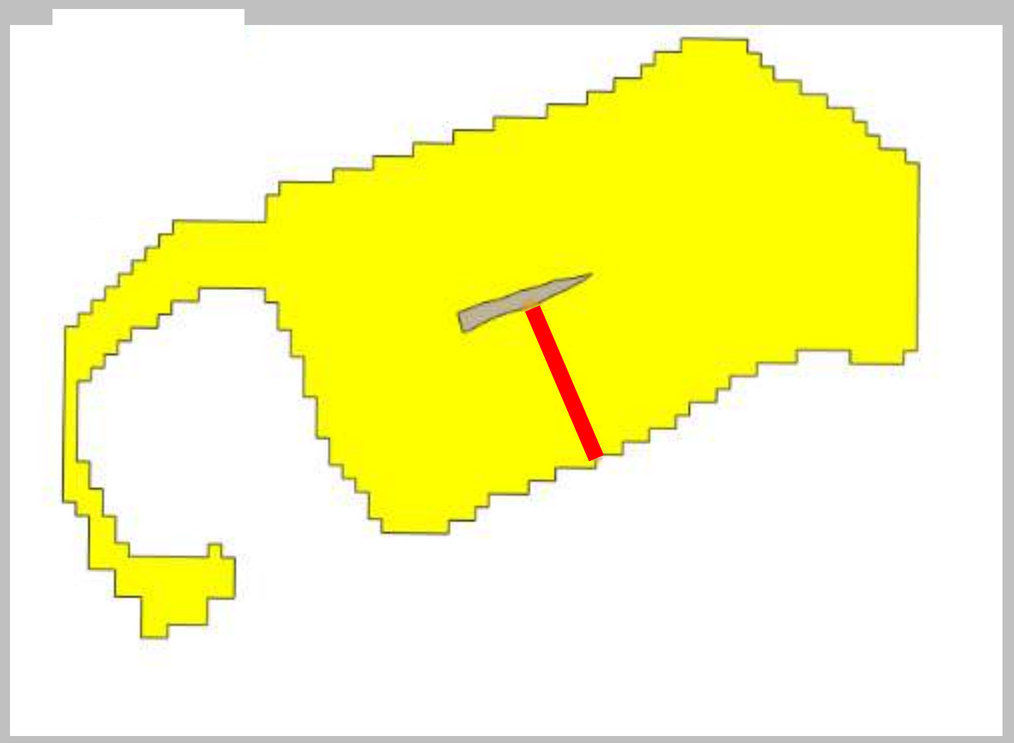
Core area (ha)

Loss along edge distance





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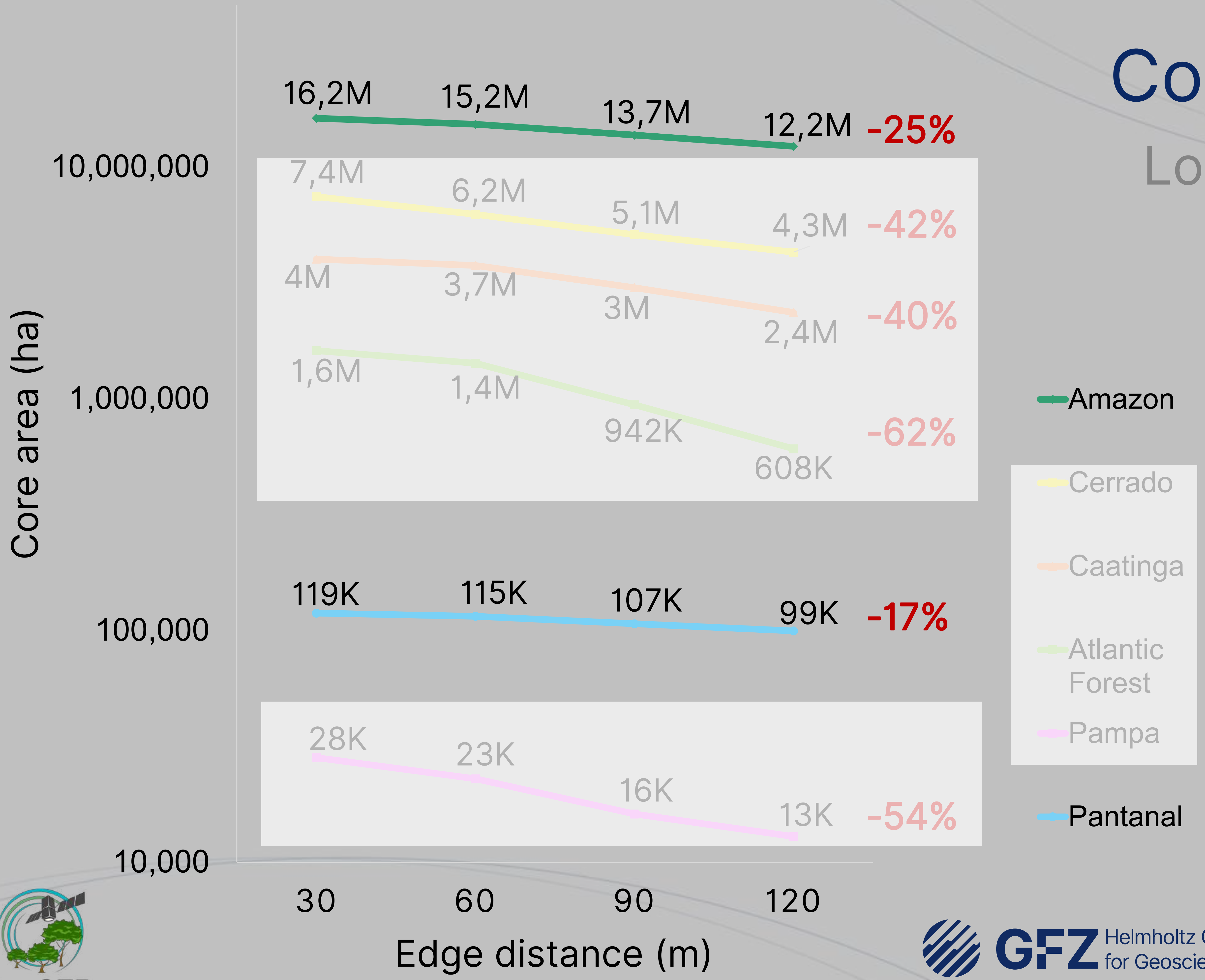
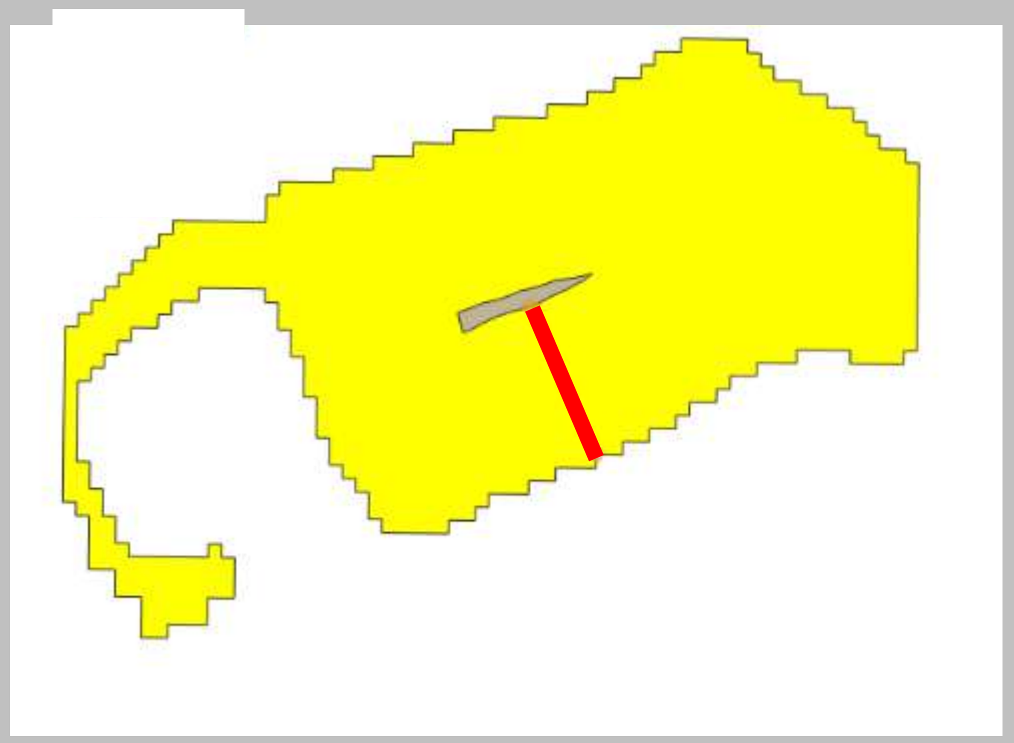
Core area (ha)

Loss along edge distance





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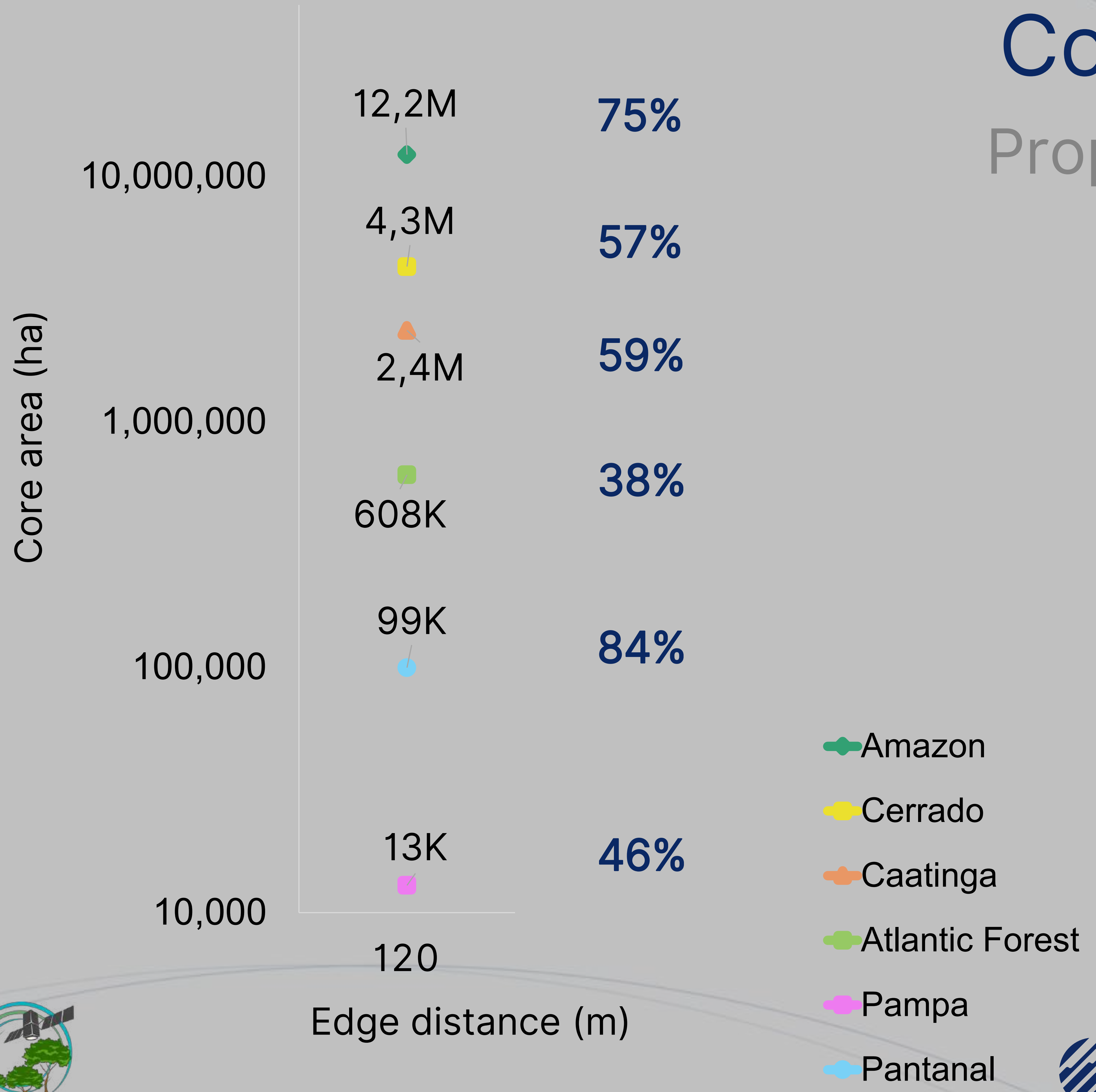
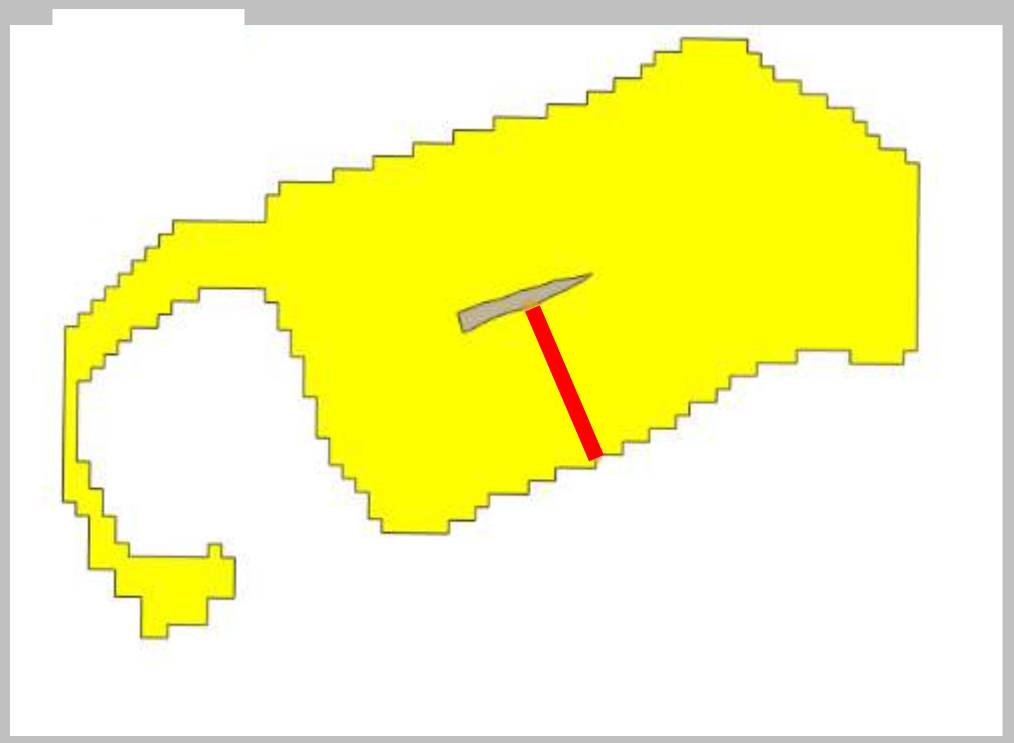
Core area (ha)

Proportion by biome





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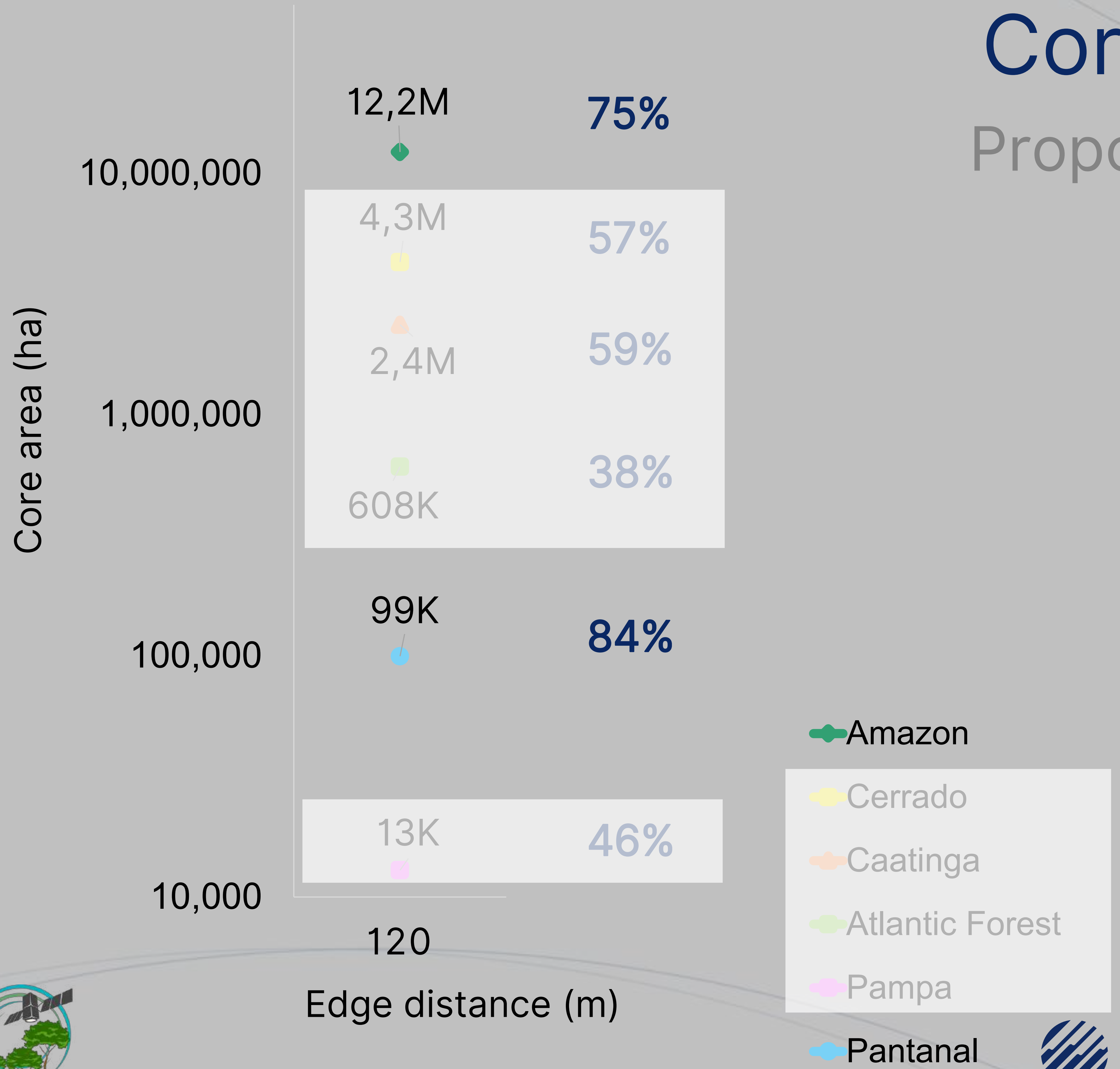
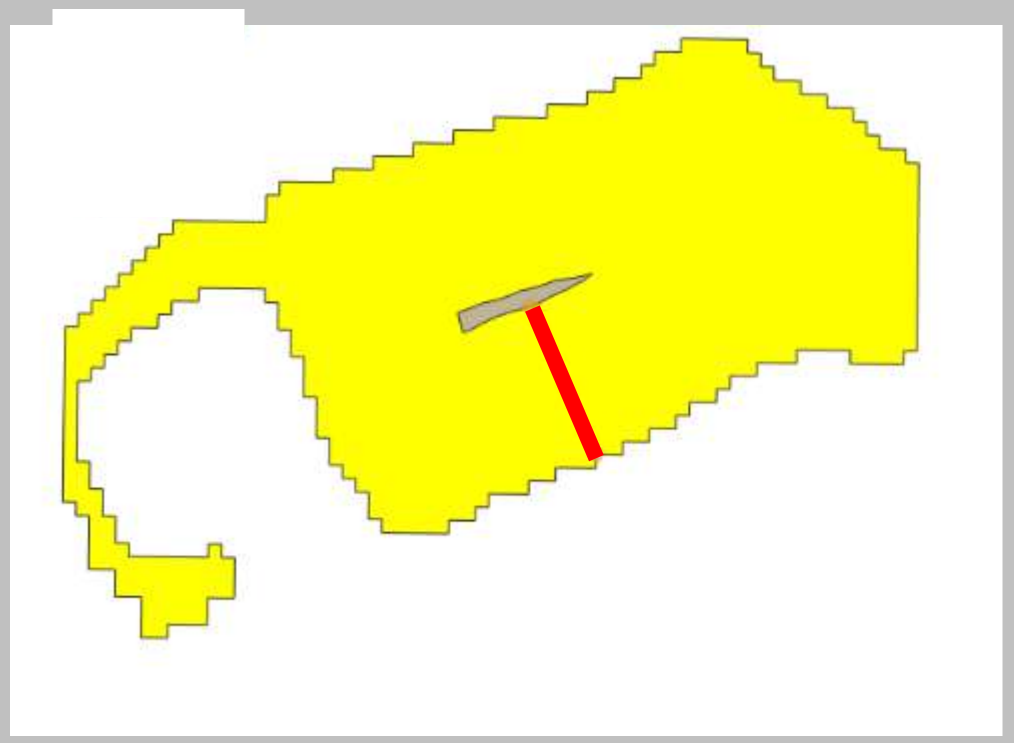
Core area (ha)

Proportion by biome





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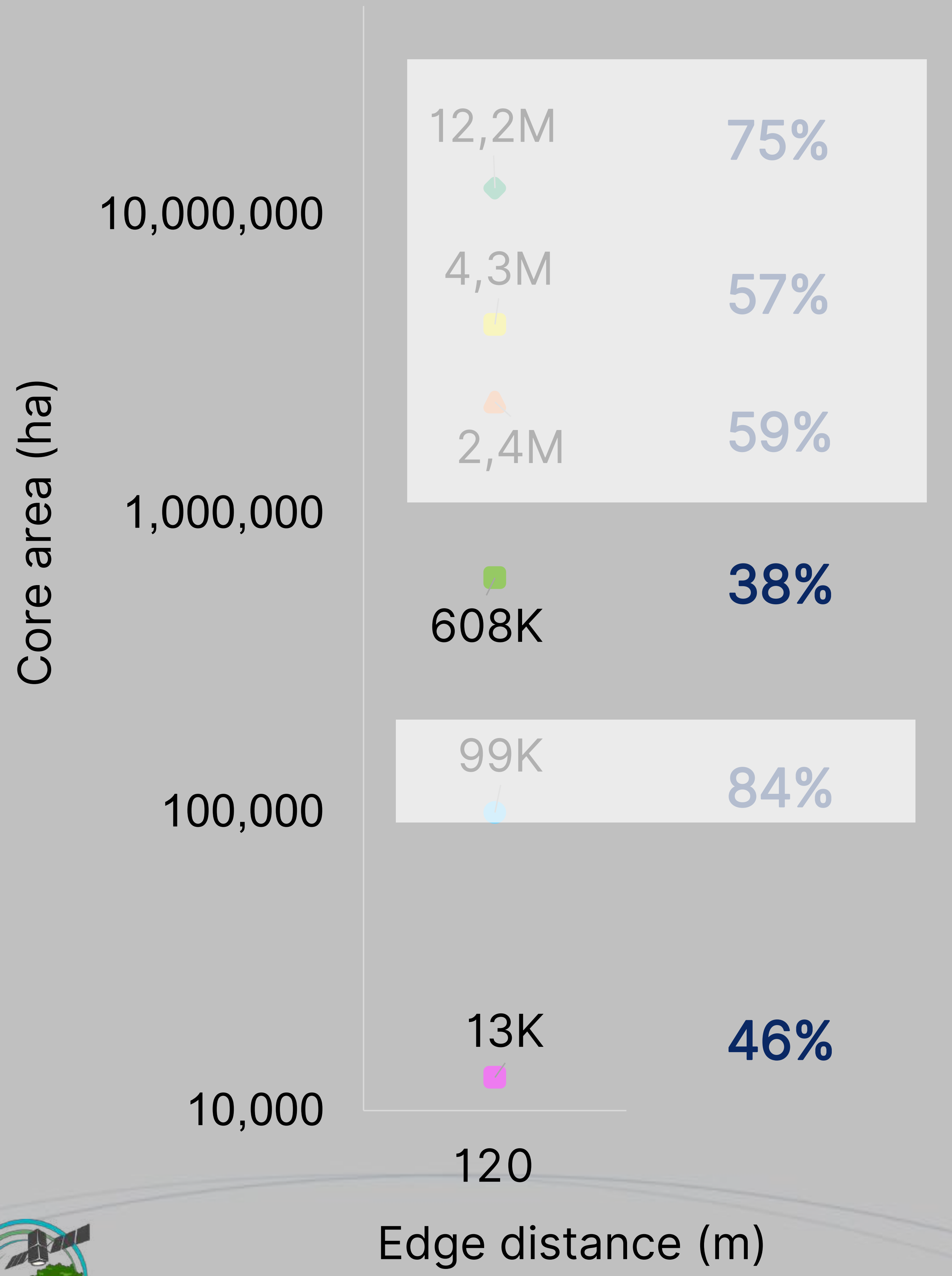
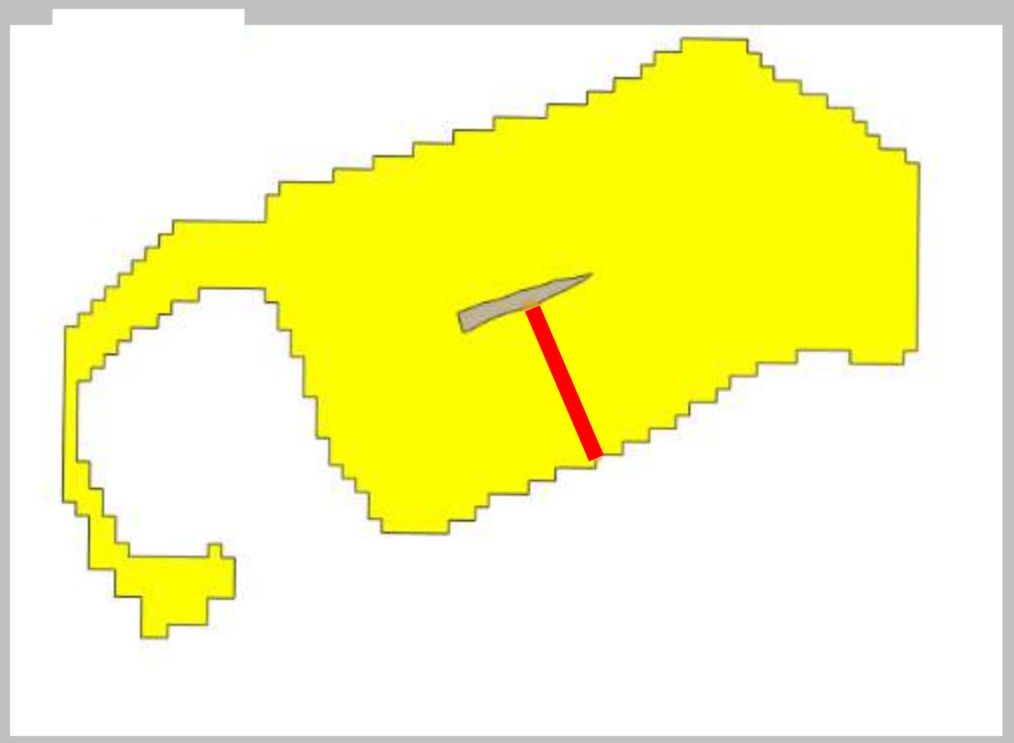
Core area (ha)

Proportion by biome



Smaller proportions
=
Smaller fragments
=
Greater edge effect*



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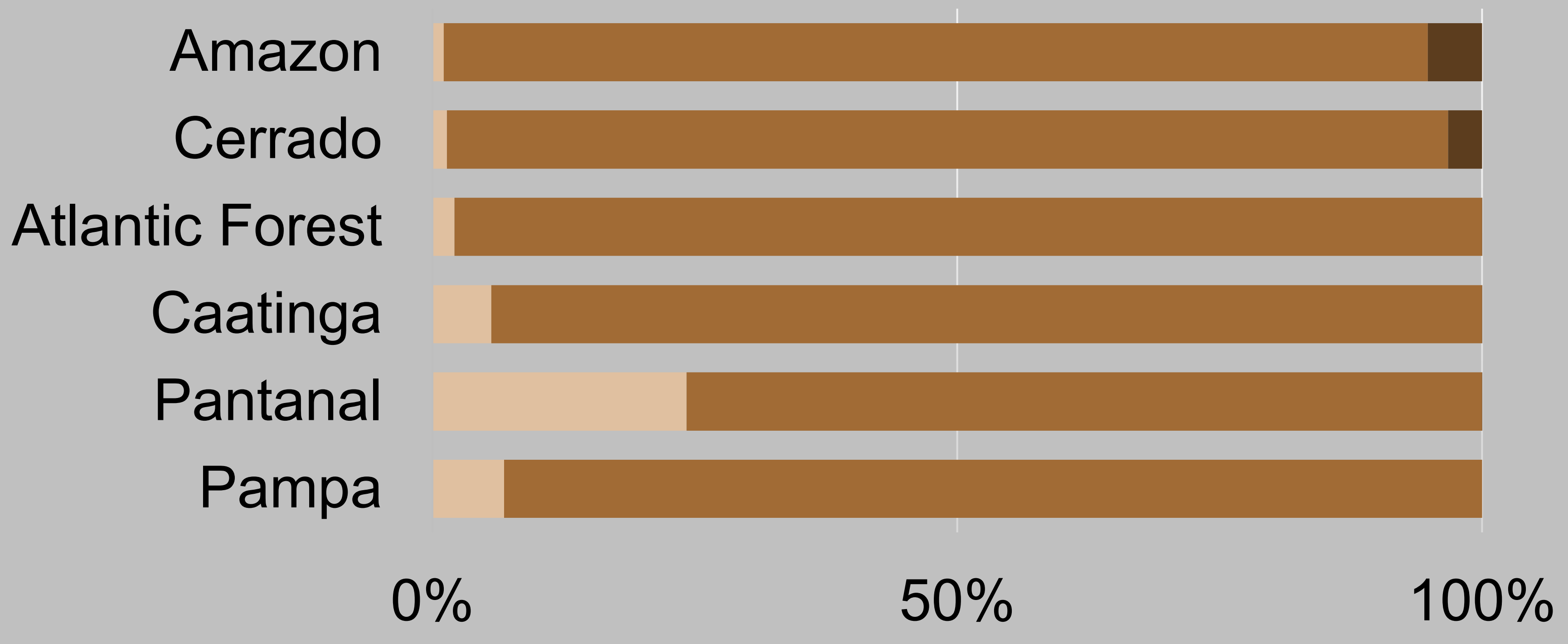
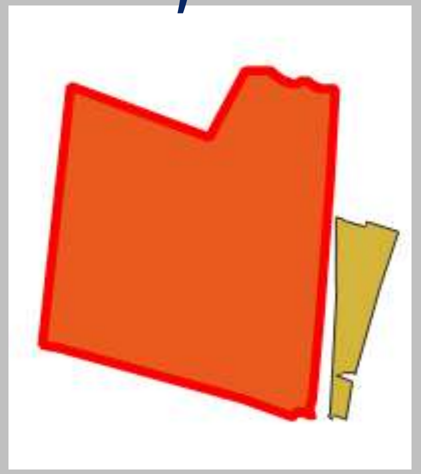
Fractal dimension index

Results

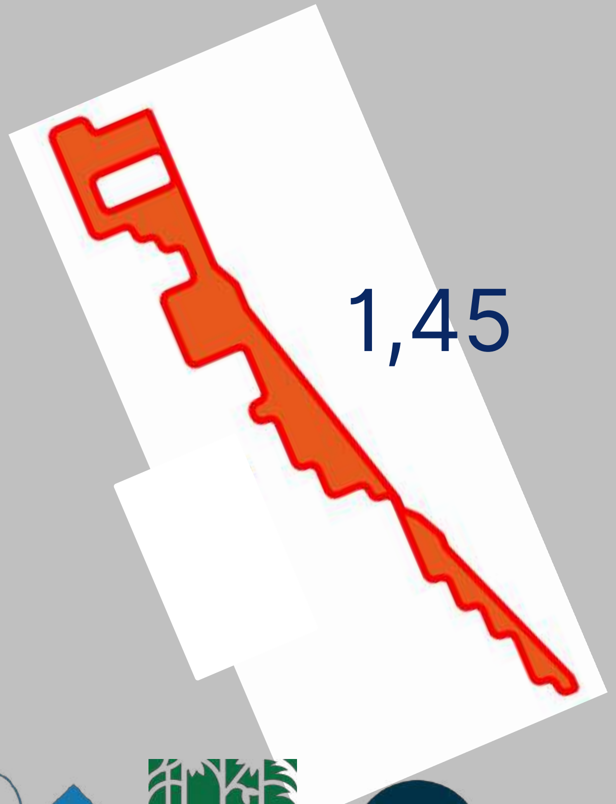


1,18



1,30

1,45



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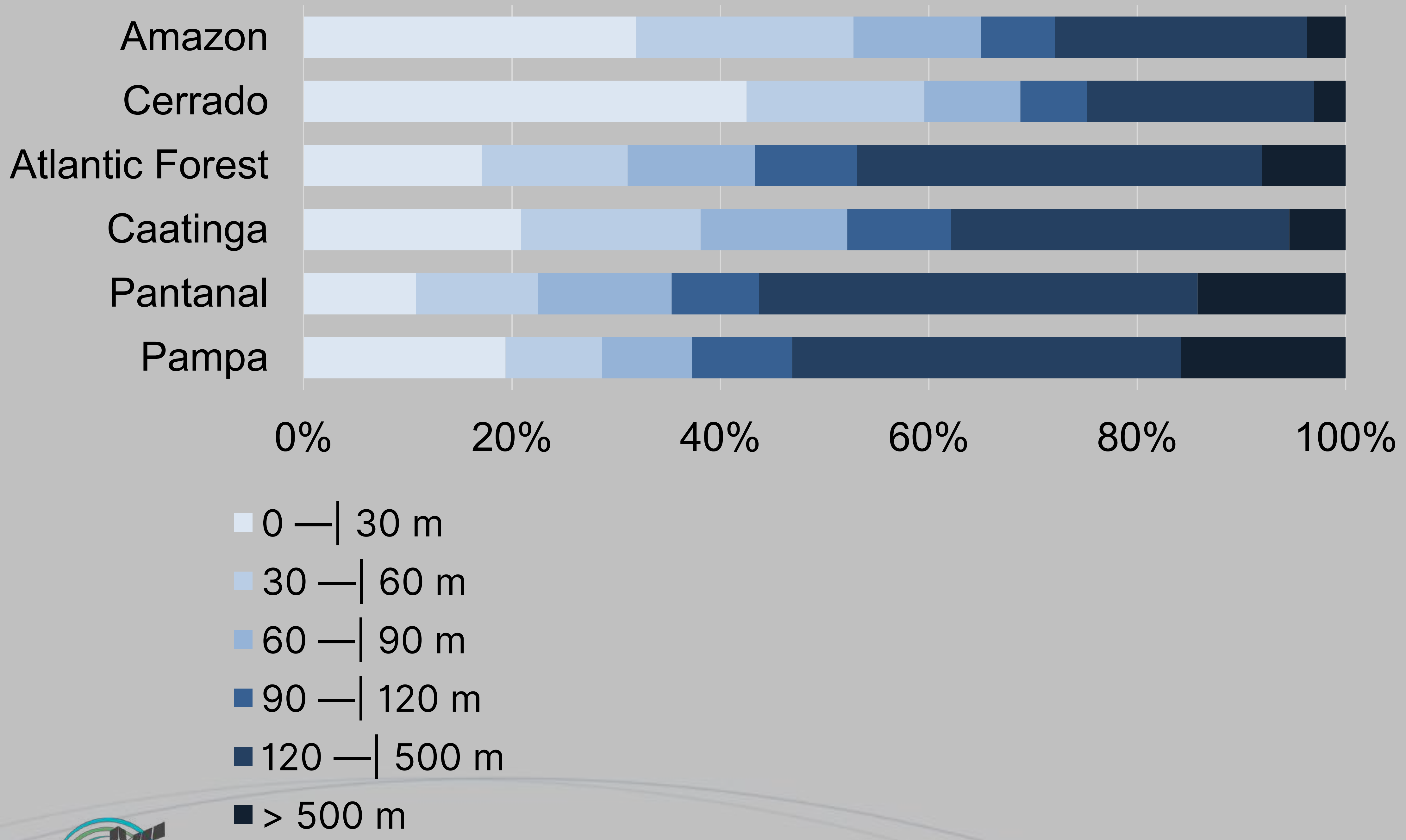
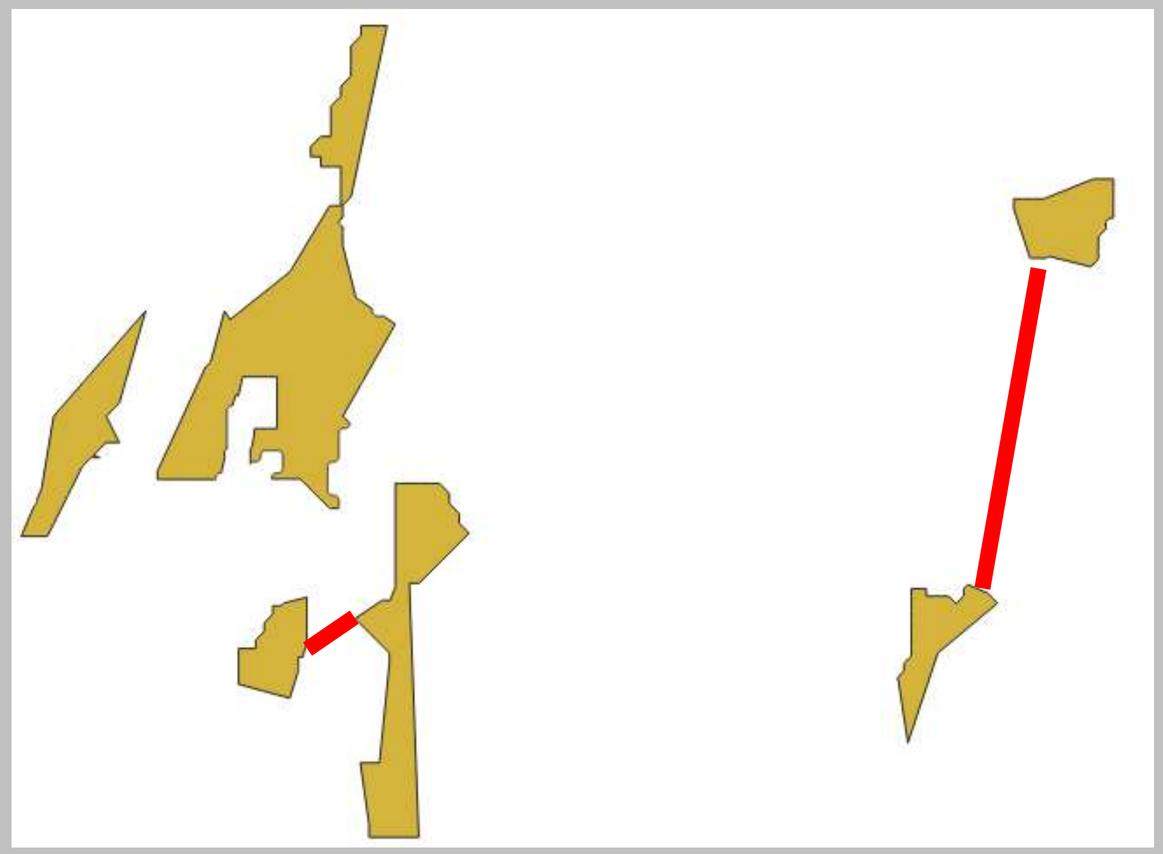
Distance to the nearest neighbor (m)

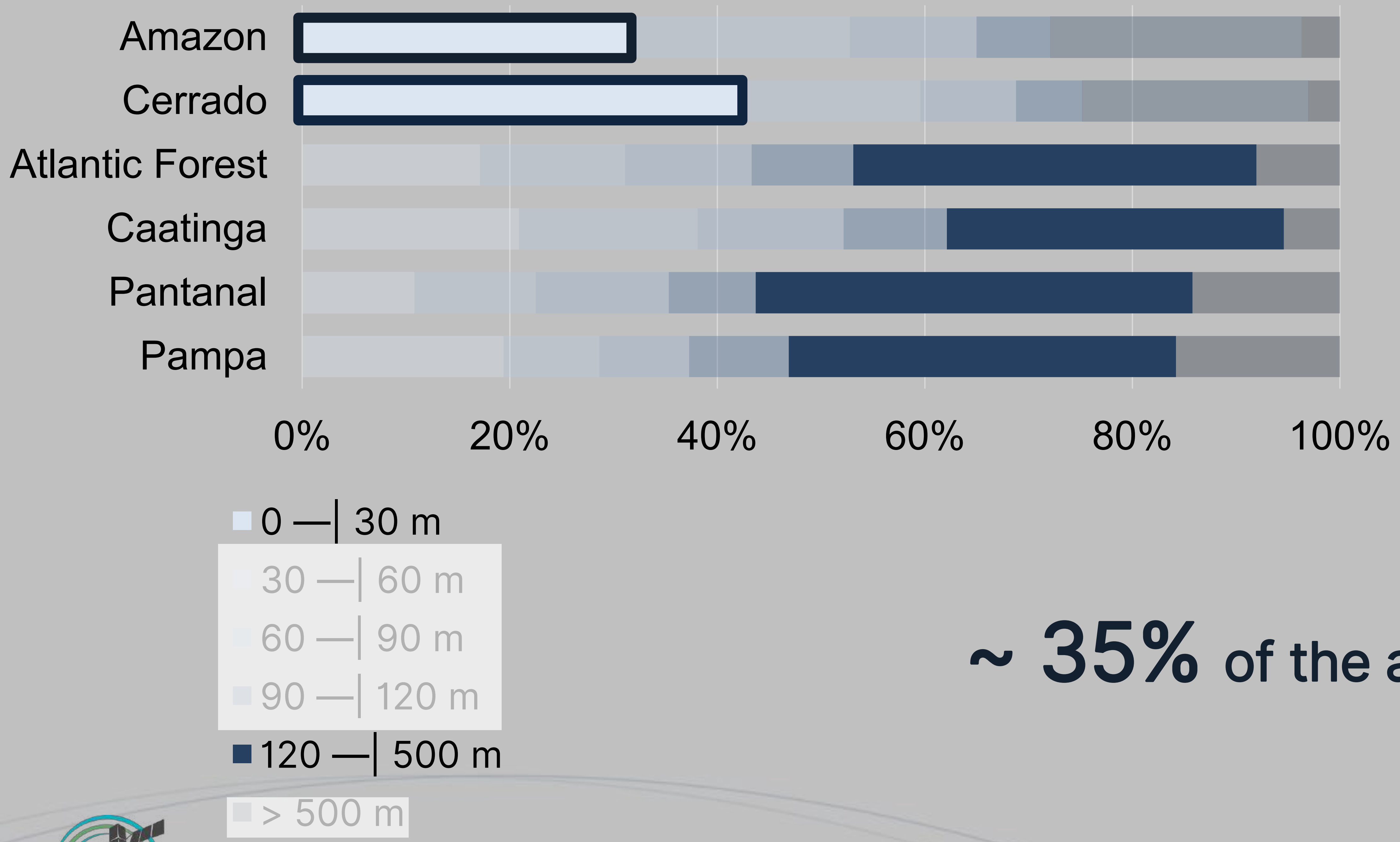
Results

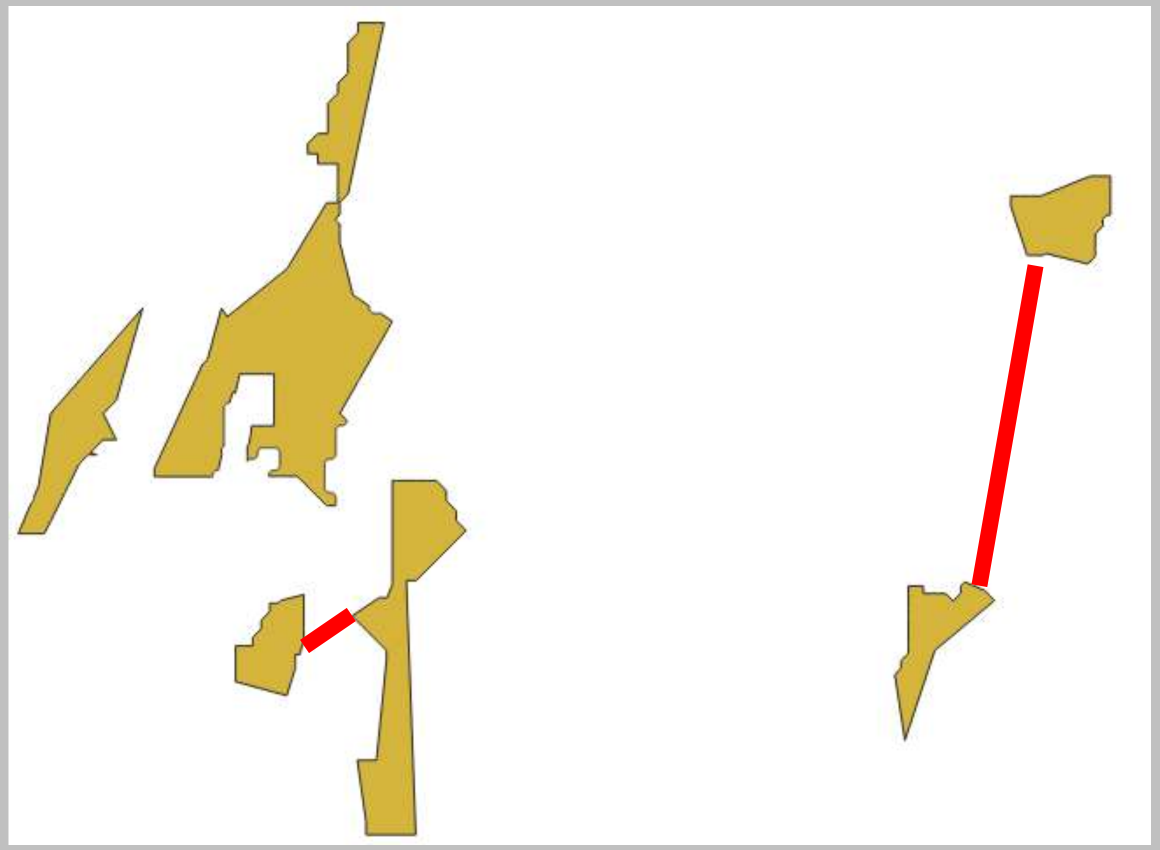




Distance to the nearest neighbor (m)

Results

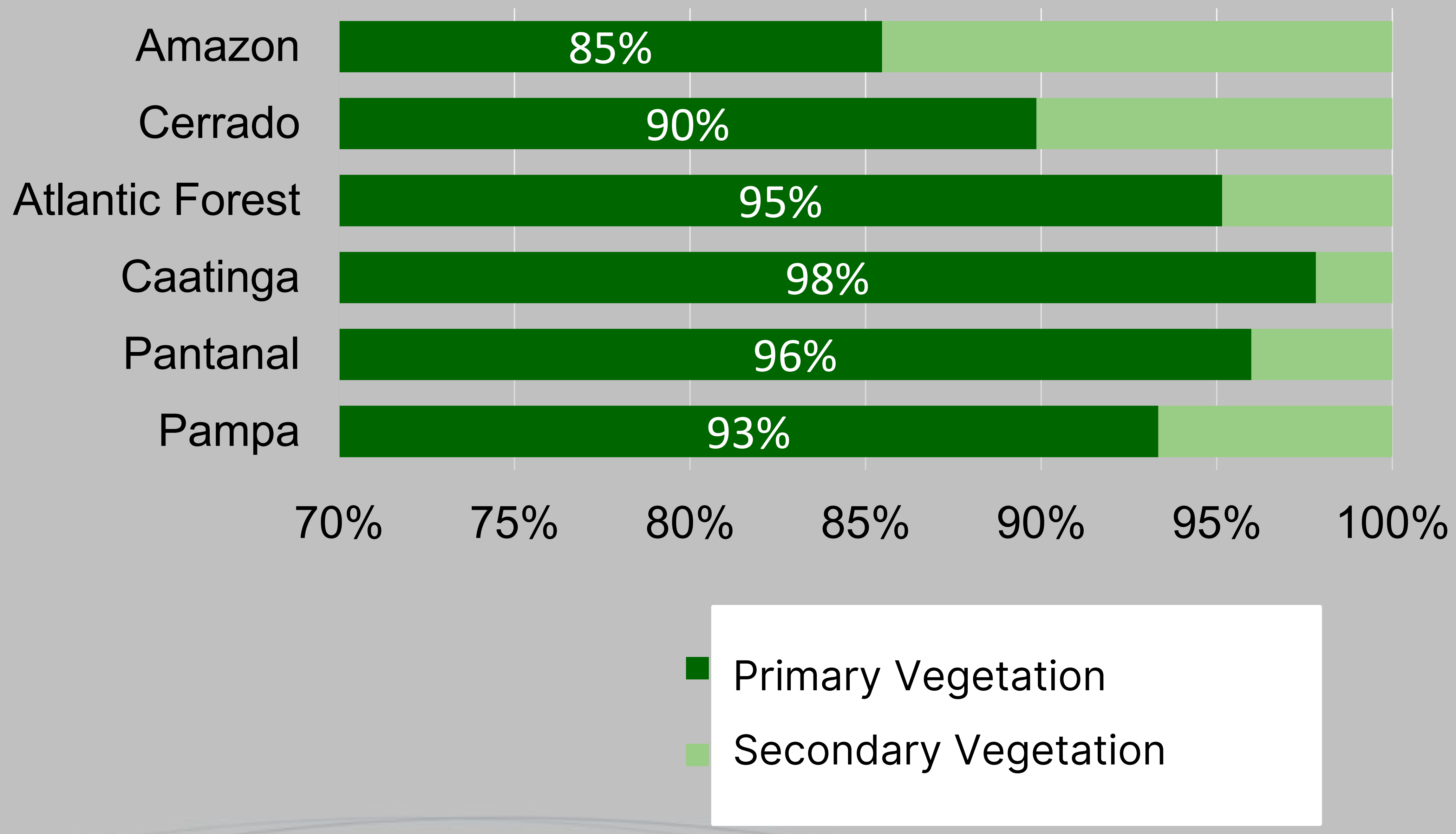


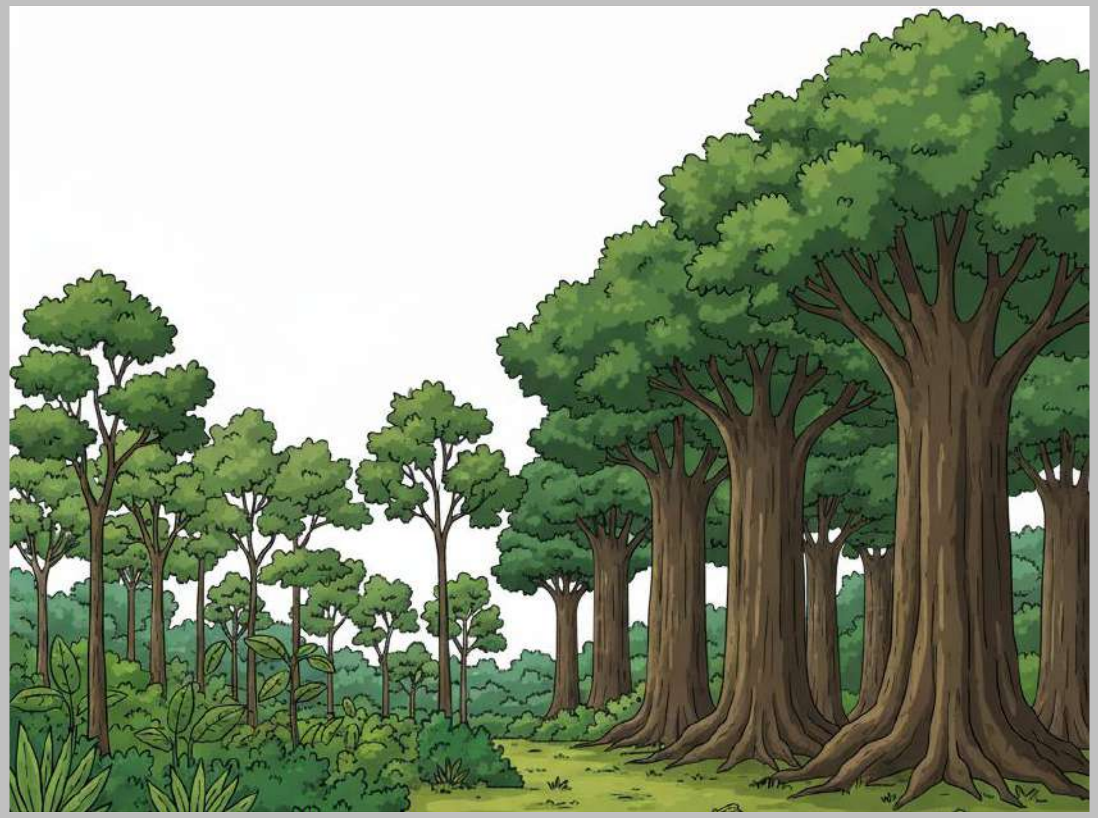


~ **35%** of the area

Type of nearest neighboring vegetation

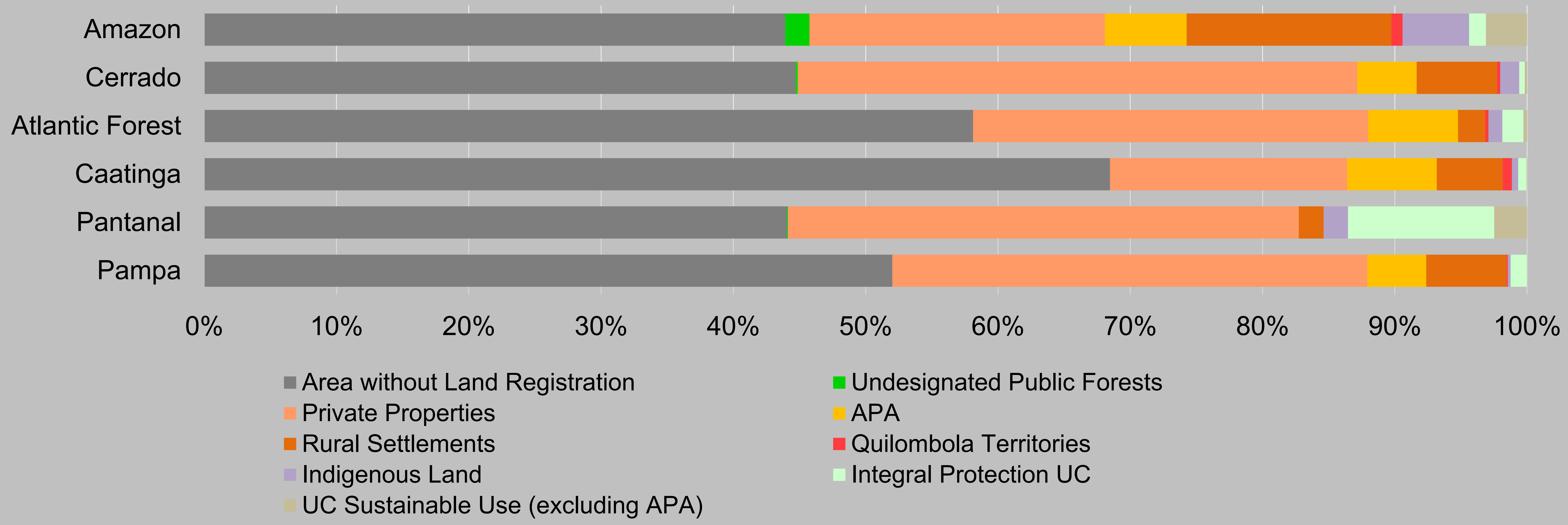
Results





Land Tenure

Results



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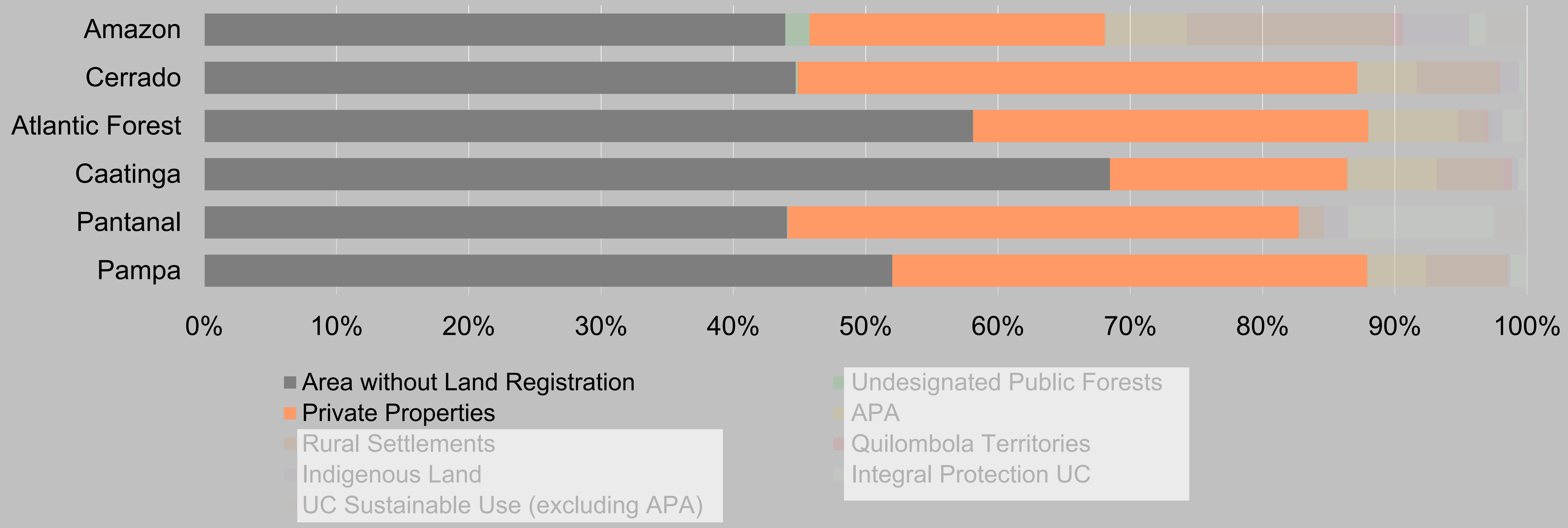
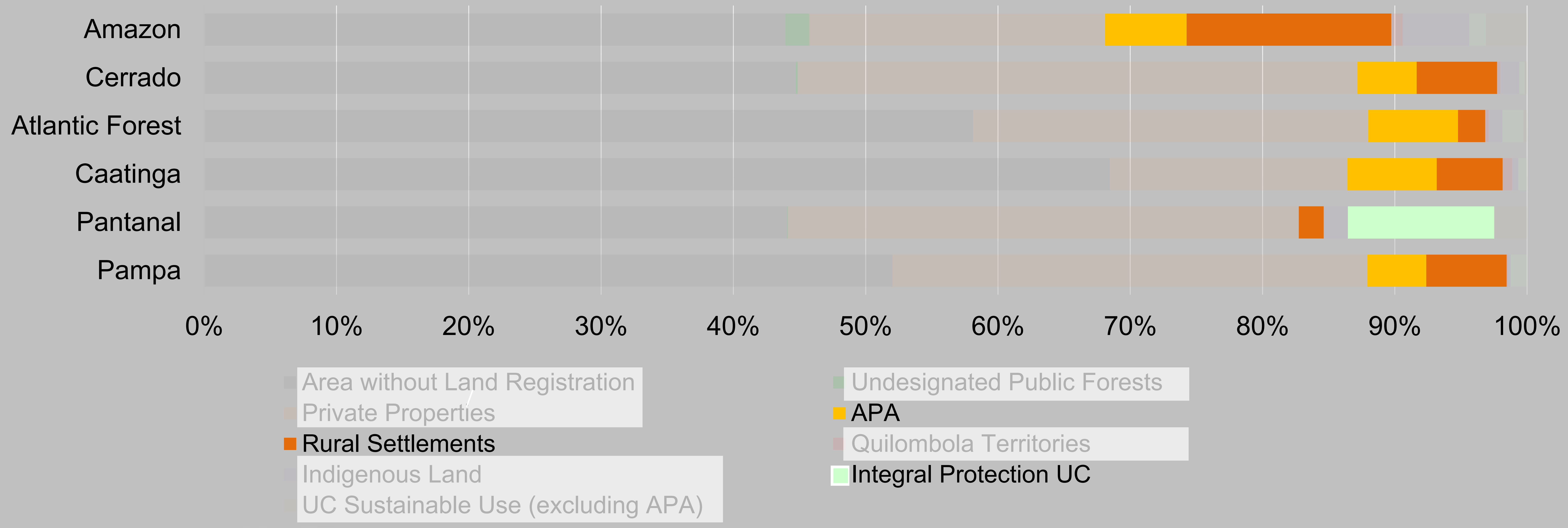
Land Tenure

Results



Land Tenure

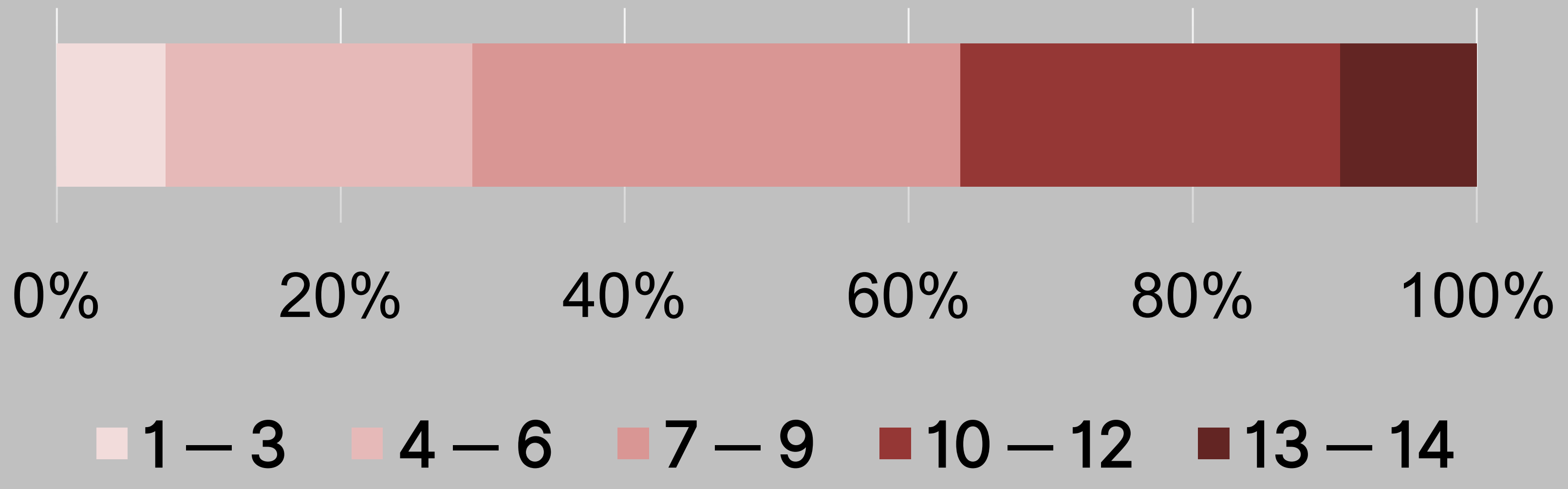
Results

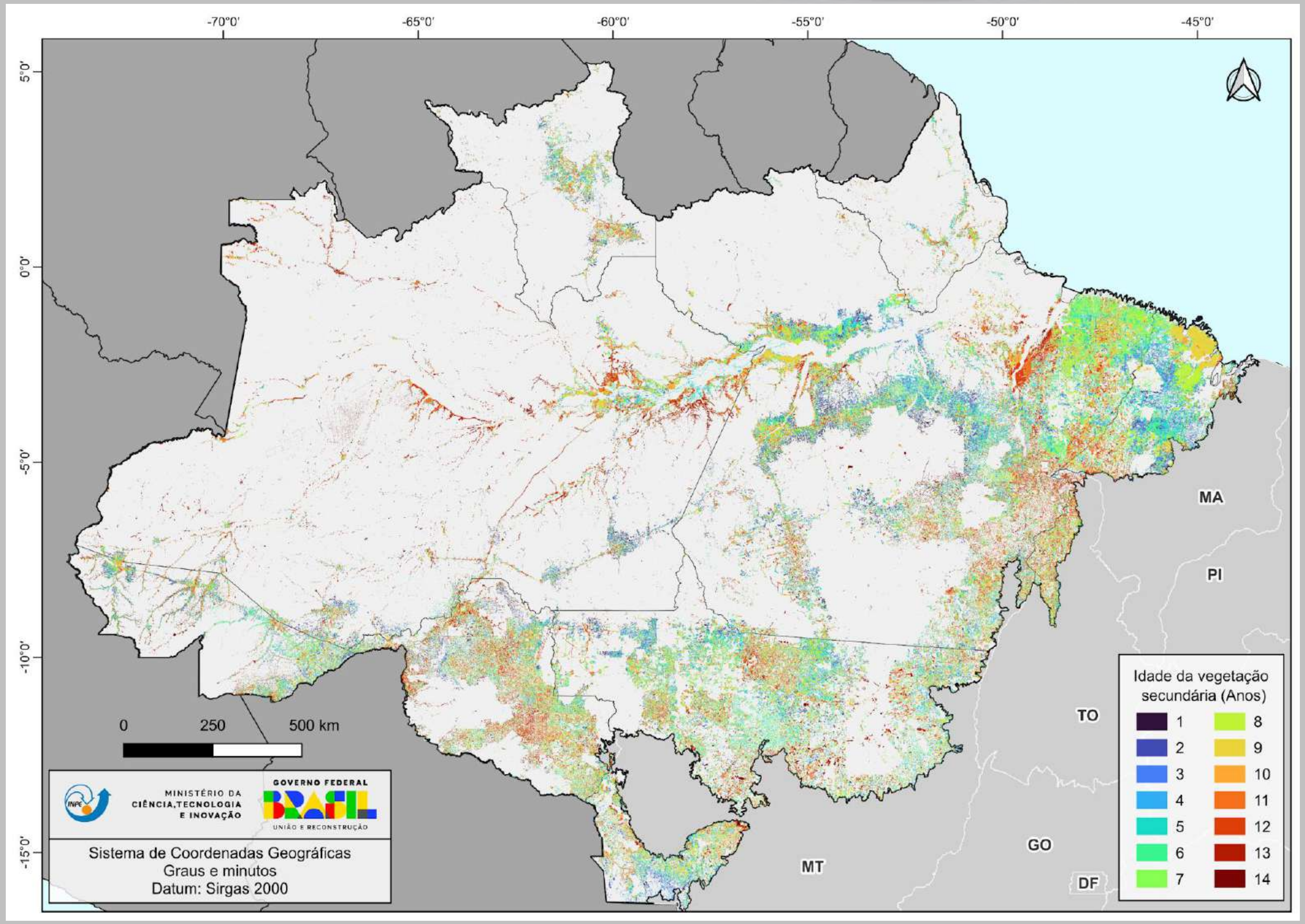


Age

Results

Amazon





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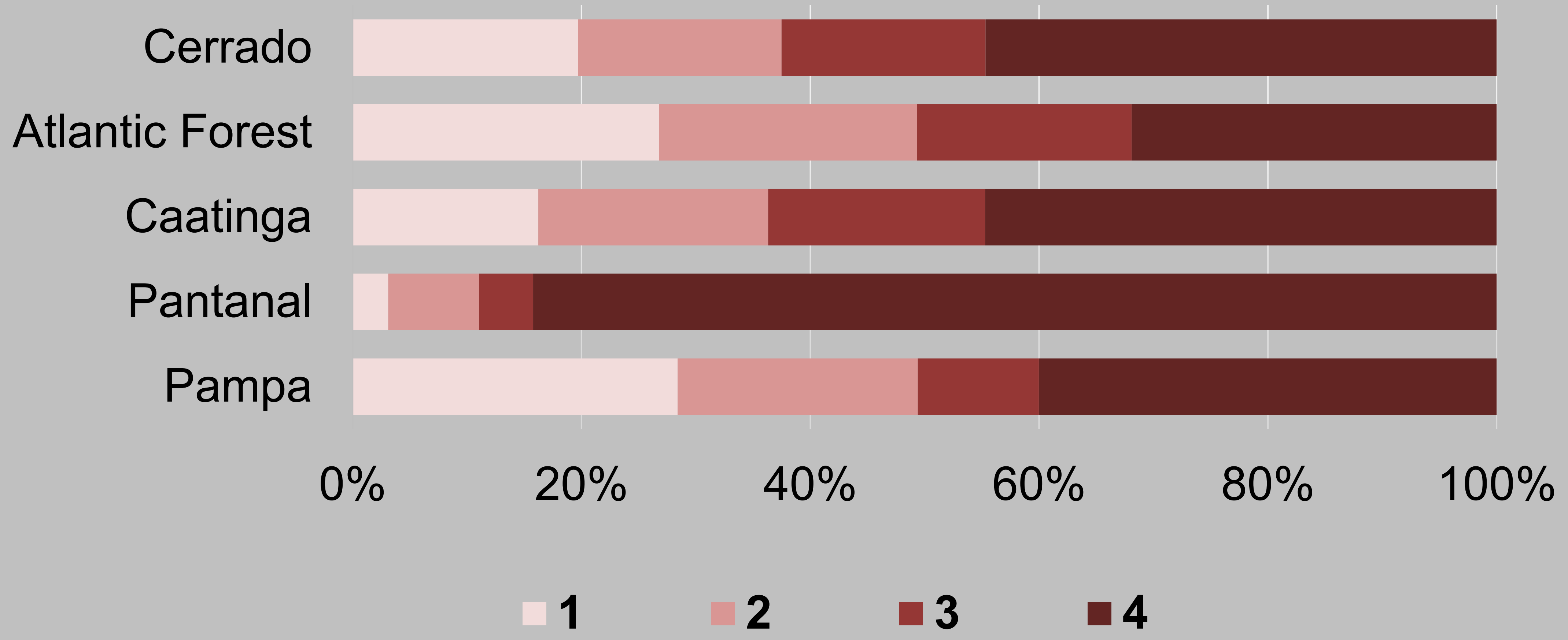
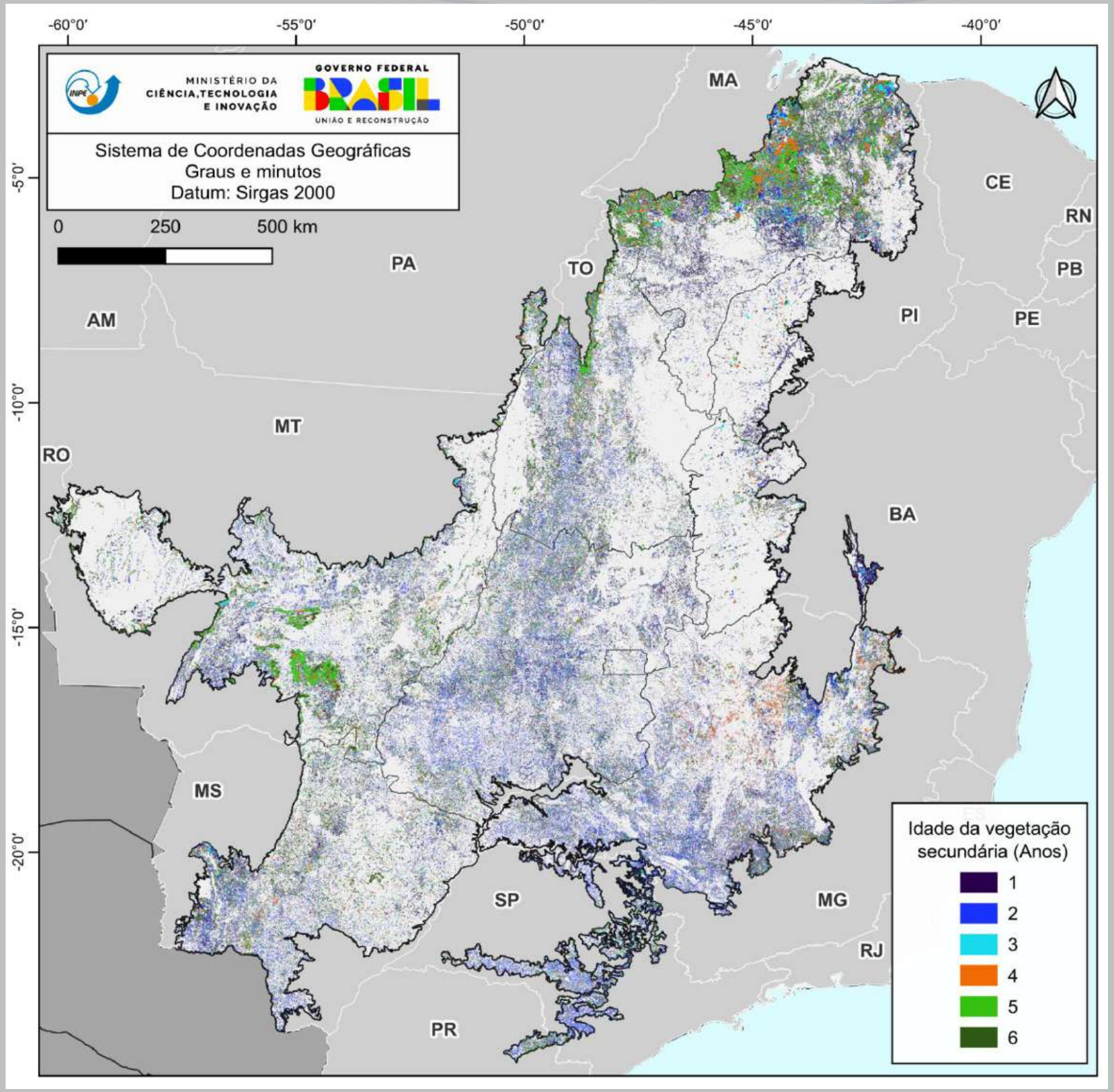
Age

Results





Cerrado

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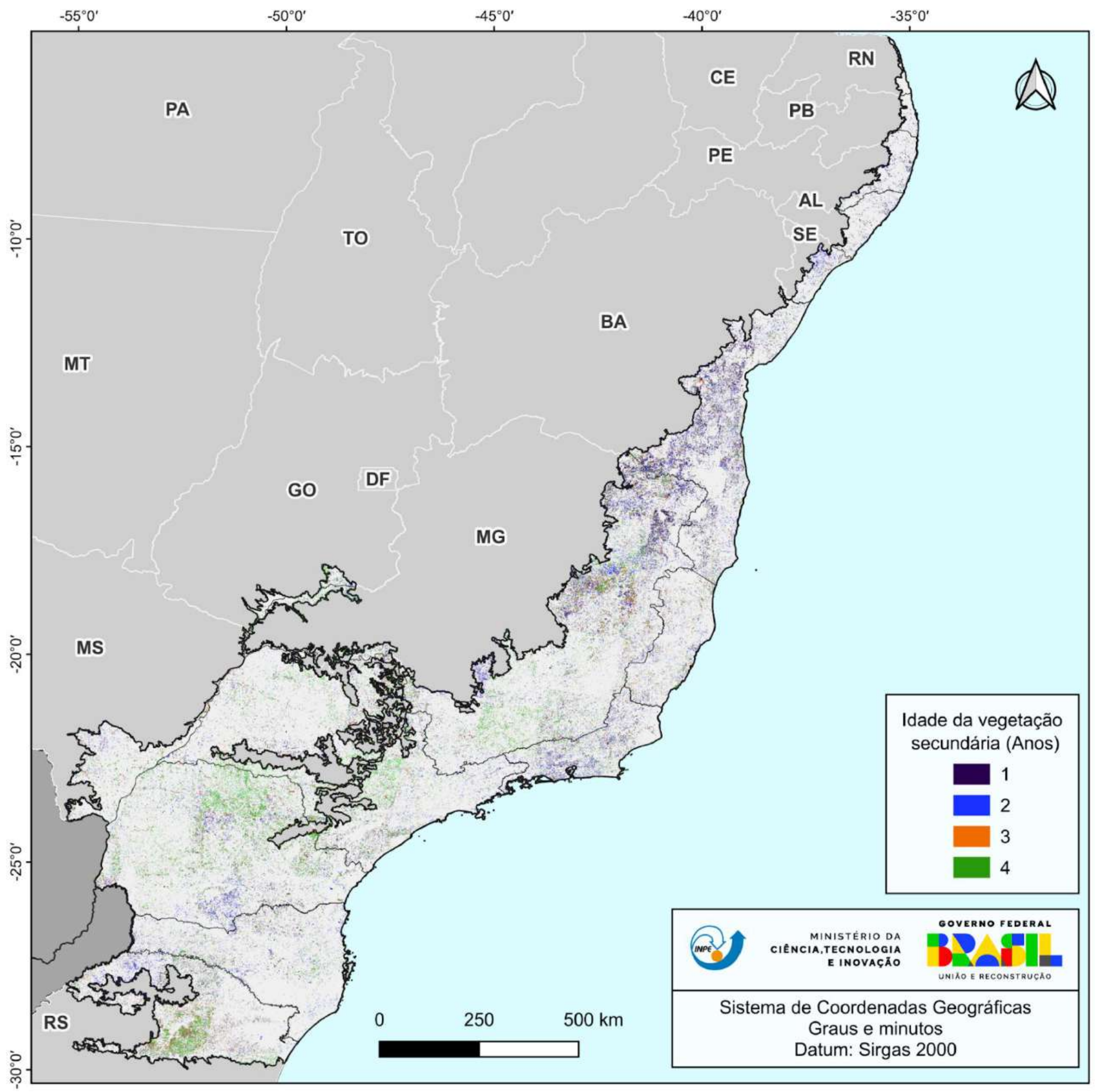
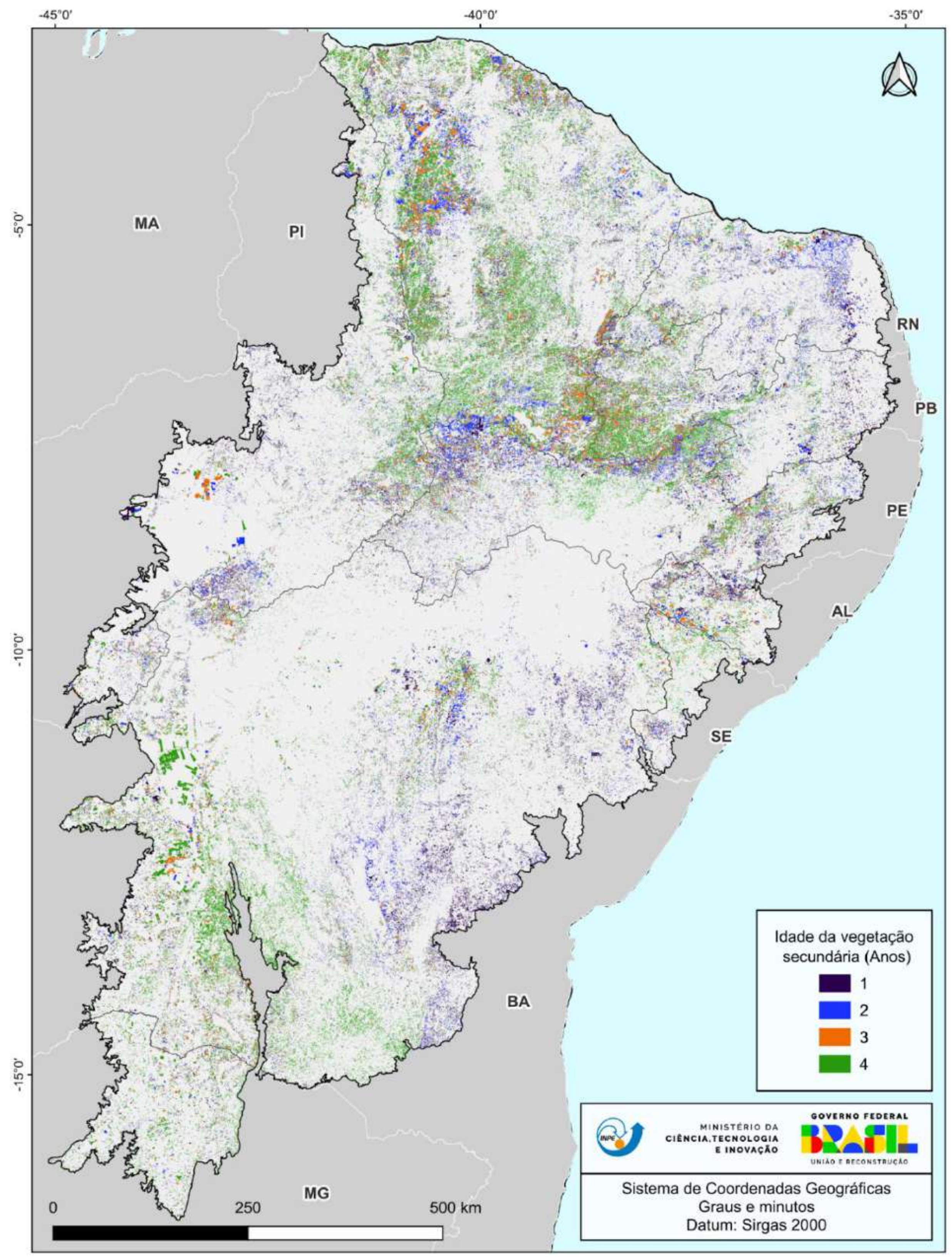
Atlantic Forest



Caatinga



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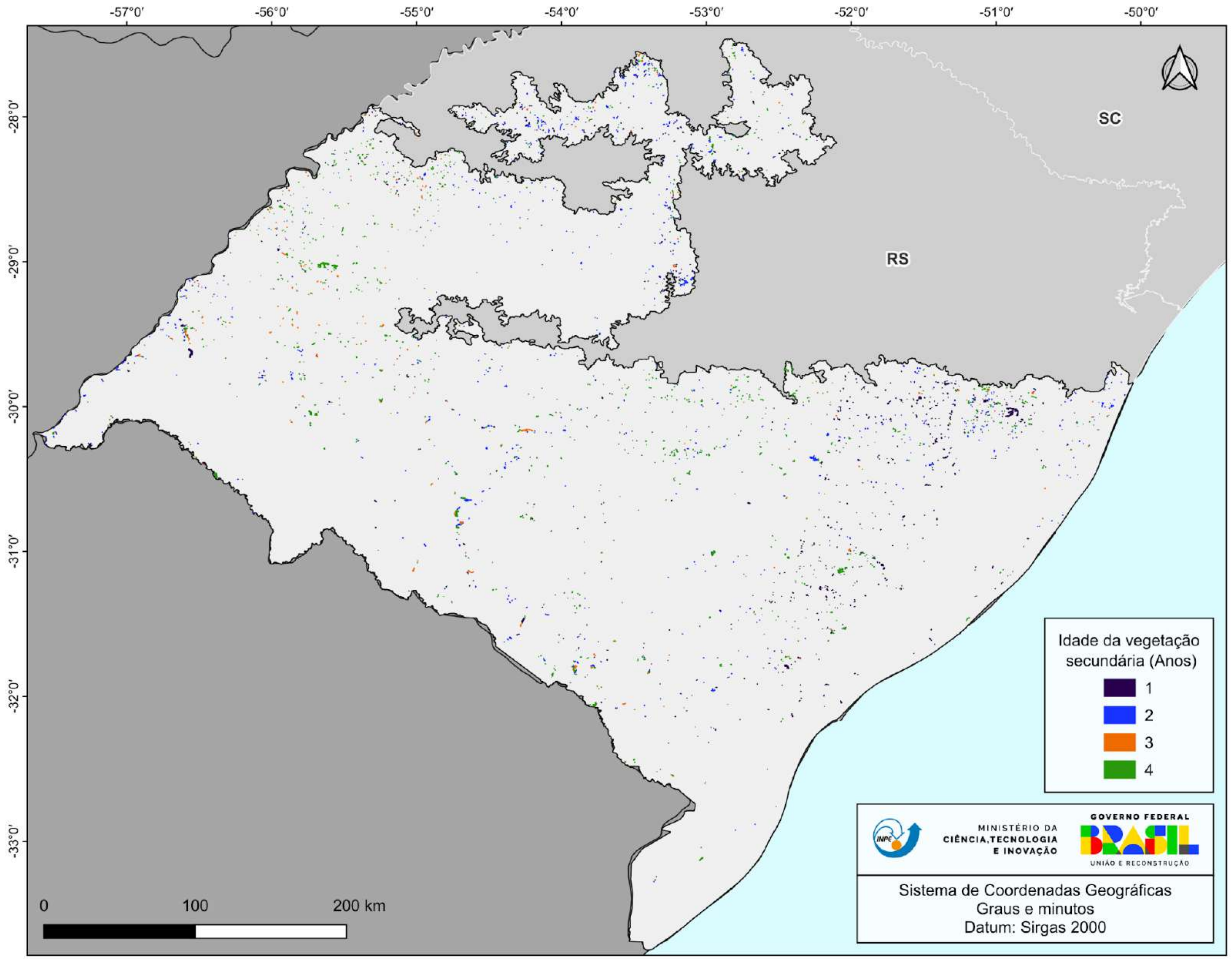
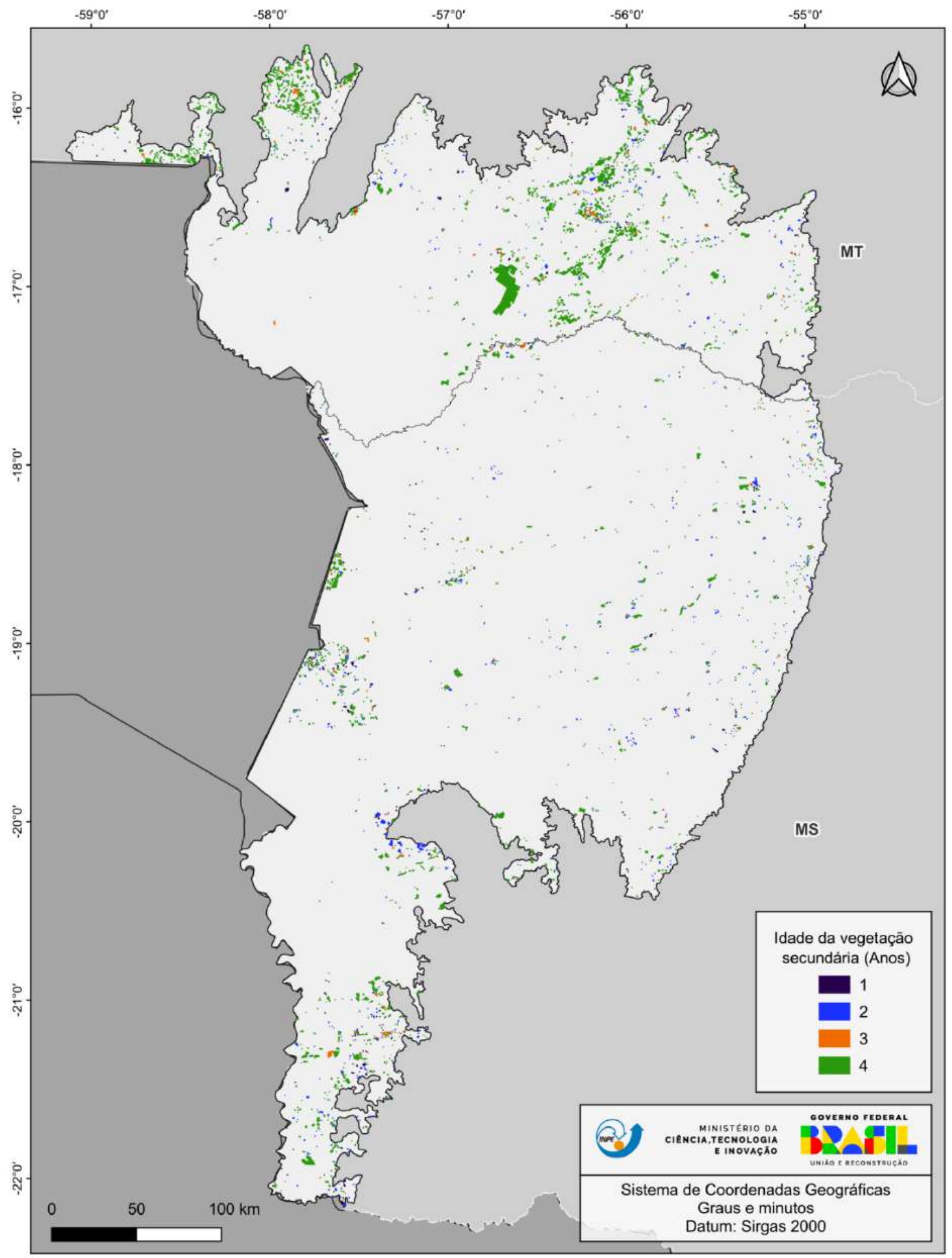
Pampa



Pantanal



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Thank you!

Obrigada!

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MEIO AMBIENTE E
MUDANÇA DO CLIMA

GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

INPE
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÕES
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

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Forest regeneration and the climate regulation ecosystem service in the Amazon

Lais Oliveira

Session 2.2: Other metrics for identifying secondary forest success

São José dos Campos, 30 Oct 2025

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Contextualization

Biogeochemical and biogeophysical process

LULC changes

- Biogeochemical
  - Greenhouse gases
  - Aerosols
  - Pollutants
- Biogeophysical
  - Heat fluxes
  - Water fluxes
  - Wind (direction and magnitude)

↑ LULC changes ↑ Process ↓ **Climate stability**
Ability of forests to regulate climate

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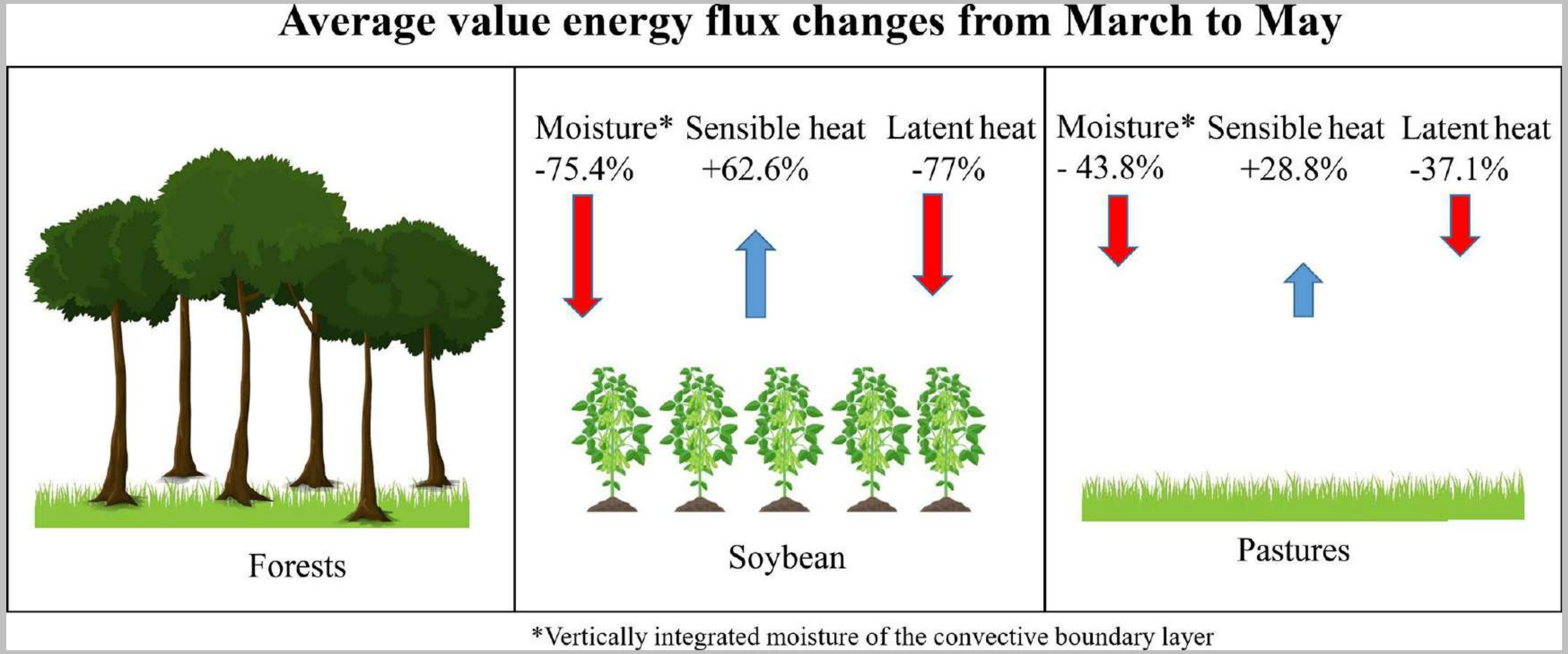
Contextualization

Climate regulation → Energy and water balance

- Different Land covers → different fluxes
- Soybean and Pastures:

Moisture and latent heat

Sensible heat



Zhang *et al.*, (2023)

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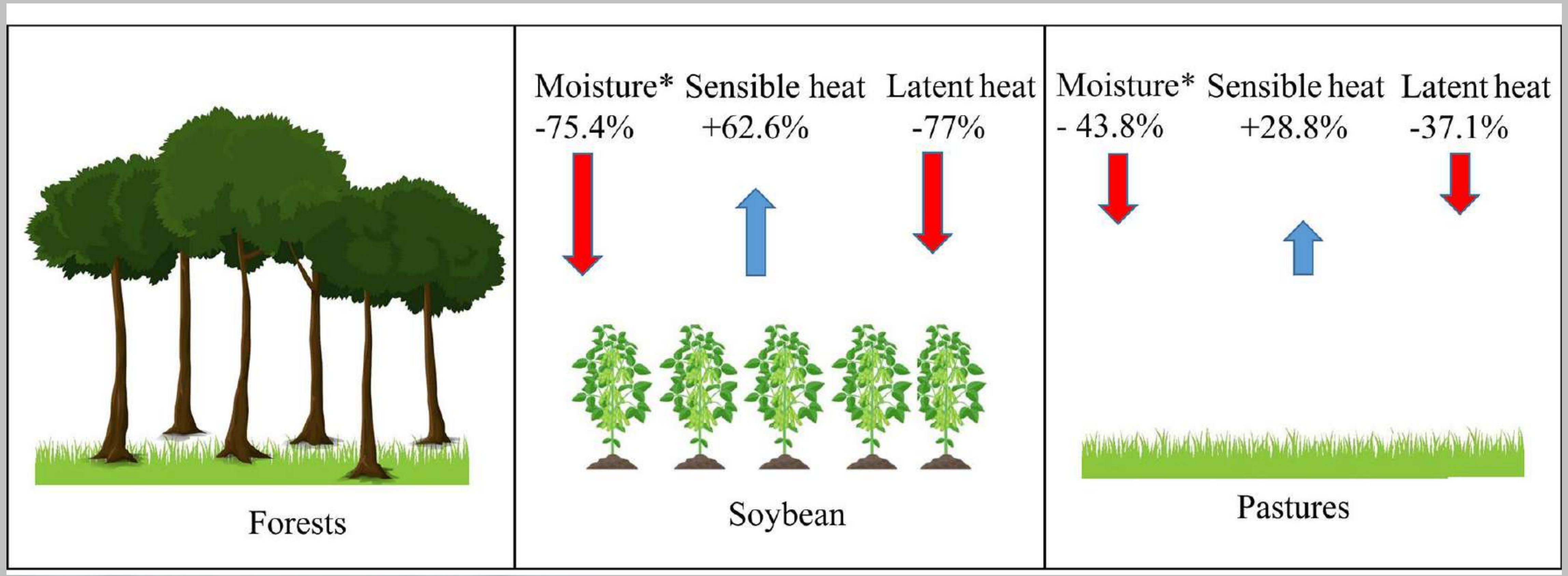
Main question

Can secondary forests (SF) regulate local climate with the same potential as primary forests (PF)?



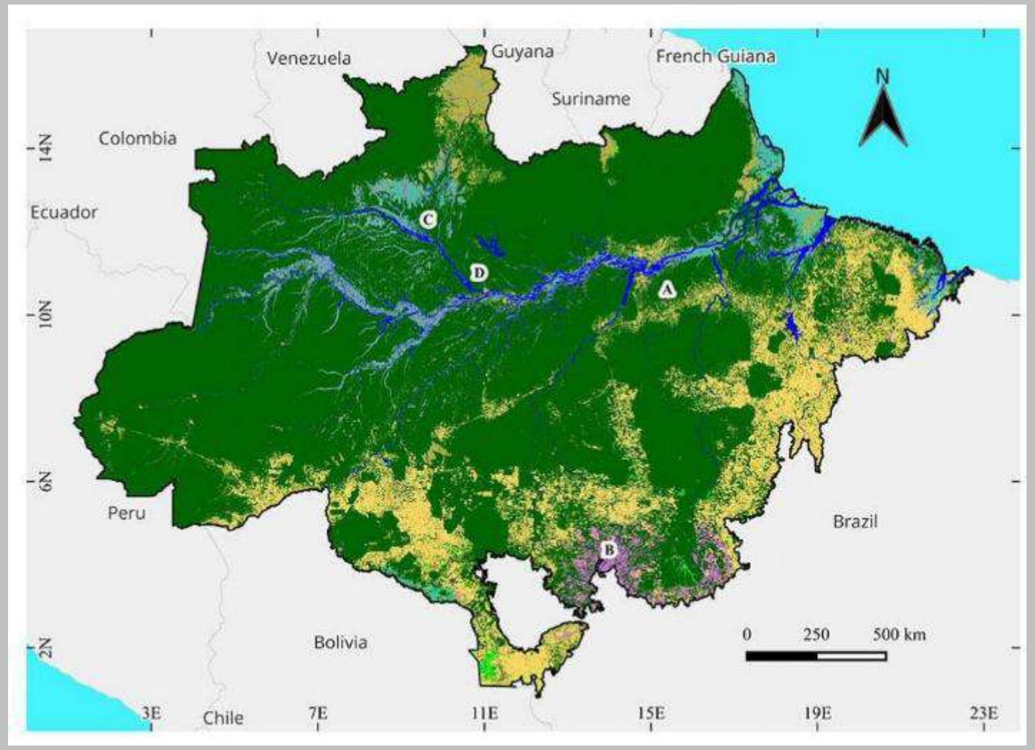
Zhang *et al.*, (2023)

Secondary forests

Study area

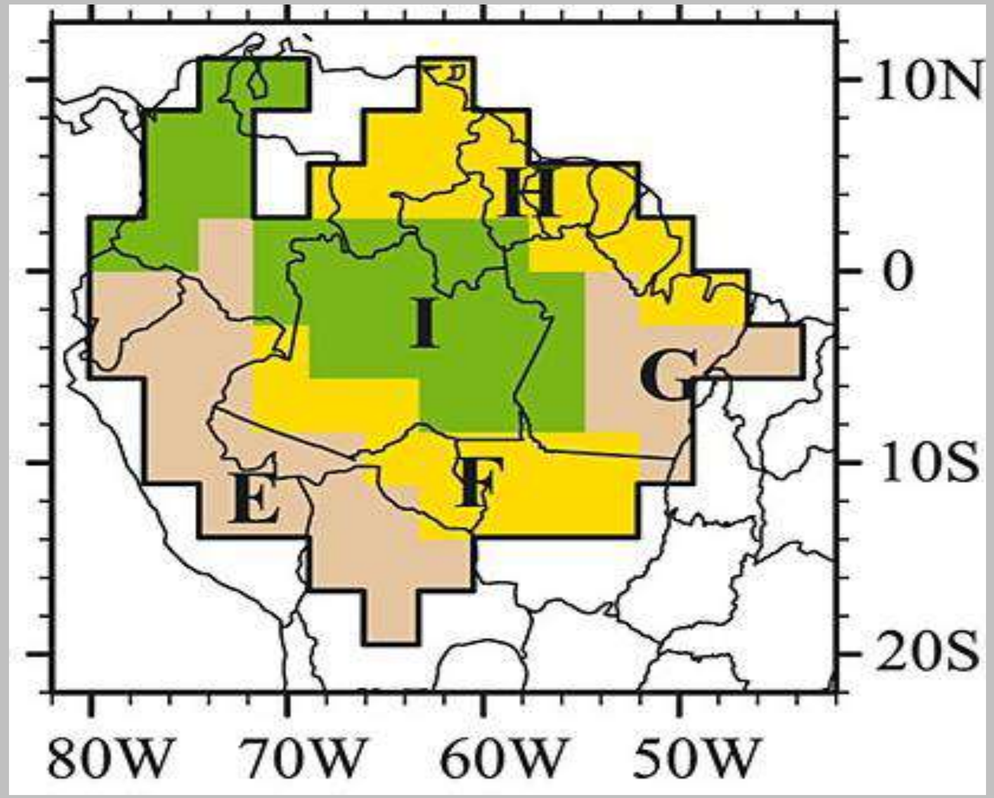
Different patterns

Land use change



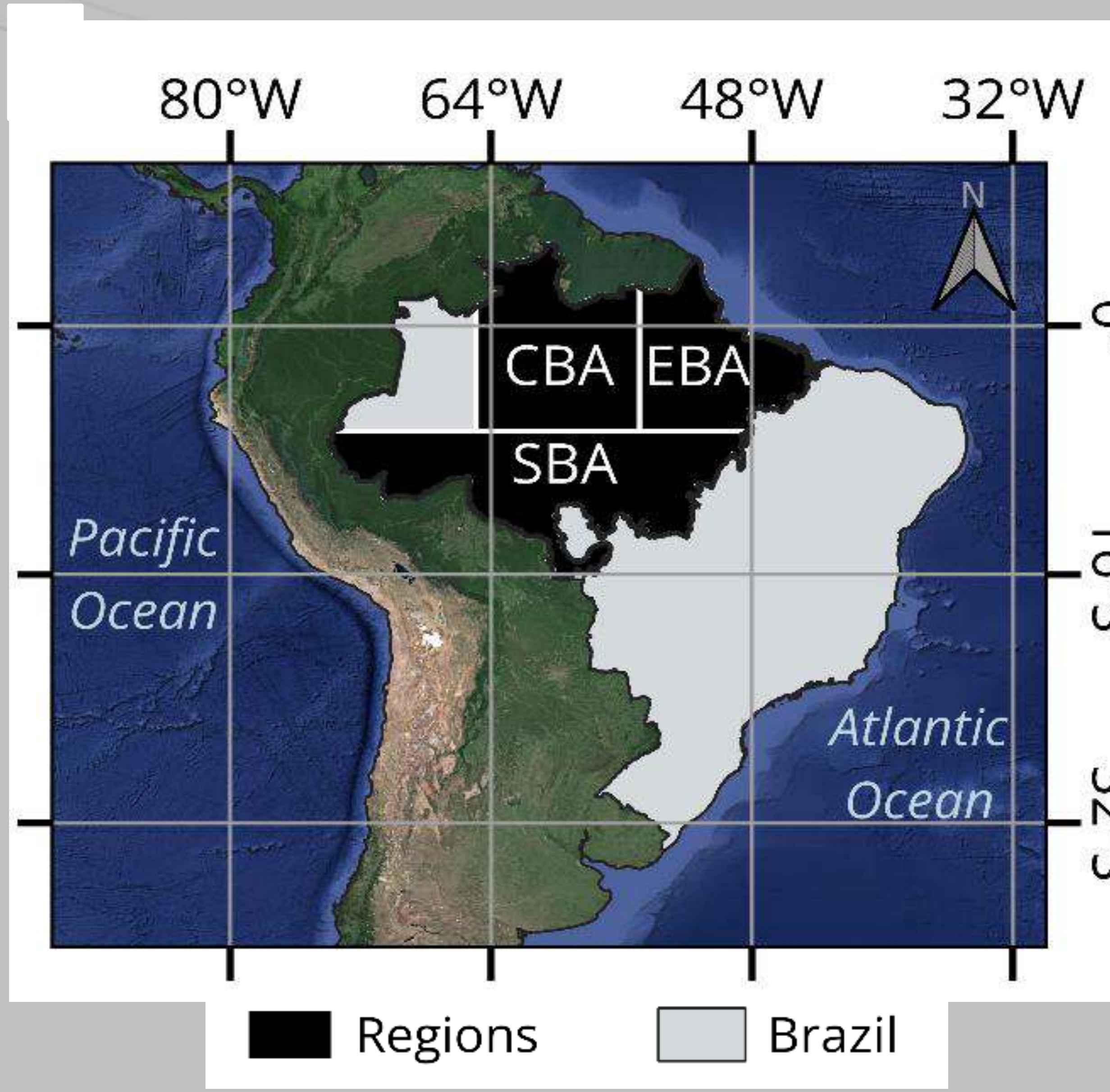
Adapted of Souza Jr. *et al.*, (2023)

Bioclimatic regions



Pires & Costa (2013)

- Remains in forest bioclimatic equilibrium
- Tendency to bioclimatic seasonalization
- Bioclimatic savannization



Central Brazilian Amazon (CBA)
Eastern Brazilian Amazon(EBA)
Southern Brazilian Amazon (SBA)

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What we are developing

Analysis

Descriptive

Understand the *behavior* of *observed data*

Inferencial

Test the *consistency* and *significance* of empirically observed relationships

Variables

Precipitation

Evapotranspiration

Land surface temperature

X

Fracional forest cover

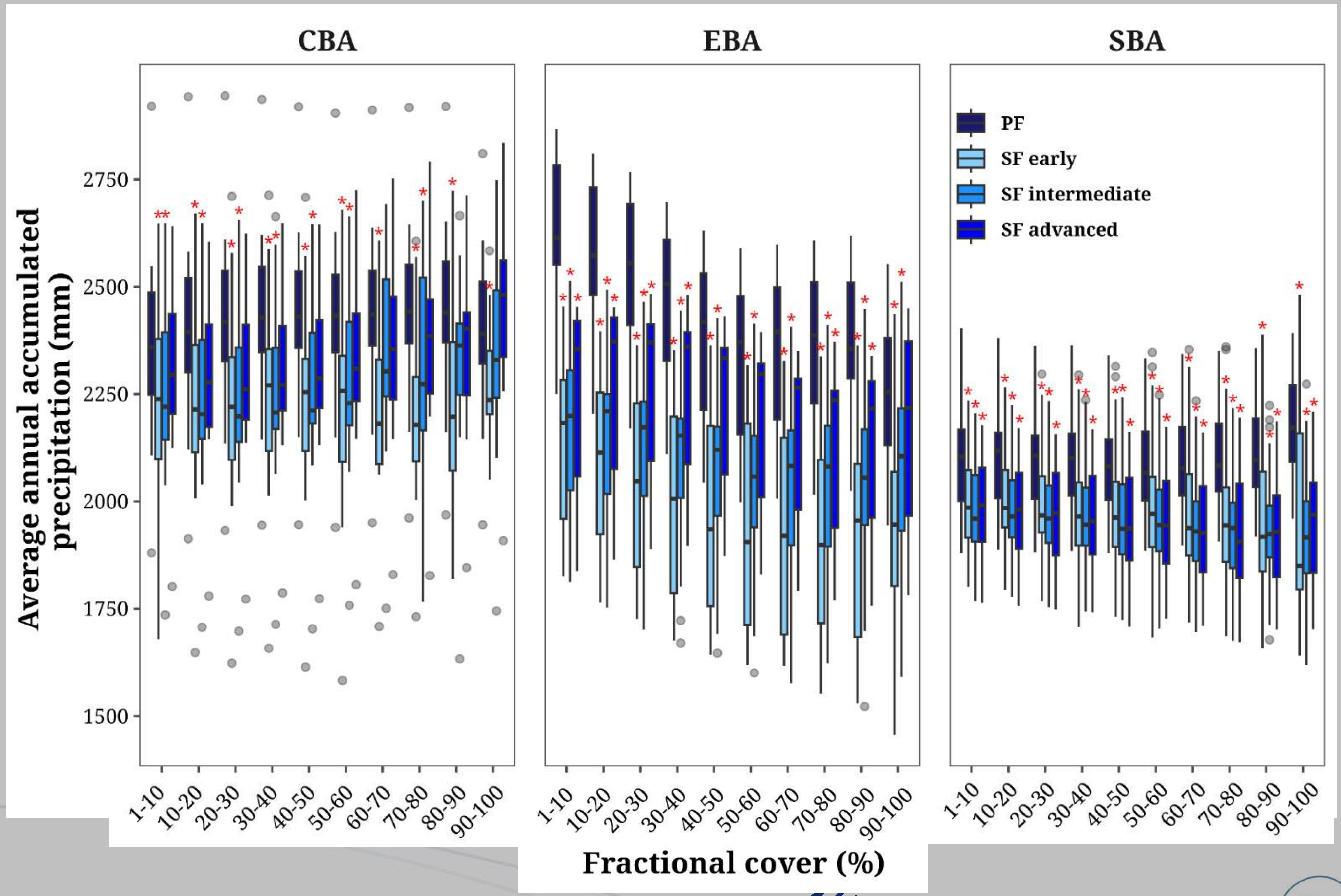
Primary

Secondary

- Early
- Intermediary
- Advanced

Our discovers

Observed data - Precipitation



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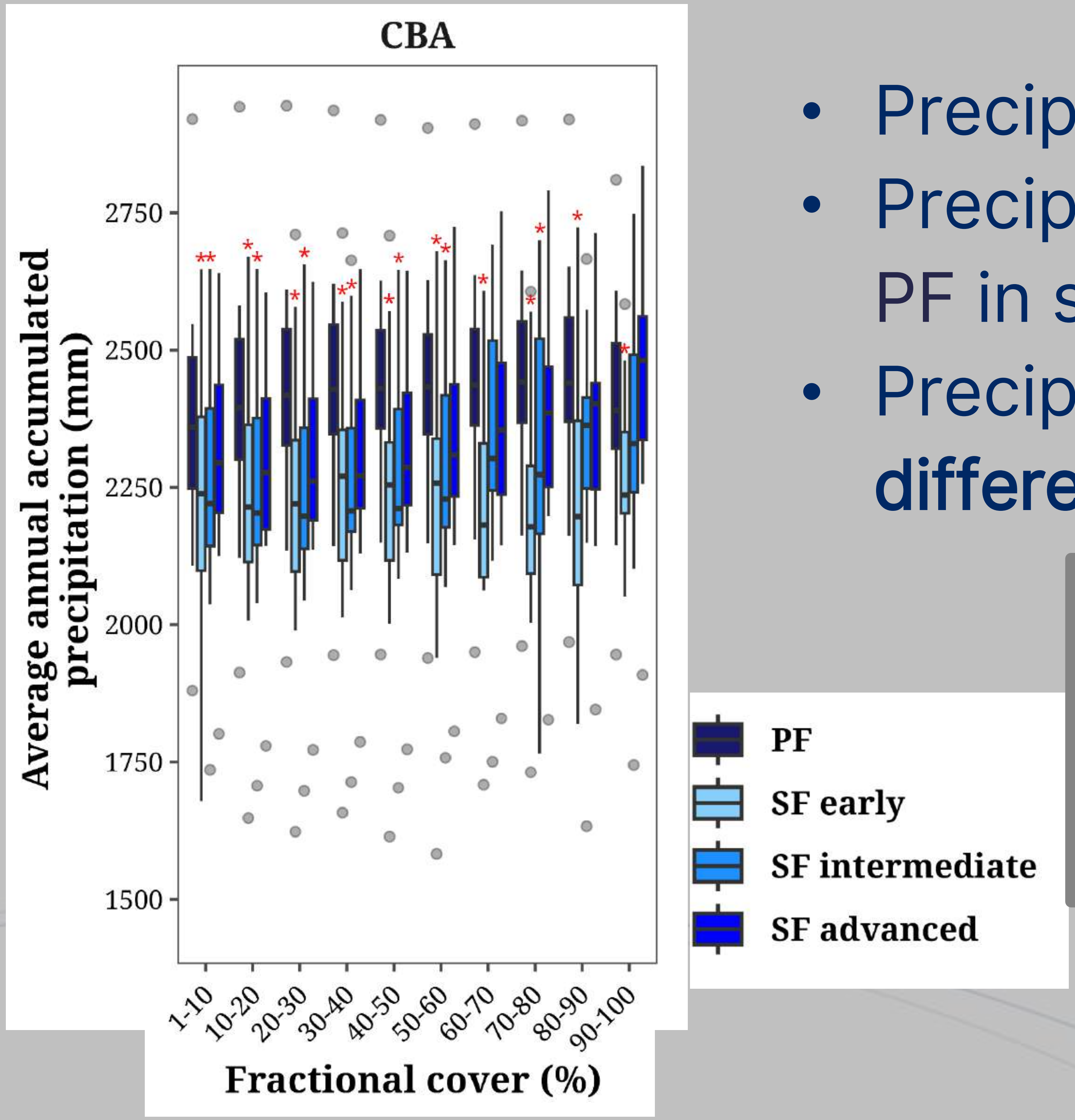
Our discovers

Observed data - Precipitation



- Precipitation in SF early **is lower** than in PF
- Precipitation in SF intermediary **is lower** than in PF in some forest fractional cover ranges
- Precipitation in SF advanced **not statistically different** of PF

The ability of SF to regulate climate like PF **increases** with both **fractional cover** and **successional stage** advancement

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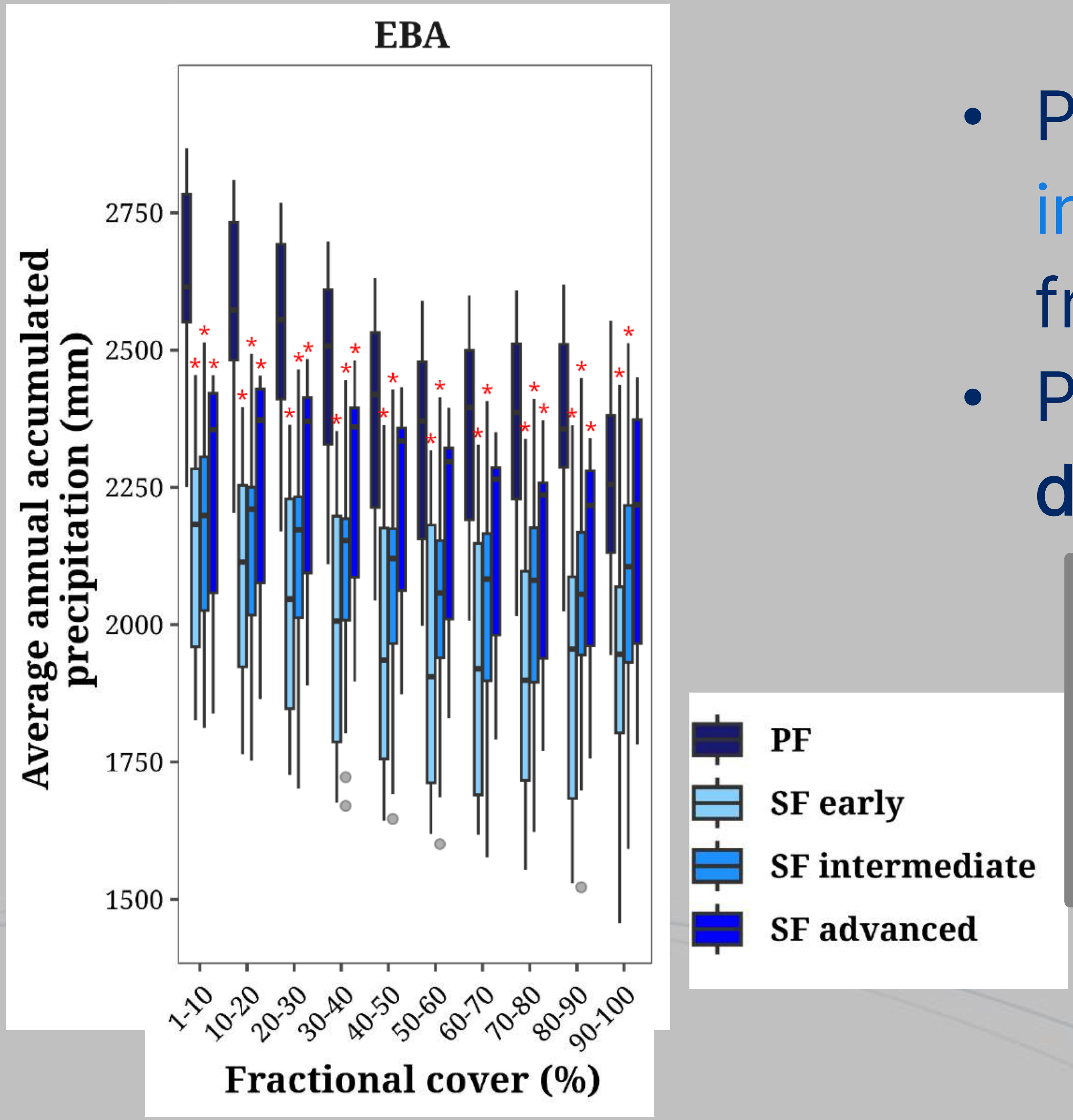
Observed data - Precipitation



- Precipitation in SF early and SF intermediary **is lower** than in PF in all forest fractional cover ranges
- Precipitation in SF advanced **not statistically different** of PF in same ranges

Even in the intermediary stage, SF **still cannot** reach the climate regulation potential of PF

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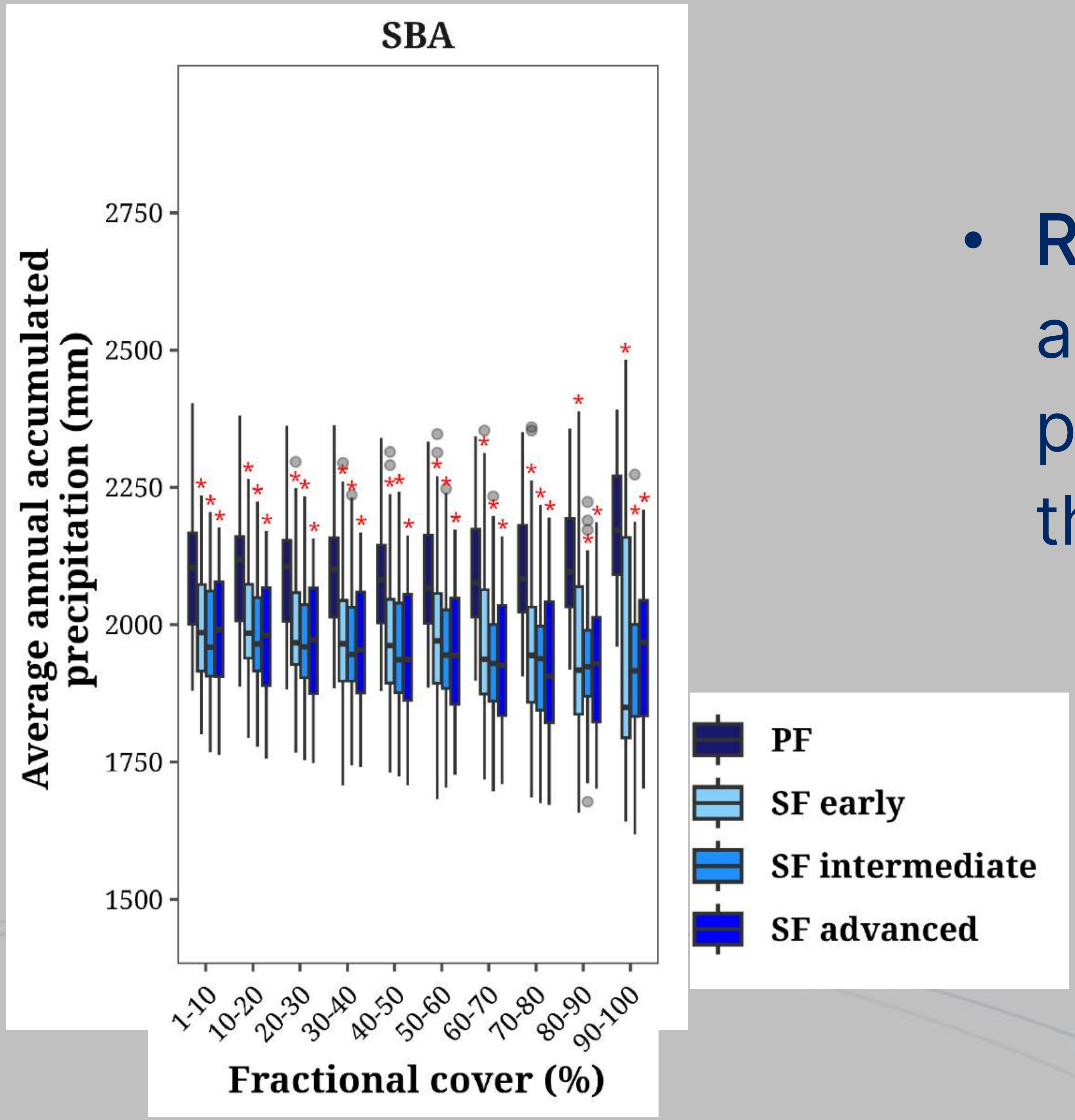
Observed data - Precipitation



- **Regardless** of the **successional stage** of SF and **fractional forest cover** range, precipitation in the SF **is statistically lower** than in the PF.

SF **still cannot** reach the climate regulation potential of PF

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Concluding remarks

- We adopted **simple approaches** to explore how climate responds to **forest cover** and **successional stage**.
- These methods are a **first step** toward understand processes that are **still not well known** in the Amazon.
- Results show that **secondary forests help regulate climate**, but their **potential is not yet fully recovered**.
- There is **still much to learn** about how forest regeneration affects **local and regional climate**.
- **Future studies** should improve and expand these approaches to better capture the **complexity of climate–forest interactions**.

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For reflection

There has never been a more urgent need to revive damaged ecosystems than now.

UNITED NATIONS DECADE ON
ECOSYSTEM RESTORATION
2021-2030

Thank you for your attention!

lais.rosa@ufv.br

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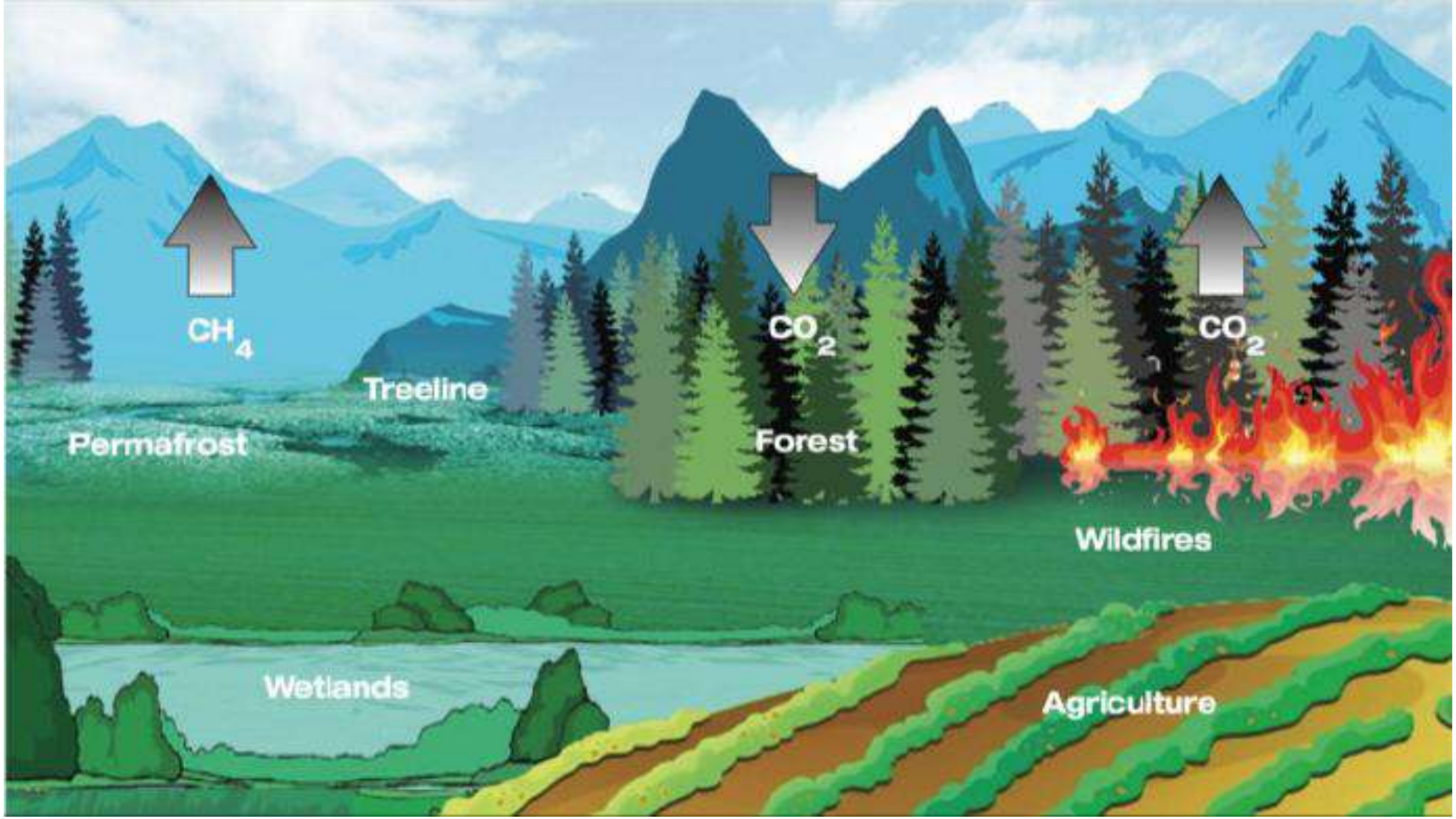
Secondary Forests growth with NISAR

Sassan Saatchi
Science Team Member
Jet Propulsion Laboratory
California Institute of Technology
CEO, CTREES


CH_4
CO_2
CO_2
Treeline
Permafrost
Forest
Wildfires
Wetlands
Agriculture

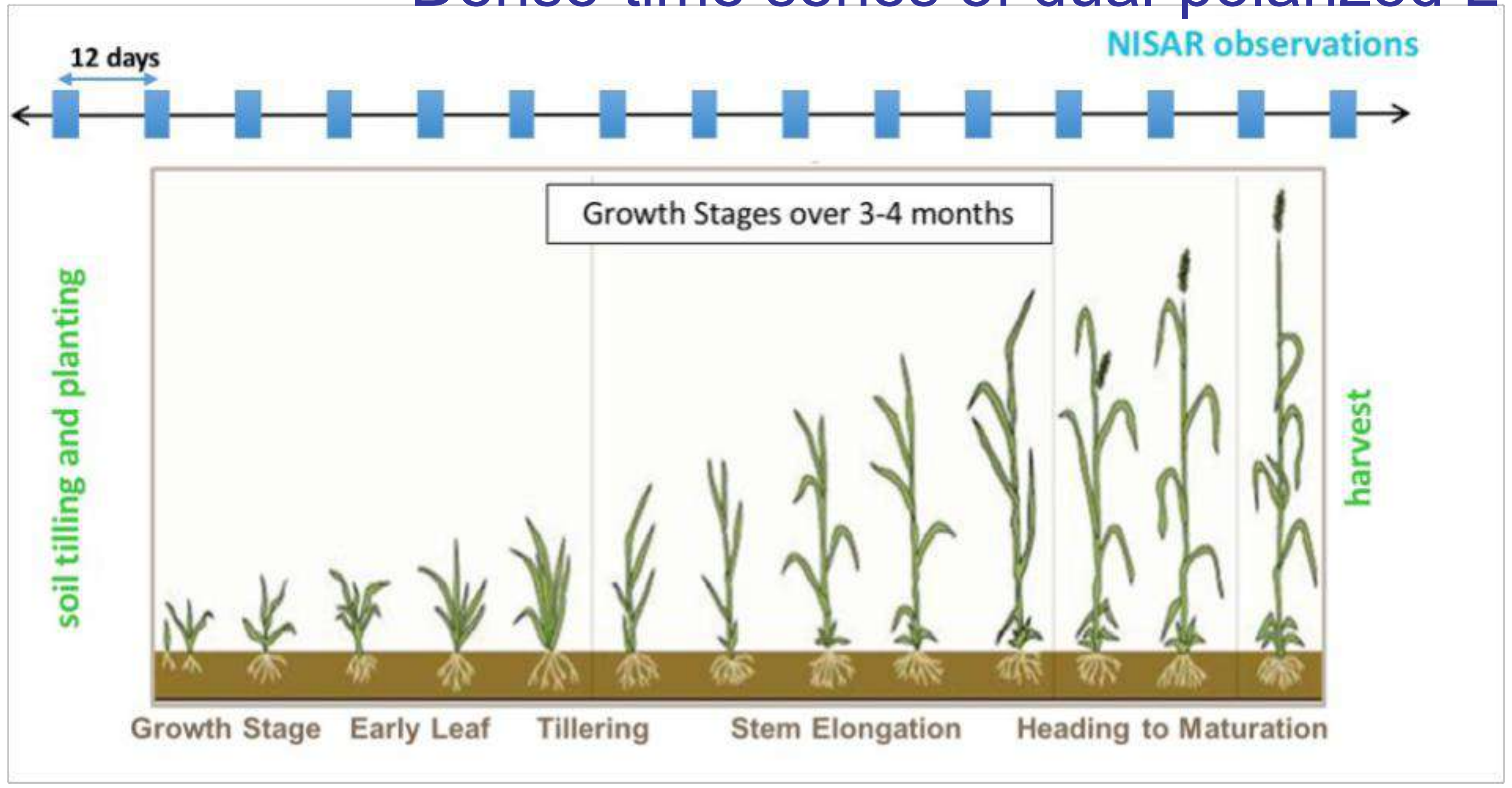
NISAR Ecosystem Science

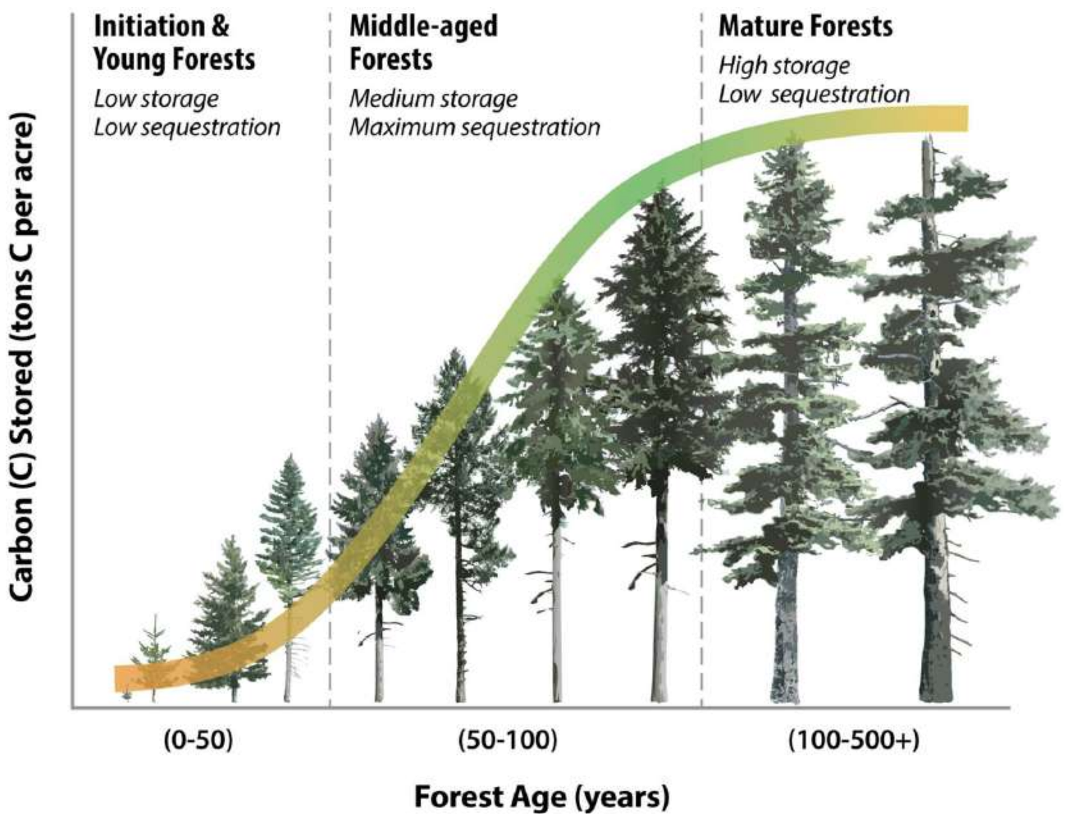
Biomass: **Annually map aboveground woody vegetation biomass at the hectare scale. Accuracy shall be within 20 Mg/ha for 80% of areas of biomass less than 100 Mg/ha.**

Disturbance: **Map global areas of vegetation disturbance at 1 ha resolution annually for areas losing at least 50% canopy cover with a classification accuracy of 80%**
Map crop area at 1 ha resolution every 3 months with a classification accuracy of 80%.
Agriculture:

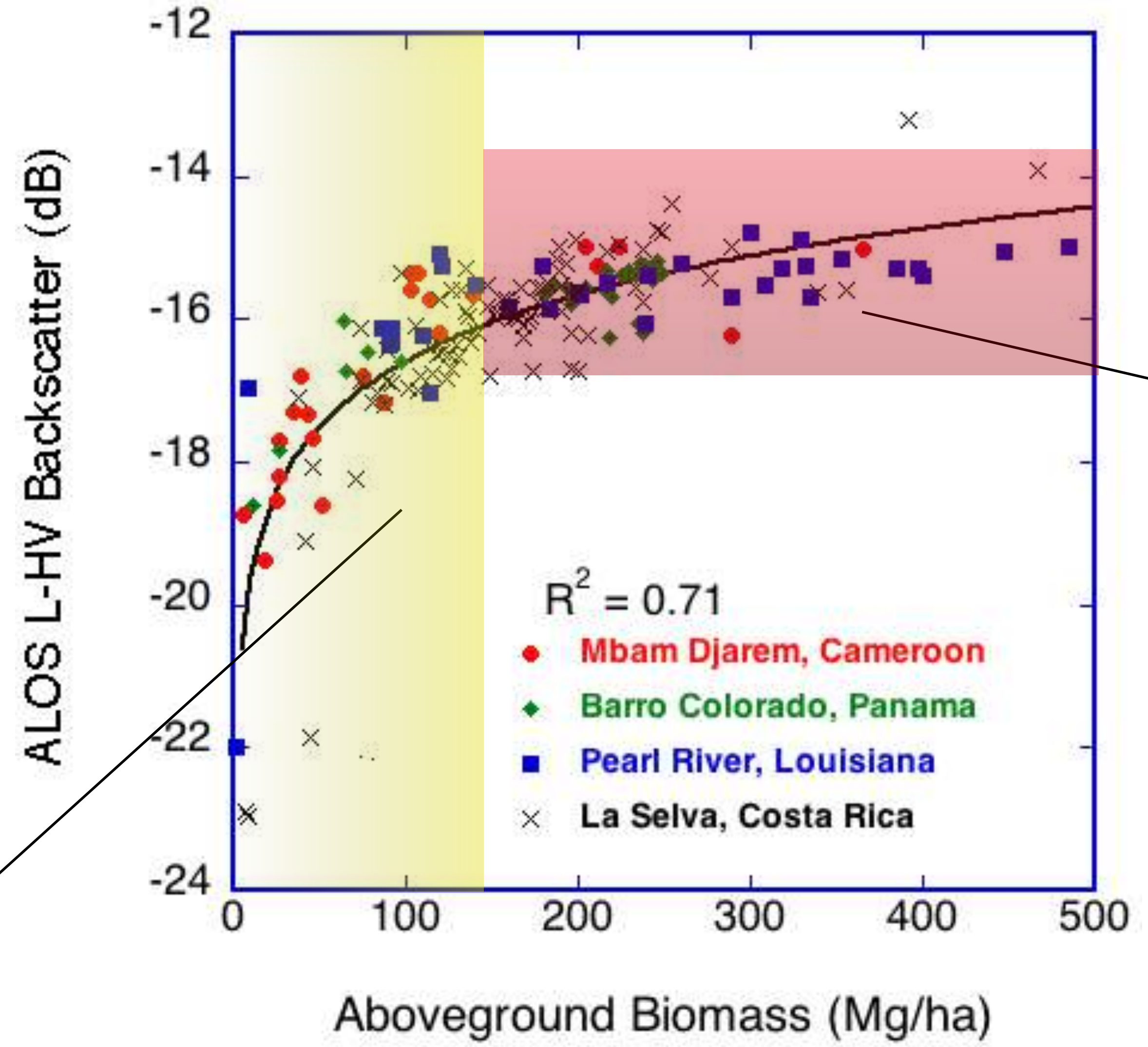
Inundation: **Map inundation extent within inland and coastal wetlands areas at a resolution of 1 hectare every 12 days with a classification accuracy of 80%.**

Dense-time series of dual-polarized L-band & S-band data





L-band SAR Sensitivity to Biomass



High Priority Fusion Region
Lower to no sensitivity of radar
Domain of data fusion and synergism with GEDI and BIOMASS

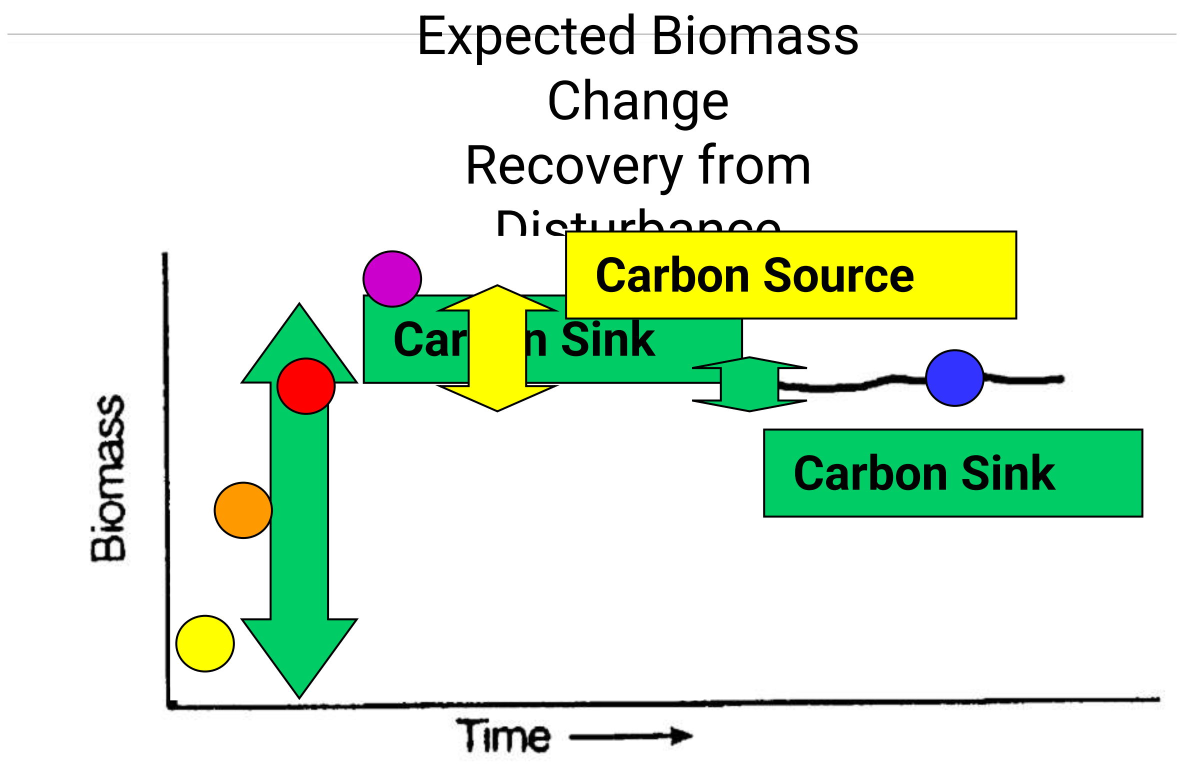
Biomass < 150 Mg/ha
Low Priority Fusion Region
Higher sensitivity of radar
Domain of NISAR Performance

Global Biomass Product must be derived from Fusion Approach

For low biomass density (150 Mg/ha) radar sensitivity is high but impacted by structure & environment

For high biomass density (>150 Mg/ha) data fusion with GEDI and/or BIOMASS required

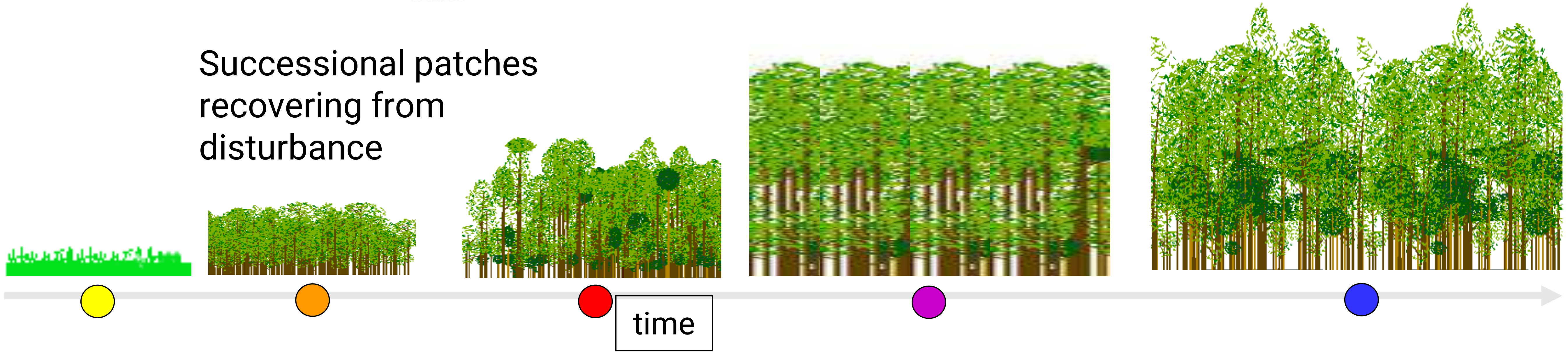
Trees, Forests, Time, Space, Scale

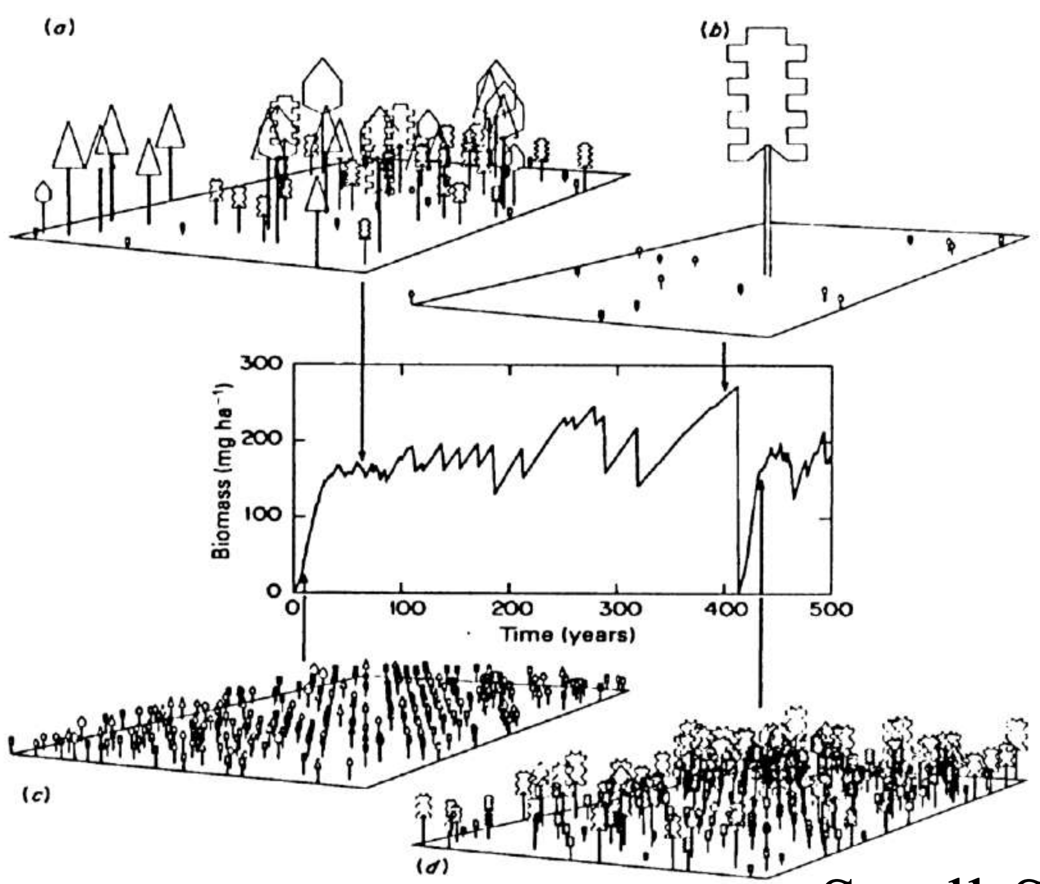


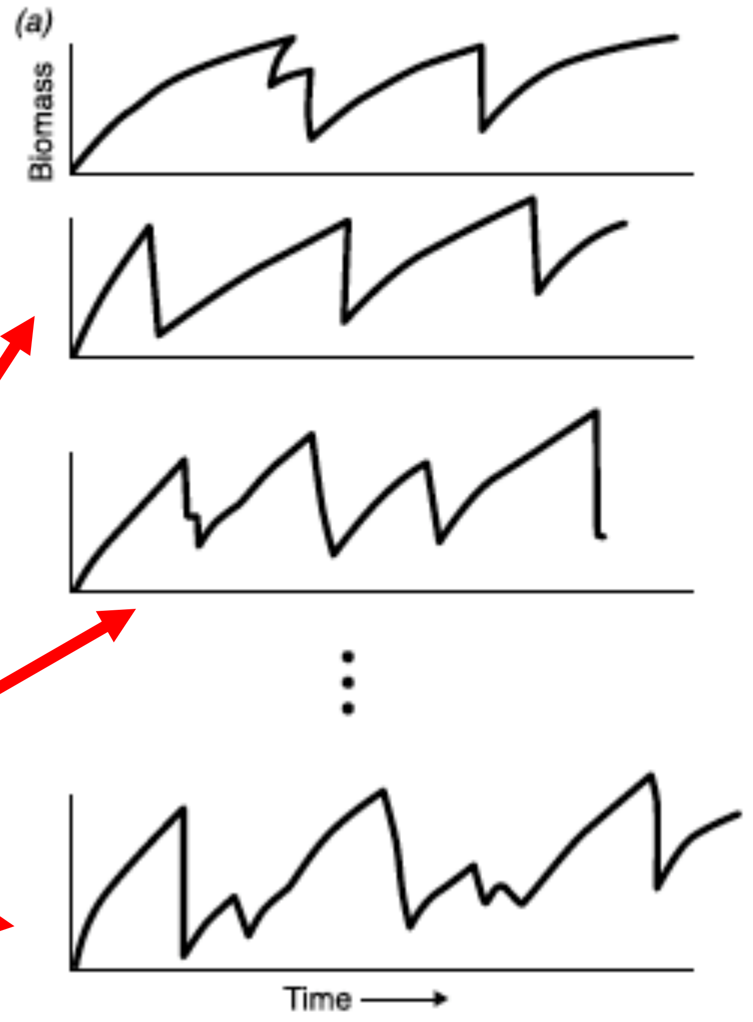
Carbon disturbance recovery dynamics are non-linear as the all-aged successional patches become desynchronized to produce the mixed-aged mature-forest mosaic.

Mature forest is a mosaic.

Successional patches recovering from disturbance



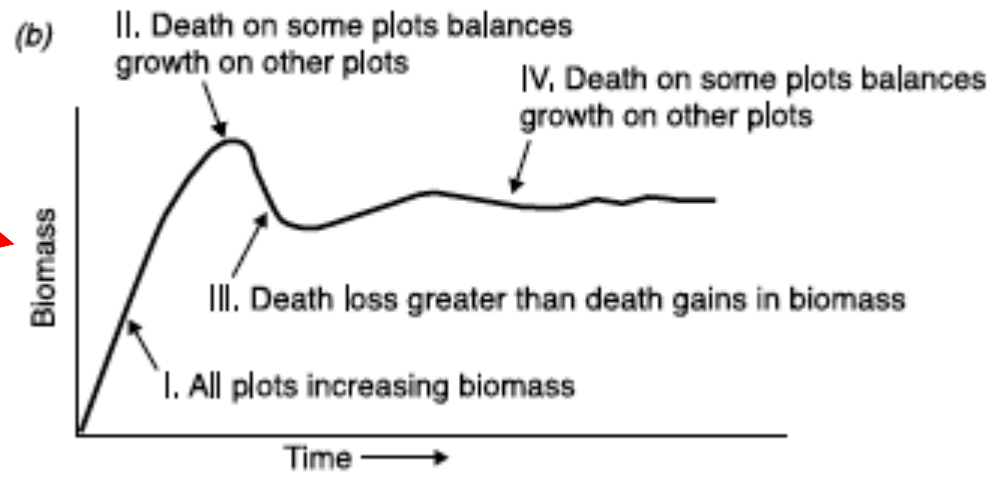




Small-Scale Dynamics

≠

Large-Scale Dynamics

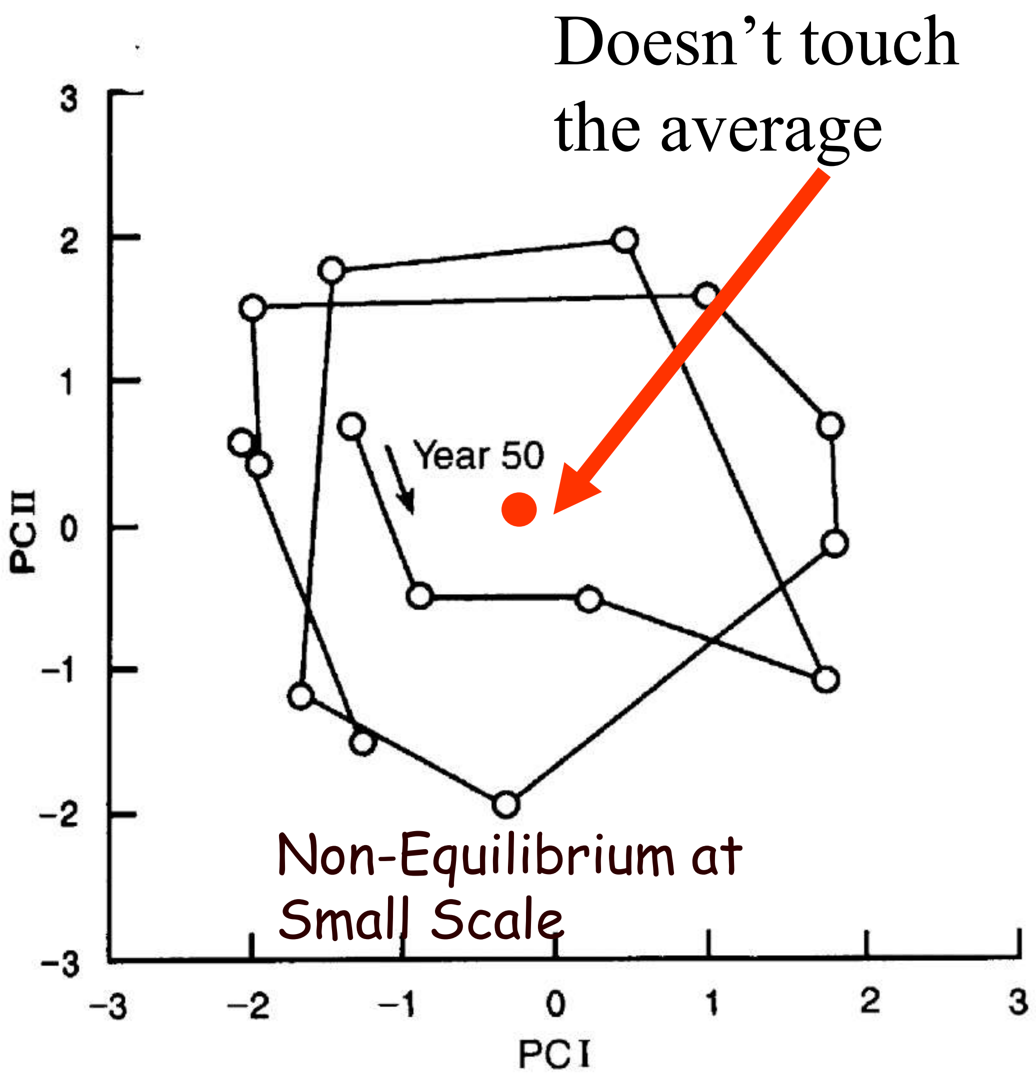


The non-equilibrium dynamics cause forest behave differently at small area from expected landscape scale. (Shugart & Saatchi, 2011)

Scale of Disturbance & Recovery

Shugart, Saatchi, Hall, 2010

Forest Biomass Dynamics Can be Studied at two scale:
At a large scale: a forest stand seeks an equilibrium state with a particular mean configuration. This state once attained remains the same, thereafter.
At a small scale (the so-called the gap scale): the forest ecosystem never reaches an equilibrium state and is continuously undergoing changes driven by the presence of large trees.



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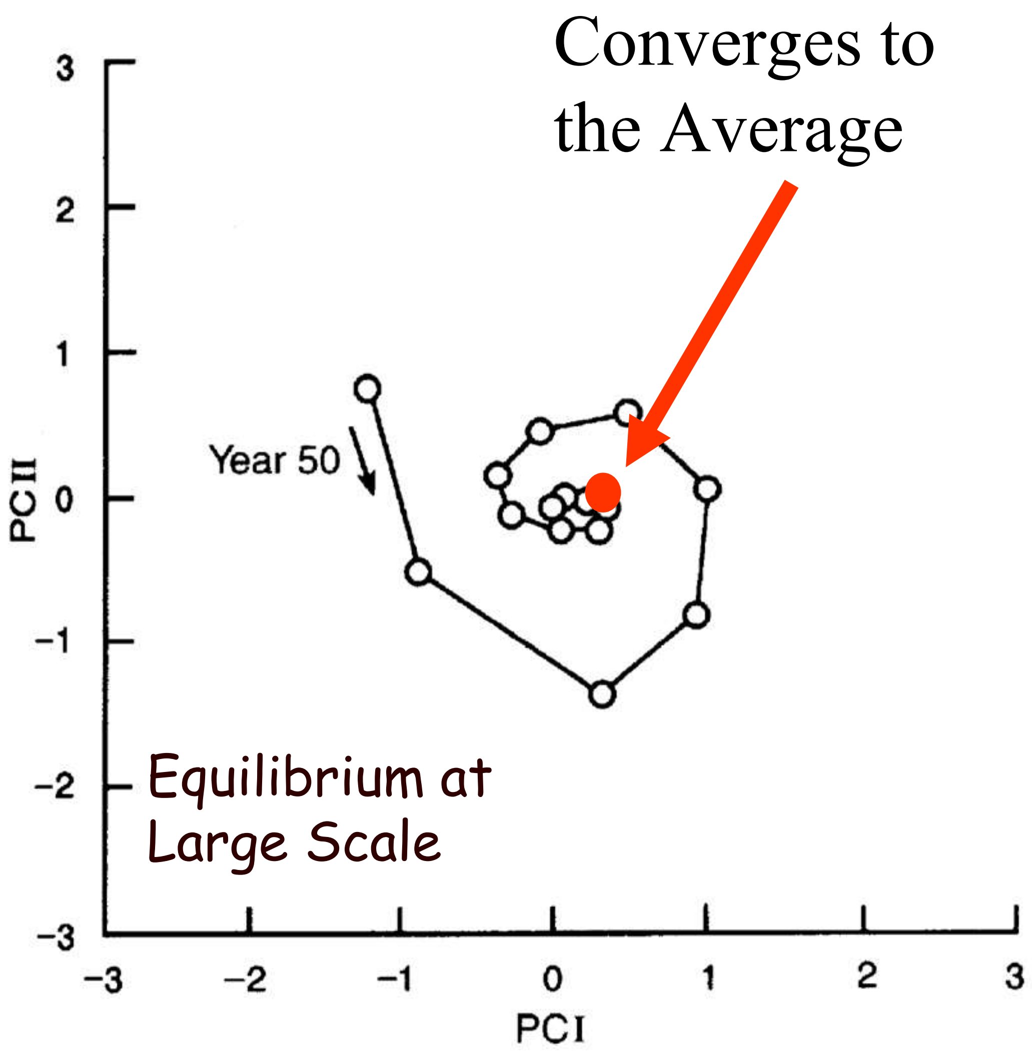
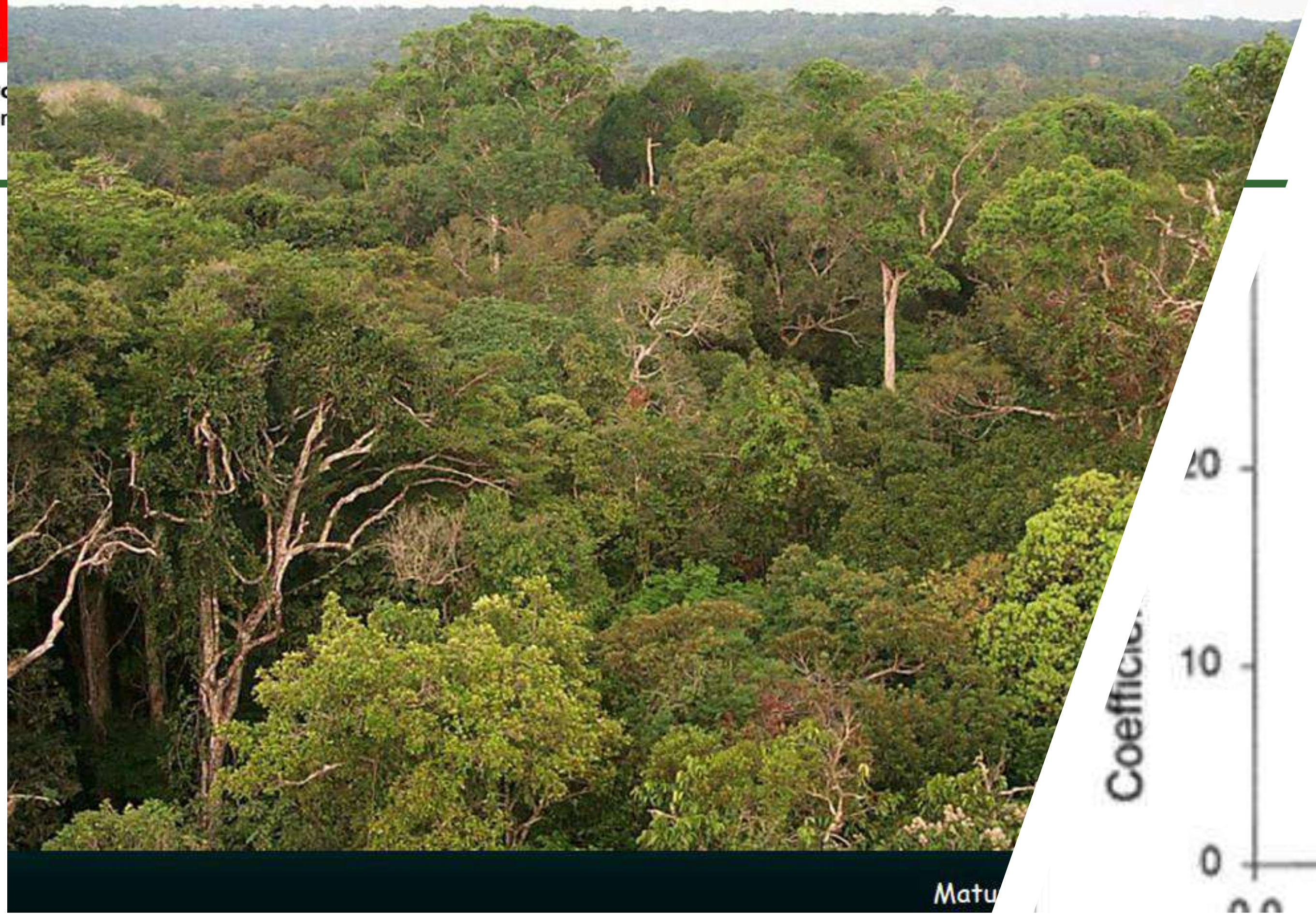
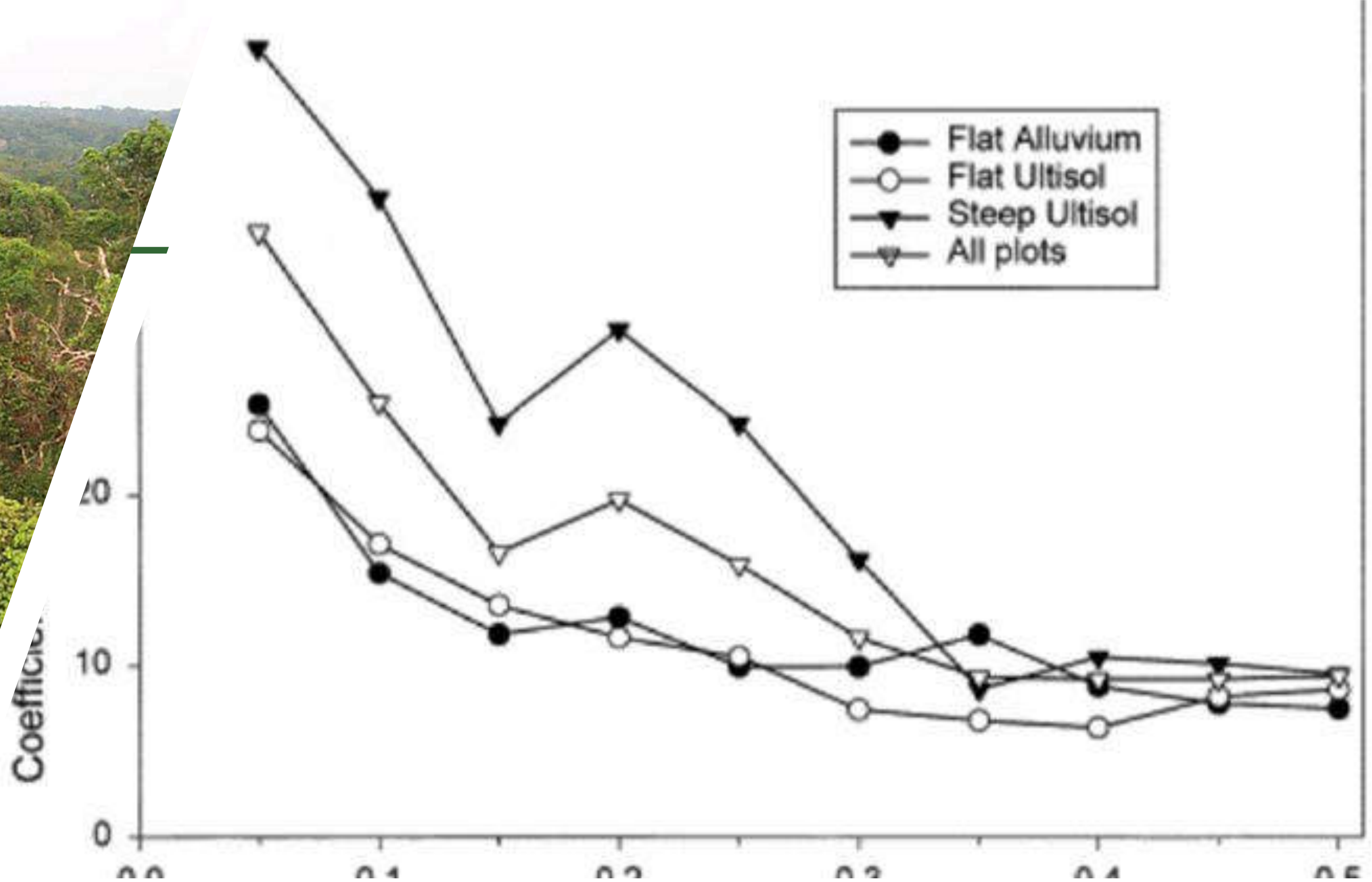
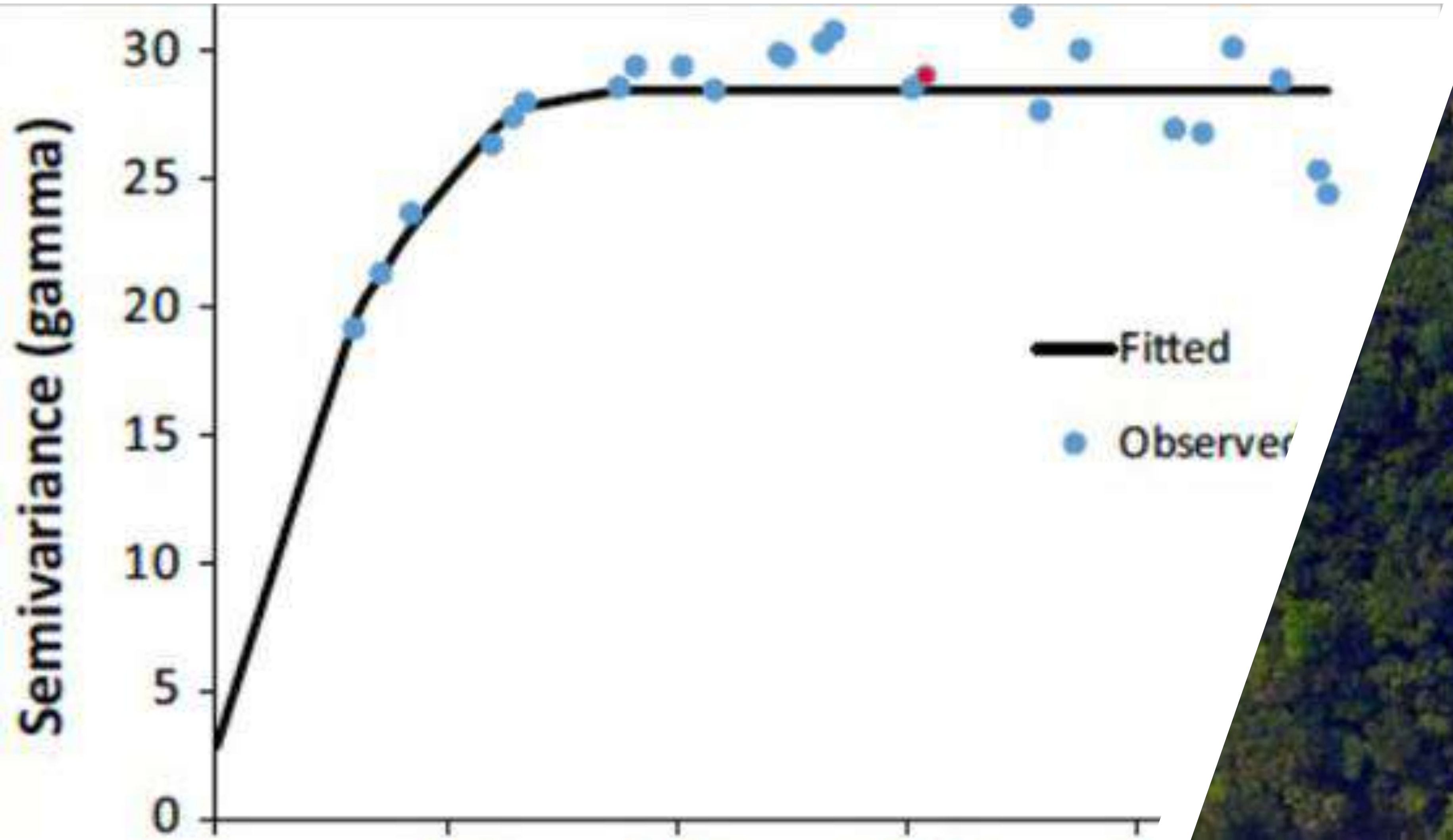


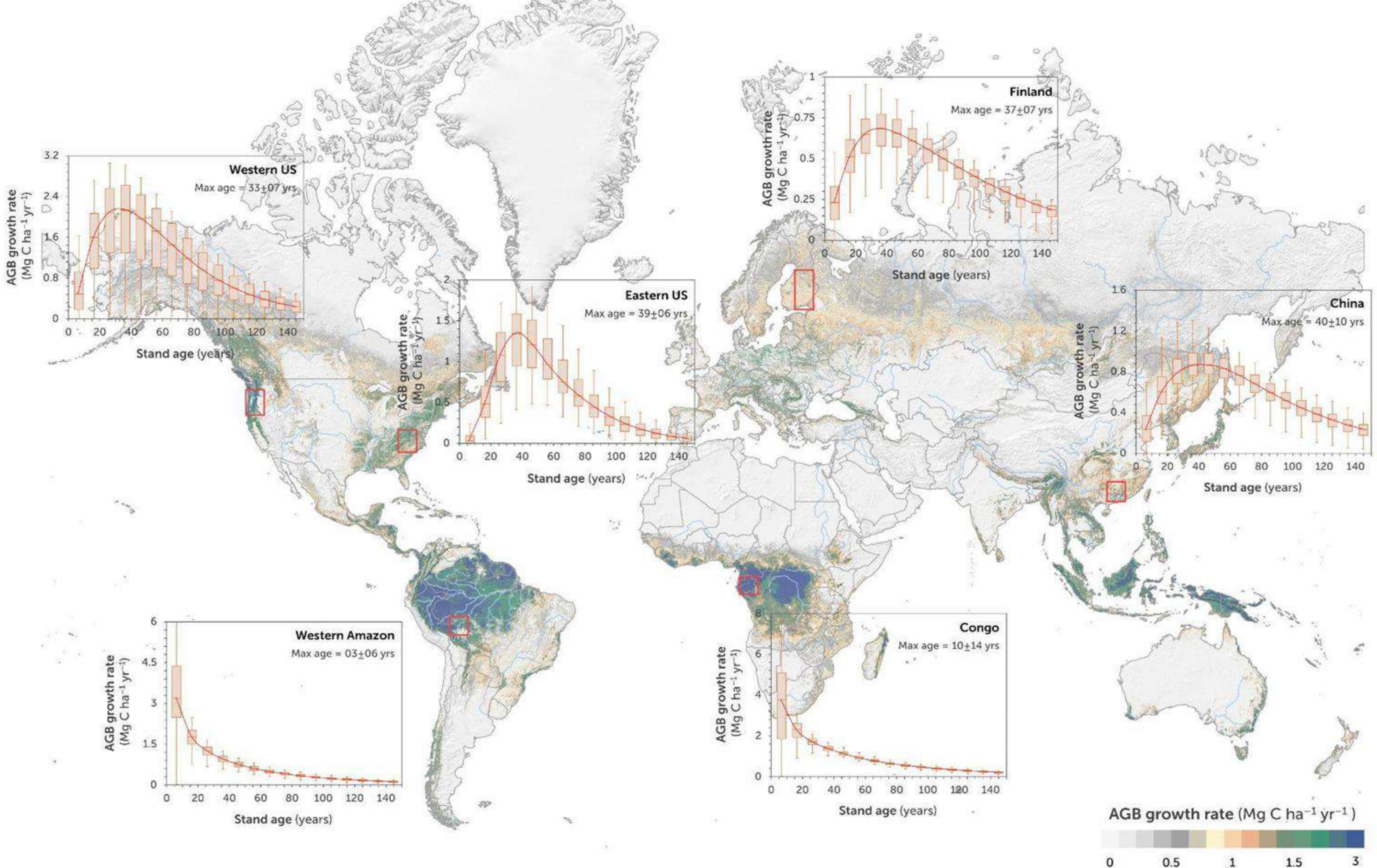
CTrees




Flat Alluvium
Flat Ultisol
Steep Ultisol
All plots
0
10

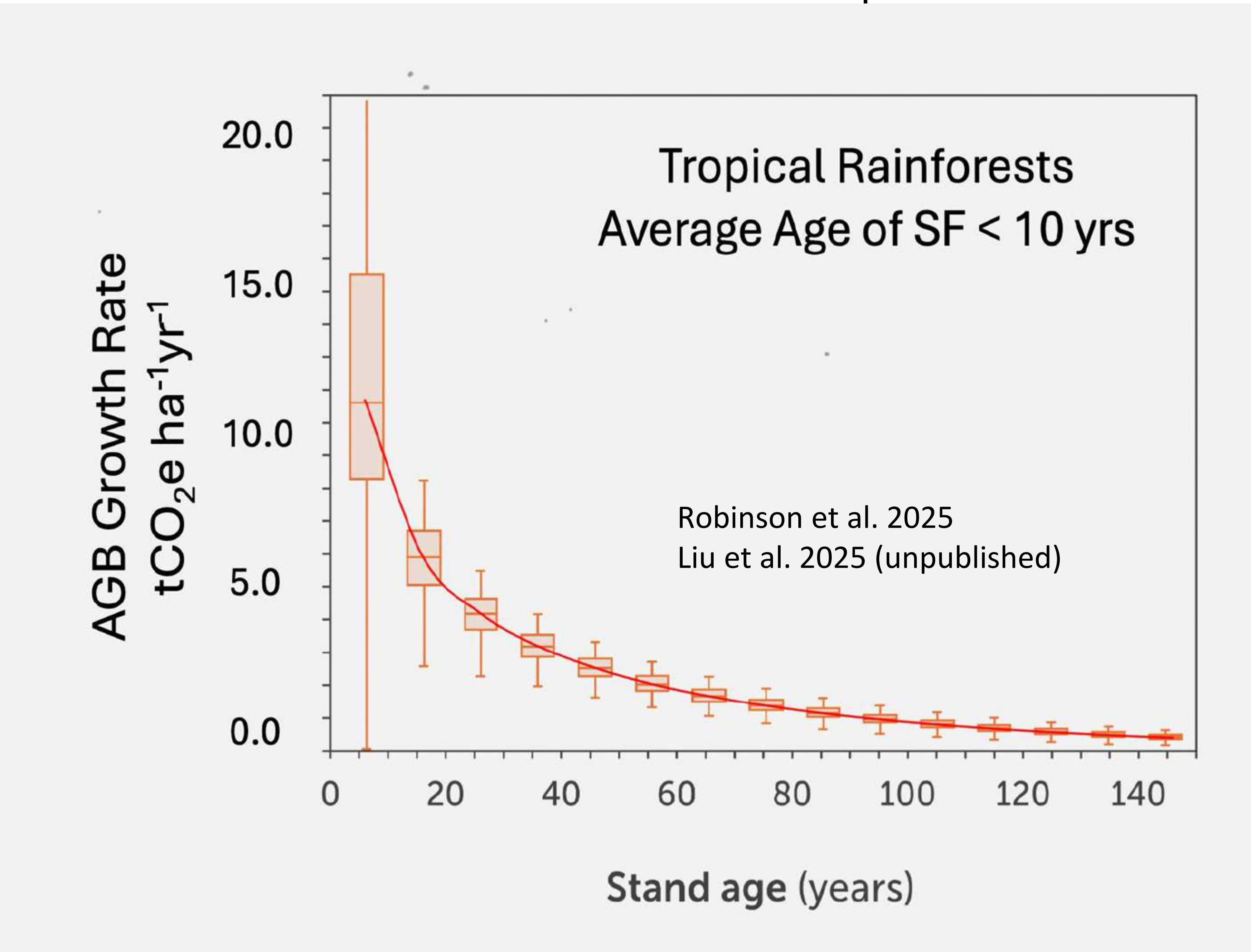

Semivariance (gamma)
30
25
20
15
10
5
0
Fitted

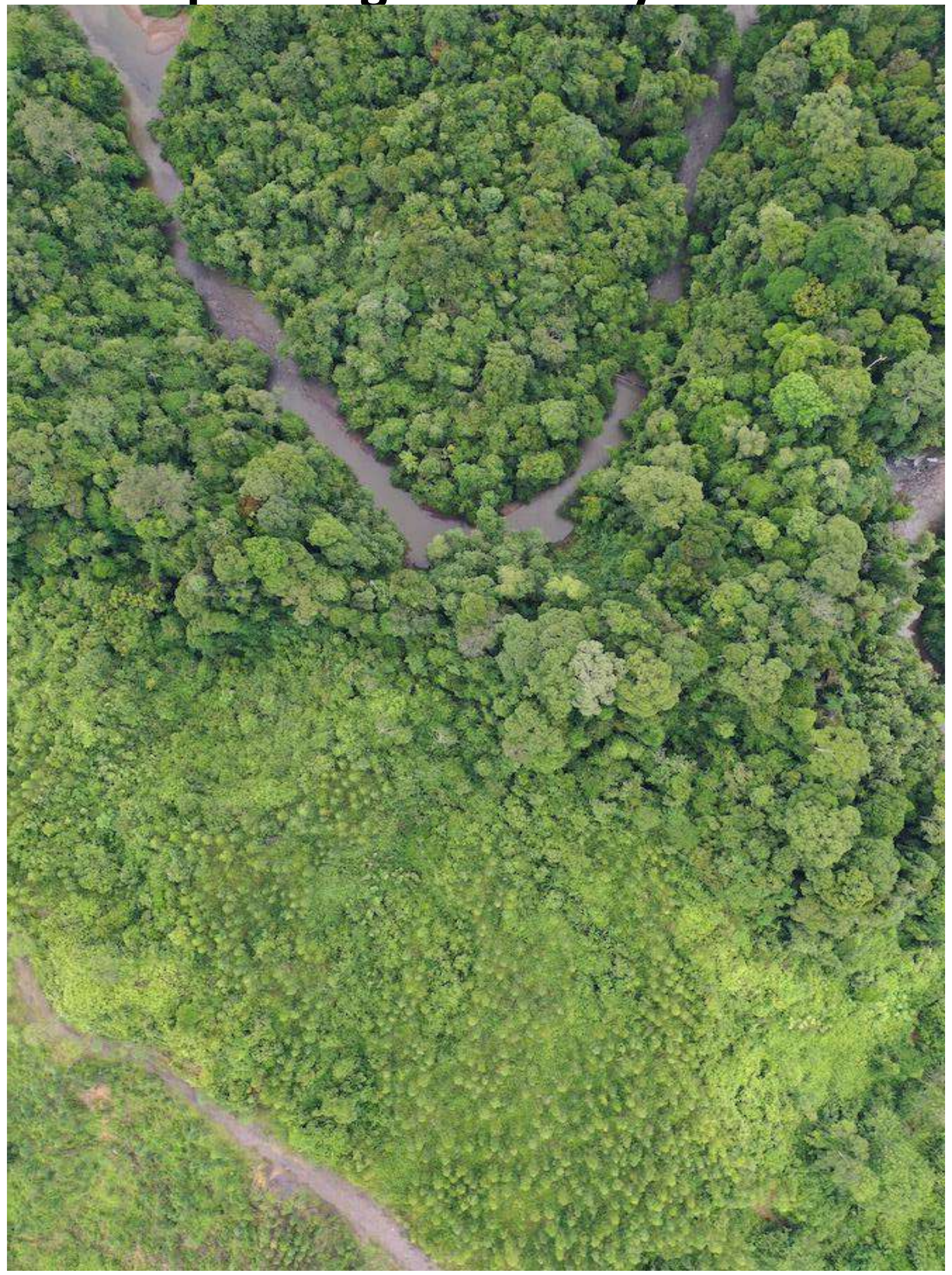
Global Forest Growth Rate
1-ha spatial resolution
Liu et al. 2025



Importance of Secondary Forests

- Tropical secondary forests (SF) in 2020
- Areas of SF < 100 years: 240 Mha
- Areas of SF < 20 years: 155 Mha
- Average Carbon Gain (2010-2020): ~400 MtCO_2e yr^{-1}
- Allowing SF grow by 2050: 1.5 GtCO_2e yr^{-1}
- The same amount of carbon from ARR requires: **~340 M ha of new tree planting in next 5 years**



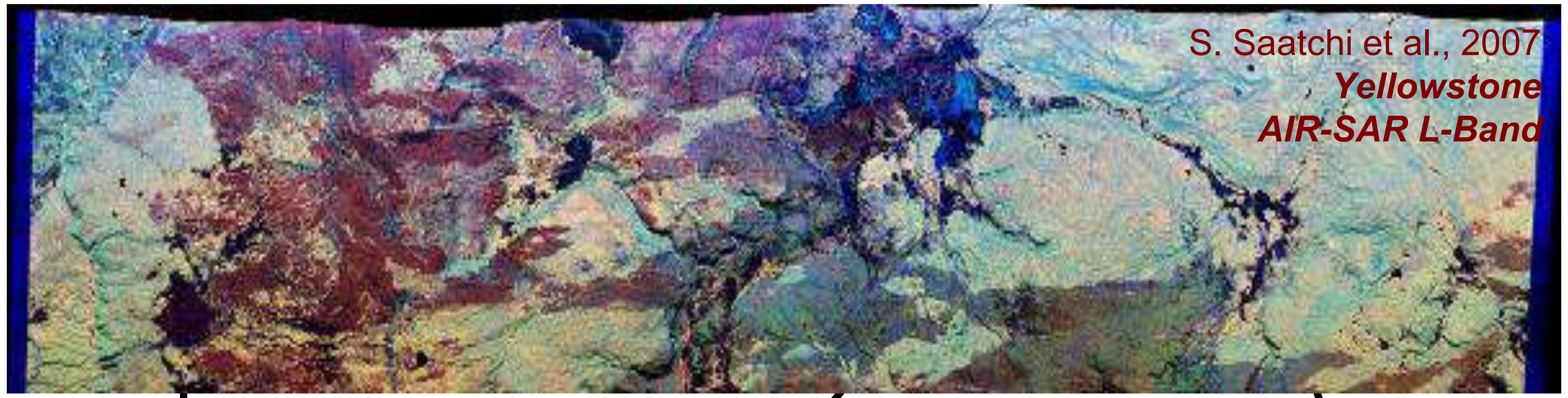


Drivers of Secondary Forests:
Culture, Market, Policy

Secondary forests (SF) are part of the global land use activities. SF short-term and long-term carbon sequestration capacity depend strongly on local, national and international policy and market forces

Global Monitoring of Vegetation Disturbance and Recovery

NISAR would provide annual vegetation disturbance and deforestation maps globally at spatial scale of ~1 ha



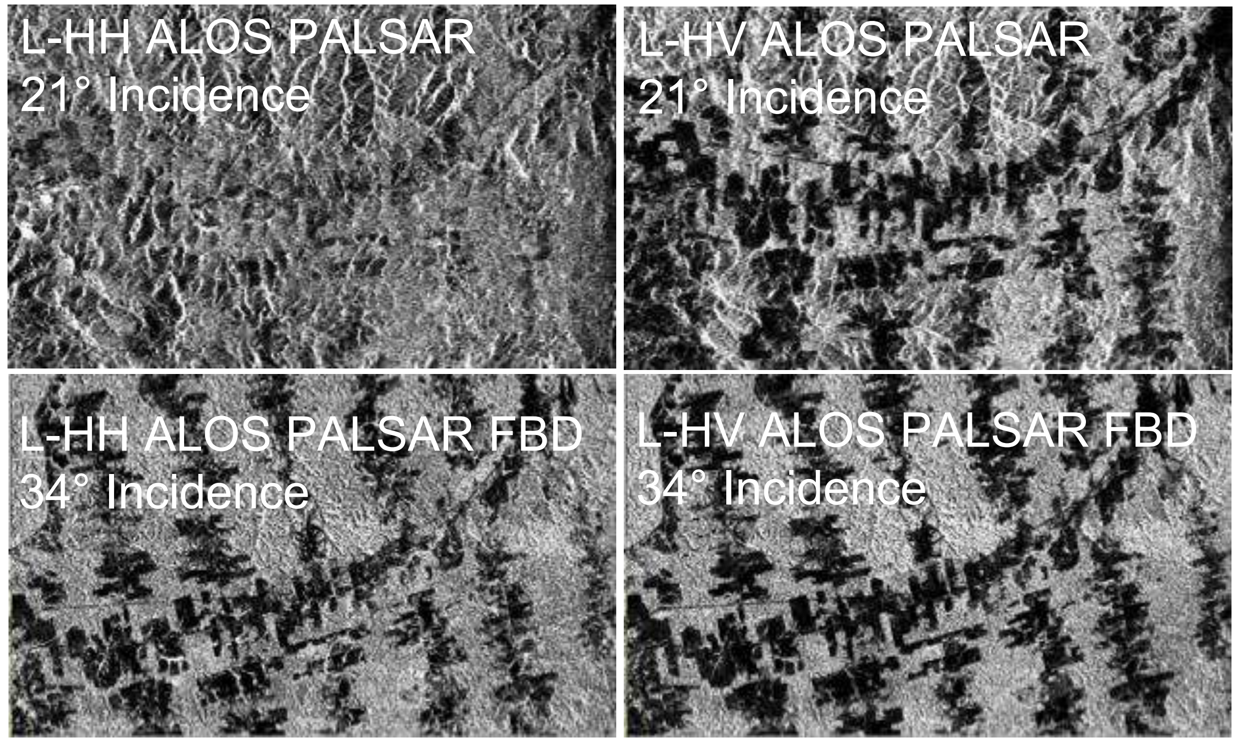
Cross-pol measurement is key to detecting structural differences in vegetation, driving requirement for multi-pol baseline and cross-pol threshold radar capability.

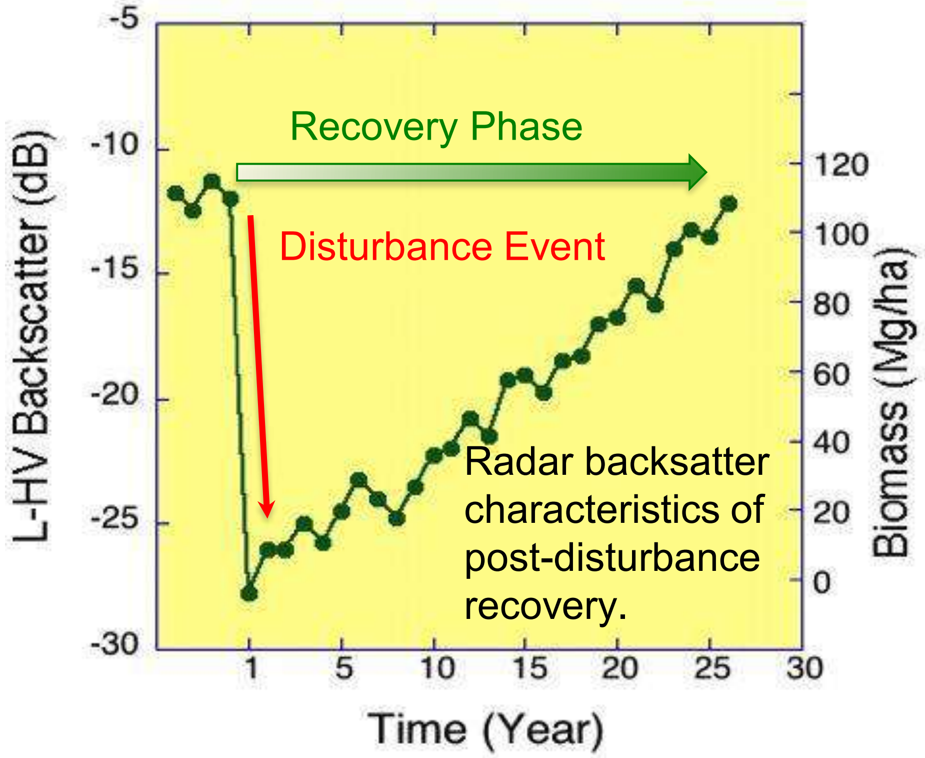
2003 Burn

Recovery after 1988 Burn

Pine Beetle Disease

NISAR would provide both acquisitions with both polarization and incident angle variations; both critical for effective disturbance monitoring.

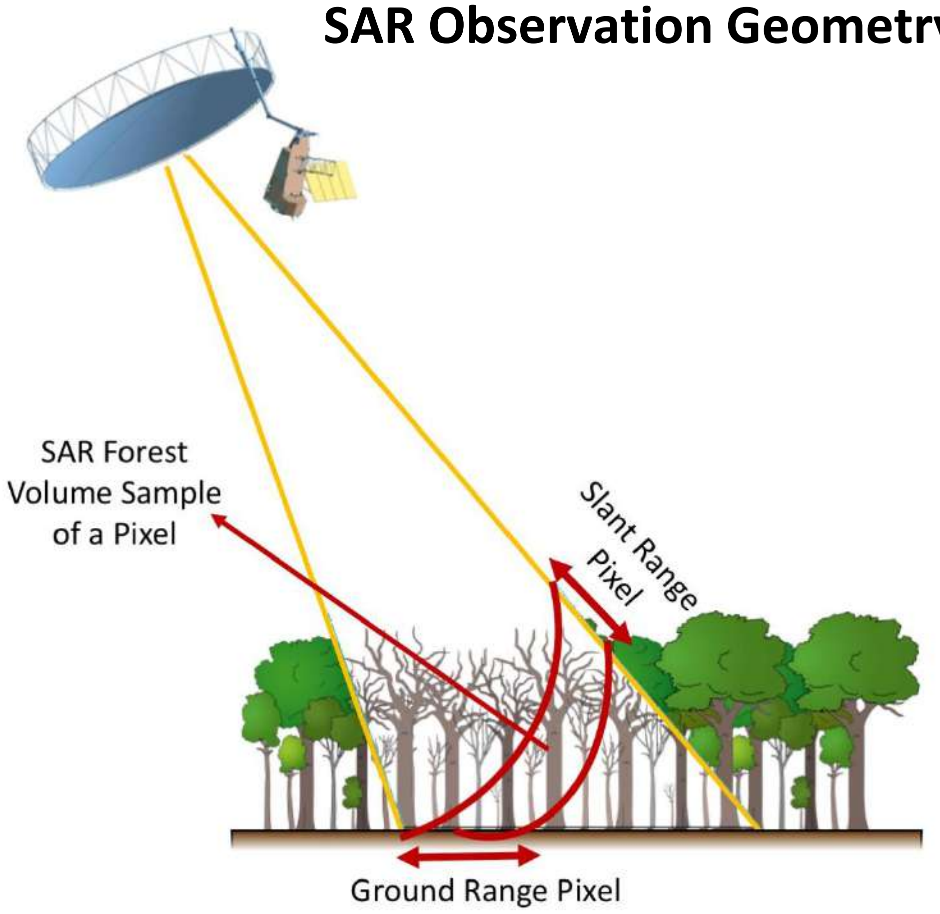




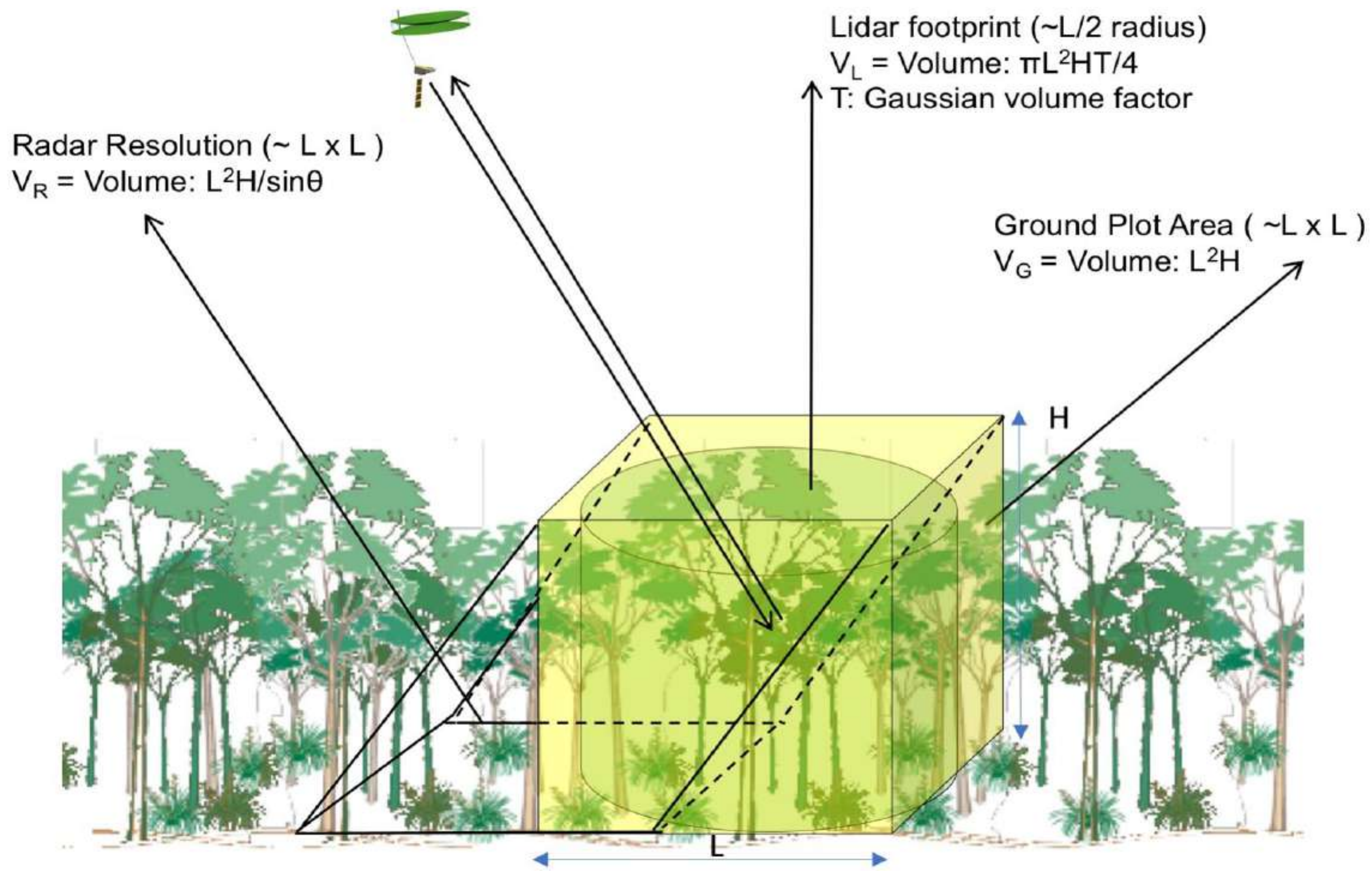
NISAR would quantify fluxes in terrestrial sources and sinks of carbon resulting from disturbance

SAR Geometry and Temporal Effects

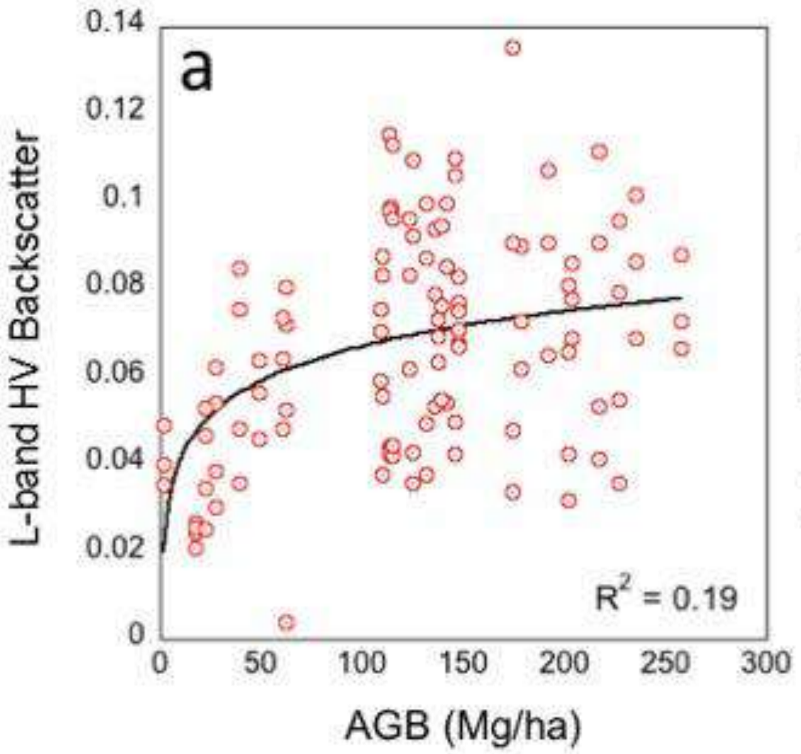
SAR Observation Geometry



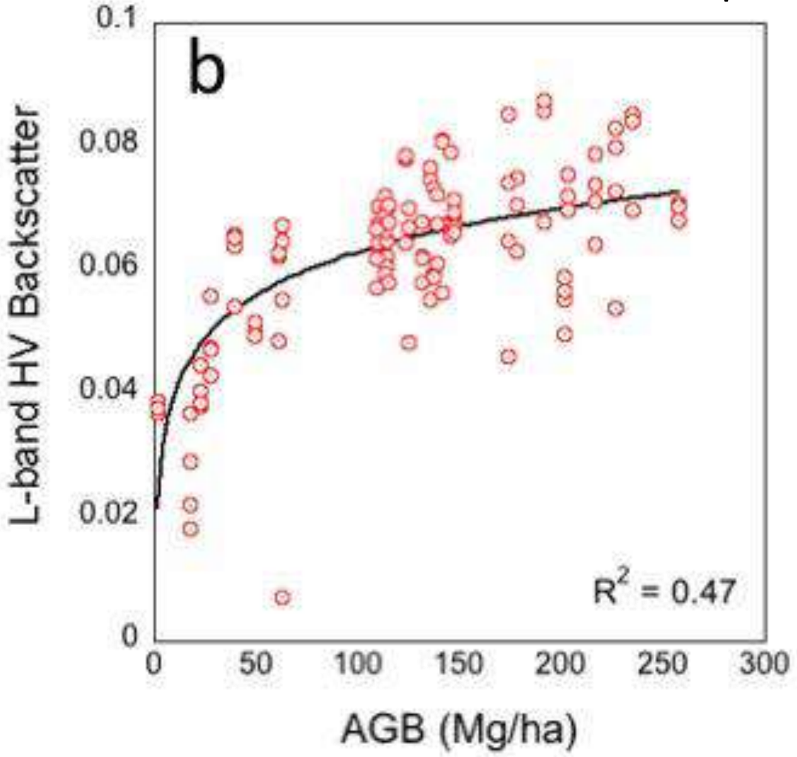
SAR Pixel vs Lidar and Ground Pixel



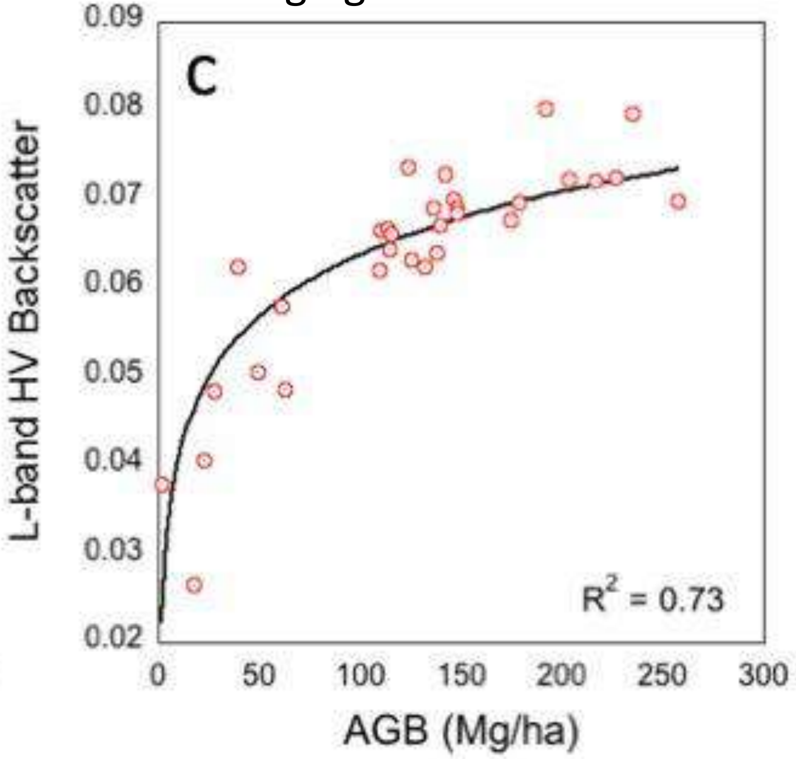
Multiple dates & multiple surface slope



After correction for surface slopes

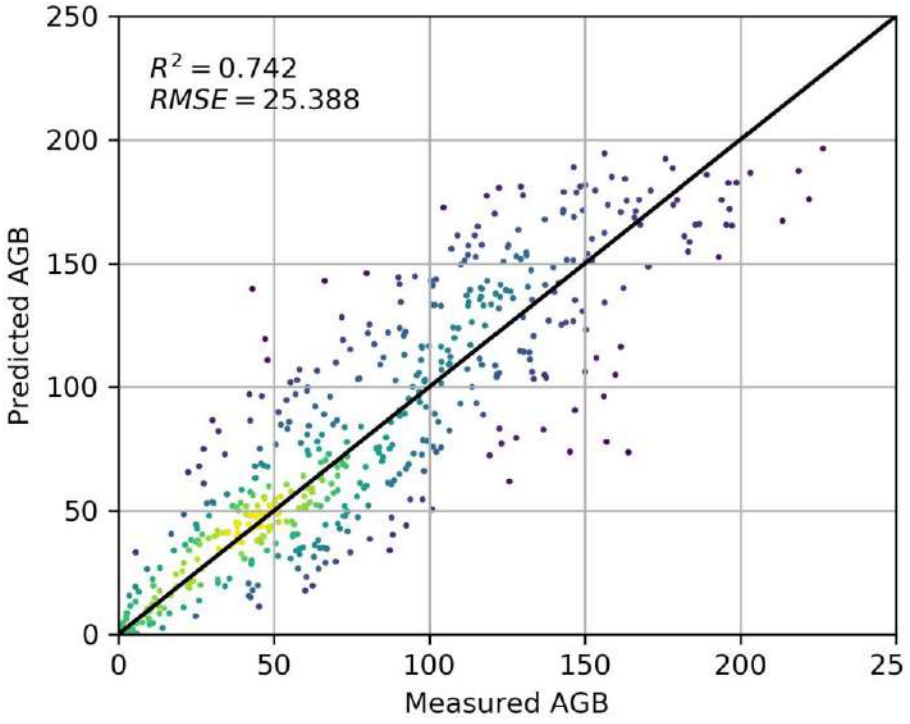


After averaging backscatter over multiple dates



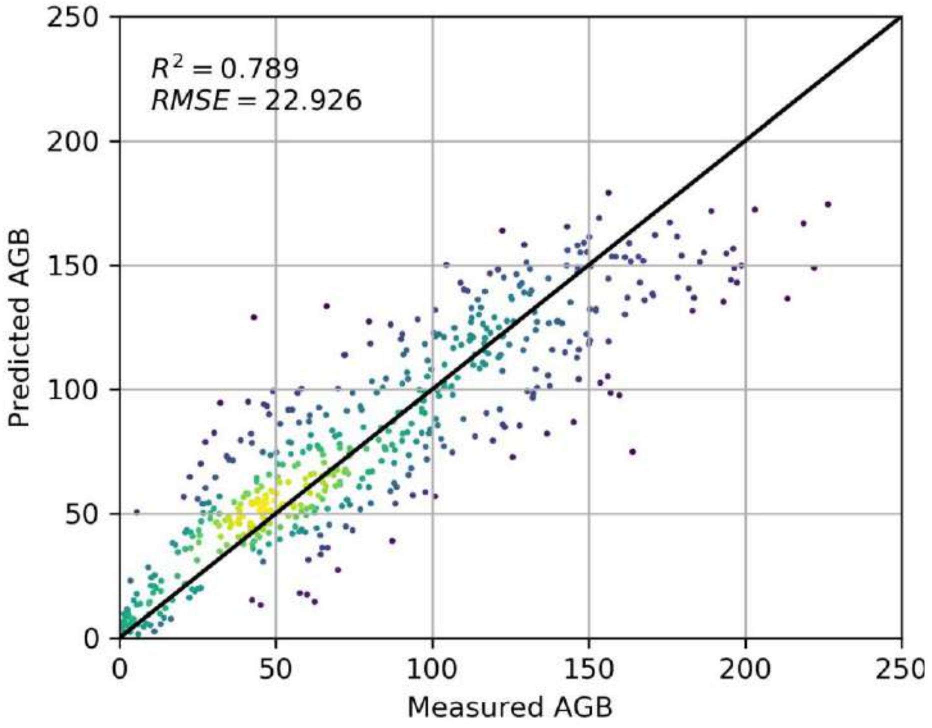
NISAR Algorithm Performance

5 scenes summer



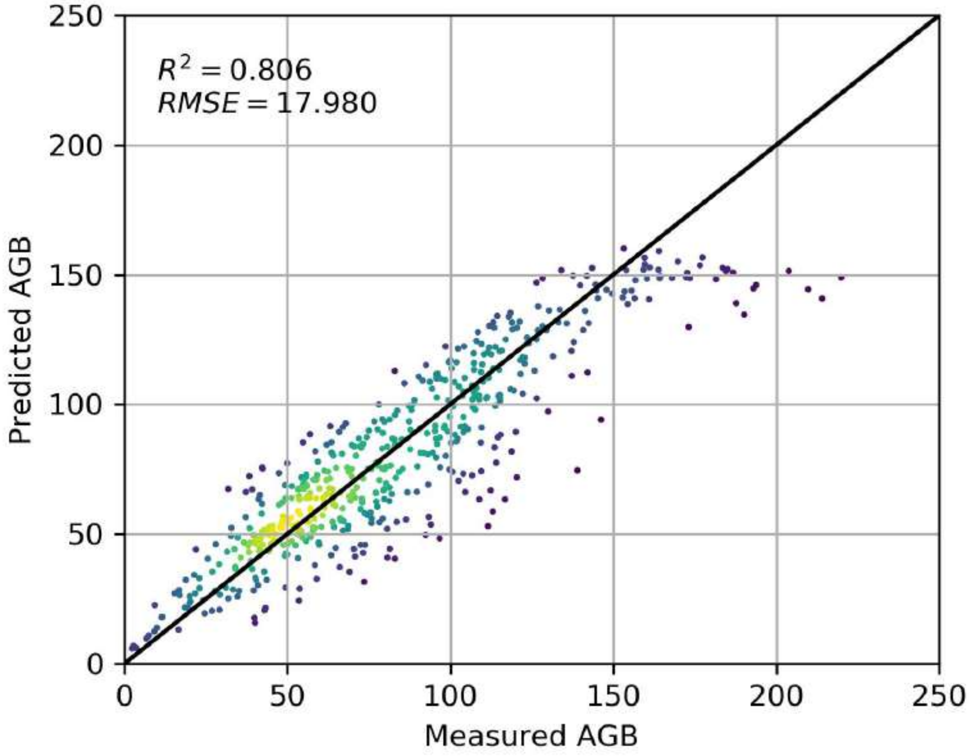
67.0% within 20 Mg/ha.
45.4% within 10 Mg/ha.

10 scenes spring & summer

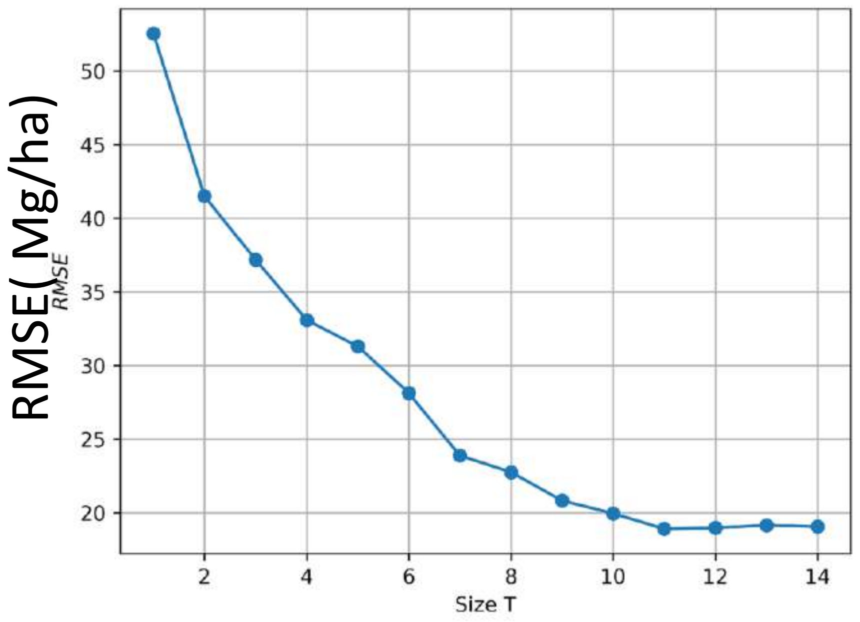


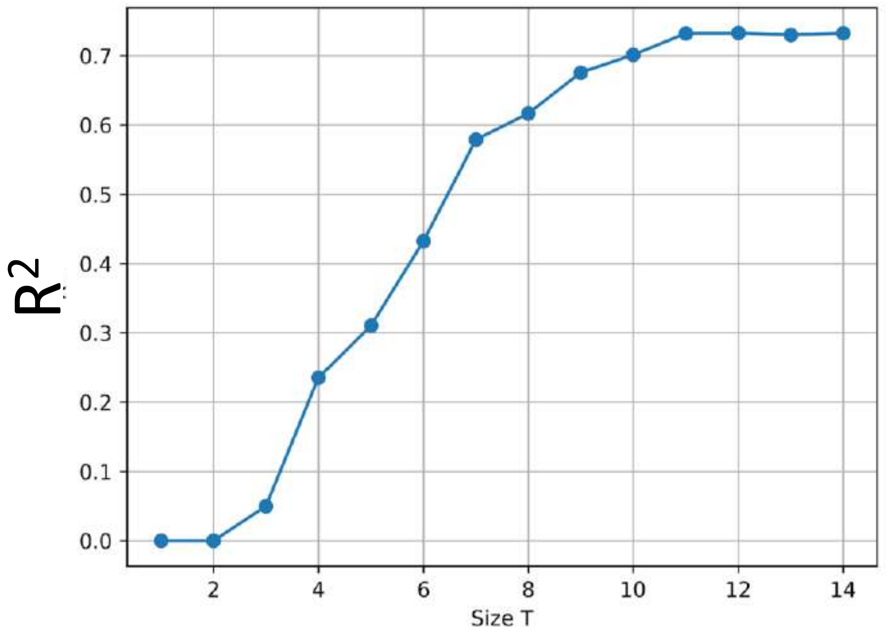
74% within ±20 Mg/ha.
46% within ±10 Mg/ha.

14 scenes spring, summer & fall



82% within ±20 Mg/ha.
51% within ±10 Mg/ha.

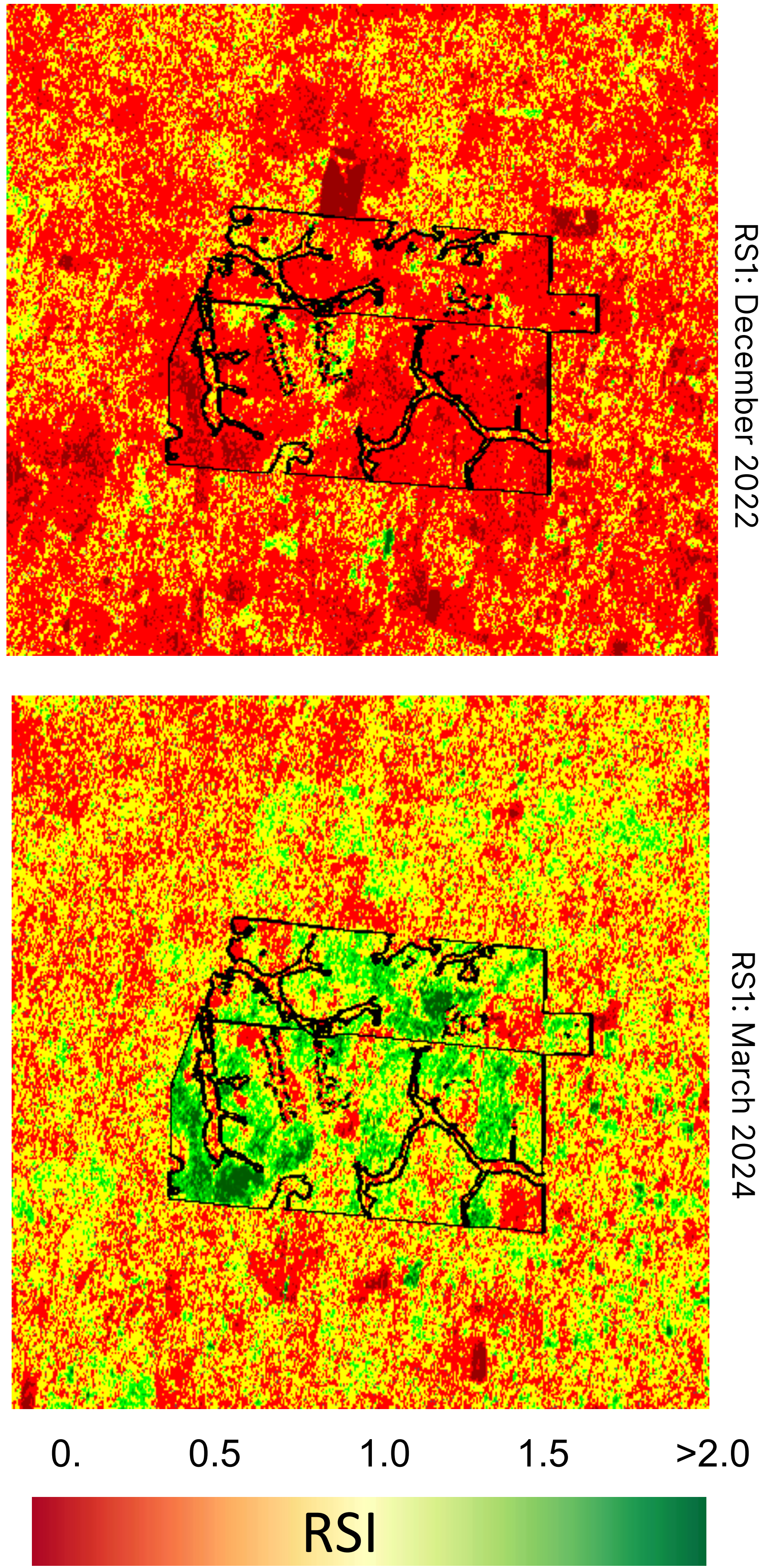




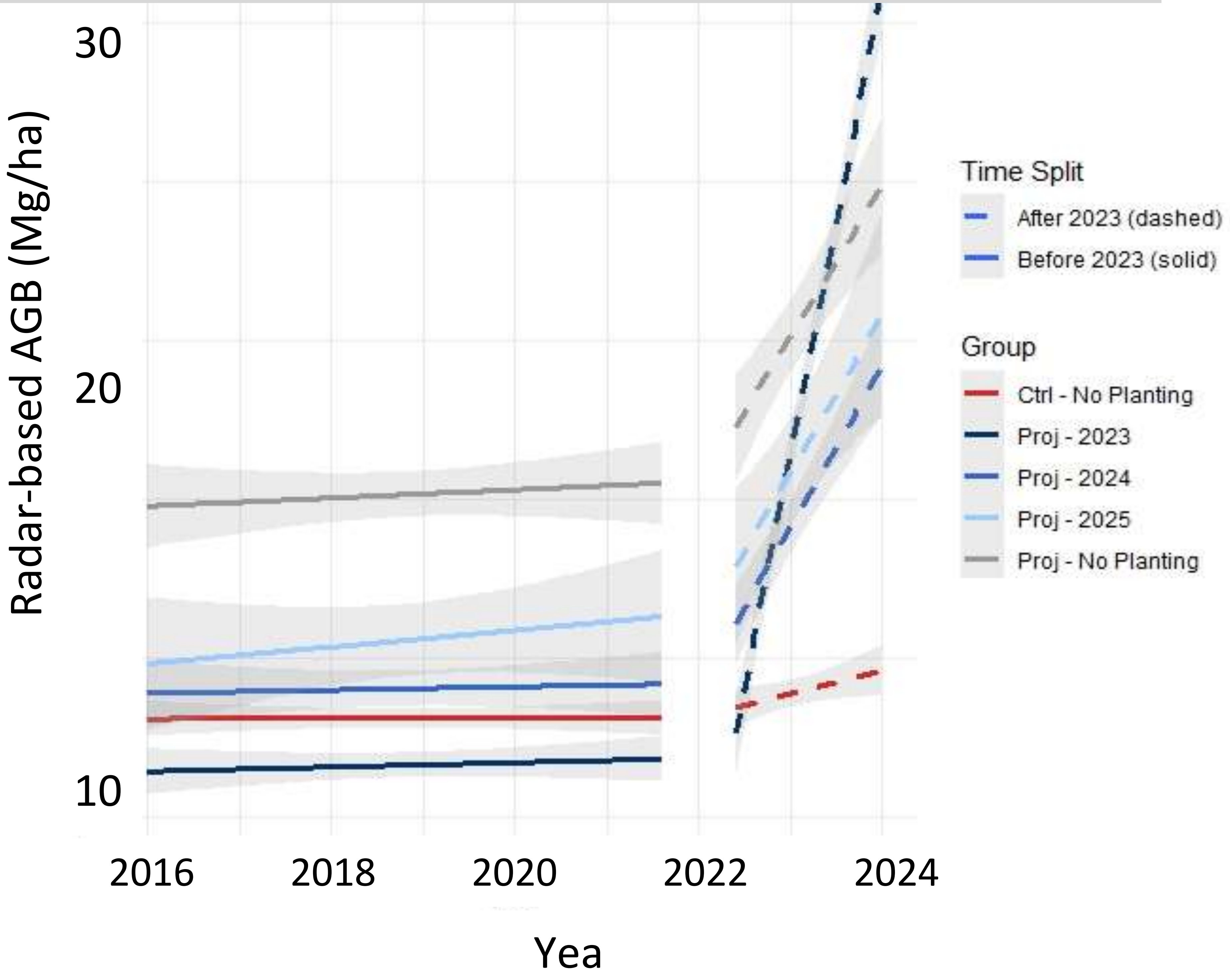
530 lidar derived biomass used in model validation

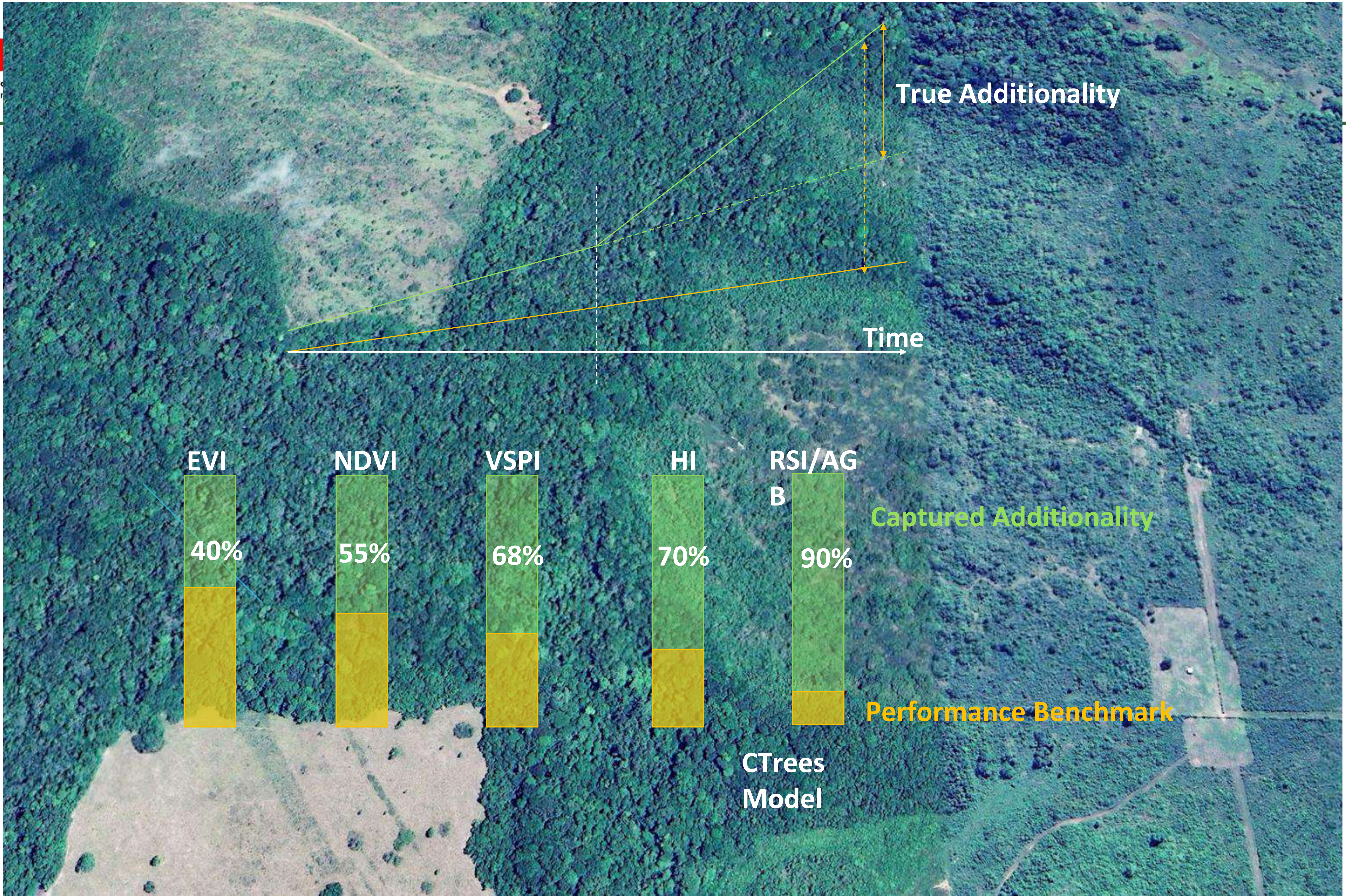
Winter scenes with snow cover require model improvement

Radar Stocking Index Captures Growth of Tree Plantation



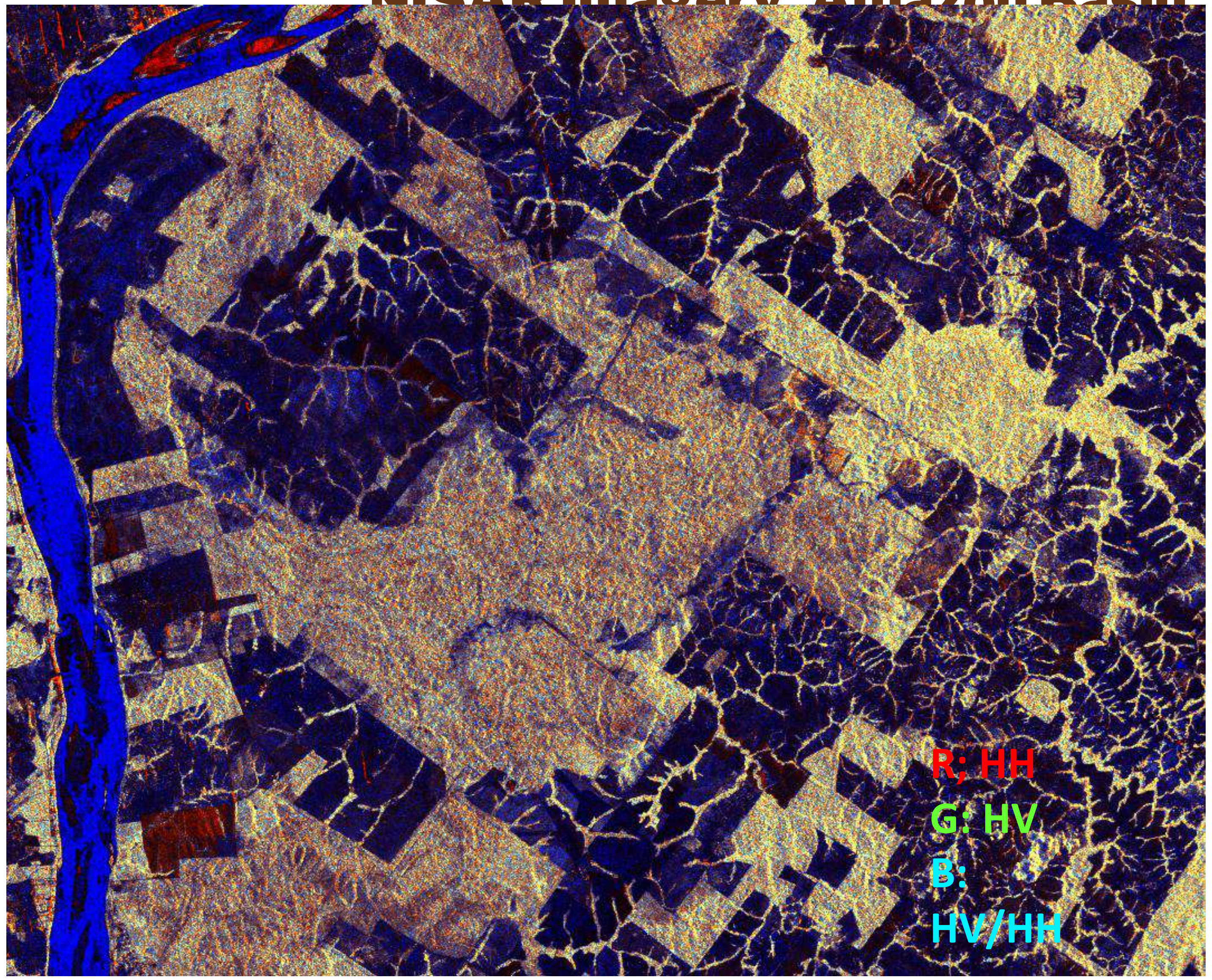
- Direct biomass and **Radar-based Stocking Index** can be used for dynamic baselining
- Estimate of additionality & tracking carbon credit available at 6-12 months after tree planting




True Additionality
Time
EVI
NDVI
VSPI
HI
RSI/AG
B
Captured Additionality
40%
55%
68%
70%
90%
Performance Benchmark
CTrees
Model

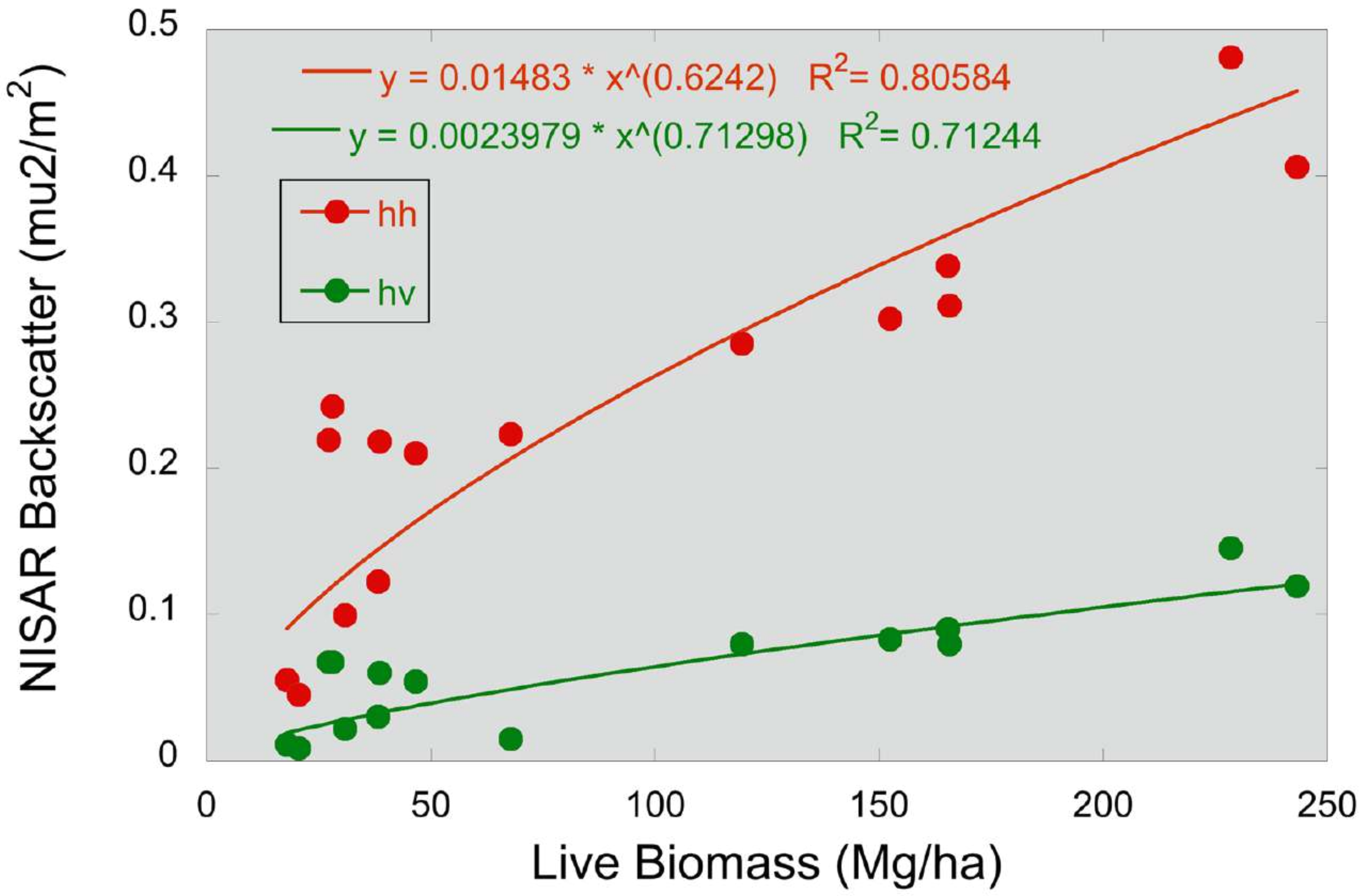
Agriculture Frontier in the State of Tocantins, Brazil (7.019 S, 49.072 W)

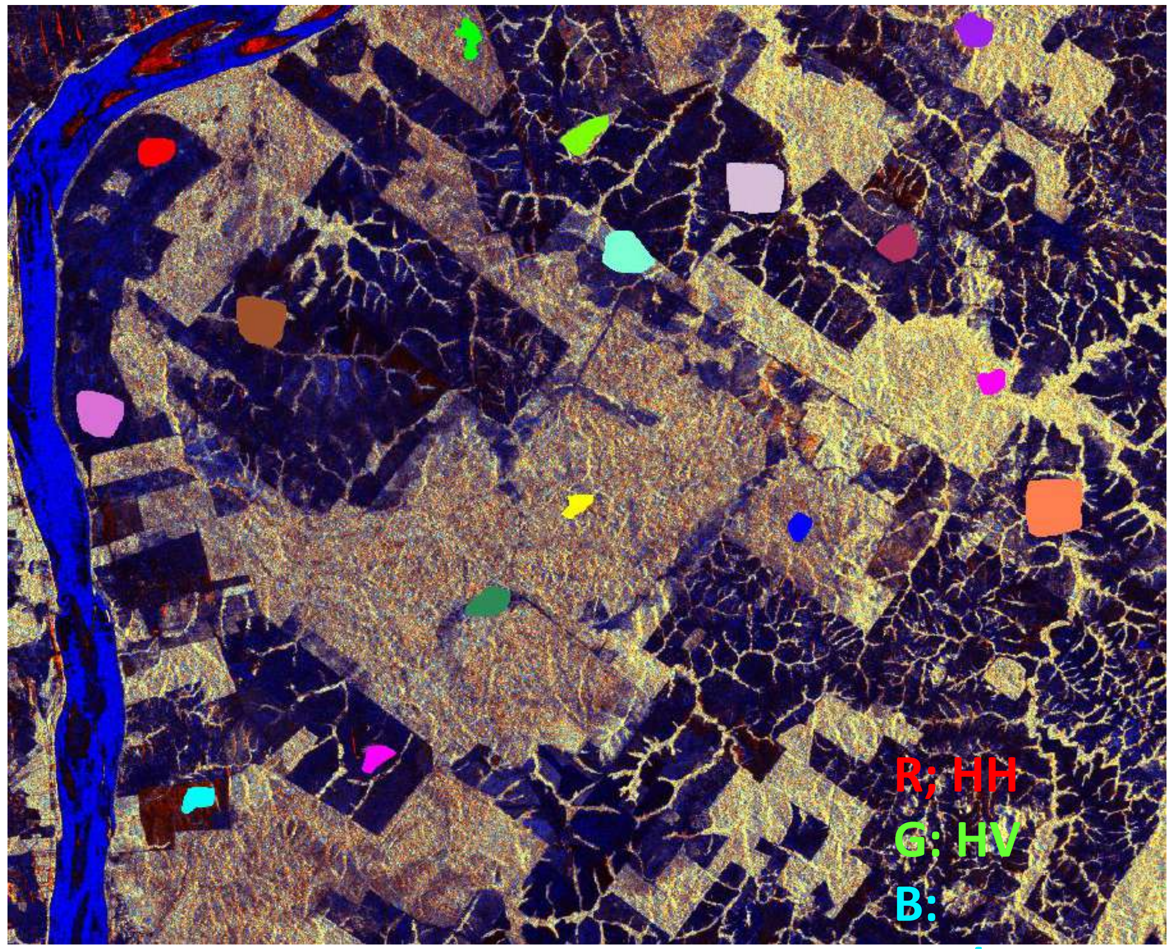
NISAR Imagery, Amazon Basin

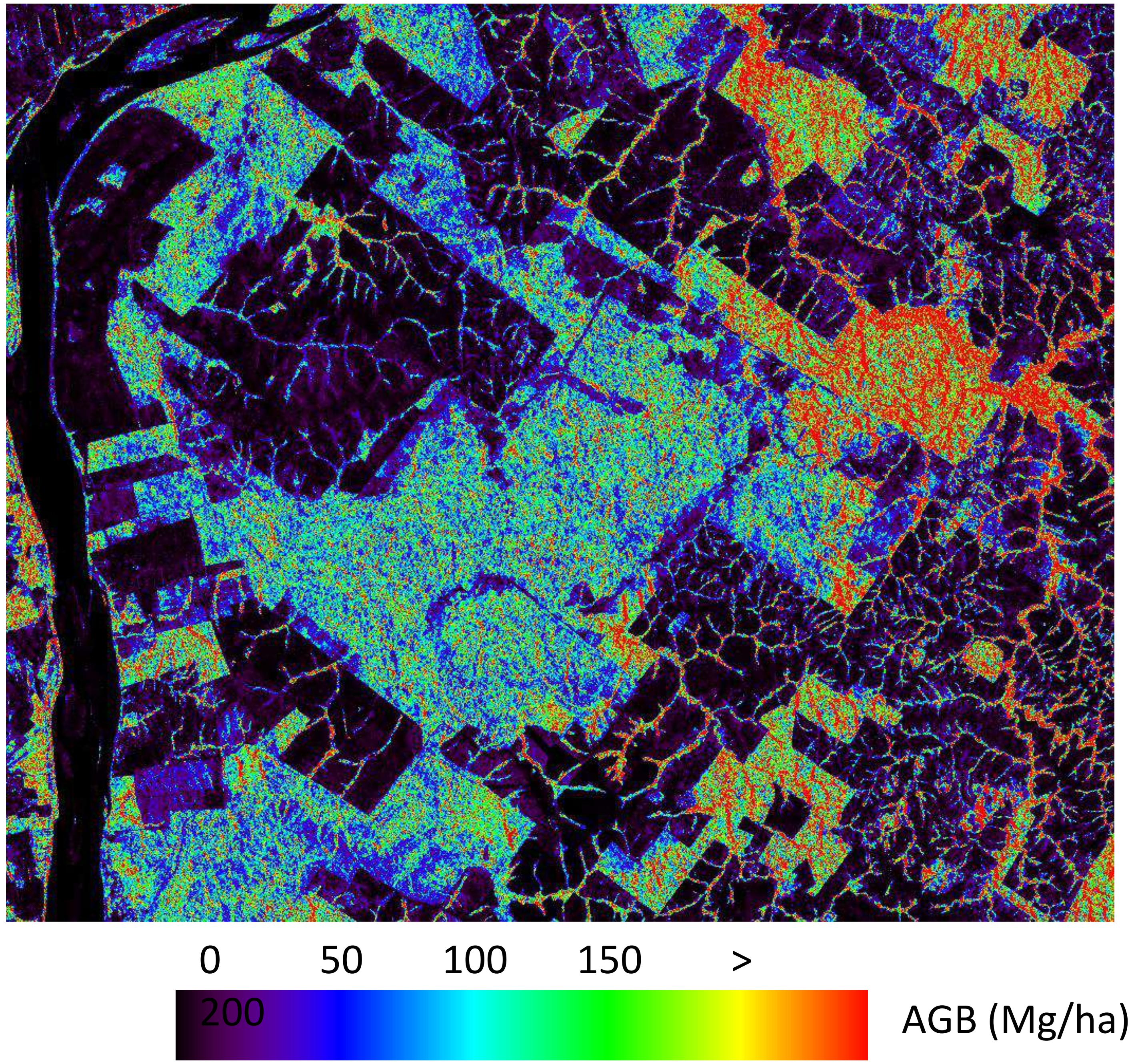


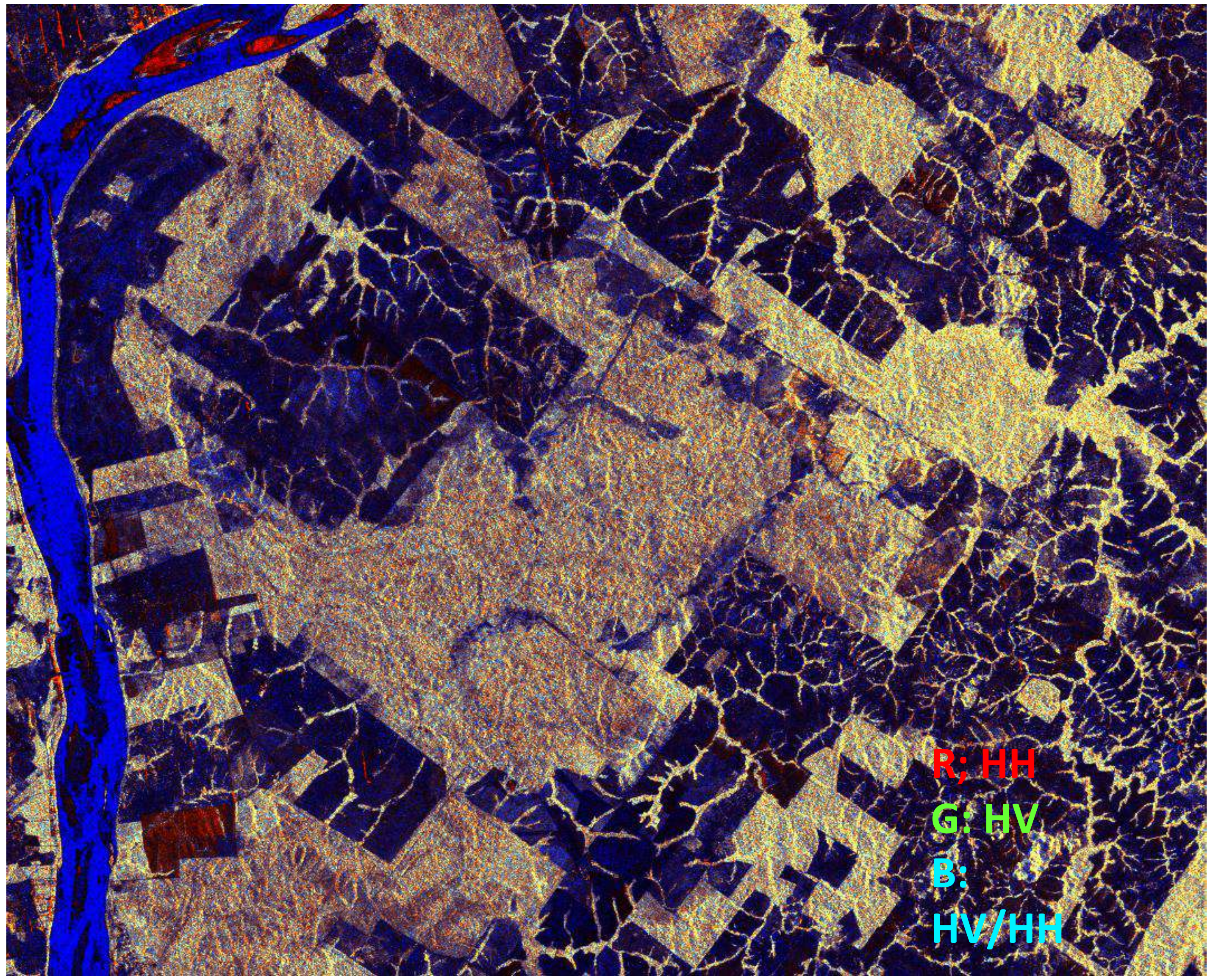
NISAR Sensitivity to AGB

Comparison of NISAR data and Global GEDI-based Biomass Map






0 50 100 150 > 200
AGB (Mg/ha)

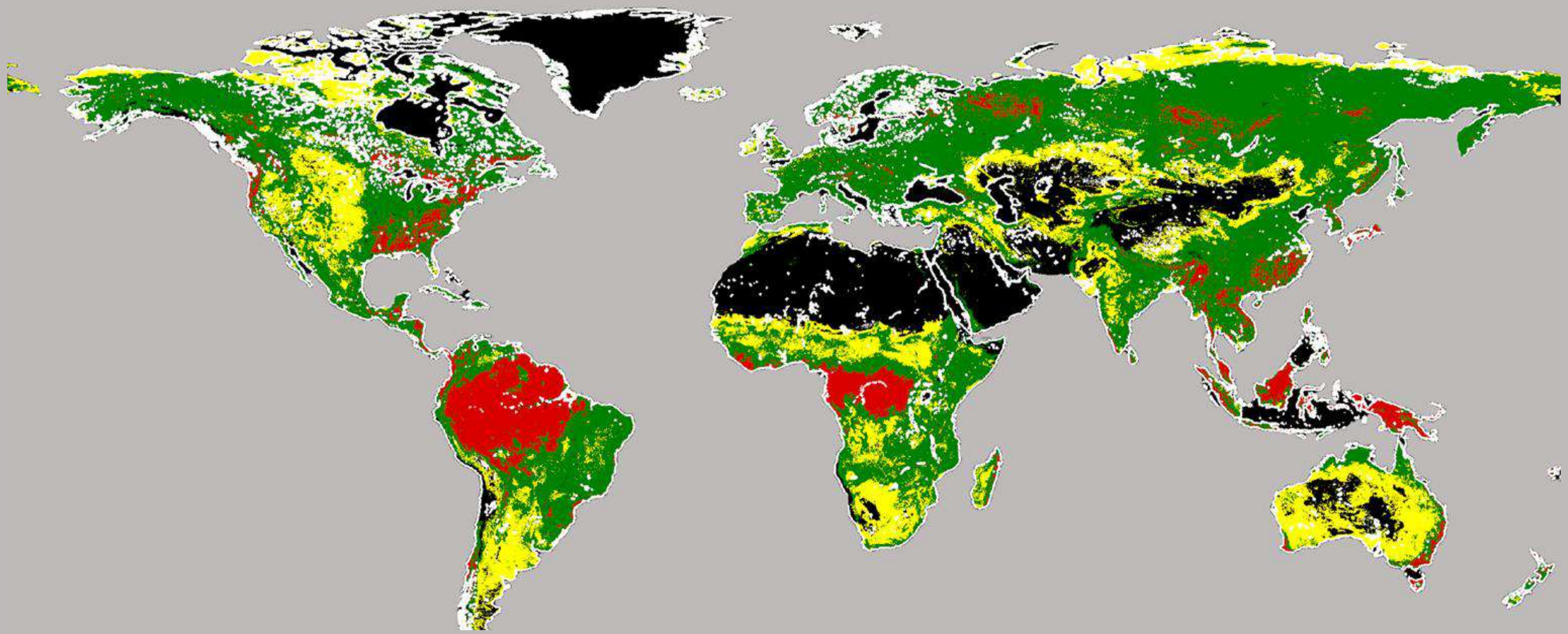

R: HH
G: HV
B: HV/HH

Global Vegetation Aboveground Biomass

< 20 Mg/ha

< 100 Mg/ha

> 100 Mg/ha

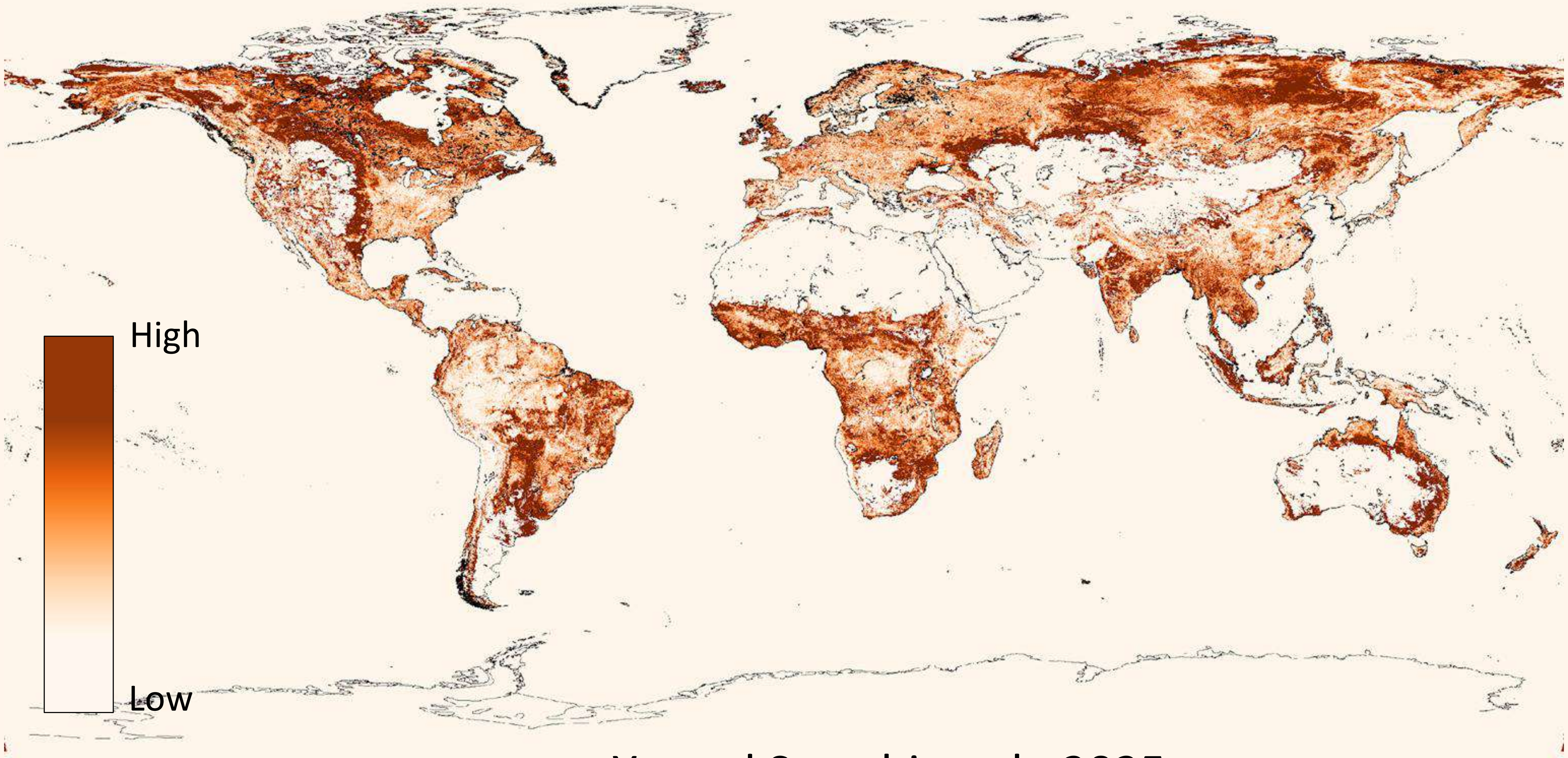


Jet Propulsion Laboratory
California Institute of Technology

Global Vegetation Biomass Dynamic

CTrees

STD of Biomass (2000-2024)
10 km Grid Cell



Yu and Saatchi et al., 2025

Summary

NISAR will provide the first forestry dedicated global observations

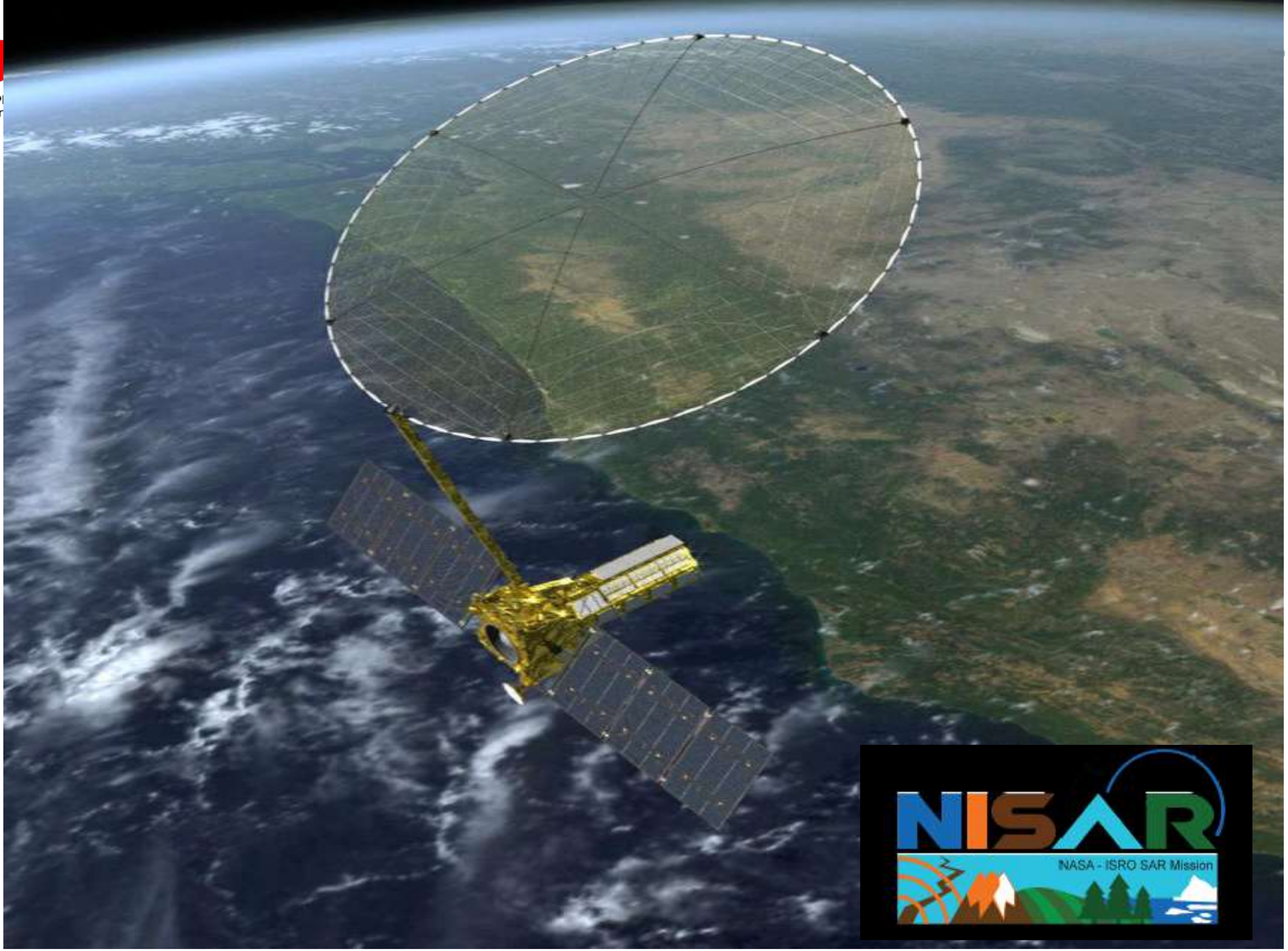
- NISAR focuses on the most dynamic components of global forests (A TRUE GEDI Satellite: Global Ecosystem Dynamic Investigation)
- Monitoring changes of forest cover from disturbance (fire, hurricane, insects, droughts)
- Monitoring recovery of forest after disturbance and land use
- Monitoring forest health and productivity by providing habitat structure, changes of canopy water content, monitoring soil moisture changes and drought stress

Image © 2023 Maxar Technologies

Google Earth

Jet Prop
Califorr

CTrees



Session 2.1 (Part 2): Estimates of carbon accumulation from various approaches

SynCER: Synthesising post-disturbance Carbon Emissions and Removals across Brazil's forest biomes

São José dos Campos, 30 Oct 2025

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Session 2.2: Other metrics for identifying secondary forest success

(eg. biodiversity, landscape metrics, permanence)

São José dos Campos, 30 Oct 2025

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Catarina Jakovac

Patterns and Drivers of Vegetation Structure in Amazonian Secondary Forests

20th June 2025

UFSC

REGENERA AMAZÔNIA

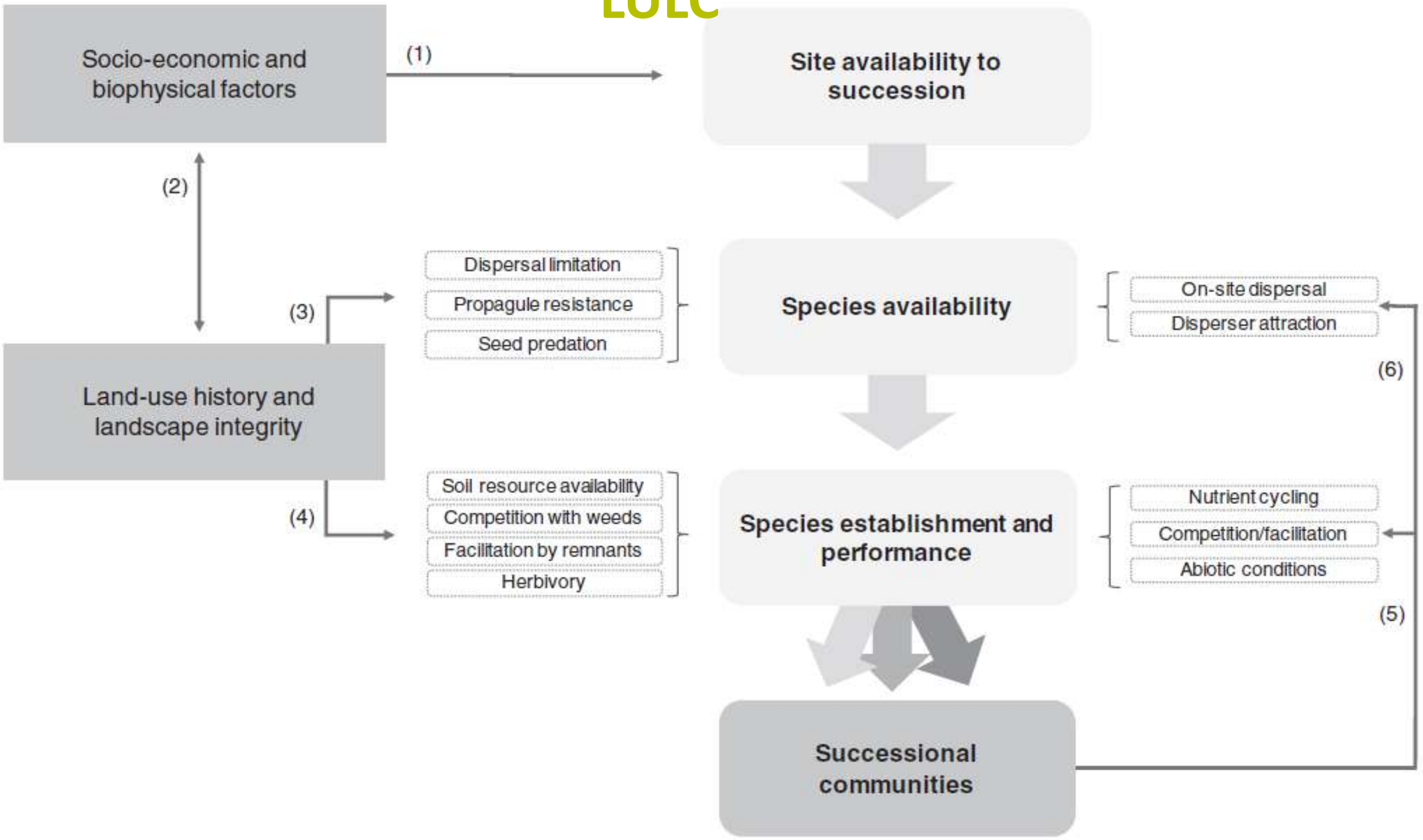
LAB REFLOR Laboratório de Restauração e Ecologia Florestal

SIN BIO SE CENTRO DE SÍNTESE EM BIODIVERSIDADE E SERVIÇOS ECOSSISTÊMICOS

serrapilheira

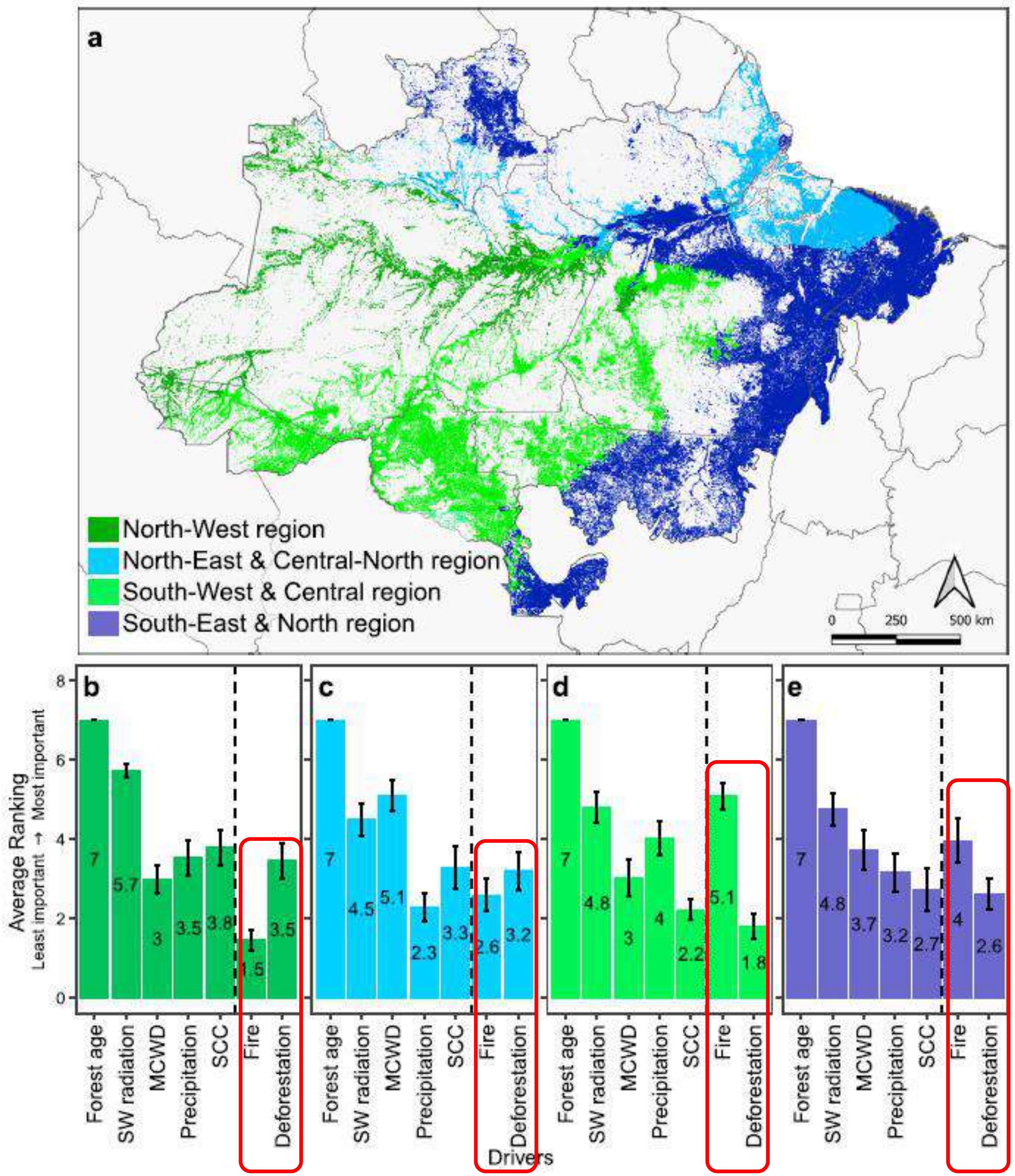
Continental scale = Environmental conditions

Regional scale = Environ + LULC



Jakovac et al 2021, Land use effects on secondary succession

Environmental conditions and anthropogenic factors vary across space



of disturbances: fire and deforestation (Fig. 3). Our analysis shows distinct regrowth regimes emerging in these four heterogeneous climate regions (Fig. 3), with regrowth in some regions conditioned largely by natural, environmental drivers, and others by anthropogenic disturbance drivers (Fig. 2b–e). In the North-

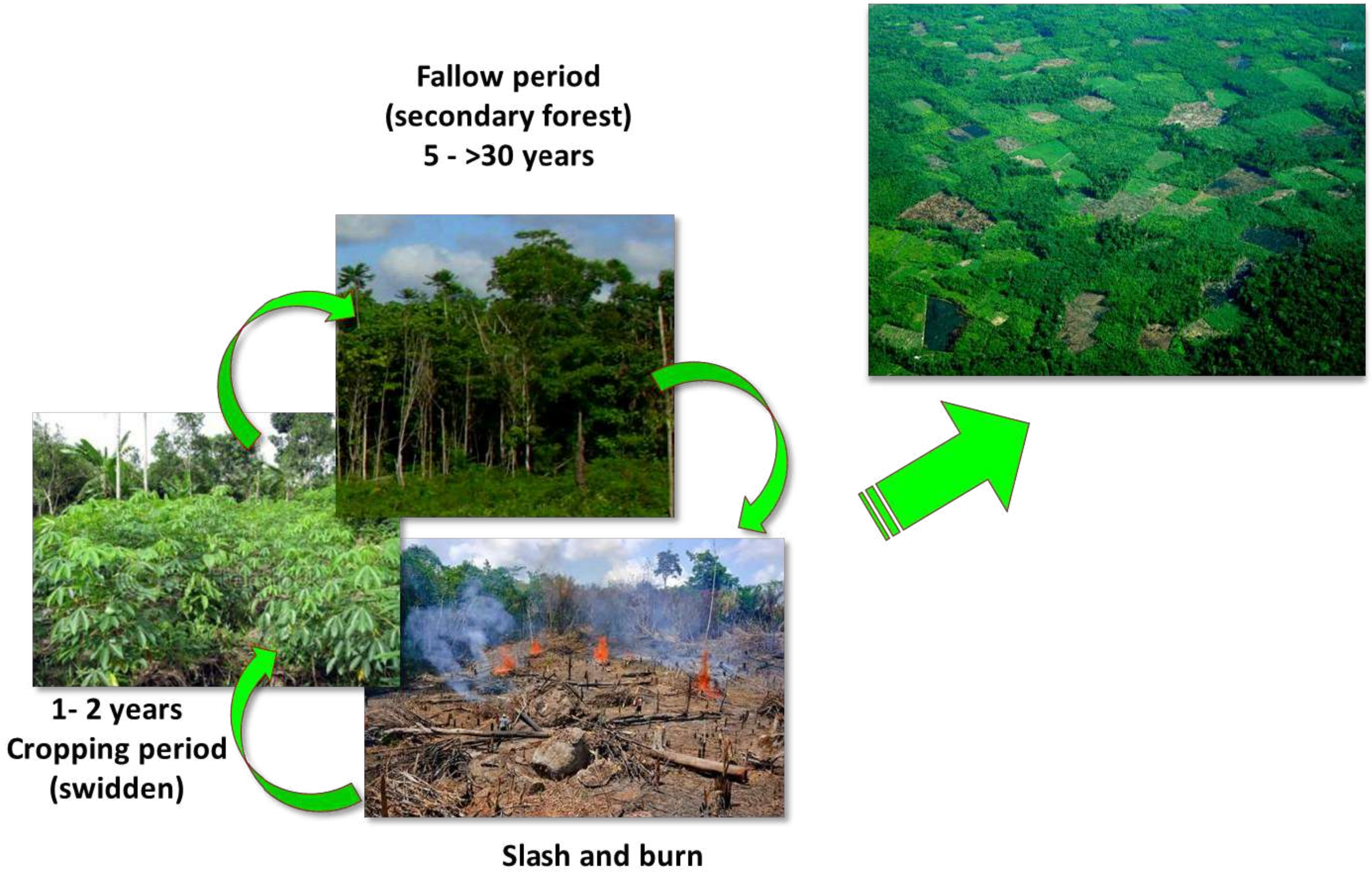
Drier (more seasonal) regions were more affected by anthropogenic drivers. Why?

- ? less resilient to anthropogenic impacts
- ? higher fire and deforestation frequency (broader gradiente = stronger effect)
- ? lower forest cover in the landscape due to longer LU lead to lower regrowth rates

Heinrich et al 2021, Large carbon sink potential of SF

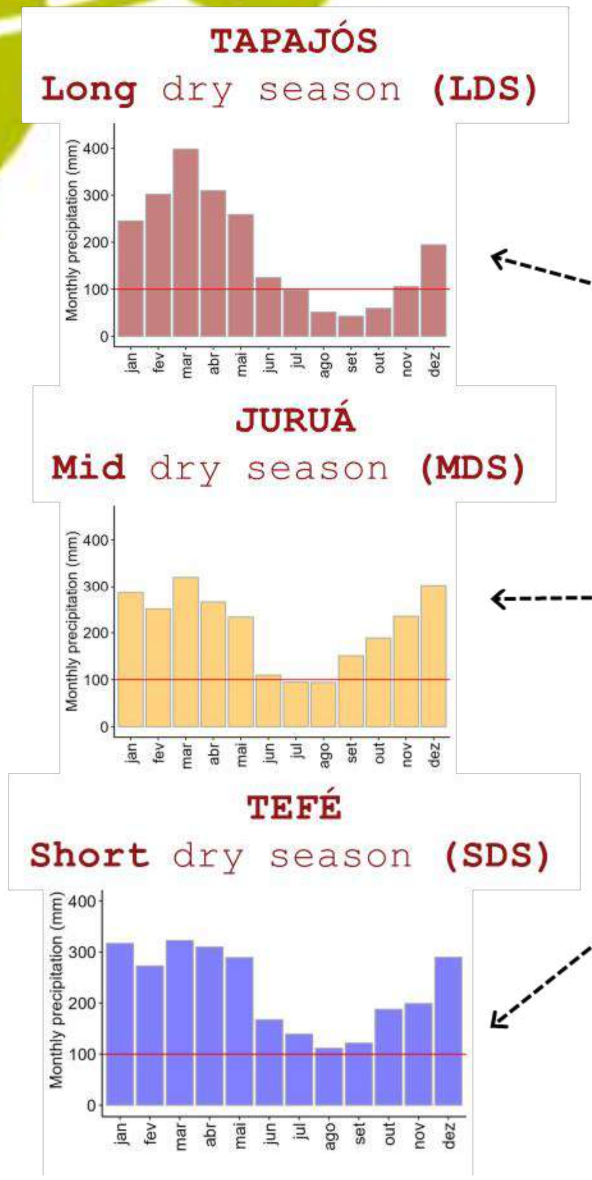
How environmental and land use drivers interact?

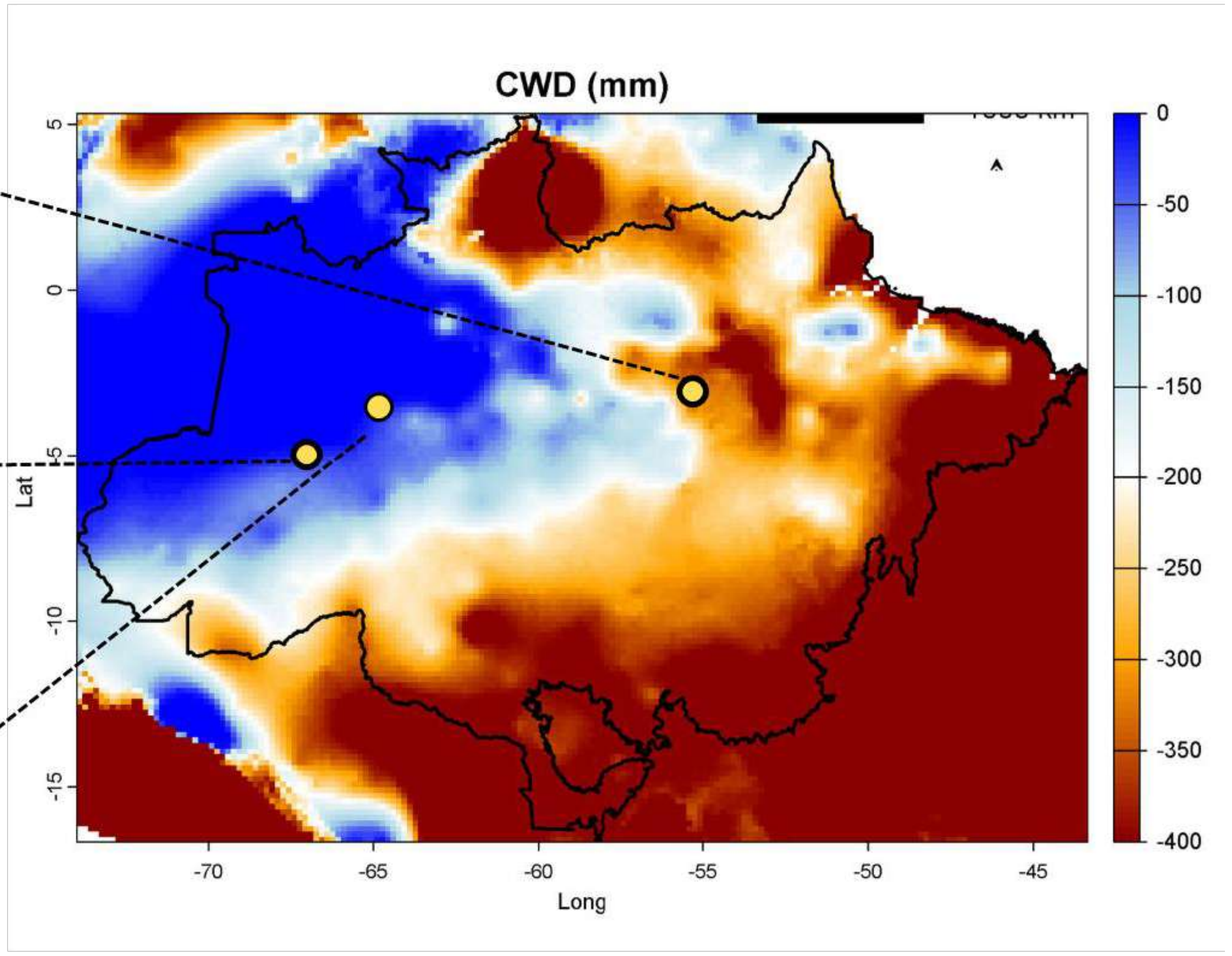
Hypothesis: Wetter regions are more strongly affected by anthropogenic impacts than drier regions, because species did not evolve with fire.



How environmental and land use drivers interact?

Climatic gradient

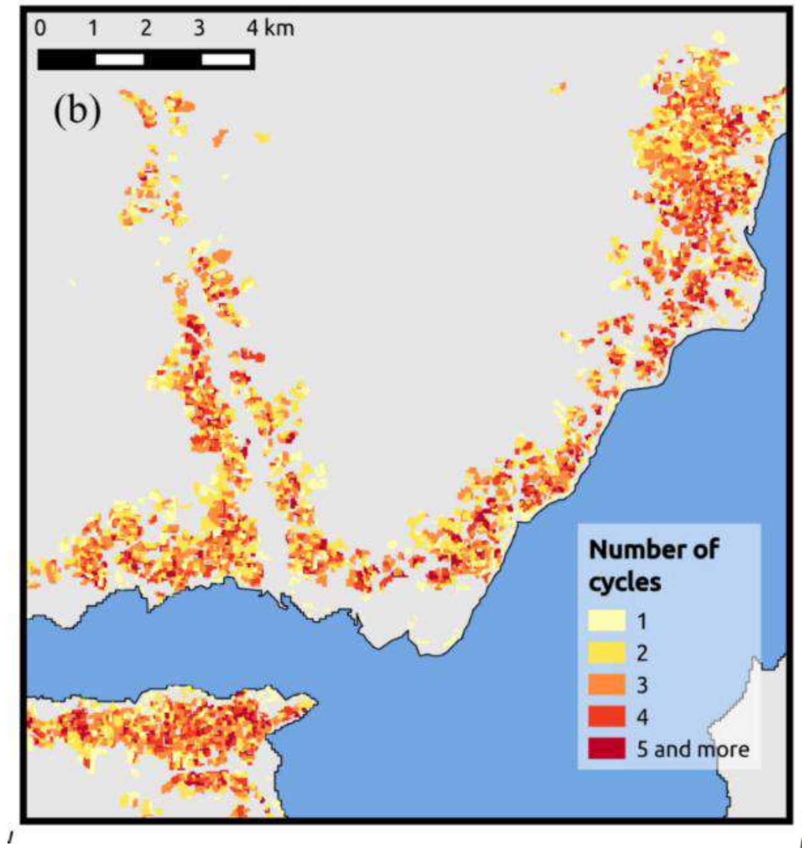




Same-aged Young SF: 4-8 yrs old

n= 88 forest inventory plots

Land use gradients

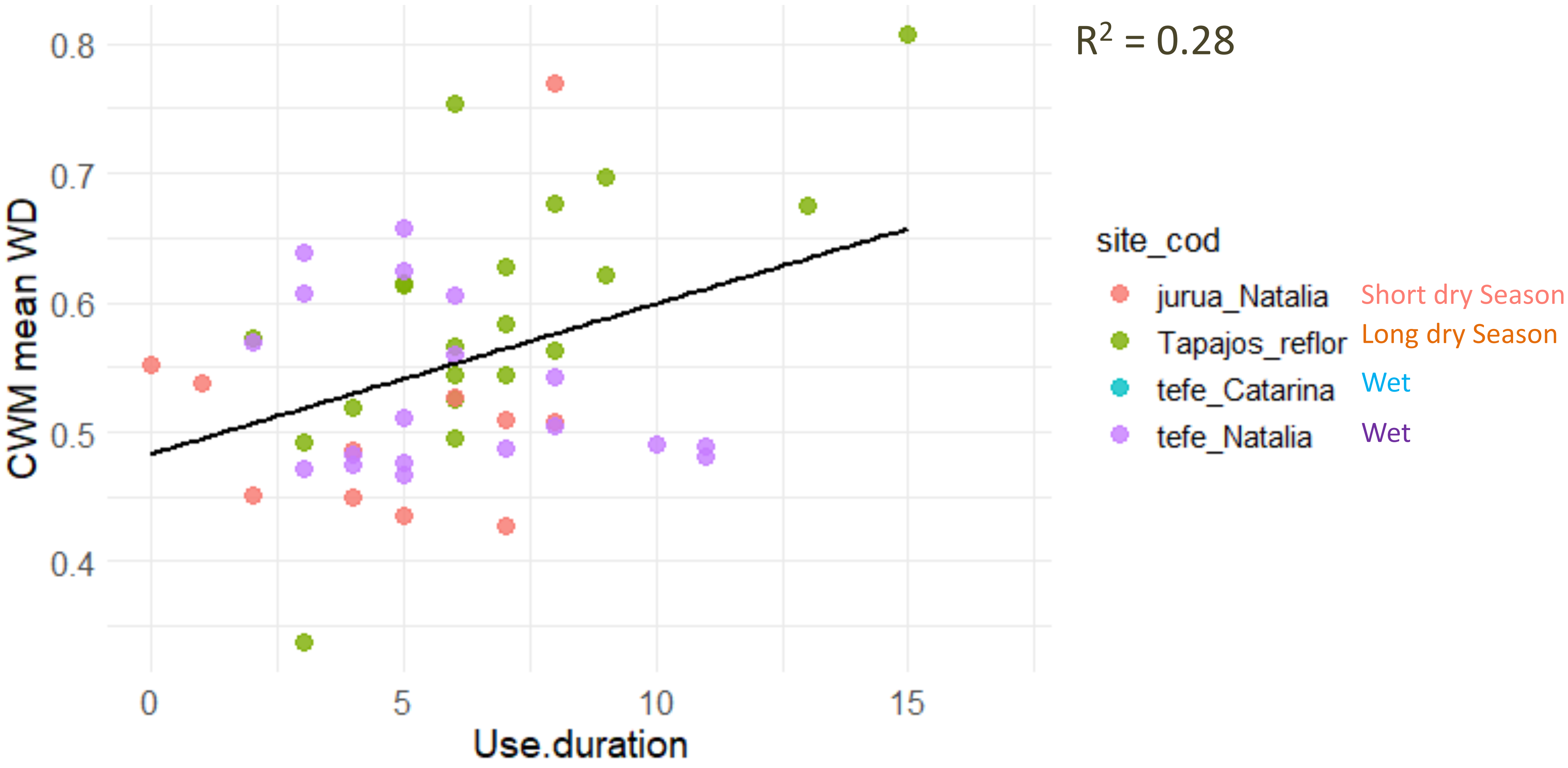


FARMER INTERVIEWS

- # slash and burn events
- Date OGF was cut
- Age of SF

Vegetation structure

- Increase wood density
- No interaction effects of site * LU
  - Change in species composition to more conservative species and reduced dominance by "classic pioneer species"



n= 55 plots

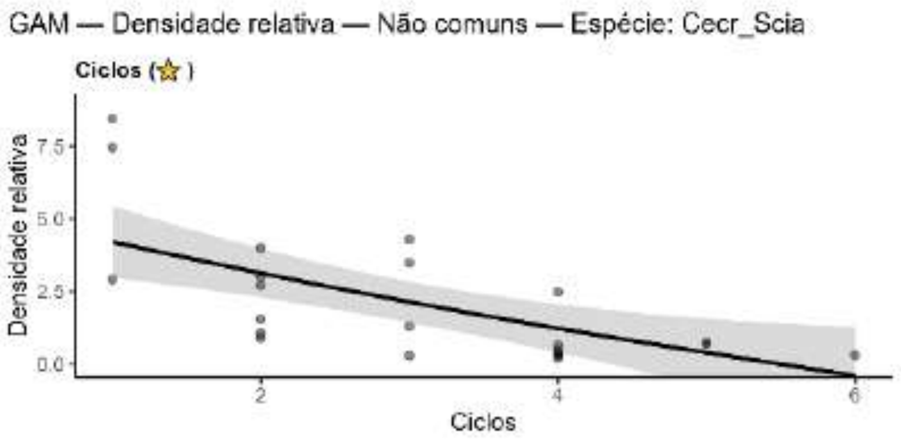
Jakovac, Giles et al *in prep.*

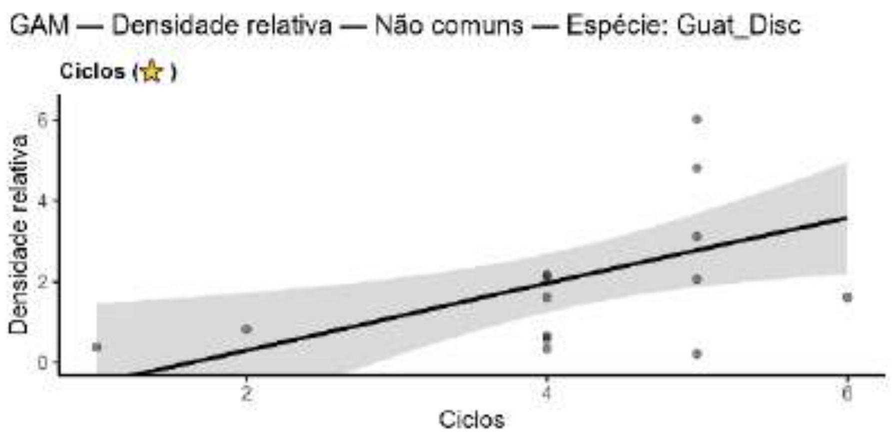
Vegetation structure

➢ Change in wood density is related to changes in species composition

Wood density

Shift species composition





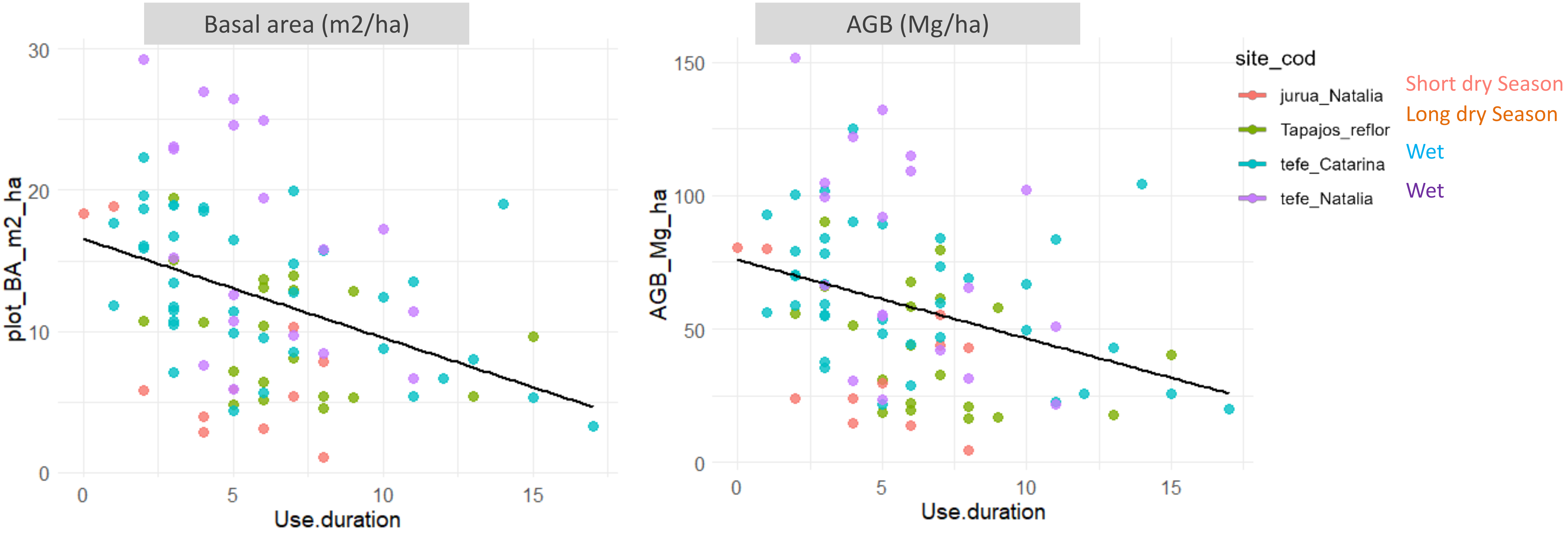
Regrowth rate

Duration/frequency of previous land use

Jakovac, Giles et al *in prep*.

Vegetation structure

- Decrease basal area
- Decrease AGB
- No interaction effect of site * LU



n = 88 plots

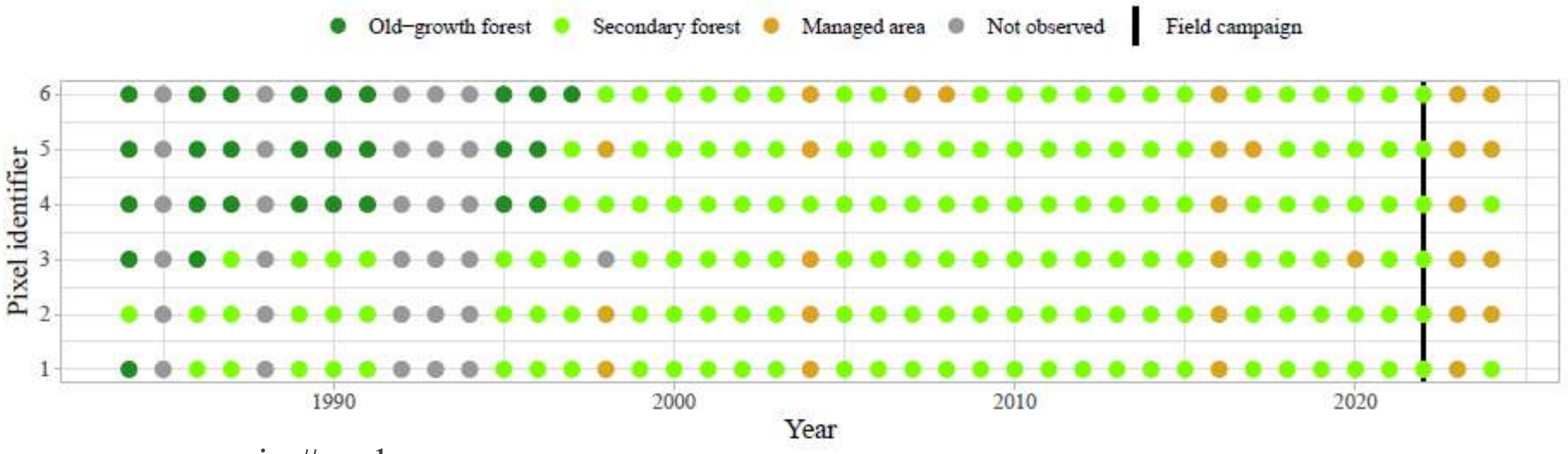
Jakovac, Giles et al *in prep*.

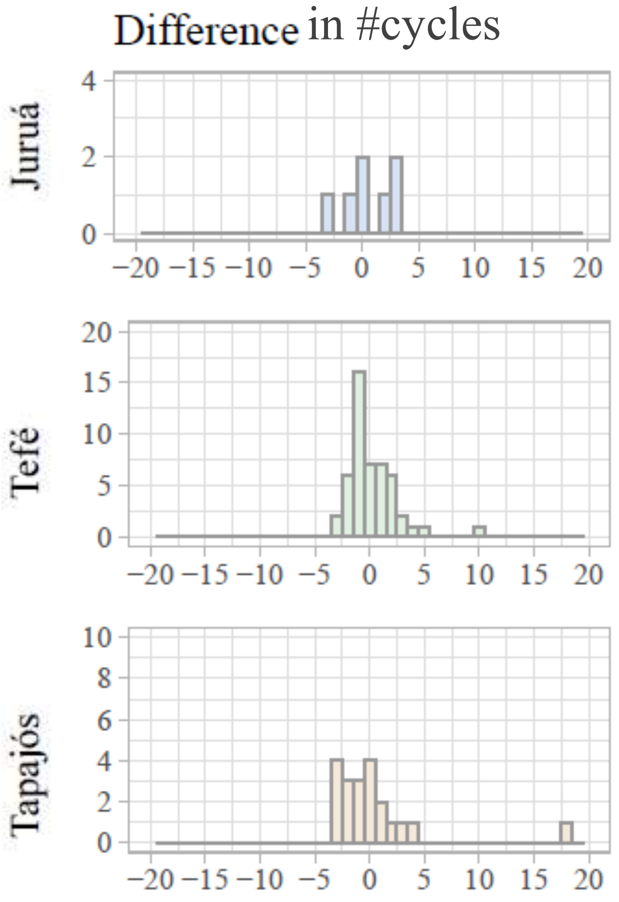
How environmental and land use drivers interact?

- Higher duration of land use (and frequency of deforestation) reduces AGB recovery
- The effect size of land use is similar across climatic regions (preliminary)
- Reduction in AGB is driven by basal area and height more than by wood density
- Vegetation diversity…

Retrieving land-use history (interviews x RS)

LULC classification along landsat time series - CMAP





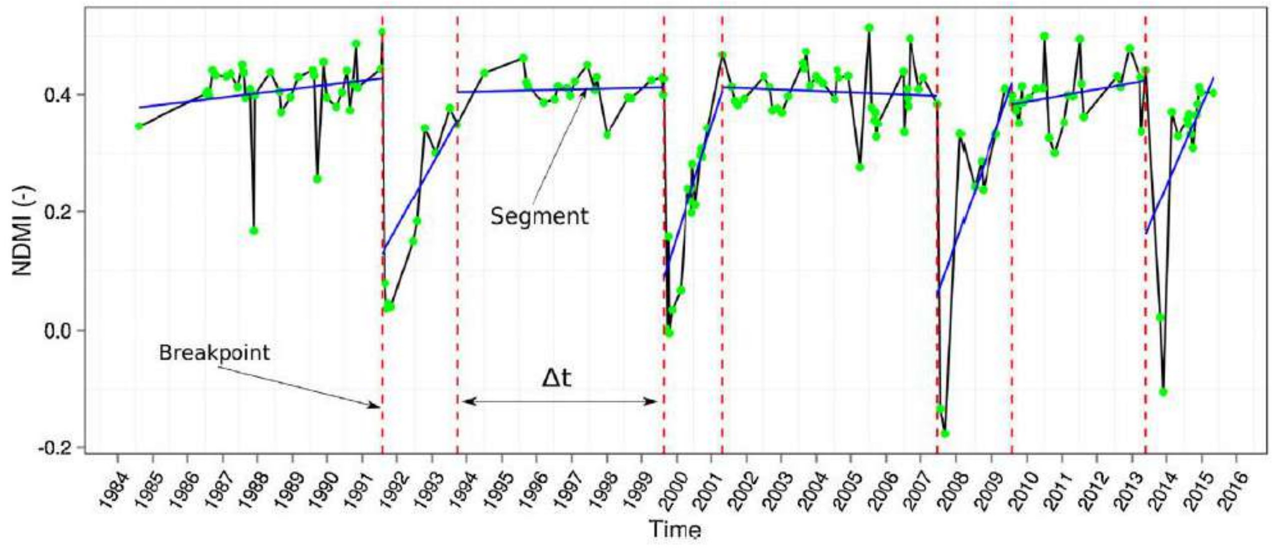
Comparison with local landowner interviews shows CMAP effectively estimates:

 # cycles: mean diff -0.8 ± 1.9 cycles (55% of samples within ±1 cycle)

SF age: 0.4 ± 3.0 years (93% of samples within ±3 years for age)

(n = 88 samples)

Breakpoint detection



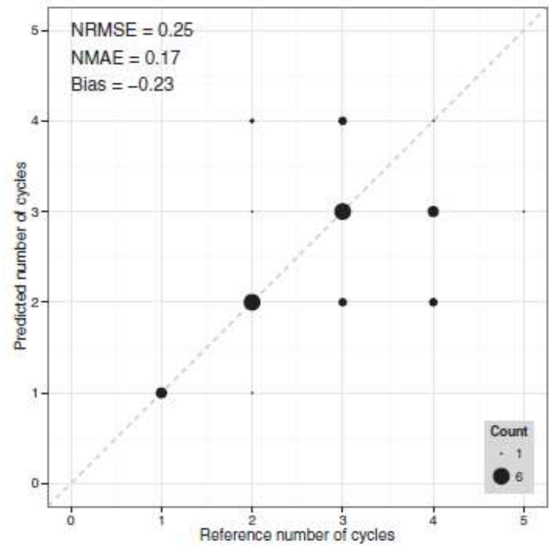


Fig. 6. Scatter plot of predicted number of cultivation cycles against information reported by farmers.

Mean diff of −0.23 cycles;

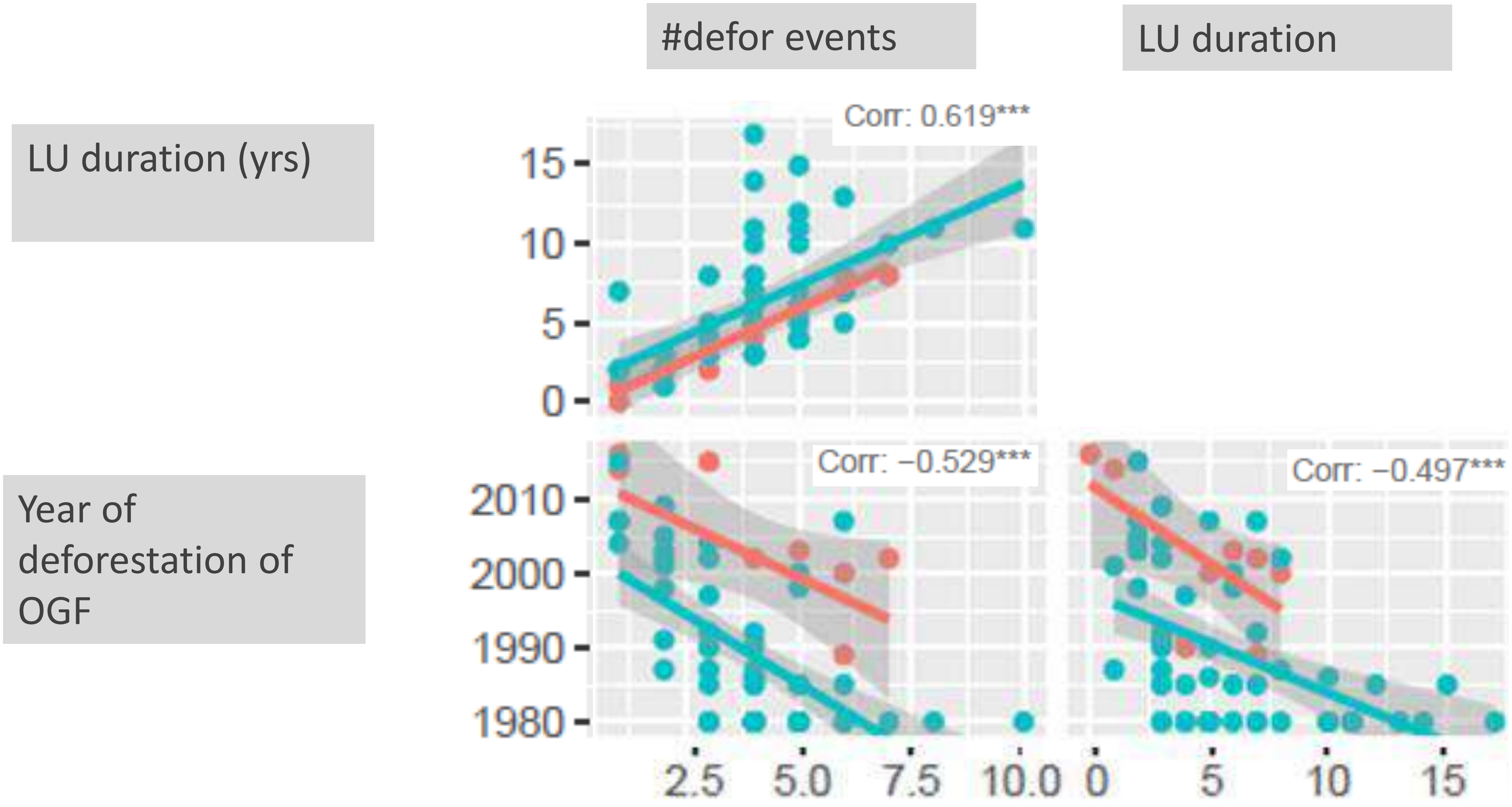
No strong systematic error of over-or underestimation

Reis, Escada, Giles,..., Jakovac et al *in press*

Dutrieux, Jakovac et al 2016

Proxies for Land-use history

- #deforestation events since OGF deforestation
- Land use duration = total time in agric/pasture use since deforestation
- Year of OGF deforestation (e.g. PRODES)



Jakovac, Giles et al *in prep.*

Retrieving land-use history

Limitations

- Requires long time series (landsat, 30m res)
- Secondary forest patches are small (require high res)

- Rapid vegetation recovery = short time window to detect "deforestation" events may underestimate deforestation frequency and overestimate SF age

- Current SF patches are mosaics with different LU histories

6 months cassava field

Reis, Escada, Giles,..., Jakovac et al *in press*

Obrigada

catacj@gmail.com

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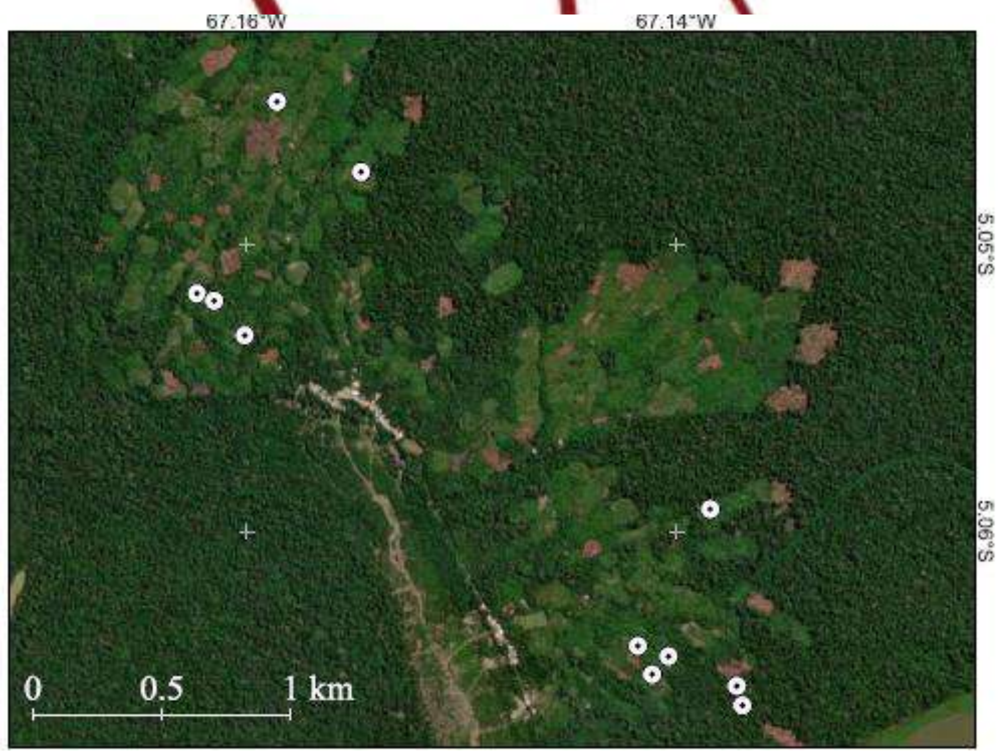
Ecologia Florestal

serrapilheira

UNIVERSIDADE FEDERAL
DE SANTA CATARINA

Proxies for Land-use history

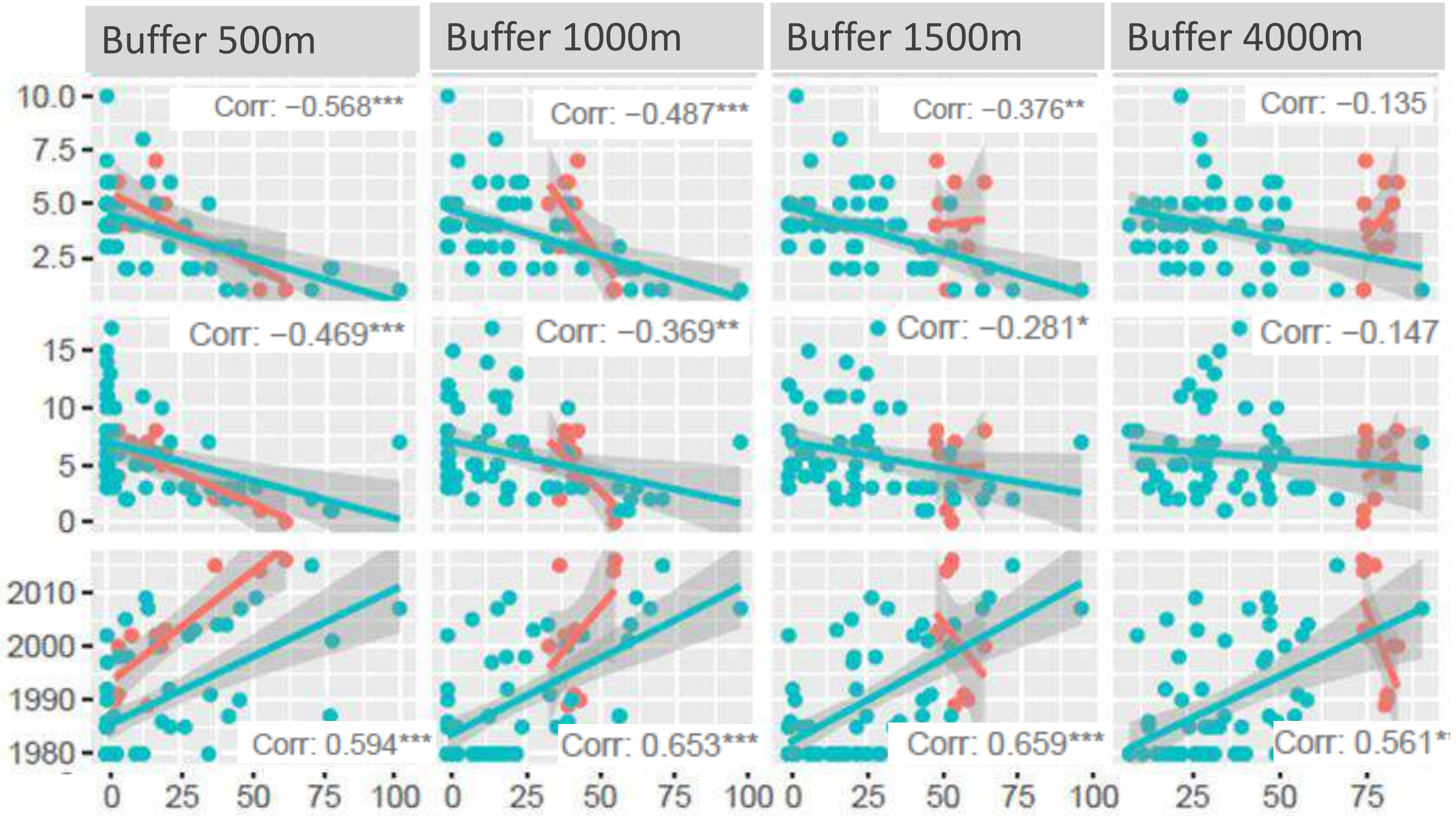
- **Landscape forest cover**



#deforestation events

LU duration (yrs)

Year of deforestation of OGF



Jakovac, Giles et al *in prep.*

Simple ecological indicators benchmark regeneration success of Amazonian forests

André Giles

Session 2.2: Other metrics for identifying secondary forest success

São José dos Campos, 30 Oct 2025

REGENERA AMAZÔNIA

LAB REFLOR Laboratory of Restoration and Ecology of Forests

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Regeneration Success

Ecological Integrity

Low limitation to successional trajectories

1. High landscape integrity (Forest cover/Species availability)
2. Low Intensity previous land-use

Sample illustration

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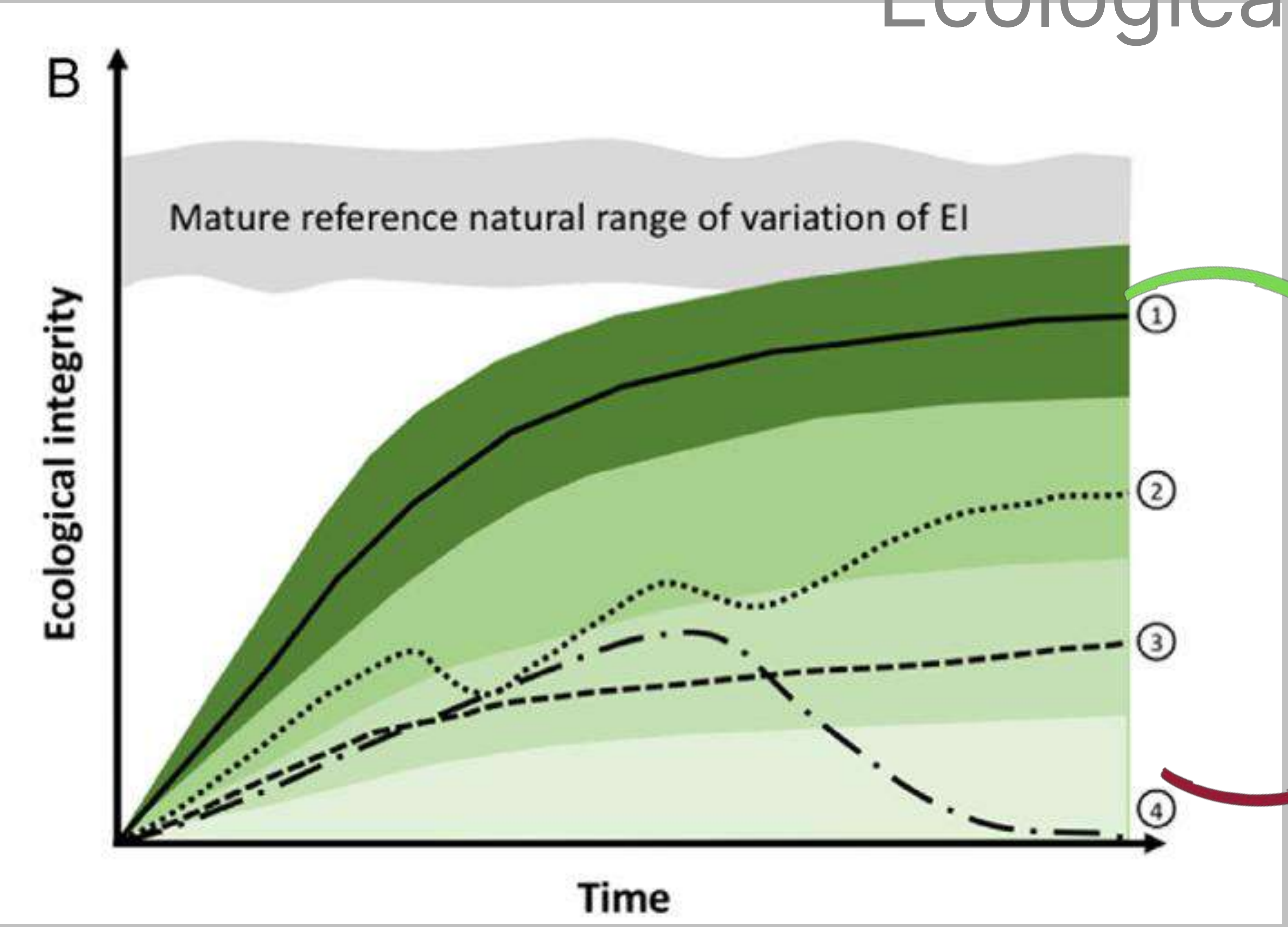
Regeneration Success

Ecological Integrity



- Diversity
- Forest structure
- Functioning

Sample illustration

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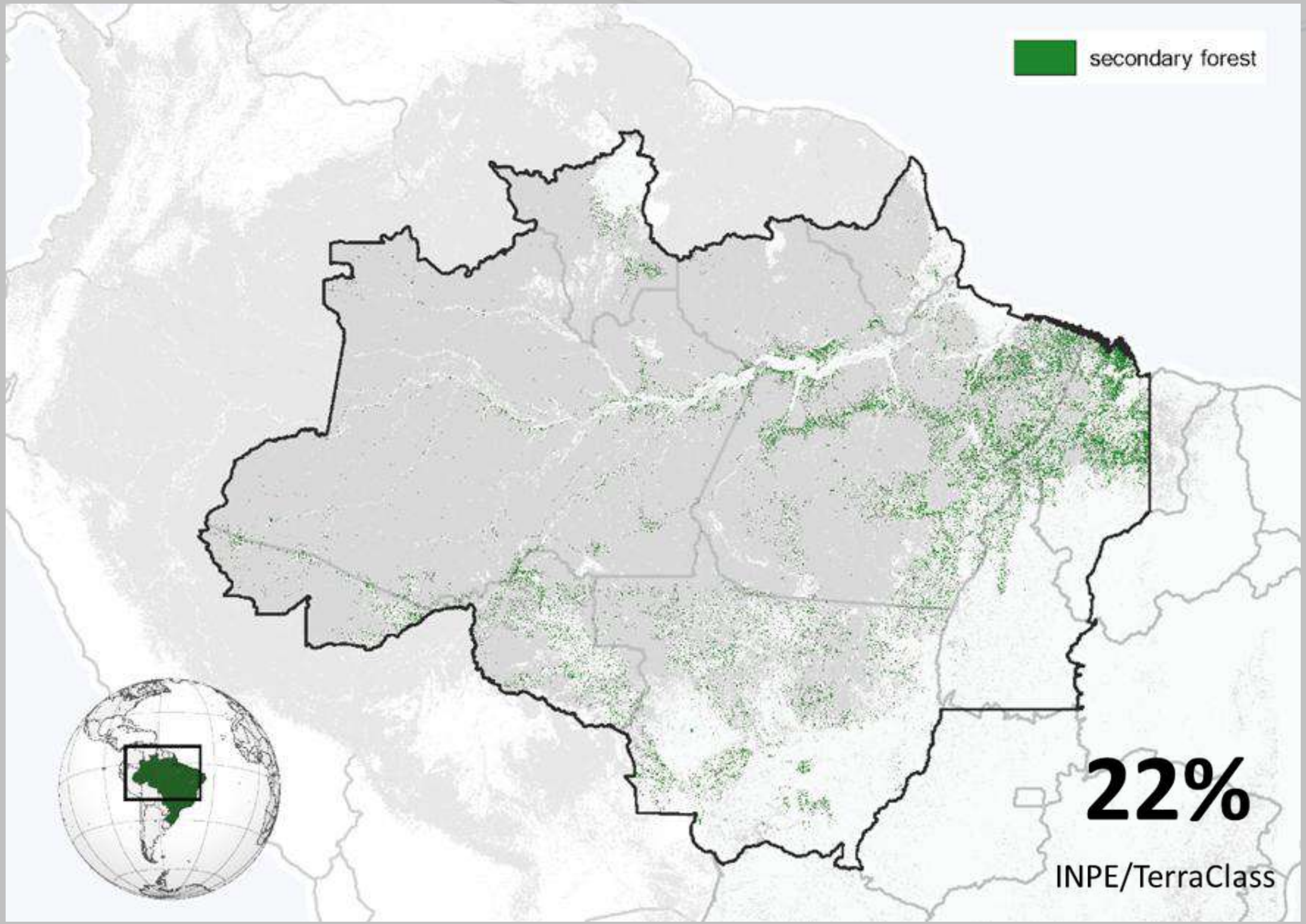
1. The drivers of forest regeneration in the Amazon

1. Set ecological indicators to evaluate regeneration success



Methods

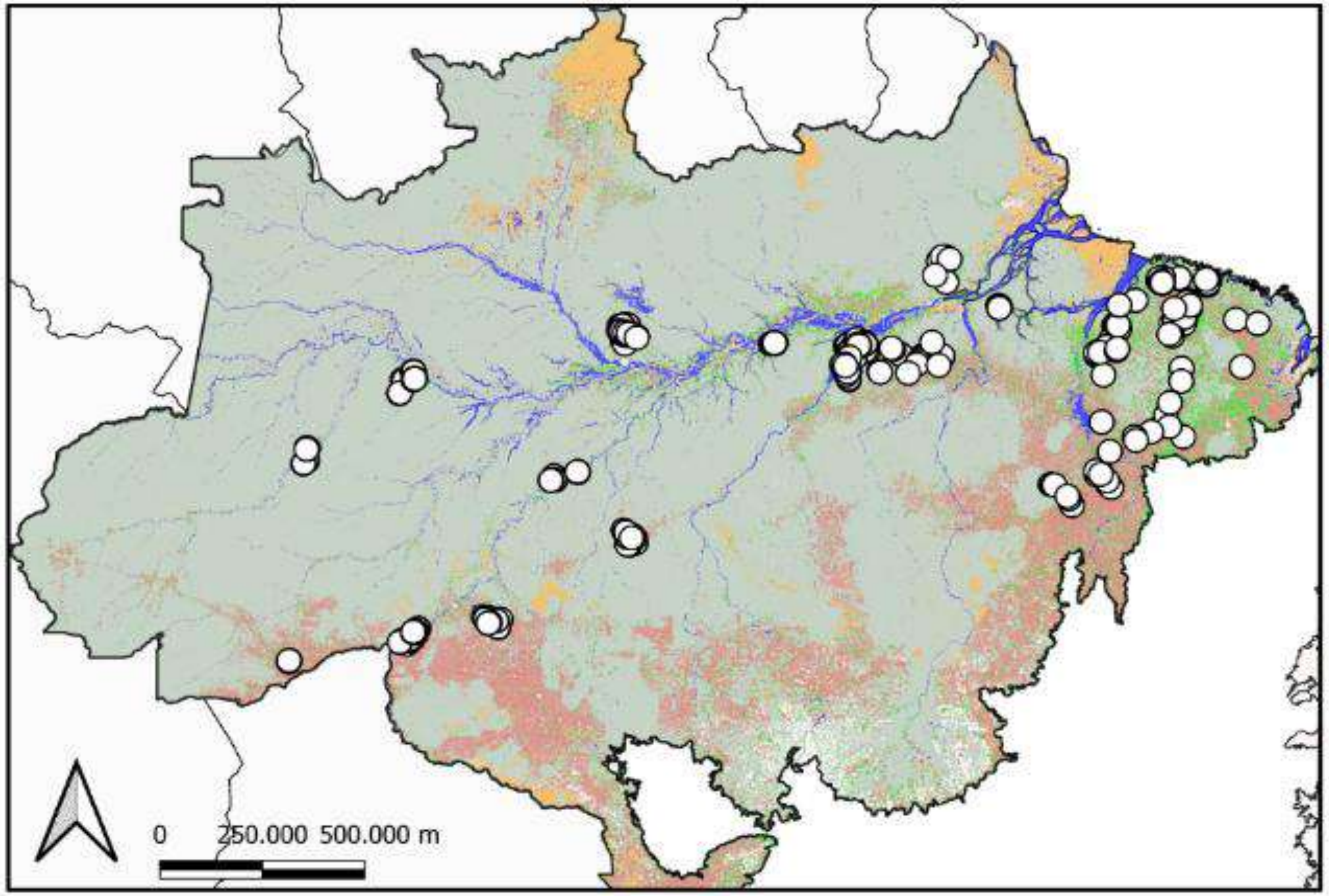
Data compilation

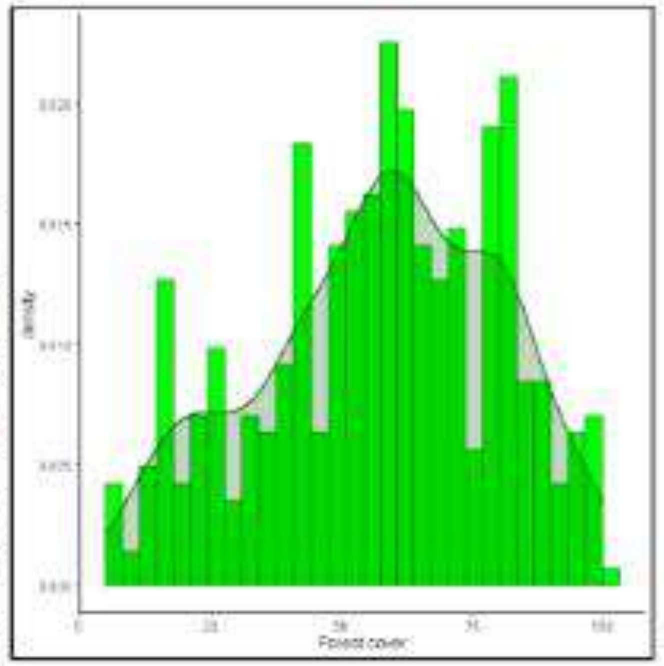
- 448 SFs plots
- 24 sites
- 150 000 trees

  > 5 cm DAP

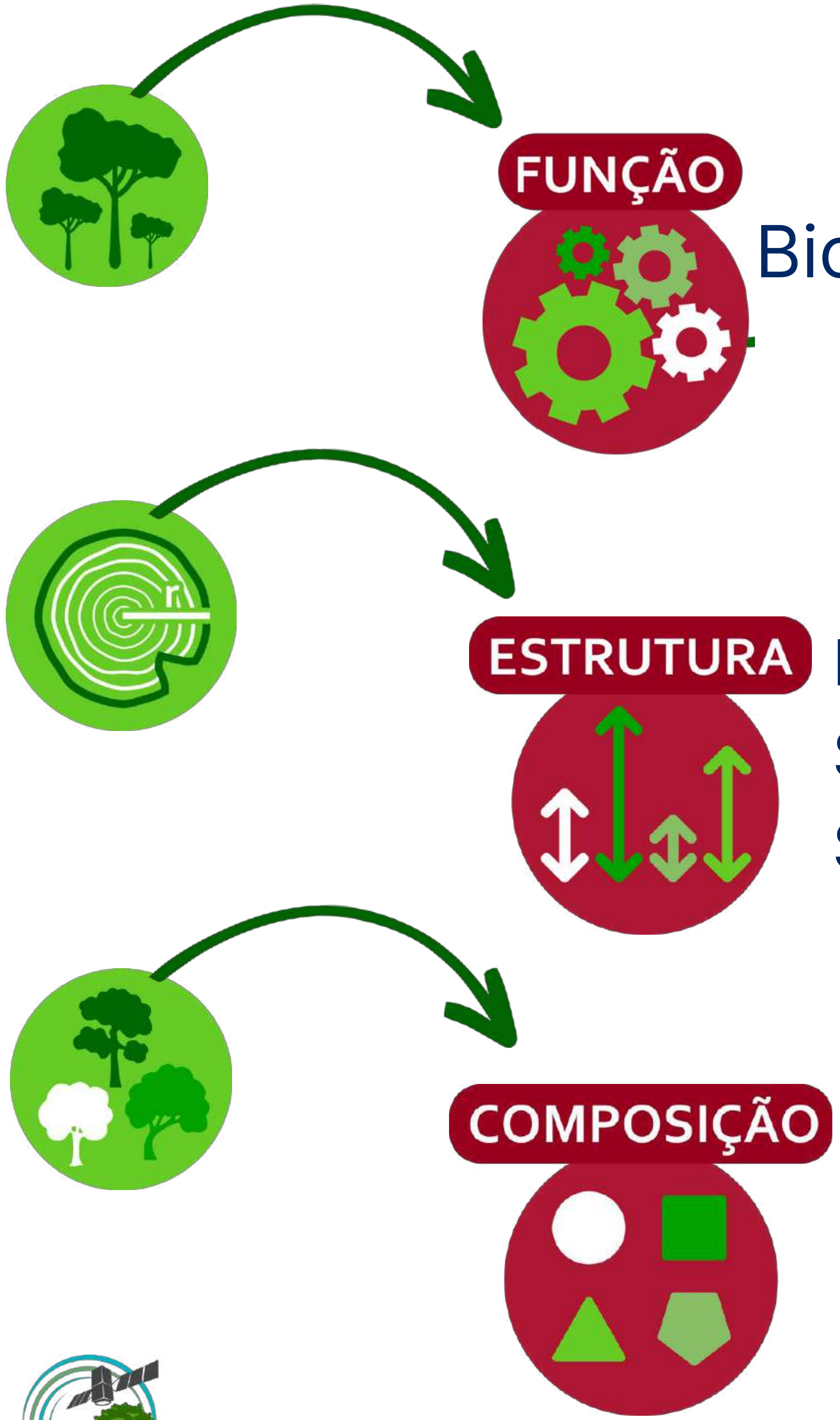
- 5 - 70 years
- 88% < 30 years
- 1.500 a

  3.000 mm ano-1





Methods



Biomass

Basal area
SH
Stem density

Species Richness
(Sp 100 ind.)
Species Diversity
(Hill 1)

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Methods

Biomass

Basal area
SH
Stem density

Species Richness
(Sp 100 ind.)
Species Diversity
(Hill 1)

Climate (CHELSA)
CWD, temperature, seasonality

Soils (SoilGrids & Zuquim et al. 2023)
pH, base saturation, CEC, and bulk density

Anthropogenic impacts (MapBiomas)
Land-use duration
Forest cover
Deforestation frequency
Fire frequency

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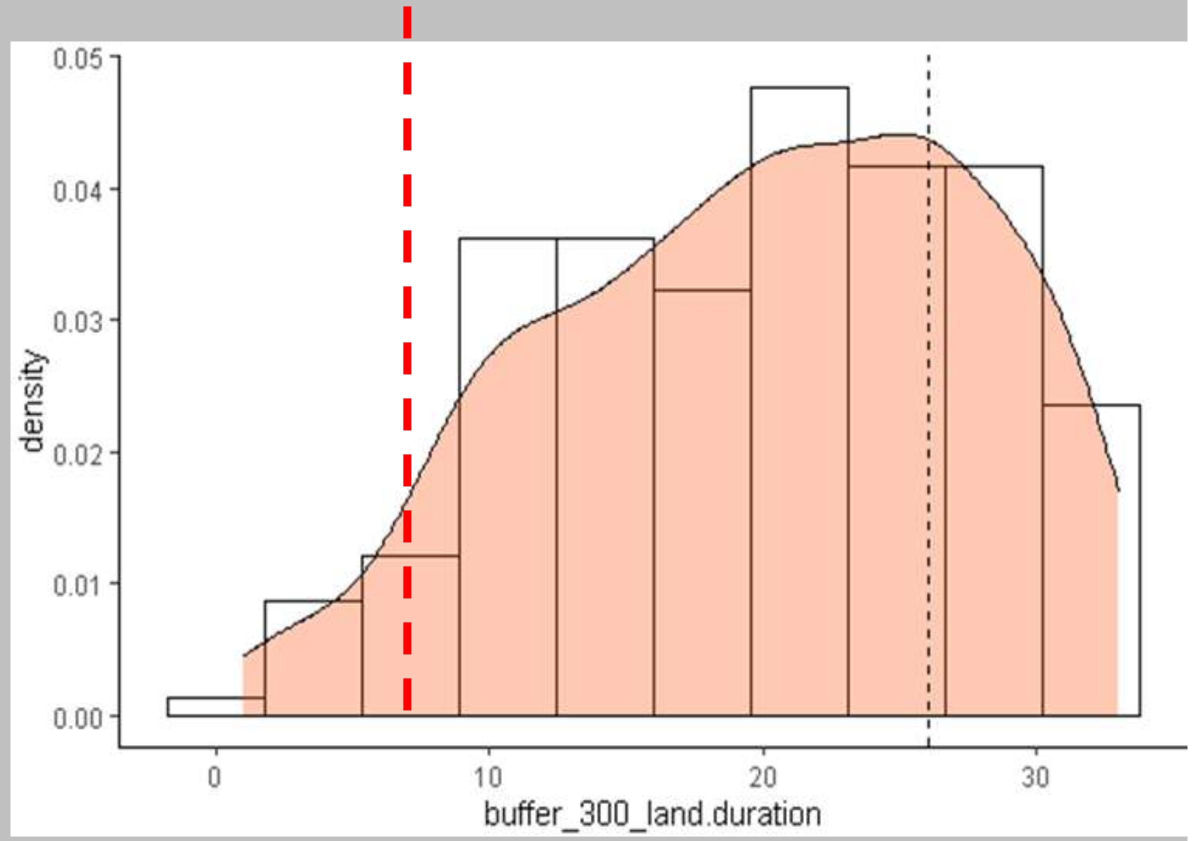
Drivers of Forest Regeneration

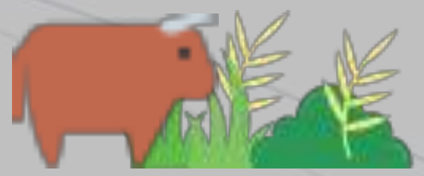
Setting Reference Values

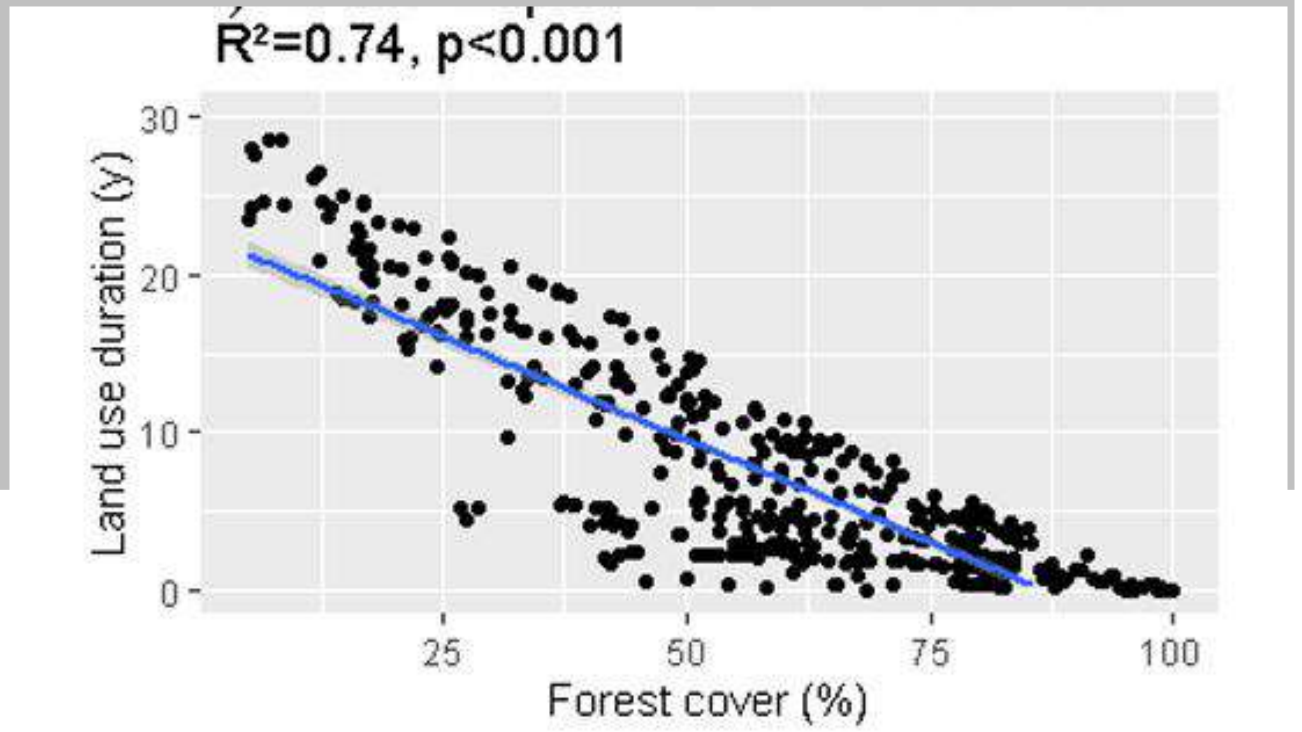
EI= Age + Soil + Previous land-use + Error

Deforestation Frequency (<1 Deforest.)



Land-use Duration (<8 years)





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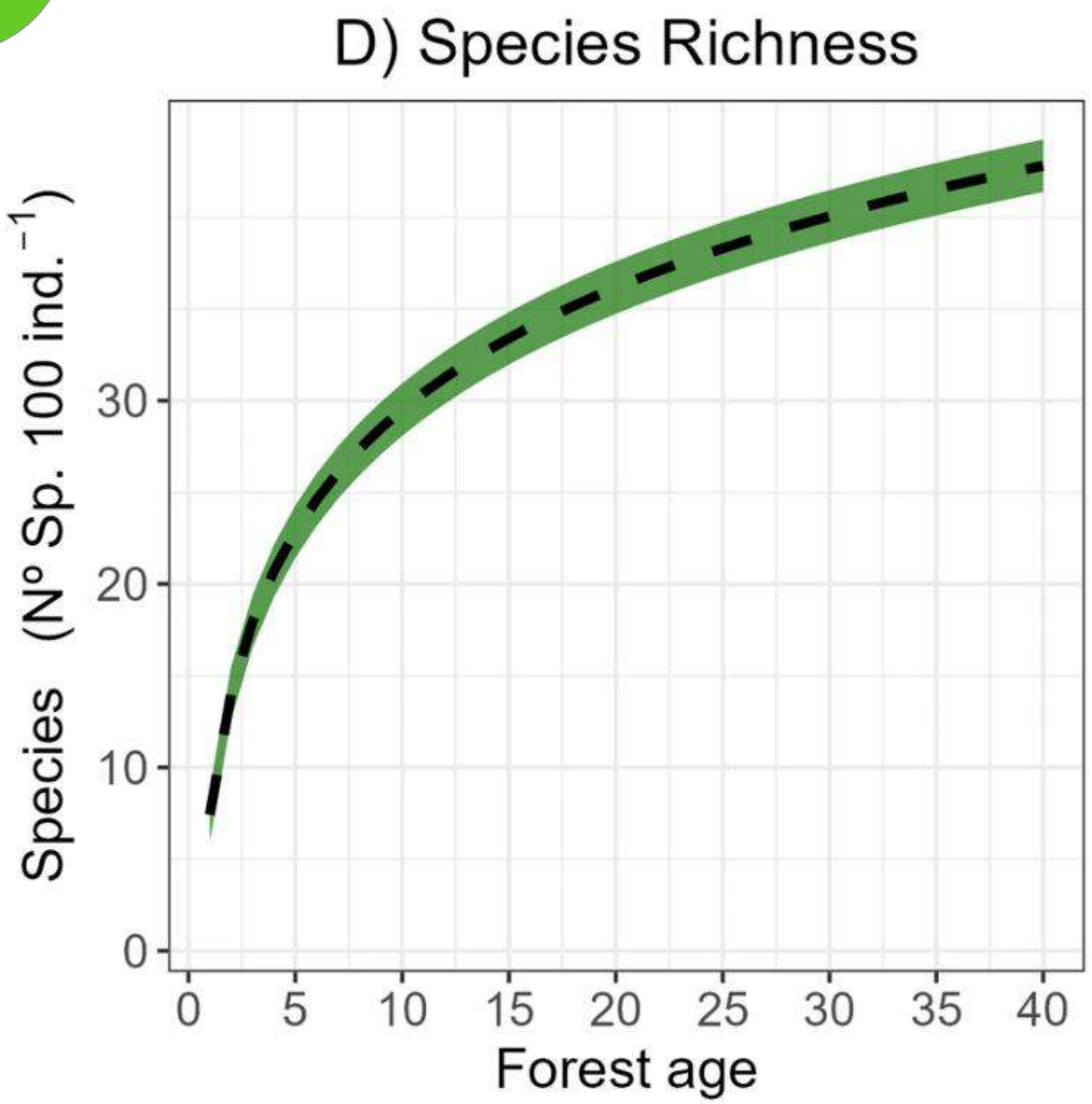
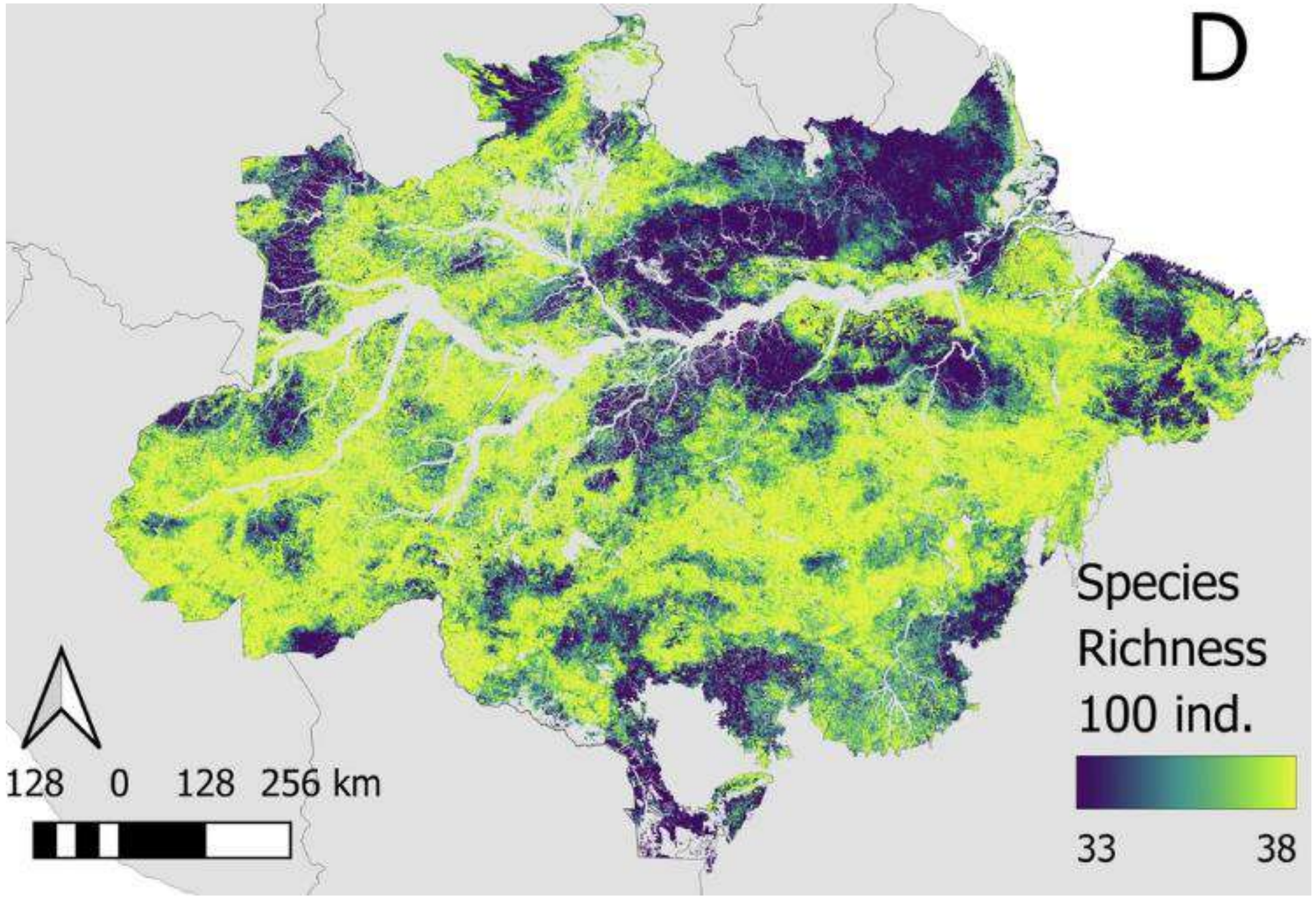
Setting reference values





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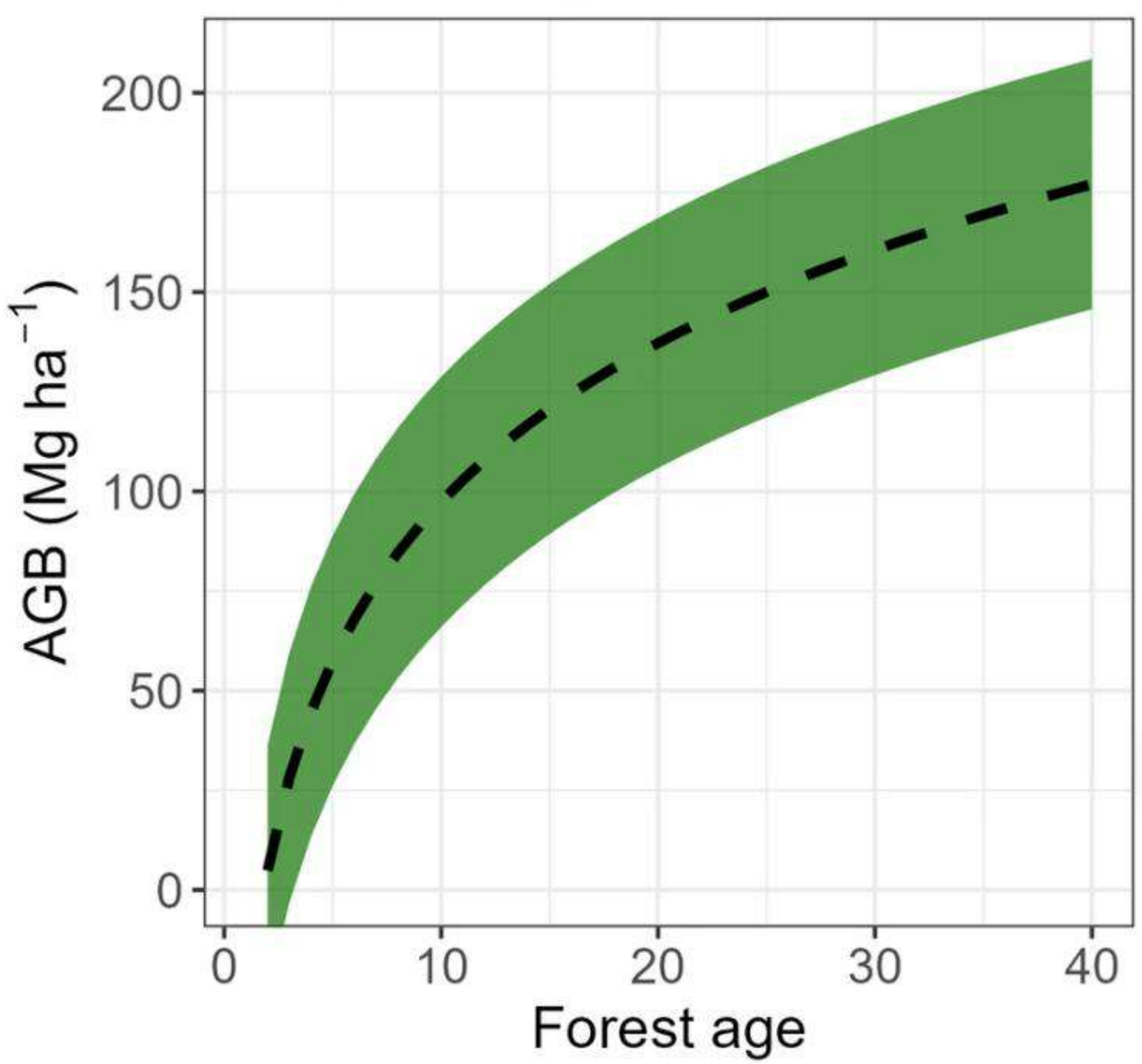
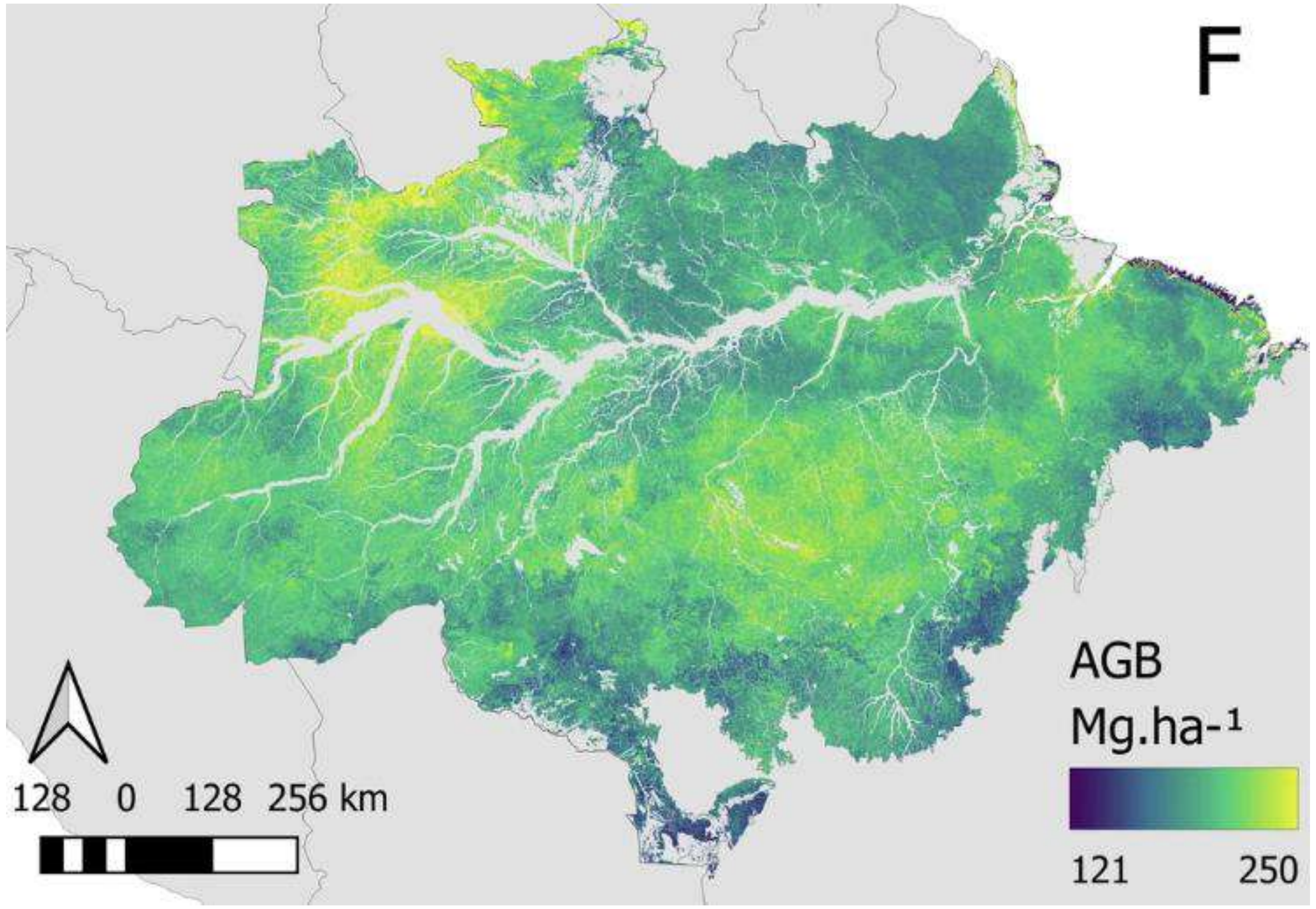
Setting reference values





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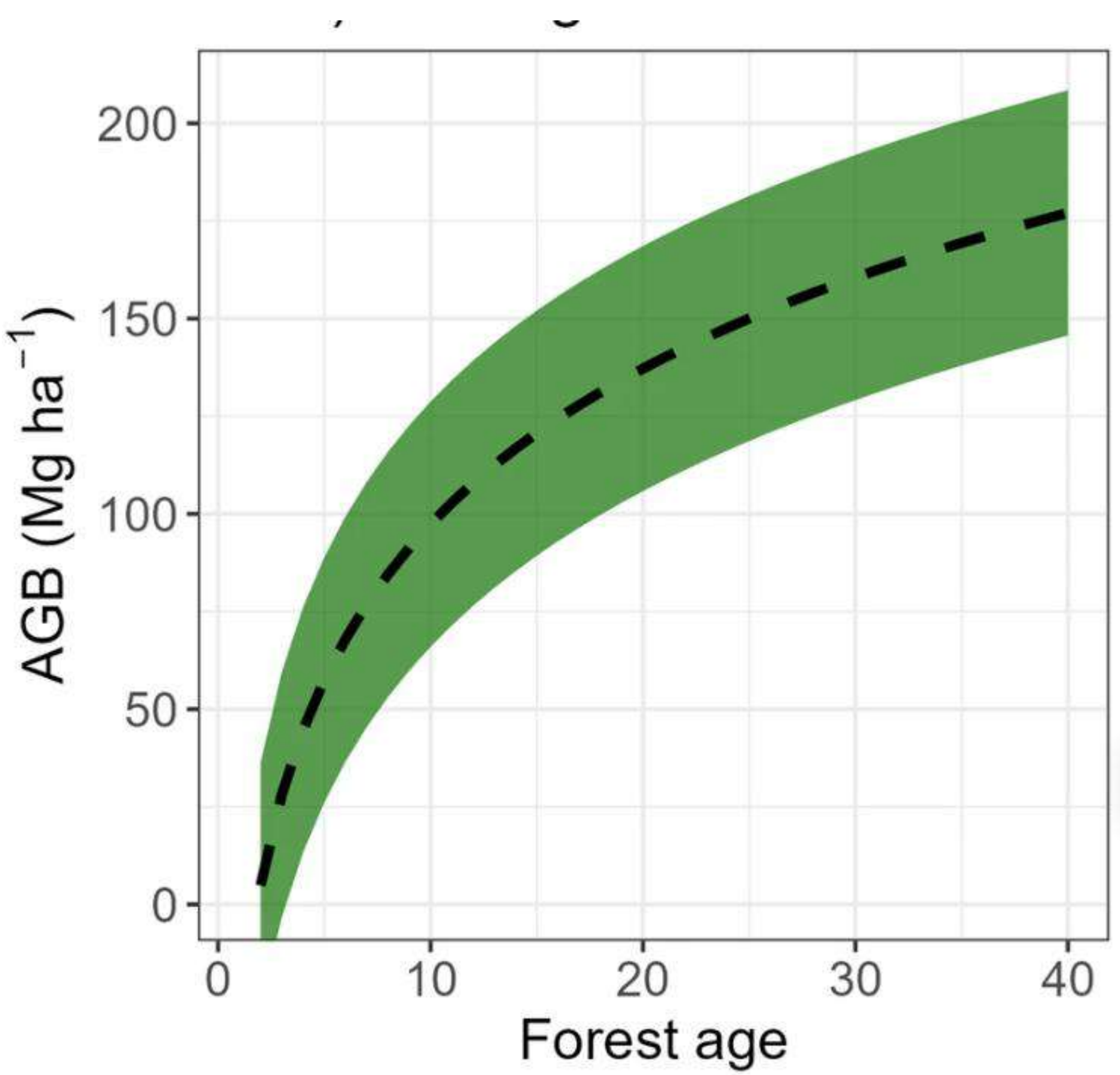
Setting reference values



5 years	10 years	15 years	20 years
43 (Mg. ha−1)	83.4 (Mg. ha−1)	106.2 (Mg. ha−1)	123 (Mg. ha−1)

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Implications

• We identify the main drivers of Amazon forest regeneration and provide reference values for ecological integrity across successional stages and regions.

• These reference values guide restoration outcomes, reduce policy uncertainties, and support the effective implementation of public policies

Next steps

- Identify these indicators and reference values using remote sensing tools (Ecological Integrity from remote sensing)

- Increase the predictive capacity from early-years and across successional trajectories (SF Permanence).

- Integrate field and remote sensing data

Furthermore Information

Article | Open access | Published: 20 December 2024

Simple ecological indicators benchmark regeneration success of Amazonian forests

André L. Giles, Juliana Schietti, Milena F. Rosenfield, Rita C. Mesquita, Daniel Luis Mascia Vieira, Ima C. G. Vieira, Lourens Poorter, Pedro H. S. Brancalion, Marielos Peña-Claros, João Siqueira, Luis Oliveira Junior, Mário Marcos do Espírito-Santo, Priscila Sanjuan de Medeiros Sarmento, Joice N. Ferreira, Erika Berenguer, Jos Barlow, Fernando Elias, Henrique Luis Godinho Cassol, Richarlly C. Silva, Sabina Cerruto Ribeiro, Natália Medeiros, André B. Junqueira, Paulo Massoca, Marciel Jose Ferreira, … Catarina C. Jakovac

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https://www.regenera-amazonia.eco.br/

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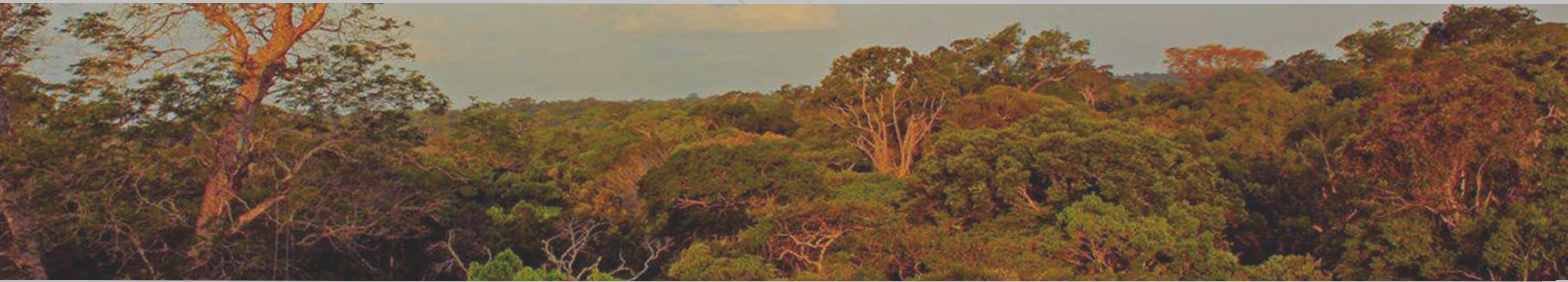

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Obrigado
Thank you
Gracias

andregiles.bio@gmail.com

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SIN BIO SE
CENTRO DE SÍNTESE EM BIODIVERSIDADE E SERVIÇOS ECOSSISTÊMICOS

CNPq
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES

Monitoring carbon and biodiversity during natural regeneration: contributions from Sustainable Amazon Network (RAS)

Rodrigo Nascimento

Session 2.2: Other metrics for identifying secondary forest success.

São José dos Campos, 30 Oct 2025

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RAS

Aims, distribution, and contributions

- Multidisciplinary network founded in 2009
- >400 plots data
- Biodiversity groups
  - Trees, lianas and palms (small and large)
  - Birds
  - Dung beetles
- Soil conditions (macro, micronutrients, and texture) and microclimate
- Integration between ecological and social dimensions

Joice Ferreira   Jos Barlow

Co-founders

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

rstb.royalsocietypublishing.org

A social and ecological assessment of tropical land uses at multiple scales: the Sustainable Amazon Network

Toby A. Gardner[1,2], Joice Ferreira[3], Jos Barlow[2], Alexander C. Lees[4], Luke Parry[2], Ima Célia Guimarães Vieira[4], Erika Berenguer[2], Ricardo Abramovay[5],

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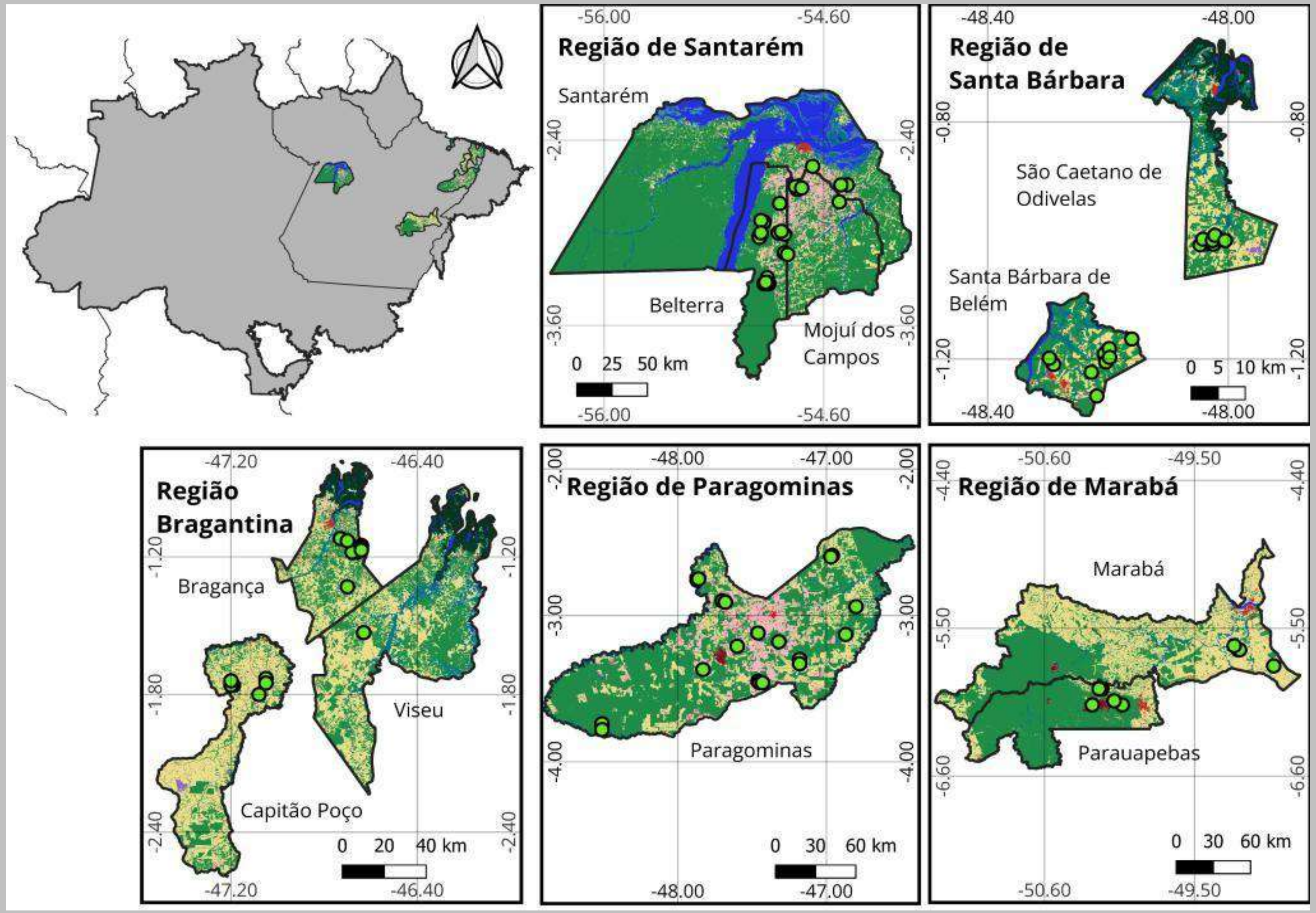
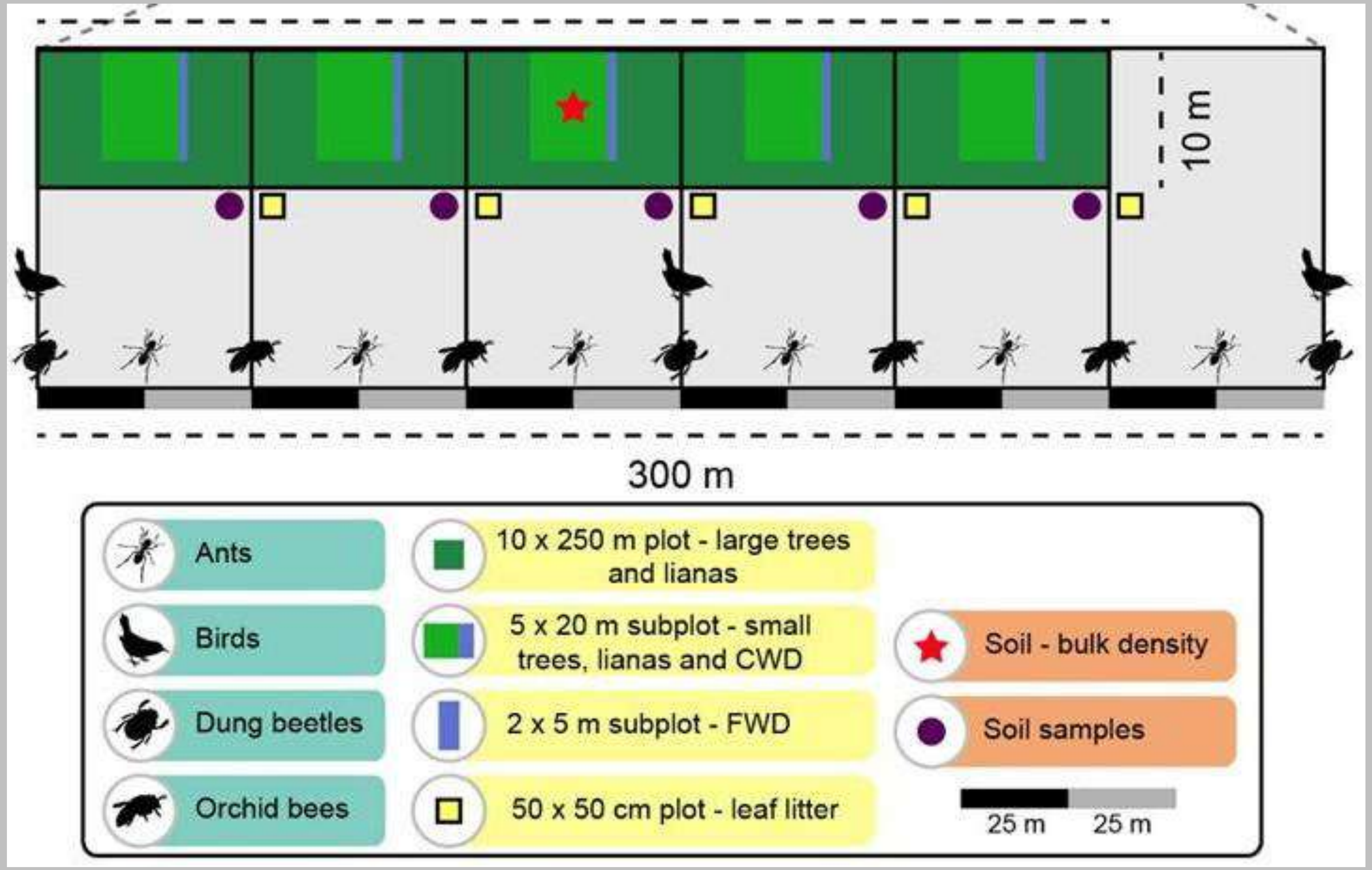
Sampling methods





*Santarém Region – intensive RAS research sites

Nunes et al. 2022 PNAS

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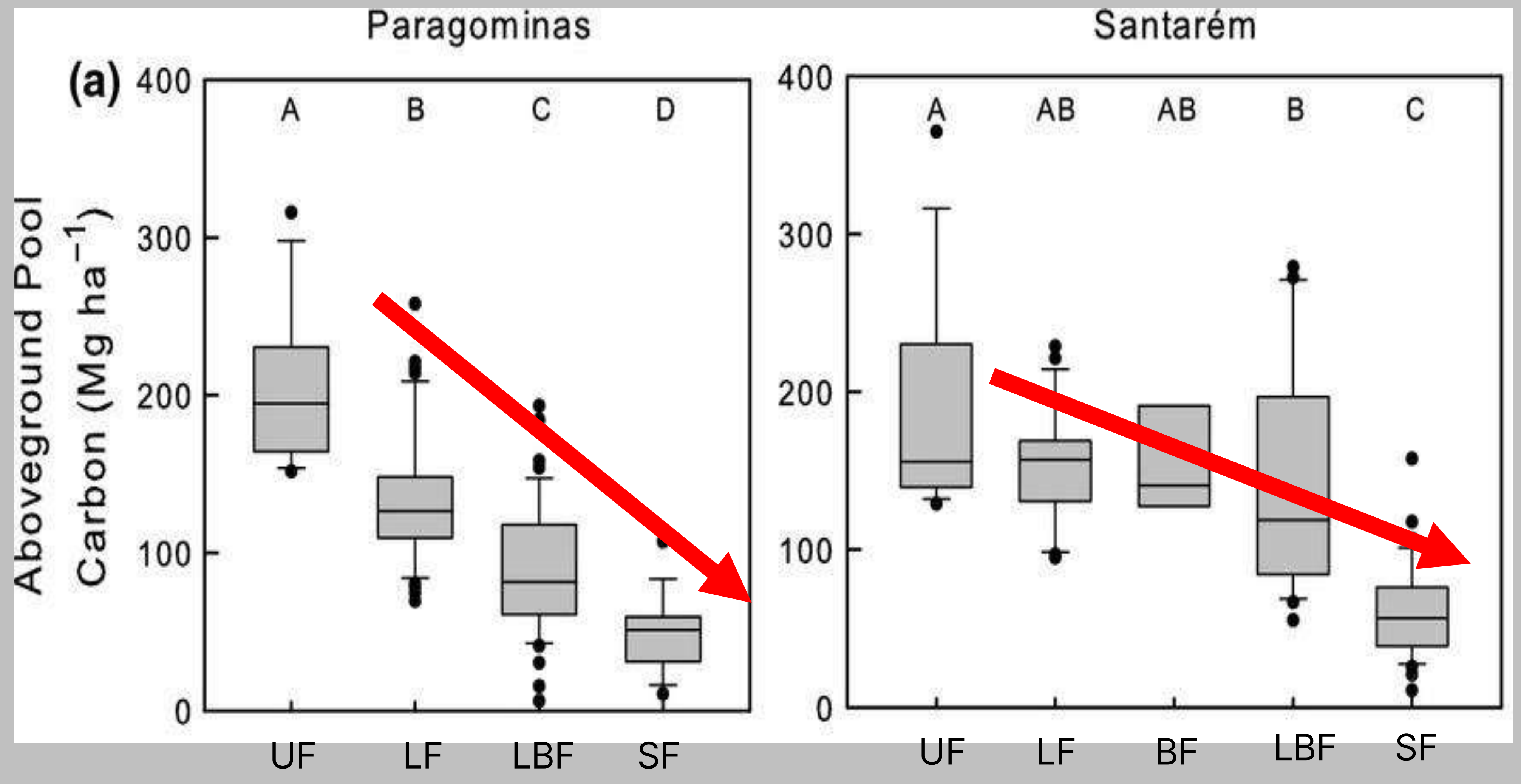
Some key messages about carbon estimates from field data

Disturbances significantly impact forest carbon stocks



Berenguer et al., 2014 GCB

Even highly degraded primary forests store more carbon than secondary forests

Secondary forests stock ~ 75 and 67% less carbon respectively than primary forests.

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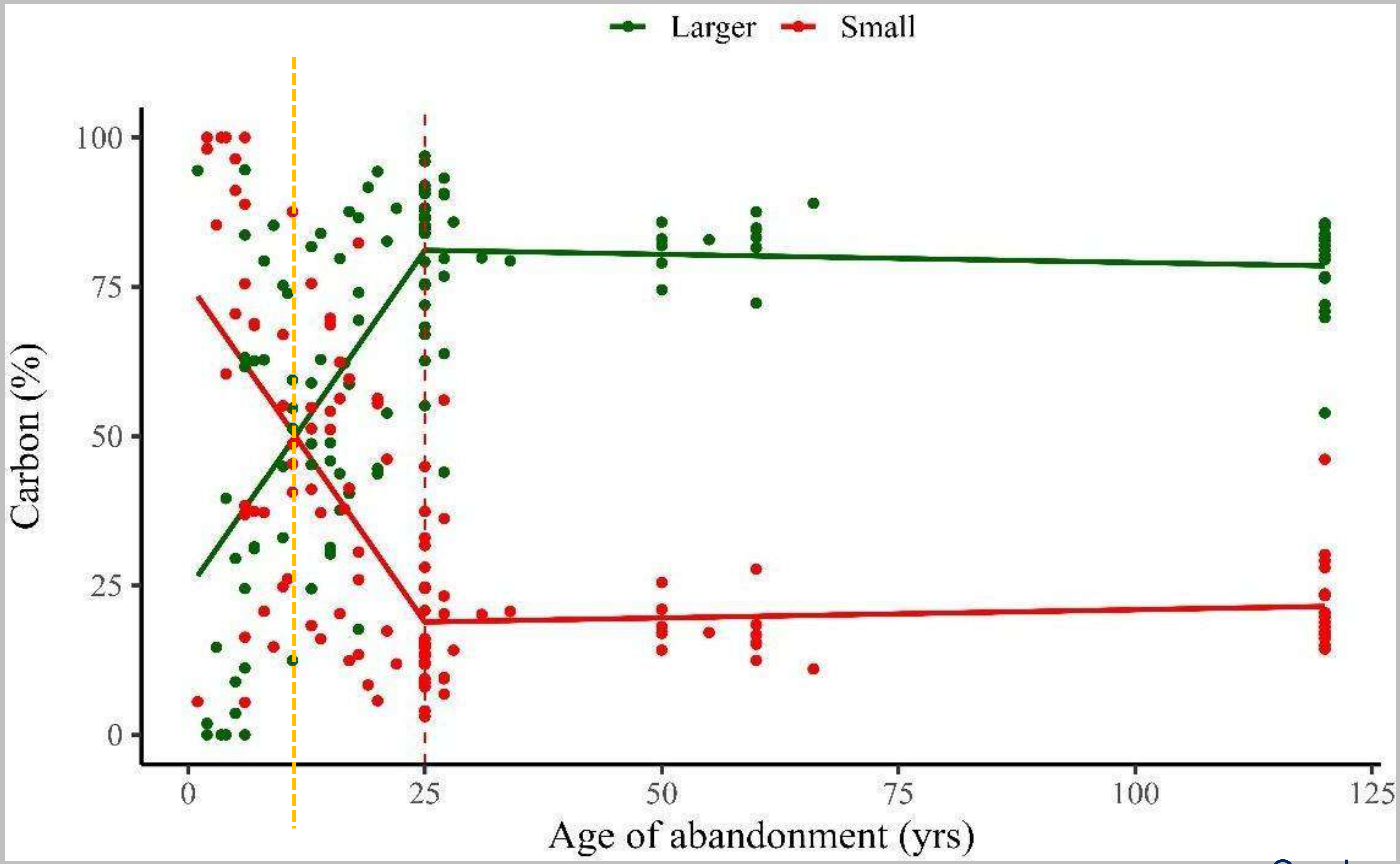
Furthermore, small individuals are very important in the initial carbon stocks



82%

18%

Cardoso et al. Submitted - Ecosphere

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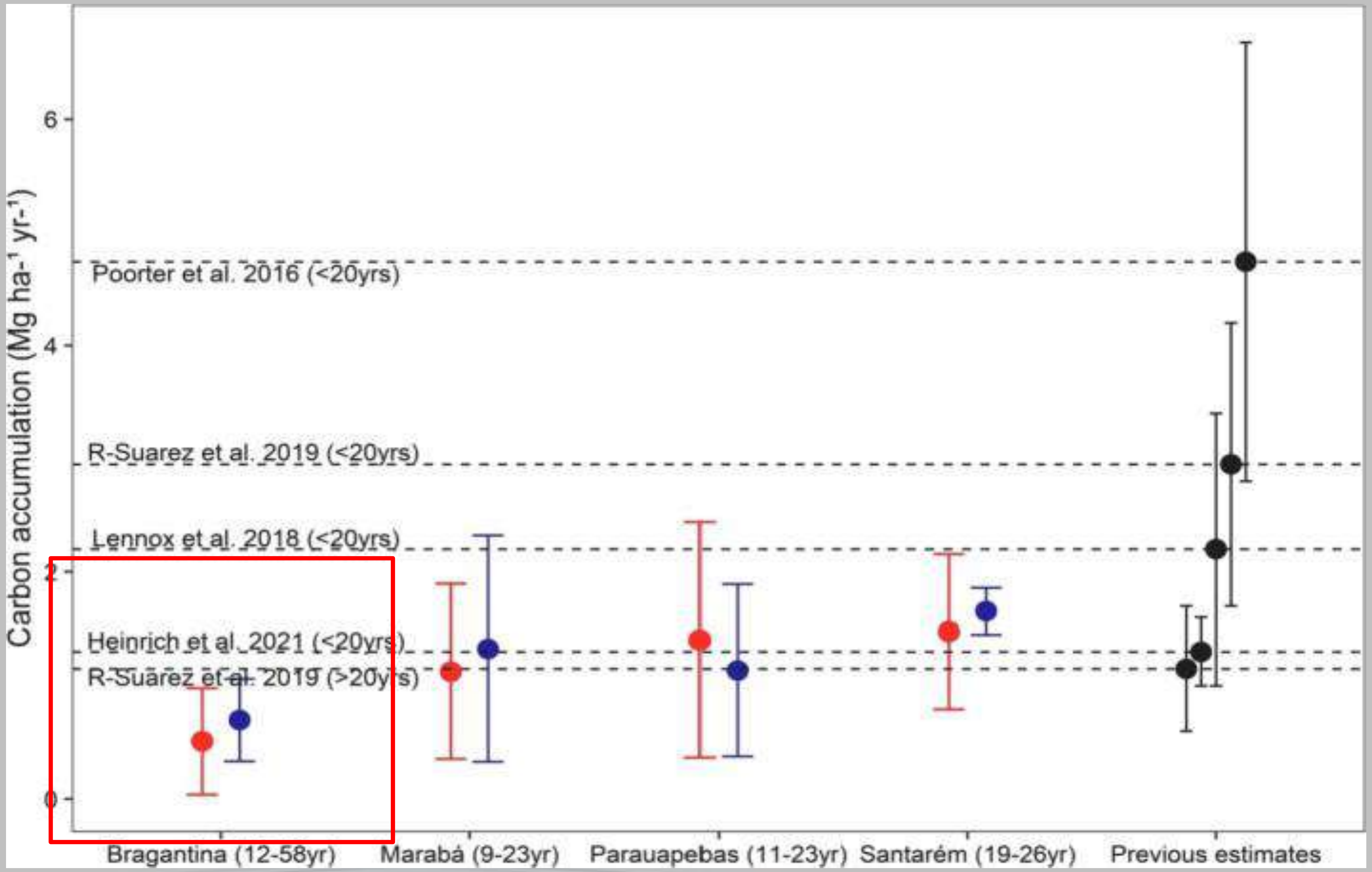
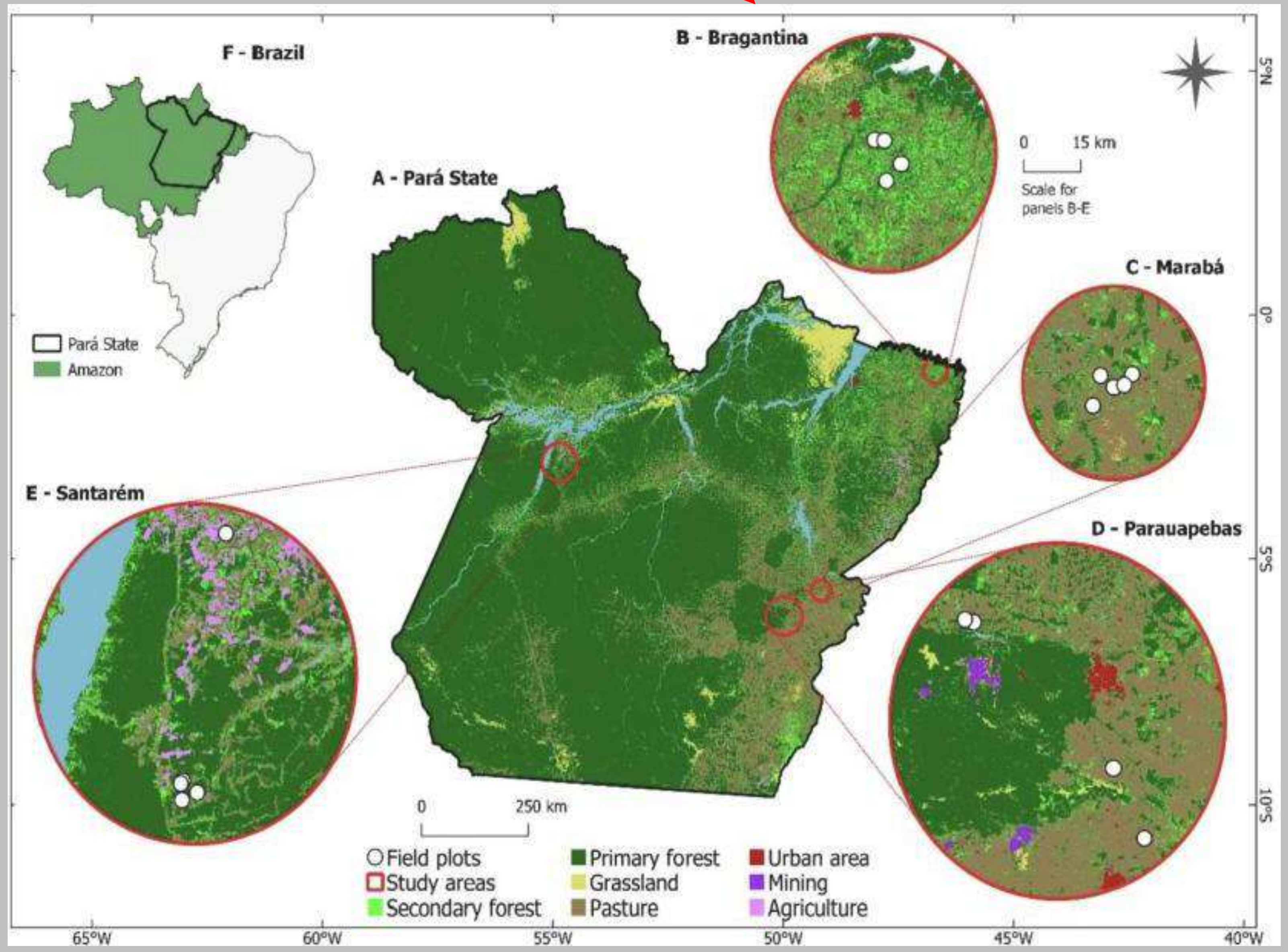
Carbon accumulation varies greatly between regions





Elias et al. (2022)-FORECO

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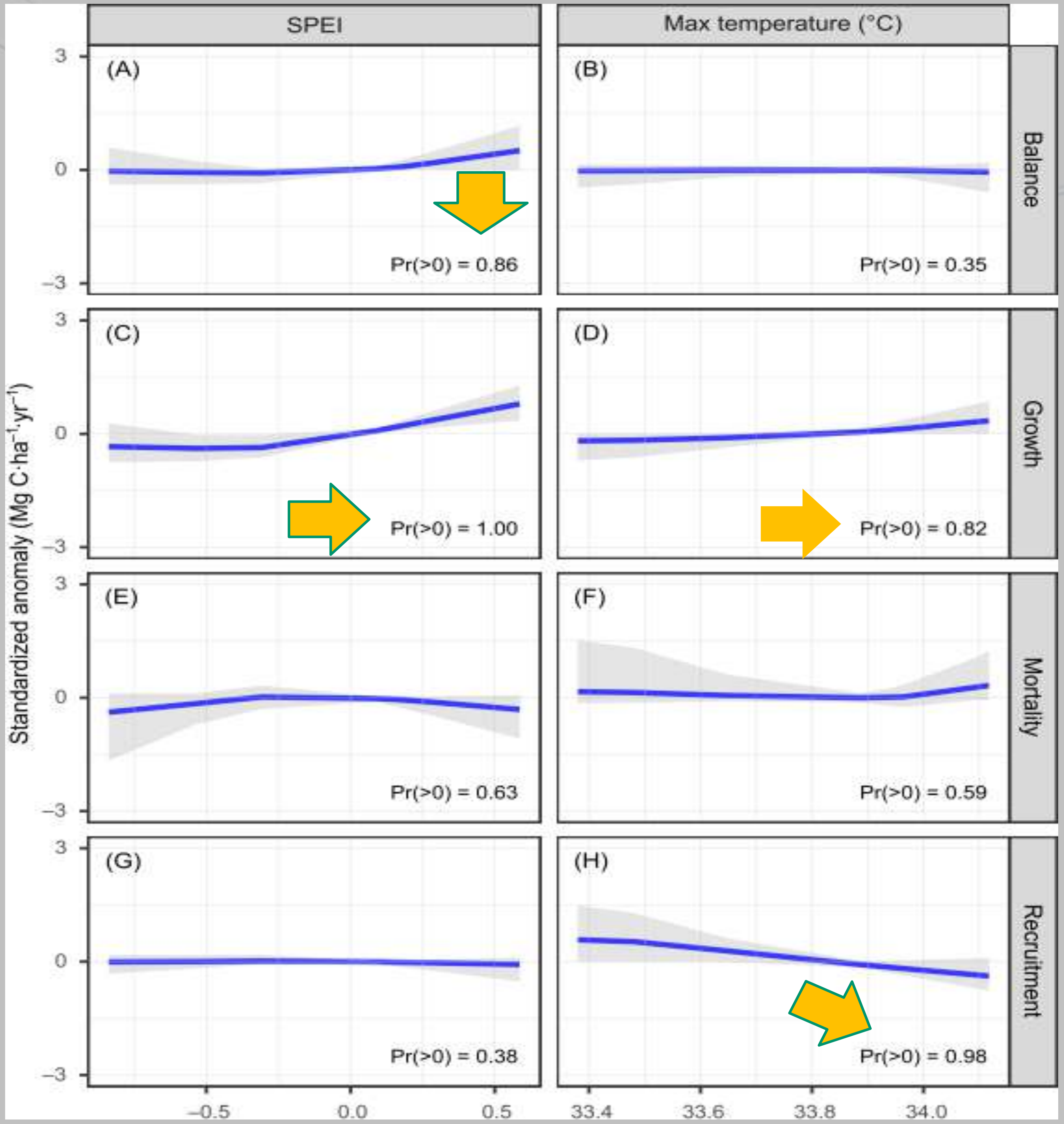
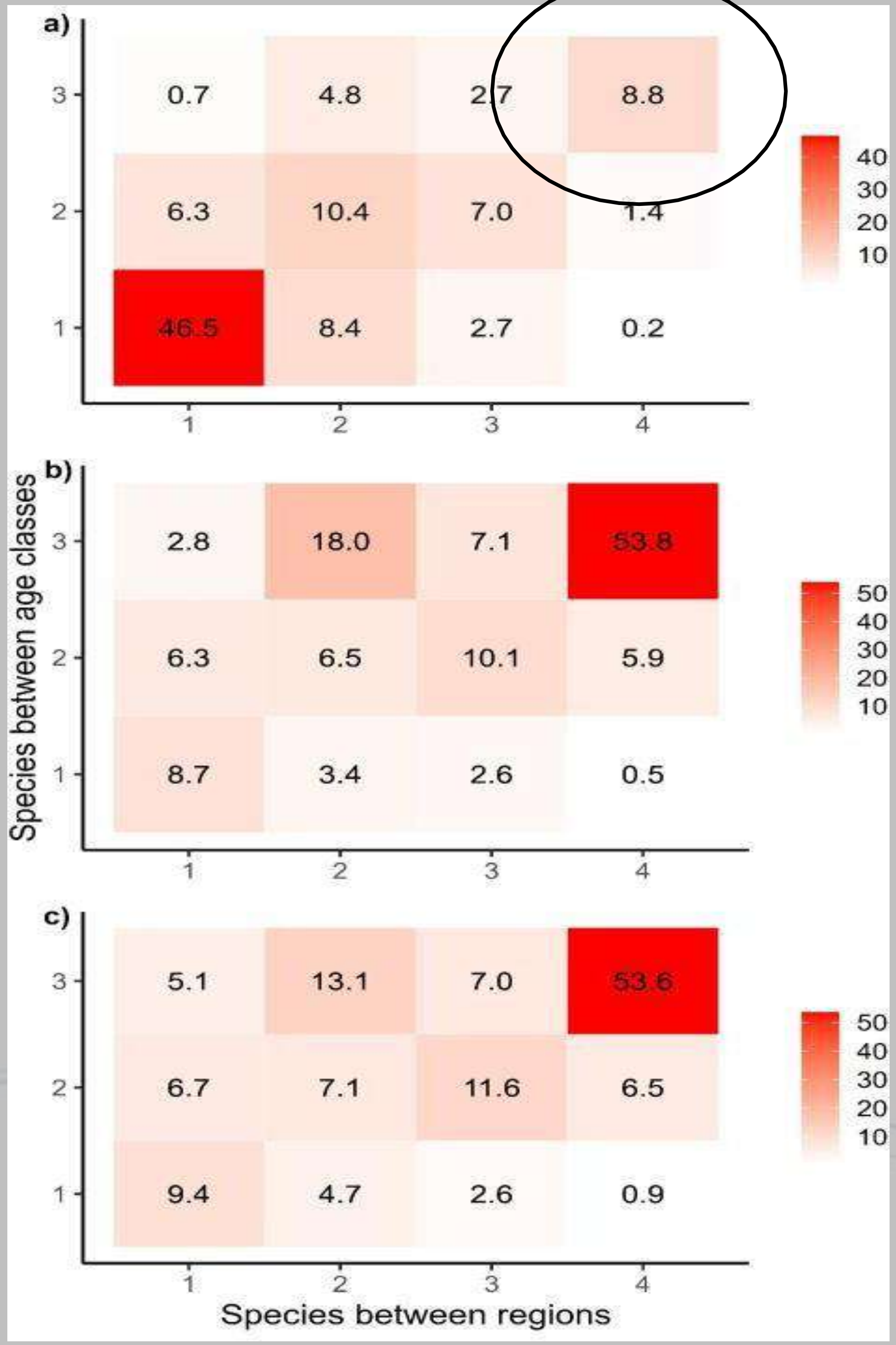
- The carbon balance of secondary forests is negatively affected by severe droughts
- Growth reduction



Elias et al. (2020)-Ecology

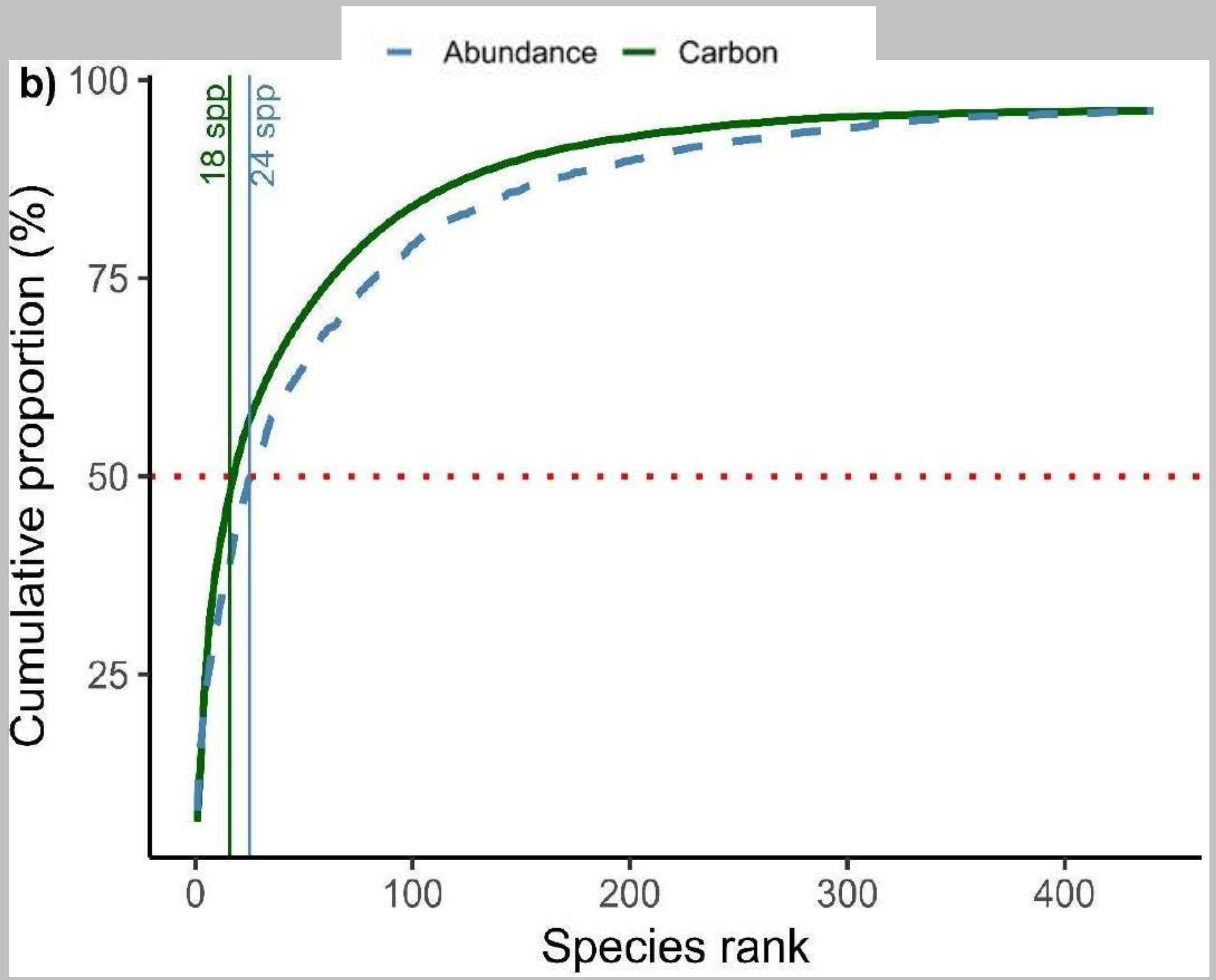
Hyperdominance of carbon and abundance in secondary forests - ~ 5% of spp.

~ 9% occur in all regions and successional stages



Carbon

Abundance



Elias et al in prep

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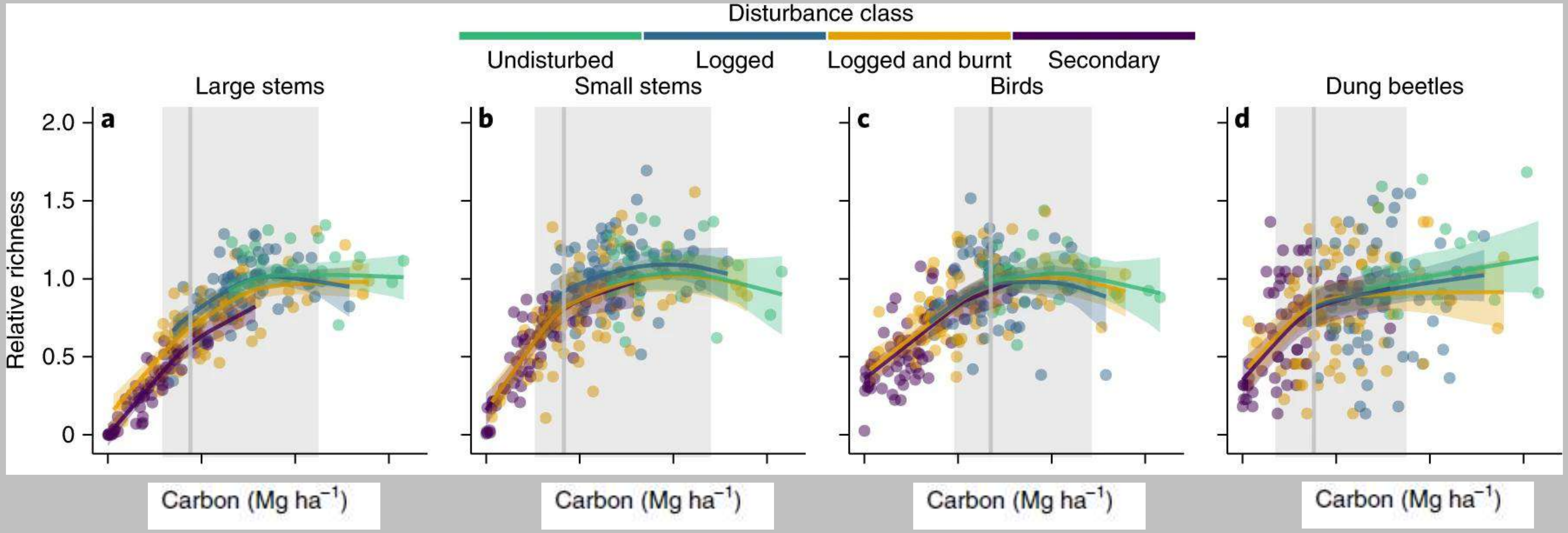
Biodiversity grows alongside carbon



Ferreira, Lennox et al. 2018. Nature Clim.Ch.

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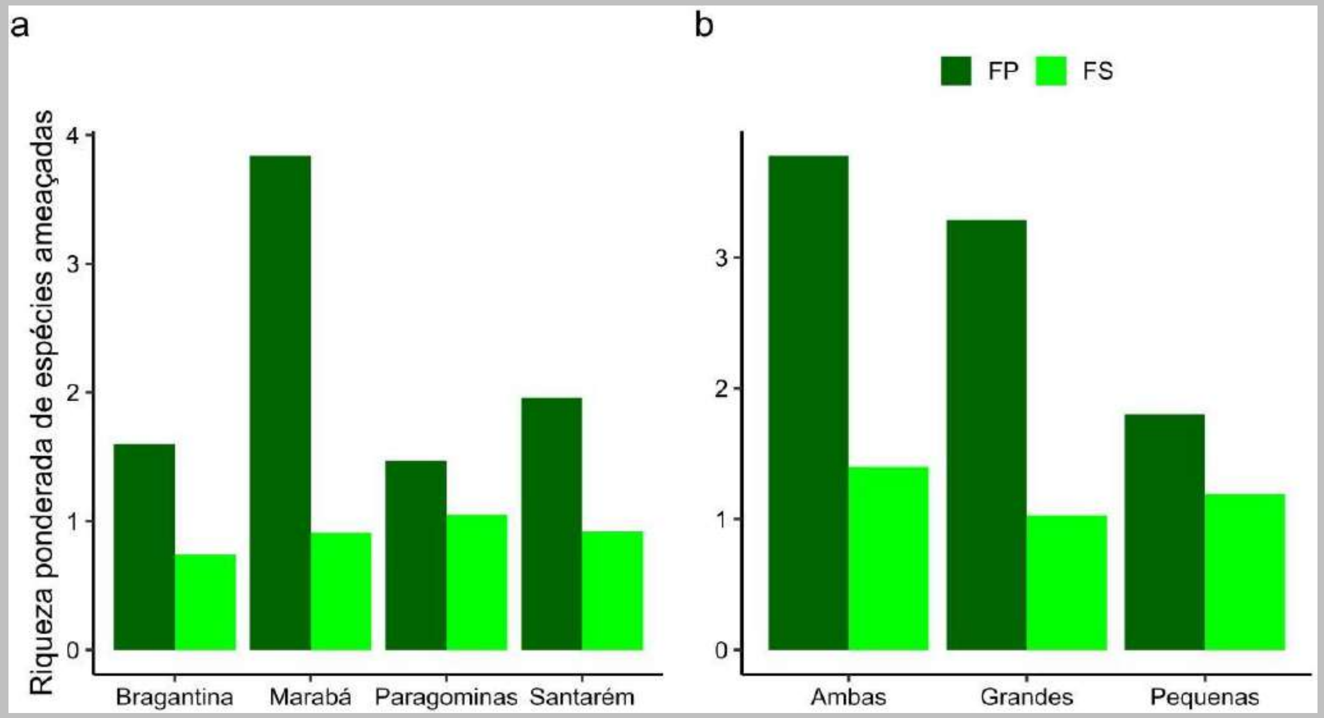
Ongoing research and contributions to public policies

Endangered species



Lima et al. in prep.

Microclimate

Functional traits

Tree Physiology

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Article Contents

Abstract

JOURNAL ARTICLE ACCEPTED MANUSCRIPT

Unraveling intraspecific trait variation in Amazonian secondary forests: interactions among succession, soils, plant height, and species strategies

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Karoline Chaves, Fernando Elias, Vanessa Negrão-Rodrigues, Luane G Botelho, Beatriz V Barbosa, Jucelino S Coutinho, Tailane S Sousa, Euciney E S Barbosa, Anthony Barbosa, Ely S C Gurgel ... Show more

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Flora

Volume 326, May 2025, 152712

Exploring plant functional traits and their relationship to biomass dynamics in secondary forests in Eastern Amazonia

Luane Botelho [a d], Fernando Elias [b 1], Beatriz V. Barbosa [d], Karoline C. Silva [c], Vanessa Negrão-Rodrigues [c], Euciney E.S. Barbosa [d], Jucelino S. Coutinho [c], Joice Ferreira [e], Jos Barlow [f], Grazielle Sales Teodoro [d 1]

Public policies

GOVERNO DO ESTADO DO PARÁ
SECRETARIA DE ESTADO DE MEIO AMBIENTE E SUSTENTABILIDADE

Ver no Diário Oficial

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DOE Nº 32.987, DE 07/10/2015

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LEI Nº 10.750, DE 31 DE OUTUBRO DE 2024
DOE Nº 36.017, DE 04/11/2024

Institui o Plano Estadual Amazônia Agora (PEAA).

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Thank you, and see you next time!

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https://ras-network.org/

rodrigoliveira.nascimento@gmail.c

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SynCER: Synthesising post-disturbance Carbon Emissions and Removals across Brazil's forest biomes

(12:30-13:30) Lunch

São José dos Campos, 30 Oct 2025

SynCER: Synthesising post-disturbance Carbon Emissions and Removals across Brazil's forest biomes

Workshop and breakout groups

São José dos Campos, 30 Oct 2025

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SynCER: Synthesising post-disturbance Carbon Emissions and Removals across Brazil's forest biomes

Plenary: Feedback from discussions

São José dos Campos, 30 Oct 2025

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