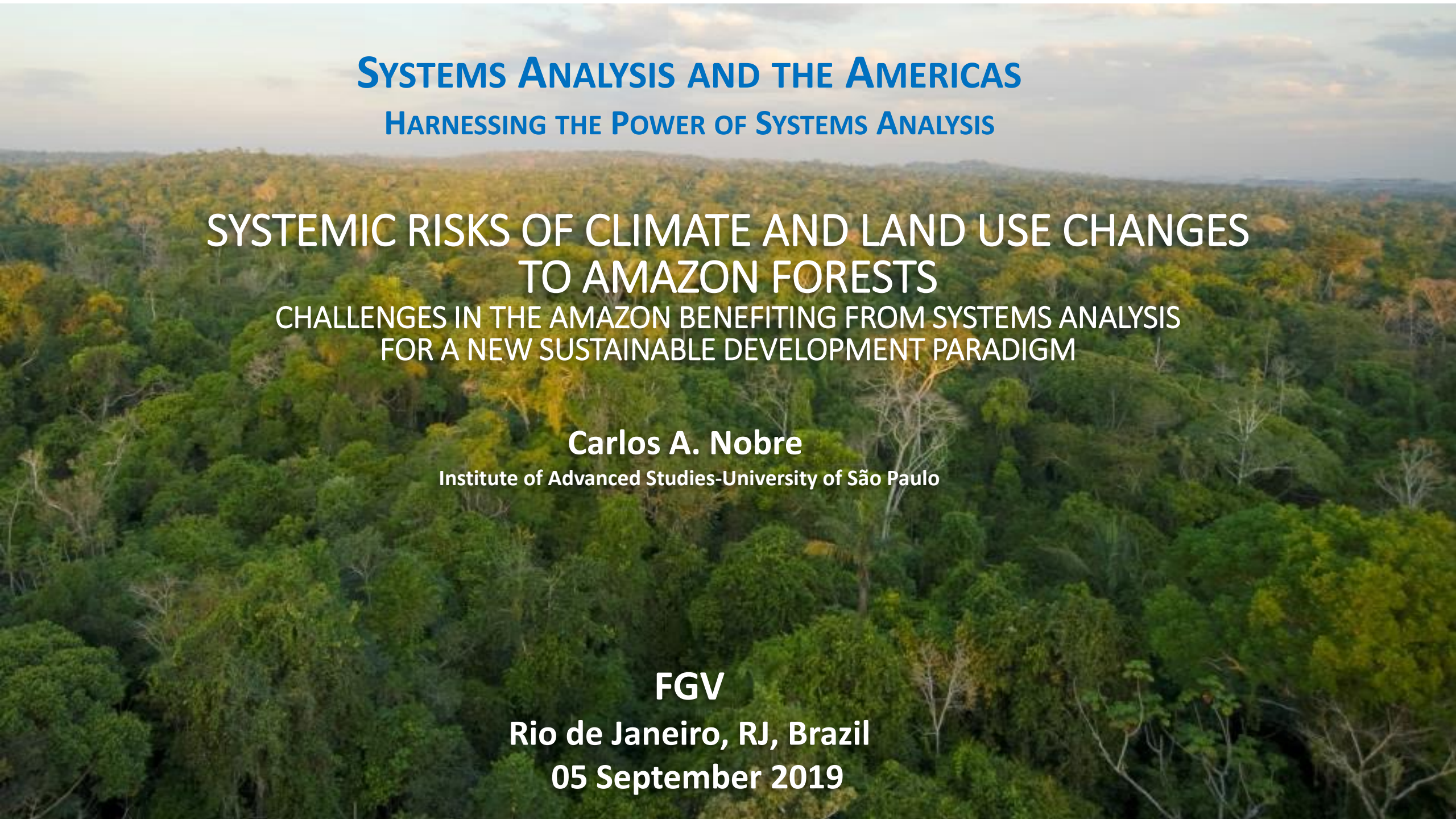


SYSTEMS ANALYSIS AND THE AMERICAS

HARNESSING THE POWER OF SYSTEMS ANALYSIS

SYSTEMIC RISKS OF CLIMATE AND LAND USE CHANGES TO AMAZON FORESTS

CHALLENGES IN THE AMAZON BENEFITING FROM SYSTEMS ANALYSIS FOR A NEW SUSTAINABLE DEVELOPMENT PARADIGM

Carlos A. Nobre

Institute of Advanced Studies-University of São Paulo

FGV

Rio de Janeiro, RJ, Brazil

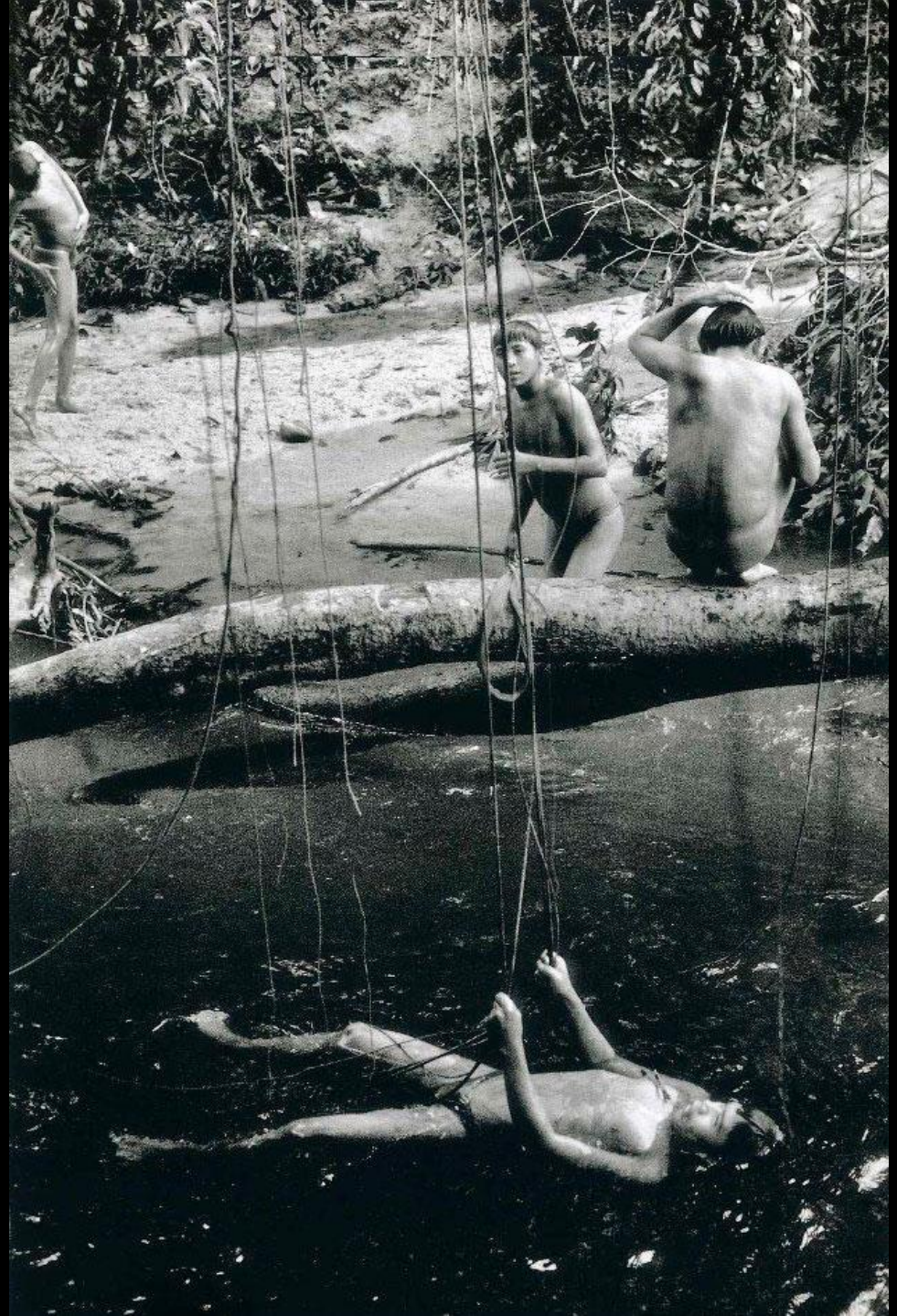
05 September 2019

Sir Jackie Stewart Niki Lauda Sir Stirling Moss
Lewis Hamilton Hans-Joachim Stuck Jochen Mass
THE GREEN HELL
LEGENDARY DEMANDING DEADLY
MURRAY WALKER & DAVID CROFT
HANNES M SCHALLE

R.J.A. GOODLAND/ H.S. IRWIN
Amazon jungle:
green hell to red desert?
an ecological discussion
of the environmental impact of the
highway construction
program in the Amazon basin
DEVELOPMENTS
IN LANDSCAPE MANAGEMENT
AND URBAN PLANNING 1

BOLIVIAN CHACO
GREEN HELL
JULIAN DUGUID

Green Hell Adventures In The
Mysterious Jungles Of
Eastern Bolivia
Scholar
SELECT
JULIAN DUGUID



A ‘GREEN PARADISE’ FOR ITS PEOPLE!

Photo by Sebastião Salgado from the book “Terra”

THE AMAZON AS A REGIONAL ENTITY OF THE EARTH SYSTEM IN THE ANTHROPOCENE

Maintenance of global carbon cycle

- 15% of global NPP and a key carbon sink for anthropogenic CO_2
- Stores between 100 to 120 billion ton of carbon in the biomass

Powerful hydrology

- 18% of fresh water flow into the global oceans
- Amazon river discharge of 220,000 m^3/s

Biodiversity richness

- > 10% of species

Climate stabilization

- Key heat source for the atmosphere
- Annual rainfall = 2400 mm

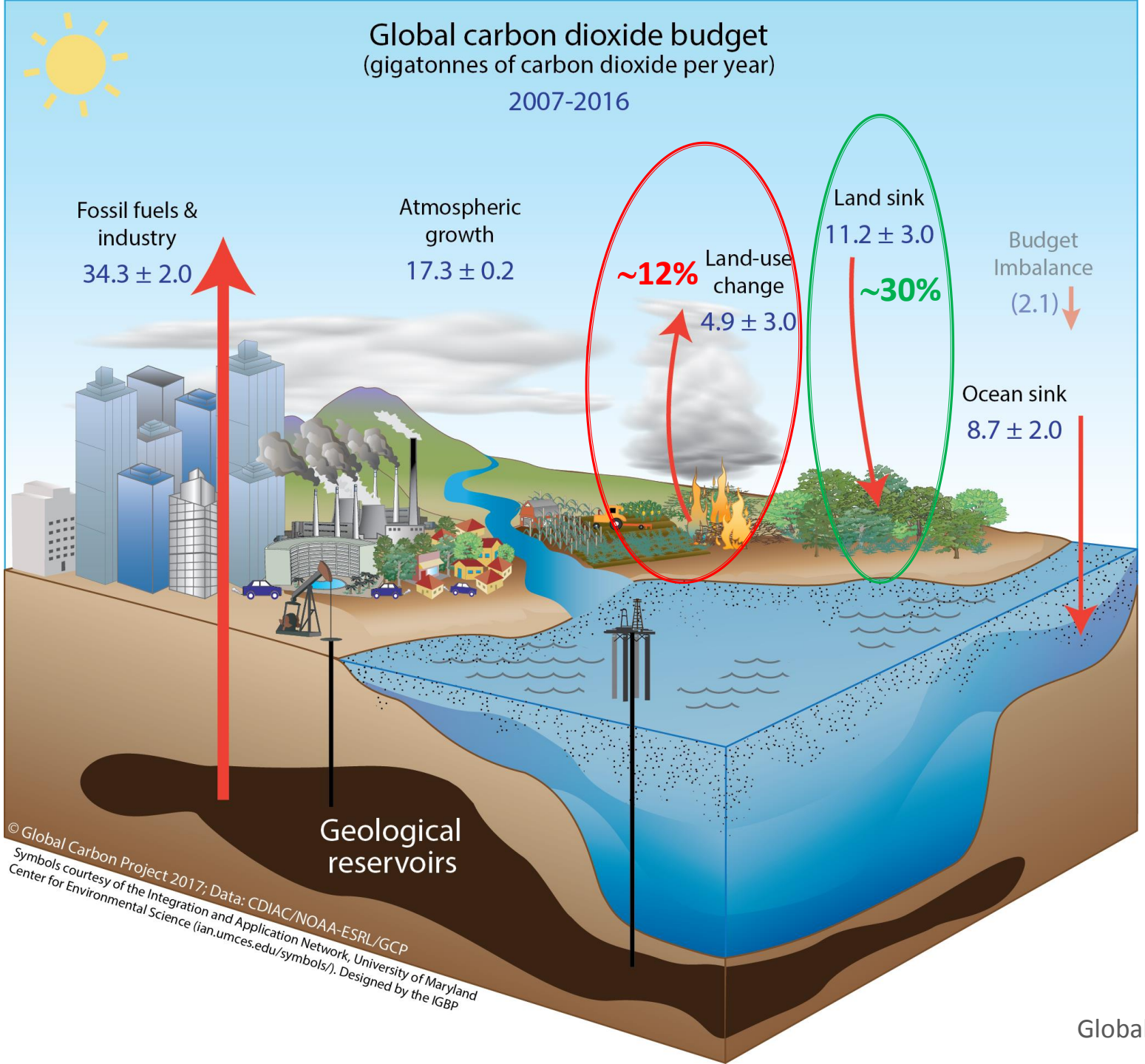
Helps to maintain cultural and ethnic diversity

- Over 300 indigenous populations, language diversity

A ‘GREEN PARADISE’ FOR PLANET EARTH!

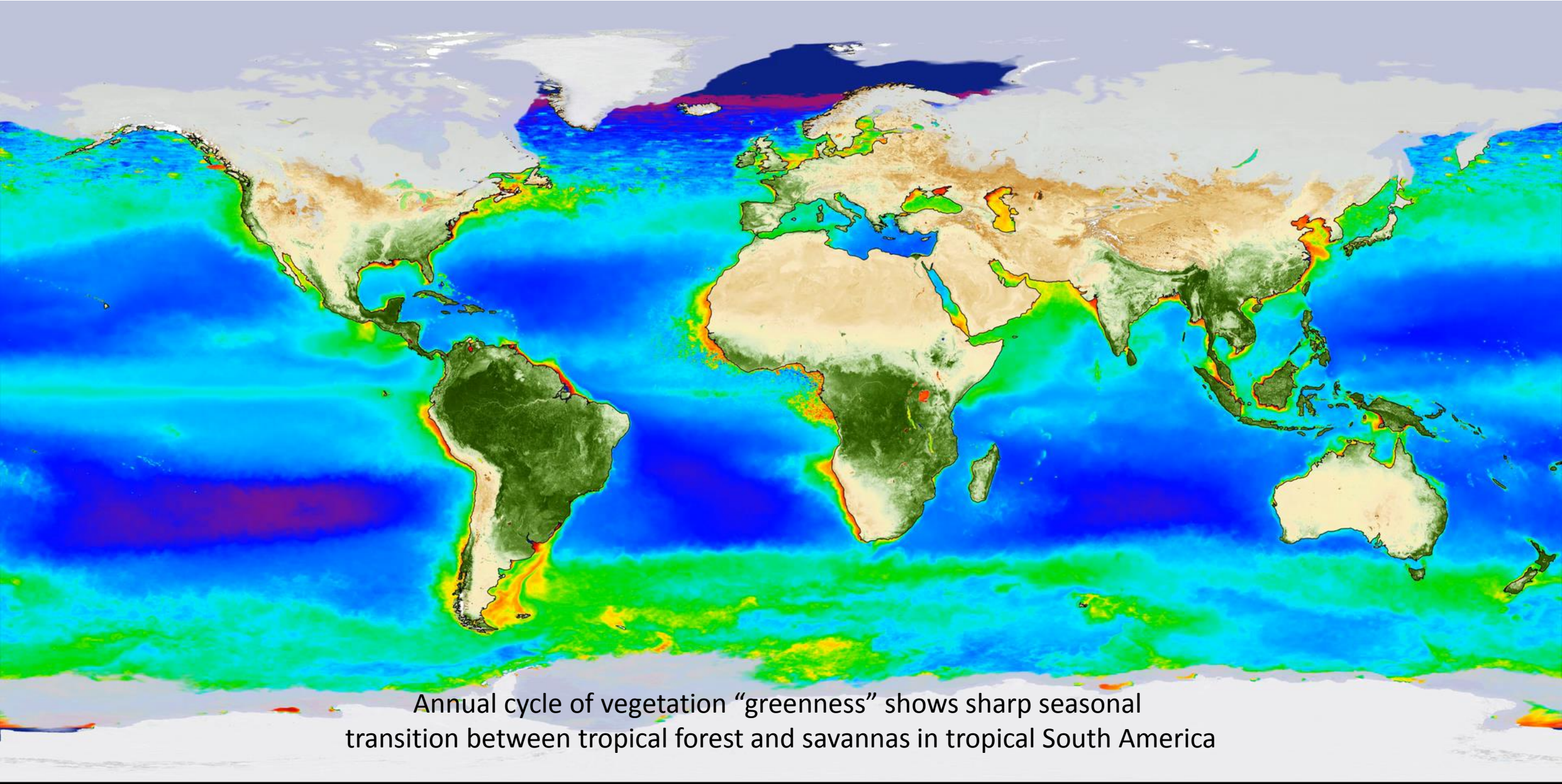
© Celestia

Forests are the most important sink of carbon dioxide emitted by human activities!



Global Carbon Project, 2017

Amazon forest has a net removal rate of
~1 to 2 billion tonnes/year of carbono dioxide
from the atmosphere
Image: serpaj-brasil.blogspot.com/



Annual cycle of vegetation “greenness” shows sharp seasonal transition between tropical forest and savannas in tropical South America

Simplified Schematics of Changes in Biophysical Processes Arising from Large-Scale Conversion of Amazon Tropical Forests into Pastures

Tropical Forest

Conversion

Pasture

Higher Humidity ➔ More Rainfall

2.4 m/year

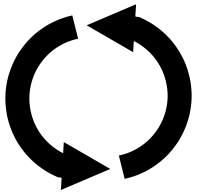
Lower Humidity ➔ Less Rainfall*

-10 to -20%

*Based on modeling results

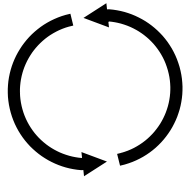
Deforestation ➔ Delay of Onset of Rainy Season

Evapotranspiration
3.5 mm/day
higher in the dry season



Stronger Water Recycling

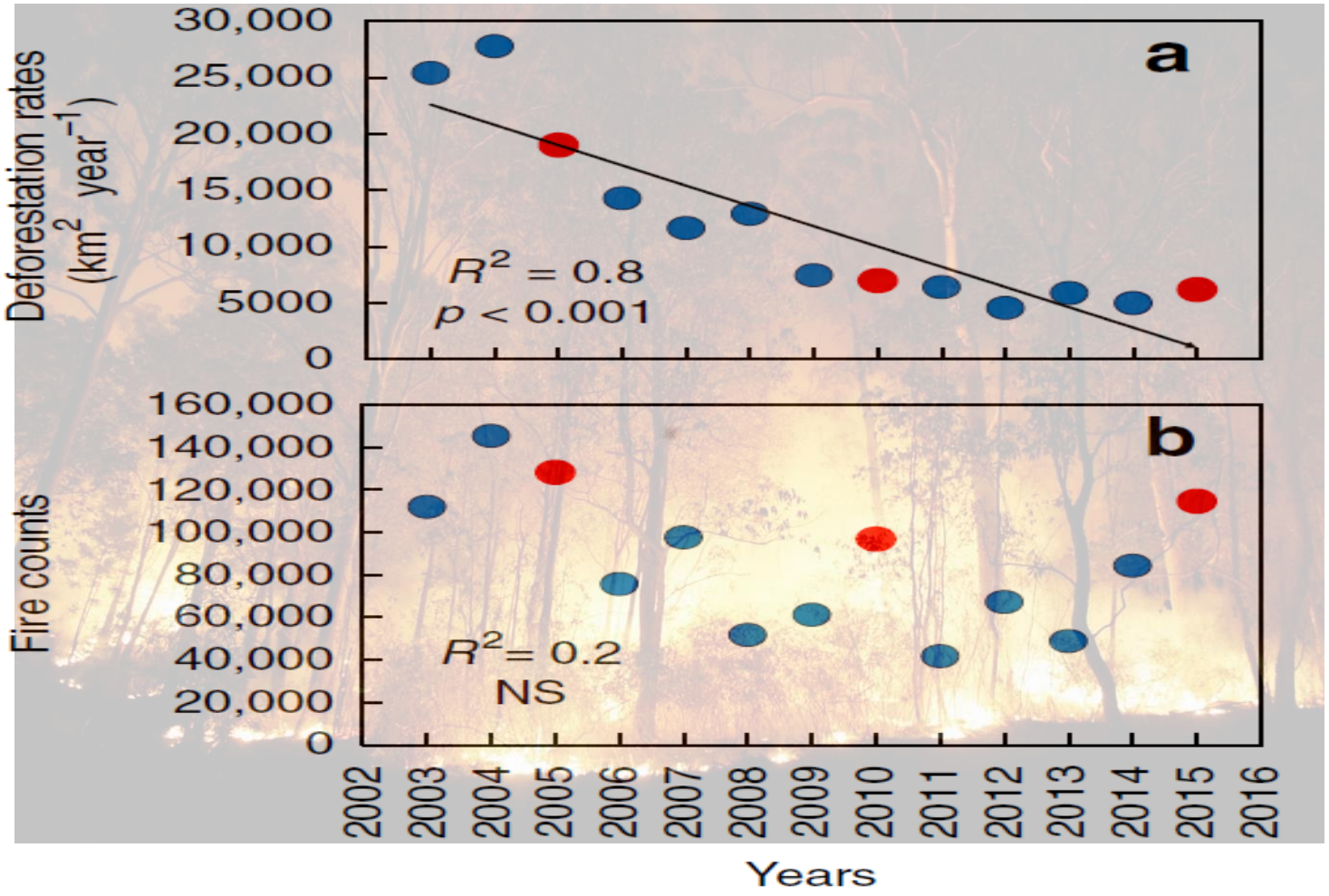
Evapotranspiration
1.5 mm/day in
the dry season



Weaker Water Recycling

Image: Agência Brasil

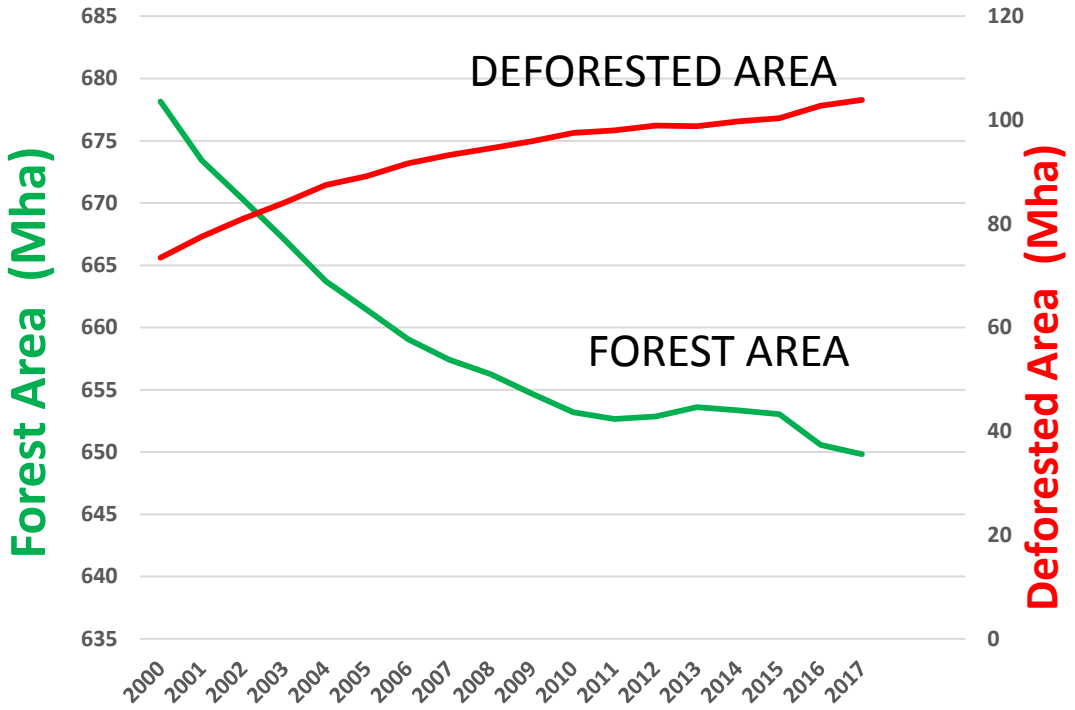
FOREST FIRES ARE INCREASING IN THE AMAZON!



Drought Years

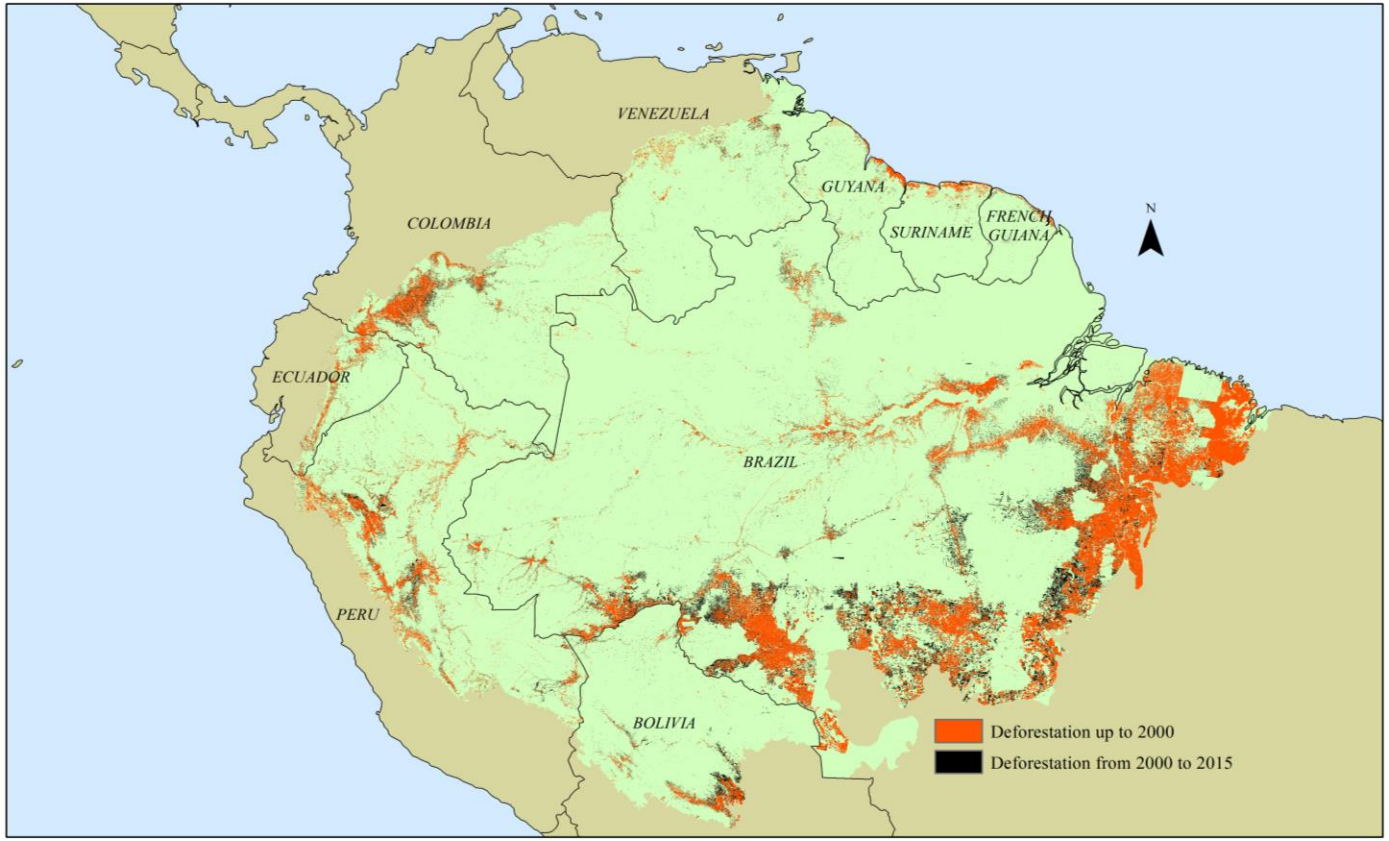
Aragão et al., 2018

PATTERN OF AMAZON DEFORESTATION: OVER 1 MILLION KM² (≈15%-17%) OF THE AMAZON FOREST HAVE BEEN CLEARED



Total area of forest **(green)** and of deforested area **(red)** from 2000 to 2017

Data from http://plataforma.amazonia.mapbiomas.org



Deforestation up to 2000

Deforestation from 2000 to 2015

Mapping of deforestation of the Amazon forest biome for two distinct periods: the total accumulated up to 2000 (red color) and the increment from 2000 to 2015 (black color). Source: RAISG.

A SYSTEMS ANALYSIS APPROACH
‘TIPPING POINTS’ OF FOREST-CLIMATE EQUILIBRIUM IN THE AMAZON

HOW CLOSE TO AN AMAZON TIPPING POINT?

Tropical forest in equilibrium with historical climate

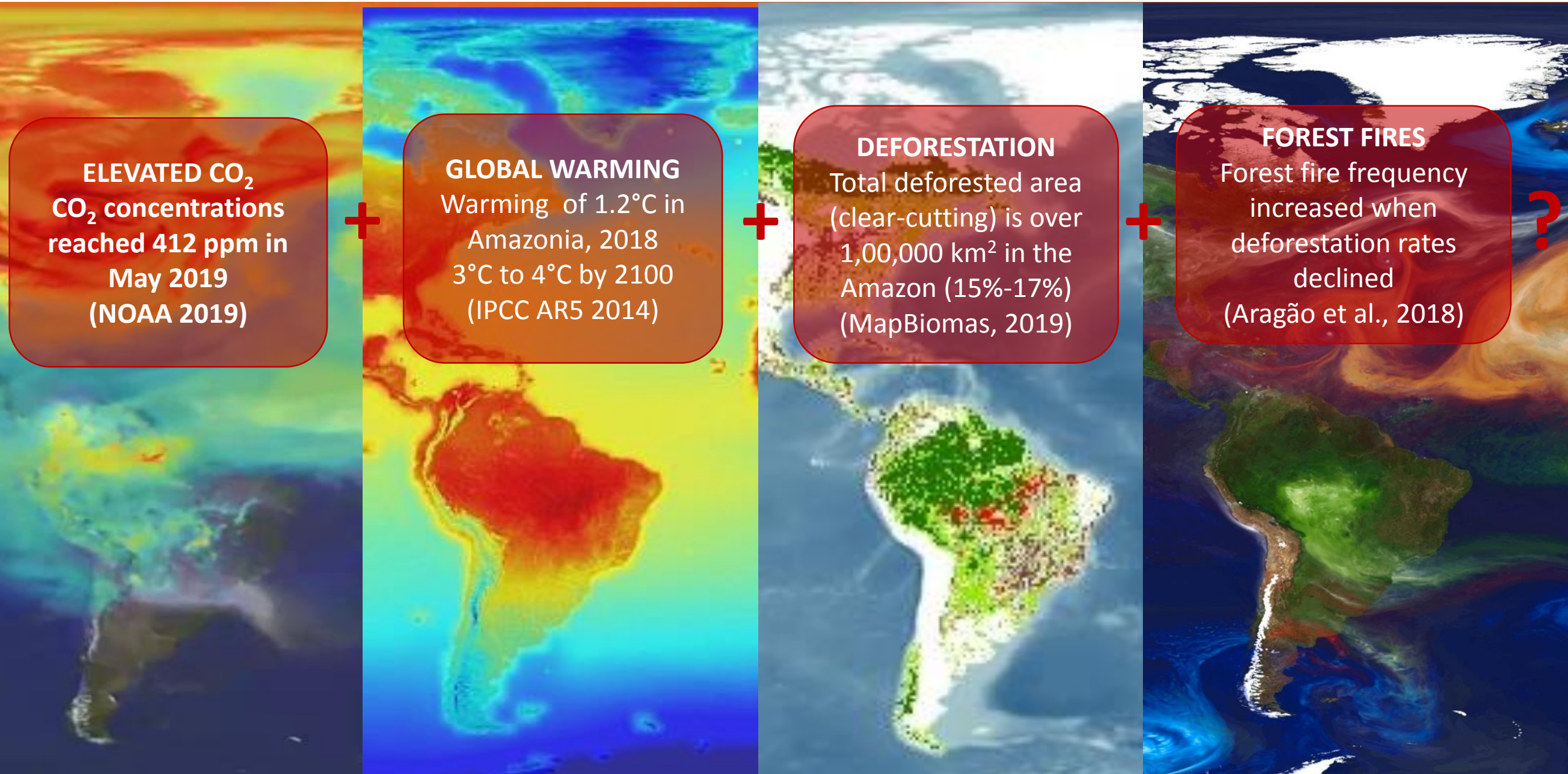
Amazon covered mostly by forests

Savanna state triggered by climate change and/or deforestation and forest fires

Forests in the West

Savannas in the East-Southeast

WHAT ARE THE SYNERGISTIC EFFECTS OF ANTHROPOGENIC DRIVERS OF ENVIRONMENTAL CHANGE IN THE AMAZON?



ELEVATED CO_2
CO_2 concentrations reached 412 ppm in May 2019 (NOAA 2019)

+

GLOBAL WARMING
Warming of 1.2°C in Amazonia, 2018
3°C to 4°C by 2100 (IPCC AR5 2014)

+

DEFORESTATION
Total deforested area (clear-cutting) is over 1,00,000 km^2 in the Amazon (15%-17%) (MapBiomas, 2019)

+

FOREST FIRES
Forest fire frequency increased when deforestation rates declined (Aragão et al., 2018)

?

PROJECTED DISTRIBUTION OF NATURAL BIOMES IN SOUTH AMERICA

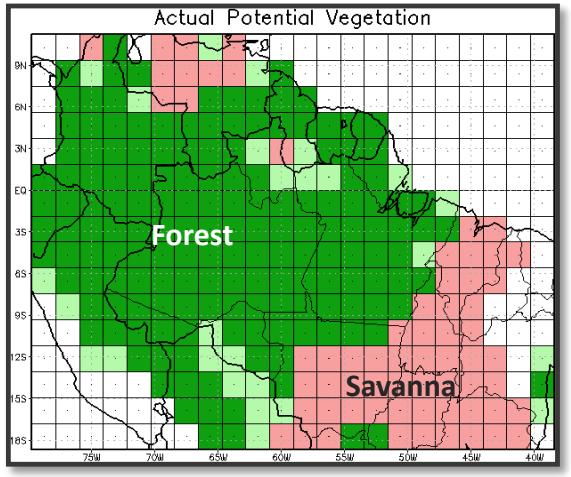
More than 2/3 of the models used (≥ 6 models) coincide for 2050 from 9 Earth System Models for the RCP 8.5 emission scenarios

COMBINED EFFECTS BY 2050

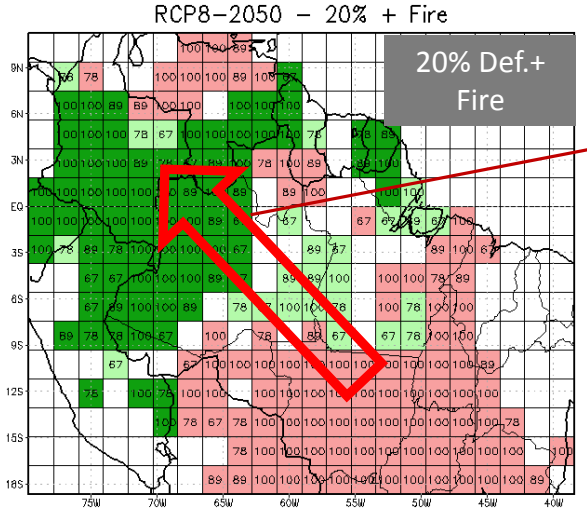
Climate Change (RCP8.5) + Deforestation (20%) + Increased Fire + CO_2 'Fertilization' effect

SIMULTANEOUS HUMAN DRIVERS OF CHANGE

- Tropical Seasonal Forest
- Savannah
- Tropical Evergreen Forest



Control Simulation



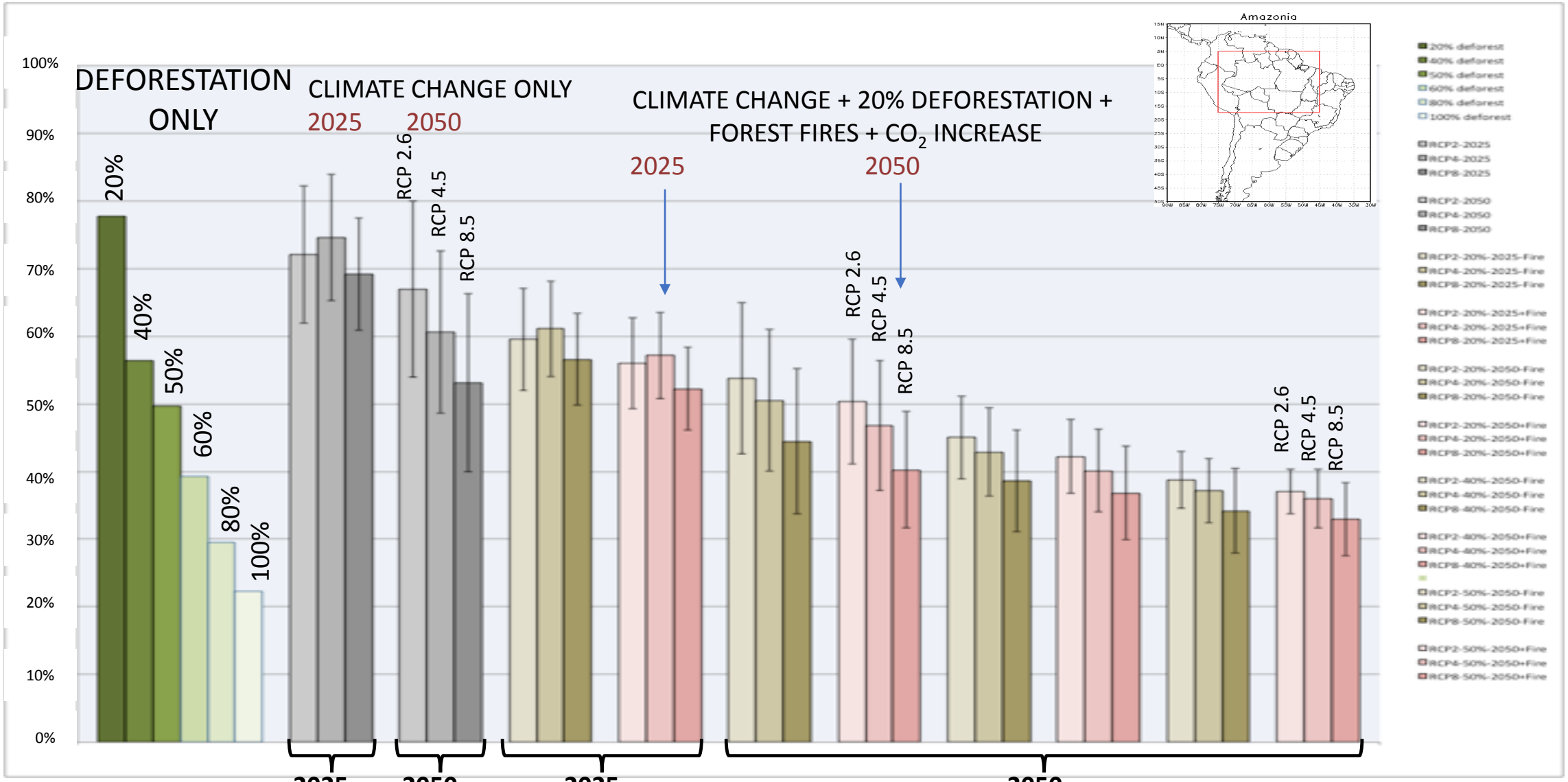
Projected Biome Changes

Forest remains In the west of the Basin

Between 50% and 60% of the forest would disappear!

Nobre et al., 2016 PNAS

FRACTION OF THE REMAINING FOREST AREA FOR THE ENTIRE AMAZONIA
CLIMATE CHANGE PROJECTIONS – CMIP5 – 9 EARTH SYSTEM MODELS (ESM)

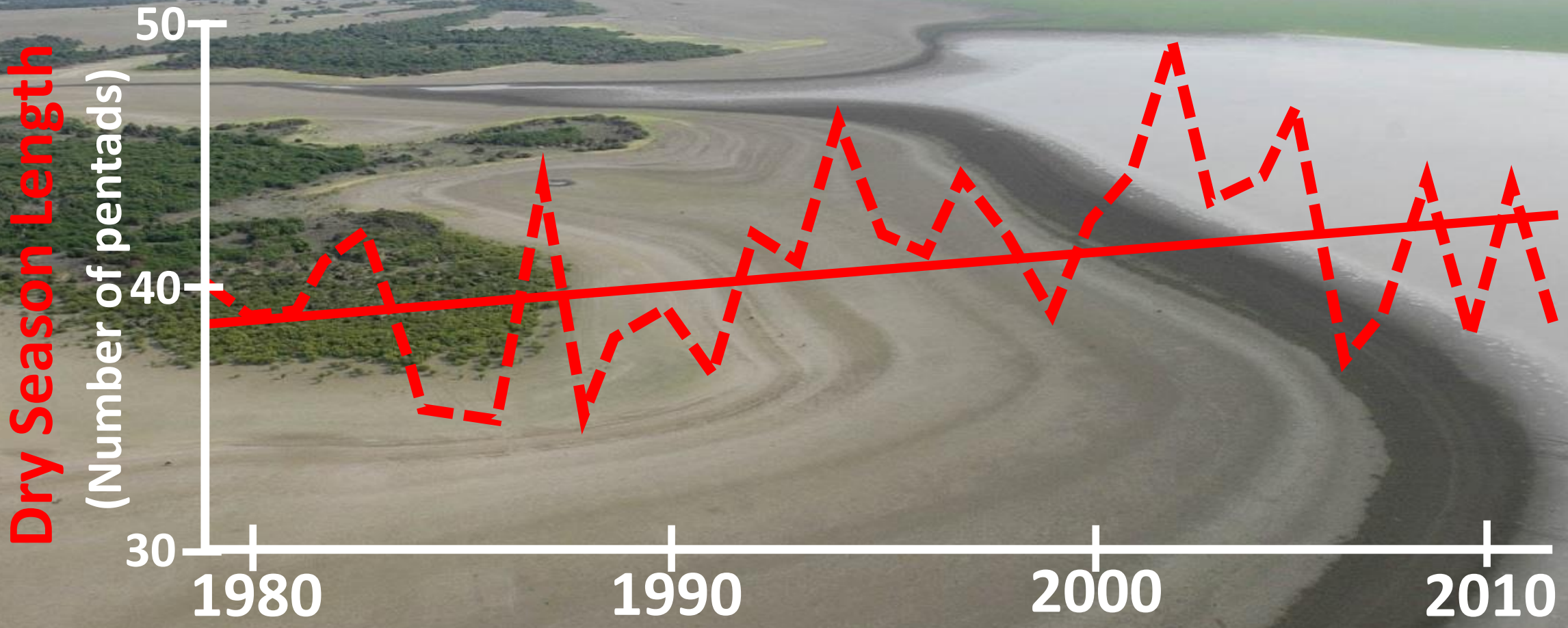


Nobre et al., 2016 PNAS

2005 Drought

http://www.altinomachado.com.br/2005/10/

IS DRY SEASON LENGTH INCREASING IN THE AMAZON?



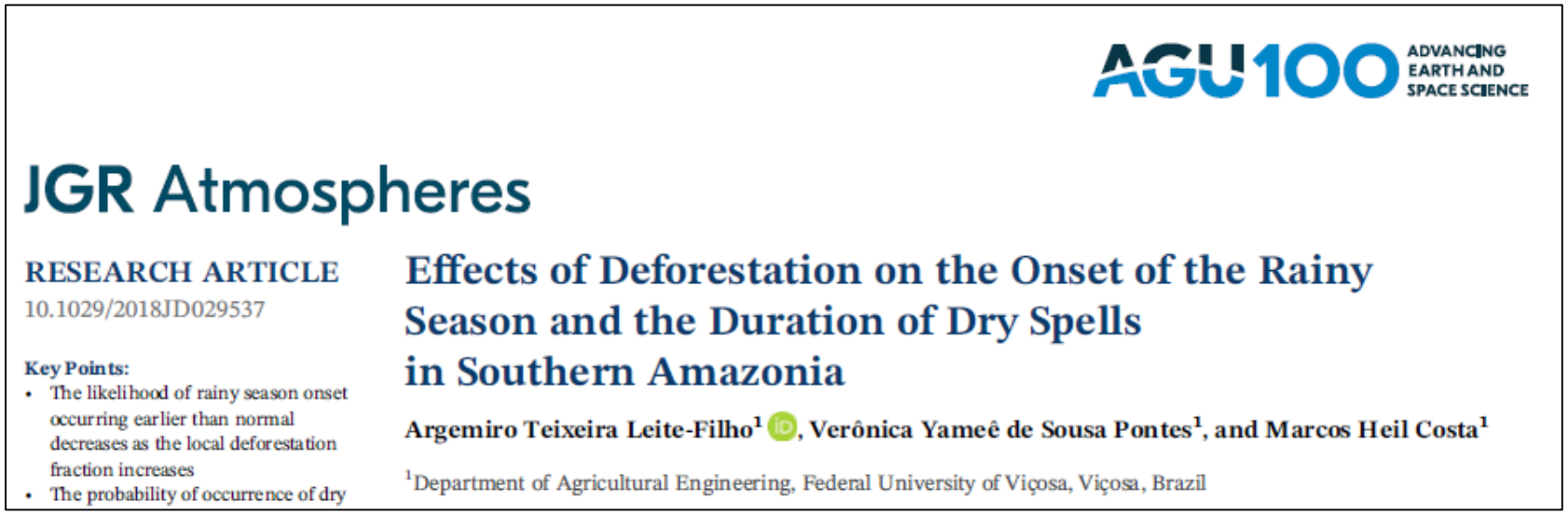
The Dry Season in central-southern Amazon has increased by 6 days per decade since the 1980's.

If it becomes longer than 4 months, the risks of savannization increase exponentially!

Fu et al. 2013 (ADAPTED)

In Southern Amazonia...

Deforestation has already caused a delay at the onset of the rainy season!



AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR Atmospheres

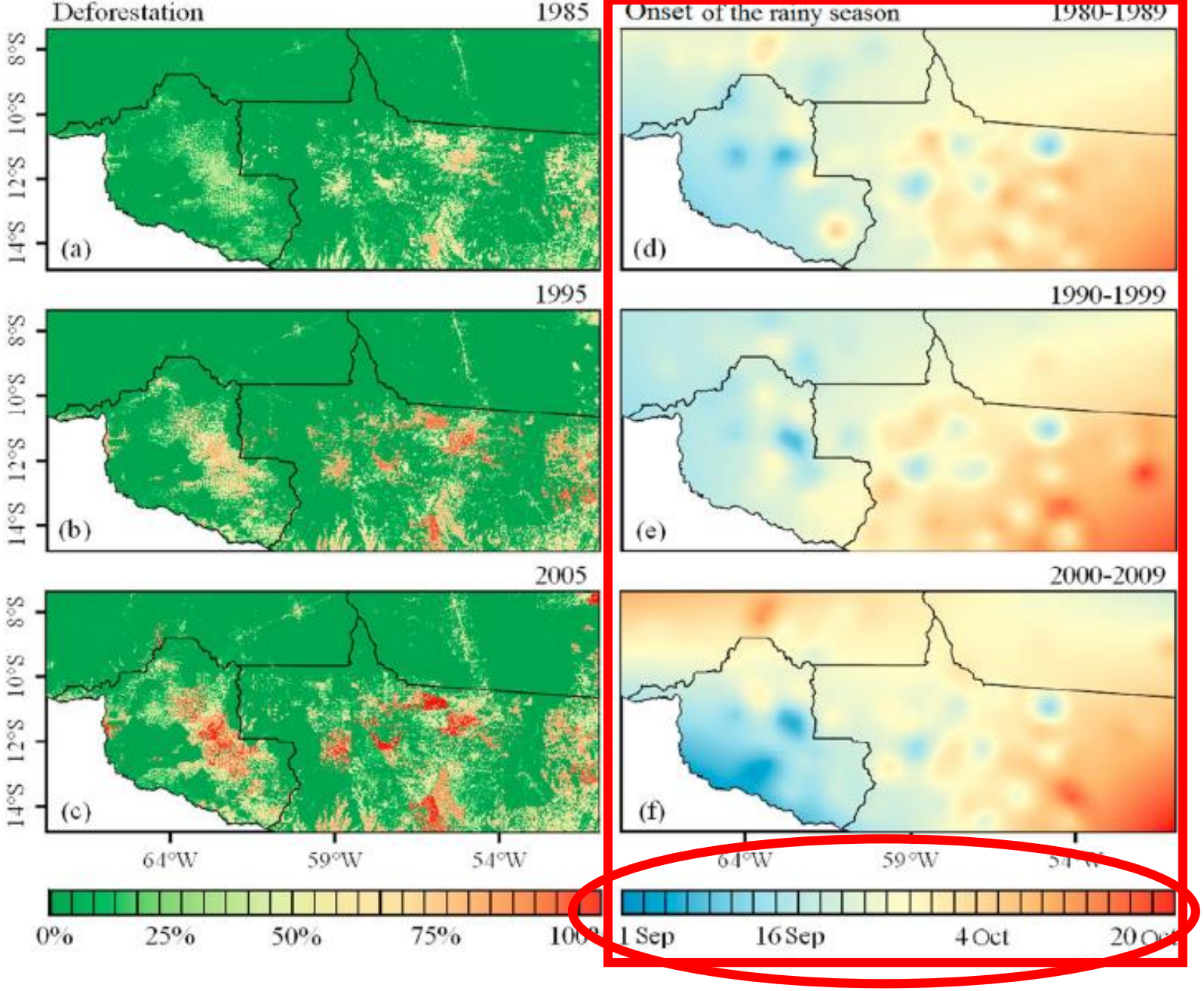
RESEARCH ARTICLE
10.1029/2018JD029537

Key Points:
- The likelihood of rainy season onset occurring earlier than normal decreases as the local deforestation fraction increases
- The probability of occurrence of dry

Effects of Deforestation on the Onset of the Rainy Season and the Duration of Dry Spells in Southern Amazonia

Argemiro Teixeira Leite-Filho[1], Verônica Yameê de Sousa Pontes[1], and Marcos Heil Costa[1]

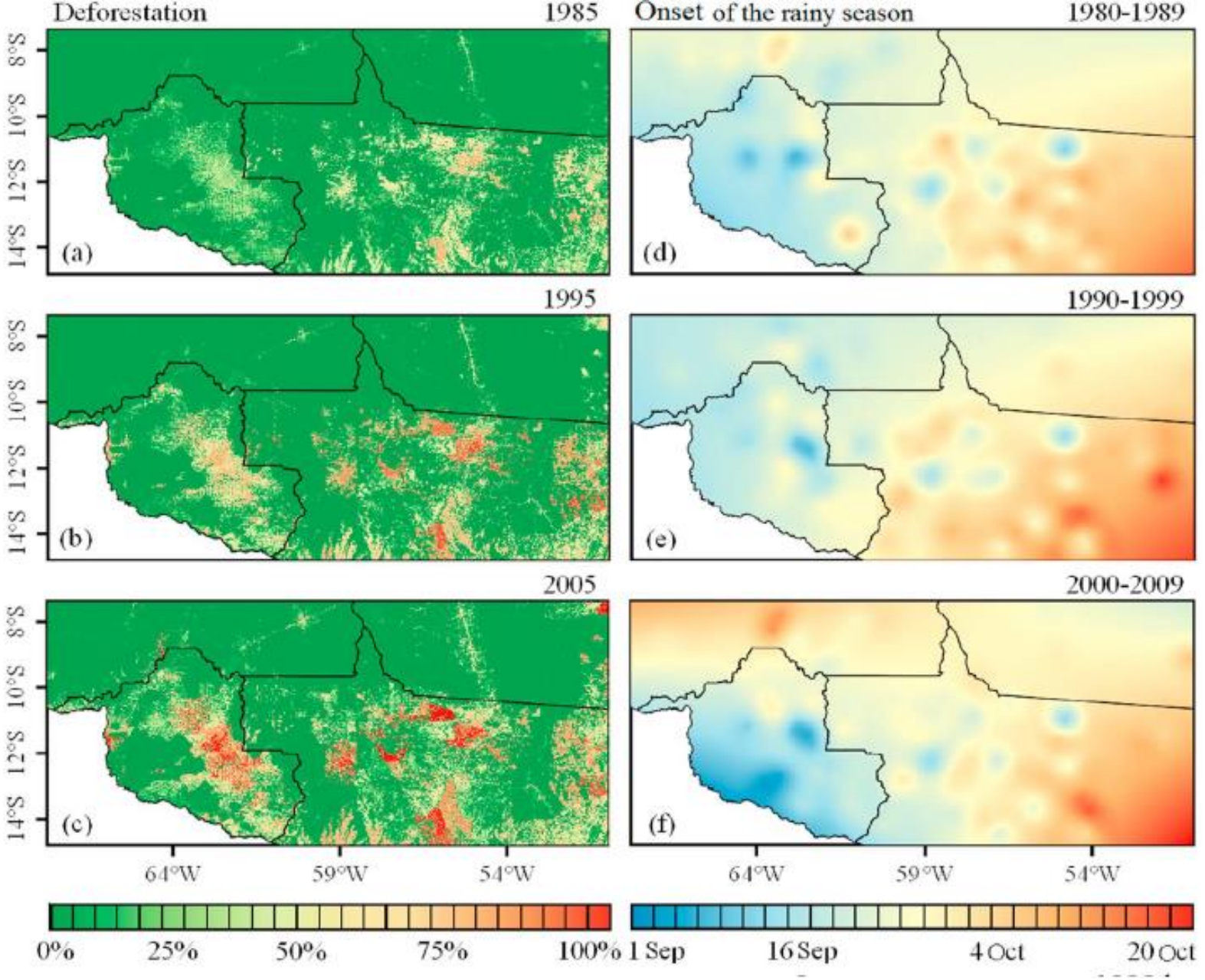
[1]Department of Agricultural Engineering, Federal University of Viçosa, Viçosa, Brazil



Evolution of Deforestation

Delay of the rainy season, which can reach almost 2 months in some regions!

Leite-Filho et al., 2019 - Effects of deforestation on the onset of the rainy season and the duration of dry spells in southern Amazonia. Journal of Geophysical Research: Atmospheres.



Other keyfindings

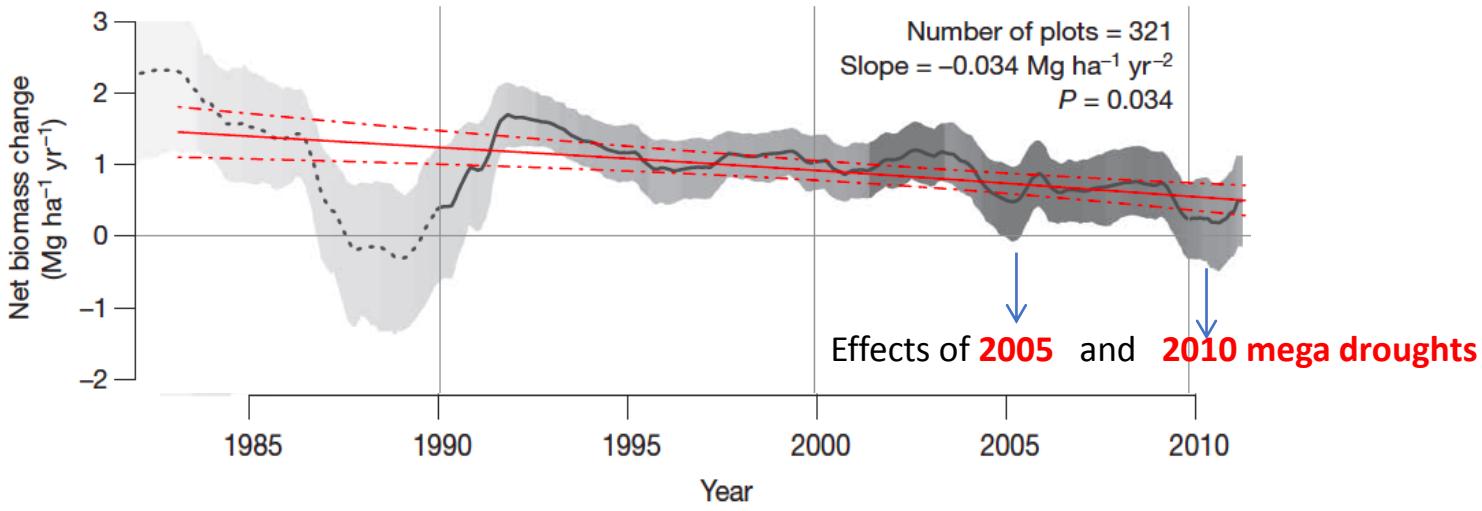
- Areas with greater deforestation also have greater chance to experience dry spells.
- Climatic risk to agriculture on this region: Double-cropping system, in which soybeans are harvested in time for the second crop to mature while climatic conditions are favorable.

Leite-Filho et al., 2019 - Effects of deforestation on the onset of the rainy season and the duration of dry spells in southern Amazonia. Journal of Geophysical Research: Atmospheres.

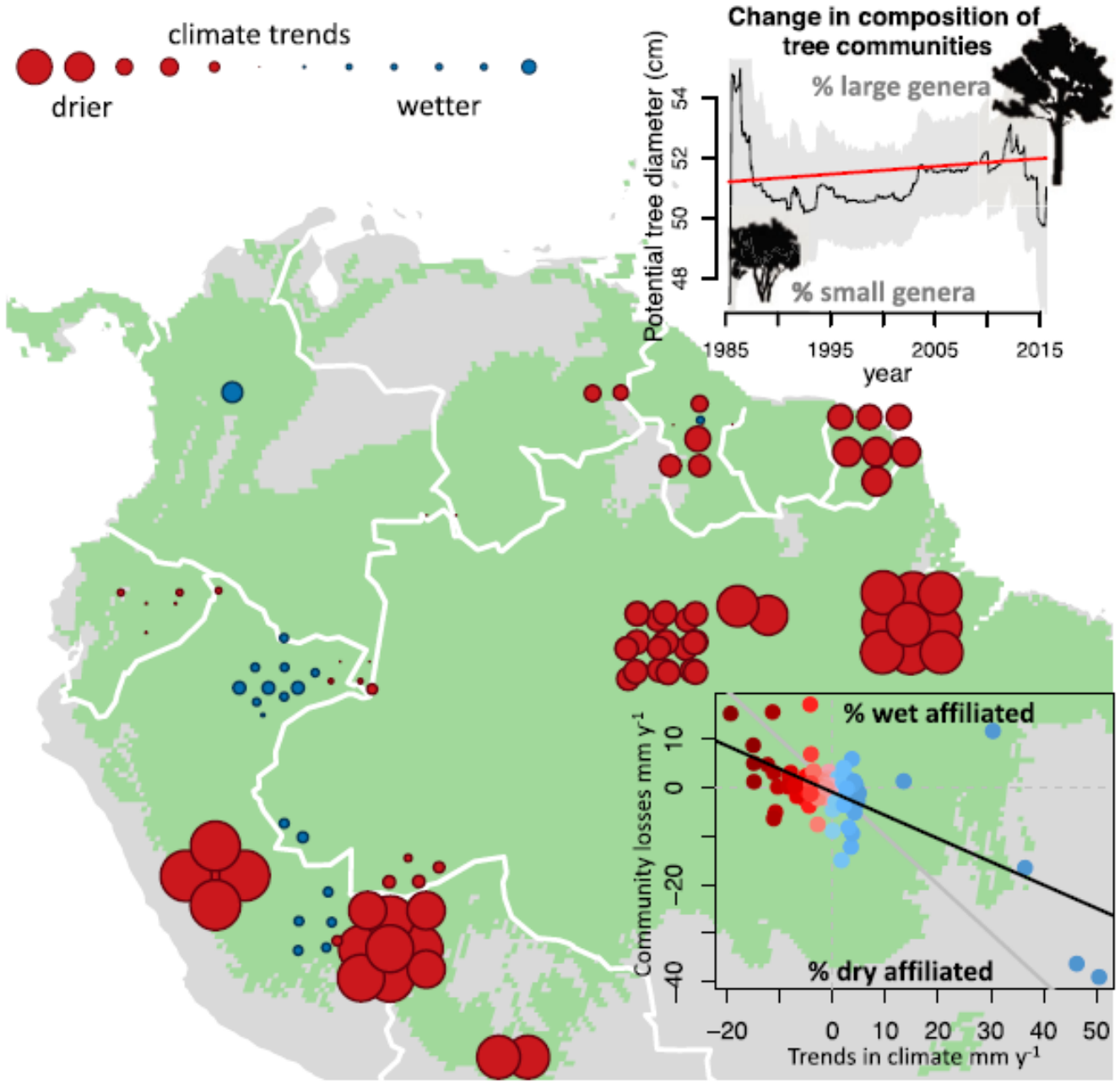
THE AMAZON FOREST IS A KEY CARBON SINK

- Forest biomass is increasing in the Amazon (~1 tonC/ha/yr) (~ 3.7 tonCO_2/ha/yr)
- This carbon sink capacity has decreased 30% since 1990's

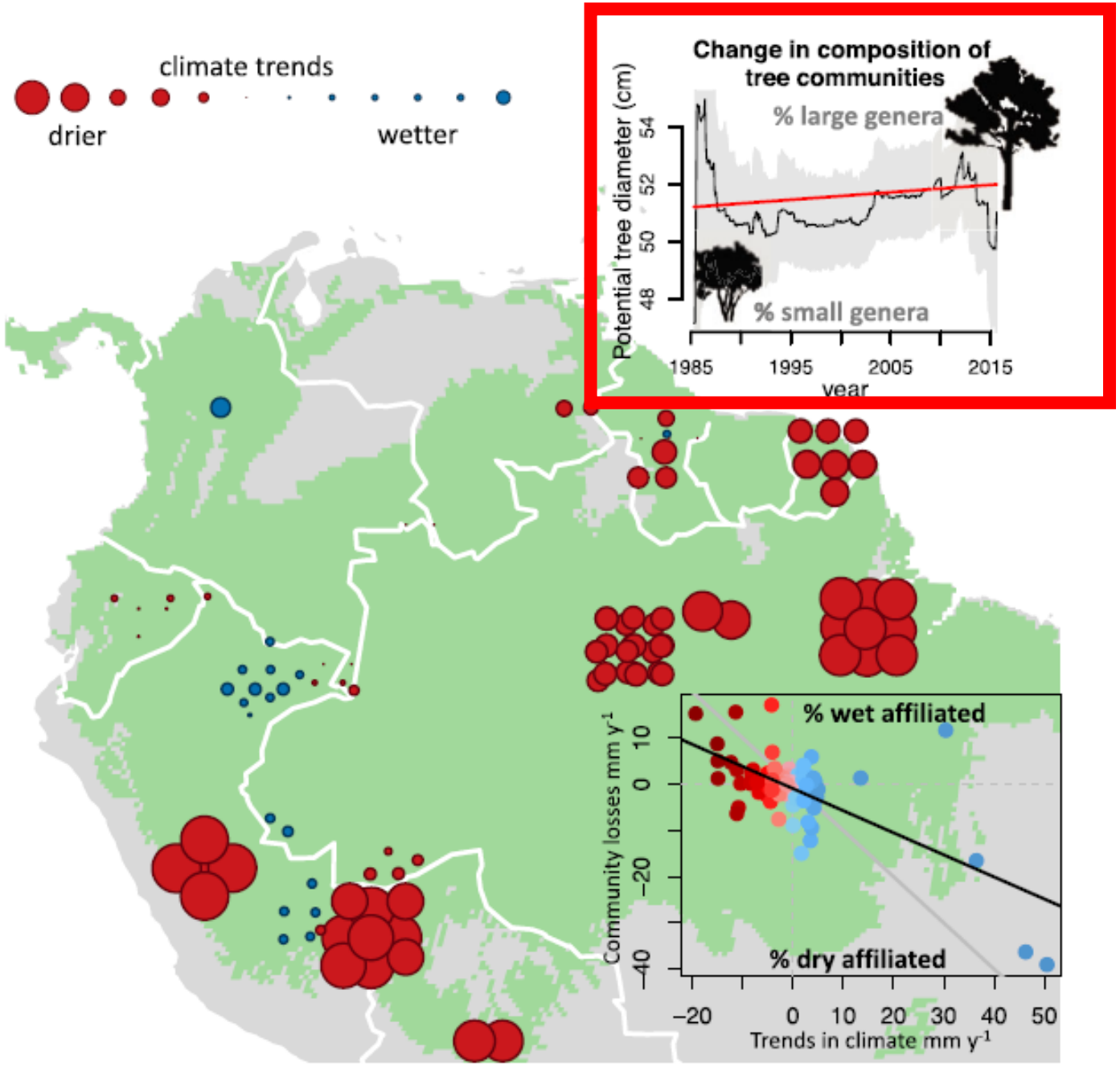
… and a considerable number of other studies point out the possibility of the Amazon forest dieback (Nobre et al. 2016 PNAS)



Adapted from Brienen et al. 2015 Nature

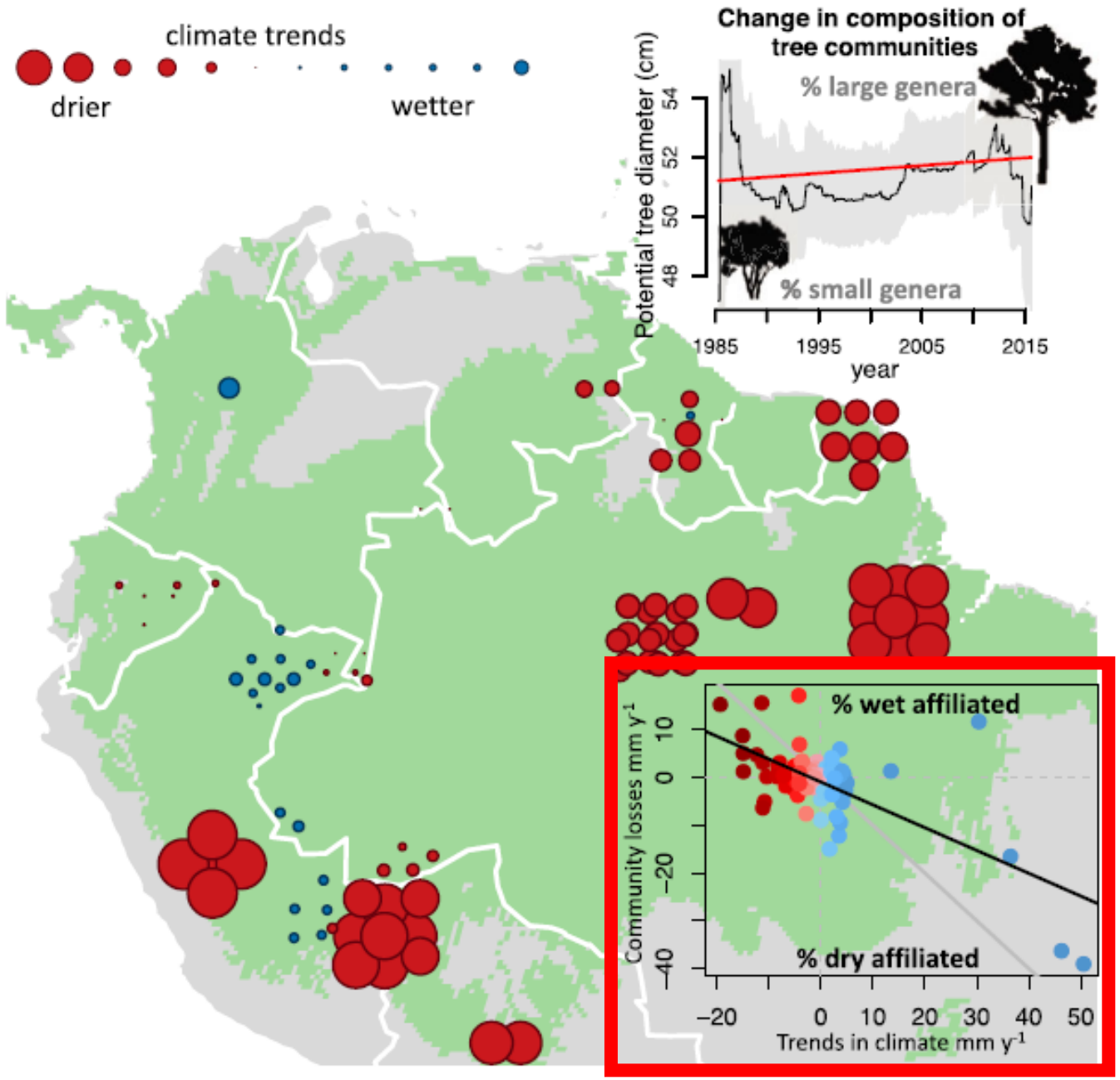


Esquivel-Muelbert et al. (2018) – Global Change Biology – Compositional response of Amazon Forests to climate change



Tendency to Increase in large genera trees

Esquivel-Muelbert et al. (2018) – Global Change Biology – Compositional response of Amazon Forests to climate change



Reduction in wet affiliated Taxa

Increase in dry affiliated taxa

Esquivel-Muelbert et al. (2018) – Global Change Biology – Compositional response of Amazon Forests to climate change

SCIENCE ADVANCES | EDITORIAL

Amazon Tipping Point

Thomas E. Lovejoy is University Professor in the Department of Environmental Science and Policy at George Mason University. Email: tlovejoy@eurtfoundation.org

Carlos Nobre is a Member of the Brazilian Academy of Sciences and Senior Fellow of World Resources Institute Brazil.

In the 1970s, Brazilian scientist Eneas Salati shattered the long held dogma that vegetation is simply the consequence of climate and has no influence on climate whatsoever (*1*). Using isotopic ratios of oxygen in rainwater samples collected from the Atlantic to the Peruvian border, he was able to demonstrate unequivocally that the Amazon generates approximately half of its own rainfall by recycling moisture 5 to 6 times as airmasses move from the Atlantic across the basin to the west.

From the start, the demonstration of the hydrological cycle of the Amazon raised the question of how much deforestation would be required to cause the cycle to degrade to the point of being unable to support rain forest ecosystems.

High levels of evaporation and transpiration that forests produce throughout the year contribute to a wetter atmospheric boundary layer than would be the case with non-forest. This surface-atmosphere coupling is more important where large-scale factors for rainfall formation are weaker, such as in central and eastern Amazonia. Near the Andes, the impact of at least modest deforestation is less dramatic because the general ascending motion of airmasses in this area induces high levels of rainfall in addition to that expected from local evaporation and transpiration.

Where might the tipping point be for deforestation-generated degradation of the hydrological cycle? The very first model to examine this question (*2*) showed that at about 40% deforestation, central, southern and eastern Amazonia would experience diminished rainfall and a lengthier dry season, predicting a shift to savanna vegetation to the east.

Moisture from the Amazon is important to rainfall and human wellbeing because it contributes to winter rainfall for parts of the La Plata basin, especially southern Paraguay, southern Brazil, Uruguay and central-eastern Argentina; in other regions, the moisture passes over the area, but does not precipitate out. Although the amount contributing to rainfall in southeastern Brazil is smaller than in other areas, even small amounts can be a welcome addition to urban reservoirs.

The importance of Amazon moisture for Brazilian agriculture south of the Amazon is complex but not trivial. Perhaps most important is the partial contribution of dry season Amazon evapotranspiration to rainfall in southeastern South America. Forests maintain an evapotranspiration rate year-round, whereas evapotranspiration in pastures is dramatically lower in the dry season. As a consequence, models suggest a longer dry season after deforestation.

In recent decades, new forcing factors have impinged on the hydrological cycle: climate change and widespread use of fire to eliminate felled trees and clear weedy vegetation. Many studies show that in the absence of other contributing factors, 4 degrees Celsius of global warming would be the tipping point to degraded savannas in most of the central, southern, and eastern Amazon. Widespread use of fire leads to drying of surrounding forest and greater vulnerability to fire in the subsequent year.

We believe that negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to non-forest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation.

The severity of the droughts of 2005, 2010 and 2015-16 could well represent the first flickers of this ecological tipping point. These events, together with the severe floods of 2009, 2012 (and 2014 over SW Amazonia), suggest that the whole system is oscillating. For the last two decades the dry season over the southern and eastern Amazon has been increasing. Large scale factors such as warmer sea surface temperatures over the tropical North Atlantic also seem to be associated with the changes on land.

We believe that the sensible course is not only to strictly curb further deforestation, but also to build back a margin of safety against the Amazon tipping point, by reducing the deforested area to less than 20%, for the commonsense reason that there is no point in discovering the precise tipping point by tipping it. At the 2015 Paris Conference of the Parties, Brazil committed to 12 million ha of reforestation by 2030. Much or most of this reforestation should be in southern and eastern Amazonia. The hydrological cycle of the Amazon is fundamental to human well-being in Brazil and adjacent South America.

–Thomas E. Lovejoy and Carlos Nobre

REFERENCES

1. E. Salati, A. Dall'Olio, E. Matsui, J. R. Gat, Recycling of Water in the Amazon, Brazil: an isotopic study. *Water Resour. Res.* **15**, 1250–1258 (1979).
2. G. Sampaio, C. A. Nobre, M. H. Costa, P. Satyamurty, B. S. Soares-Filho, M. Cardoso, Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. *Geophys. Res. Lett.* **34**, L17709 (2007).

10.1126/sciadv.aat2340

Citation: T. E. Lovejoy, C. Nobre, Amazon Tipping Point. *Sci. Adv.* **4**, eaat2340 (2018).

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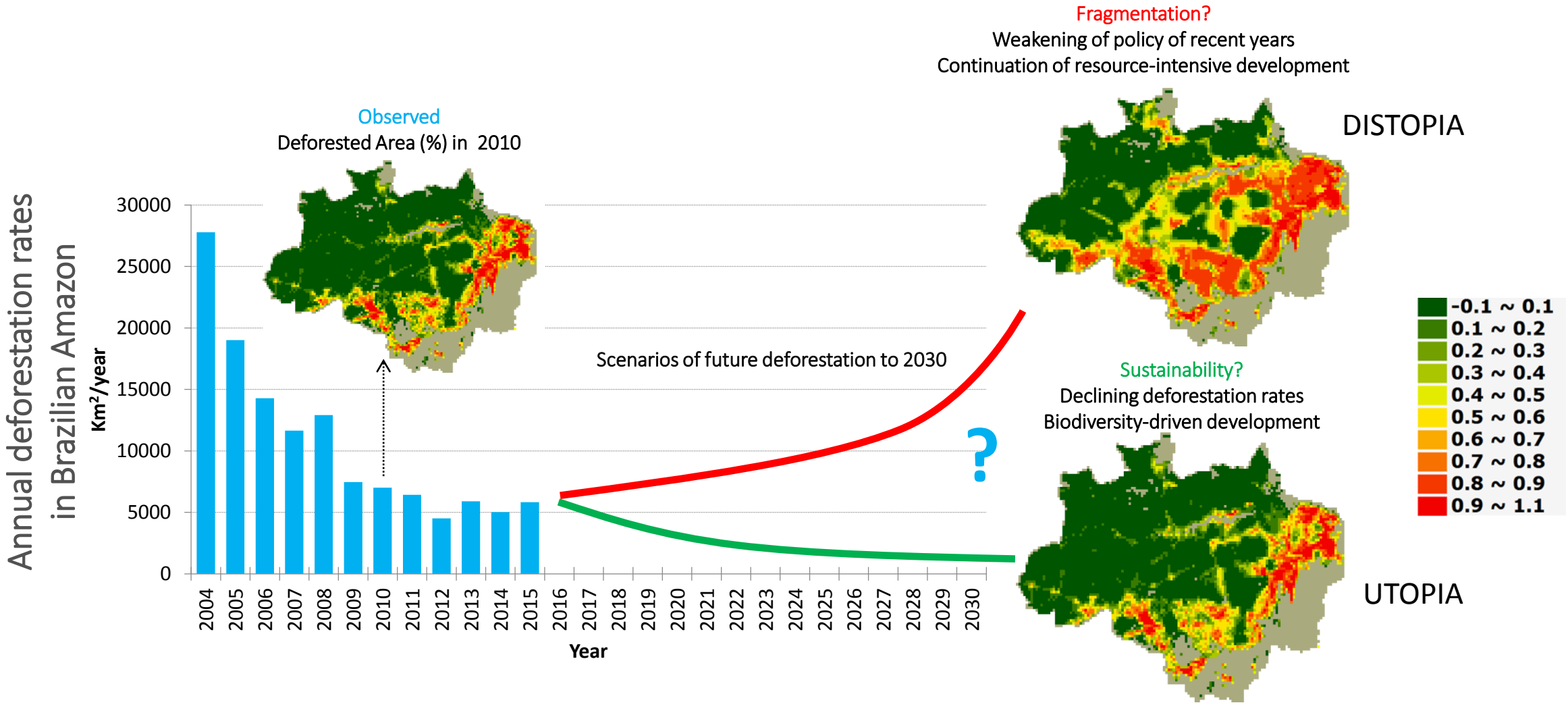
DRIVERS OF CHANGE

- Global Climate Change
- Regional Deforestation
- Increasing forest fires
- CO_2 increase

Potential tipping point
20% - 25% of total area deforested

CAN WE STOP AMAZON DEFORESTATION?

FUTURE LAND USE CHANGE IN THE AMAZON: SUSTAINABILITY OR FRAGMENTATION?

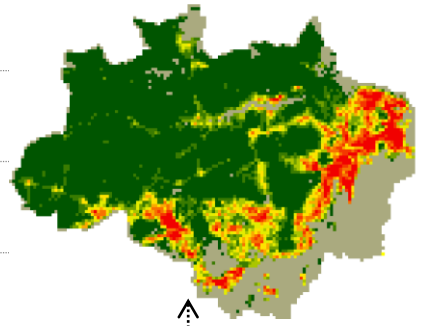


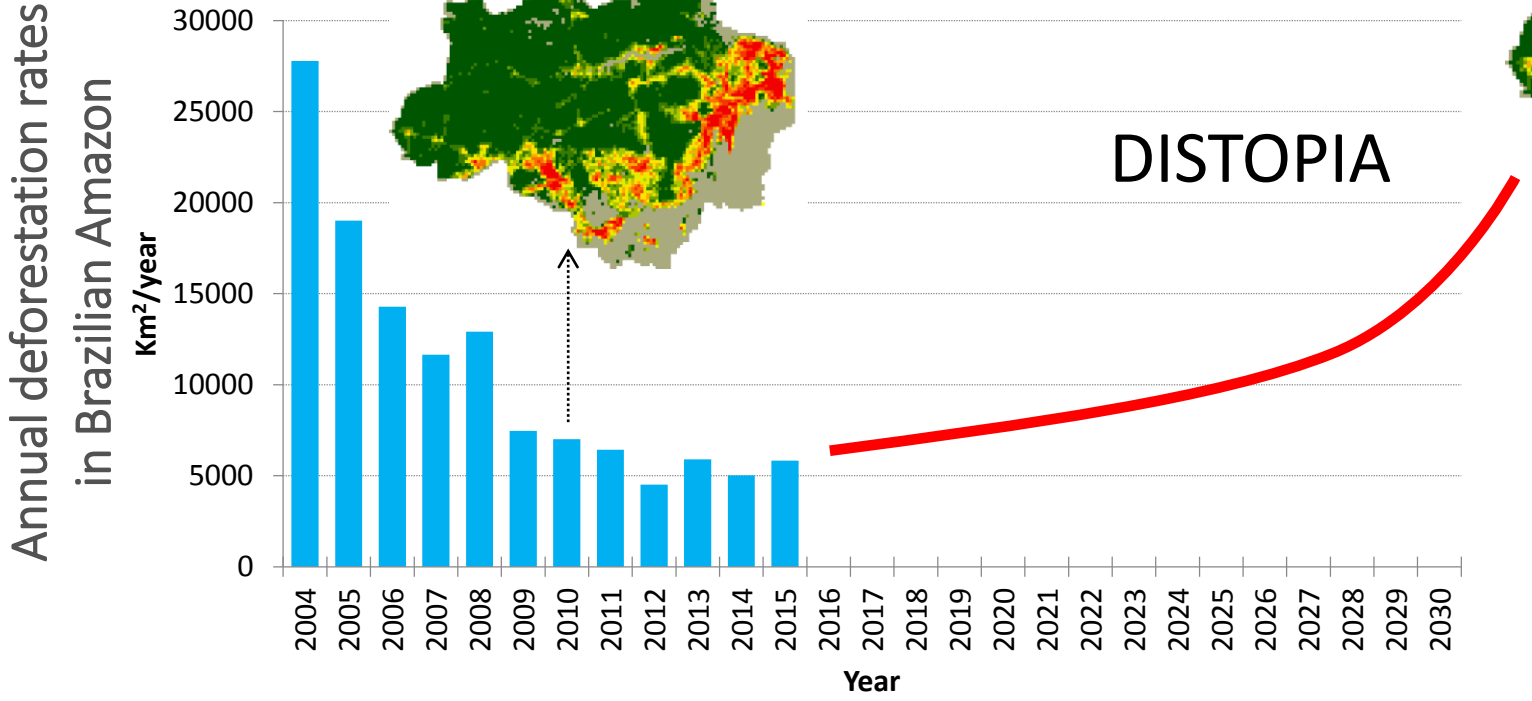
Source: PRODES – INPE and Aguiar et al., 2013

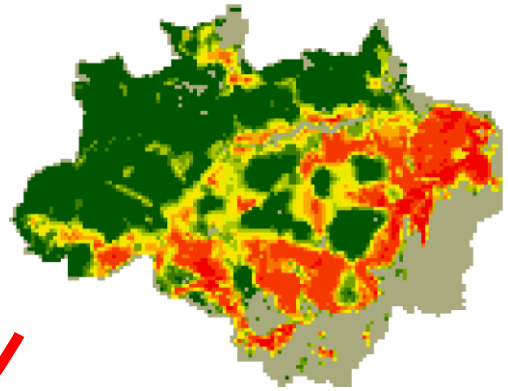
FUTURE LAND USE CHANGE IN THE AMAZON: SUSTAINABILITY OR FRAGMENTATION?

Fragmentation?
Weakening of policy of recent years
Continuation of resource-intensive development

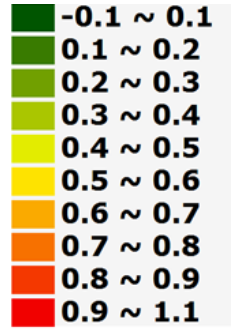
Observed
Deforested Area (%) in 2010







Scenarios of future deforestation to 2030



Source: PRODES – INPE and Aguiar et al., 2013

RESOURCE-INTENSIVE DEVELOPEMENT

THE GLOBAL FARM

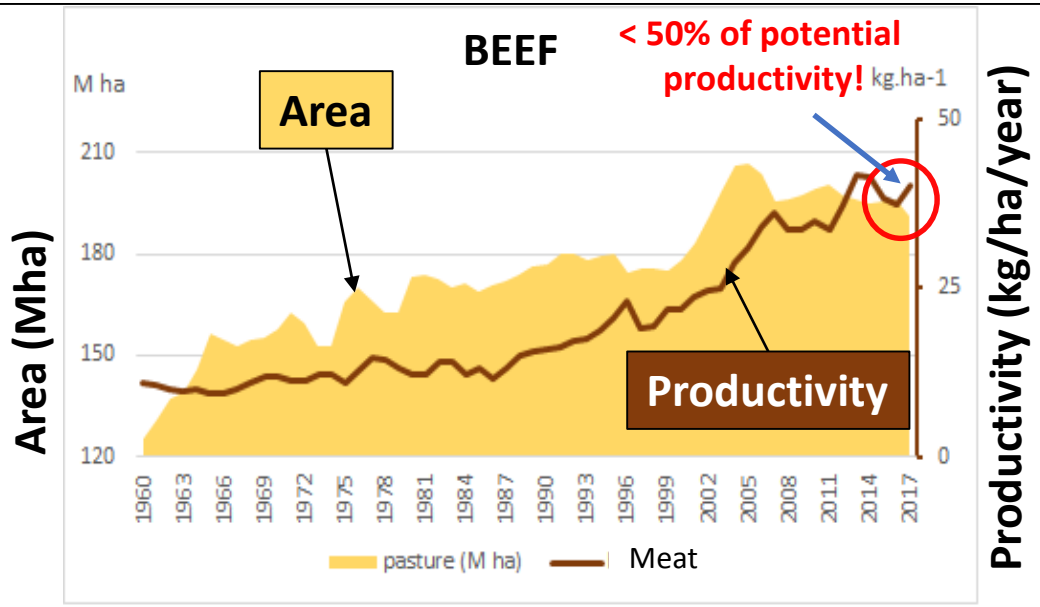
With its plentiful sun, water and land, Brazil is quickly surpassing other countries in food production and exports. But can it continue to make agricultural gains without destroying the Amazon?

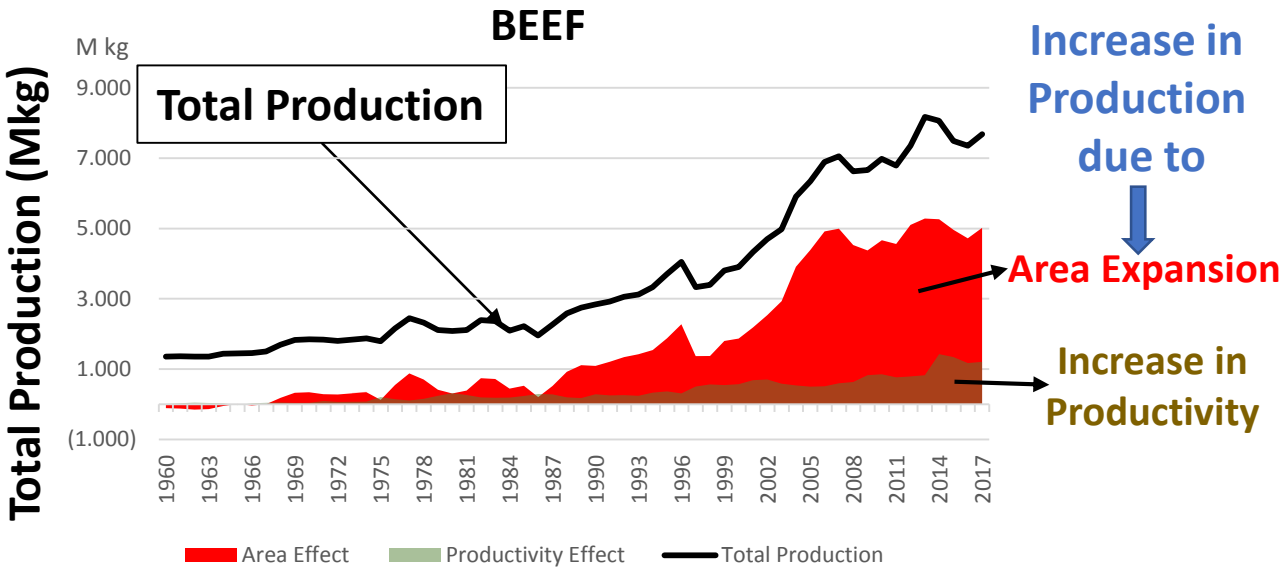
Nature **466**, 554-556 (2010)

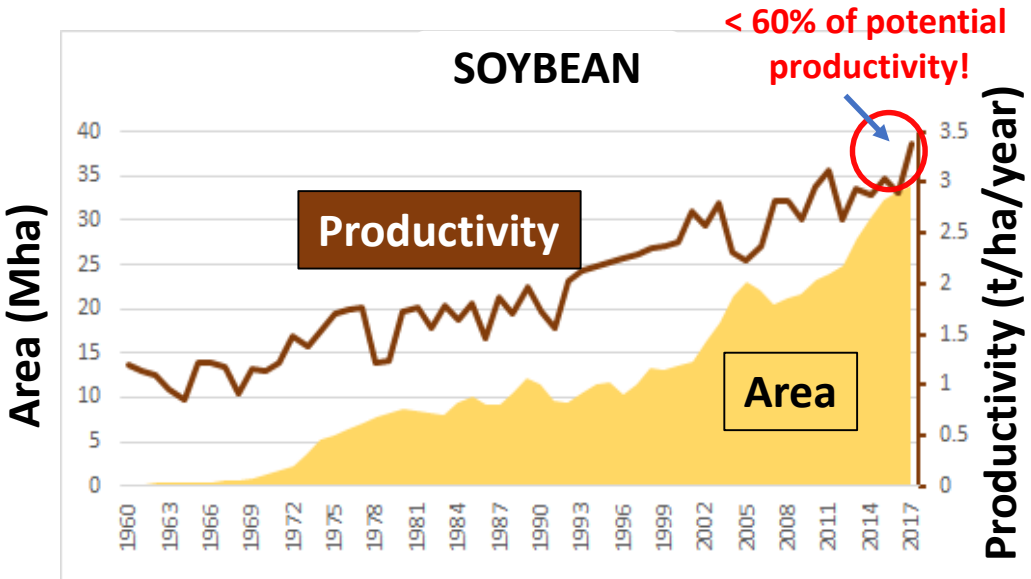
AND THE GLOBAL CATTLE RANCH

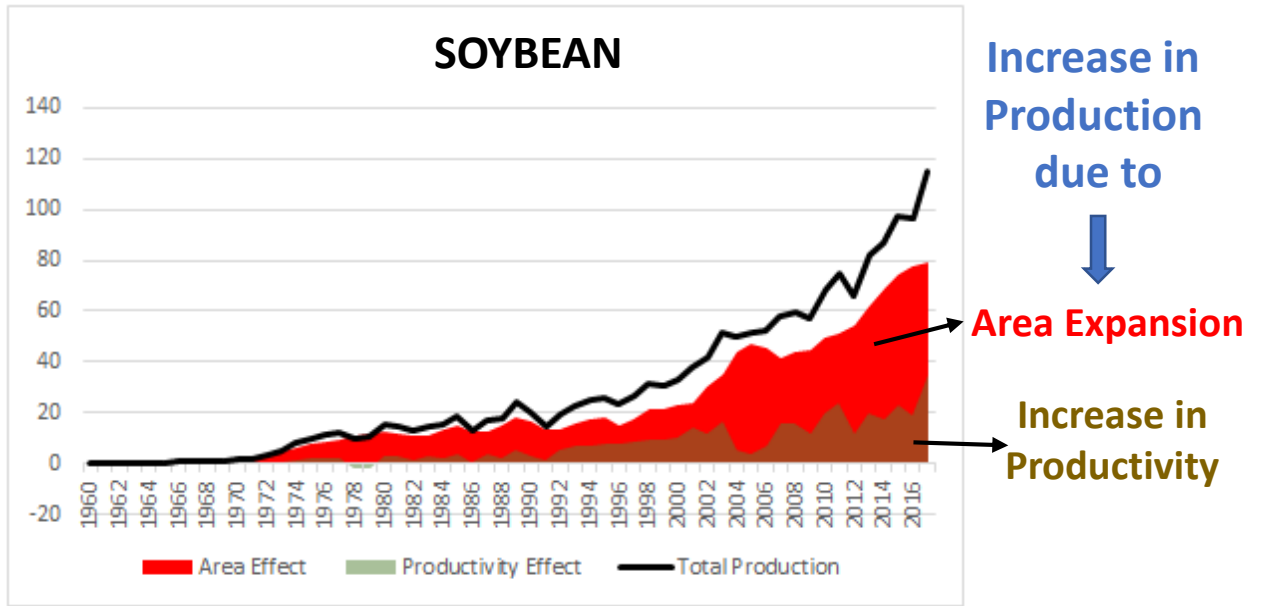
Image: http://oglobo.globo.com/

Beef and Soybean Production in Brasil from 1960 to 2017 due to Extensification (Area Effect) versus Productivity Effect









Barbieri and Nobre, 2019 (in preparation)

LETTERS

Edited by **Jennifer Sills**

Make EU trade with Brazil sustainable

Brazil, home to one of the planet's last great forests, is currently in trade negotiations with its second largest trading partner, the European Union (EU). We urge the EU to seize this critical opportunity to ensure that Brazil protects human rights and the environment.

Brazil's forests, wetlands, and savannas are crucial to a great diversity of Indigenous peoples, the stability of our global climate, and biodiversity conservation (*1*). By working toward dismantling anti-deforestation policies, Brazil's new administration threatens Indigenous rights and the natural areas they protect (*2*).

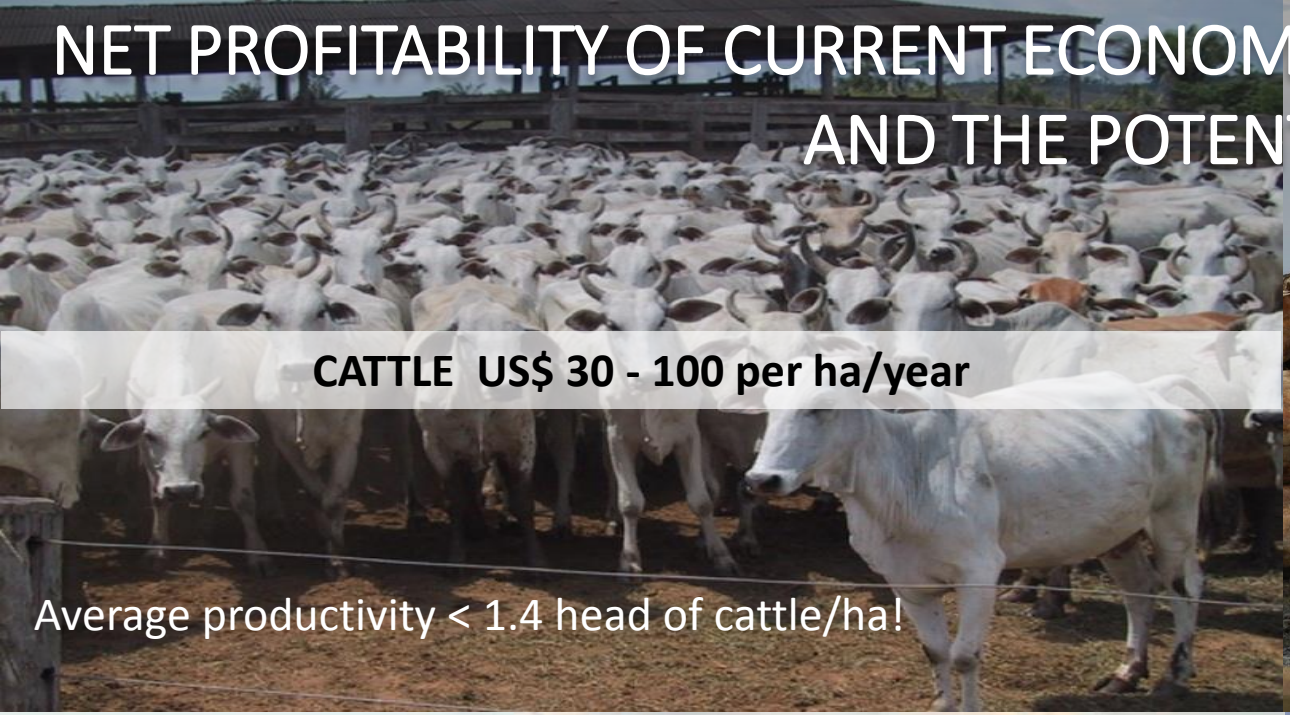
with Brazil conditional on: (i) upholding the United Nations Declaration on the Rights of Indigenous Peoples; (ii) improving procedures to trace commodities associated with deforestation and Indigenous rights conflicts; and (iii) consulting with, and gaining consent from, Indigenous Peoples and local communities to define strict social and environmental criteria for traded commodities.

The EU was founded on the principles of respecting human rights and human dignity. Today, it has the opportunity to be a global leader in supporting these principles and a habitable climate by making sustainability the cornerstone of its trade negotiations with Brazil.

Laura Kehoe[1]*, Tiago Reis[2], Malika Virah-Sawmy[3], Andrew Balmford[4], Tobias Kuemmerle[1], and 604 signatories†
[1]Oxford Martin School, University of Oxford,

- Letter by Kehoe et al., 26 April 2019, *Science*
- Over 600 signatories (mostly European scientists)
- Calling for deforestation-free, sustainable suply chains!

NET PROFITABILITY OF CURRENT ECONOMIC ACTIVITIES IN THE BRAZILIAN AMAZON AND THE POTENTIAL FOR REDD+



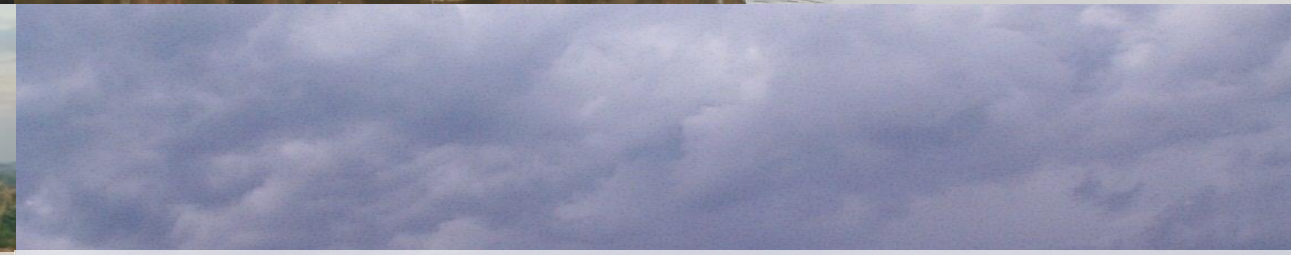
CATTLE US$ 30 - 100 per ha/year

Average productivity < 1.4 head of cattle/ha!

SELECTIVE LOGGING - $100 – 400 per ha/25-30 years

80% of logging is illegal!

Potential of REDD+ $2500 – 5000 per ha ($5-10 ton CO_2)

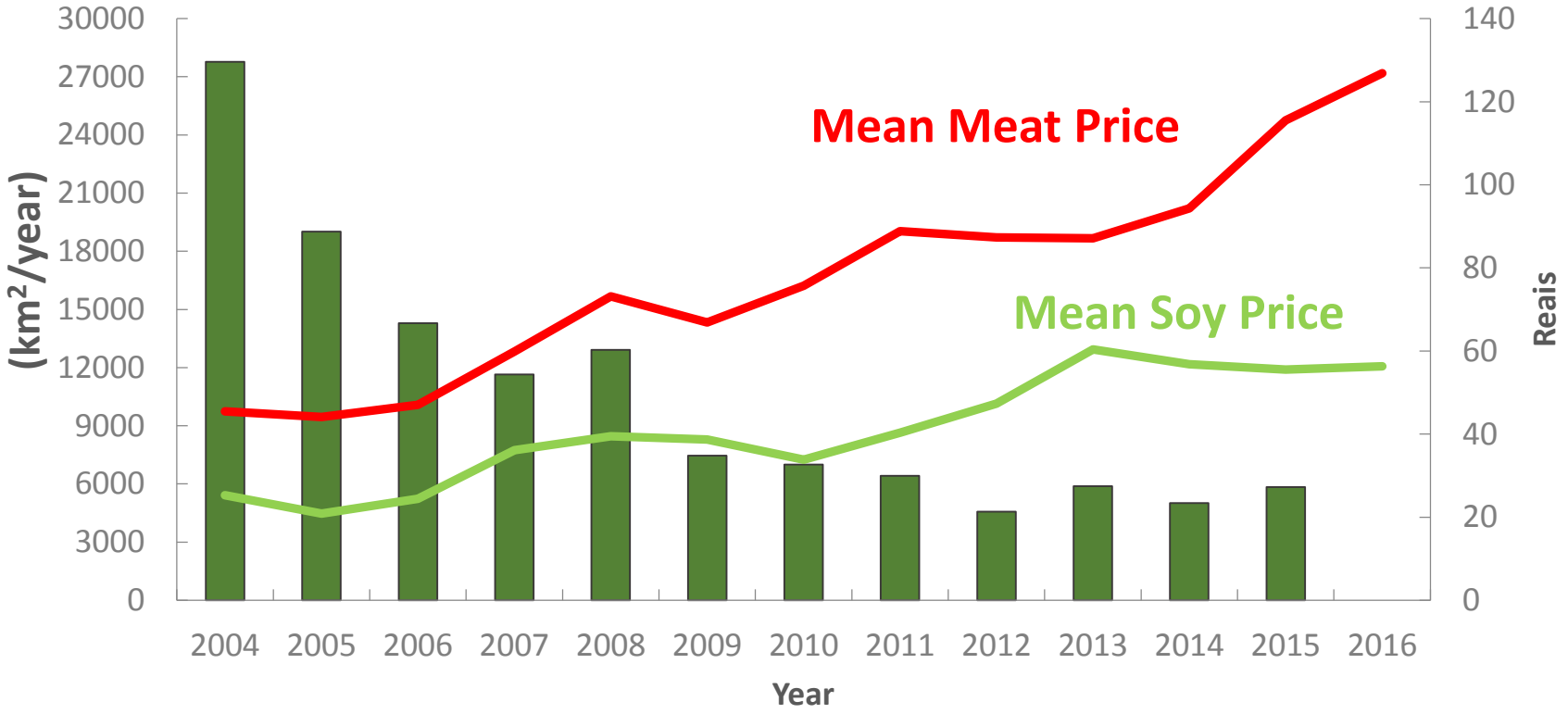


SOY $100 – 200 per ha/year

Average current **CO_2** price < $2.5 per ton!

Average productivity in the Amazon = 2.9 ton/ha/year!

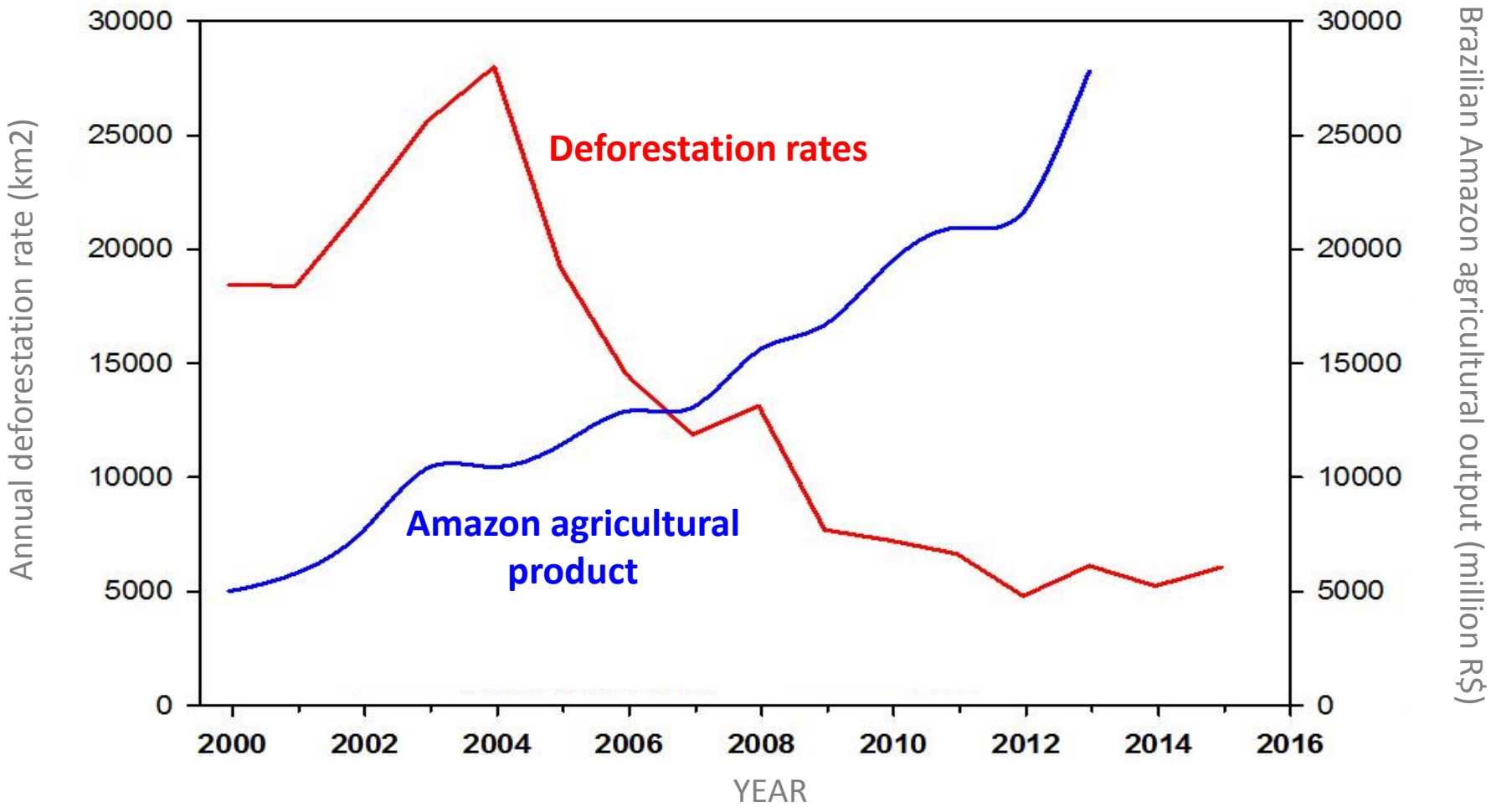
DEFORESTATION RATES AND COMMODITY PRICES (BASE 2015)



Commodity price is not coupled to deforestation rates past 2005

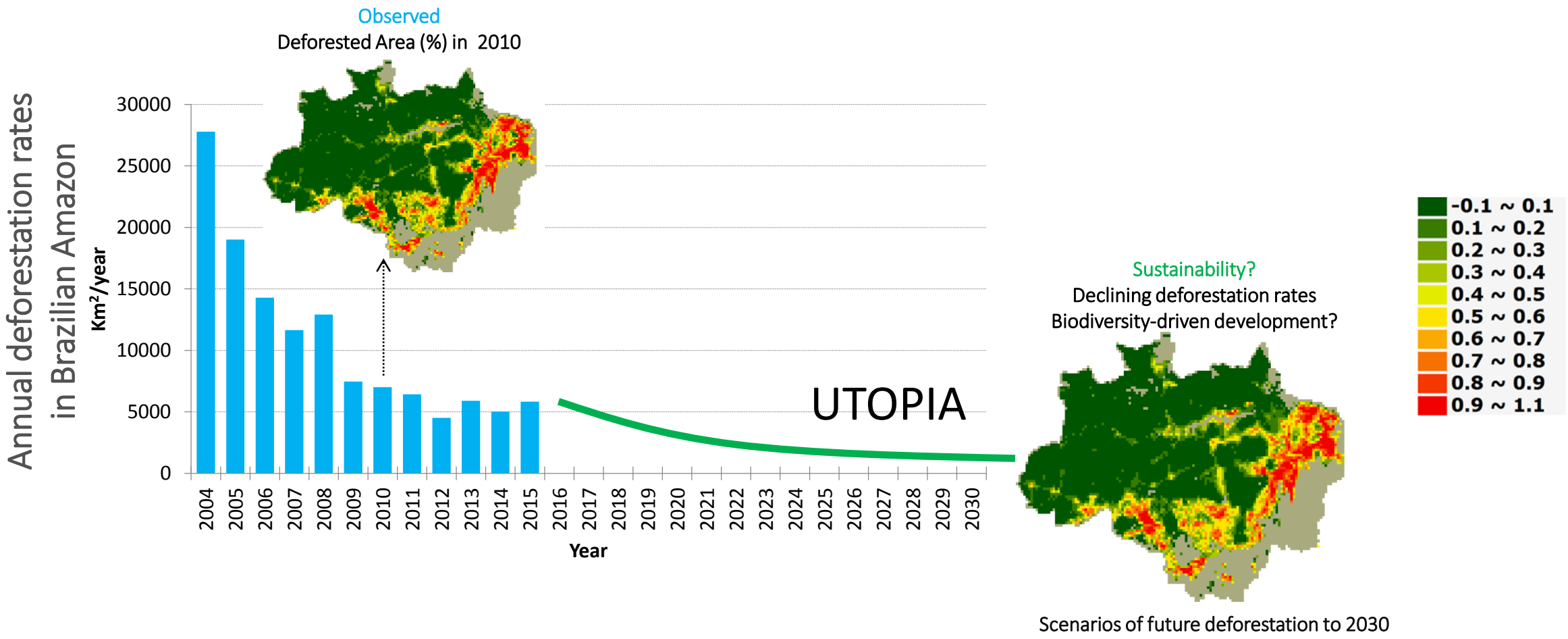
http://www.agrolink.com.br/cotacoes/Historico.aspx

GROWTH OF AGRICULTURAL OUTPUT IN THE BRAZILIAN AMAZON IS DECOUPLED FROM DEFORESTATION RATES



Nobre, Silva e Silva, 2016 (unpublished)

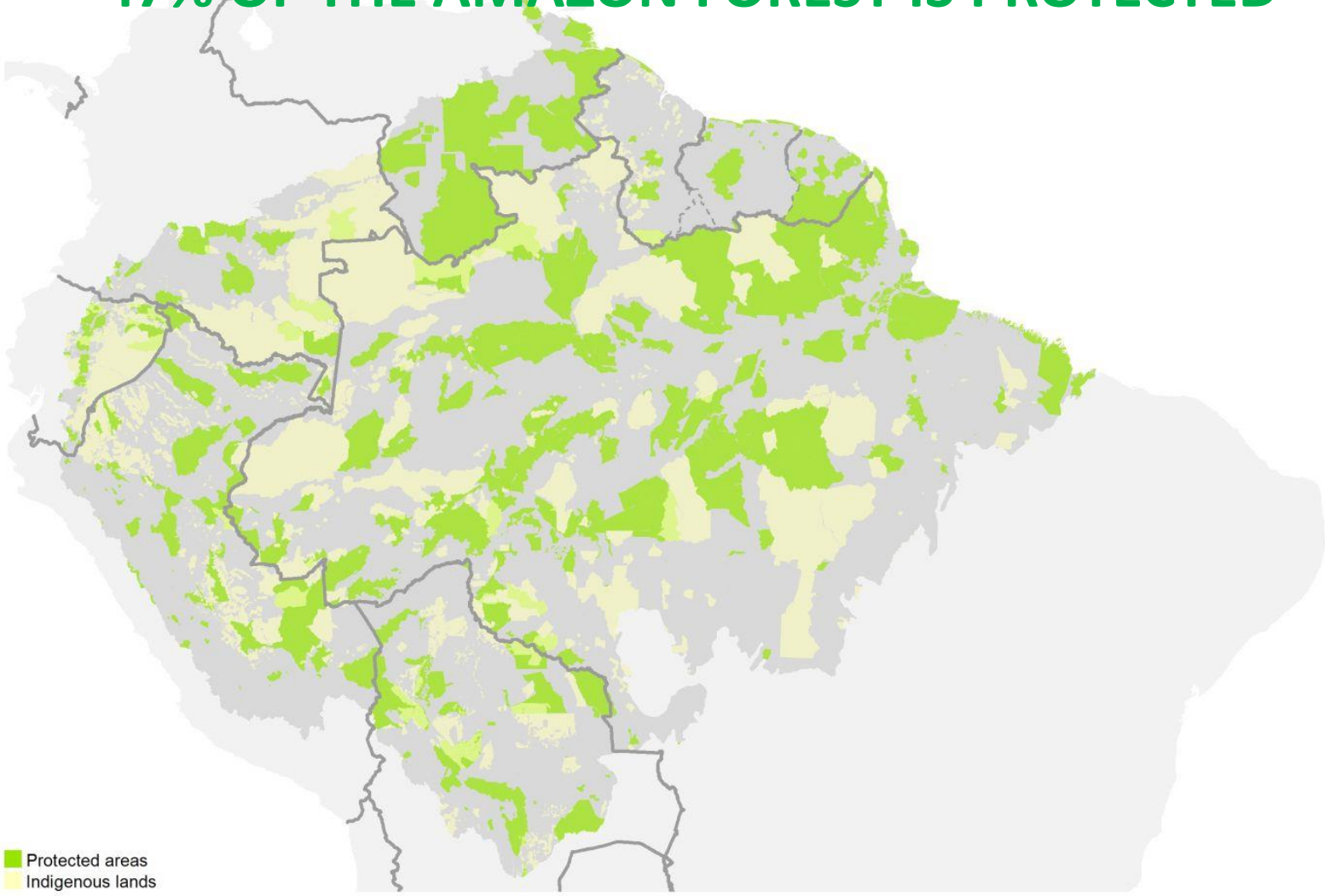
FUTURE LAND USE CHANGE IN THE AMAZON: SUSTAINABILITY OR FRAGMENTATION?



Source: PRODES – INPE and Aguiar et al., 2013

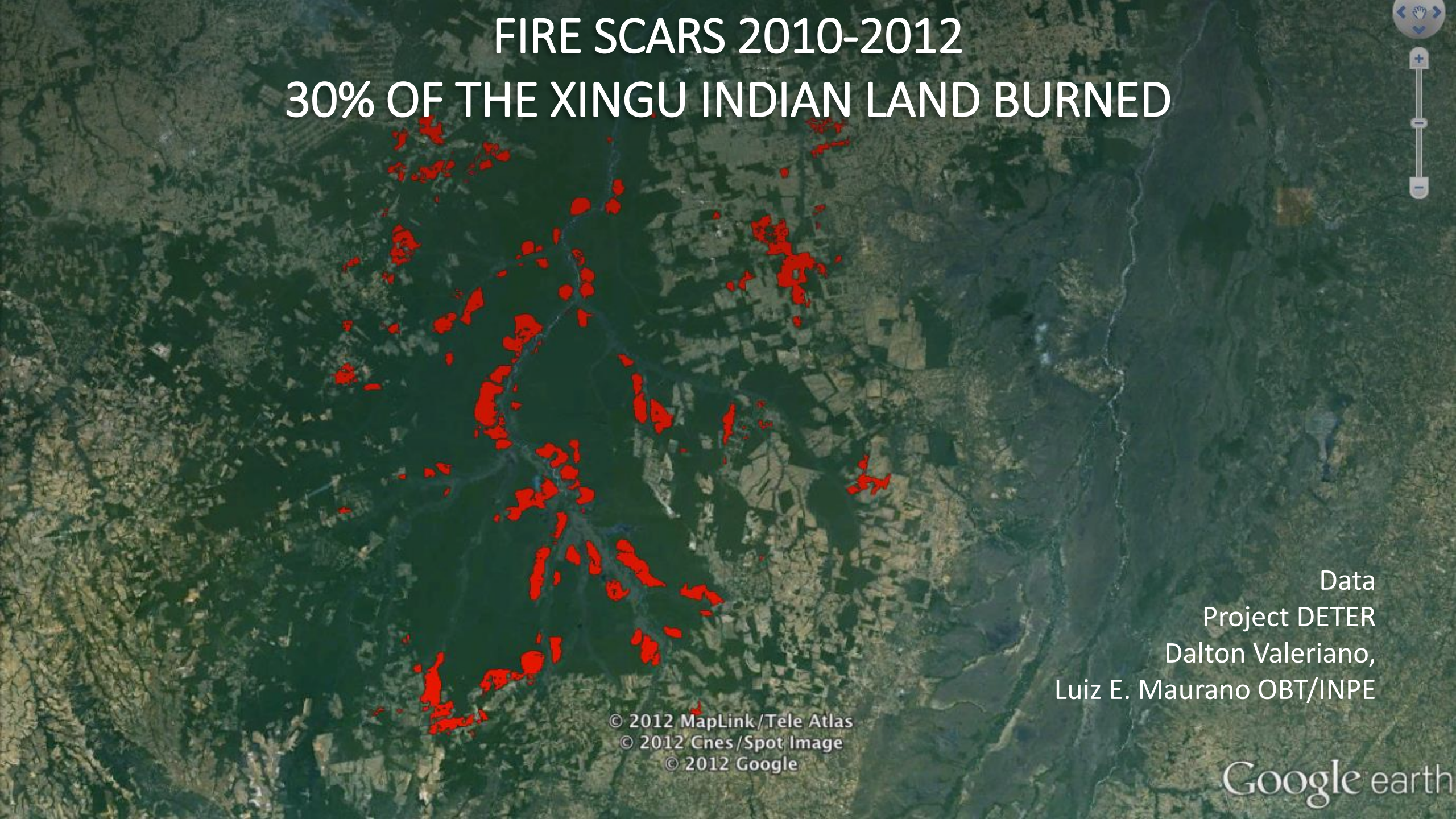
THE FIRST WAY: EXPAND PROTECTED AREAS IN THE AMAZON

47% OF THE AMAZON FOREST IS PROTECTED

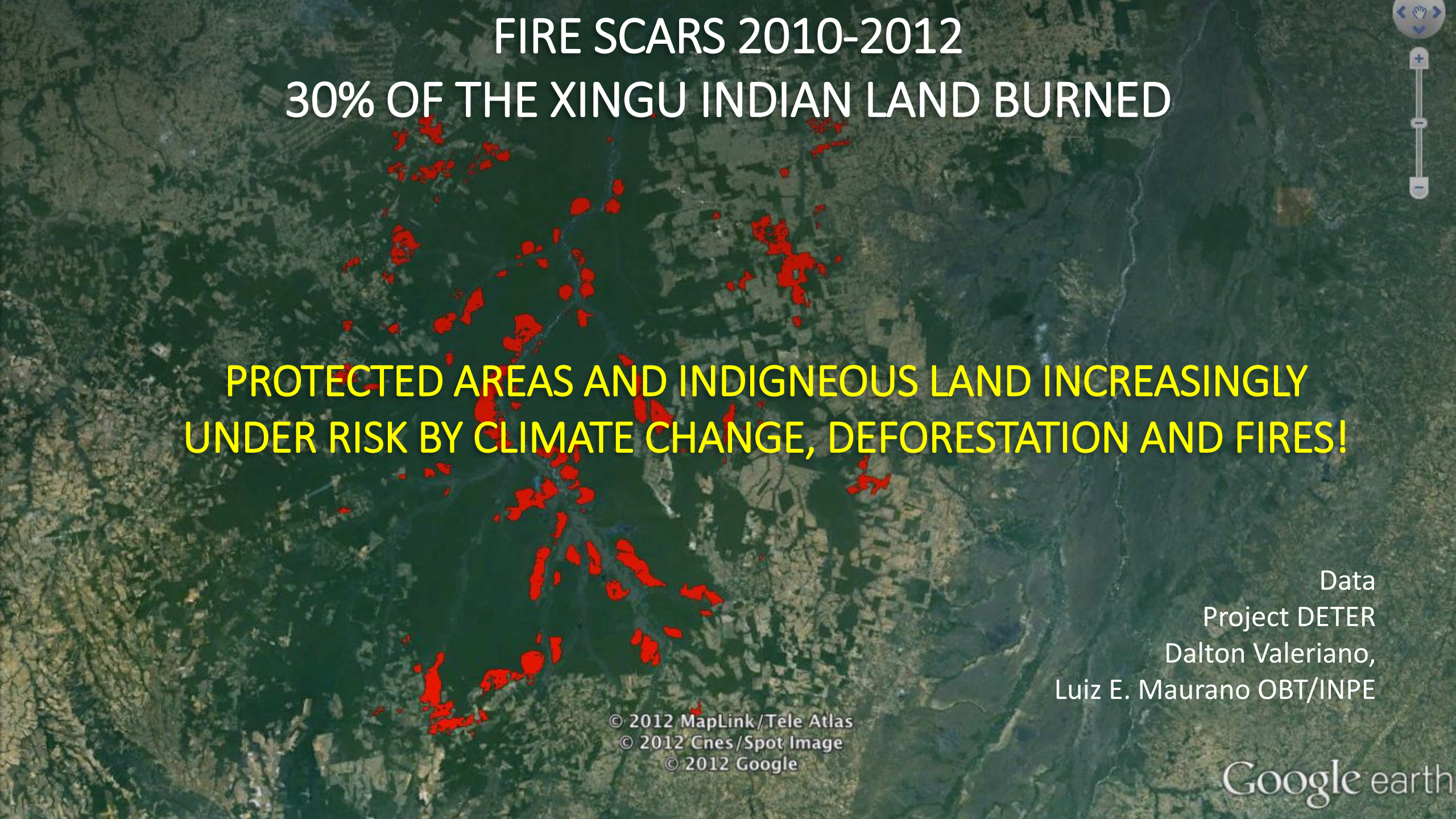


Map of protected areas (green) and indigenous lands (yellow) in the Amazonia region.
(map produced by Conservation International)

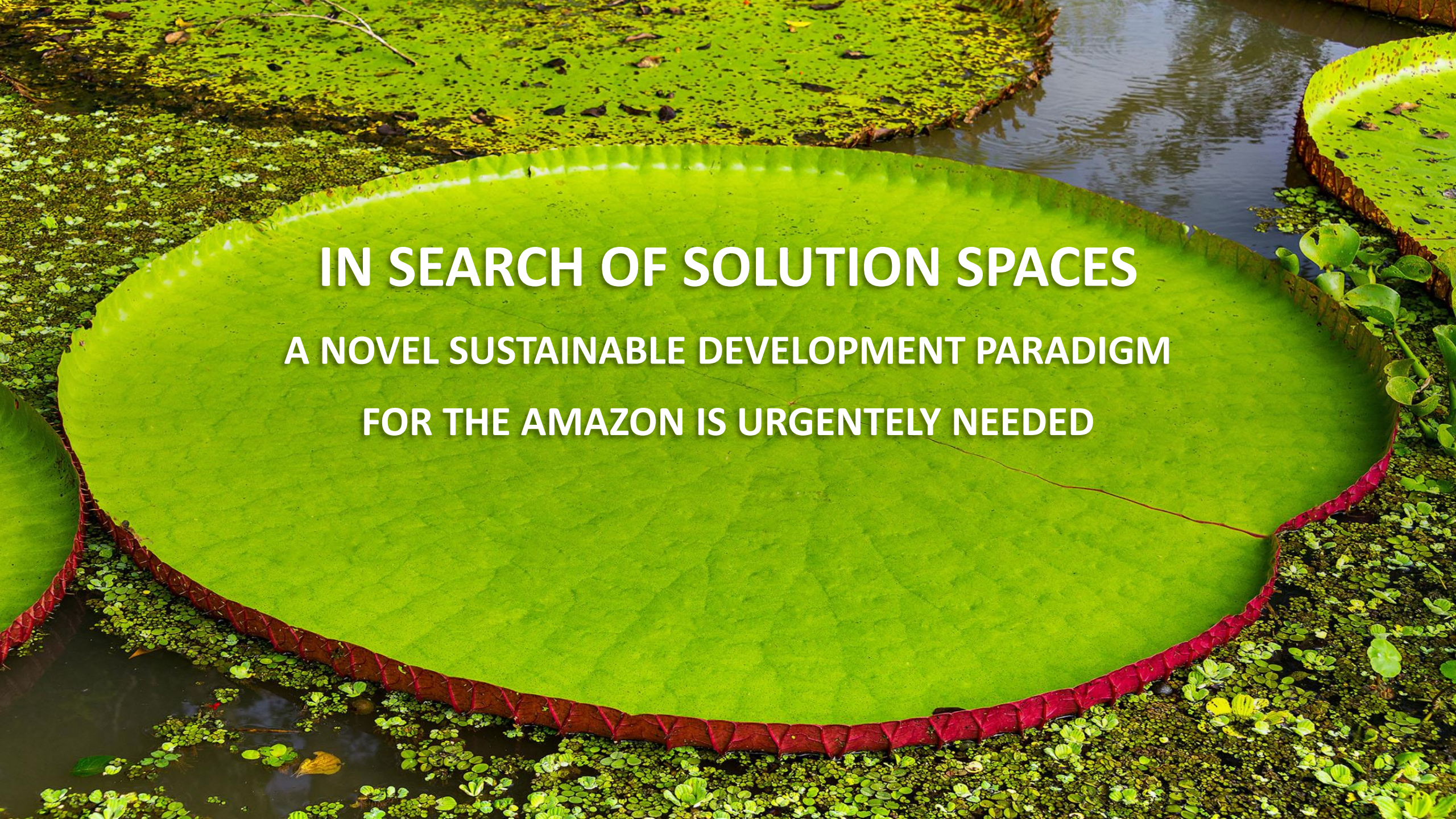
FIRE SCARS 2010-2012
30% OF THE XINGU INDIAN LAND BURNED



Data
Project DETER
Dalton Valeriano,
Luiz E. Maurano OBT/INPE


FIRE SCARS 2010-2012
30% OF THE XINGU INDIAN LAND BURNED
PROTECTED AREAS AND INDIGNEOUS LAND INCREASINGLY
UNDER RISK BY CLIMATE CHANGE, DEFORESTATION AND FIRES!
Data
Project DETER
Dalton Valeriano,
Luiz E. Maurano OBT/INPE
© 2012 MapLink/Tele Atlas
© 2012 Cnes/Spot Image
© 2012 Google
Google earth

PUSHING FOR CONSERVATION AND INCREASING EFFICIENCY OF COMMODITY PRODUCTION ARE NECESSARY CONDITIONS, BUT FAR FROM BEING SUFFICIENT TO ENSURE PROTECTION OF THE AMAZON FOREST AND ITS BIODIVERSITY
WHA ELSE?



IN SEARCH OF SOLUTION SPACES

A NOVEL SUSTAINABLE DEVELOPMENT PARADIGM FOR THE AMAZON IS URGENTELY NEEDED

SOLUTION SPACE FOR THE A M A Z O N

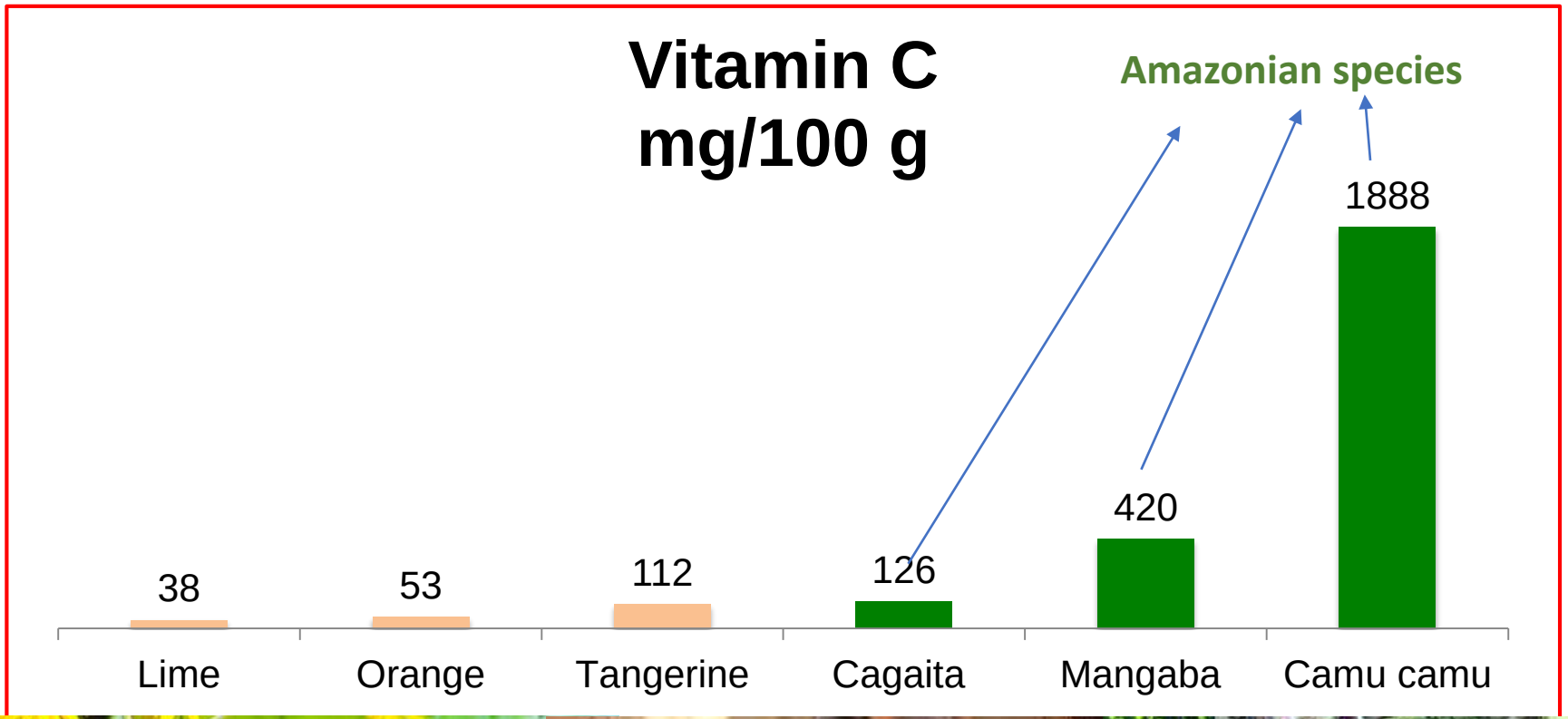
What is the potential of a biodiversity-driven bio-economy in the Amazon to produce viable value chains for food, nutraceuticals, cosmetics, fragrances, pharmaceuticals, industrial oils, genetic resources, etc.?

Hidden potential of Amazon's biodiversity

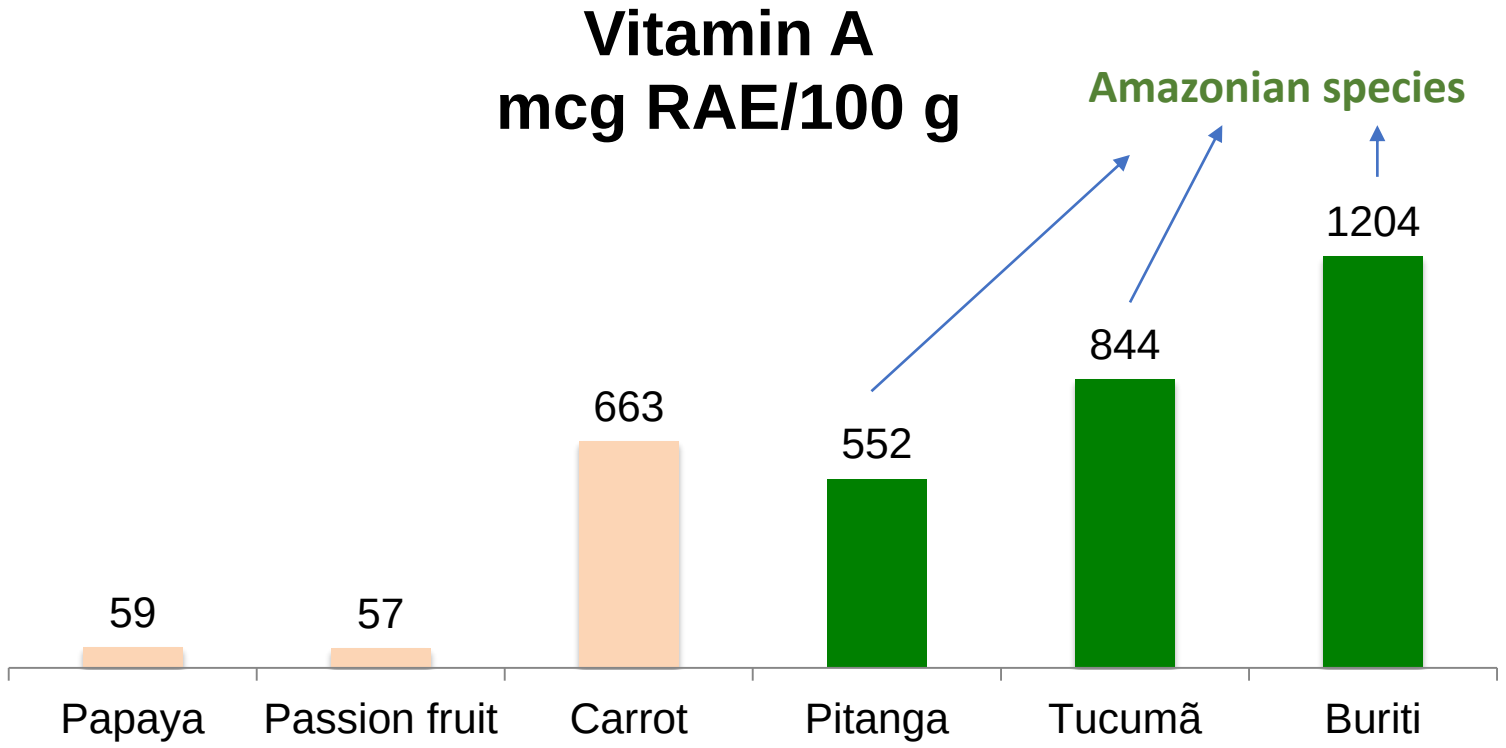
Agroferestry systems: 80 families and 469 species of plants are cultivated.

Over 245 species of Brasil's flora are bases of cosmetics and pharmaceuticals; at least 36 native plant species are used as phytoterapics

What are we missing?



What are we missing?



DEVELOPMENT OF A NOVEL BIOECONOMY IN THE AMAZON

Fostering Amazon sustainable development by setting priorities to the forest's biological assets

$200/l
Essense for fragrance oil

Fragrances for perfumery and natural flavoring for food industry

$30/l
$150/l if sold in capsules

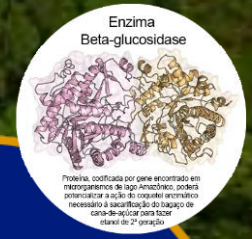
Inputs for cosmetics and functional cosmetics

Functional and nutraceutical food, exquisite flavors, unique to the Amazon

$1 billion
Direct value to Brazilian Amazon economy

Molecules and active ingredient for allopathic and herbal medicines

$4,000/g
Surucucu snake poison



Specialized molecules and enzimes for industrial processes and bioenergy

Increases by 50% in the ethanol production

ARE THERE WAYS TO UTILIZE AMAZON BIODIVERSITY SUSTAINABLY?

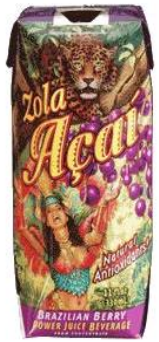
THE GLOBAL EMERGENCE OF AÇAÍ BERRY

ARE THERE WAYS TO UTILIZE AMAZON BIODIVERSITY SUSTAINABLY?

The Açaí Berry Case

Direct Economic Value of Açaí
over 250,000 tons/year
over US$ 1 billion/year to Amazon economy

Tens of products derived from açaí berry reaching global markets



New uses: natural marker for plaque

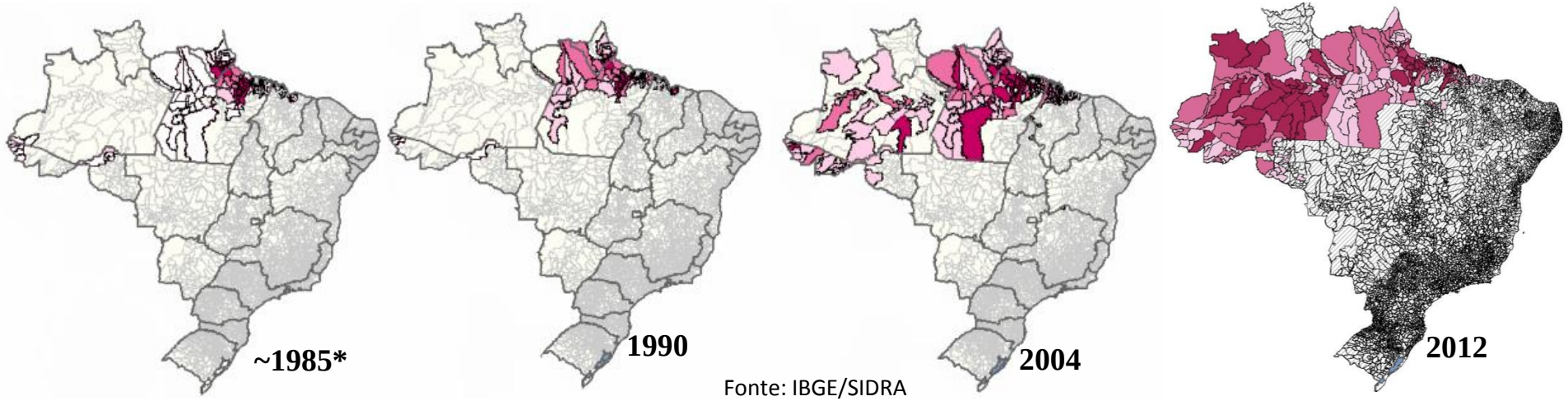
Net Profitability from Açaí Production in the Amazon
Pará State: US$ 200 ha/year (unmanaged) to over US$ 1,500 ha/year (managed)

Jardim and Anderson (1987)
Hiraoka (1994a, 1994b)
Brondizio, E. (2007)
Costa F (2017)

Açaí berry: small scale management to larger scale agroforestry systems benefiting over 300,000 people

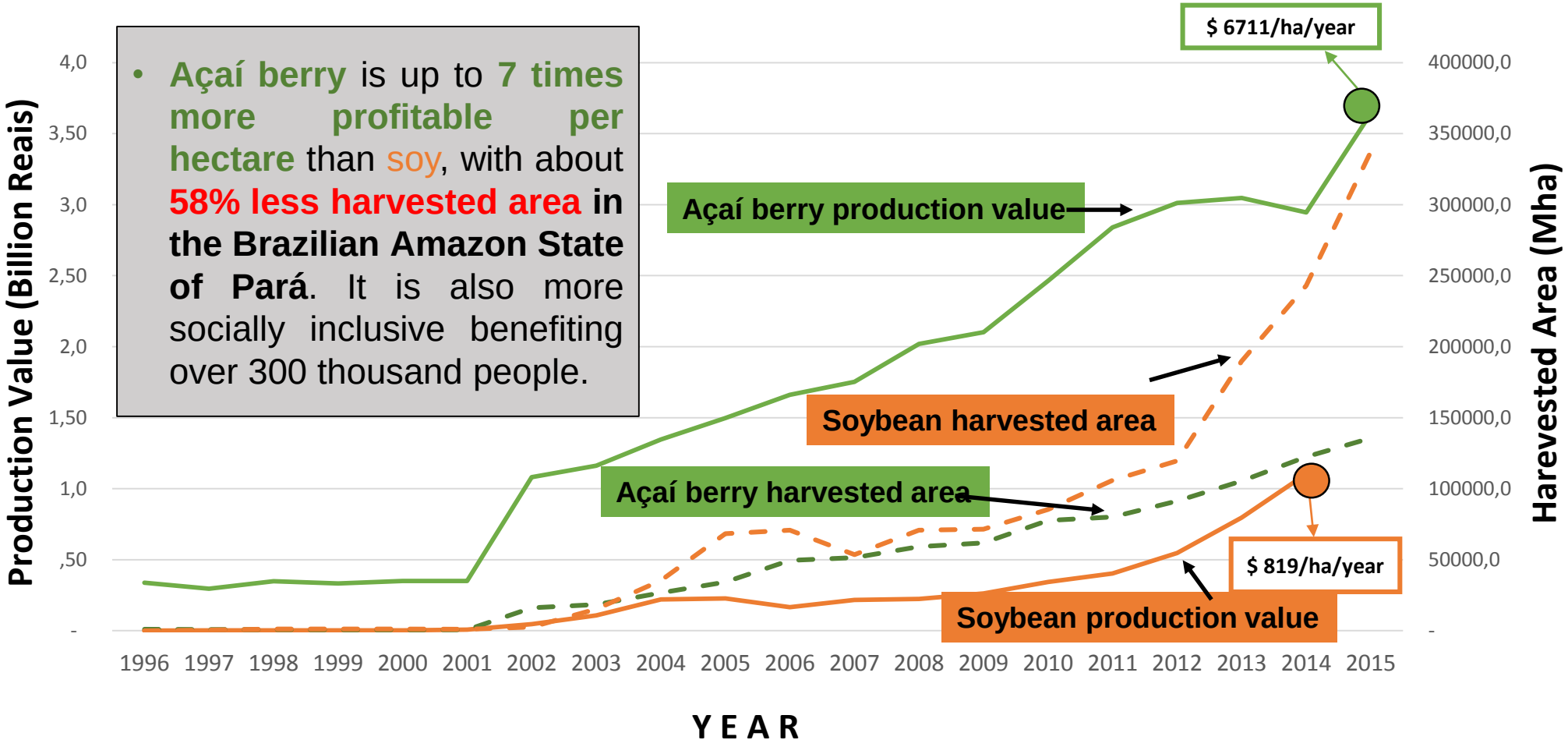
Expansion of Açaí berry production - 1985 a 2012

Brondizio 2008; 2013



Fonte: IBGE/SIDRA

Soybean versus Açaí in Pará State, Brazil



Rajão et al, Federal University of Minas Gerais, Brazil, 2019

Comparison of traditional agriculture (meat + soy) versus products from biodiversity (açaí berry + cocoa + Brazil nuts) in 6 Amazonian states (Pará, Rondônia, Amazonas, Acre, Roraima, Amapá)

Meat + Soy

Value = R$ 14.5 billion/year

Area = 240.000 km^2

Açaí Berry + Cocoa + Brazil Nuts

Value = R$ 7.4 billion/year

Area = 4.000 km^2 in agroforestry systems + extractivism

Fonte: SIDRA/IBGE / PEVS, 2019

“To tip transformative change in social-ecological systems in a desirable direction” T. Lenton
The urgent need of a Great Acceleration of disruptive solutions

SOLUTION SPACE FOR THE A M A Z O N

Pillars of a Standing Forests, Flowing Rivers Biodiversity-Driven Bio-economy

- Harnessing Biological and Biomimetic Assets Sustainably with Modern Technologies
- Equitably Valuing Traditional Knowledge
- Socially-inclusive, Ecologically-sound Development
- Equitable and Fair Sharing of Benefits
- A range of applications from value chains of non-timber biodiversity products to high-end genetic resources

AMAZONIA 4.0

The Amazonia Third Way Initiative

- (1) the recognition of existing Natural knowledge/technology;
- (2) the ability for learning from Nature;
- (3) the capacity to applying biodiversity-based knowledge to human needs;
- (4) the capacity to producing biodiversity-based goods and solutions;
- (5) the insertion of biodiversity-originated products on a local-to-global bio economy;
- (6) the fair sharing of socioeconomic benefits and life quality improvement for all; and
- (7) the raising of the Amazon Biome's intrinsic value by local and global societies.

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BRAZILIAN AMAZON LOCALITIES

Locations in all Municipalities of the States of the Legal Amazon

Data source: IBGE
Image: Google

BRAZILIAN AMAZON LOCALITIES

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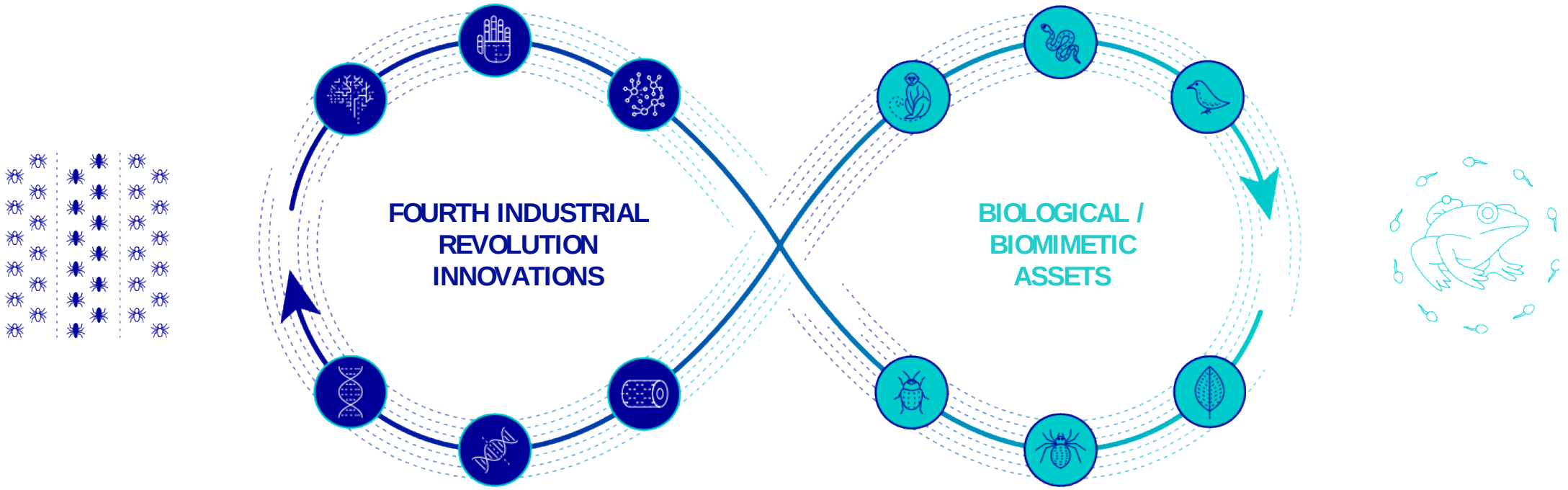
4,438 BRAZILIAN AMAZON LOCALITIES

THE AMAZON THIRD WAY COMBINES THE WORLD OF BIOLOGICAL/BIOMIMETIC ASSETS WITH ADVANCED TECHNOLOGIES IN A VIRTUOUS CIRCLE

AMAZONIA 4.0

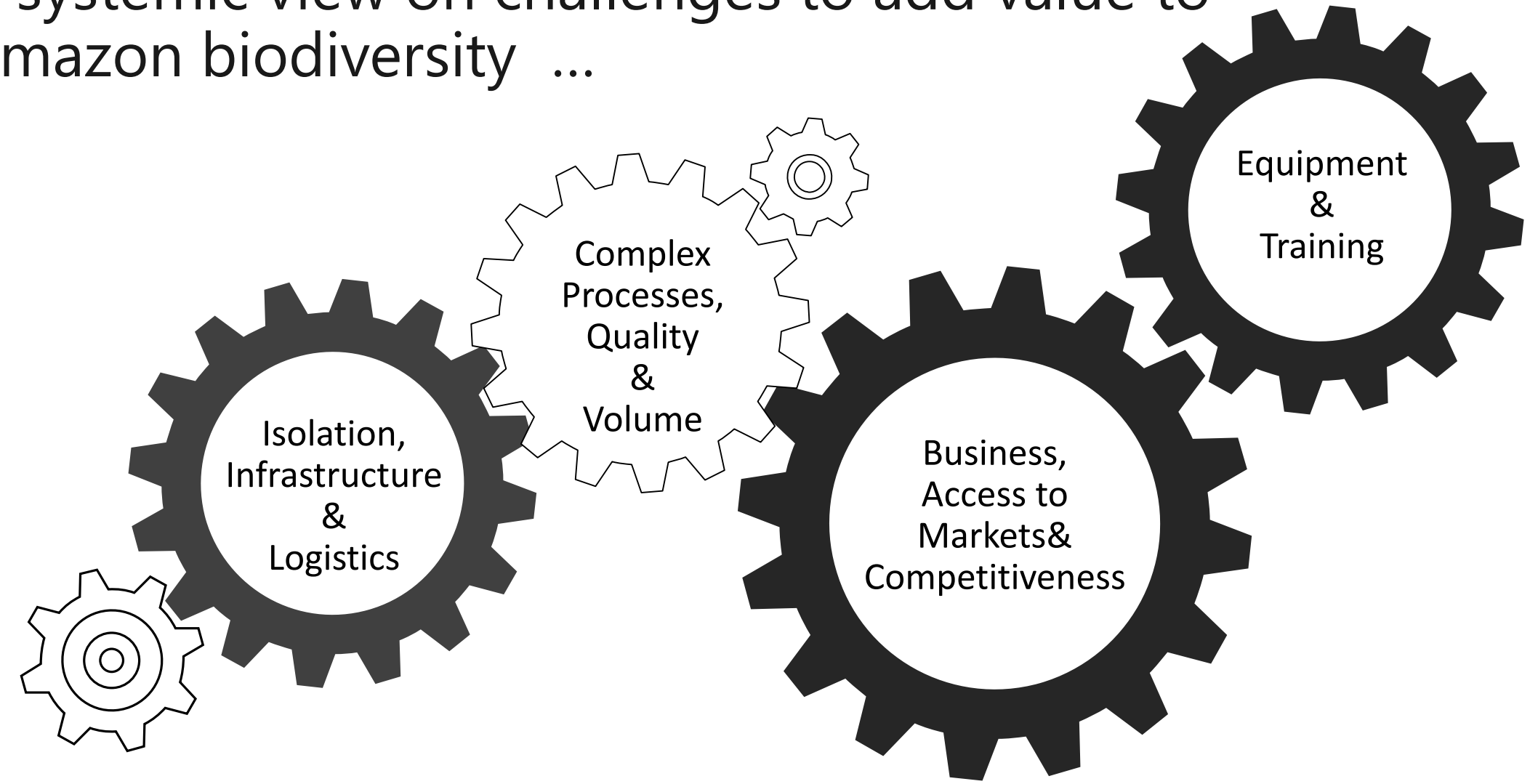


Learning from *biomimetic assets* to develop new advanced technology platforms

Developing new products, solutions and platforms leveraging *biological assets*

APPLYING THE 21ST CENTURY PARADIGM OF KNOWLEDGE SOCIATIES TO THE AMAZON

A systemic view on challenges to add value to Amazon biodiversity …



… in the hinterlands of the Amazon

The Amazon
Third Way
Initiative

Amazonia 4.0

Capacity Development and the Amazon Creative Labs

Amazon Creative Labs*

- **Developing capacities for biodiversity-driven, inclusive socioeconomic transformations in the Amazon**
- **Transportable field laboratories** on tents or on floating platforms for innovative experimentation in smaller communities
- **Interactive fusion of traditional and scientific knowledge**
- **Co-design and co-production of knowledge**

*conceptual development phase

THEOBROMA
COCOA-CUPUAÇU

BERTHOLLETIA EXCELSA
BRAZIL NUTS

AMAZON CREATE LABS

GENOMICS

SOLUTION SPACE FOR THE AMAZON

DISRUPTIVE SYSTEMS-SHIFTING FOR TROPICAL FORESTS

HARNESSING BIOLOGICAL AND BIOMIMETIC ASSETS USING FOURTH INDUSTRIAL REVOLUTION TECHNOLOGIES TO GENERATE LOCAL, SOCIALLY INCLUSIVE DEVELOPMENT AND PROTECTION OF ECOSYSTEMS

WE NEED A NEW SUSTAINABLE DEVELOPMENT PARADIGM FOR THE TROPICAL FORESTS

"To add value to the heart of the forest"
Bertha Becker

"Saving the heart of Mother Earth"
Davi Kopenawa

Science and technology must offer solutions for the emergence of an innovative, knowledge-based standing forest-flowing rivers economy and local bioindustries

Along with empowerment and quality, inclusive education for all the forest people

A NOVEL SUSTAINABLE DEVELOPMENT PARADIGM
FOR THE AMAZON PEOPLE, FOREST AND THE REST OF US

The A3W /Amazonia 4.0 team

Carlos A. Nobre
Ismael Nobre
Maritta Koch-Weser
Adalberto Veríssimo

Institutional Support by

Funding provided by

Thanks!
Obrigado!
¡Gracias!