L3 - AES

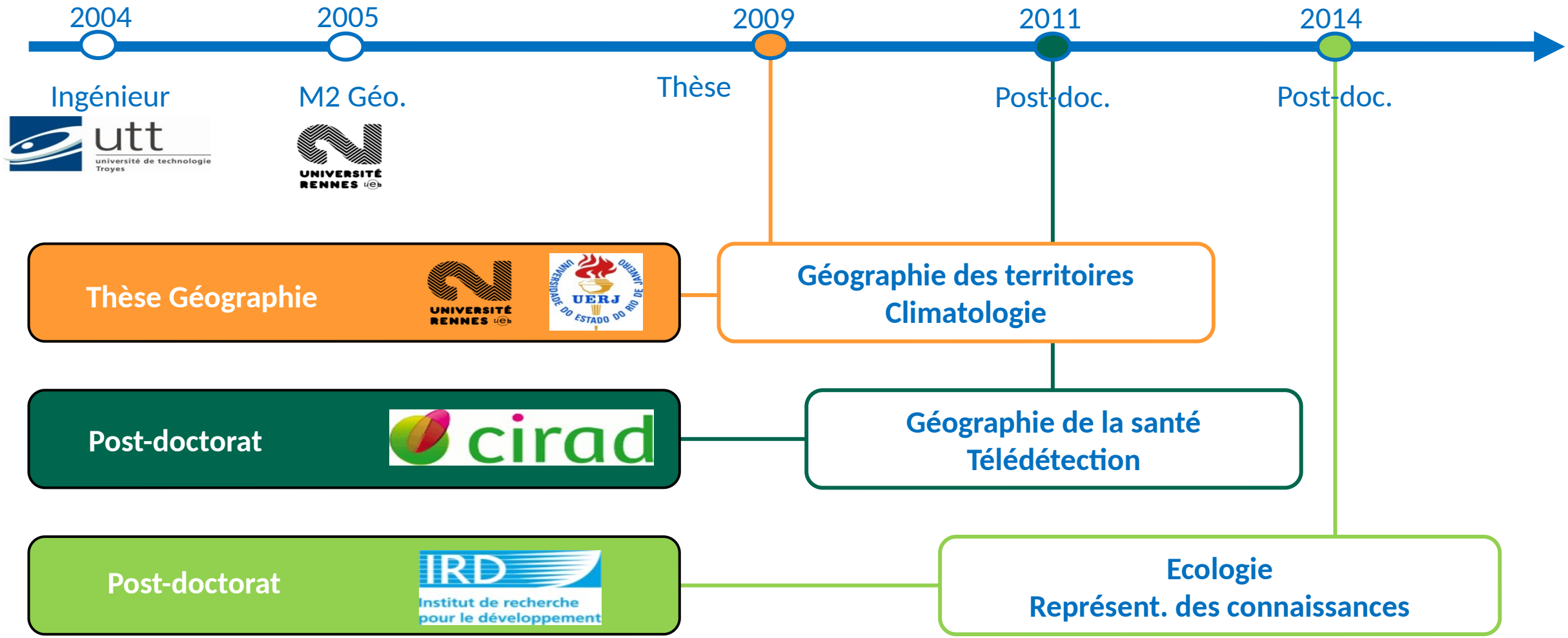
31/01/2024

Damien ARVOR

# Monitoring and understanding tropical agricultural frontiers

# Towards land use sustainability in the Brazilian Amazon ?

# Mon parcours interdisciplinaire



# Nature – Society interactions

Processes of
land occupation ?

Implications for
land use sustainability ... ?

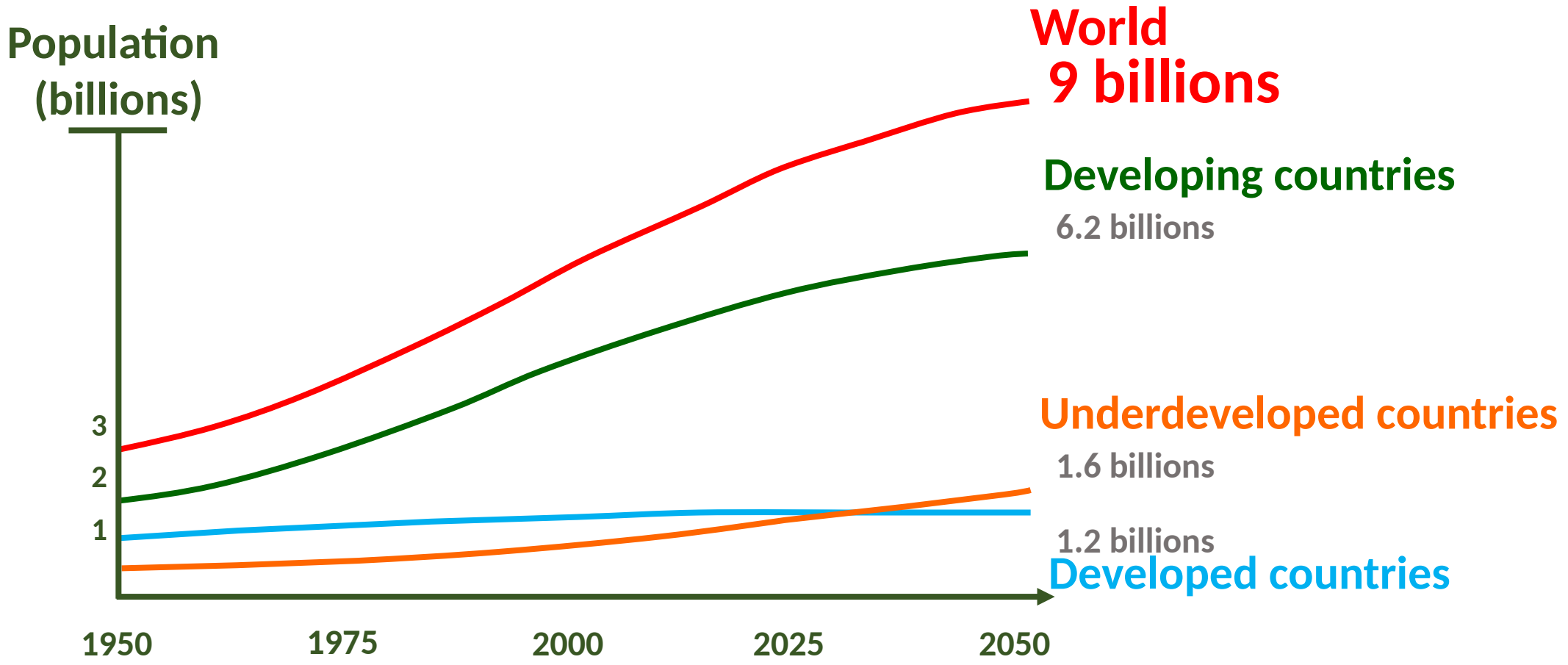
... in a
climate change context ?

Monitoring of socio-
environmental dynamics ?

Geography

Remote Sensing

# Need to feed a growing population

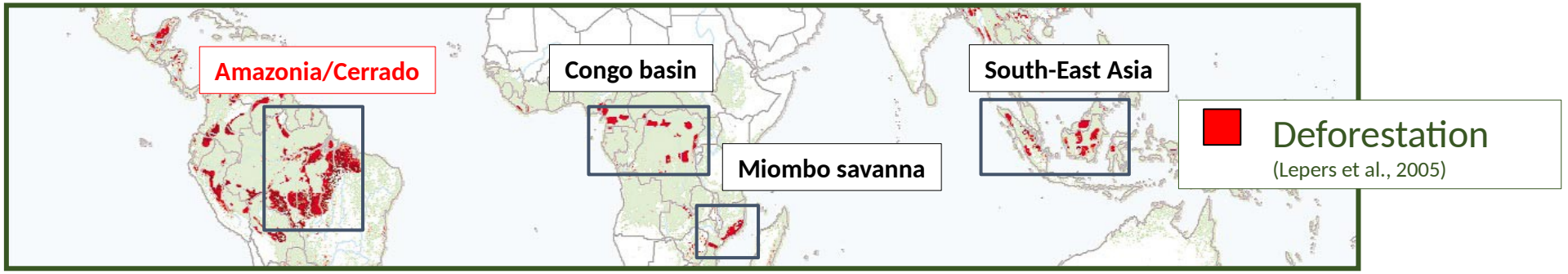



*van der Mensbrugghe et al. (2009)*

**The importance of tropical regions**

# Agricultural expansion: a driver of deforestation

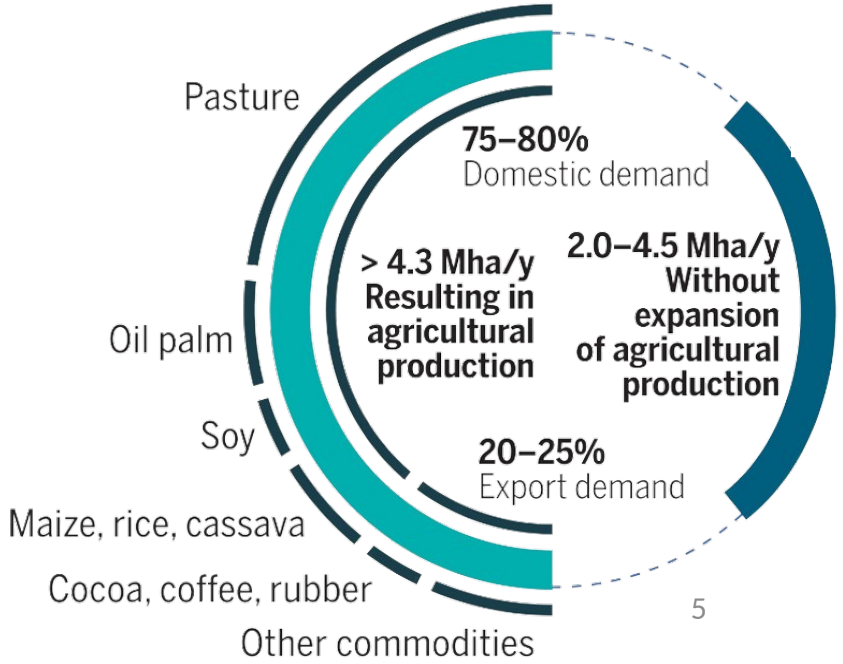
**Deforestation**




- 90 to 99% of deforestation => in agricultural landscapes
- 50% of deforestation => pasture expansion
- 20% of deforestation => soy + oil palm

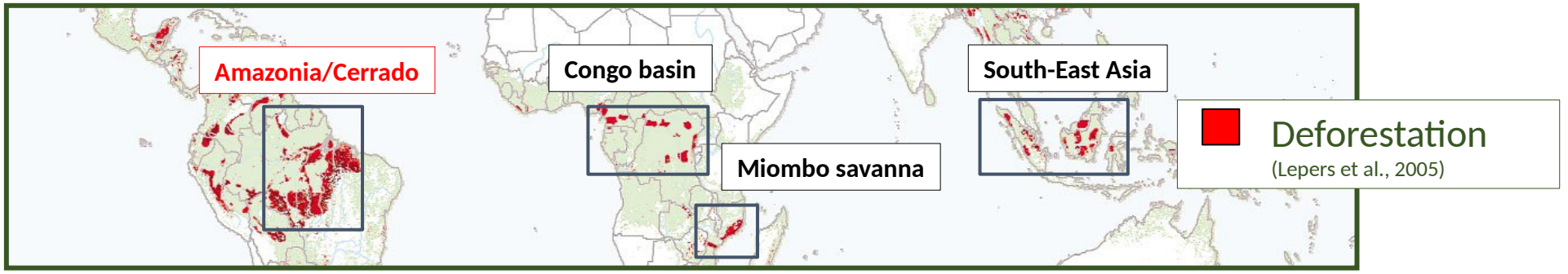
*Pendrill et al. (2022)*

**Agriculture-driven deforestation**

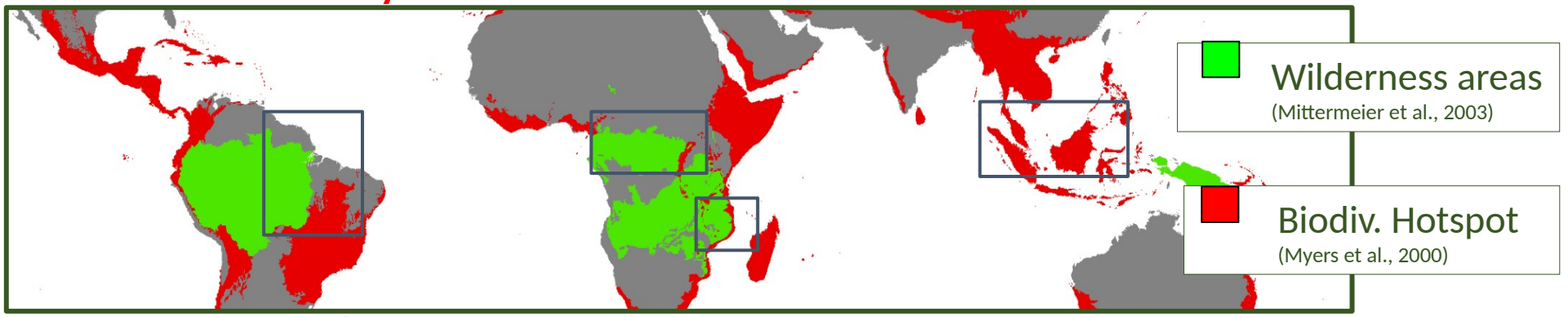


# Agricultural expansion: a driver of deforestation

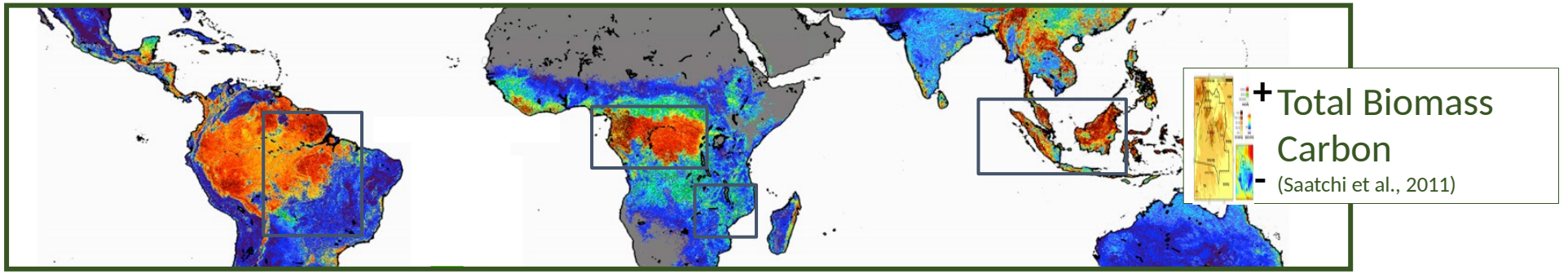
## Deforestation




## Threat to biodiversity

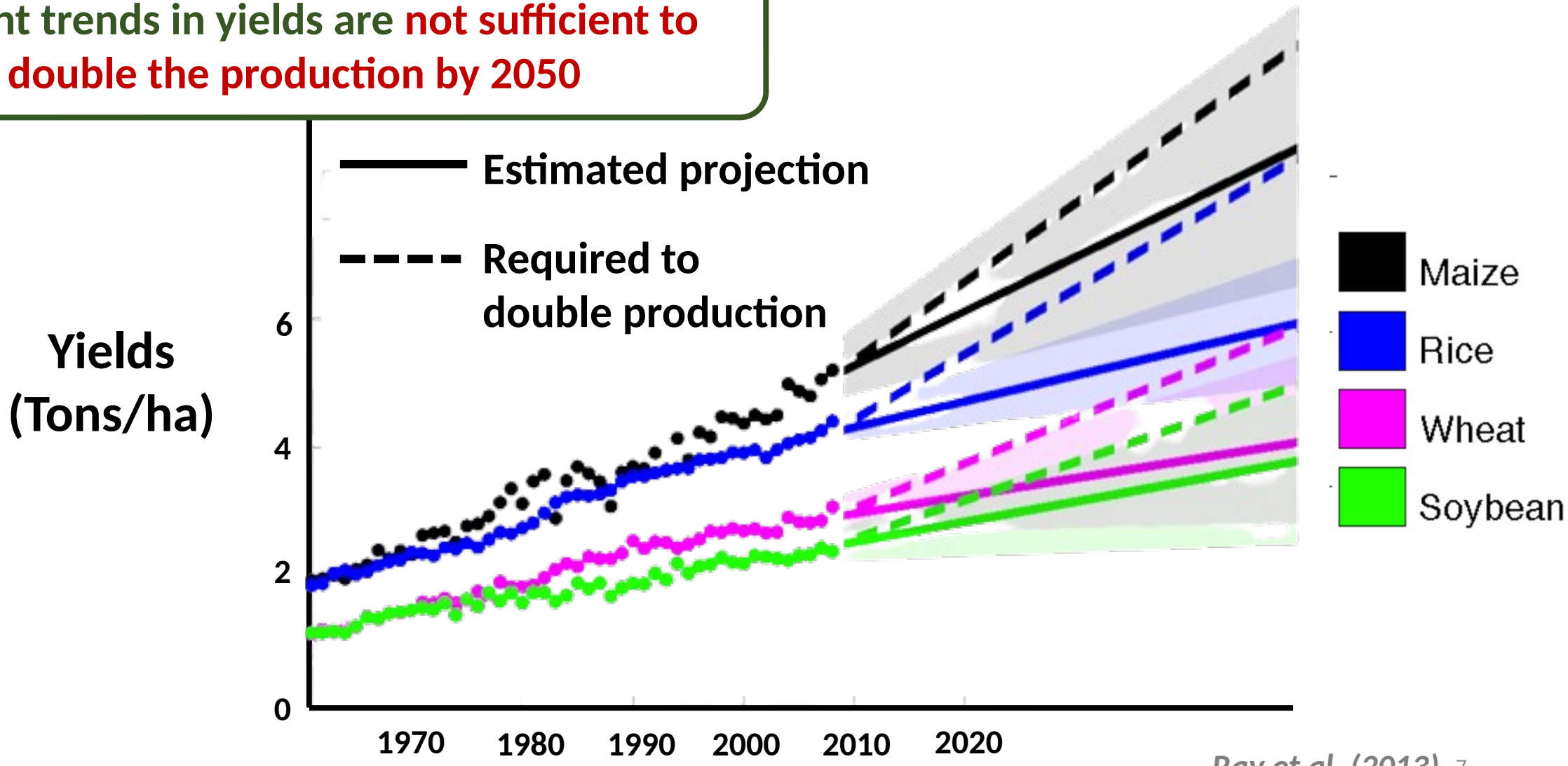



## Driver of climate change



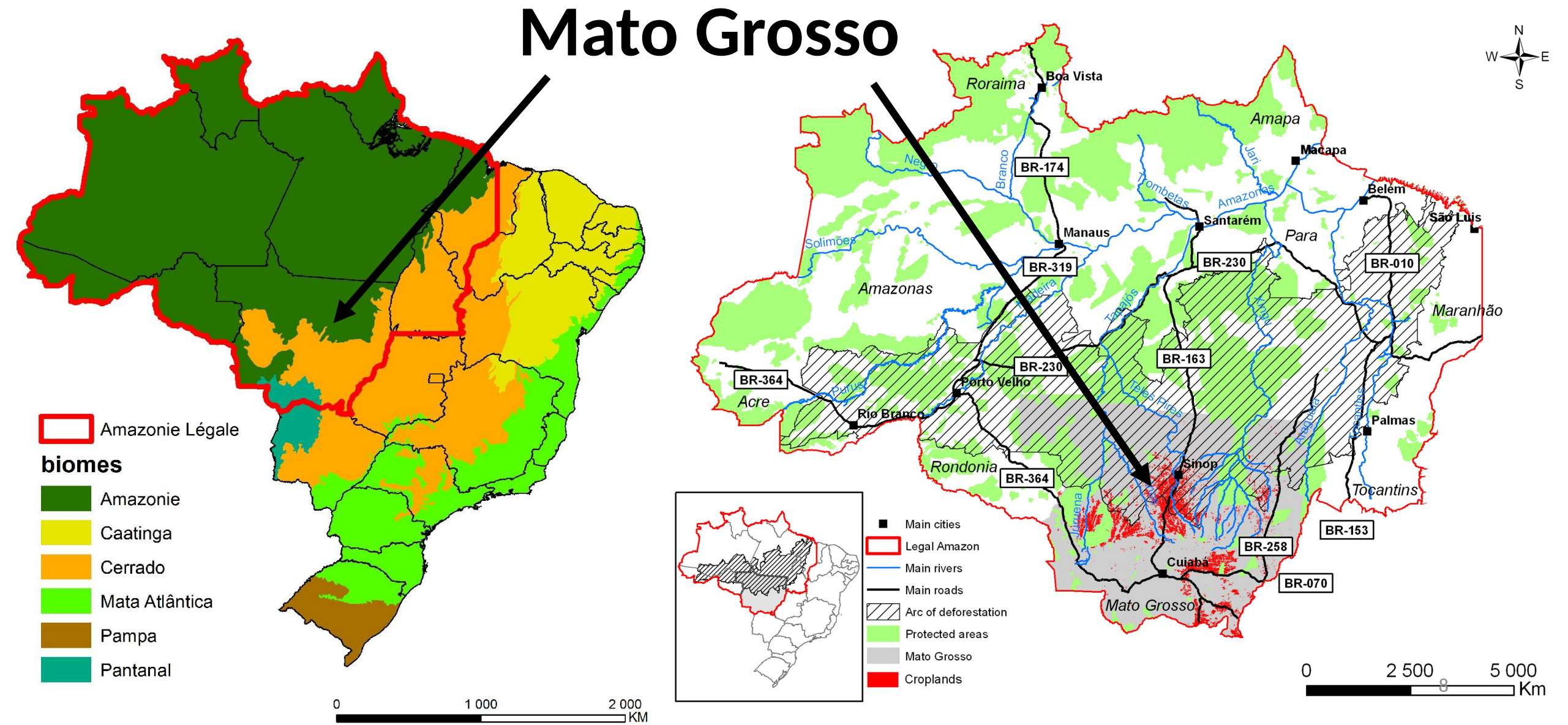
# Agricultural intensification

Current trends in yields are **not sufficient to double the production by 2050**




*Ray et al. (2013)*

# The Southern Amazon agricultural frontier

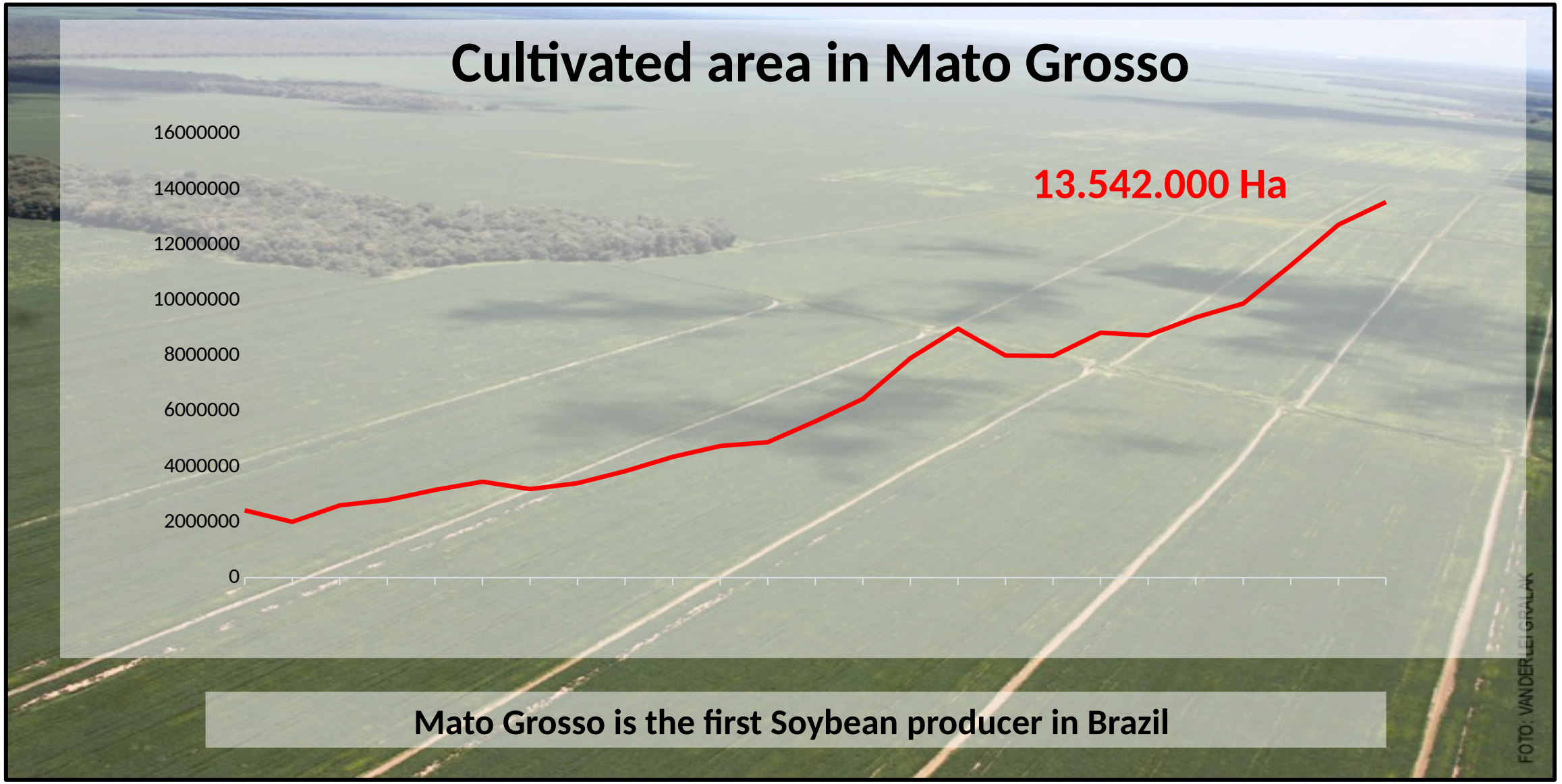


# The Southern Amazon agricultural frontier

## since the 1980 - 1990s

# The Southern Amazon agricultural frontier

## since the 1980 - 1990s



# The Southern Amazon agricultural frontier

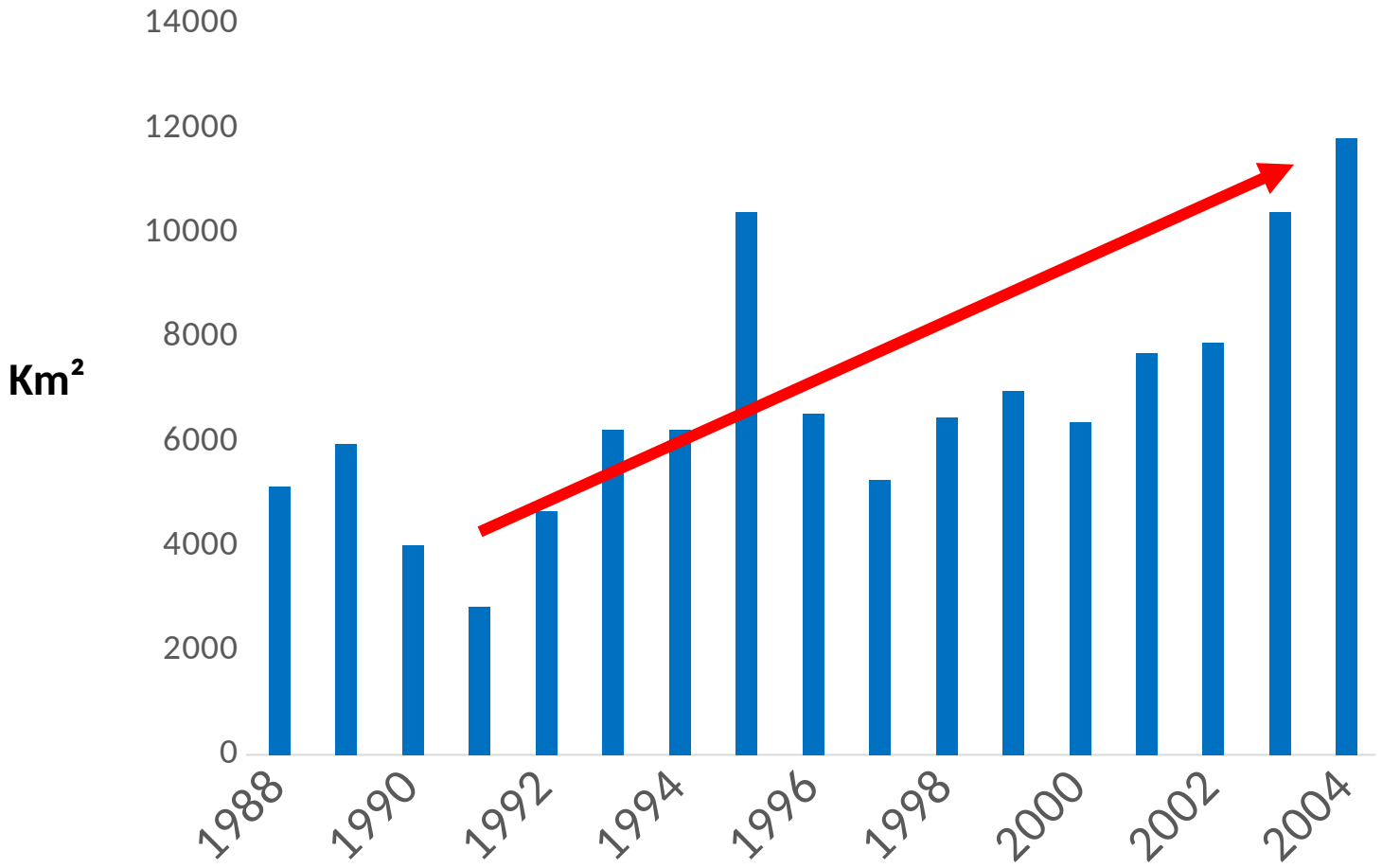
## Since the 2000s

# The Southern Amazon agricultural frontier

## Agriculture : a driver of deforestation

# The Southern Amazon agricultural frontier

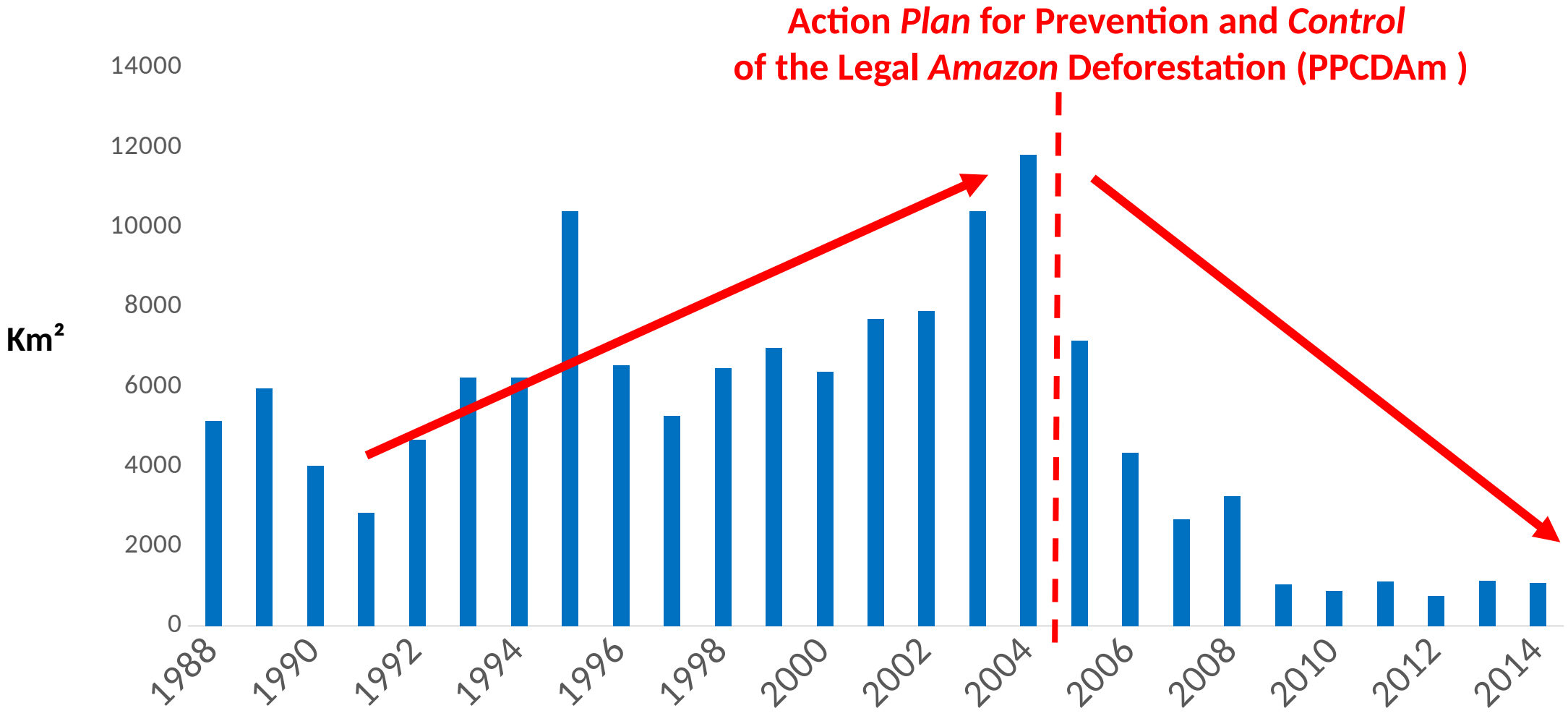
## Agriculture : a driver of deforestation




**Deforested area in Mato Grosso until 2004 (in km²)**

## High pressure on forest resources

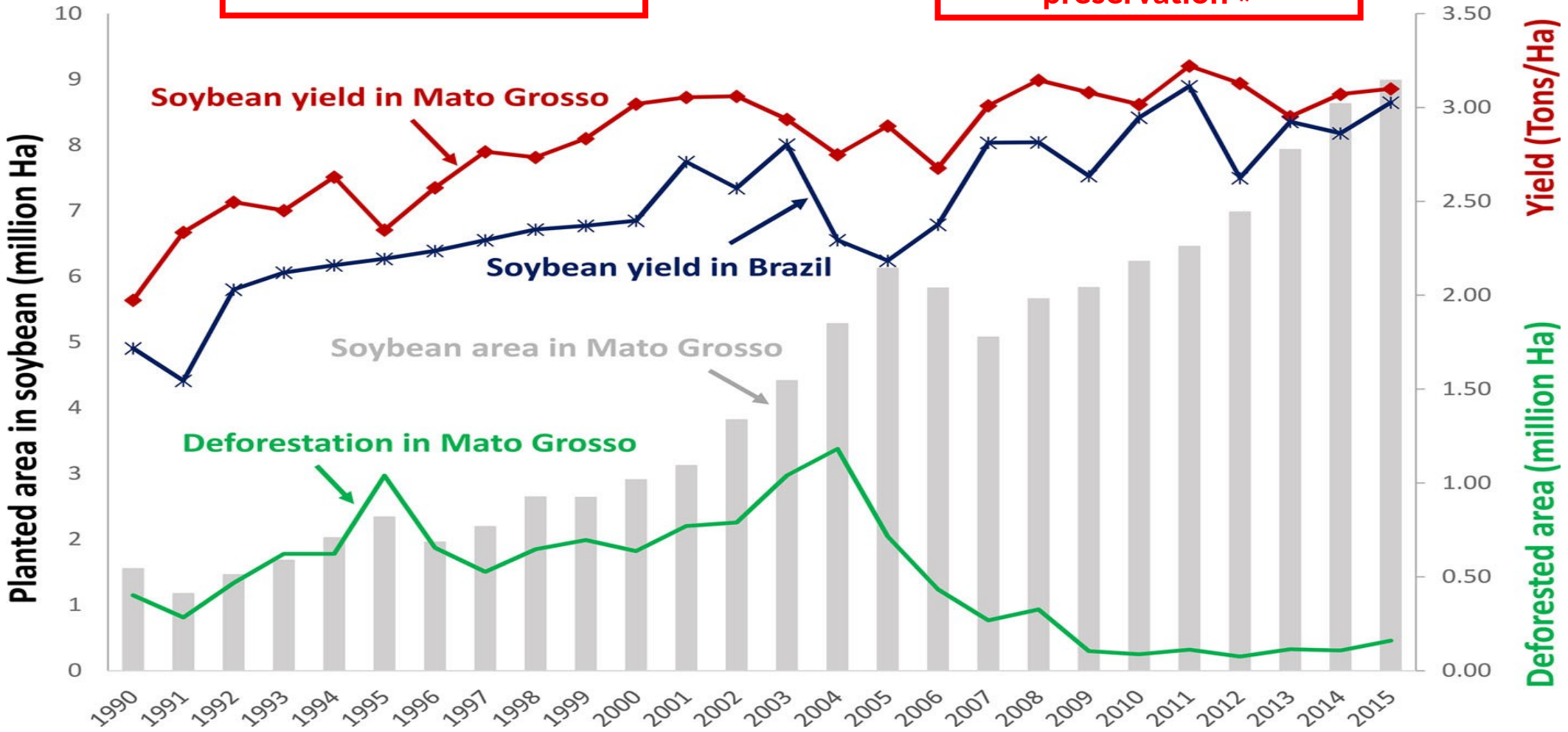
# The Southern Amazon agricultural frontier




**Decreased pressure on forest resources after 2005**

# The Southern Amazon agricultural frontier

**Agricultural growth = Environmental destruction** → **Agricultural growth AND « Environmental preservation »**



# Main research questions

| | |
|---|---|
| Processes of land occupation ? | → Focus on tropical agricultural frontiers |
| Implications for land use sustainability ... ? | → Sustainability on the Amazon frontier |
| ... in a climate change context ? | → Climate variability / change in the Amazon |
| Monitoring of socio-environmental dynamics ? | → Remote sensing: more than a data science |

# Focus on tropical agricultural frontiers


Lucas do Rio Verde

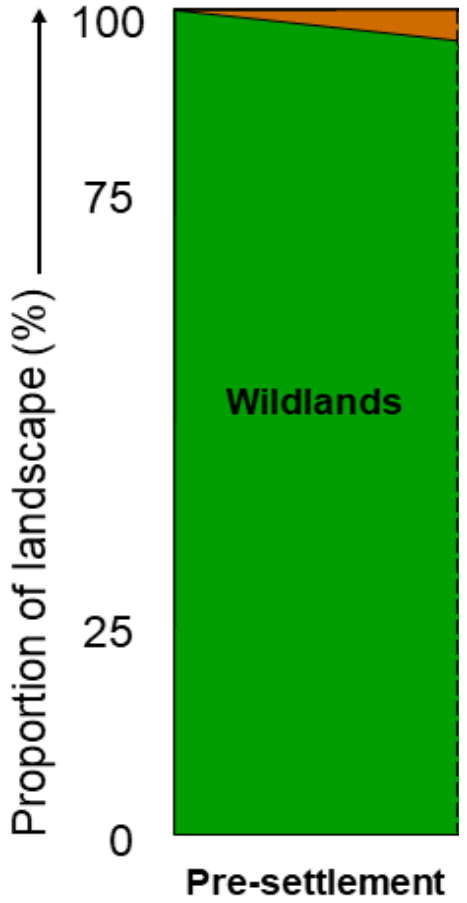

Guarantã do Norte

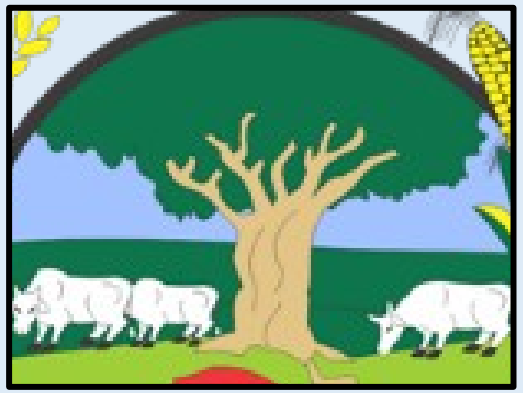
Peixoto de Azevedo


Cotriguaçu

# Conceptual framework

## Pre-settlement → Wildlands...



***Guarantã***

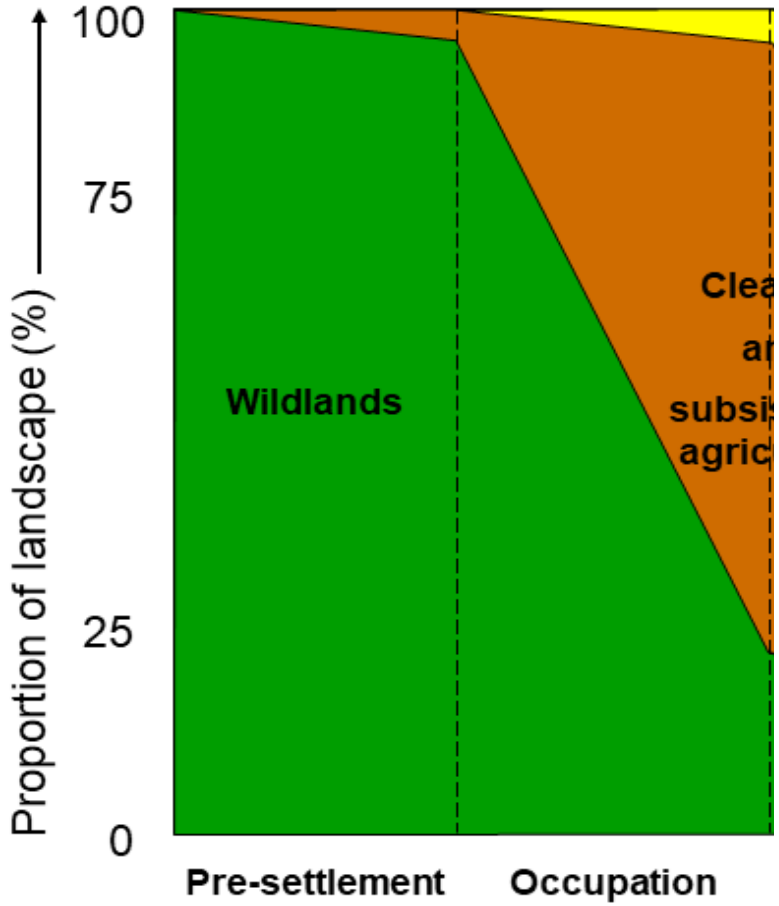
***Castanheira***

**Stages of evolution of the frontier →**

*DeFries et al. 2004*

# Conceptual framework

**Occupation** → **Clearing and subsistence agriculture**




***Café***

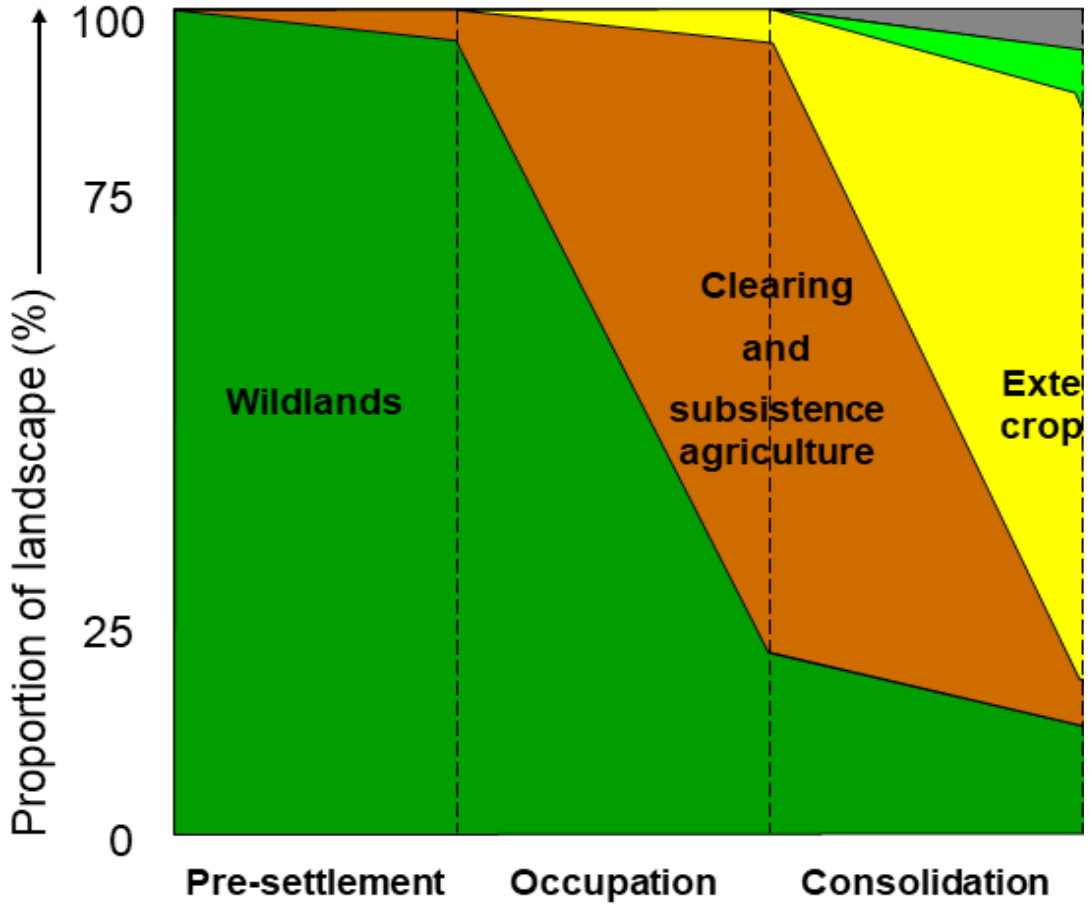
***Garimpo***

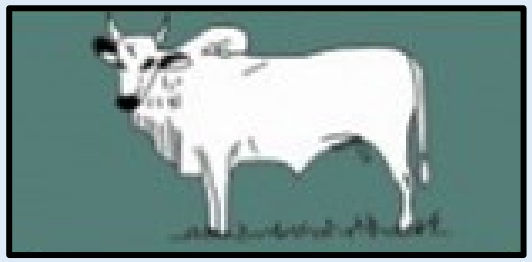
**Stages of evolution of the frontier** →

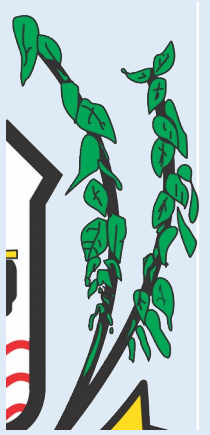
*DeFries et al. 2004*

# Conceptual framework

## Consolidation → Extensive croplands





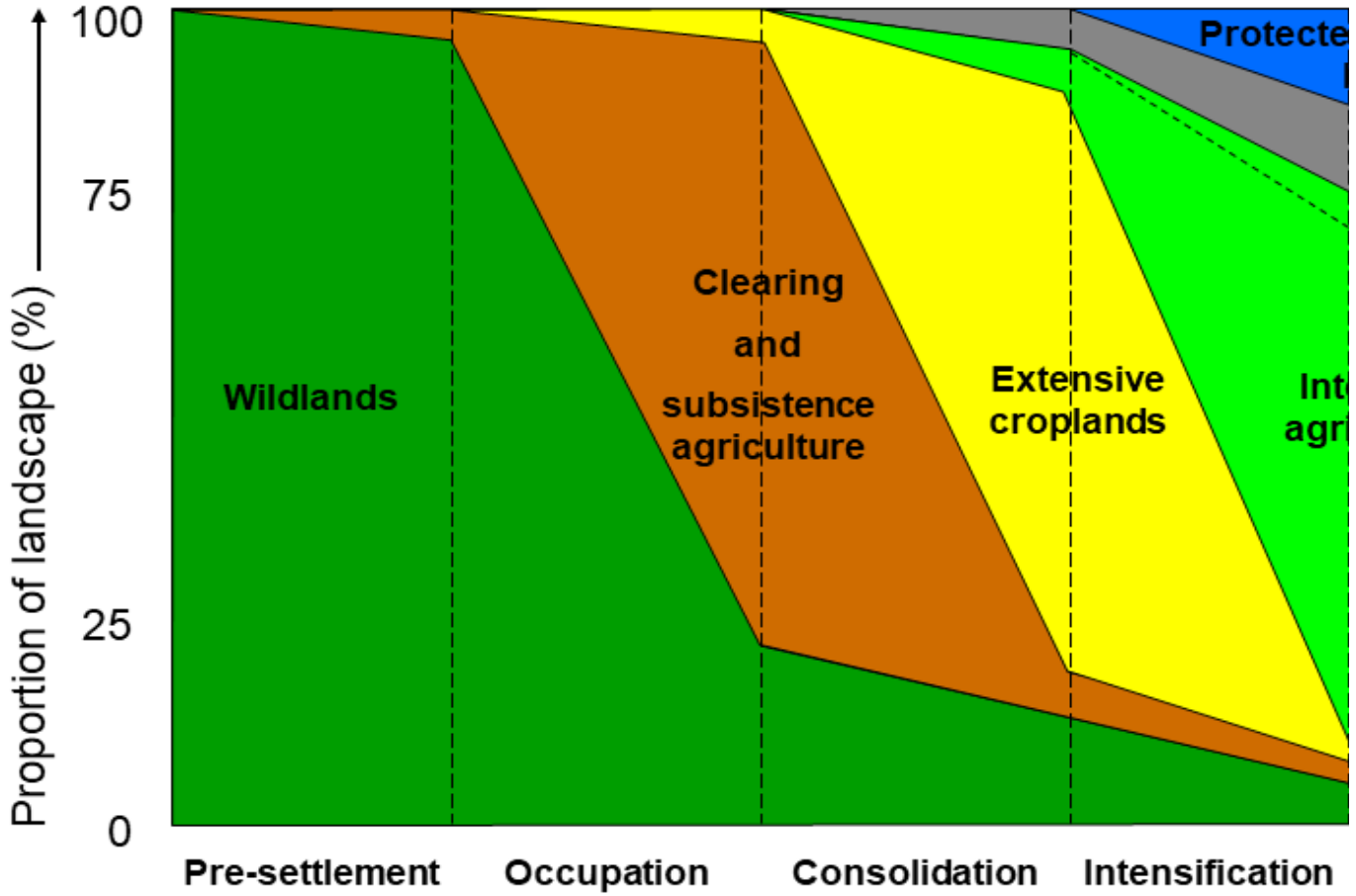
***Pecuaria*** ***Soja***

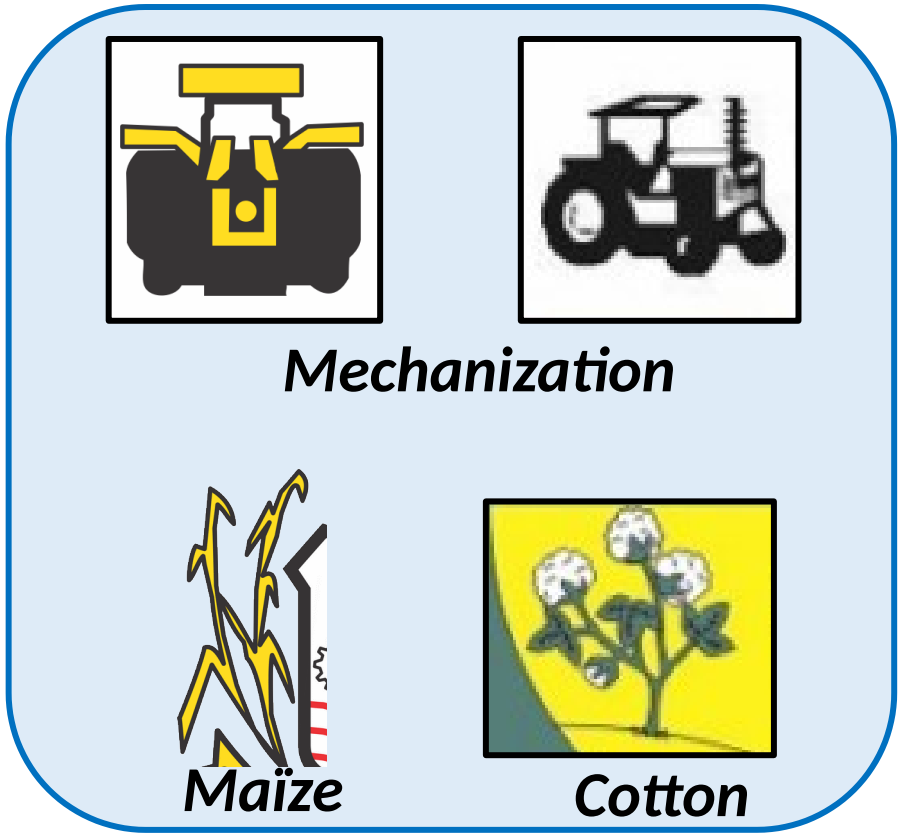
**Stages of evolution of the frontier →**

*DeFries et al. 2004*

# Conceptual framework

## Intensification → Intensive agriculture



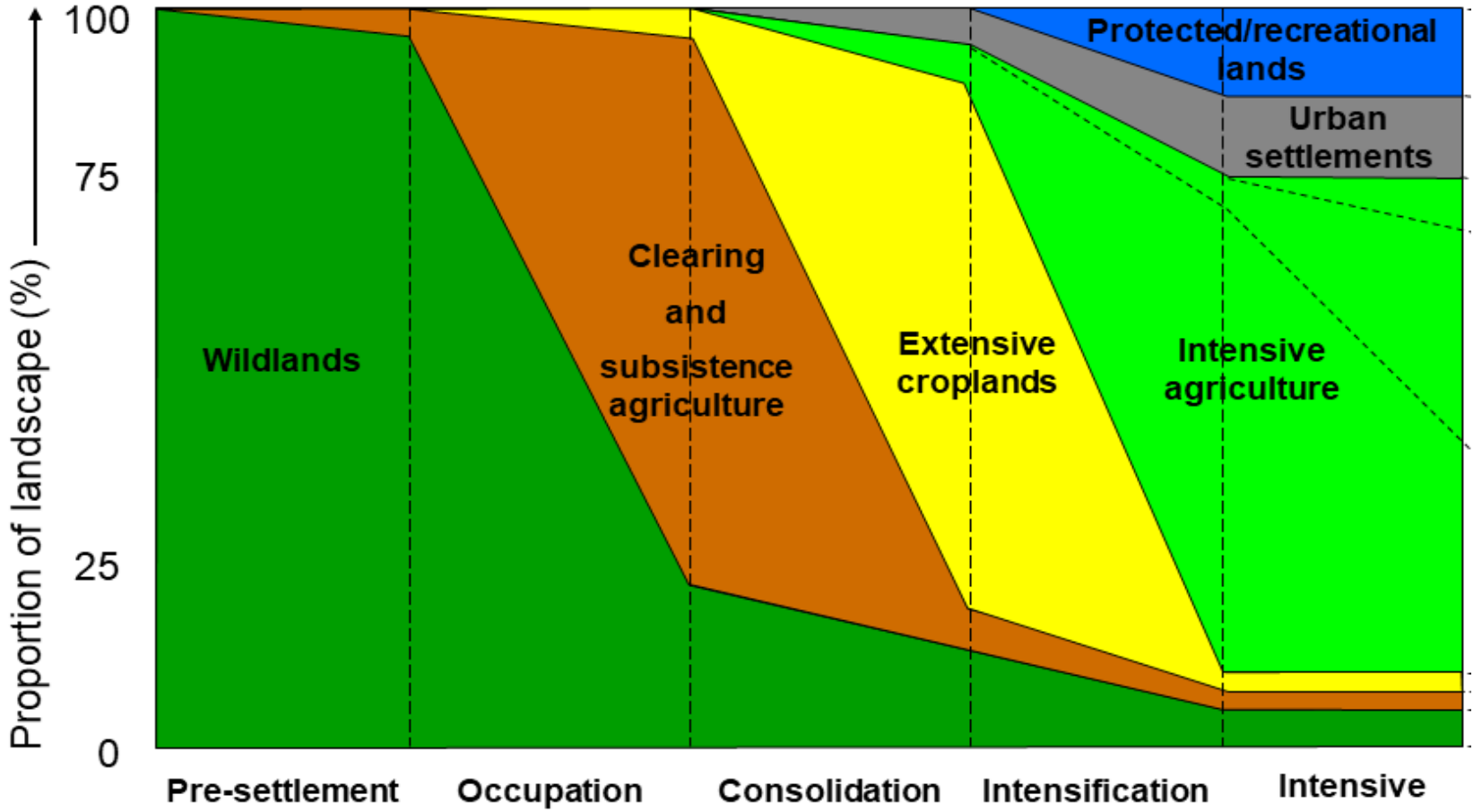




**Stages of evolution of the frontier →**

*DeFries et al. 2004*

# Conceptual framework

Intensive → Urban settlements




*Urbanization*

**Stages of evolution of the frontier** →

*DeFries et al. 2004*

# A few comments on the frontier

## 1) It does not evolve continuously

- Breaks and jumps

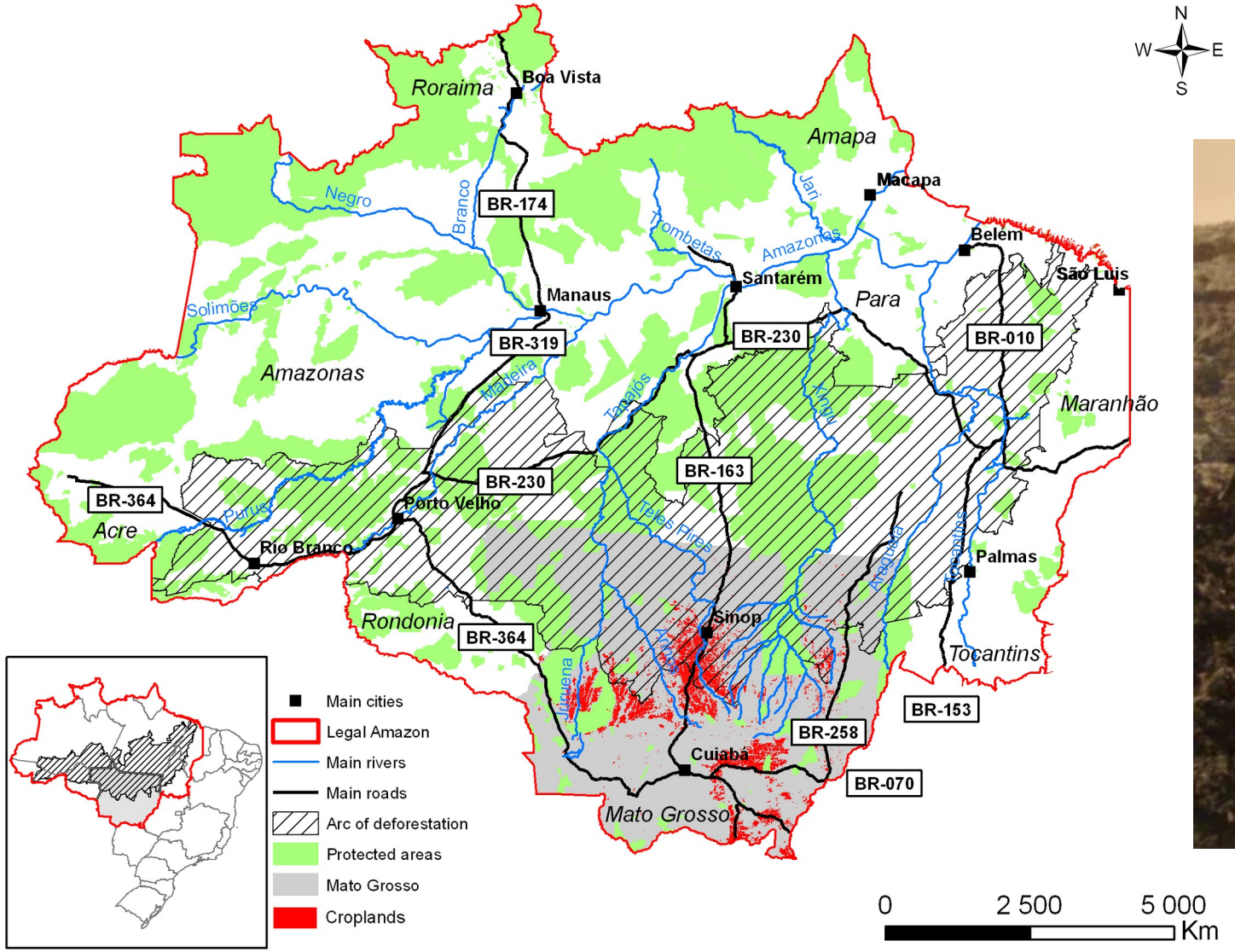
## 2) Different speed

- Thousand years in Europe
- Centuries in US
- Decades in Brazil

## 3) It can regress...

- Economic reasons
- environmental reasons
- ...

# A few illustrations




## 1970s - BR163

# A few illustrations

## 1970s - BR163

Opening Sinop's main avenue

## 2006

# A few illustrations

**Timber logging**

# A few illustrations

## Fires

## Deforestation

# A few illustrations

## Pasture

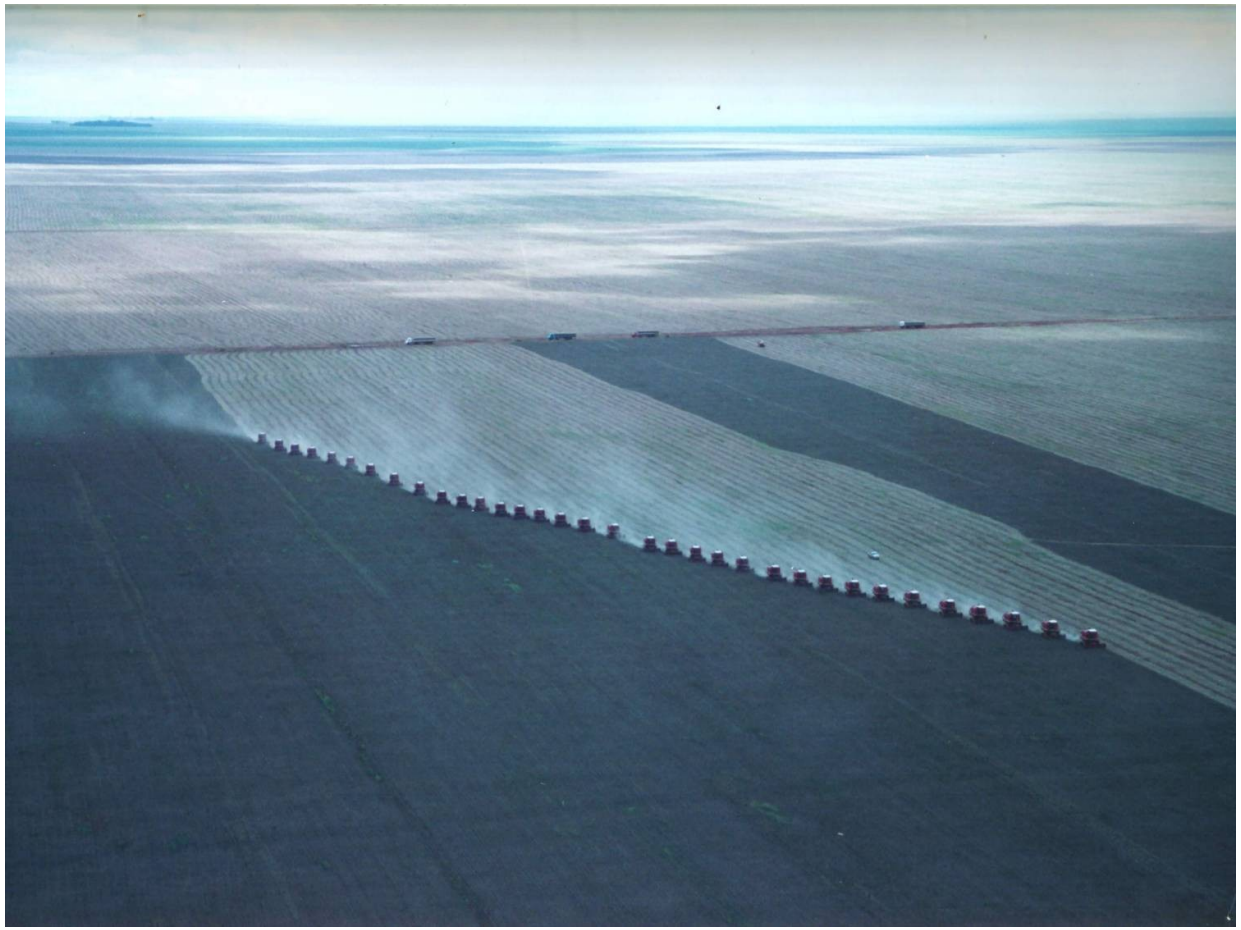
# A few illustrations

## Expansion agricole


# A few illustrations

# A few illustrations

## Intensification agricole



# A few illustrations

## Intensification agricole

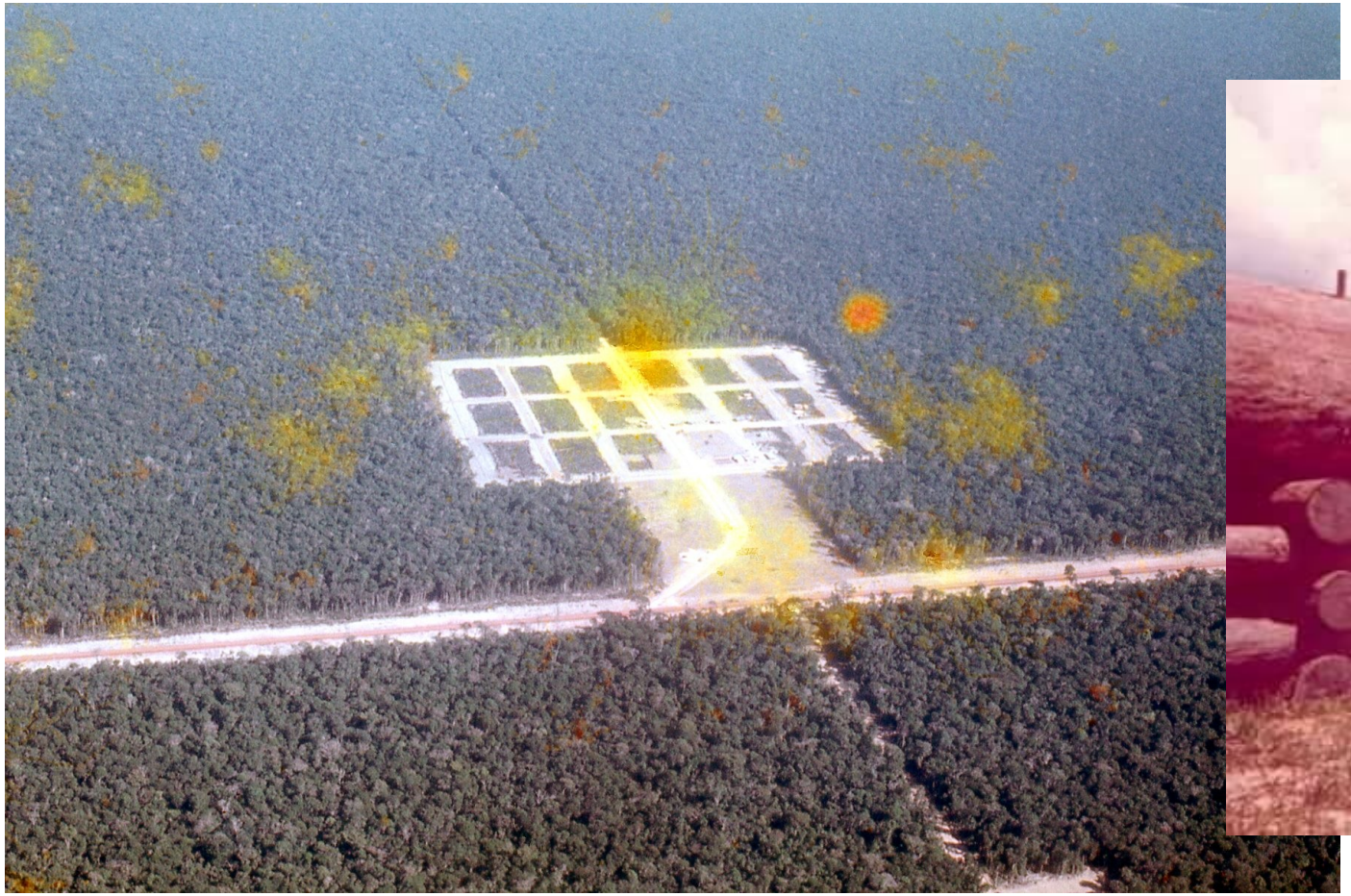
# A few illustrations

## Intensification agricole

# A few illustrations

## SINOP : Sociedade Imobiliaria do NorOeste do Parana

**1972**



# A few illustrations

## SINOP : Sociedade Imobiliaria do NorOeste do Parana

**1974**

Vista aérea de Sinop no ano de sua fundação - 1974. Acervo Luiz Erardí

**1980**

# A few illustrations

## SINOP : Sociedade Imobiliaria do NorOeste do Parana

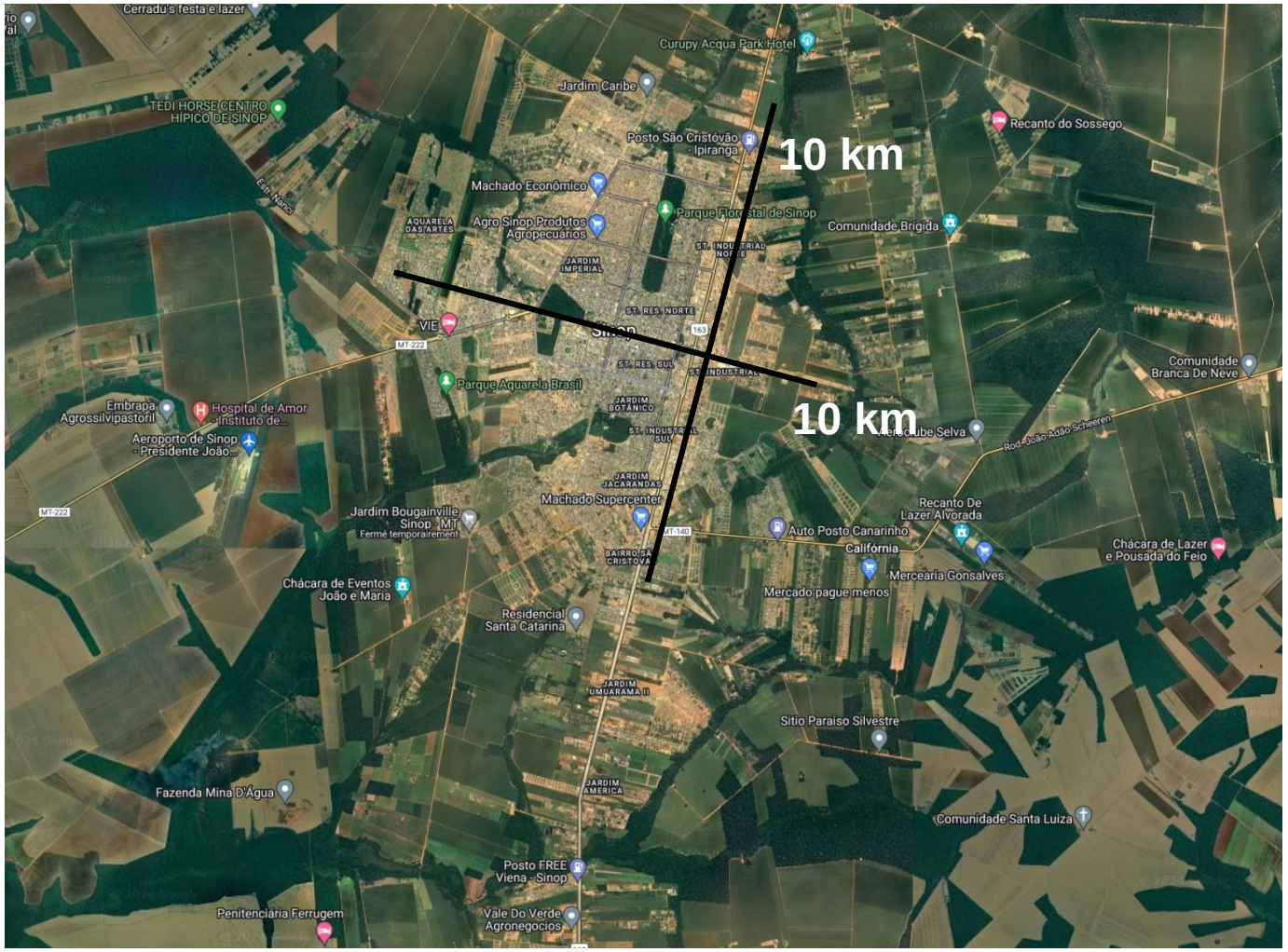
**Today**

# A few illustrations

## SINOP : Sociedade Imobiliaria do NorOeste do Parana

**Today**

**200,000 inhab.**



# A few illustrations

## Industrialisation


Lucas do Rio Verde (2006)

# A few illustrations

## Energy

### Sinop Energia (Usina Hidrelétrica Sinop)

Primeiro empreendimento hidrelétrico do Grupo EDF no Brasil, a Usina Hidrelétrica (UHE) Sinop começou sua operação em 2019, fruto da parceria entre EDF Brasil (51%), Chesf (24,5%) e Eletronorte (24,5%). Localizada em Mato Grosso, no município de Sinop, a usina tem capacidade instalada de 401,88 MW, sendo responsável pela geração de aproximadamente 50% da energia consumida no estado, o equivalente a 1,5 milhão de pessoas.

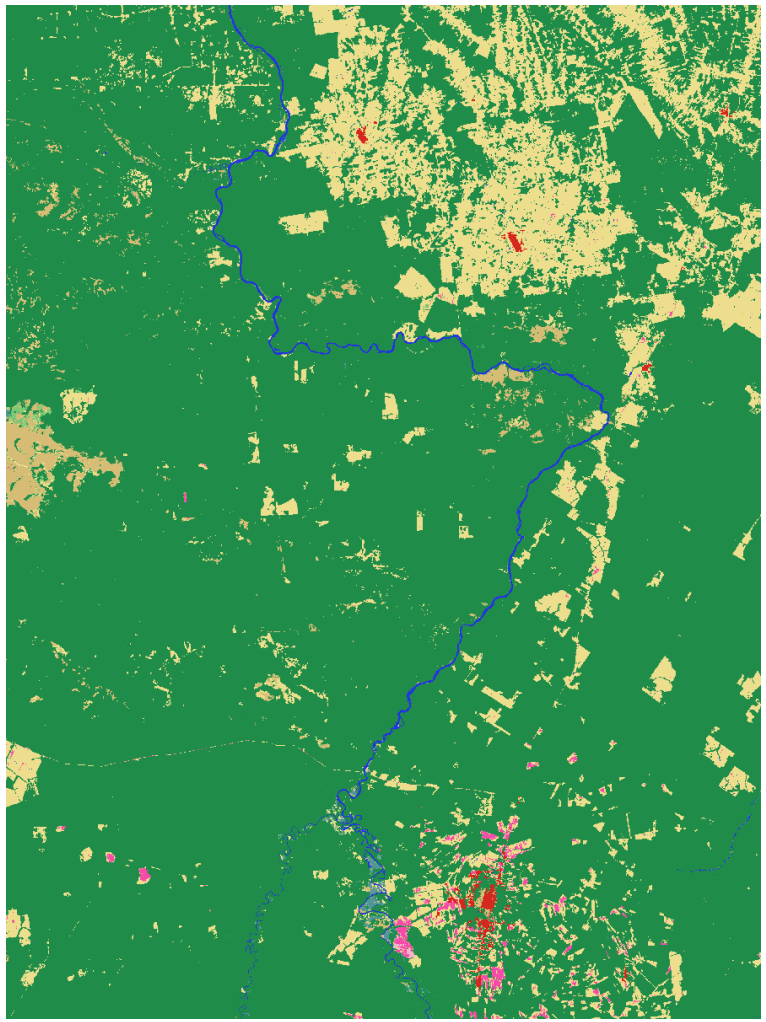
A preocupação da nossa companhia com o meio ambiente também está presente na Sinop Energia, onde são implementados sistemas de monitoramento intensivos da qualidade da água do Rio Teles Pires, um afluente do Rio Tapajós que deságua no Rio Amazonas. A medição da qualidade da água é fundamental para o negócio da UHE Sinop, com o objetivo de avaliar em tempo real o que acontece na região para reduzir eventuais impactos ambientais.

Por meio da EDF Serviços, somos responsáveis também pela operação e manutenção da UHE desde o início da operação comercial. Atualmente, a operação da usina é realizada remotamente pelo time instalado na Sala de Controle da UTE Norte Fluminense, a 2.500 km de distância.

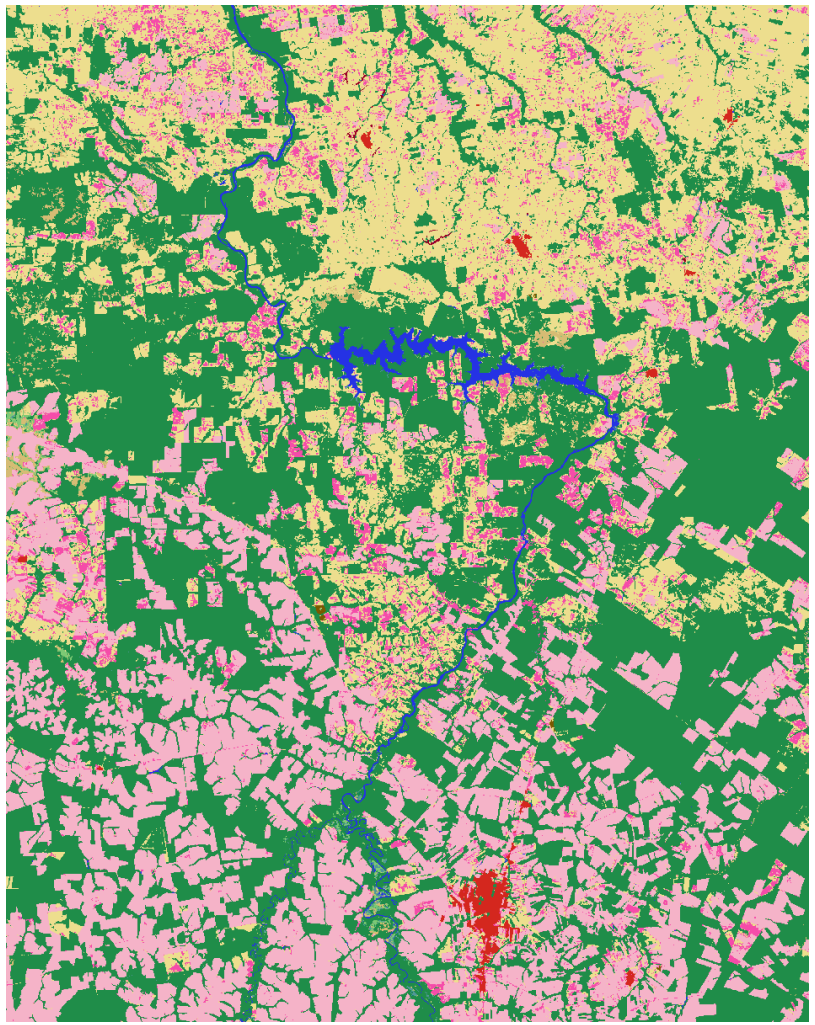
| 401,88 | 1.5 | 320 | 2019 |
|---|---|---|---|
| **MW** | **milhão** | **km²** | **out** |
| capacidade instalada | de consumidores atendidos | reservatório | início das operações |

# A few illustrations

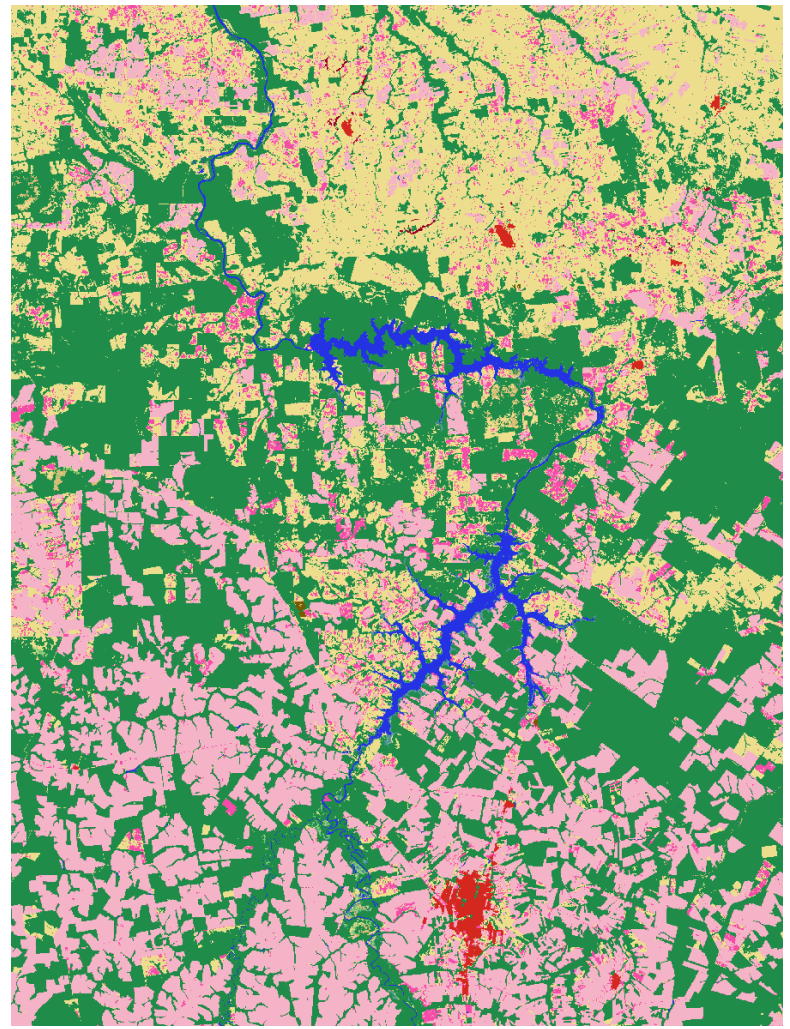
1985



2018



2022



# A few illustrations

Menu EDF EDF websites worldwide EN

## Hydroelectric

In operation since 2019, the Sinop HPP plant, EDF Brasil's first hydroelectric project in the country, after five years of construction, is capable of meeting 50% of the energy needs of the state of Mato Grosso - approximately 1.6 million people. The HPP has a reservoir of 342 km2 that borders five municipalities. The project is managed by the Brazilian company Sinop Energia, whose shareholders are EDF Norte Fluminense (51%) and the subsidiaries of Eletrobrás - Eletronorte (24.5%) and Chesf (24,5%).

Learn more about our hydropower projects

## Operating the Sinop dam remotely: a technological challenge

The Sinop Dam is operated remotely by EDF Norte Fluminense teams some 2,500km away in Macaé, Rio de Janeiro. Setting up remote operations such as these illustrates our capacity to meet complex technological challenges.

- **Project capacity:** 401.88 MW
- **Equity partner:** CHESF / Electronorte (subsidiaries of Electrobras)
- **Commissioning date:** 2019

# A few illustrations

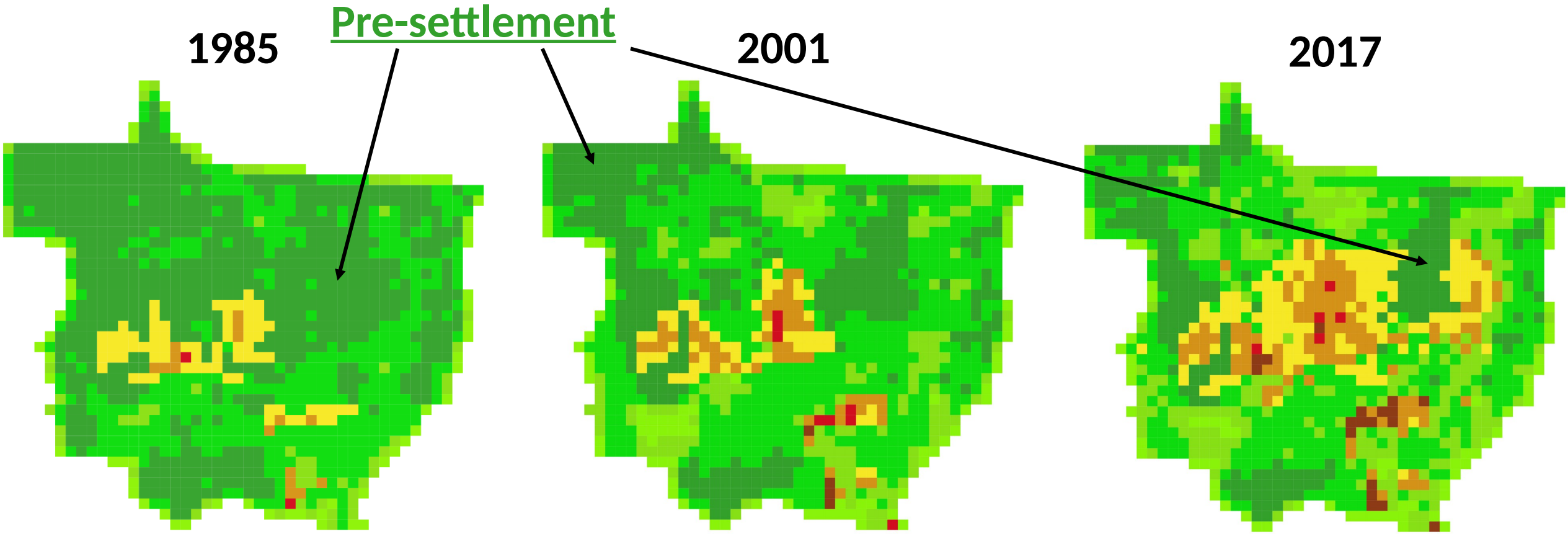
## INPASA

## Biggest ethanol plant in Latin America

# A few illustrations

## Un bon résumé

# Mapping the Mato Grosso agricultural frontier

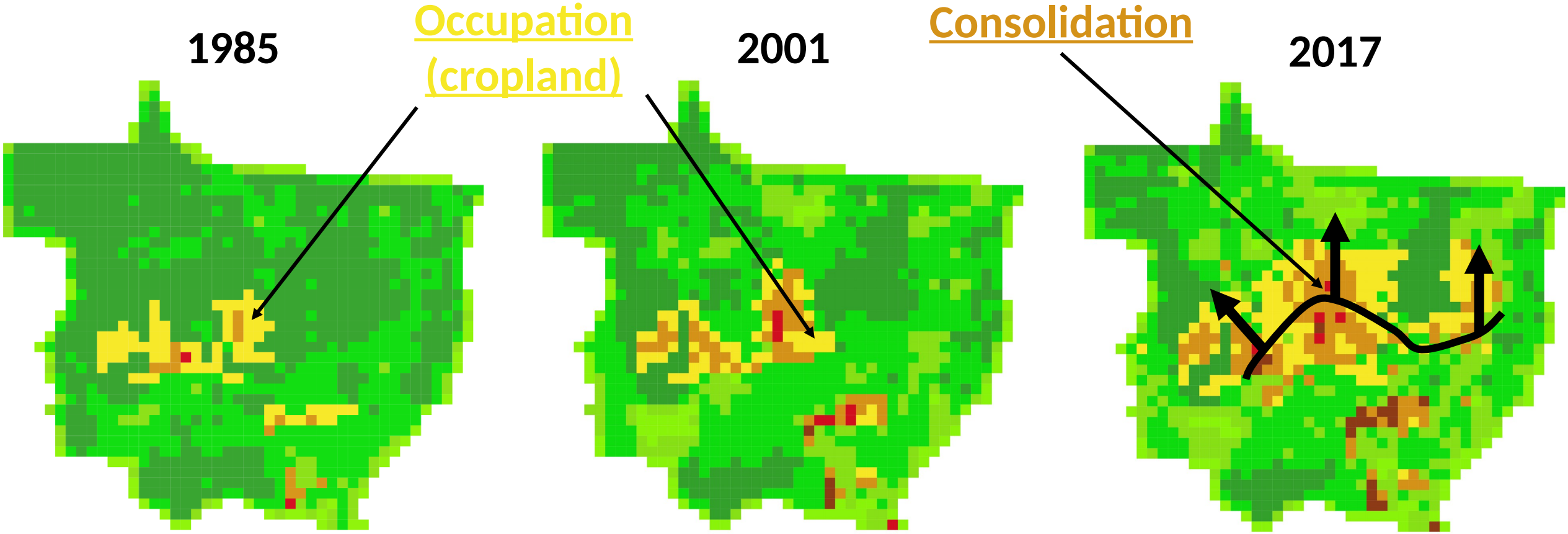



**Wildlands mainly in protected areas**



*Arvor et al. 2013*

# Mapping the Mato Grosso agricultural frontier

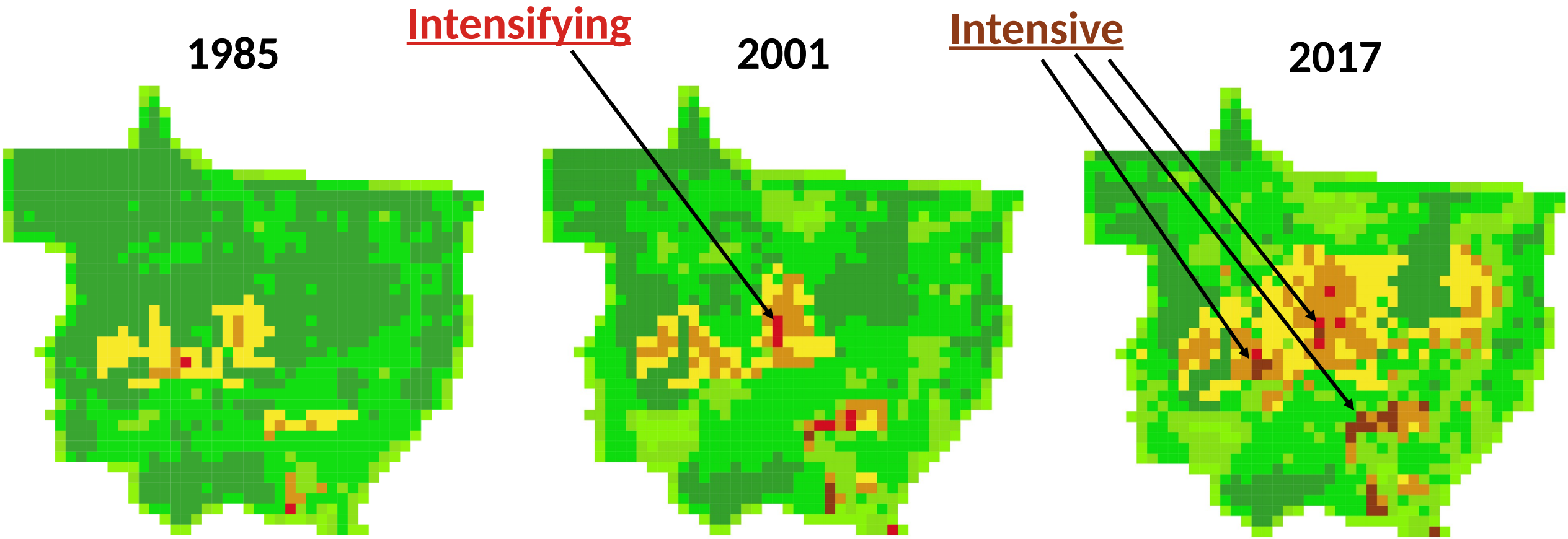



**Soybean belt at the inferface between Amazon and Cerrado**



*Arvor et al. 2013*

# Mapping the Mato Grosso agricultural frontier



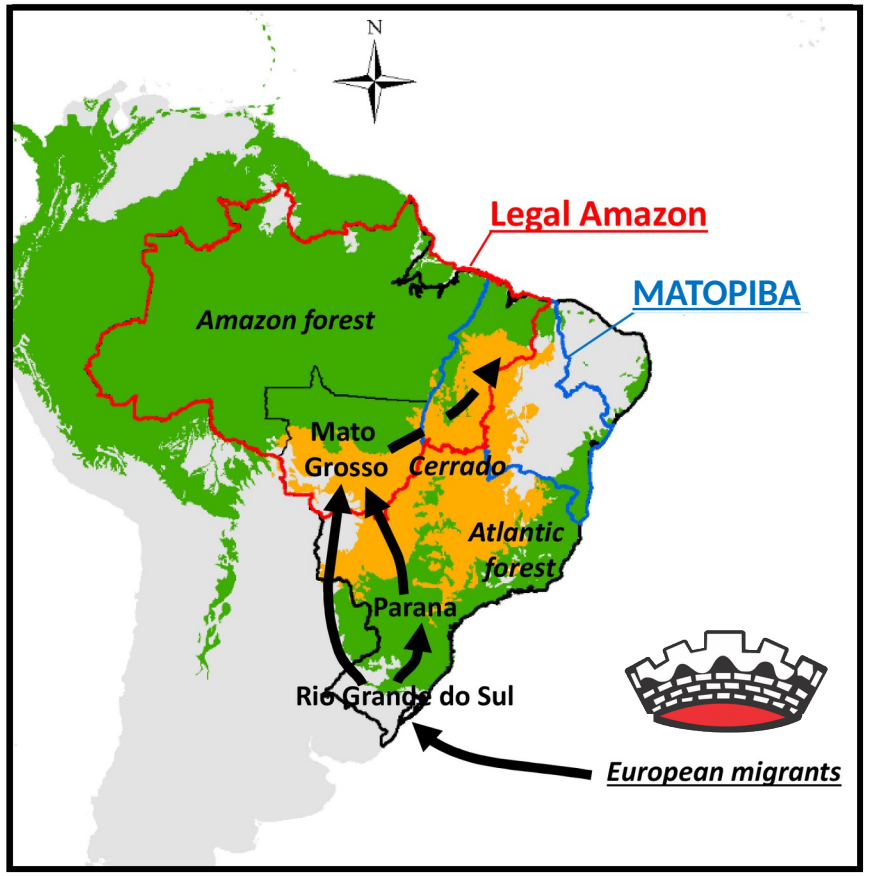

**Rapid intensification in all agricultural regions**

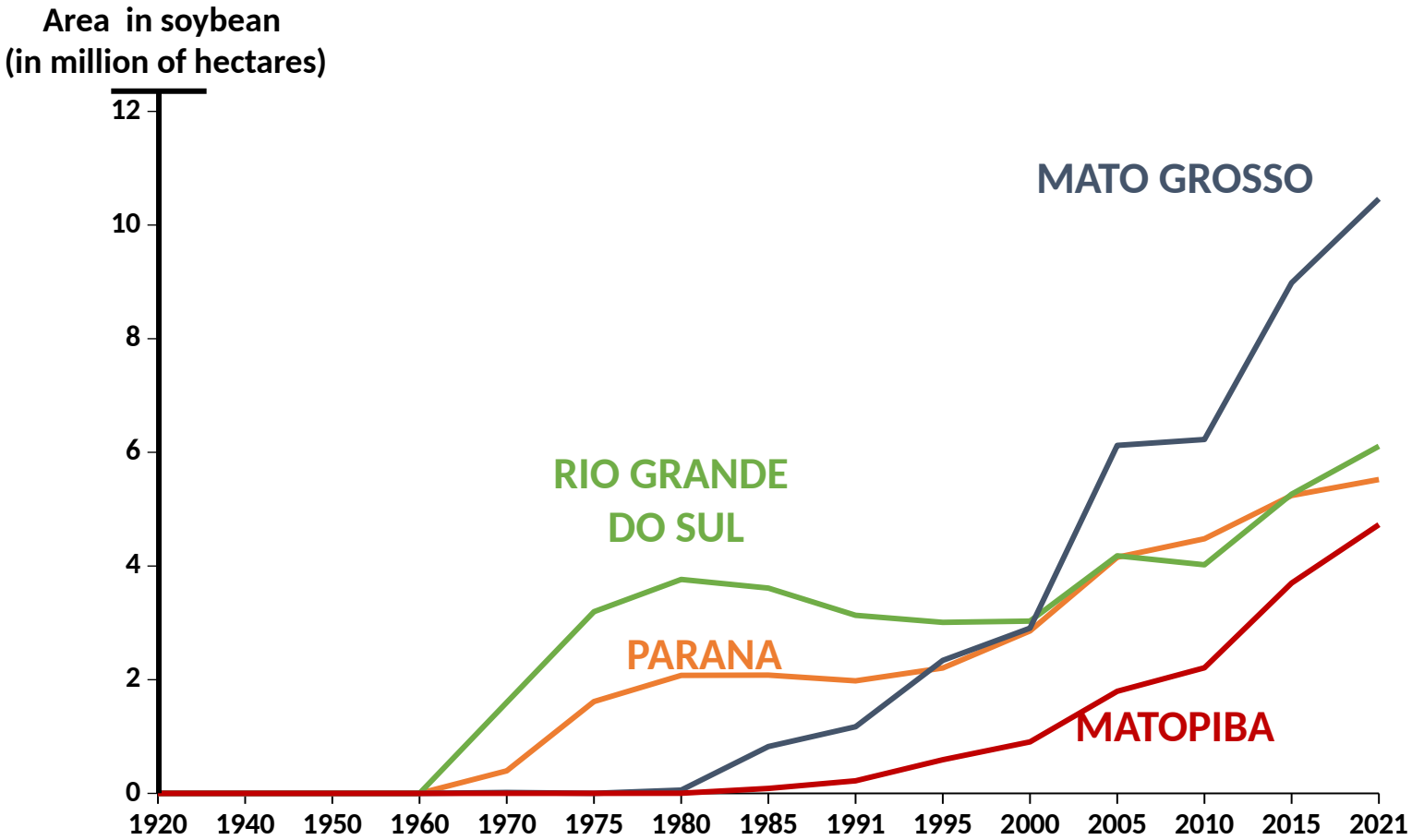


*Arvor et al. 2013*

# Beyond the Amazon

## MATOPIBA => The last wave of the agricultural frontier

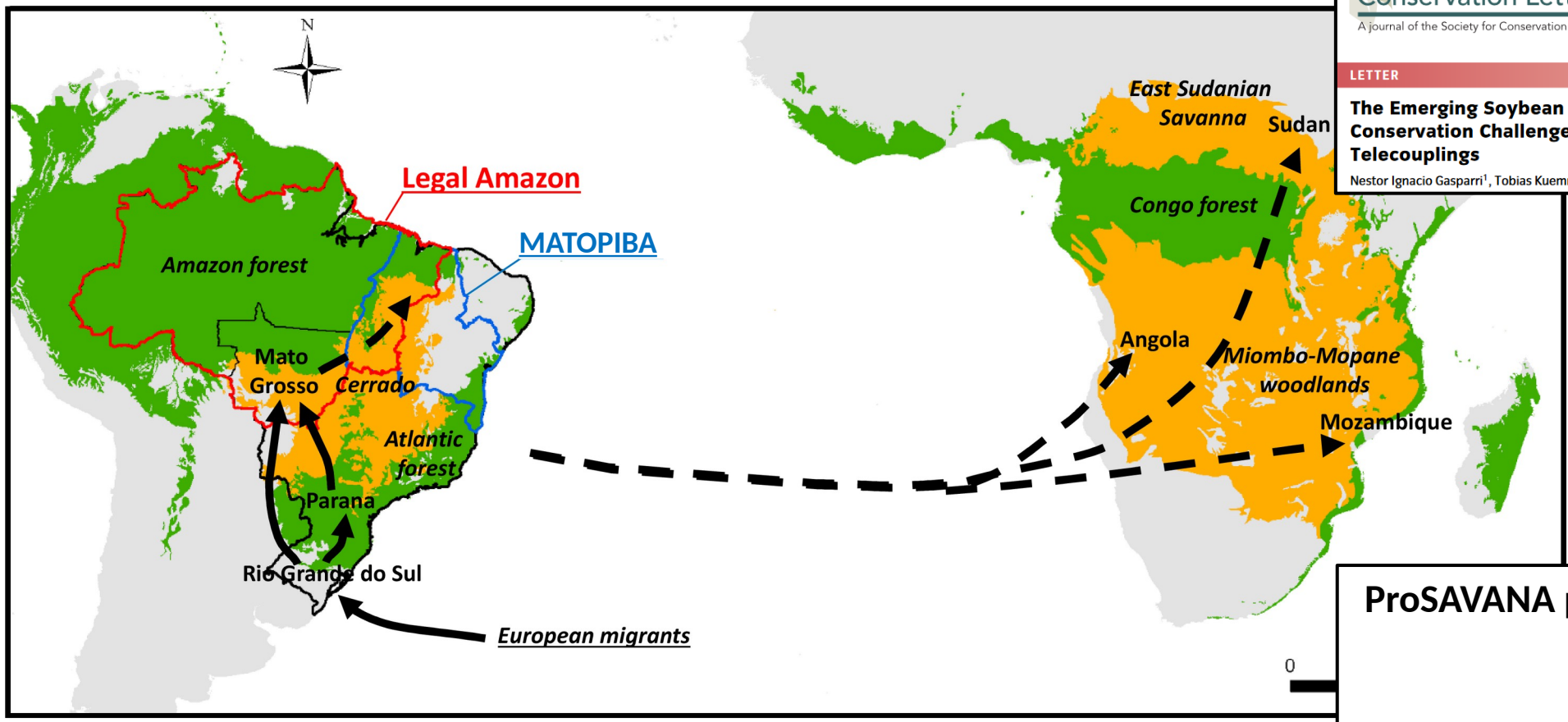



*Arvor et al. 2017*

# Beyond Brazil

## Africa : Exportation of the Brazilian agricultural model




Conservation Letters
A journal of the Society for Conservation Biology
Open Access

LETTER

**The Emerging Soybean Production Frontier in Southern Africa: Conservation Challenges and the Role of South-South Telecouplings**

Nestor Ignacio Gasparri[1], Tobias Kuemmerle[2], Patrick Meyfroidt[3], Yann le Polain de Waroux[4], & Holger Kreft[5]

*Gasparri et al. 2013*

**ProSAVANA project in Mozambique**

Embrapa

**Launched in 2010**
**Cancelled in 2017**

*Arvor et al. 2017*

# New research perspectives

## The oil palm agricultural frontier in Indonesia

*Cristina Joss (2020). Palm oil plantation in Sentabai Village, West Kalimantan, 2017 (adapted from photo by Nanang Sujana, CIFOR)*

### Differences

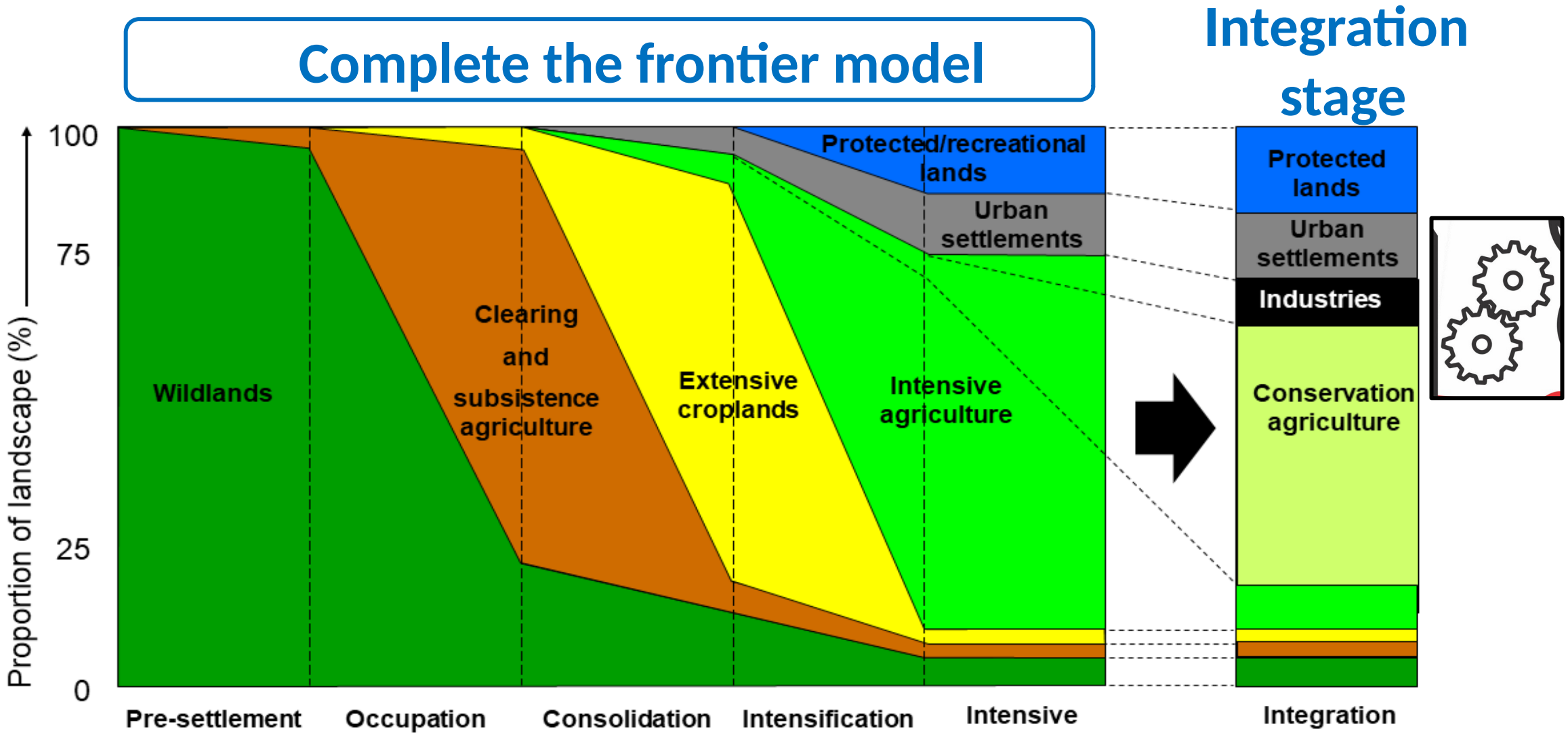
- Perennial tree plantations
- Highly capitalized industrial plantations
- Many smallholders: 40% of production

### Similarities

- Rapidly expanding frontier
- Emerging environmental considerations
  - Oil palm moratorium
  - Sustainable oil palm certification
  - Landscape restoration

# New research perspectives

## Complete the frontier model

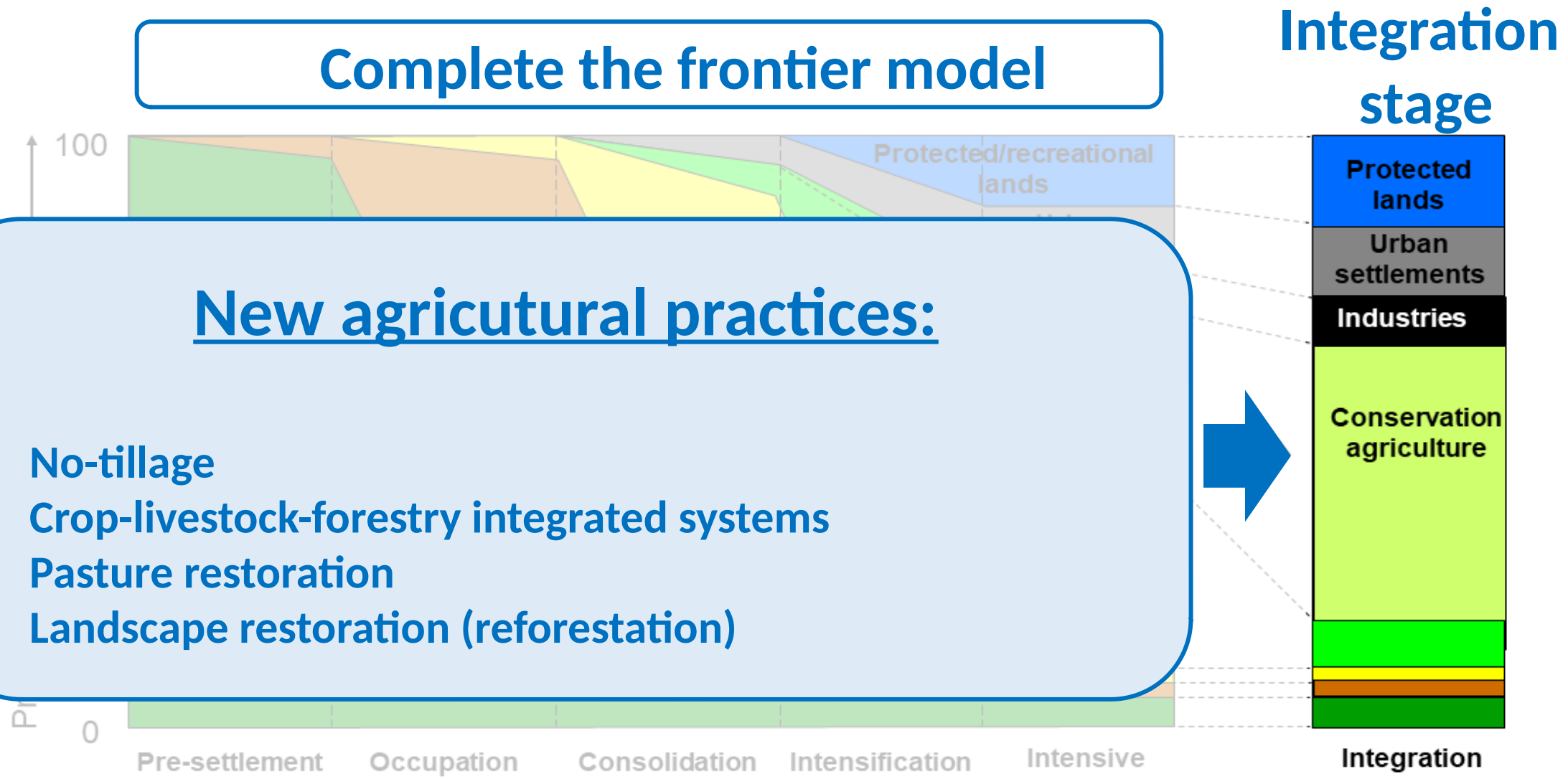





*Arvor et al. 2013*

# New research perspectives

## Complete the frontier model

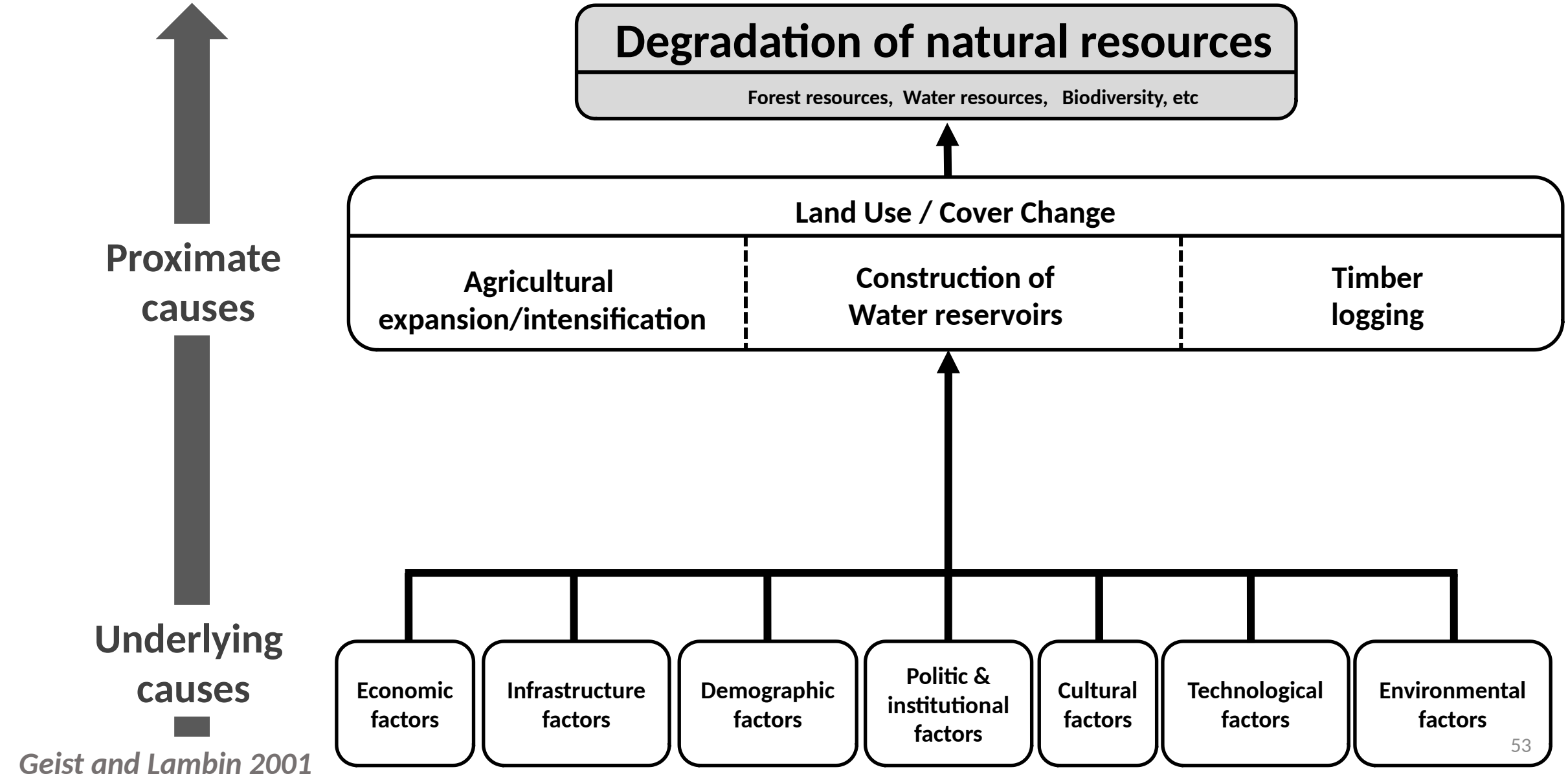



## New agricutural practices:

- No-tillage
- Crop-livestock-forestry integrated systems
- Pasture restoration
- Landscape restoration (reforestation)

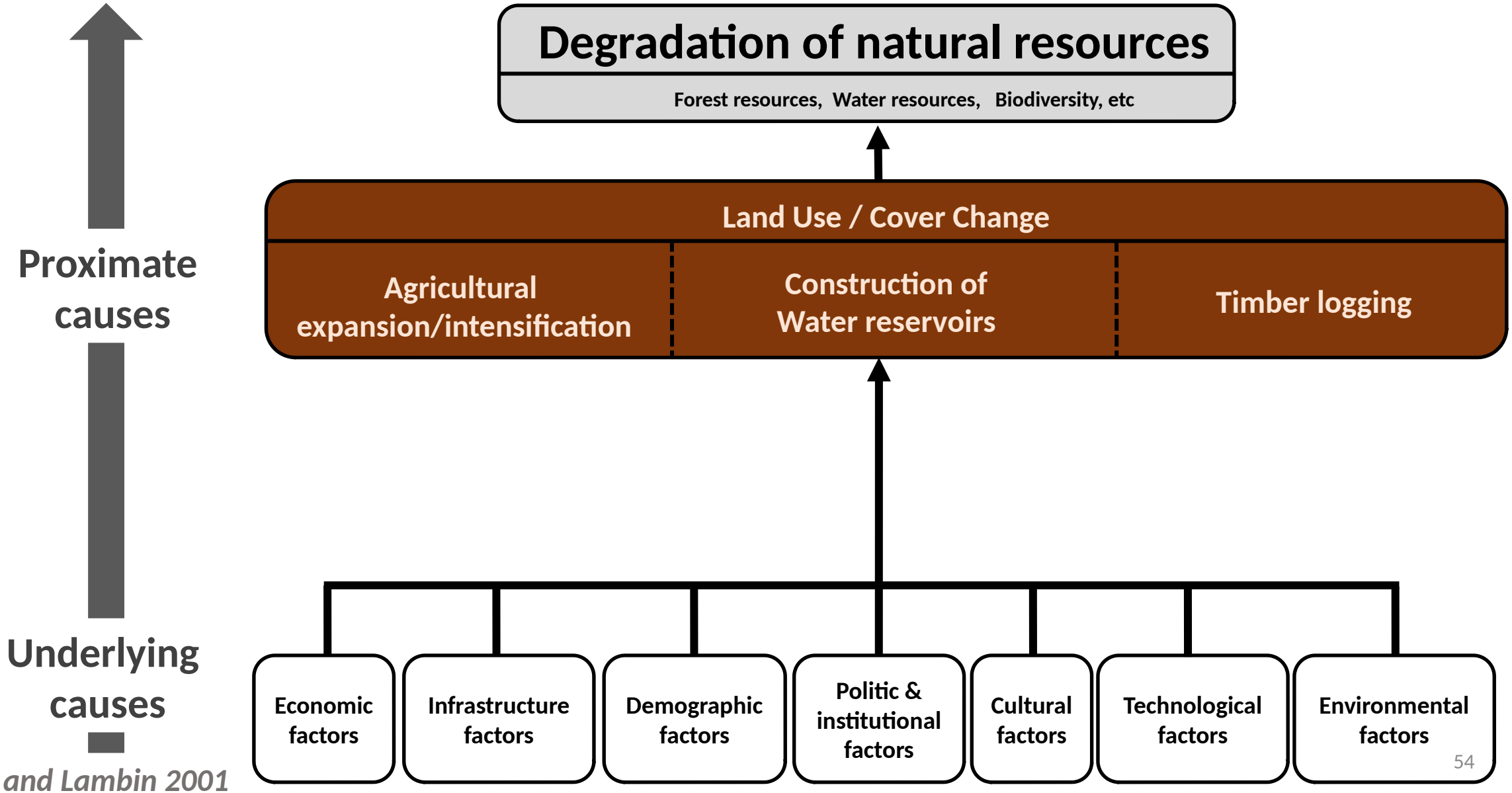
# Land use sustainability on the Brazilian Amazon frontier

# Conceptual framework



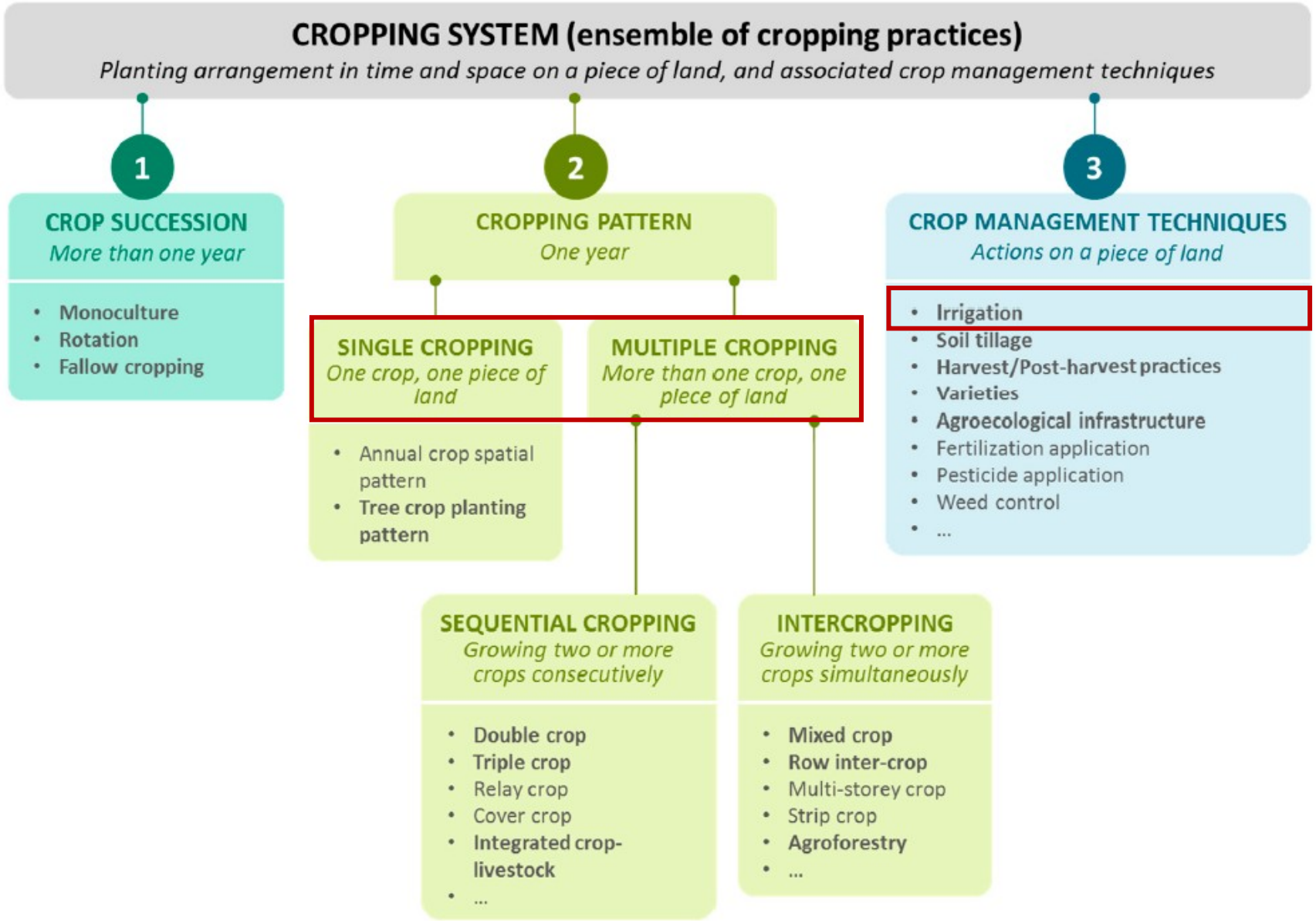

*Geist and Lambin 2001*

# Conceptual framework




*Geist and Lambin 2001*

# Agricultural expansion and intensification

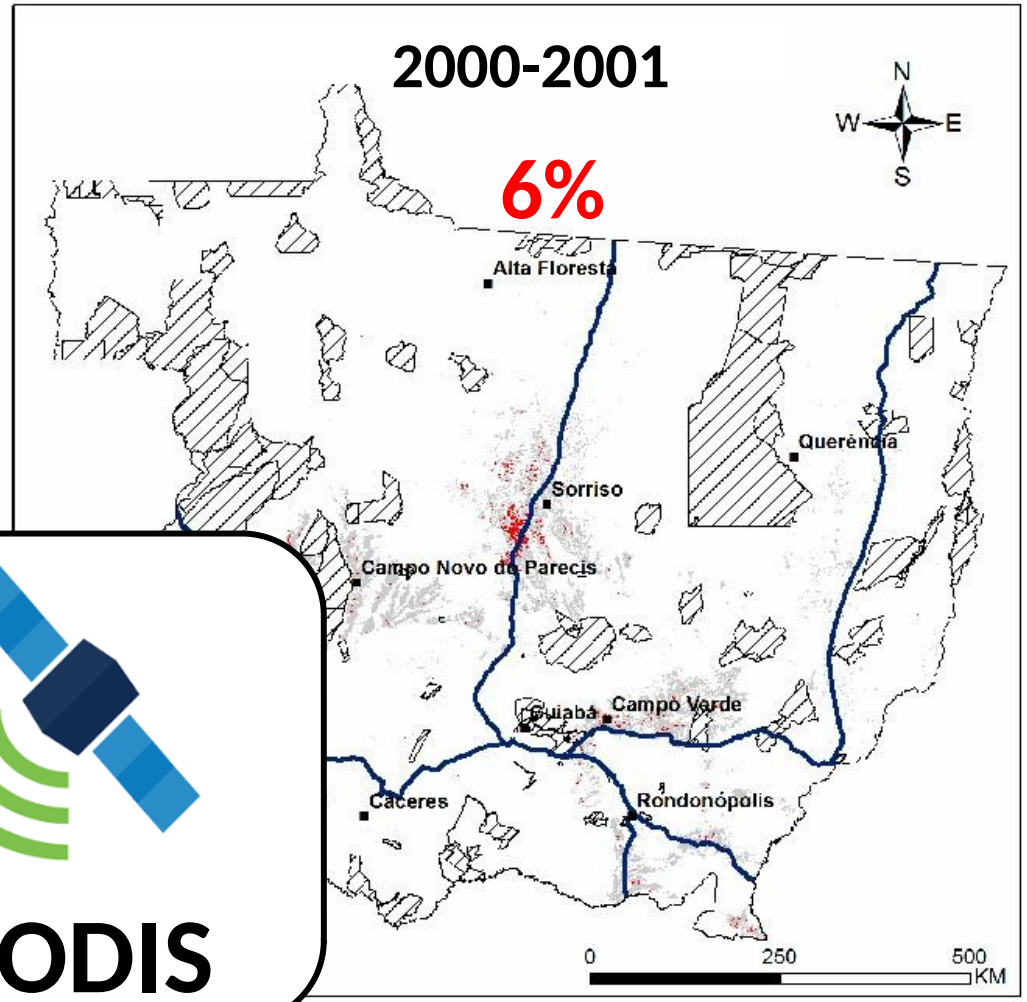


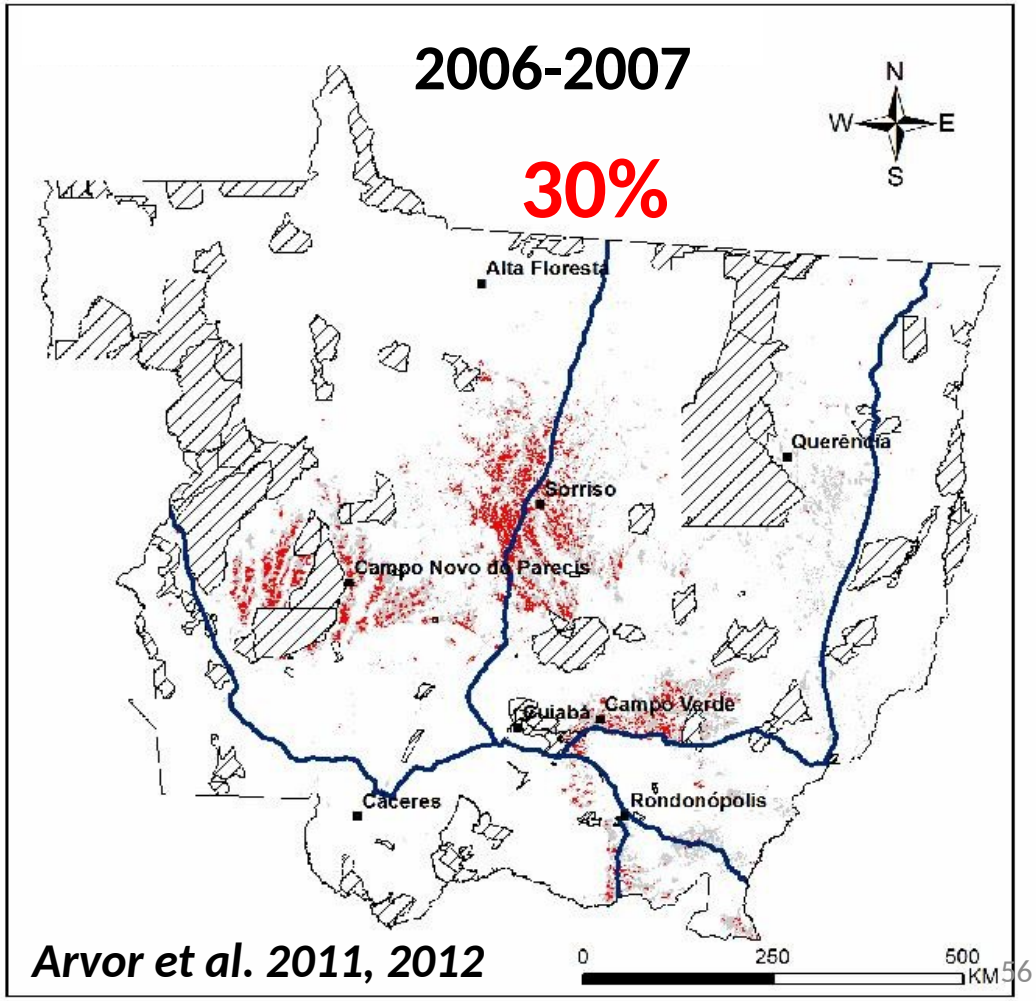



*Bégué et al. 2018*

# Agricultural expansion and intensification

## Increased proportion of double cropping systems



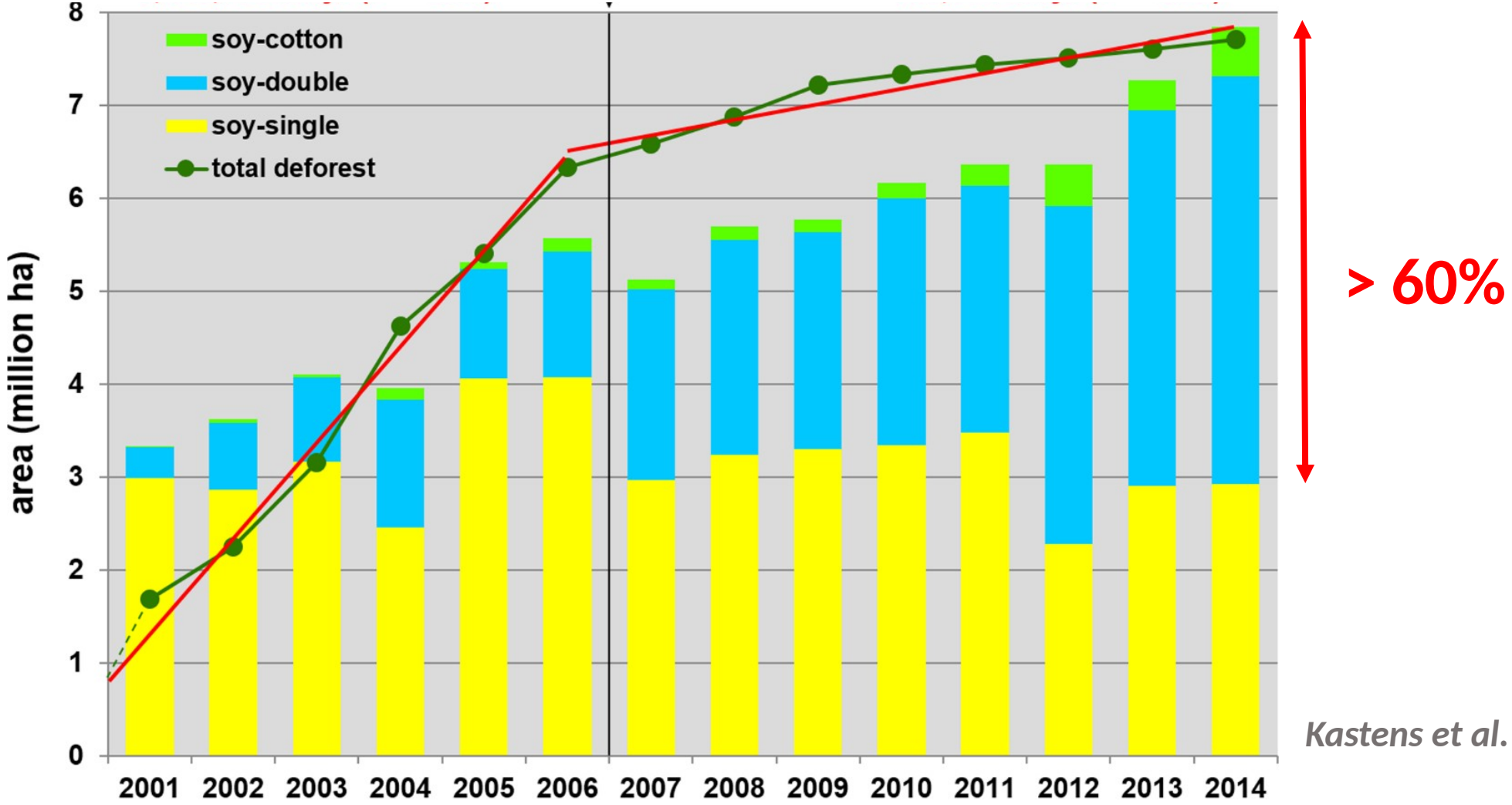




MODIS

*Arvor et al. 2011, 2012*

# Agricultural expansion and intensification

## Increased proportion of double cropping systems




*Kastens et al. 2017*

# Agricultural expansion and intensification

## Mapping center pivot irrigation systems

Center pivot irrigation systems in Bahia state, Brazil

www.correio24horas.com.br

# Agricultural expansion and intensification

## Mapping center pivot irrigation systems

In 2017:

- Total area: 70 654 ha
  (12% underestimation)
- Number of pivots: 612
- Mean radius: 310 to 870 m

Adaptation to climate change?

Impacts on water resources?

Sentinel 2

*Tang et al. 2021*

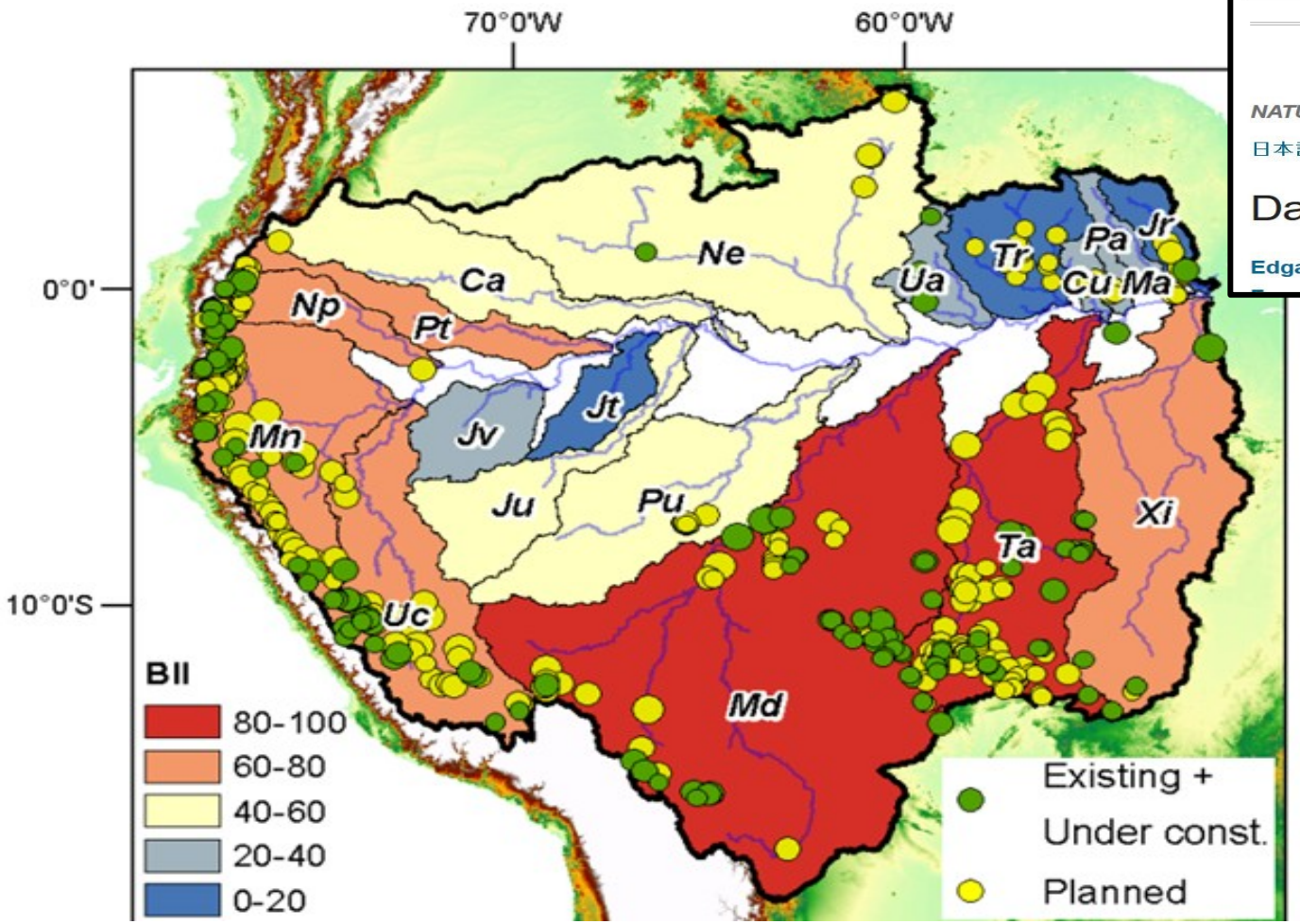
# Proliferation of water reservoirs

## There are many studies on the construction of hydropower dams planned in the Amazon...


Construction of the Belo Monte dam in Altamira (Para State)

# Proliferation of water reservoirs

## Basin Integrity Index





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2017

NATURE | PERSPECTIVES

日本語要約

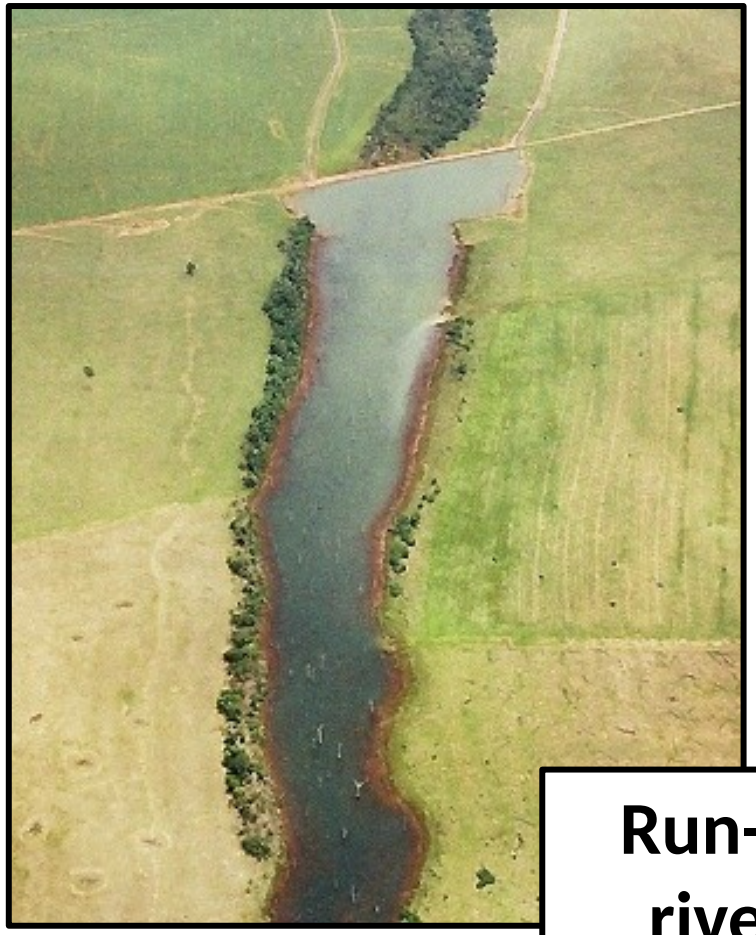
Damming the rivers of the Amazon basin

Edgardo M. Latrubesse, Eugenio Y. Arima, Thomas Dunne, Edward Park, Victor R. Baker,

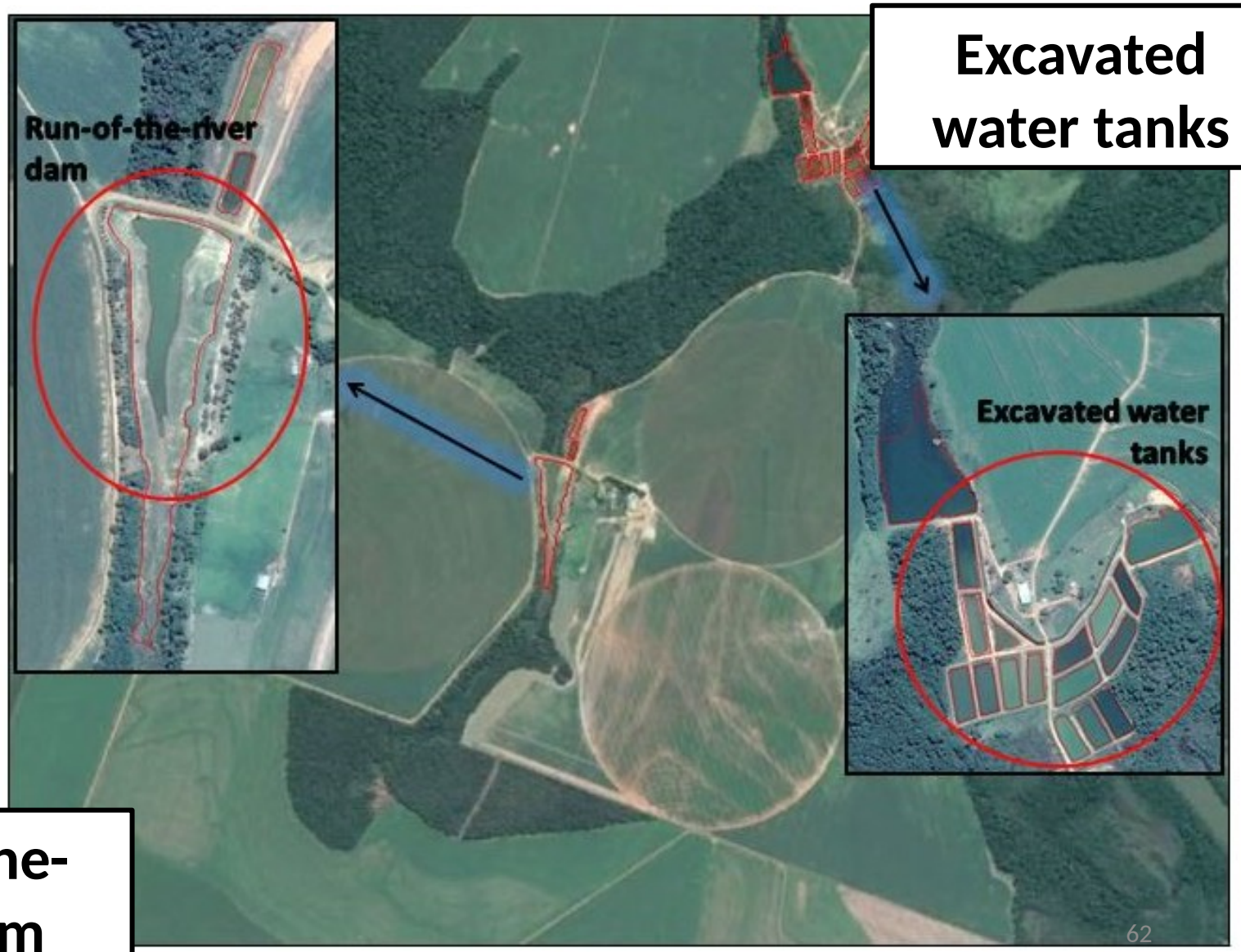
- 140 constructed and under construction dams
- 428 built and planned dams ≥1MW in the Amazon basin.
- Southern Amazon basins are more affected

# Proliferation of water reservoirs

**Diversification through fish farming**



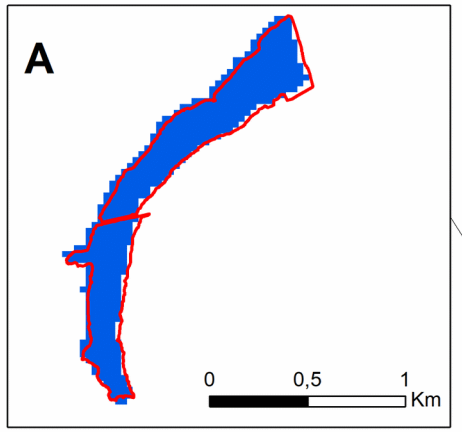
**Run-of-the-river dam**

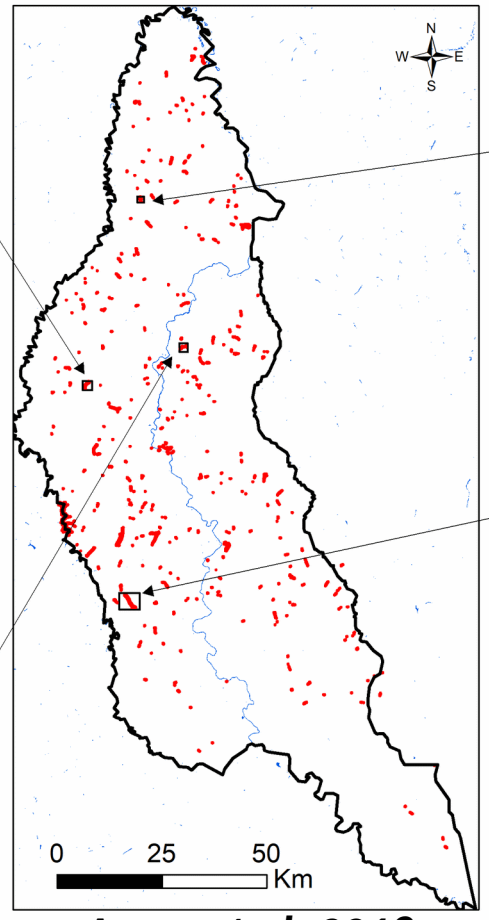



**Excavated water tanks**

# Proliferation of water reservoirs

## 30 years analysis in Sorriso (MT)

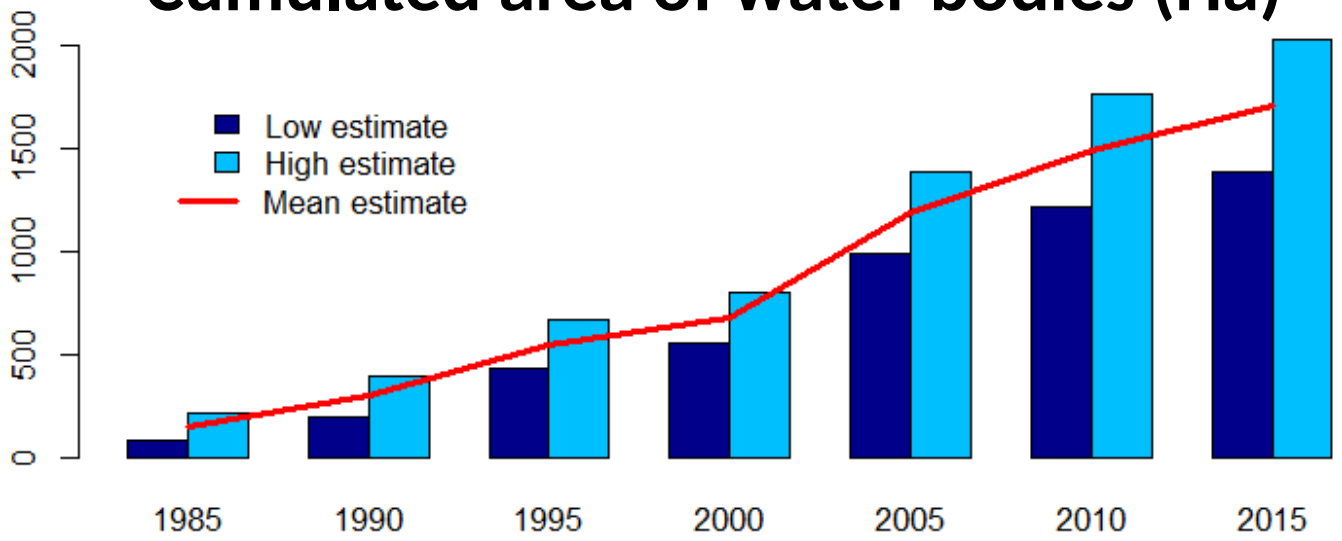



Landsat

*Arvor et al. 2018*

## Cumulated area of water bodies (Ha)




**In 2015:**

- **Total area: 1700 ha**
- **Number of reservoirs: 522**

**Cumulated impacts at watershed scale?**

**Sorriso = 6.66% of the Teles Pires watershed**

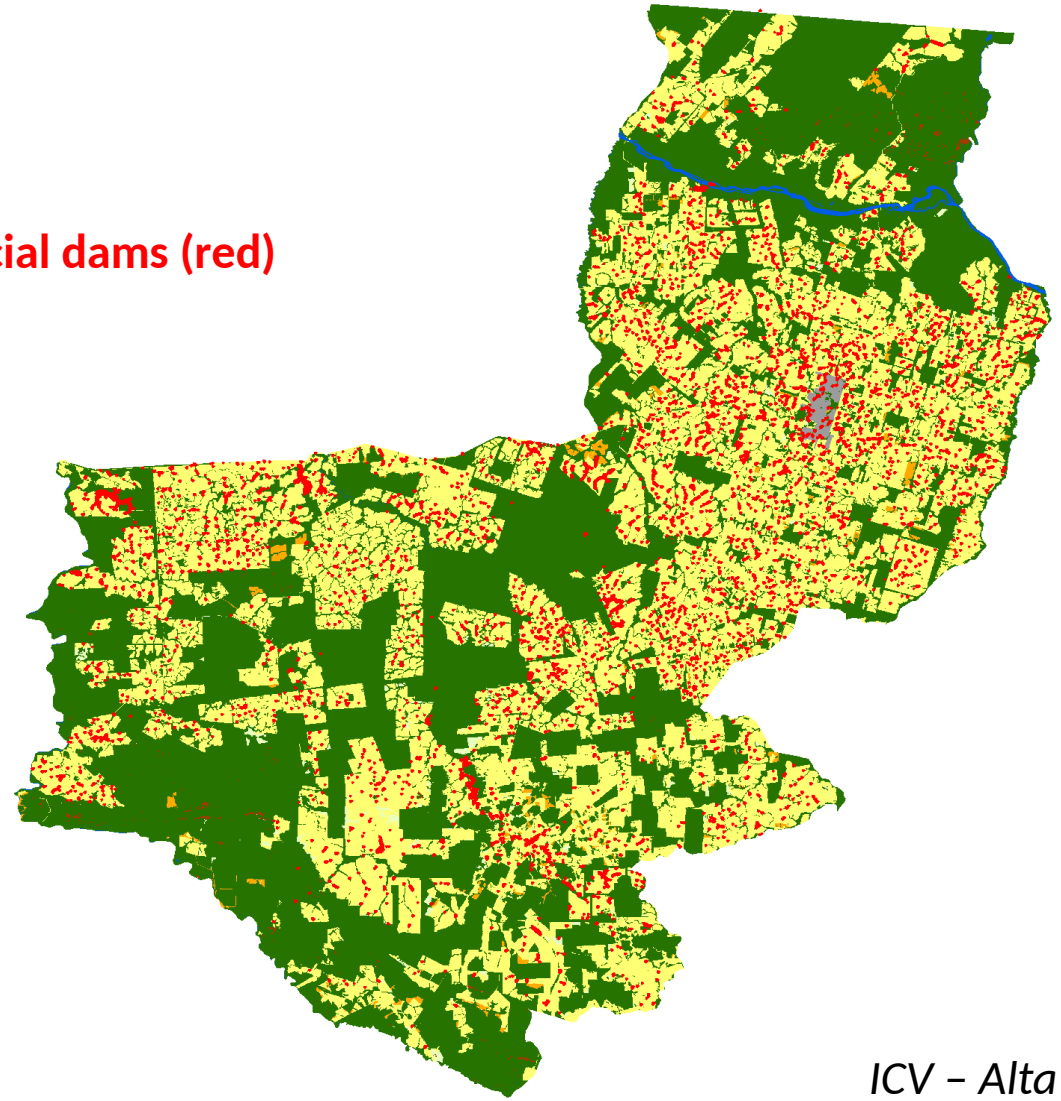
# Proliferation of water reservoirs

## The case study of Alta Floresta - MT

**30 km² of waterbodies identified (3000 ha)**

**-**

**4800 dams**




*ICV – Alta Floresta*

# Proliferation of water reservoirs

## Impact cumulé des retenues d'eau sur le milieu aquatique

Le ministère en charge de l'Environnement a sollicité, avec l'appui de l'Onema, une expertise scientifique collective (ESCo) auprès d'Irstea, en partenariat avec l'Inra, sur l'impact cumulé des retenues d'eau sur le milieu aquatique. L'étude de ces impacts cumulés est désormais requise en préalable à la création de nouveaux ouvrages alors que peu de connaissances et méthodologies sont disponibles, notamment en ce qui concerne les impacts cumulés. Les conclusions de cette expertise ont été rendues et débattues le 19 mai 2016.

- **Lack of knowlegde**
- **Trends towards the destruction of small dams**

*http://www.ea.inra.fr/Toutes-les-actualites/Expertise-Impact-cumule-des-retenues-d-eau-sur-le-milieu-aquatique*

# Timber logging

https://www.amazonconservation.org/maap-126-drones-and-legal-action-in-the-peruvian-amazon/

## Forest degradation > deforestation

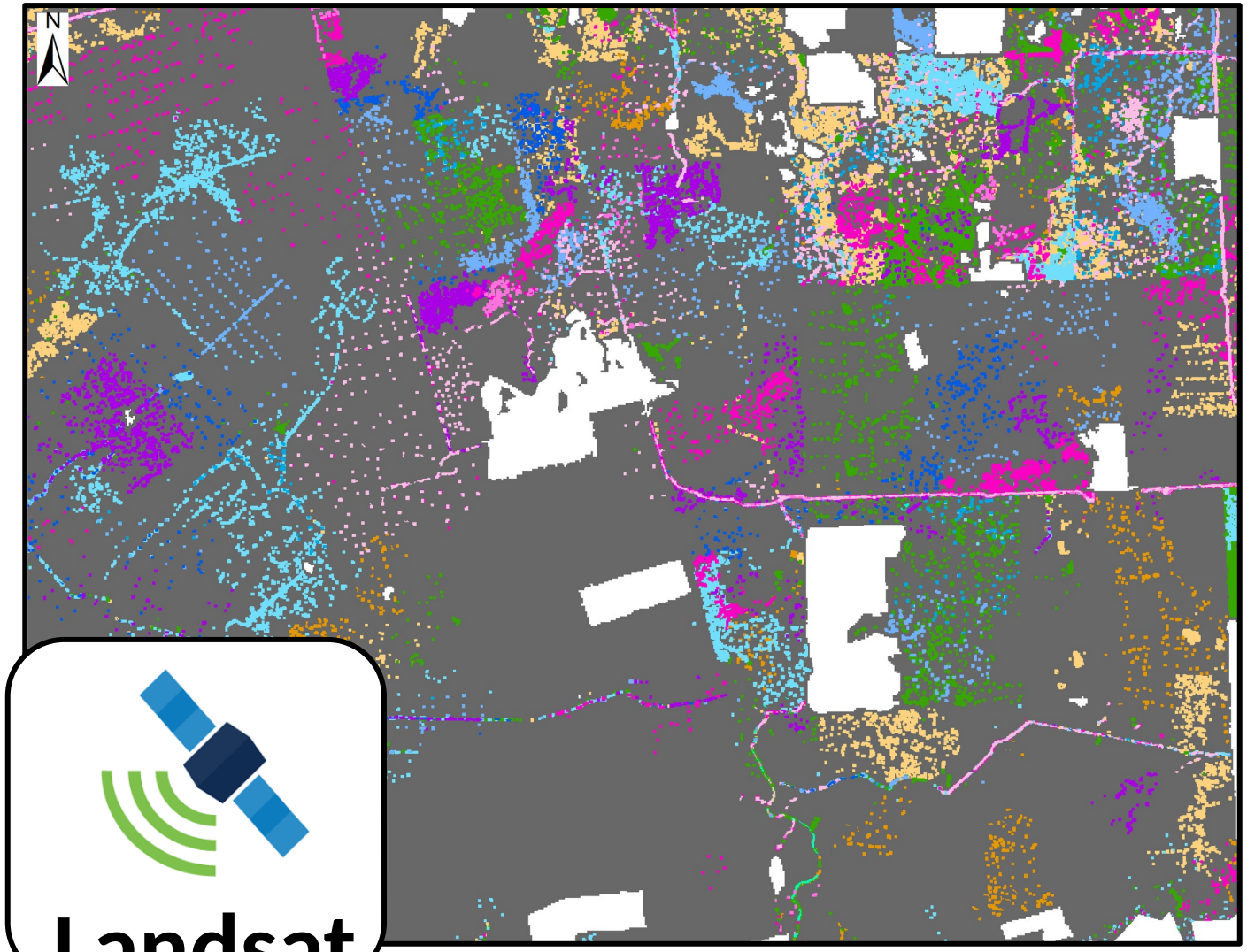
337,427 km² vs 308,311 km² between 1992-2014

## Major causes of degradation

- Fires
- Landscape pattern
- Timber logging

# Timber logging

## Disturbances in forest areas / year




Landsat

**From**
**annual disturbances**
**in forest canopy**
**...**

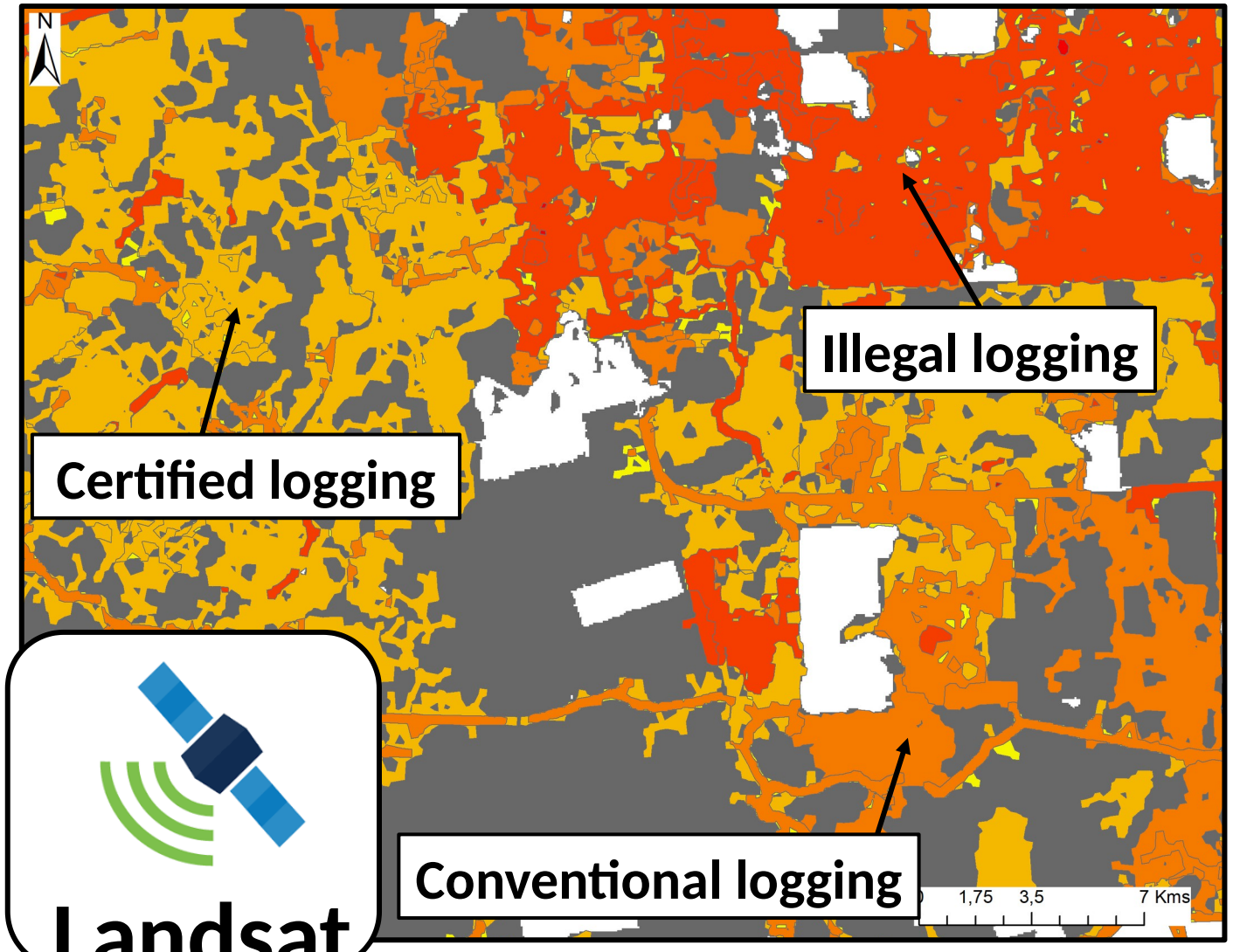
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Fires
Forest mask (PRODES)



*Betbeder et al. 2021*

# Timber logging

**Density of disturbances in forest areas**




**From**
**annual disturbances**
**in forest canopy**
**…**

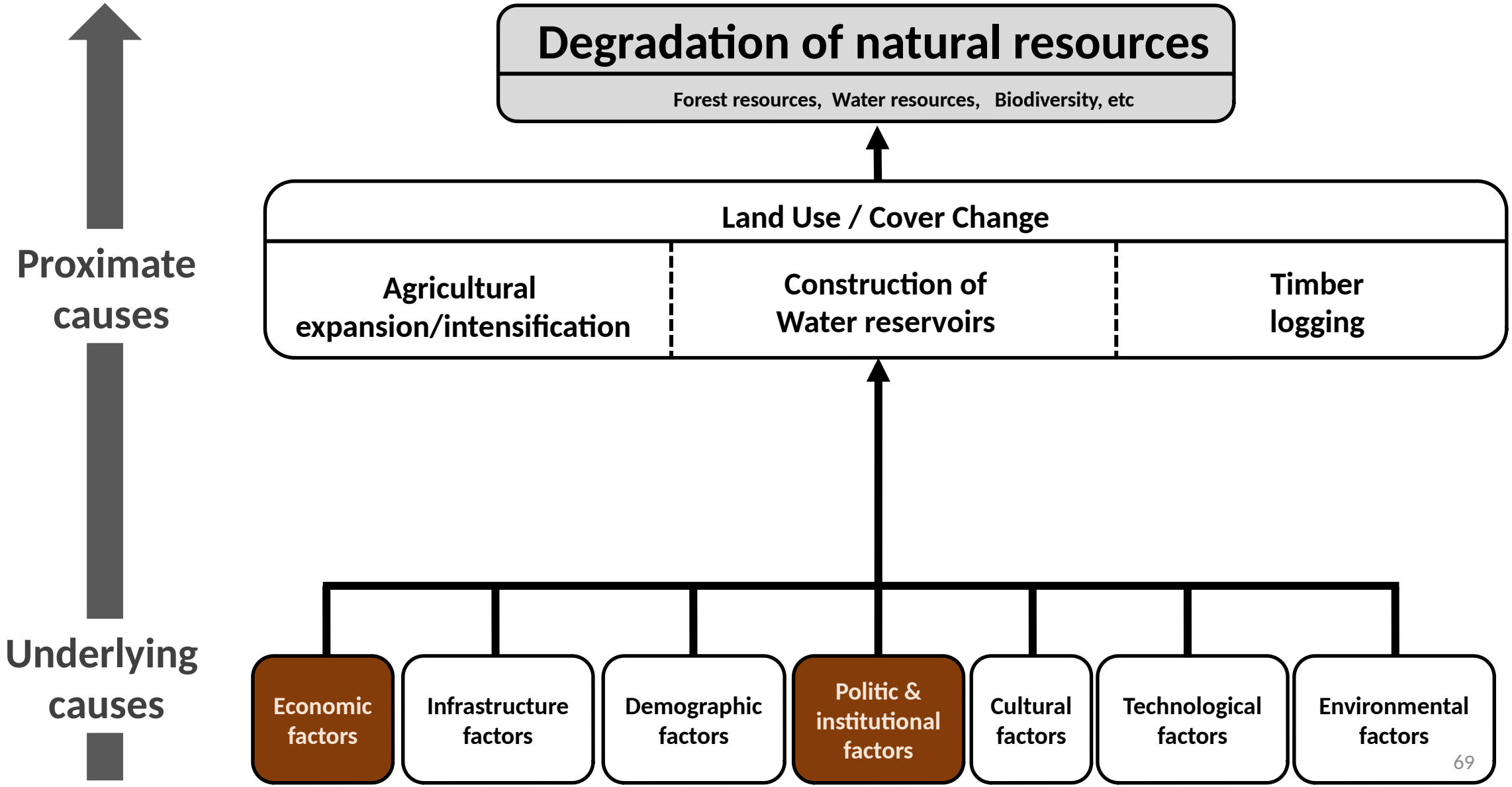
**… to**
**causes of forest degradation ?**

- Certified logging
- Conventional logging
- Illegal logging

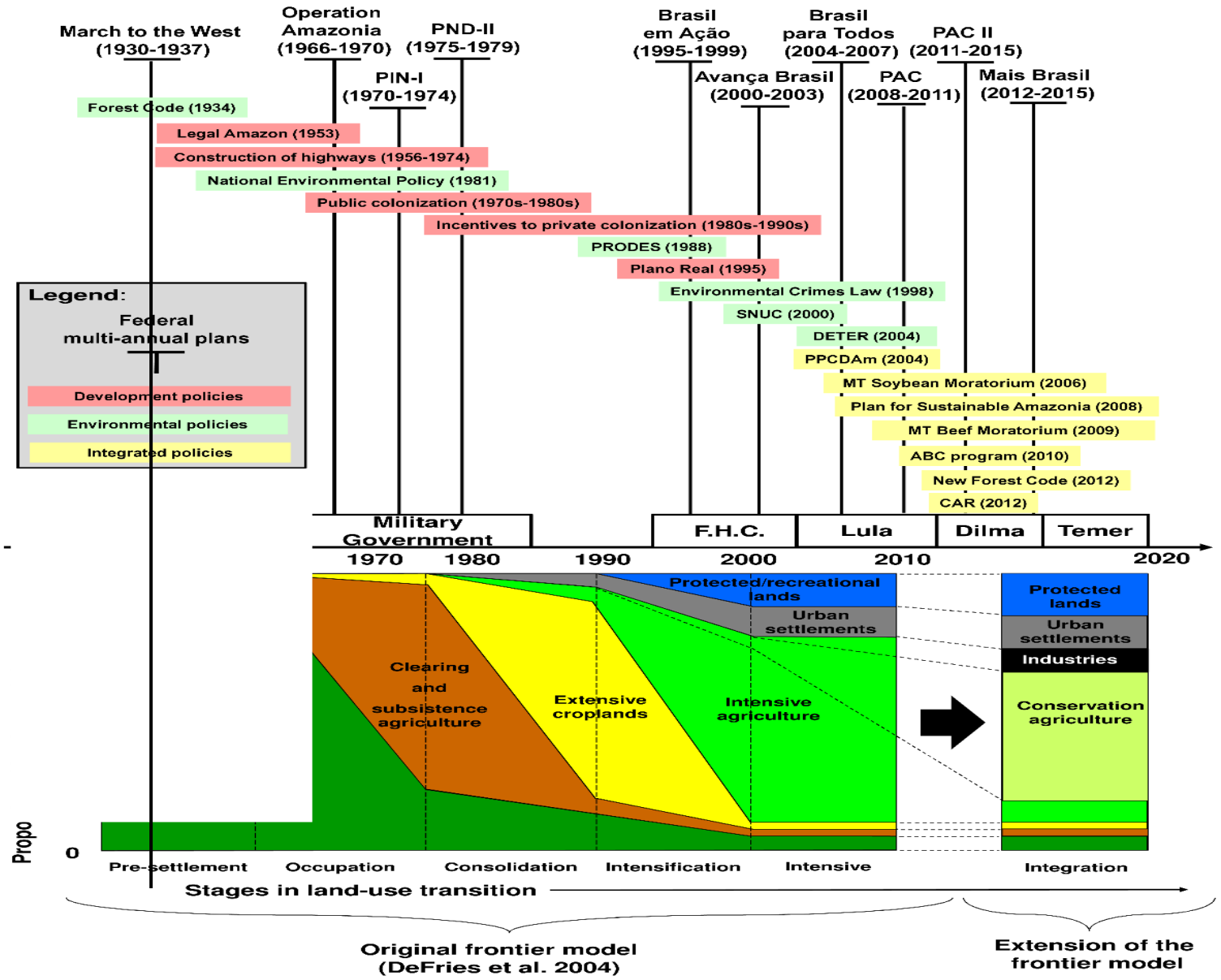


***Betbeder et al. 2021***

# Conceptual framework



# Public policies on the Amazon frontier




From ambivalent policies …

Development policies X Environmental policies

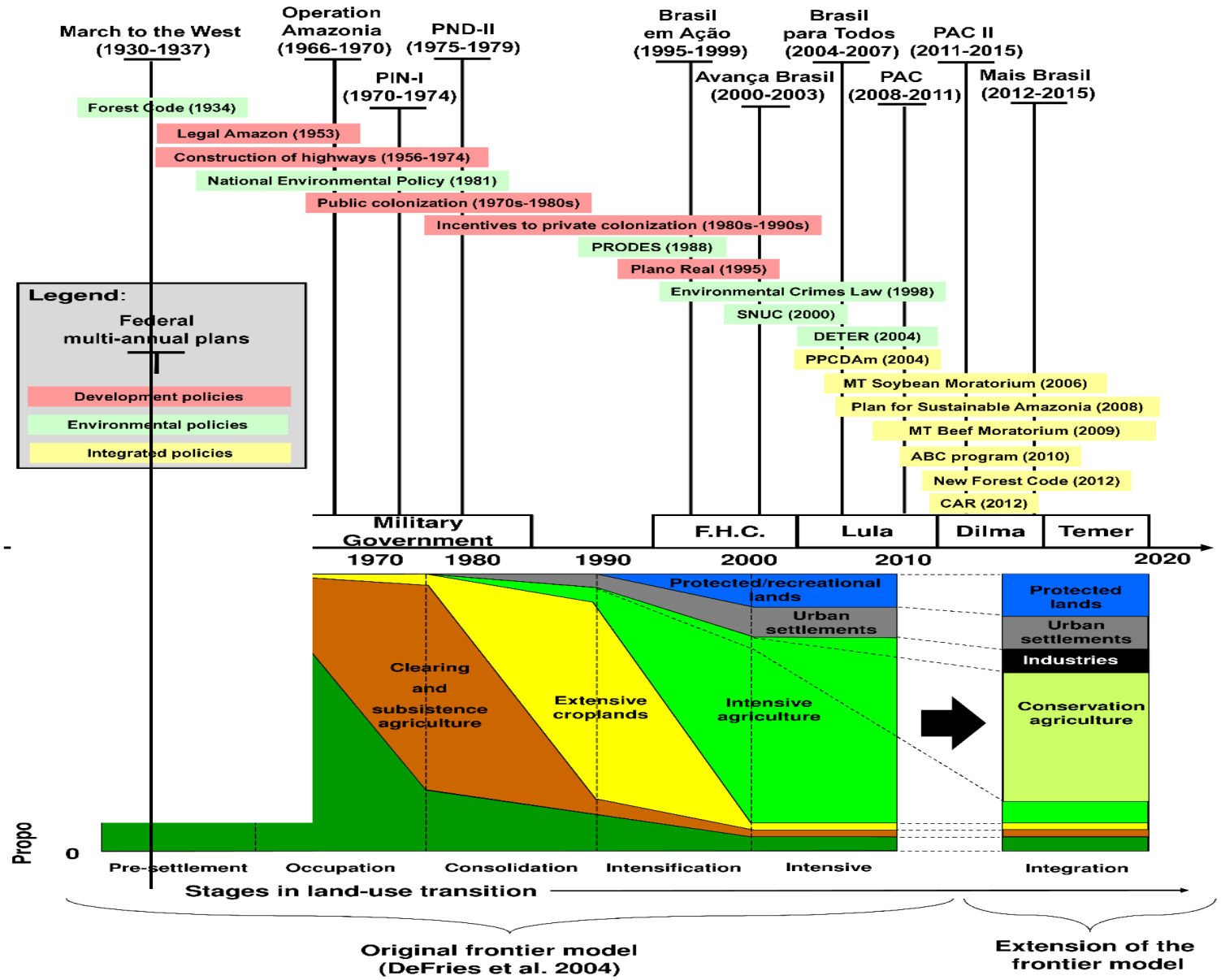
Integrated policies

… to integrated policies …



*Arvor et al. 2018*

# Public policies on the Amazon frontier




**From ambivalent policies …**

**Development policies** X **Environmental policies** → **Integrated policies**

**… to integrated policies …**

**… to Bolsonaro government**

- Increase in fire rates
- Increase in deforestation
- Invasions of protected areas…

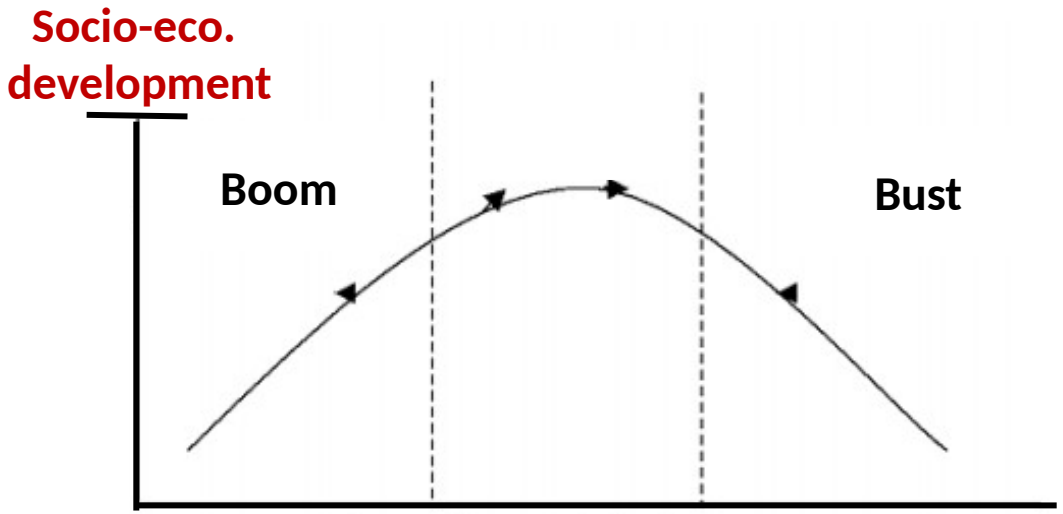


*Arvor et al. 2018*

# Socio-economic development and deforestation


# Socio-economic development and deforestation

## From the boom-and-bust hypothesis…





*Rodrigues et al. 2009*

*Tritsch et al. 2016*

# Socio-economic development and deforestation

## From the boom-and-bust hypothesis...

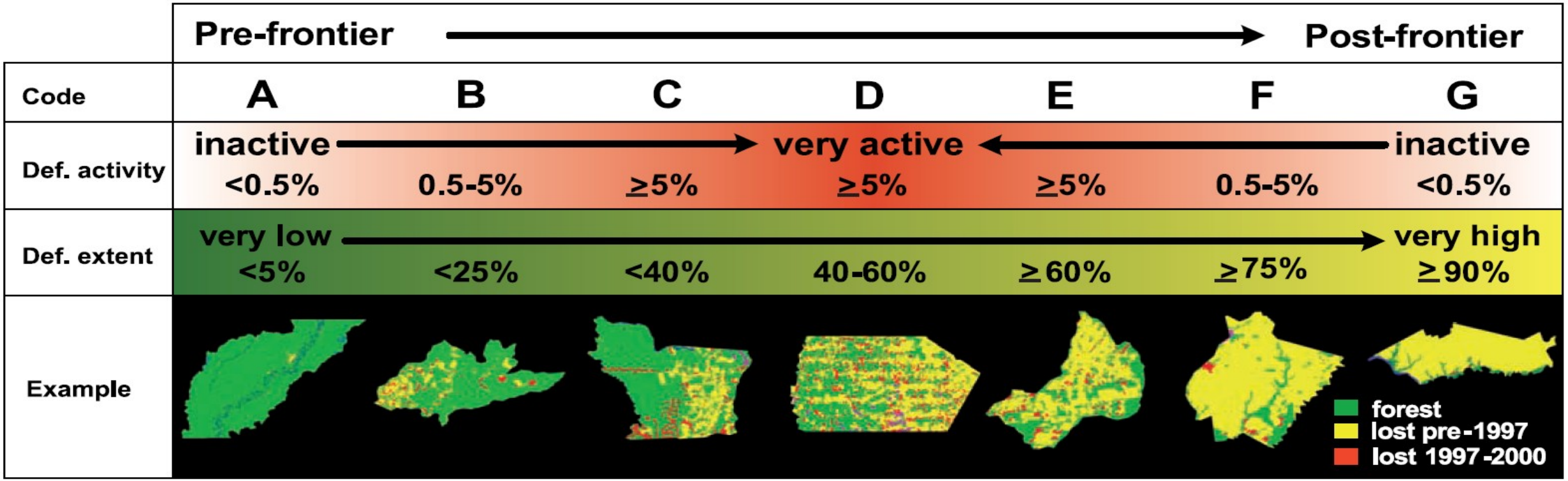
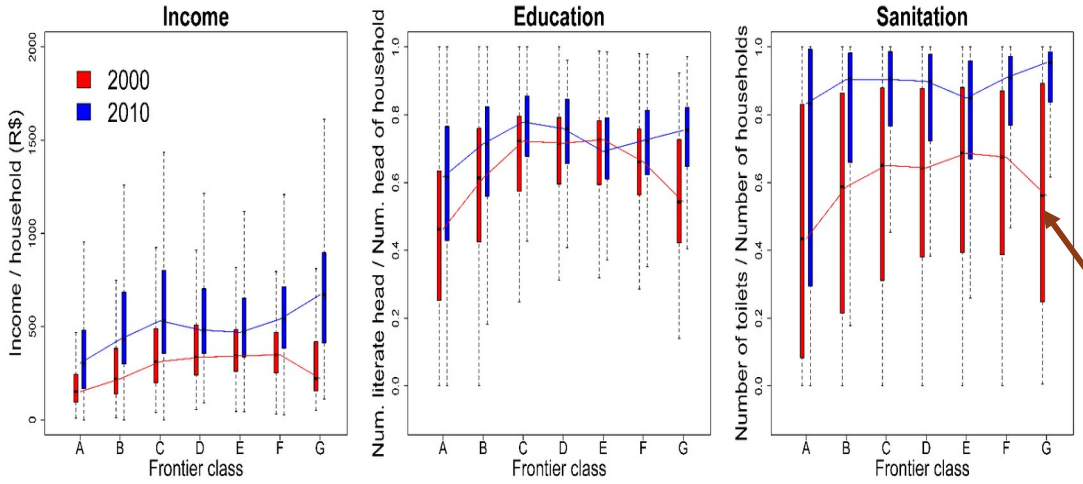



**Fig. 1.** Definition of frontier classes A to G according to recent deforestation activity (percentage of municipality area deforested between 1997 and 2000) and deforestation extent (percentage of the original forest that had been lost by 2000). A representative municipality is mapped as an example of each class (spatial scale variable) (*5*, *13*).

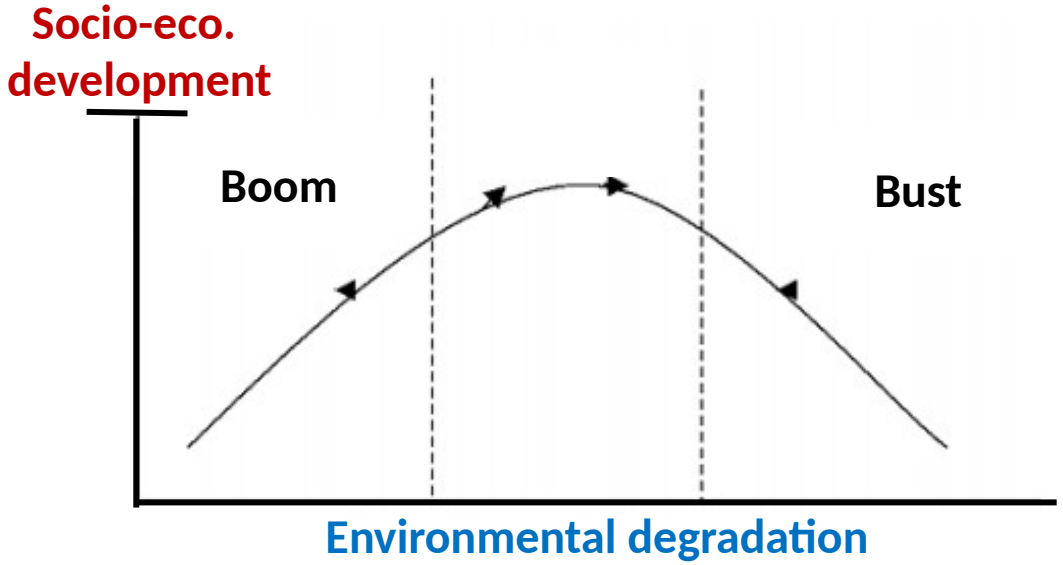
# Socio-economic development and deforestation

## From the boom-and-bust hypothesis…

### Income vs deforestation




Pre-frontier → Active frontier → Post-frontier




**2000:**
**Low development**
**in highly deforested areas**

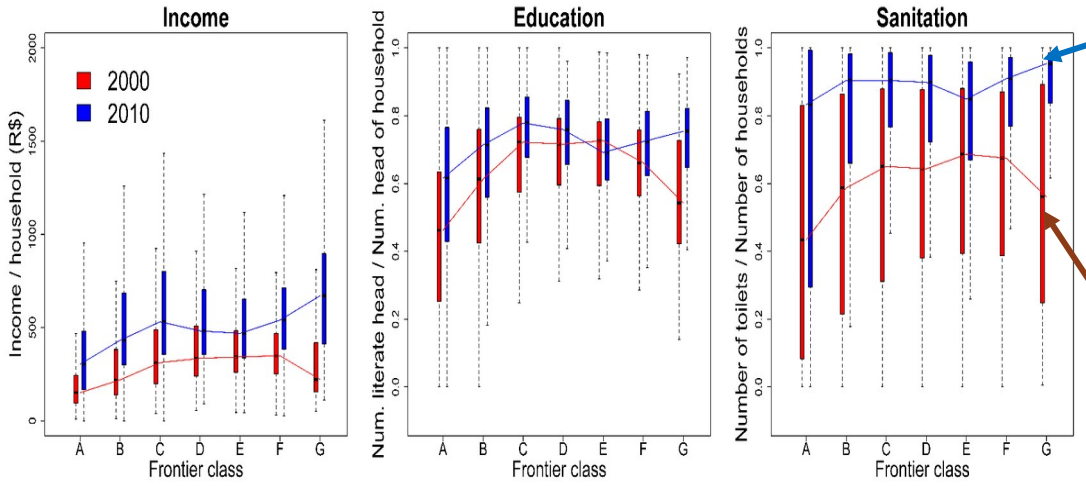


*Tritsch et al. 2016*

# Socio-economic development and deforestation

## From the boom-and-bust hypothesis…

### Income vs deforestation




**2010:**
**High development**
**in highly deforested areas**

**2000:**
**Low development**
**in highly deforested areas**

**Pre-frontier** → **Active frontier** → **Post-frontier**



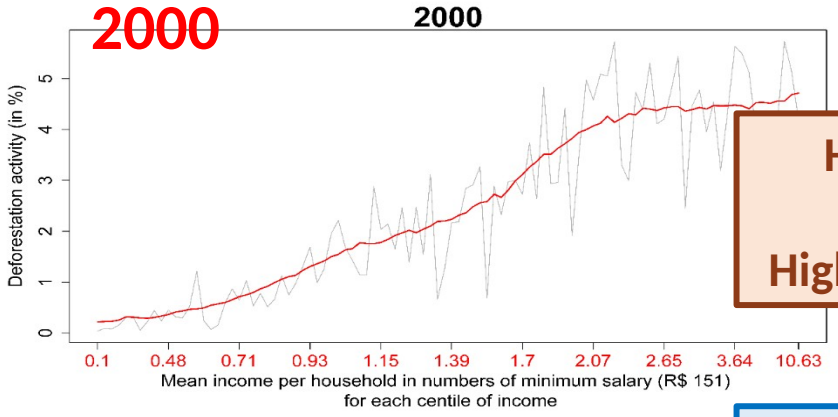
*Tritsch et al. 2016*

# Socio-economic development and deforestation

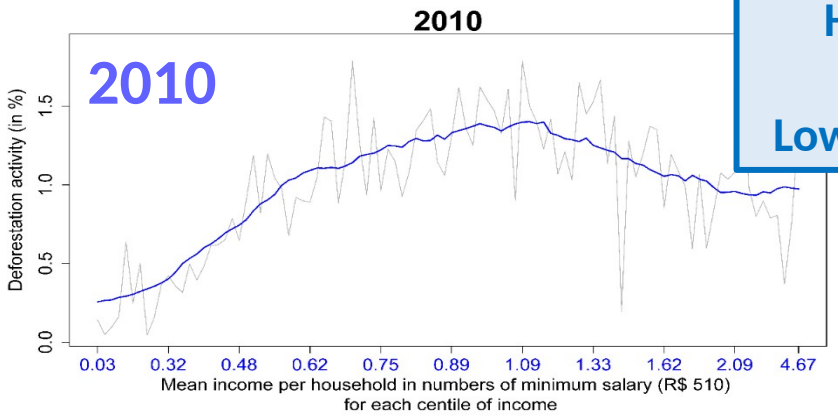
**… to the emergence of the Environmental Kuznets Curve**

## Deforestation vs income

2000




**High income = High deforestation**




**High income = Low deforestation**

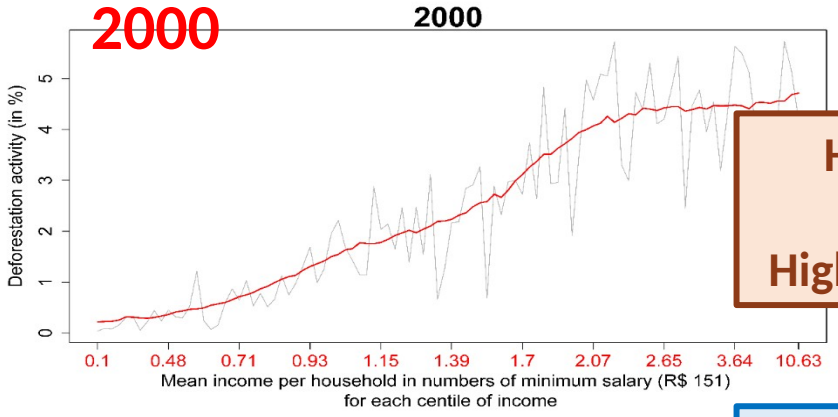


*Tritsch et al. 2016*

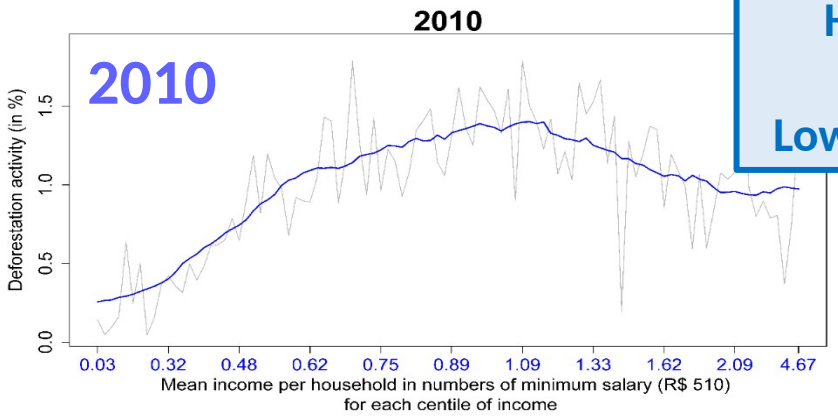
# Socio-economic development and deforestation

## … to the emergence of the Environmental Kuznets Curve

### Deforestation vs income

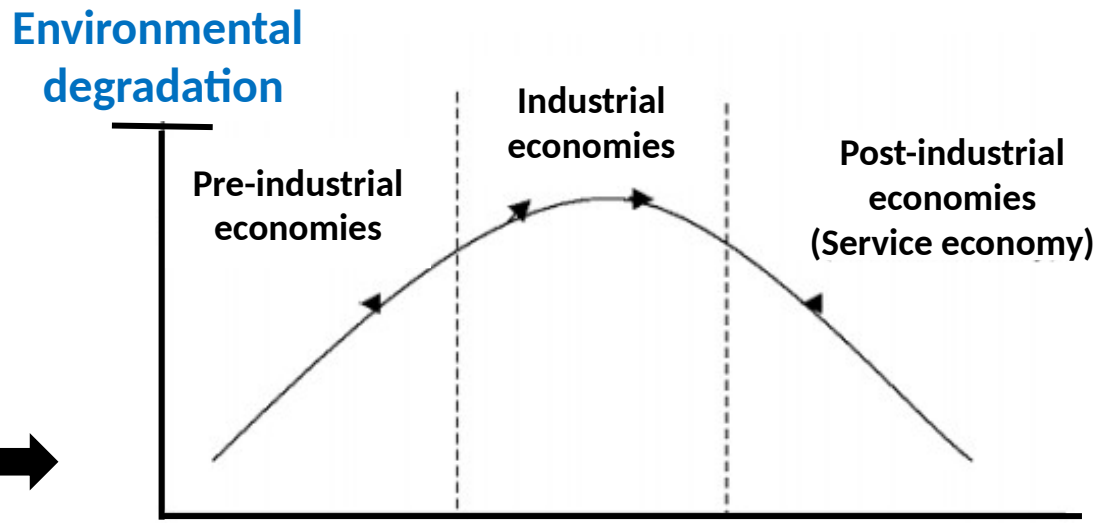



High income
=
High deforestation




High income
=
Low deforestation

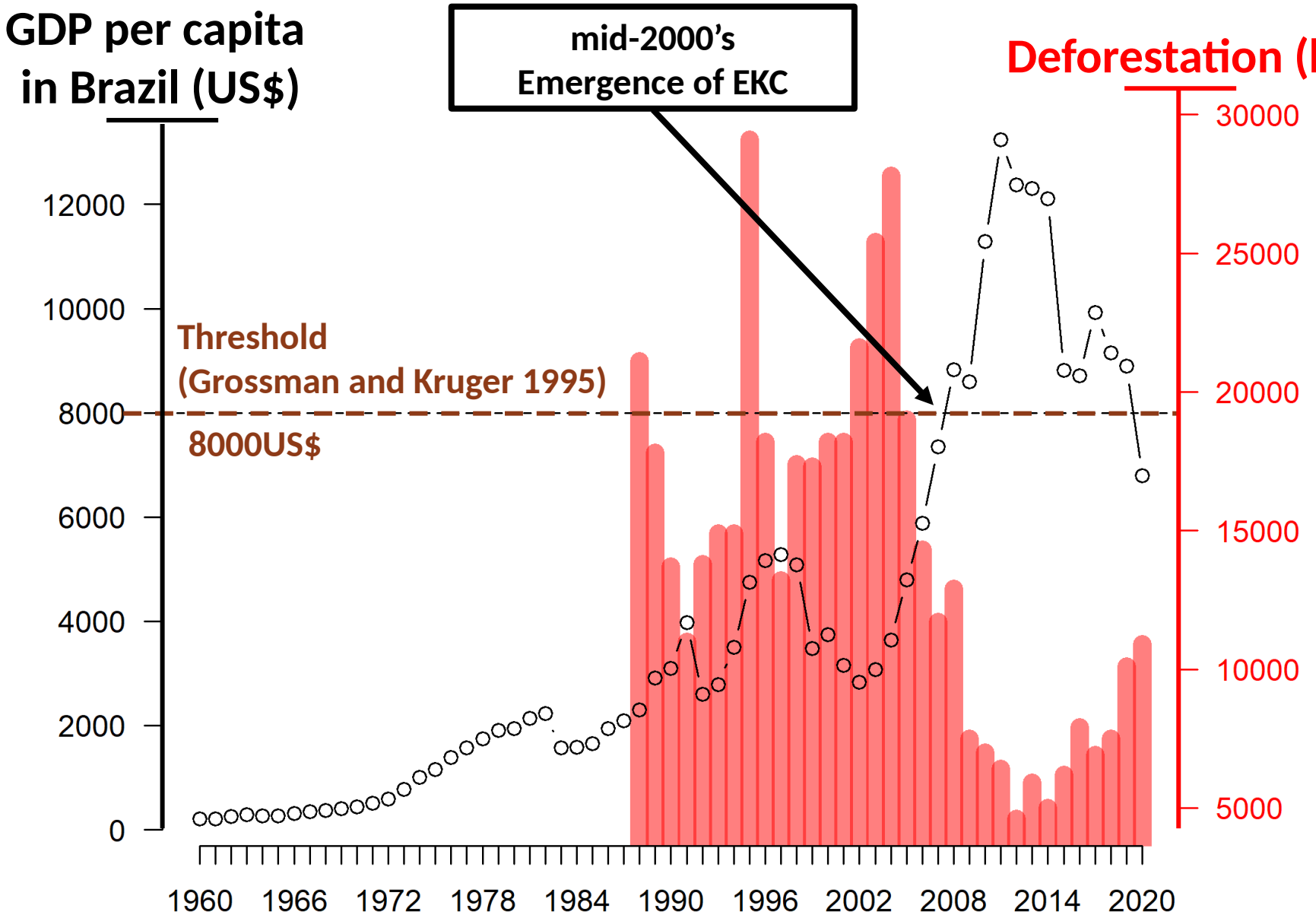
### Environmental Kuznets Curve






*Tritsch et al. 2016*

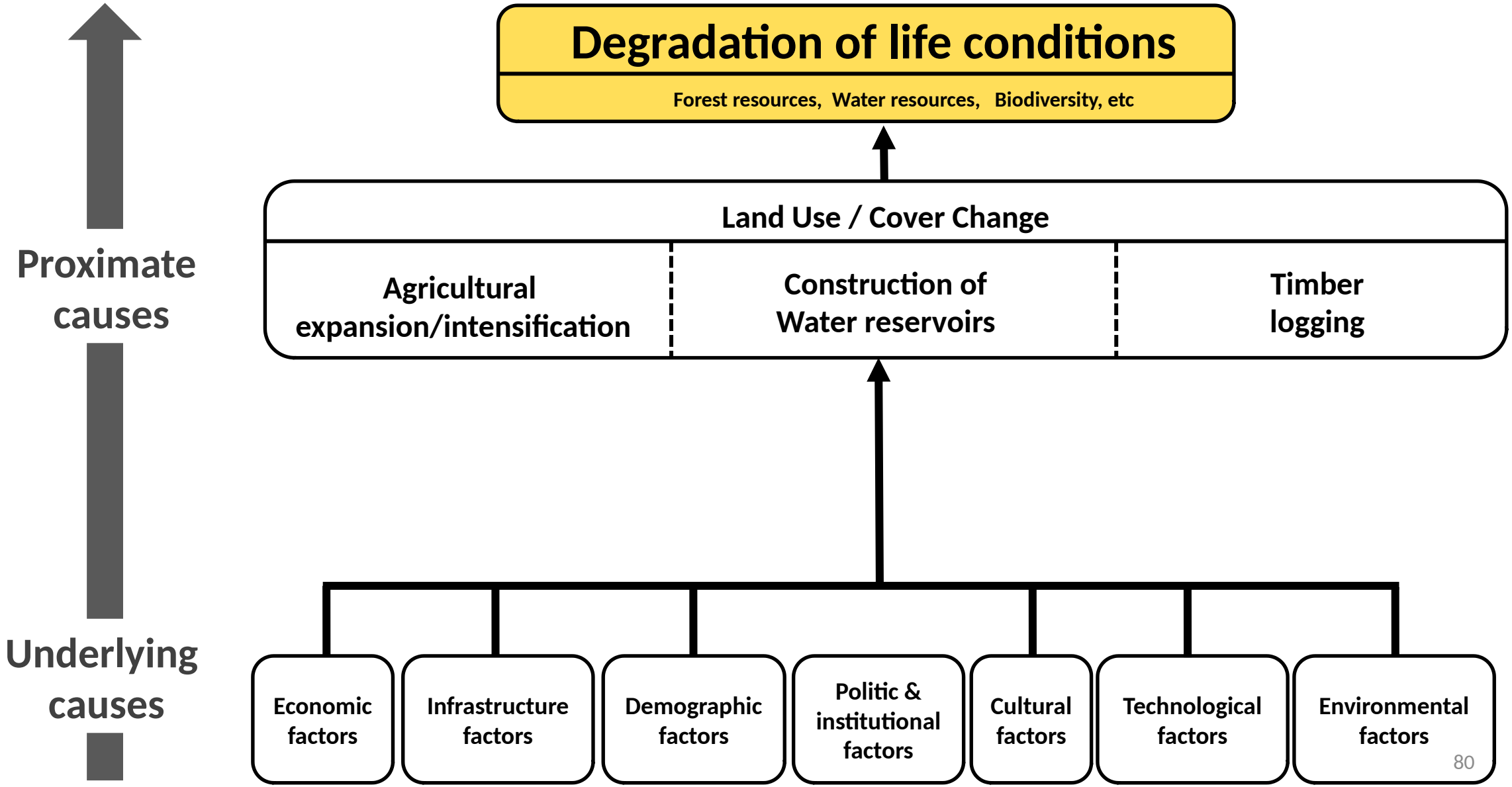
# Socio-economic development: a driver of environmental preservation?




**Strong correlation between GDP and deforestation ($R^2$ = 0,62)**

**What future in a crisis context ?**

# New research perspectives



# Agricultural expansion/intensification => health conditions

## Crop production vs agro-chemicals

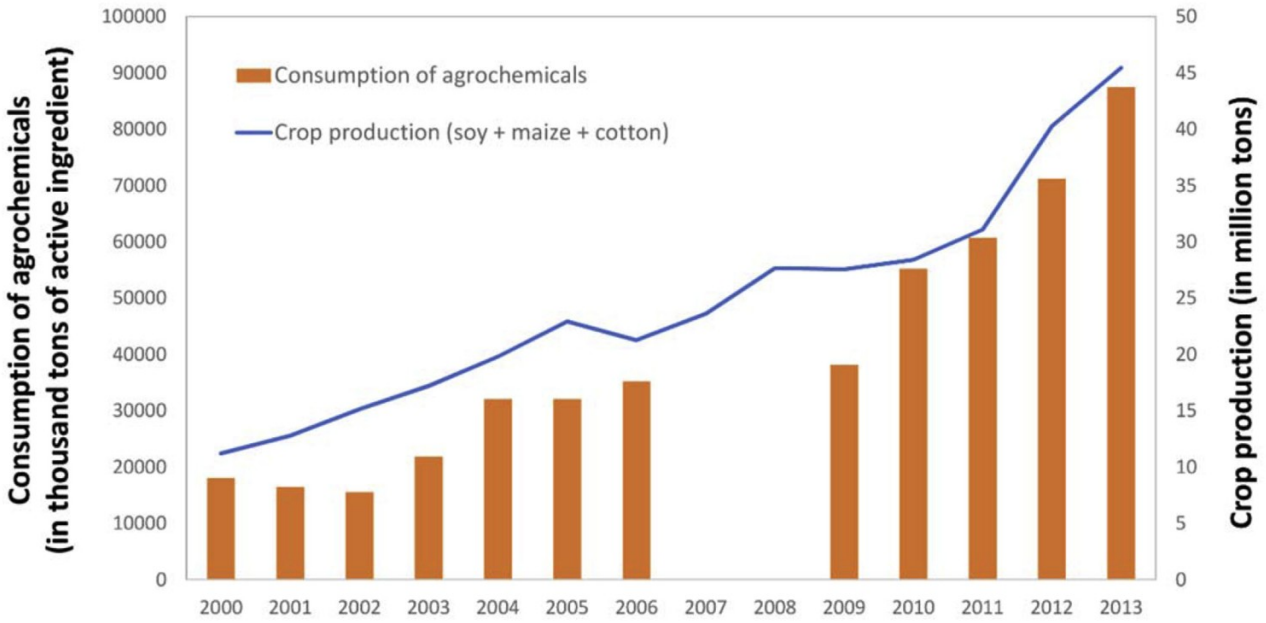
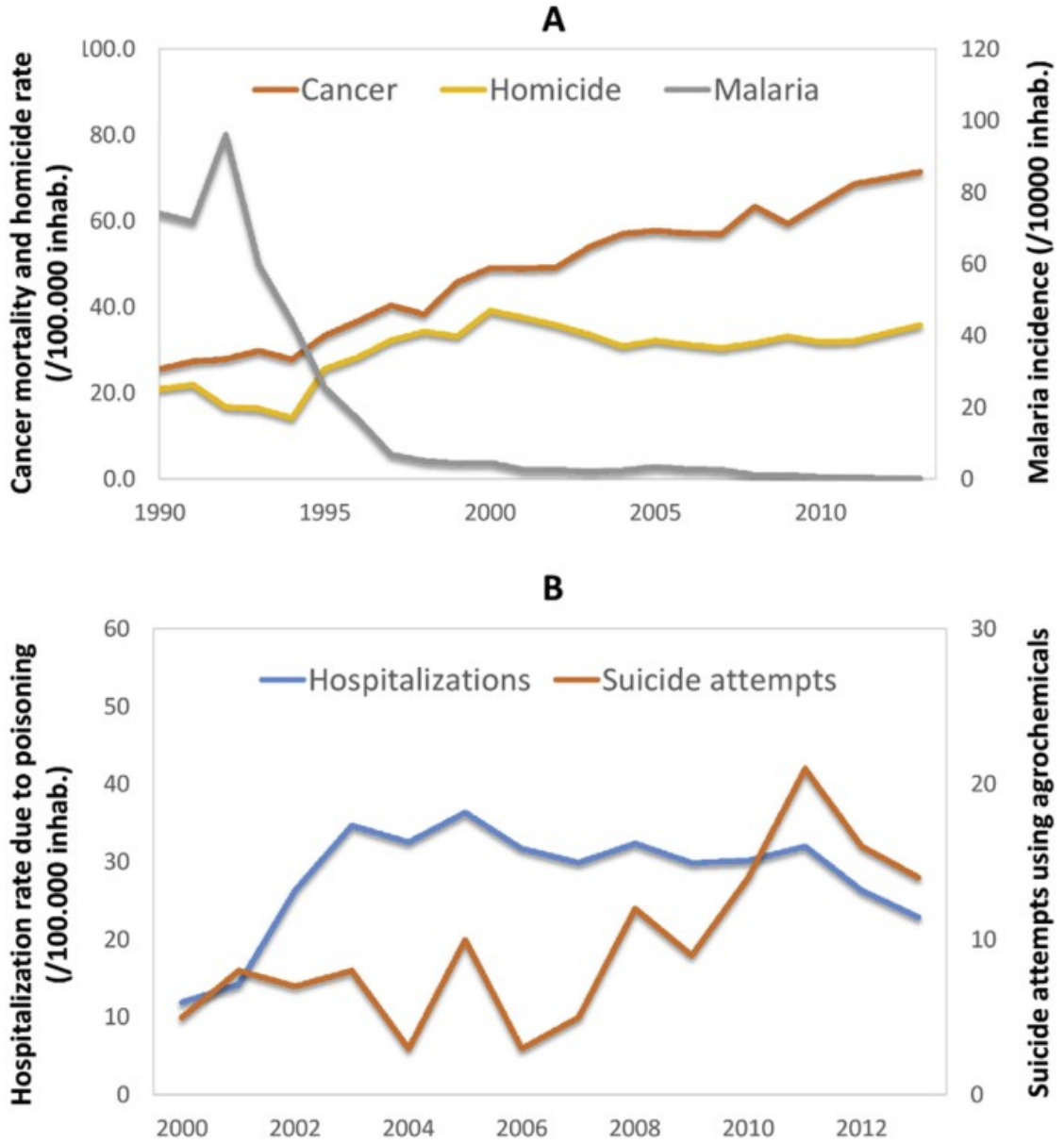


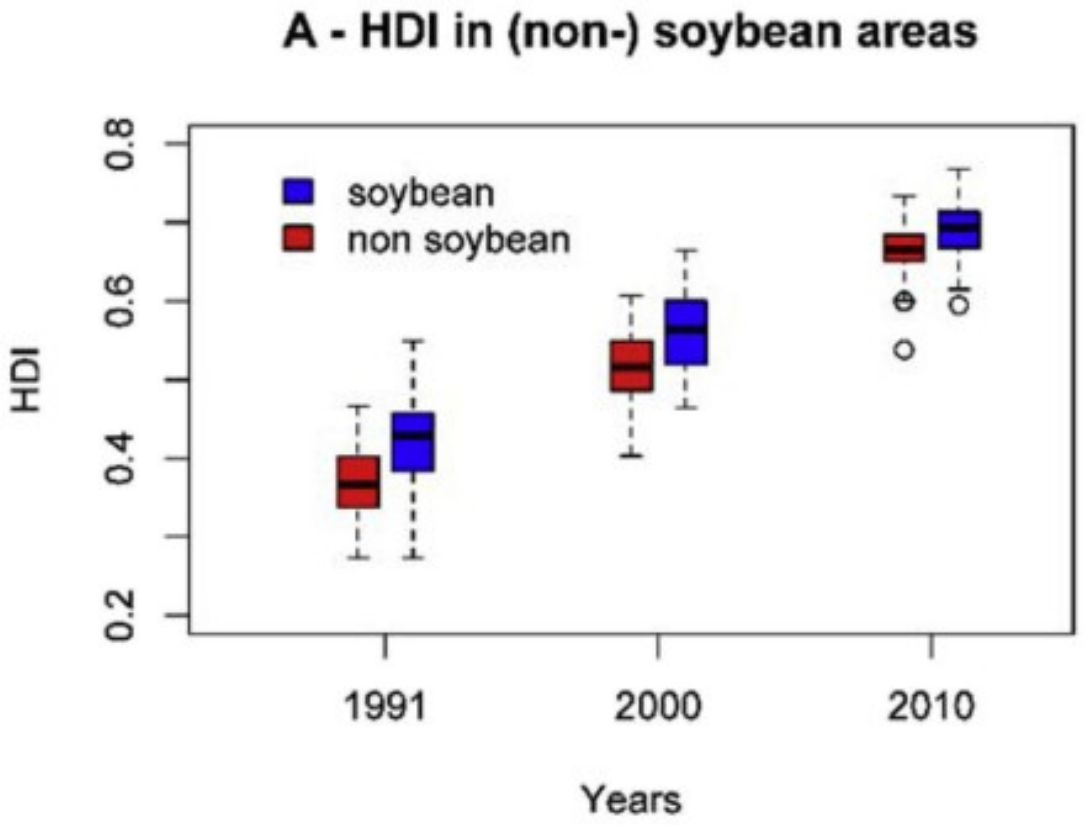

**Fig. 2.** Comparative evolution of crop production (soy + maize + cotton) and the consumption of agrochemicals in Mato Grosso from 2000 to 2013 (no data available for 2007 and 2008).

**Health metrics…**
**what relation with agrochemicals ?**



# Agricultural expansion/intensification => life conditions

**Human development Index...**




**...and...**

**...Violence**

FOLHA DE S.PAULO

s praias educação coronavírus saúde ambiente mobilidade mortes

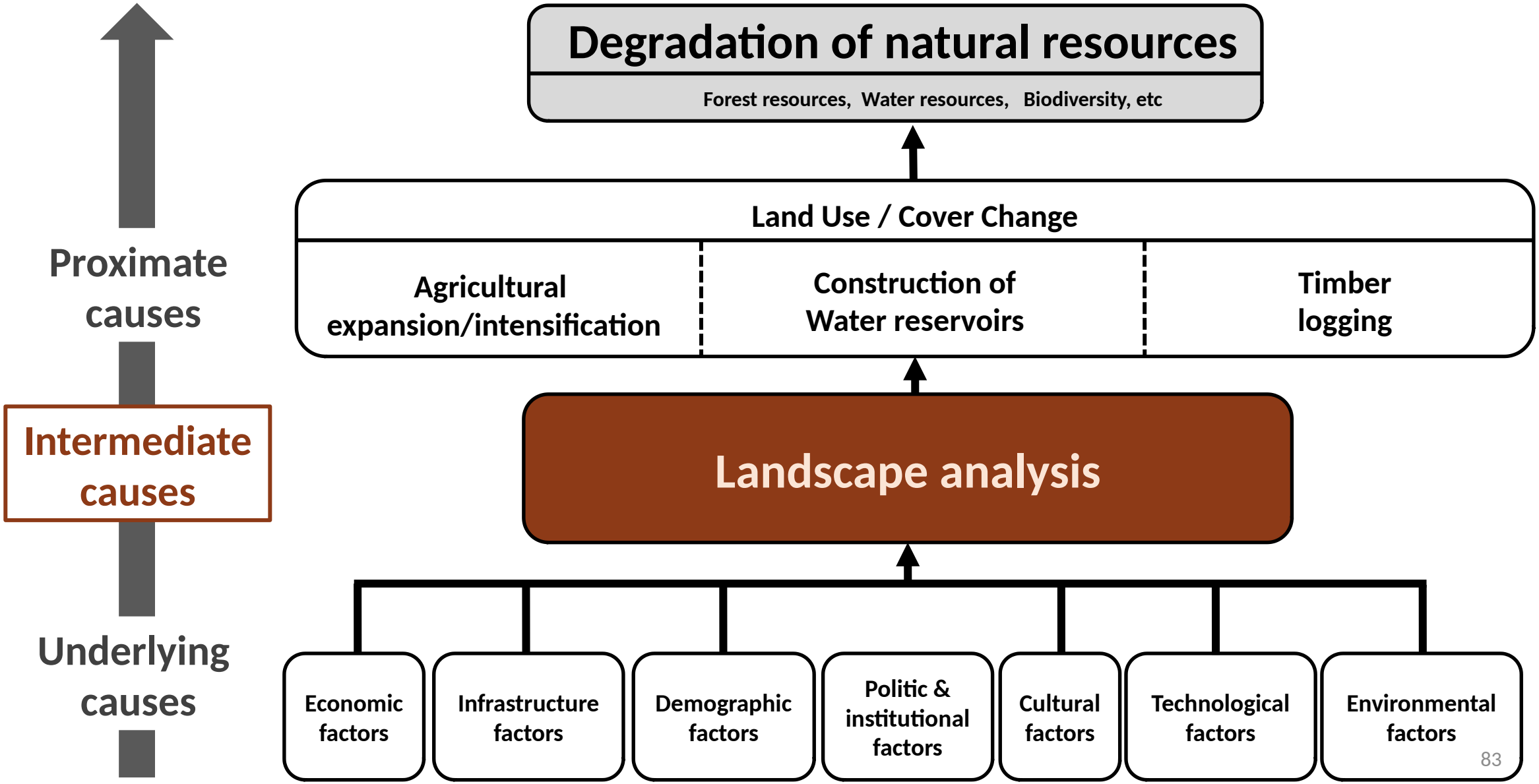
Especial: R$1,90 no 1º mês

VIOLÊNCIA

## Sorriso, capital do agro, vira epicentro de guerra de facções no Centro-Oeste

Comando Vermelho e PCC se enfrentam na rica cidade de Mato Grosso desde o ano passado, em batalha que já resultou em mais de cem mortes

# New research perspectives

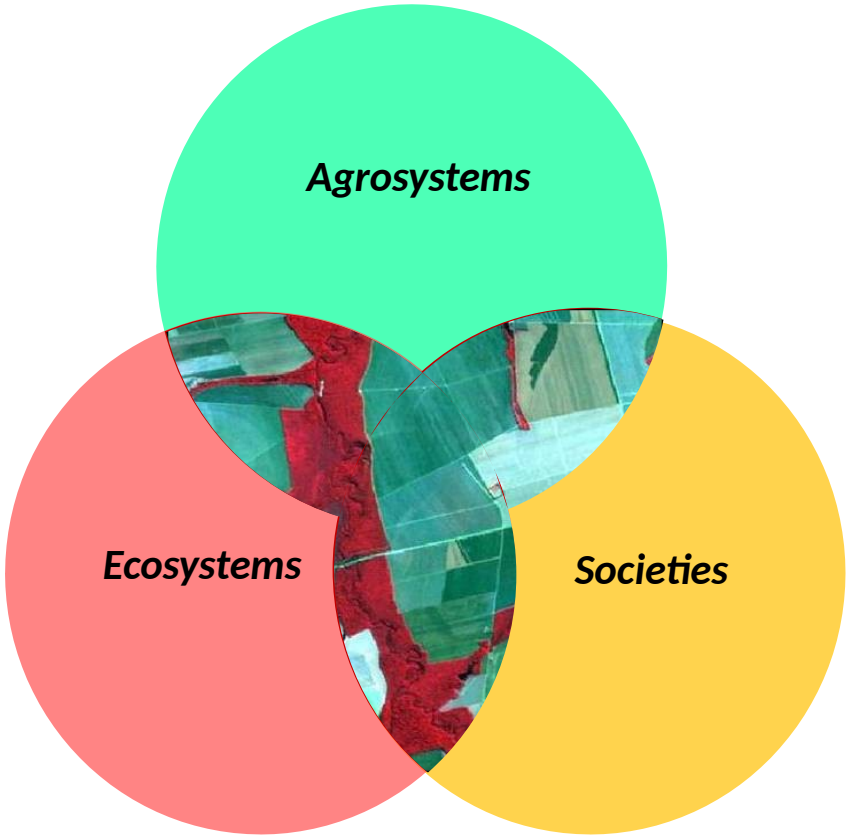


# New research perspectives

## From pixel to landscape

**Indicator of nature-society interactions**

Agricultural landscape
in Bolivia



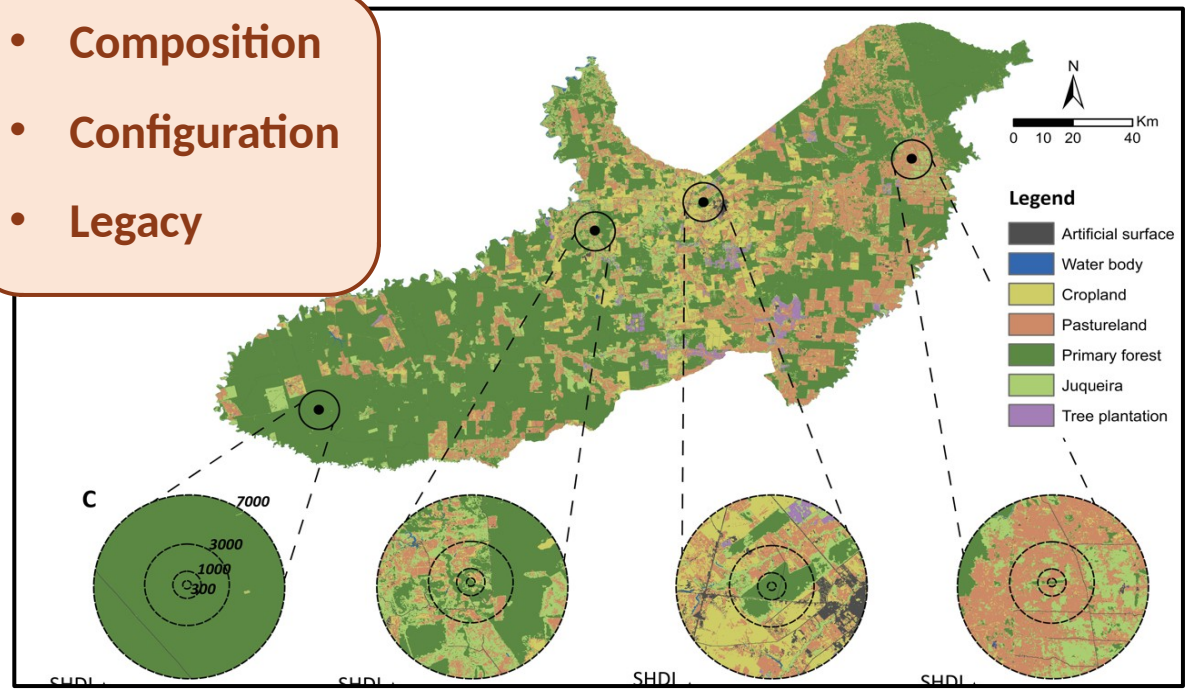

Another agricultural landscape
in Bolivia

# New research perspectives

## Various dimensions of landscape characterization

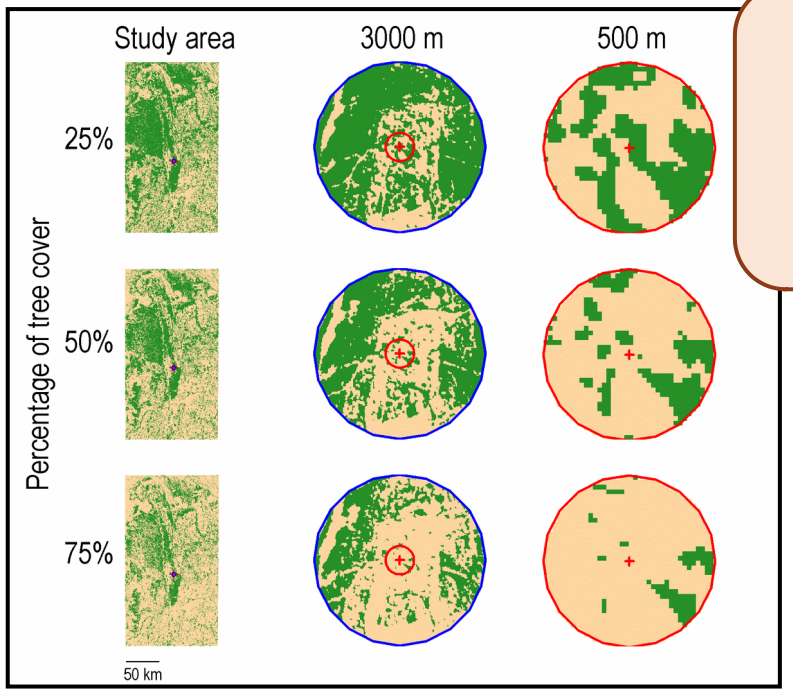
### Application to landscape ecology

- Composition
- Configuration
- Legacy




6 landscape metrics explained
58% of variance in forest Aboveground Biomass

*Bourgoin et al. 2021*

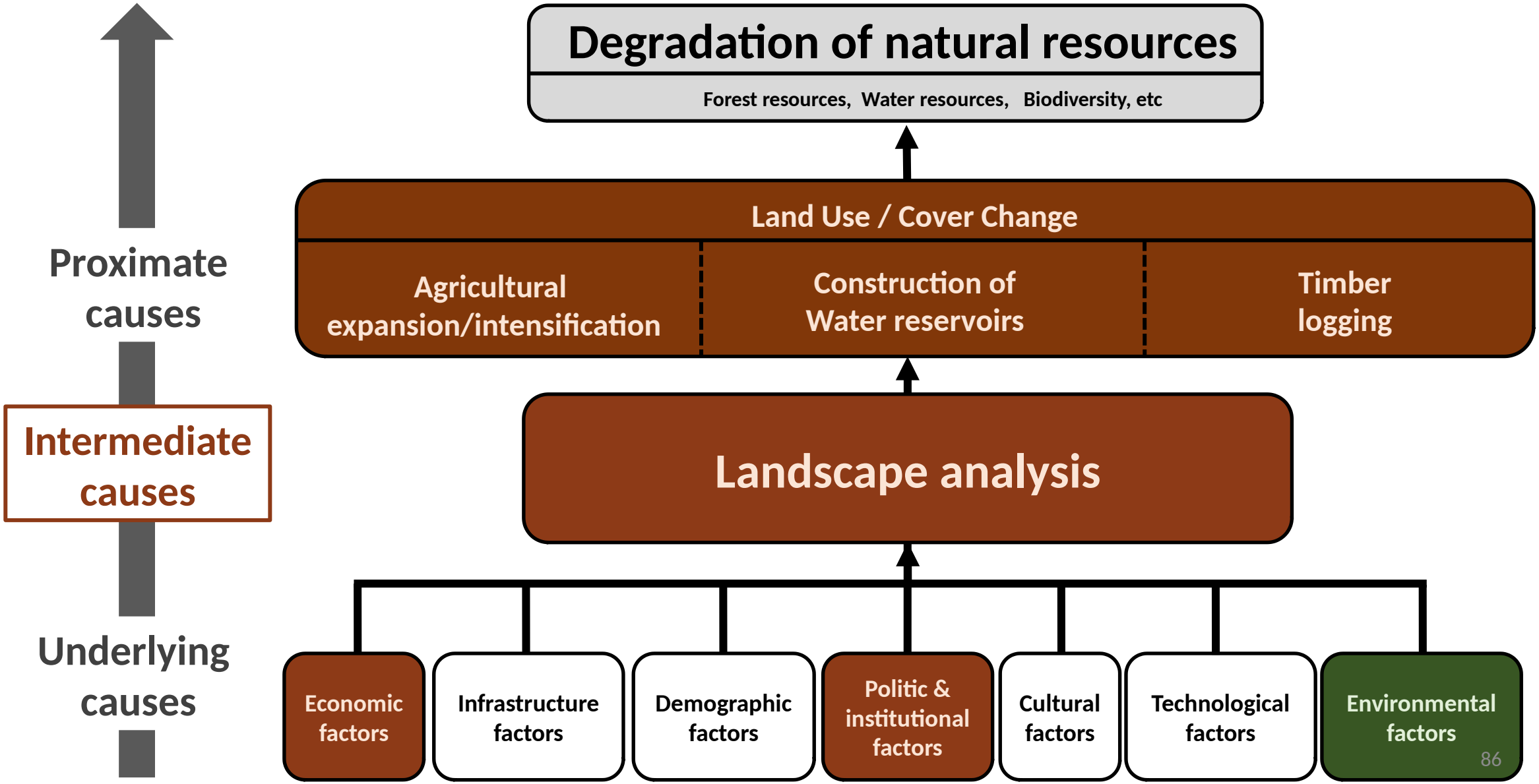



- Thematic
- Scale

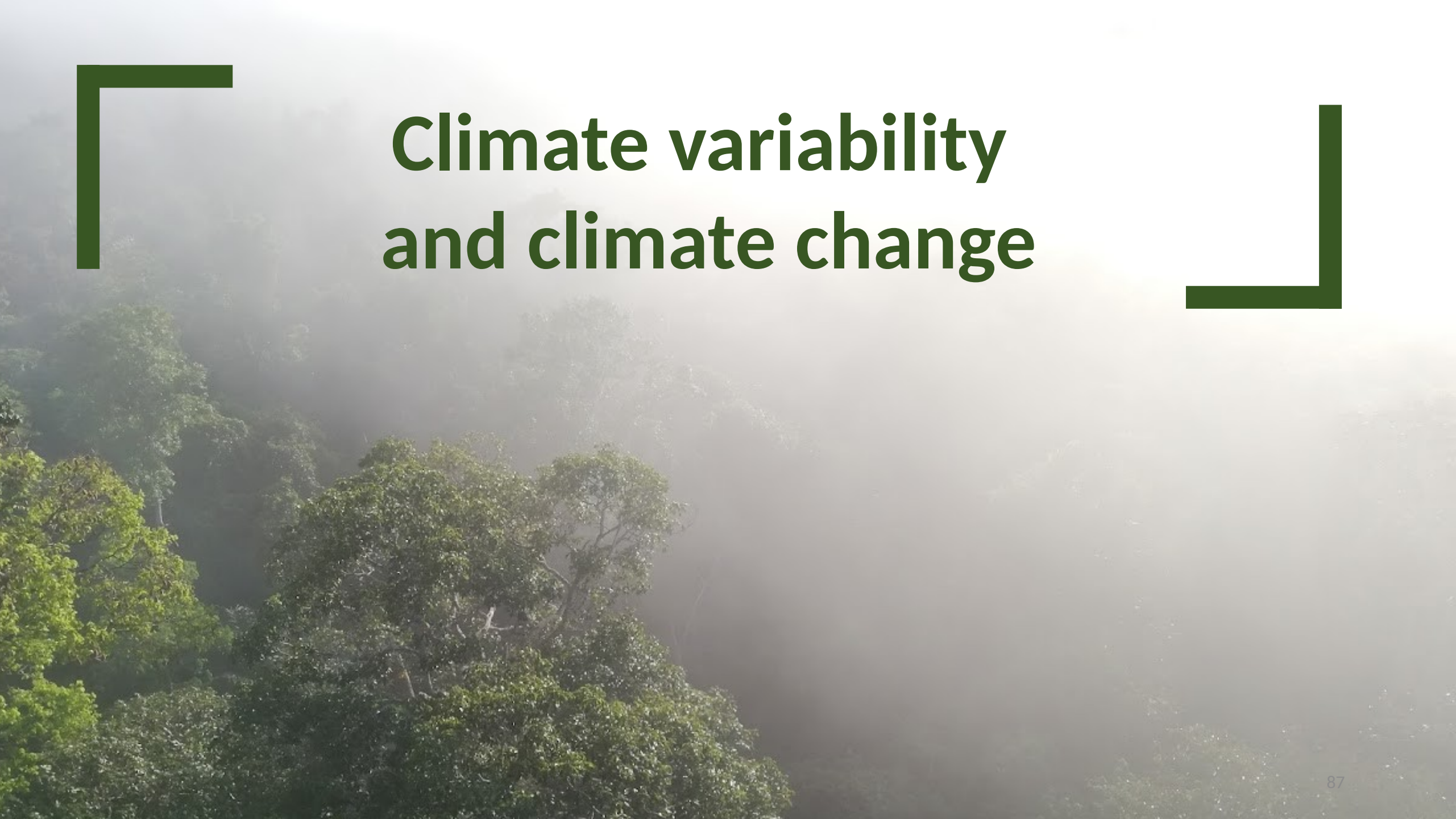
Species diversity depends on
1) the scale of analysis and 2) the definition of forest cover

*Amiot et al. 2021*

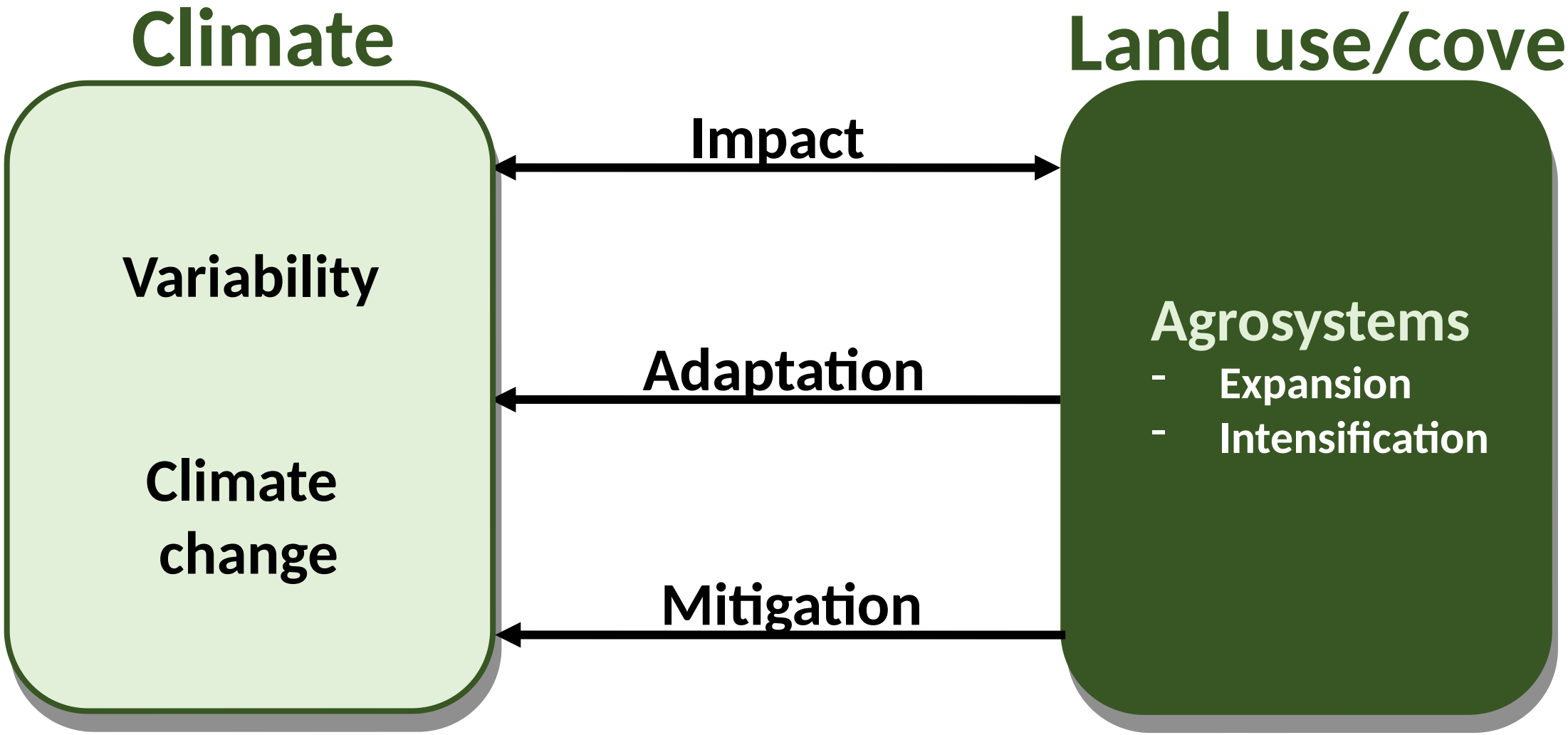
# Conceptual framework



# Climate variability and climate change



# Conceptual framework



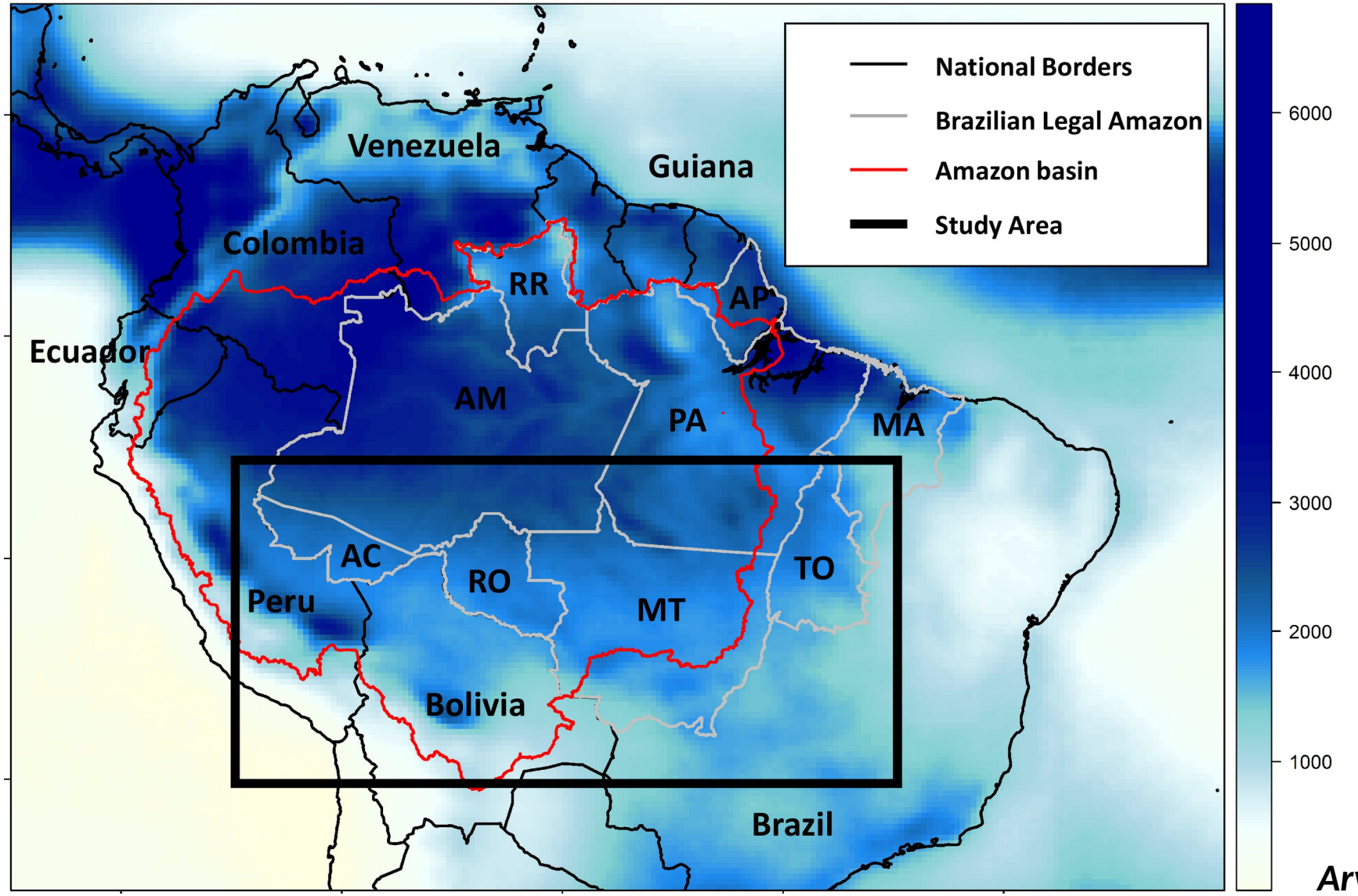
# Rainfall monitoring

TRMM

PERSIANN

CHIRPS

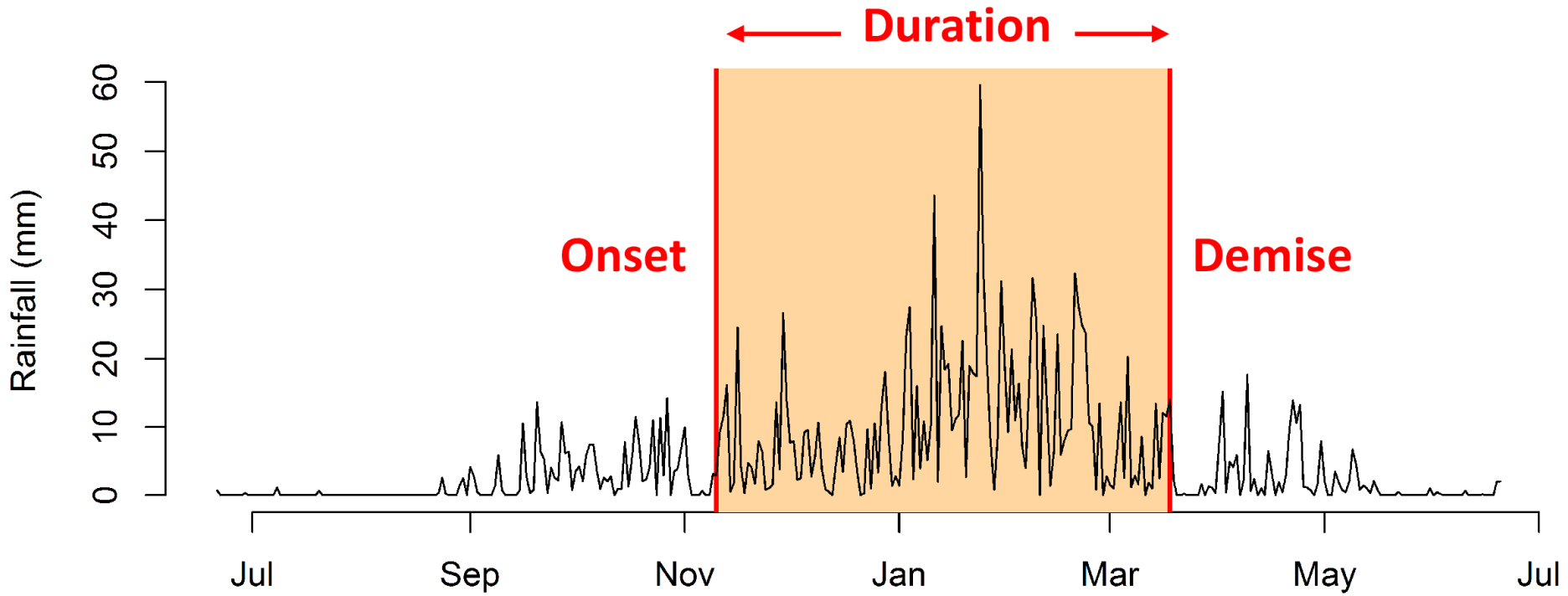
## Mean annual rainfall (mm) for the 1983-2014 time period




*Arvor et al. 2017*

# Rainfall monitoring

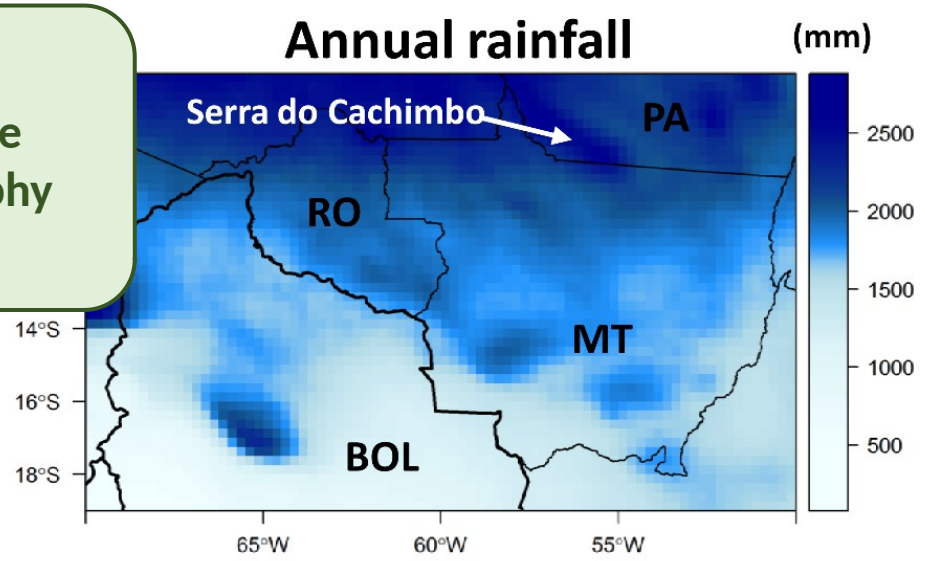
**A focus on the temporality of the rainy season**

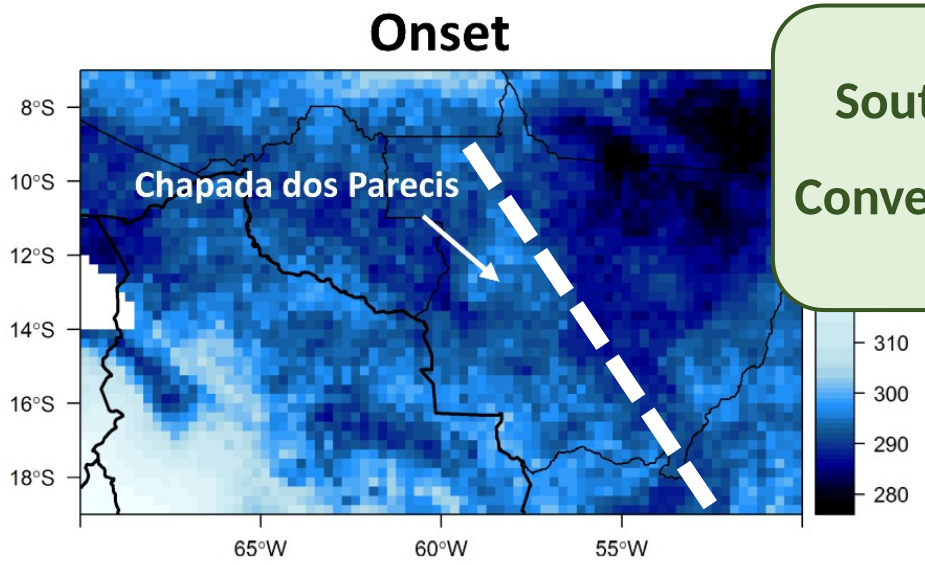



**Implementation of the Anomalous Accumulation (AA) method** (Liebmann et al. 2001)

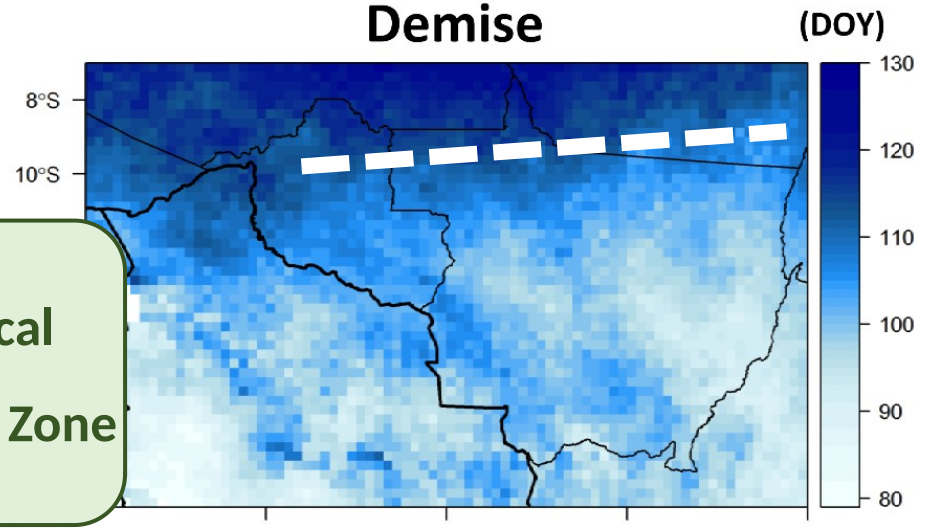
# Climate variability: spatial

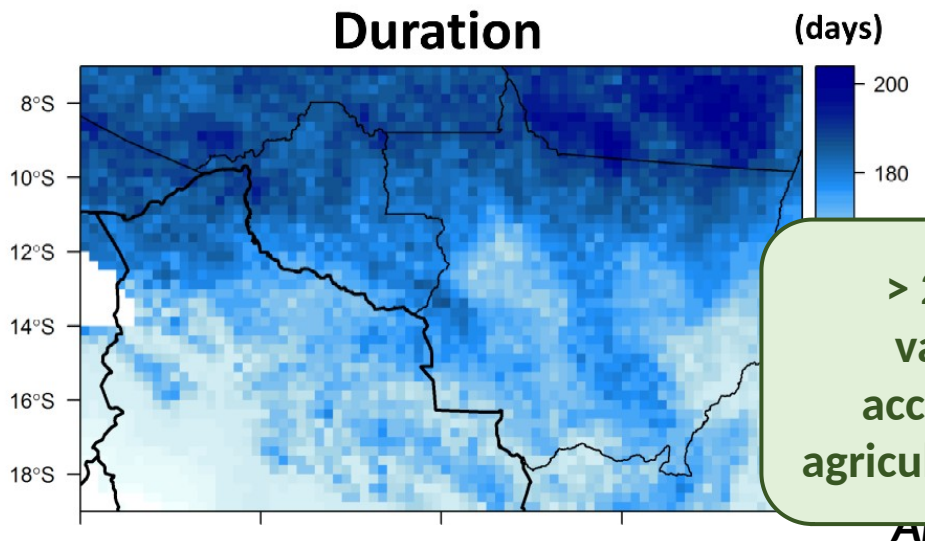
Importance of topography




South Atlantic Convergence Zone



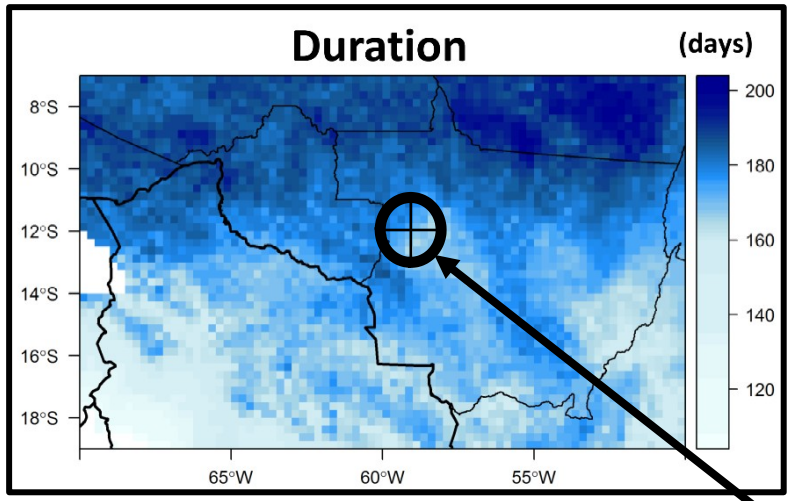

Inter-Tropical Convergence Zone

> 2 weeks variation according to agricultural region



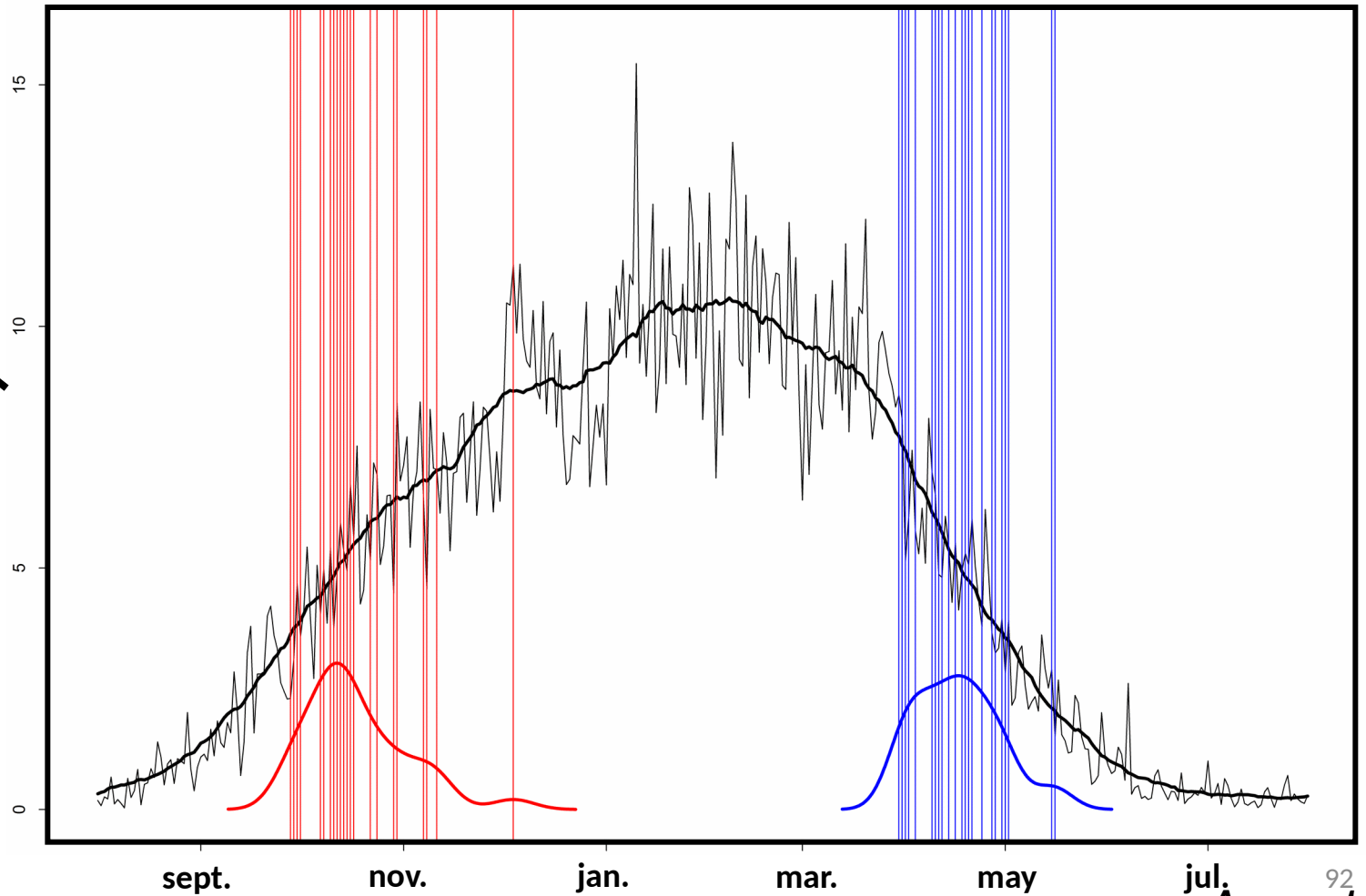
Arvor et al. 2017

# Climate variability: temporal




Onset dates

Demise dates




**Mean daily rainfall (mm)**

**High interannual variability**

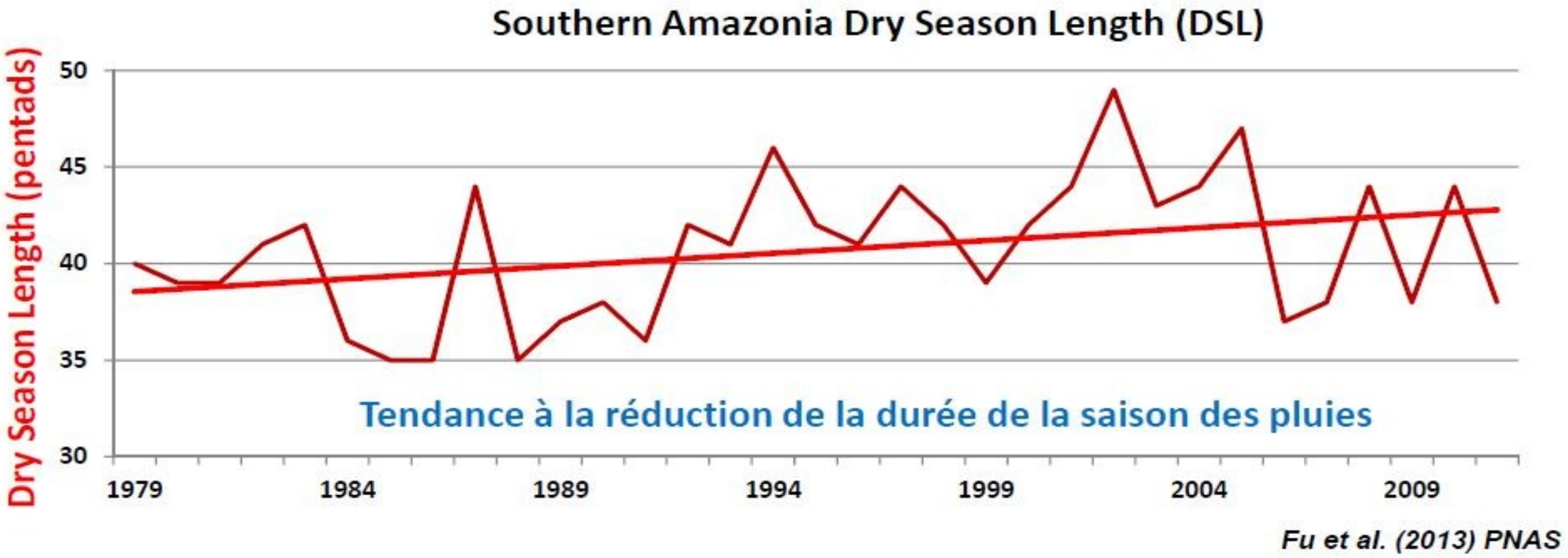


*Arvor et al. 2017*

# Climate change: rainy season

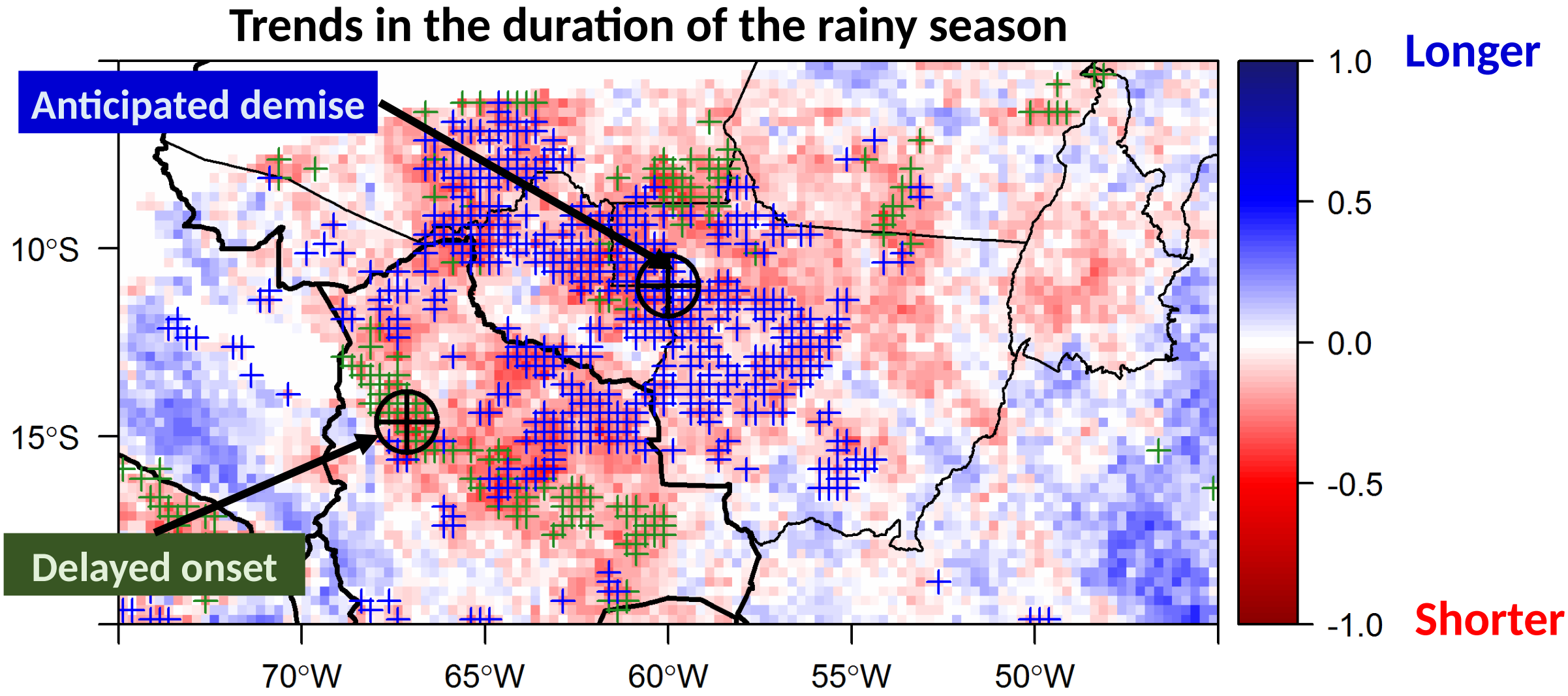
# Climate change: rainy season

**The dry season is becoming longer…**




*Fu et al. (2013) PNAS*

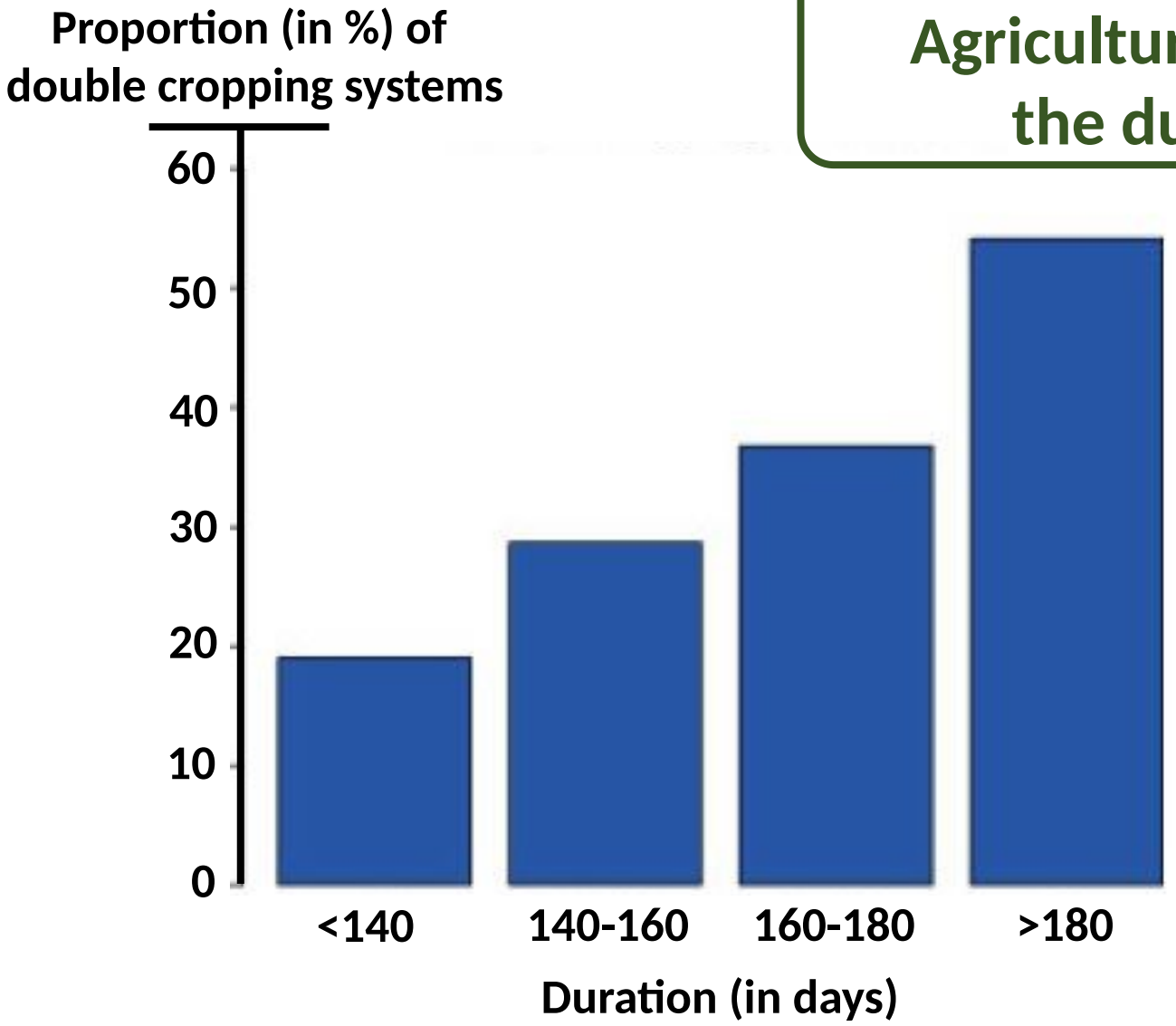
# Climate change: rainy season






*Arvor et al. 2017*

# Climate change and agricultural intensification




**Agricultural intensification depends on the duration of the rainy season**

**What future for double cropping systems in a climate change context?**



*Arvor et al. 2013*

# Climate change and agricultural intensification

***« Roughly 70% of the change in agricultural output caused by climate was determined by changes in frequency and/or changes in area.”***

e

| Total (%) | -1°C | Mean | +1°C |
|---|---|---|---|
| −30% | 7.0 | −2.4 | −9.5 |
| −20% | 9.1 | −1.1 | −8.6 |
| −10% | 10.5 | −0.2 | −8.2 |
| Local mean | 11.0 | 0.0 | −8.3 |
| 10% | 10.5 | −0.5 | −9.1 |
| 20% | 9.1 | −1.9 | −10.6 |
| 30% | 6.8 | −4.1 | −12.7 |

**“Cool and dry conditions were associated with the largest gains.”**

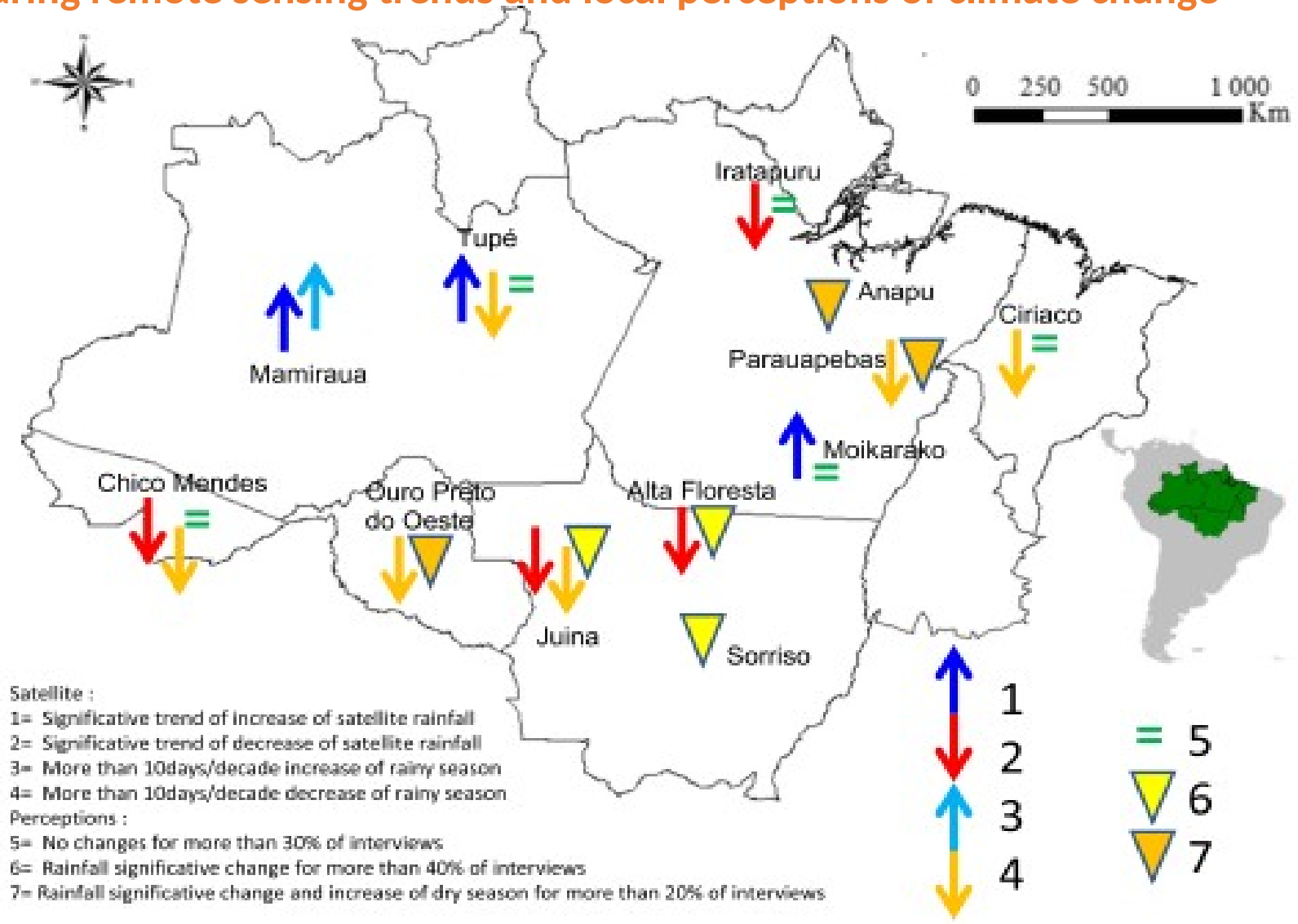
**“Hot and wet conditions were associated with the largest losses.”**

**Need for a better analysis of rainfall repartition during the rainy season**

*Cohn et al. Nature Climate Change 2016*

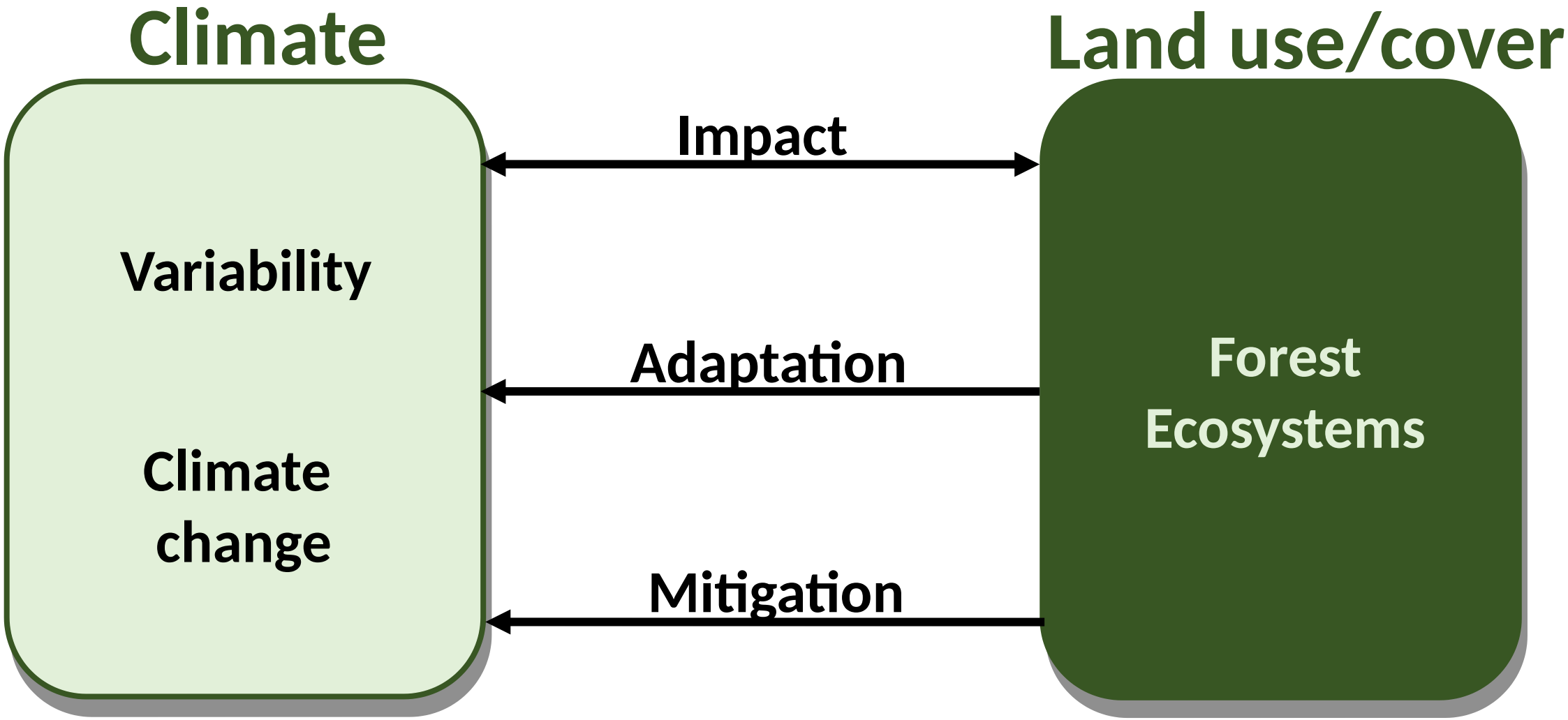
# Climate change : perceptions

## Comparing remote sensing trends and local perceptions of climate change




Dubreuil et al. 2017. Climatic Change

# New research perspective



# Climate variability and forest phenology

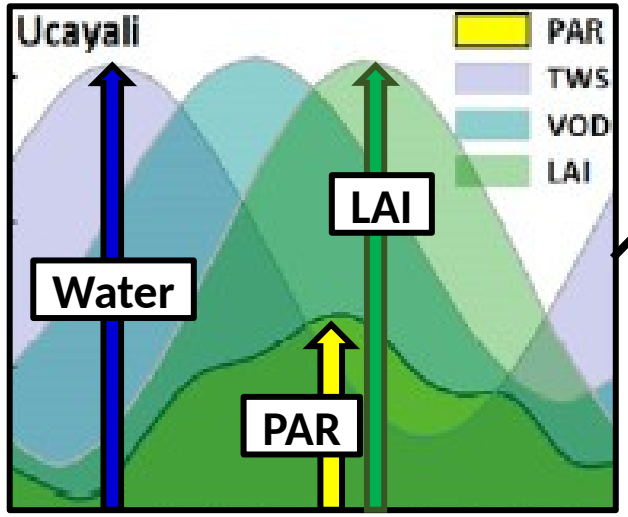
## Light-limited forests

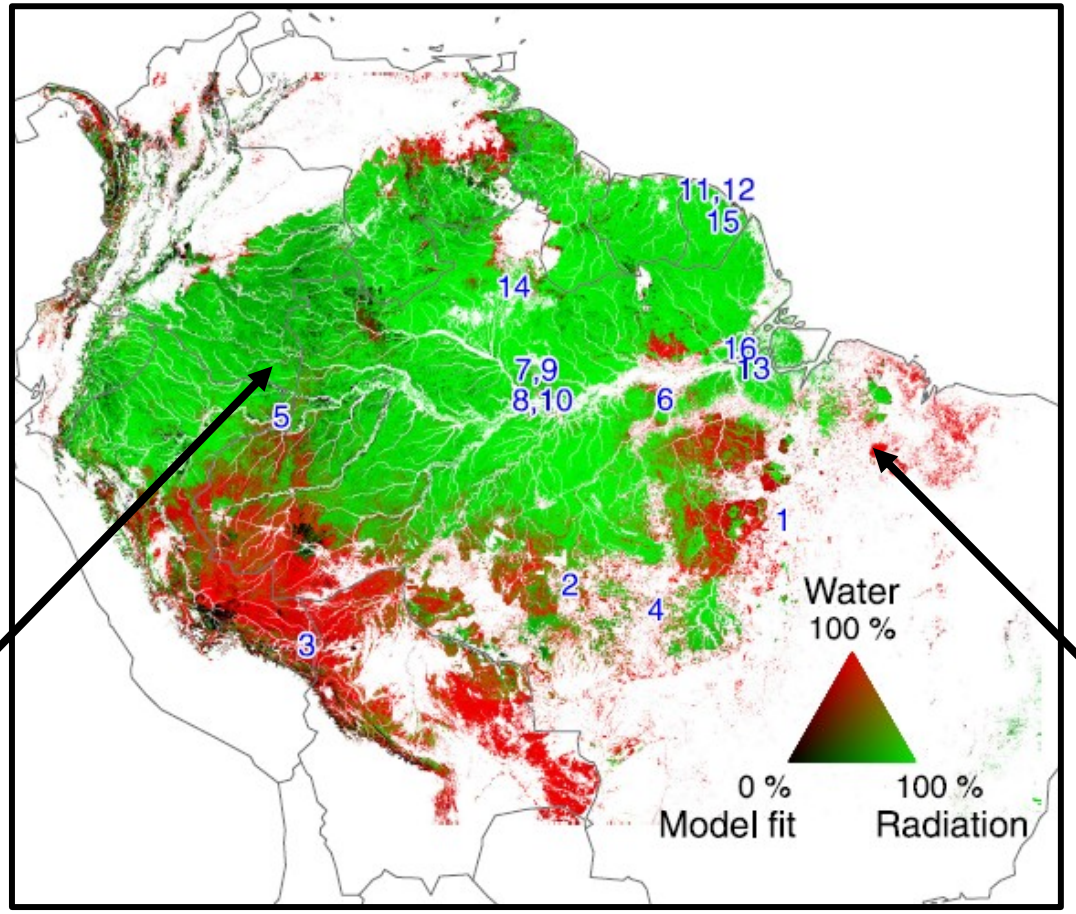
Phenology

⇕

PAR

(Photosyntetically Active Radiation)



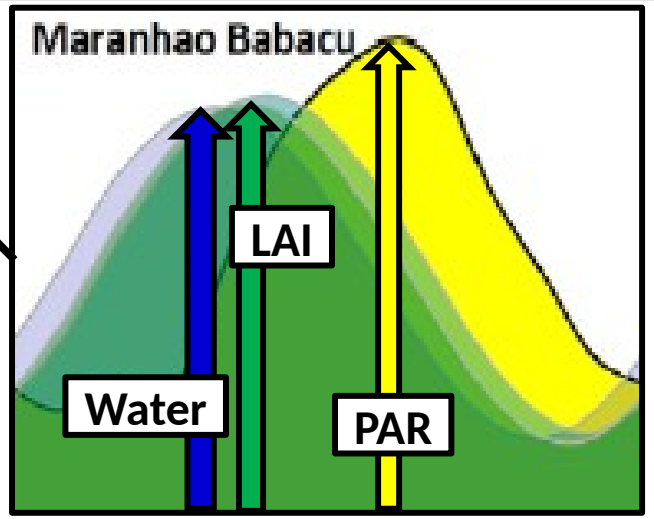

*Wagner et al. 2017*

## Water-limited forests

Phenology

⇕

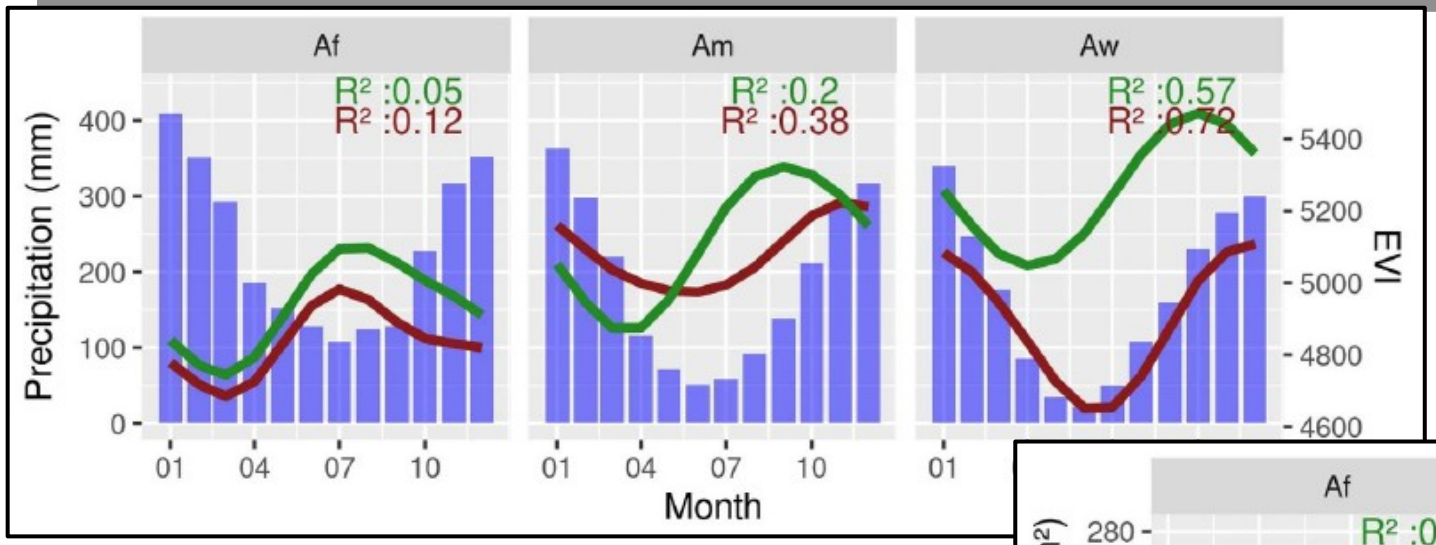
Water




*Jones et al. 2014*

# Climate variability and forest phenology

## Does forest degradation affect the phenology-climate interactions?

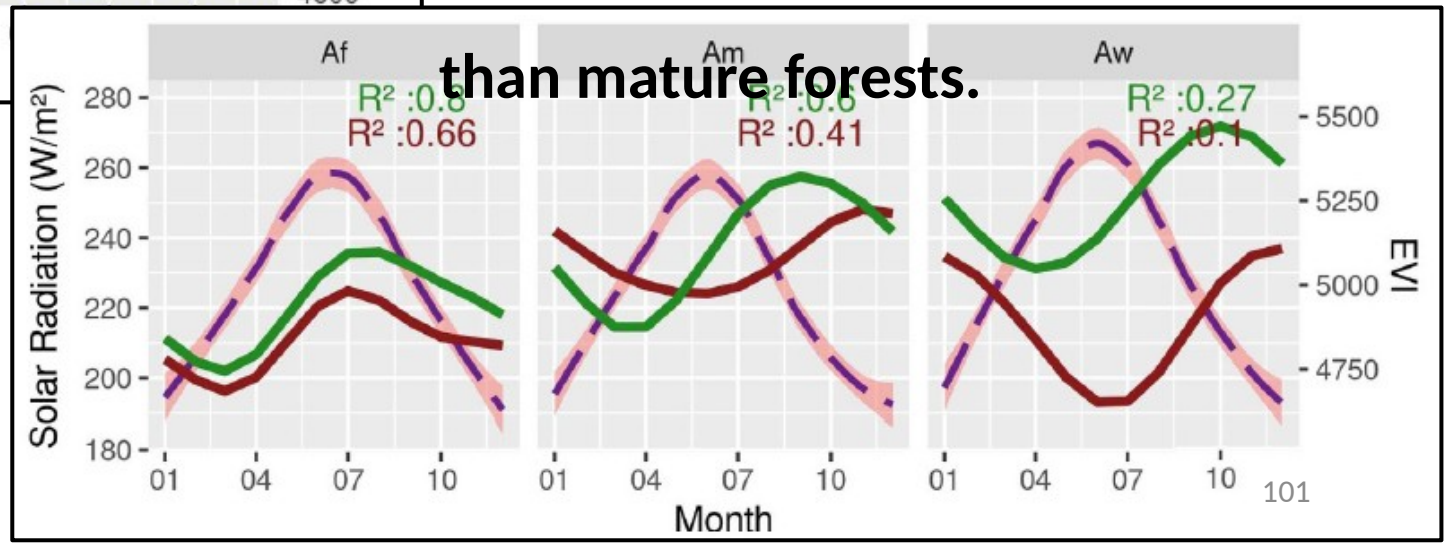



**Phenology of fire-degraded forests is:**

- **better correlated with rainfall**
- **less correlated with solar radiation**

***Le Roux et al. 2022***

**than mature forests.**




**Fire-degraded forests**
**=>**
**water-limited forests ?**

# Climate change and forest phenology

**Is climate change a driver of forest degradation?**

↳ Increased severity of droughts = more fire-degraded forests ?

**How does climate change impact forest phenology?**

↳ Shorter rainy season = expansion of water-limited forests?

**Does climate change impact the resilience of forest ecosystems?**

↳ Shorter rainy season + increased frequency of droughts
= decreased capacity of forest to recover?

# Conclusion

# Main answers to research question

**Processes of land occupation ?**

**Implications for land use sustainability … ?**

**… in a climate change context ?**

**Monitoring of socio-environmental dynamics ?**

# Main answers to research question

| | |
|---|---|
| Processes of land occupation ? | Então… |
| Implications for land use sustainability … ? | Pois é… |
| … in a climate change context ? | Veja só… |
| Monitoring of socio-environmental dynamics ? | Vixe Maria… |

# Main answers to research question

Processes of
land occupation ?

Implications for
land use sustainability … ?

… in a
climate change context ?

Monitoring of socio-
environmental dynamics ?


Vixe Maria…

# Main answers to research question

Processes of
land occupation ?

Implications for
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Monitoring of socio-
environmental dynamics ?


Vixe Maria…

# Merci / Thank you / Obrigado