Land Use Intensity Assessment – a Systematic Approach

Daniel Müller

VOLANTE Summer School – University of the Aegean, Lesvos

17 June 2013

Agriculture …

… allowed to sustain 7 billion people

… shaped the biosphere

The Environmental Footprint of Agriculture

- 40% of **land** used by agriculture
- 70% of **water** withdrawals
- 30% of greenhouse gas **emissions**
- 2x global **nutrient** cycles
- Largest driver of **biodiversity** loss

Foley et al. (2011), *Nature*

Rising Demand for Agricultural Products

- → **Population**
  - 2.5 billion more by 2070
  - Growing affluence

Rising Demand for Agricultural Products

- → **Population**
  - ○ 2.5 billion more by 2070
  - ○ Growing affluence
- → **Diets**
  - ○ Meat
  - ○ Processed food

Rising Demand for Agricultural Products

→ **Population**
- 2.5 billion more by 2070
- Growing affluence

→ **Diets**
- Meat
- Processed food

→ **Bioenergy**
- Traditional (80%)
- Modern (20%)

Rising Demand for Agricultural Products

→ Population

- 2.5 billion more by 2070
- Growing affluence

→ Diets

- Meat
- Processed food

→ Bioenergy

- Traditional (80%)
- Modern (20%)

guardian.co.uk

Key Concerns on Supply-Side

→ **Resource scarcity**

- Land, soil
- Water, fertilizer
- Energy

Key Concerns on Supply-Side

→ **Resource scarcity**
- Land, soil
- Water, fertilizer
- Energy

→ **Climate change**
- Volatility, extreme events
- Mitigation and adaptation

Key Concerns on Supply-Side

→ **Resource scarcity**
- Land, soil
- Water, fertilizer
- Energy

→ **Climate change**
- Volatility, extreme events
- Mitigation and adaptation

→ **Technology**
- Slower growth
- Difficult access

Key Concerns on Supply-Side

→ **Resource scarcity**
- Land, soil
- Water, fertilizer
- Energy

→ **Climate change**
- Volatility, extreme events
- Mitigation and adaptation

→ **Technology**
- Slower growth
- Difficult access



Looming Land Scarcity

→ Available land resources are diminishing

→ Competing interests over land

Global land use change, economic globalization, and the looming land scarcity

Eric F. Lambin[a,b,1] and Patrick Meyfroidt[b]

[a]School of Earth Sciences and Woods Institute, Stanford University, Stanford, CA 94305; and [b]Earth and Life Institute, Georges Lemaître Centre for Earth and Climate Research, University of Louvain, B-1348 Louvain-la-Neuve, Belgium

This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected in 2009.

Contributed by Eric F. Lambin, January 18, 2011 (sent for review November 21, 2010)

A Major Challenge for Humanity in the 21st Century

More agricultural production with less environmental impact

sciencedaily.com

Two Options to Increase Agricultural Production

1. **Expansion** of agricultural land
   - Most fertile land already used
   - Further expansion associated with high environmental tradeoffs

2. **Intensification** on existing agricultural land
   - More inputs per unit of land
   - Better technology

Most increase in agricultural production needs to come from **higher output per unit of land**, i.e. from <u>land-use intensification</u>

Major Research Issues

1. What are the **benefits** and **costs** of land-use intensification?

2. How can we better **conceptualize** land-use intensity from a land-system science perspective?

3. How can land-use intensity be better **measured** and **quantified**?

4. What are key future **tradeoffs** and **challenges**?

Outline

1. Historic Trends
2. Conceptualizing and Understanding
3. Measuring and Mapping
4. Tradeoffs and Challenges

Outline

1. Historic Trends
2. Conceptualizing and Understanding
3. Measuring and Mapping
4. Tradeoffs and Challenges

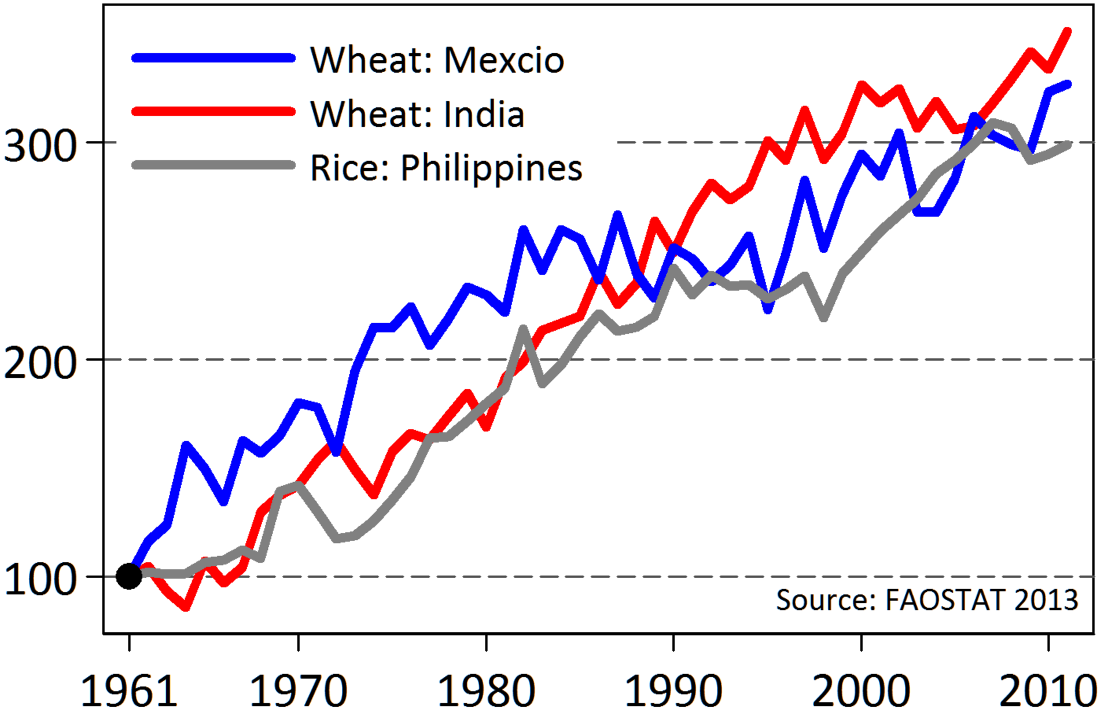
Green Revolution

- Breakthroughs in cereal productivity
- Proportion of hungry declined from 60% in 1960 to 17% in 2000 (Borlaug 2007, *Science*)

The Associated Press

Norman Borlaug

Yields (1961 = 100)



To produce the 2005 harvest with yields of 1961 would require additional 18 million km^2 cropland (Burney et al., 2010, *PNAS*)

Borlaug Hypothesis

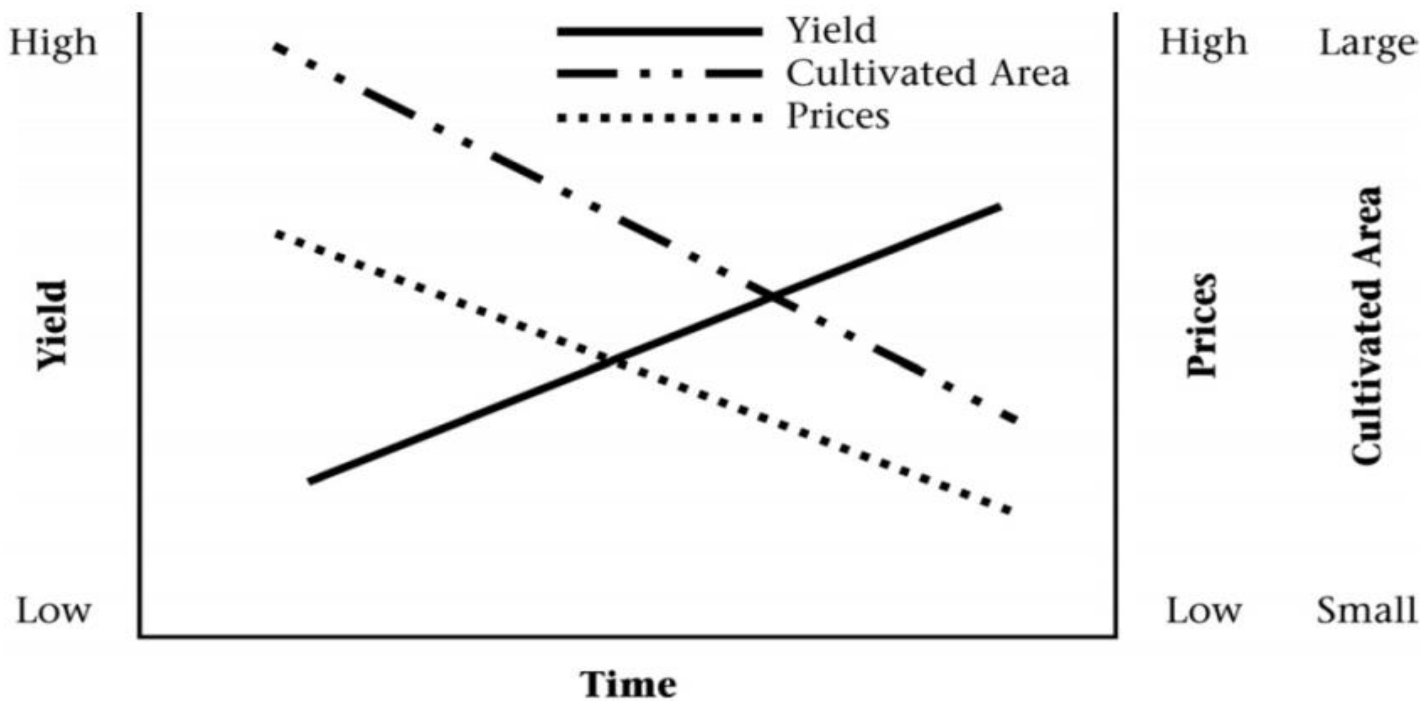
- Higher crop yields decrease land expansion

→ Provides opportunities for ecosystem services and biodiversity conservation

Norman Borlaug

The Associated Press

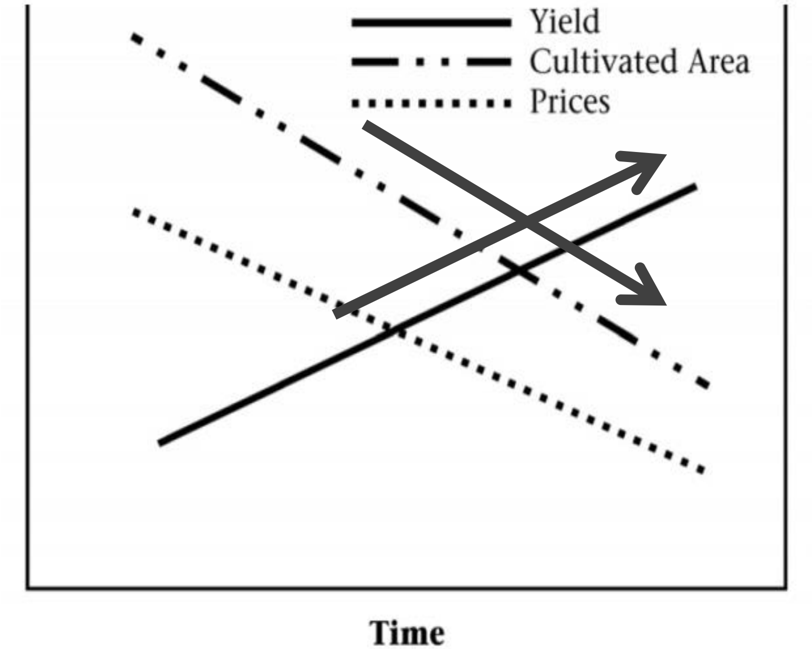
Borlaug World



Rudel et al. (2009), *PNAS*

Theory

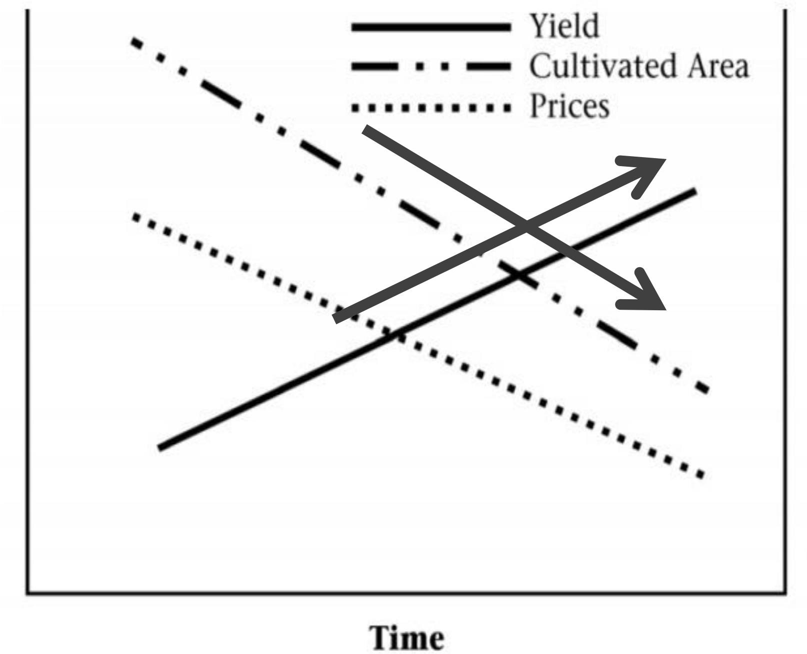
Borlaug World



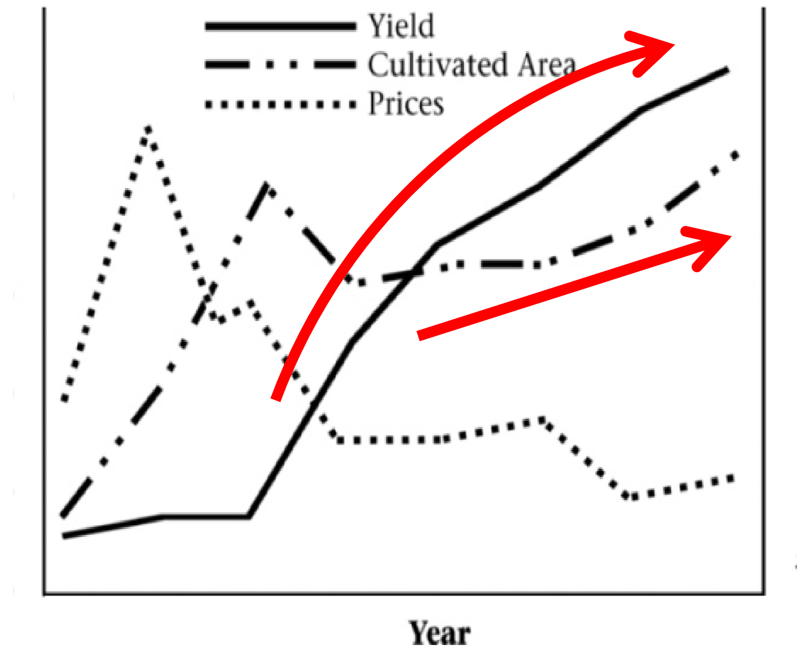
Rudel et al. (2009), *PNAS*

Theory and Evidence

Borlaug World



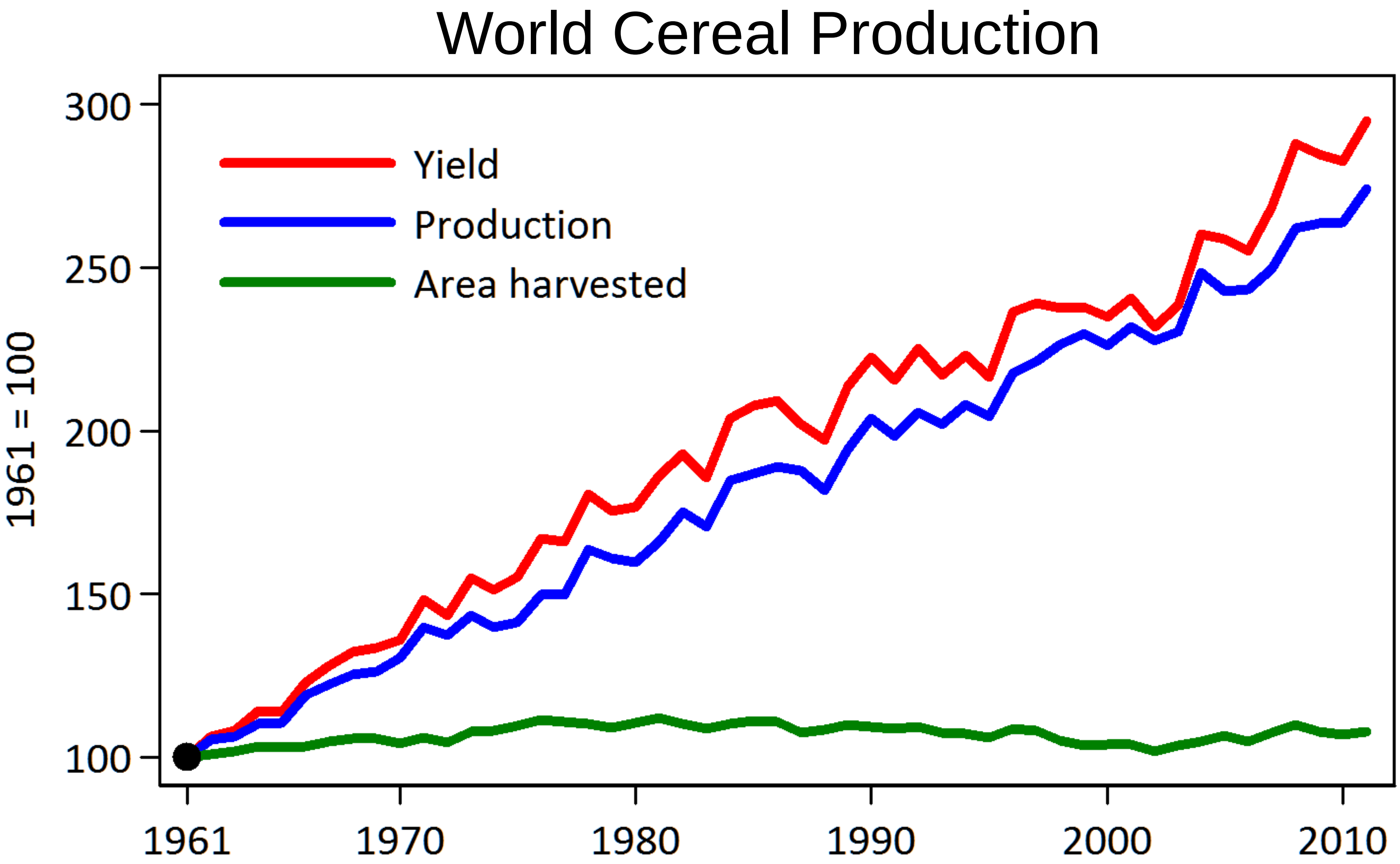
Real World



→ Improvements in efficiency and technology did not prevent further land expansion

Rudel et al. (2009), *PNAS*

Productivity Growth vs Area Expansion

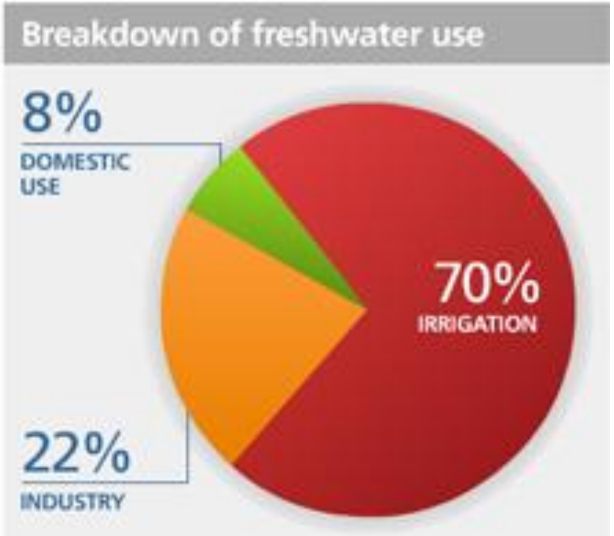


Source: FAOSTAT 2013

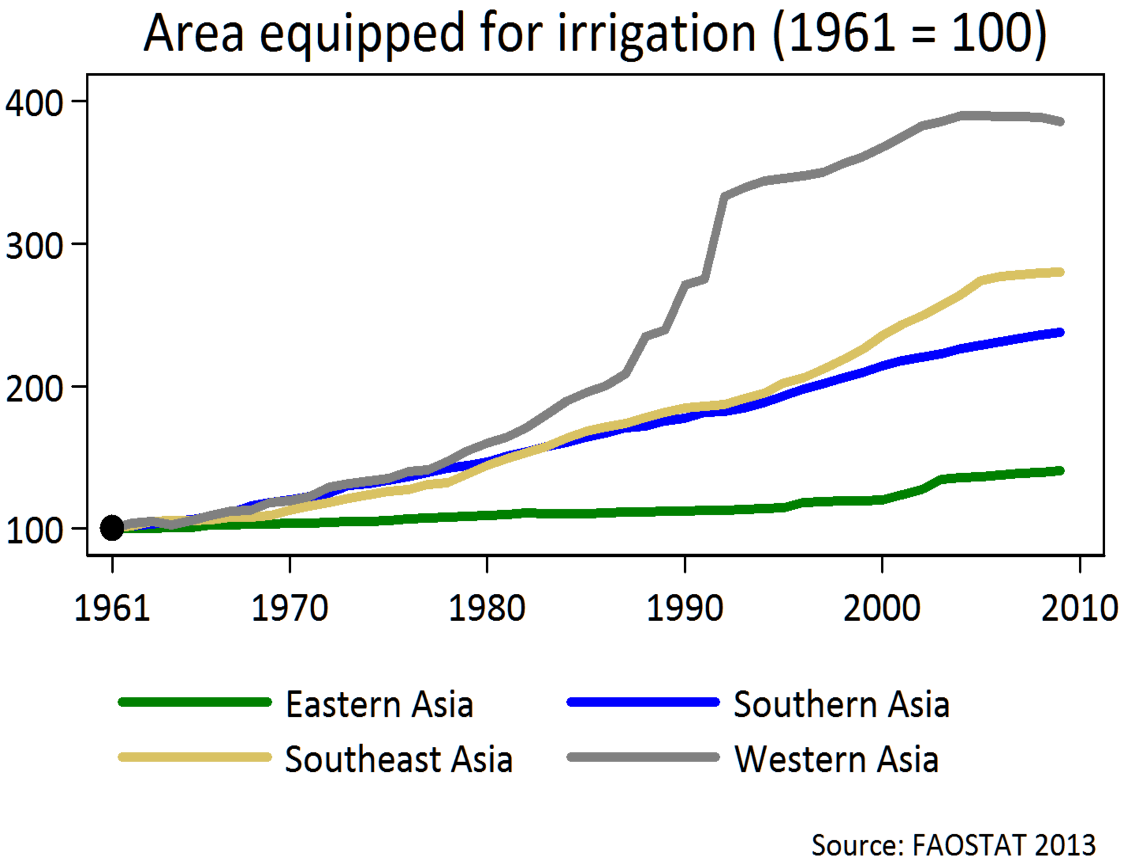
Environmental impacts of land-use intensification

Environmental Costs

1. Water consumption



Source: UN Water



Environmental Costs

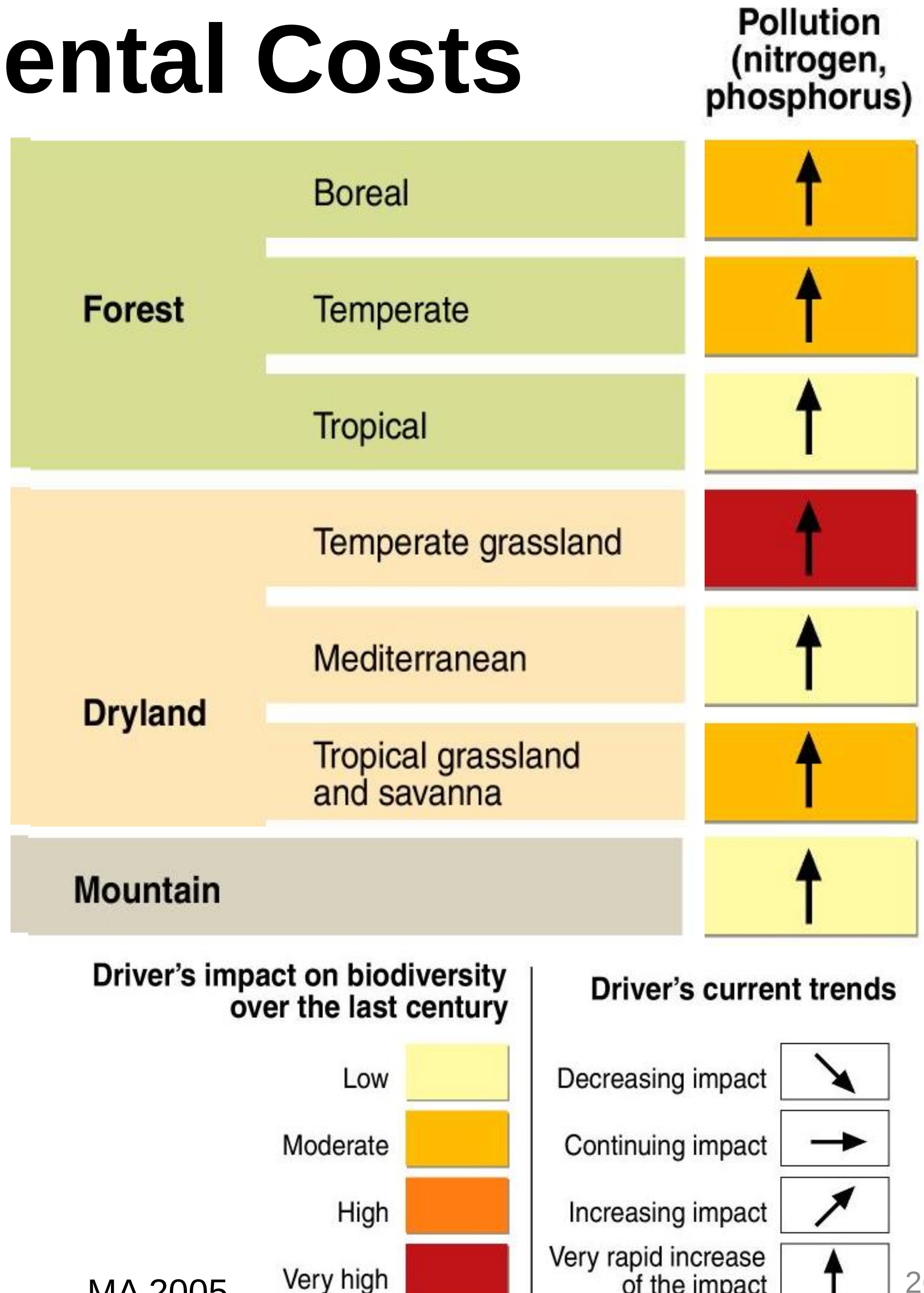
1. Water consumption
2. **Water quality**


Eutrophication from nitrate leaching


Phosphate mining

Environmental Costs

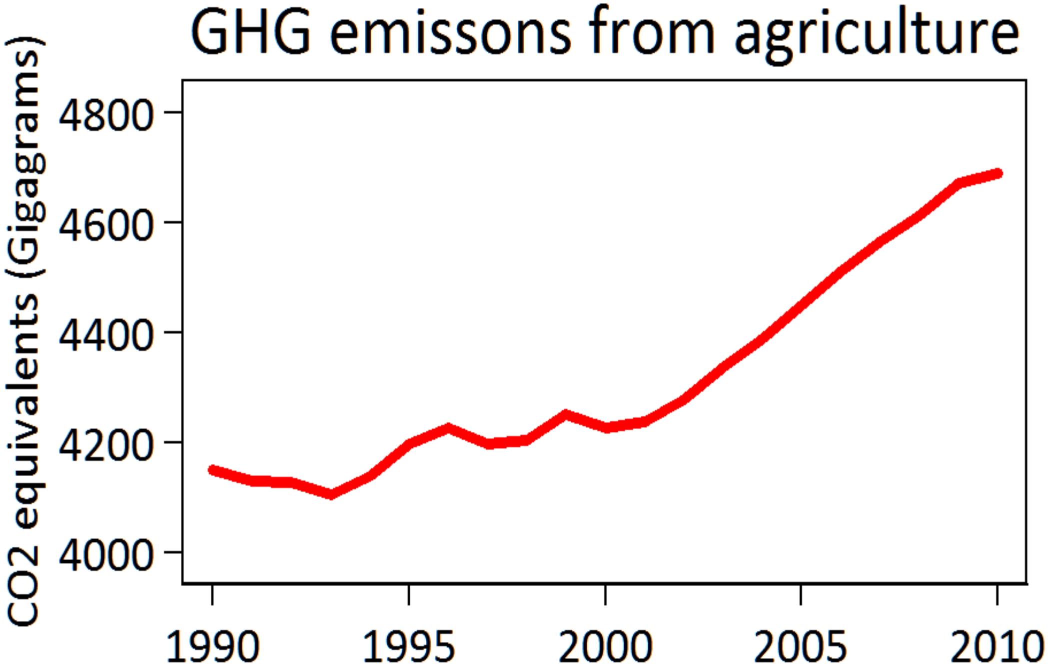
1. Water consumption
2. Water quality
3. **Biodiversity**



MA 2005

Environmental Costs

1. Water consumption
2. Water quality
3. Biodiversity
4. **GHG fluxes**



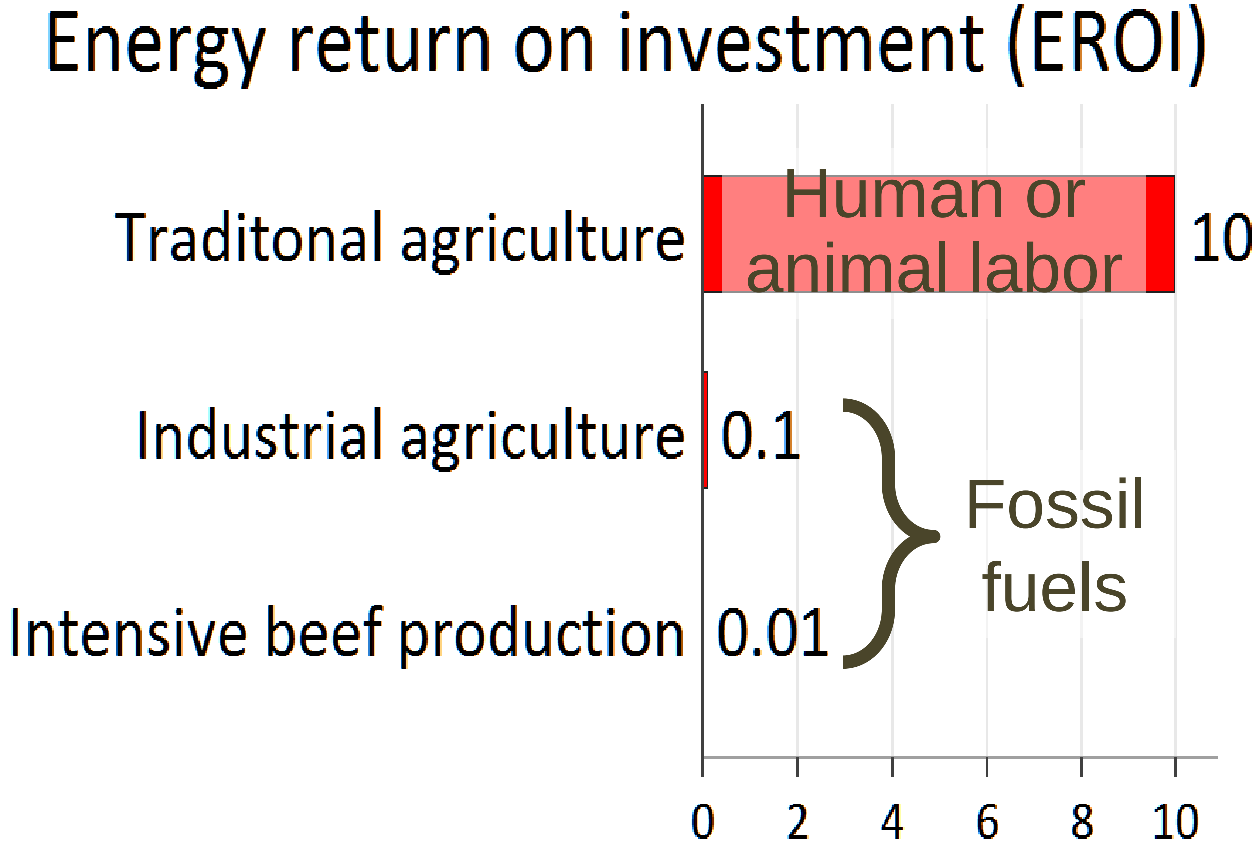
Source: FAOSTAT 2013

Environmental Costs

1. Water consumption
2. Water quality
3. Biodiversity
4. GHG fluxes
5. **Health**

Environmental Costs

1. Water consumption
2. Water quality
3. Biodiversity
4. GHG fluxes
5. Health
6. **Energy**



Note: Energy output / energy input, measured in calories.
Source: Pimentel (2008, 2009) and others.

Rebound Effects of Intensification

1. Jevons' Paradox

- Improvements in ***efficiency*** may not lead to reduction in resource consumption

→ Higher efficiency in land use often associated with negative environmental impacts

2. Paperless Office Paradox

- Development of ***substitutes*** may not lead to reduction in resource consumption

→ Technological advances to solve land-use dilemmas may have undesirable consequences

York (2006), *Human Ecology Review*; Lambin & Meyfroidt (2011), *PNAS*

A better understanding of the outcomes of land-use intensification is required

Wikipedia

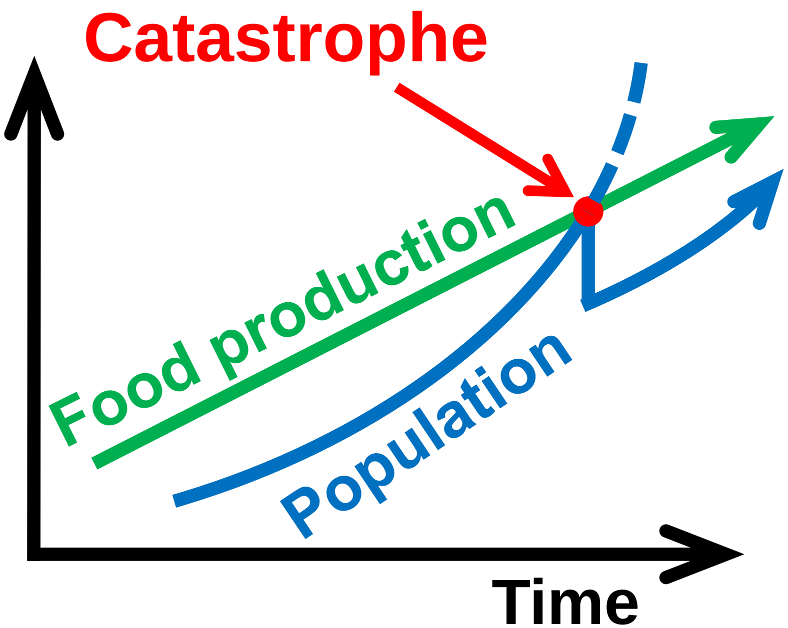
Outline

1. Historic Trends
2. Conceptualizing and Understanding
3. Measuring and Mapping
4. Tradeoffs and Challenges

Malthusian Perspective

- Population growth outpaces agricultural growth
- Balance restored by population checks (famine, war)

Thomas Malthus



→ Population growth **depends** on higher food supply

Malthus (1798), *An Essay on the Principle of Population*

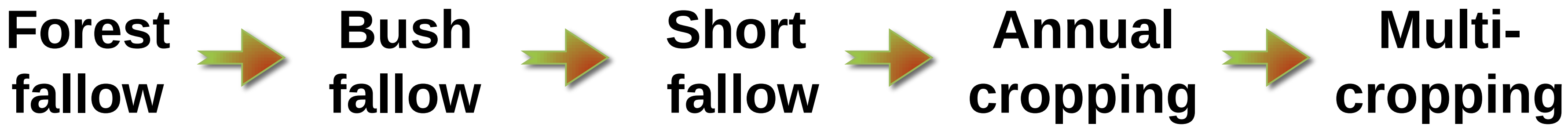
Boserupian Intensification

Ester Boserup

- Population growth induces innovation and intensification

→ Population growth **leads** to agricultural development

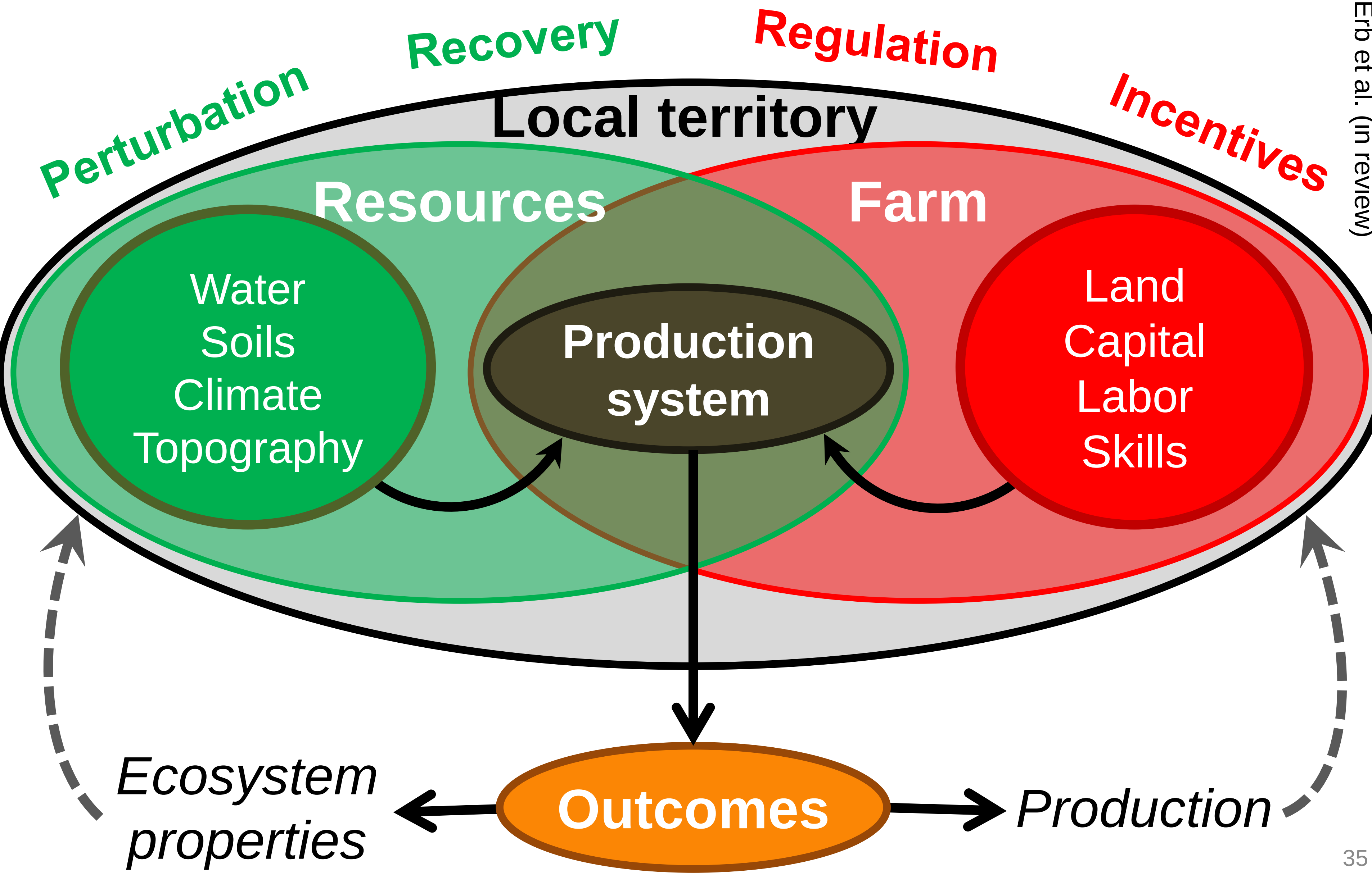
- Five stages of intensification (more labor per land)



- Shifts in intensification regimes shaped by land availability per capita

Boserup (1965), *The Conditions of Agricultural Growth*

Socioecological Framework



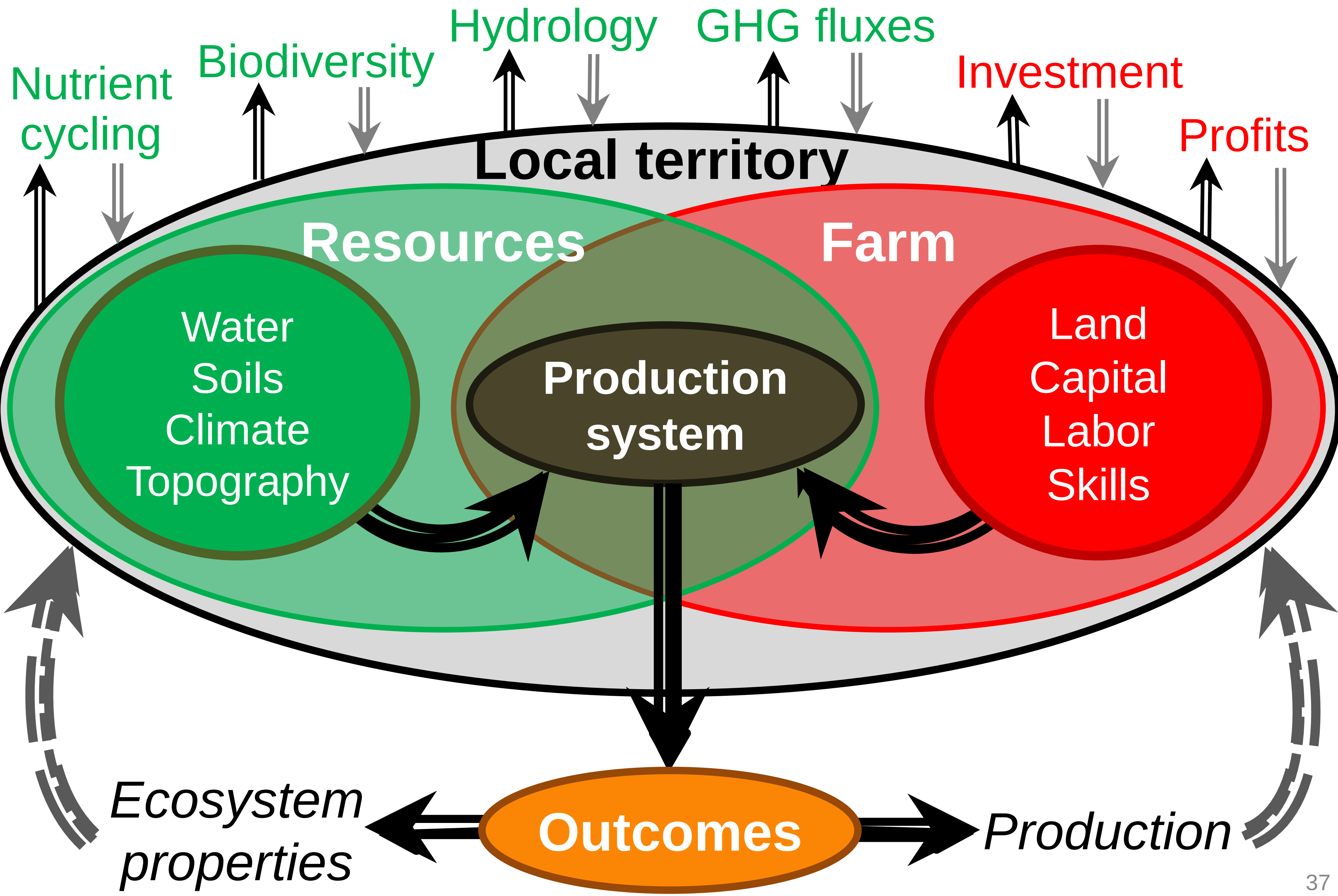
Inspired by Erb et al. (in review)

Land-Use Intensification:
More inputs per unit of land

1. **More capital**
   - Intermediate inputs
   - Mechanization
2. **More labor**
   - Family and wage labor
   - Improved skills
3. **More natural resources**
   - Water, soil
   - Energy

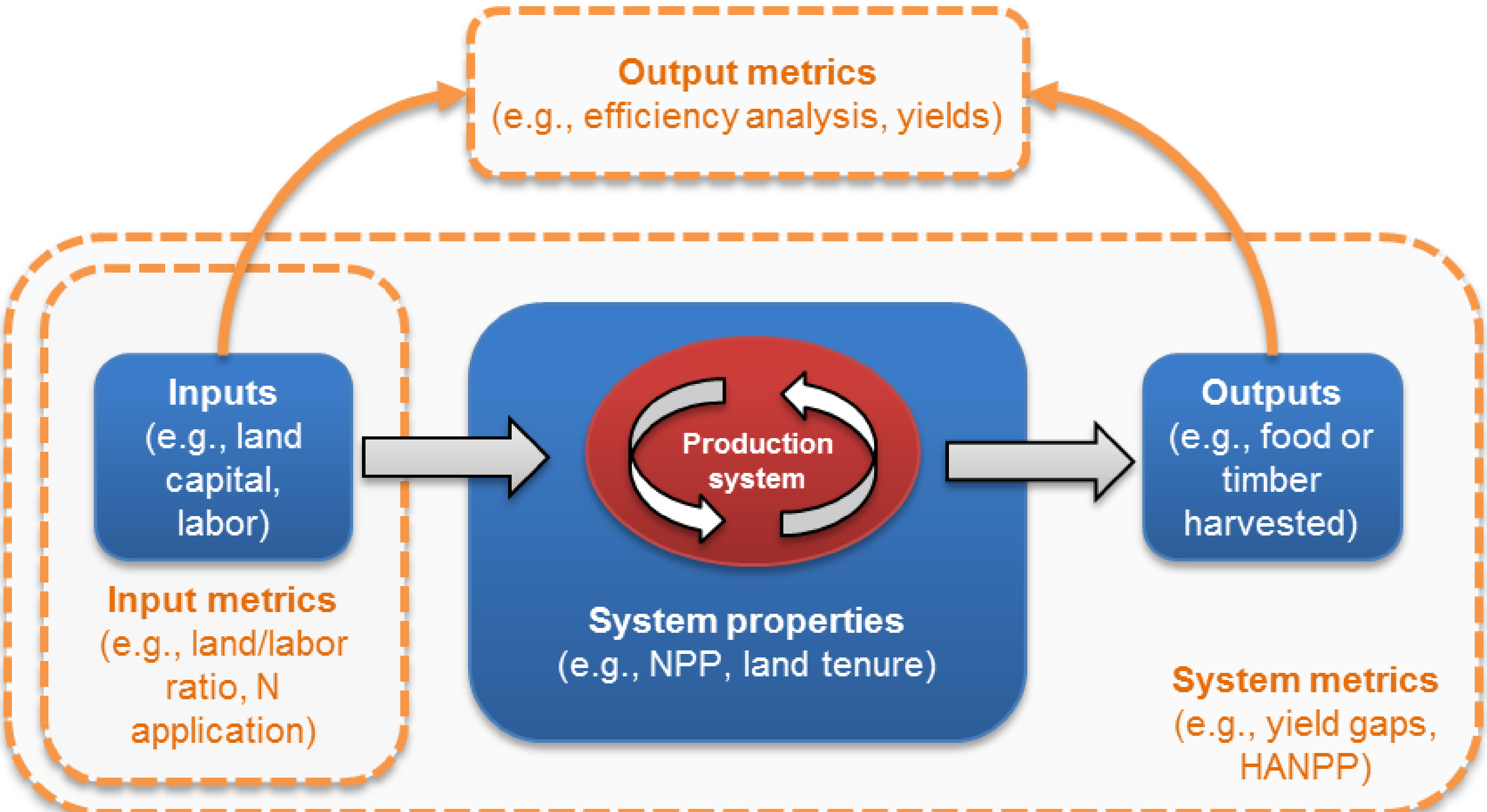
→ Land-use intensification encompasses **multiple dimensions**

Land-Use Intensification



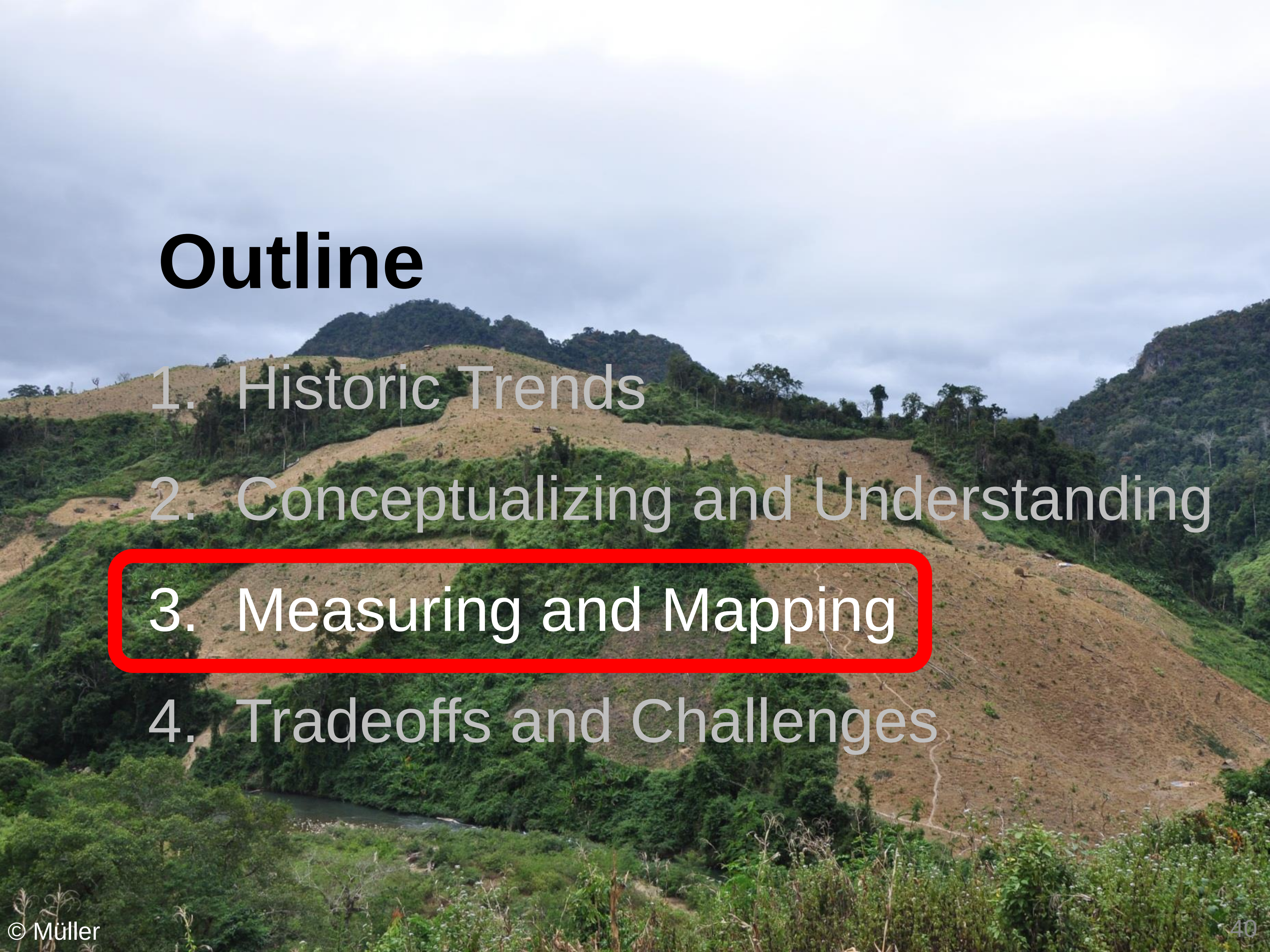
Land-use intensity is conceptually challenging

- Multi-dimensional and complex



Kuemmerle et al. (forthcoming), *Current Opinion in Environmental Sustainability*


We need to understand the multiple dimensions of land-use intensification and their feedbacks



Outline

1. Historic Trends
2. Conceptualizing and Understanding
3. Measuring and Mapping
4. Tradeoffs and Challenges

Assessing land-use intensity

- Land-use intensity is multidimensional and complex
- Assessing land-use intensity requires combining ground data with satellite data
  - Adequate ground data on land management practices are often lacking
  - Where such data exist they are often not available or only in aggregated form

Approaches for mapping land use intensity

1. Remote sensing

Direct measurements rarely possible (e.g., yields, timber harvests), often only proxies

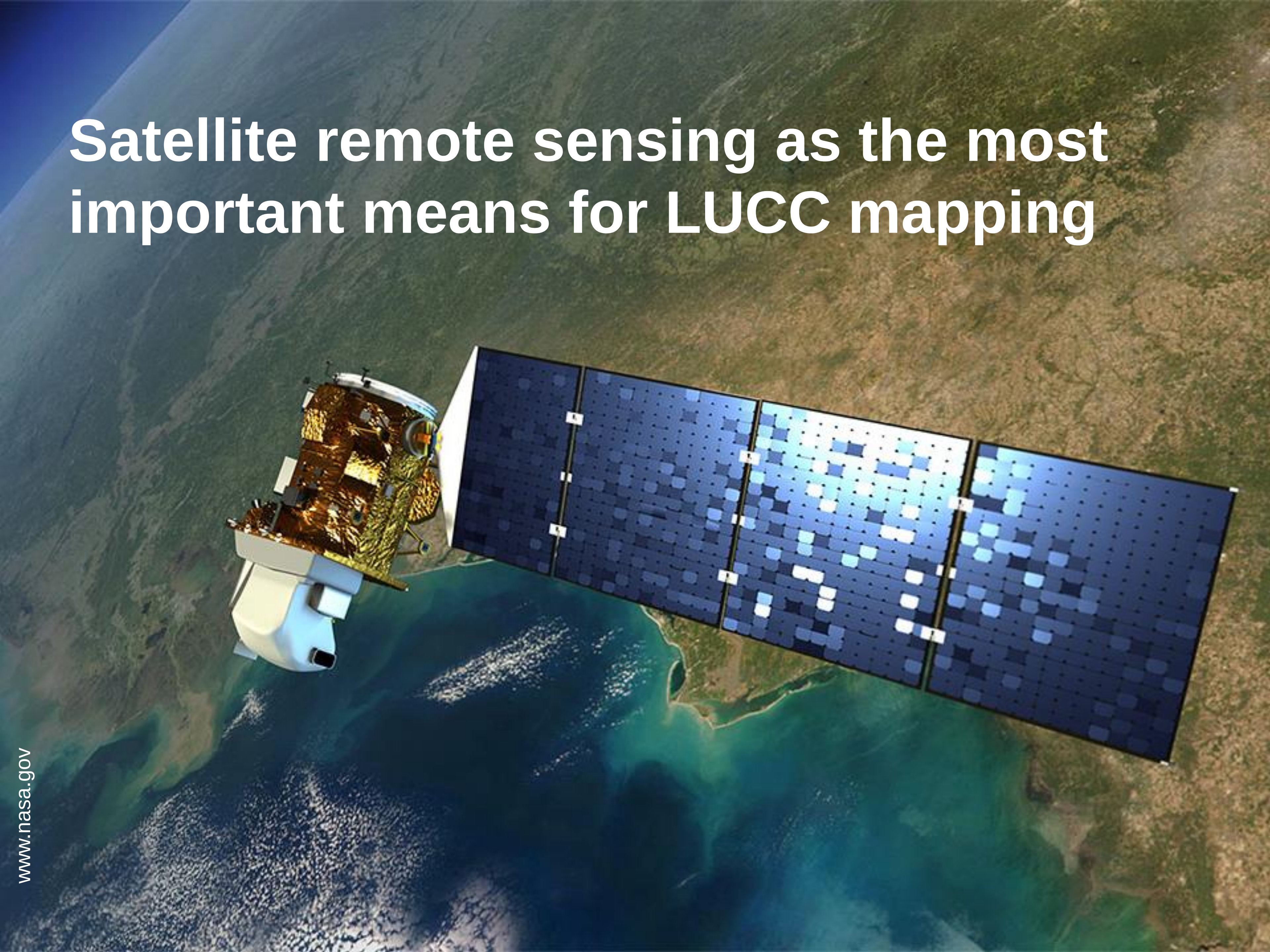
2. Interpolation

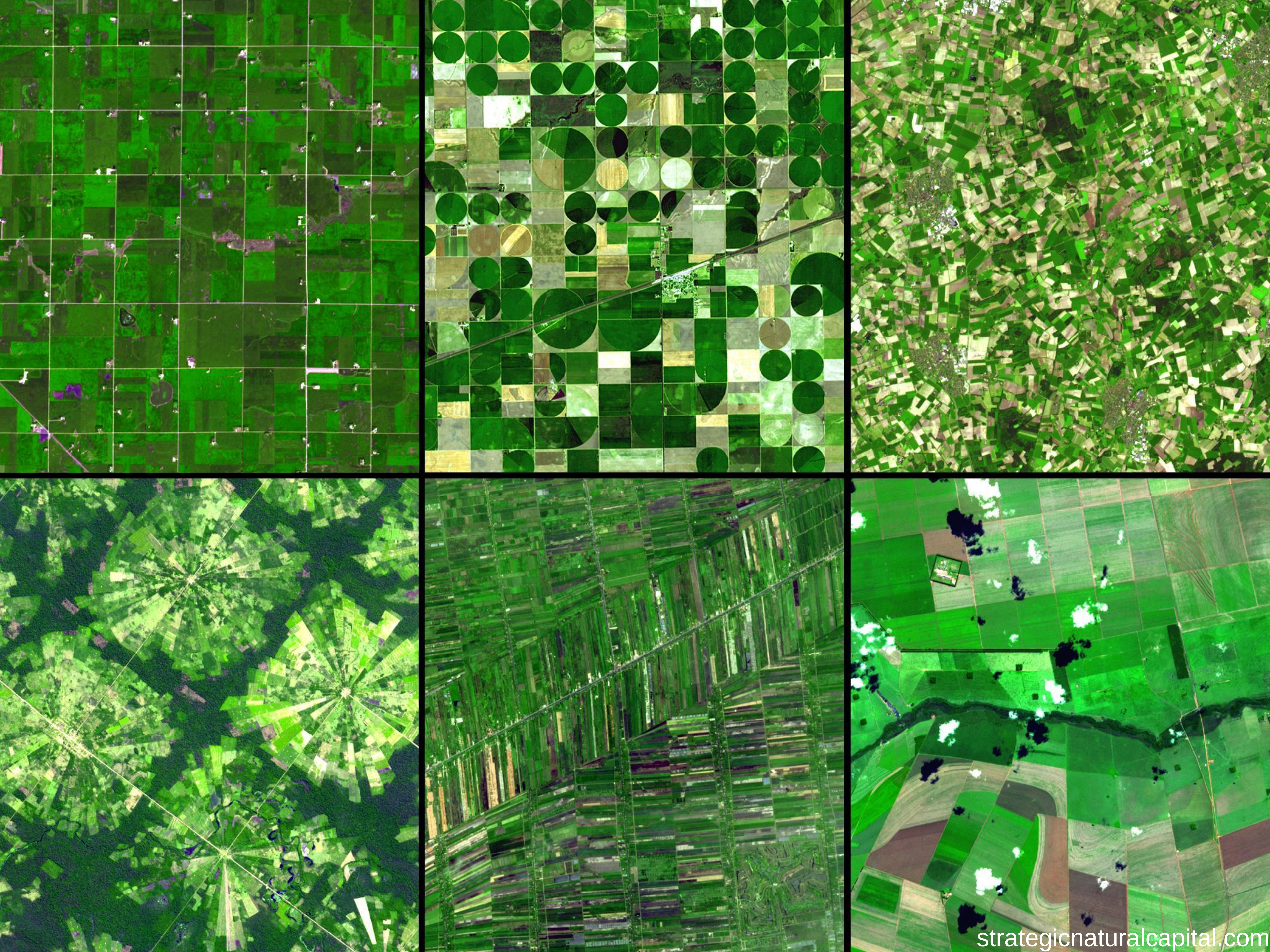
Based on ground data (e.g., point data), often in combination other spatial layers

3. Hybrid approaches

Combination of satellite data with ground-based inventory data

Satellite remote sensing as the most important means for LUCC mapping

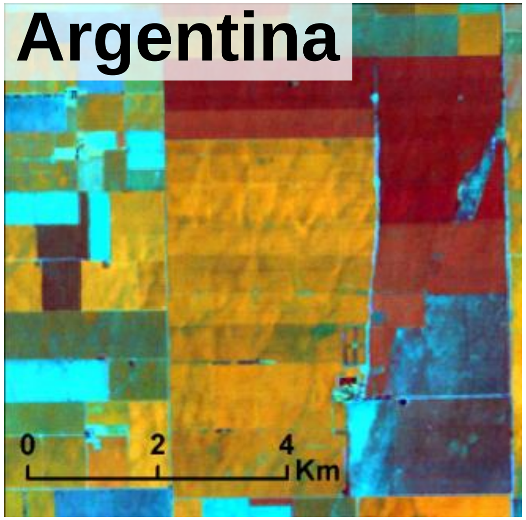


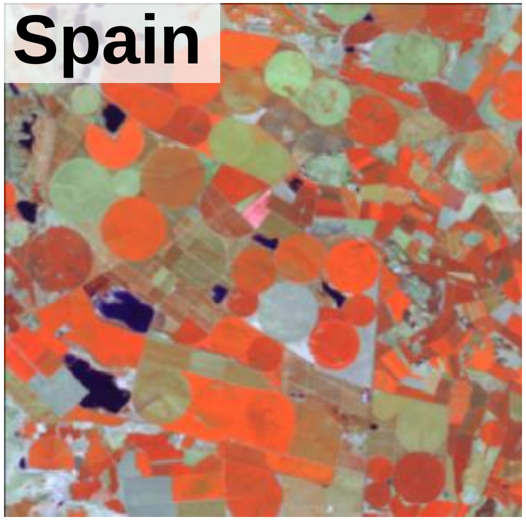


Mapping Land-Use Intensity

1. **Remote sensing**
   - Land cover, **not land use**
   - Conversions, **not changes in management**
   - Difficult to detect **non-linearity** of change

→ Direct measurements rare, often only proxies



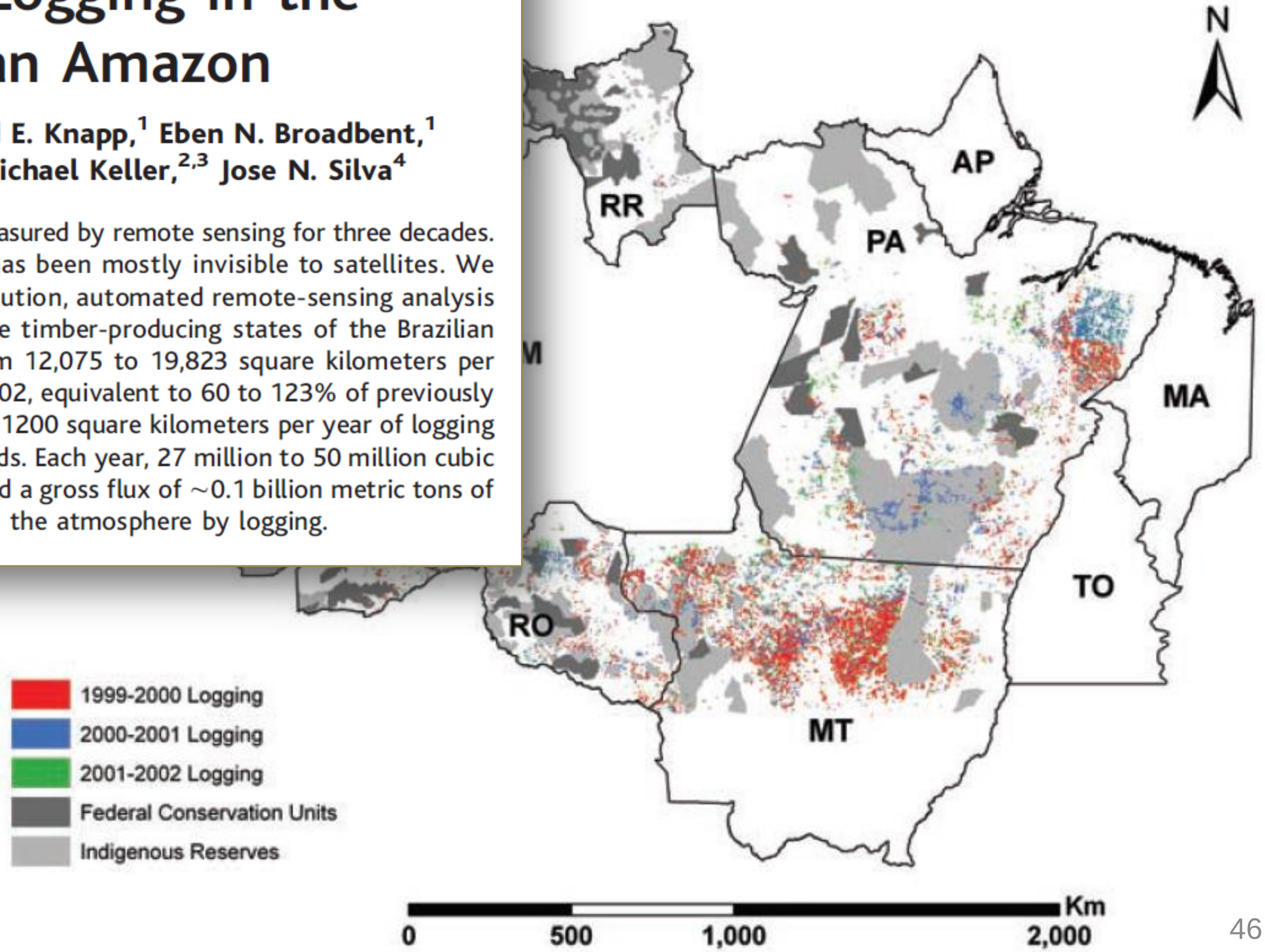


Example: Selective Logging

Selective Logging in the Brazilian Amazon

Gregory P. Asner,[1*] David E. Knapp,[1] Eben N. Broadbent,[1] Paulo J. C. Oliveira,[1] Michael Keller,[2,3] Jose N. Silva[4]

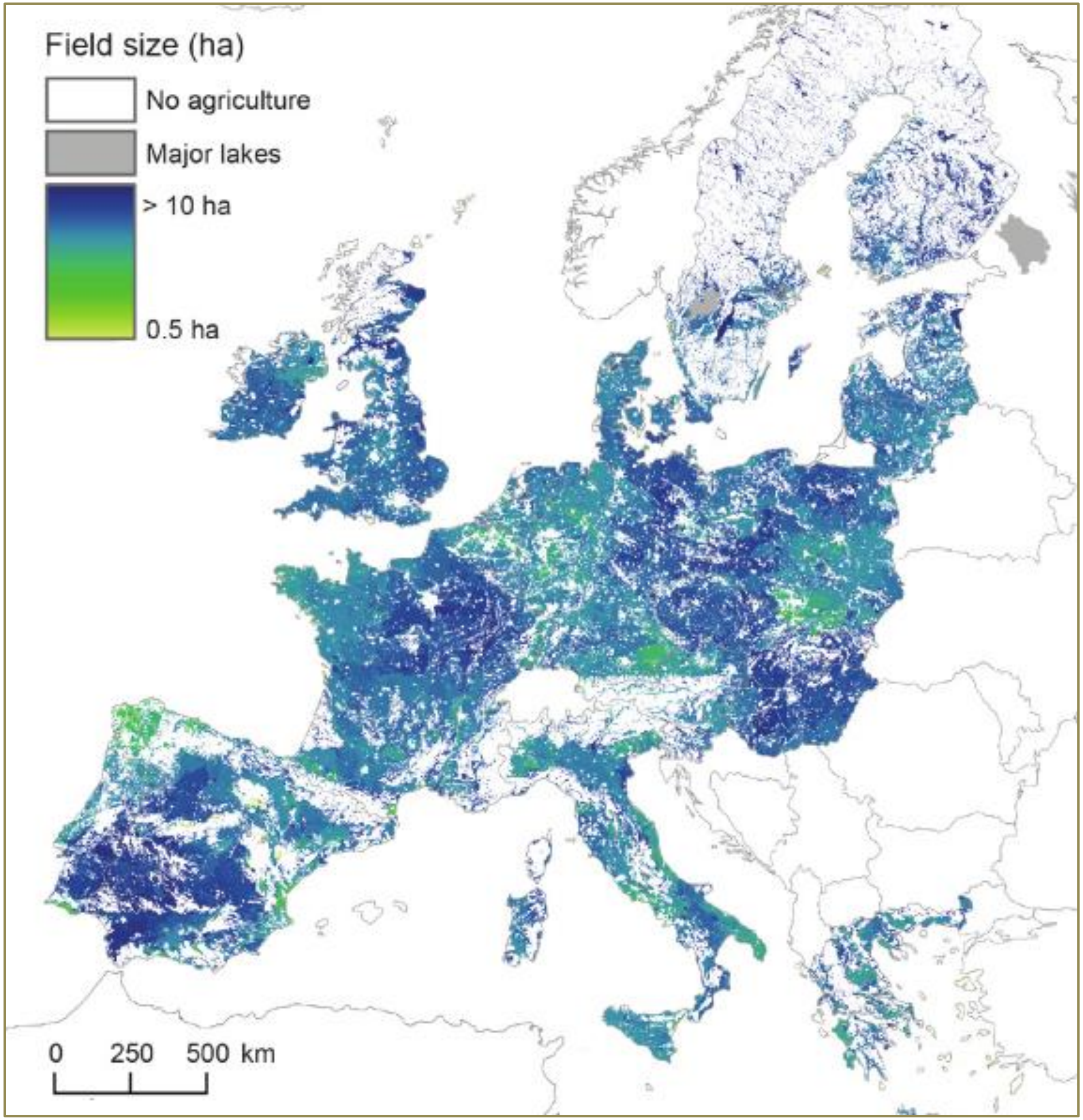
Amazon deforestation has been measured by remote sensing for three decades. In comparison, selective logging has been mostly invisible to satellites. We developed a large-scale, high-resolution, automated remote-sensing analysis of selective logging in the top five timber-producing states of the Brazilian Amazon. Logged areas ranged from 12,075 to 19,823 square kilometers per year (±14%) between 1999 and 2002, equivalent to 60 to 123% of previously reported deforestation area. Up to 1200 square kilometers per year of logging were observed on conservation lands. Each year, 27 million to 50 million cubic meters of wood were extracted, and a gross flux of ~0.1 billion metric tons of carbon was destined for release to the atmosphere by logging.



Asner et al. (2005); *Science*

Interpolation

- → LUCAS data: >230,000 points across Europe documented on the ground
- → Interpolation using kriging



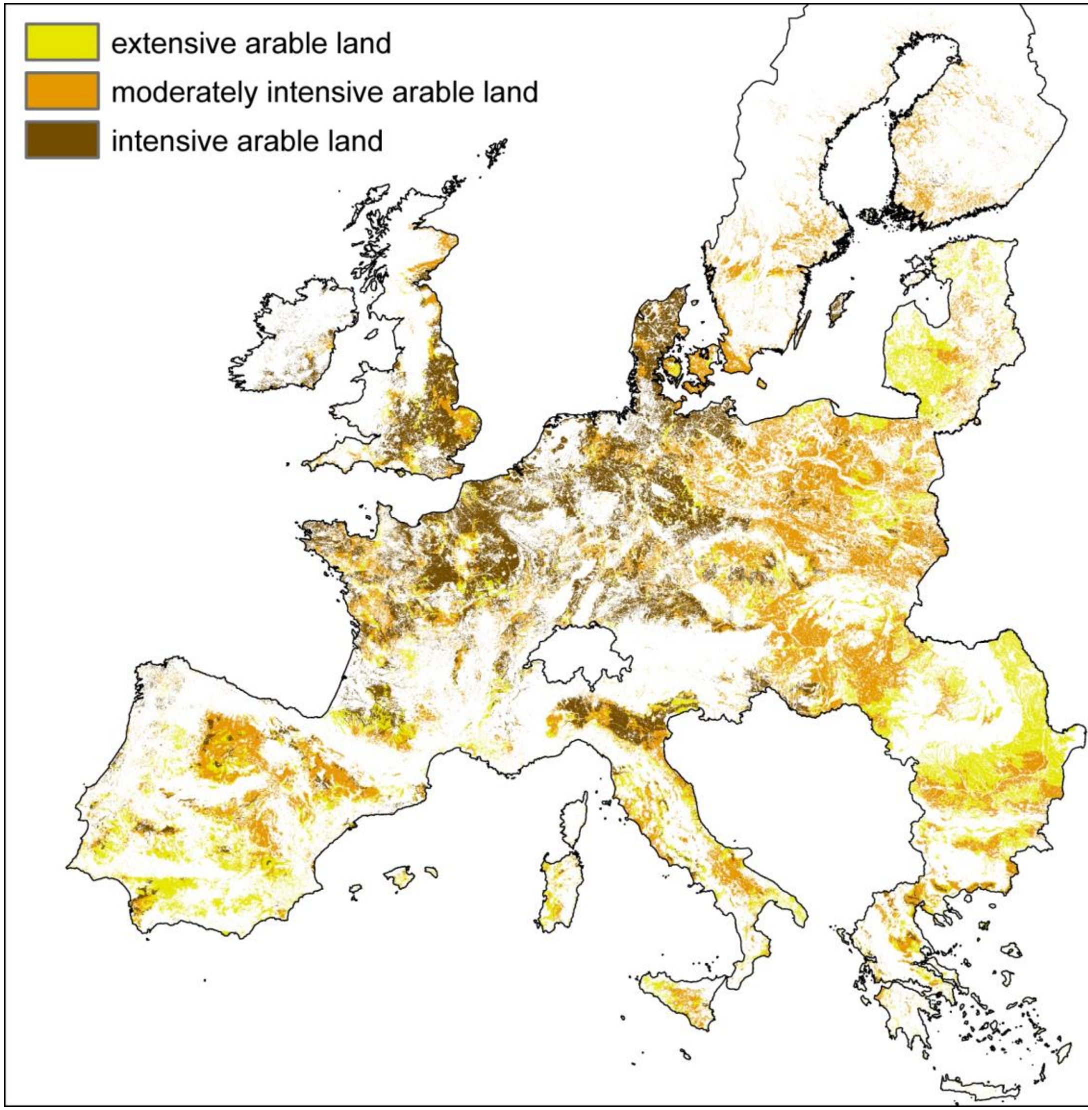
VOLANTE

van der Zanden et al. (in prep); Kuemmerle et al. (accepted), *Current Opinion in Environmental Sustainability*

Hybrid approaches

→ Disaggregating fertilizer statistics using regression modeling

→ Nitrogen application:
- low (<50 kg/ha)
- medium (50-150 kg/ha)
- high (>150 kg/ha)

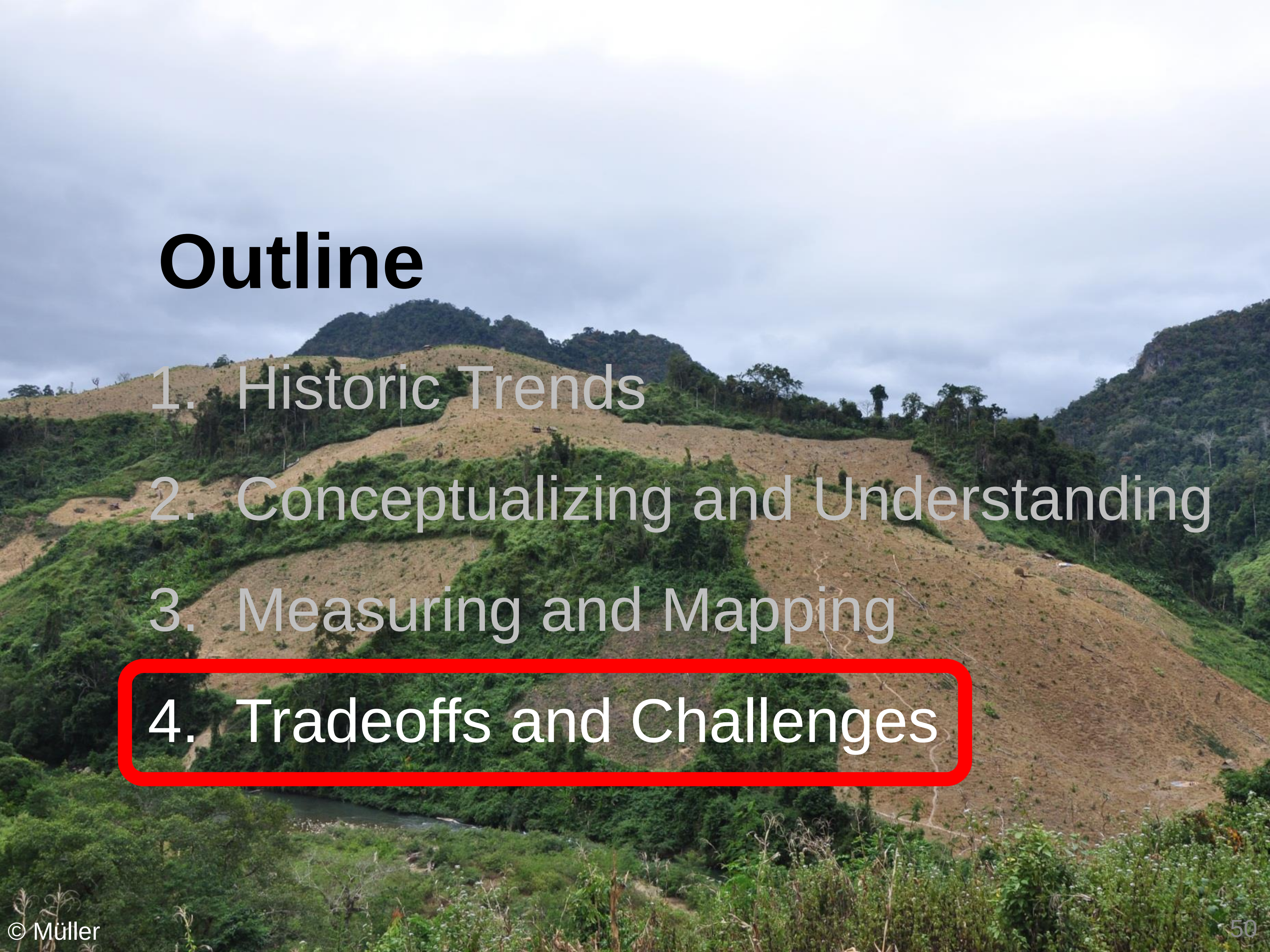


VOLANTE

Source: Temme et al. (2011), *Agriculture, Ecosystem & Environment*

Progress in Measuring, but Data Gaps Remain

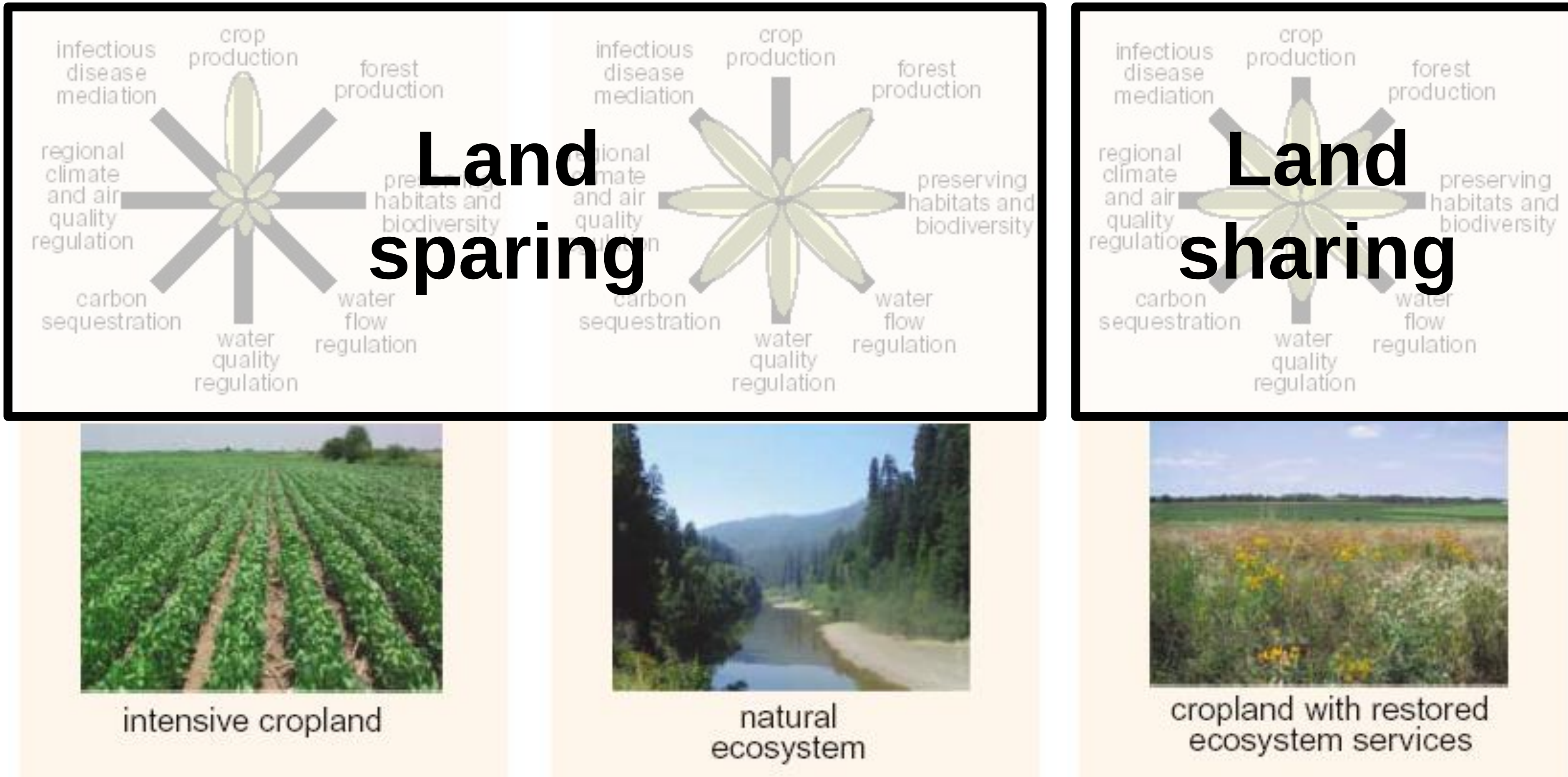
- Large **uncertainties** in spatial patterns
- Reliance on **country-level** statistics (e.g., FAO)
- Various indicators derived from **same input data**
- Few data on **changes** in land-use intensity
- Little evidence for **forestry** and **grazing** intensity



Outline

1. Historic Trends
2. Conceptualizing and Understanding
3. Measuring and Mapping
4. Tradeoffs and Challenges

Tradeoffs in Land-Use Intensification



Foley et al. (2005); *Science*

Genetically Modified Organisms?

Desert Greening

Vertical Farming

http://torontoist.com

http://http://eatinggoodly.files.wordpress.com

Agroforestry

Experimental agroforestry system in France (by INRA)

De Schutter & Vanloqueren 2011: The New Green Revolution: How Twenty-First-Century Science Can Feed the World www.thesolutionsjournal.com/node/971

Sustainable Intensification

The new silver bullet?

→ Substantial environmental trade-offs connected to conventional intensification

→ But organic yields typically lower than conventional yields

LETTER

doi:10.1038/nature11069

Comparing the yields of organic and conventional agriculture

Verena Seufert[1], Navin Ramankutty[1] & Jonathan A. Foley[2]

Research questions to identify pathways to sustainable intensification

→ Where and how large are the potentials for **sustainable** intensification?

→ Which **trade-offs** are important and where will they occur?

→ How to **transition** to sustainable intensification?

Summary: Sustainable land use

→ Challenges for transforming global land use to sustainability are enormous

→ No silver bullet – but many starting points and large opportunities

→ Solutions need to be context-specific

Take-Home Messages

1. An **integrated framework** is required to assess the **multidimensional nature** of land-use intensification.

2. Substantial **progress** was made in **measuring** land-use intensity, but considerable **data gaps** remain.

3. Assessing the **tradeoffs** of land-use intensification requires **place-based approaches** that account for ecosystem and production outcomes.

→ A key challenge is to **identify areas** where **production increases** are possible at low **environmental costs**.

Thank you very much.

Contact:

Daniel Müller
(mueller@iamo.de)

www.iamo.de

www.geographie.hu-berlin.de

www.hu-berlin.de/~muelleda

Leibniz Institute of Agricultural Development in Central and Eastern Europe

HUMBOLDT-UNIVERSITÄT ZU BERLIN

VOLANTE

COOPERATION