"Do Changes in Land Use Account for the Net Terrestrial Flux of Carbon to the Atmosphere?"

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Introduction

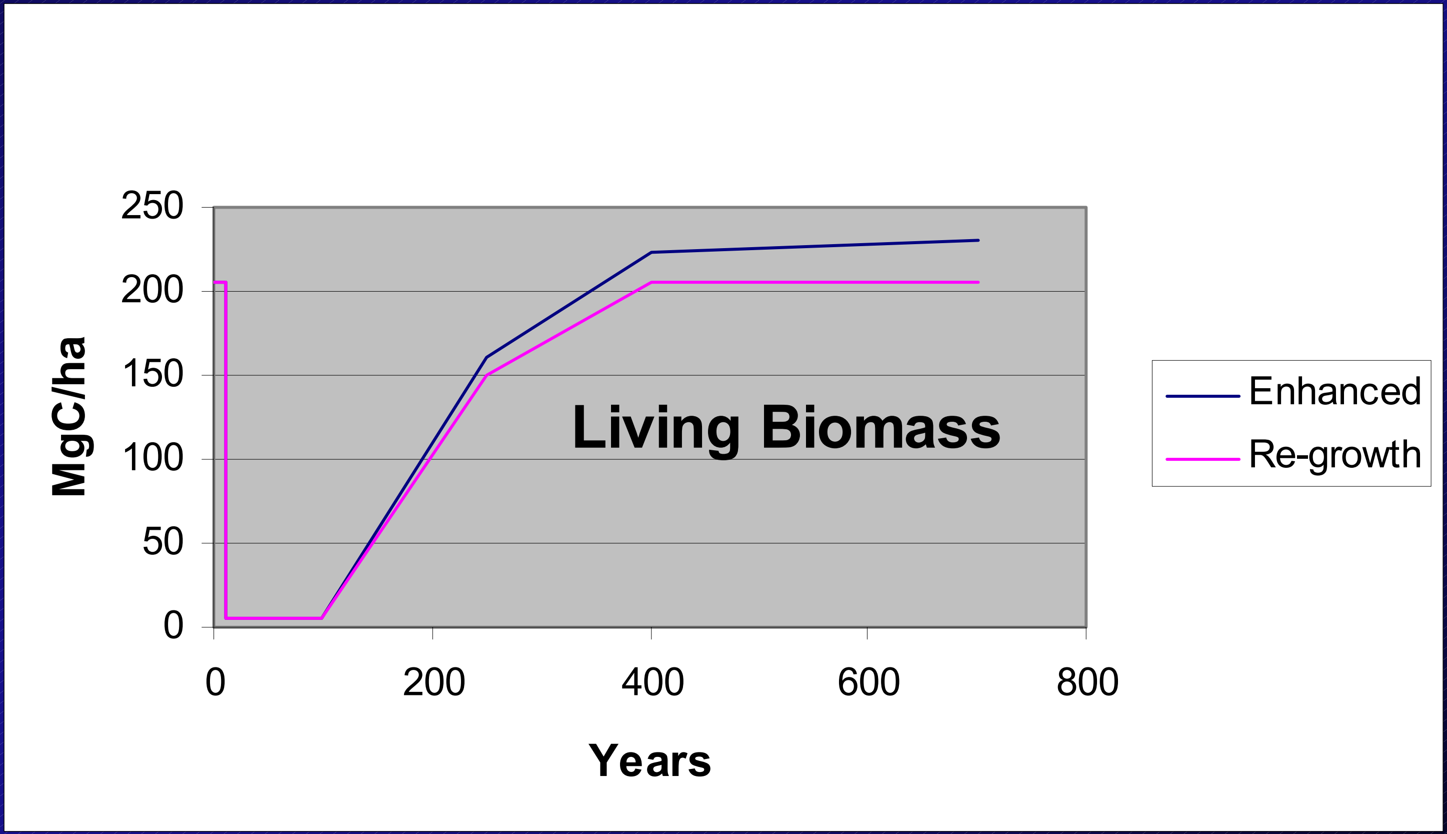
- Several lines of evidence suggest a terrestrial carbon sink (in the tropics as well as in northern mid-latitudes).

- Historically this sink has been attributed to environmentally-enhanced growth (e.g., CO_2 fertilization).

Introduction

- A recent study (Caspersen et al. 2000) suggests:
  - 98% of growth in US forests is explained by age structure (i.e., by re-growth from past disturbance).
  - Only 2% of tree growth is explained by enhanced growth.

Regrowth vs. Enhanced Growth



Introduction

- Is the terrestrial sink the result of Regrowth or Enhanced growth?

or

- Do changes in land use and management (= regrowth) dominate the net terrestrial flux of carbon?

If so…

- Good news: Implementation of the Kyoto Protocol is simple (i.e., indirect effects are unimportant).
- Bad news: The continued functioning of a terrestrial sink is limited.

Question

- Do changes in land use and management account for the terrestrial carbon flux?

Outline

- The Global Carbon Balance
- The flux of carbon from Land-Use Change
- Regrowth vs. enhanced growth as mechanism for terrestrial carbon storage
    - *Different methods*

Global Carbon Budget

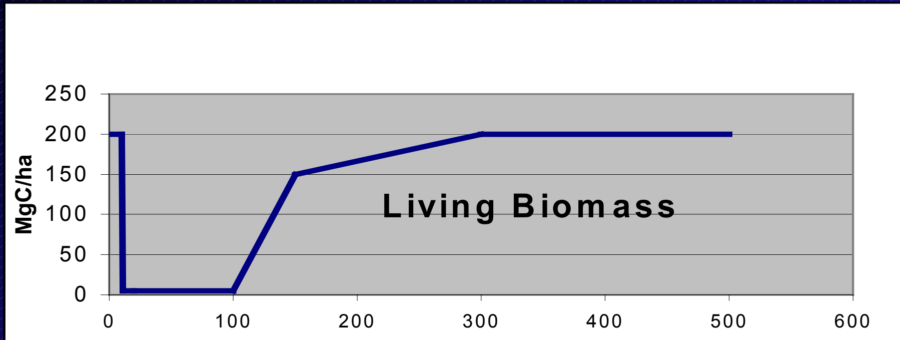
	1980s	1990s
Fossil fuel emissions	5.4 ± 0.3	6.3 ± 0.4
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.2
Oceanic uptake	-1.9 ± 0.6	-1.7 ± 0.5
Net terrestrial flux	-0.2 ± 0.7	-1.4 ± 0.7

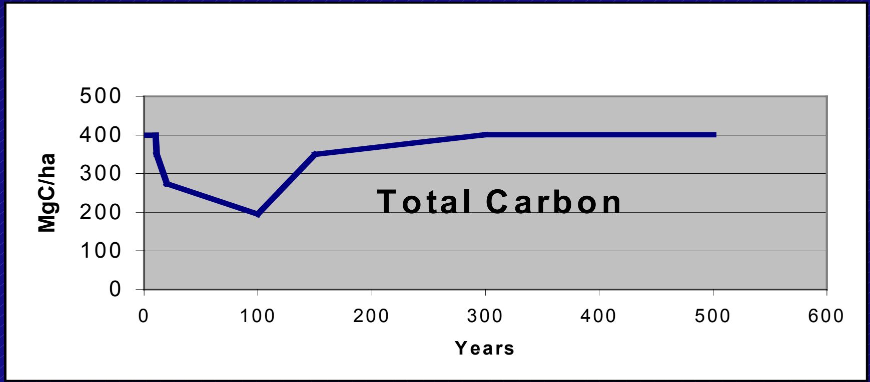
from IPCC

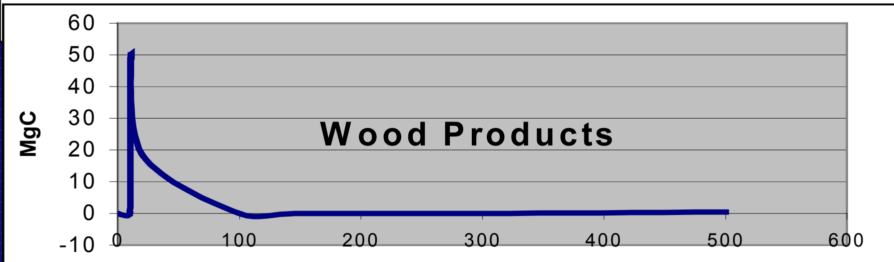
Changes in land use

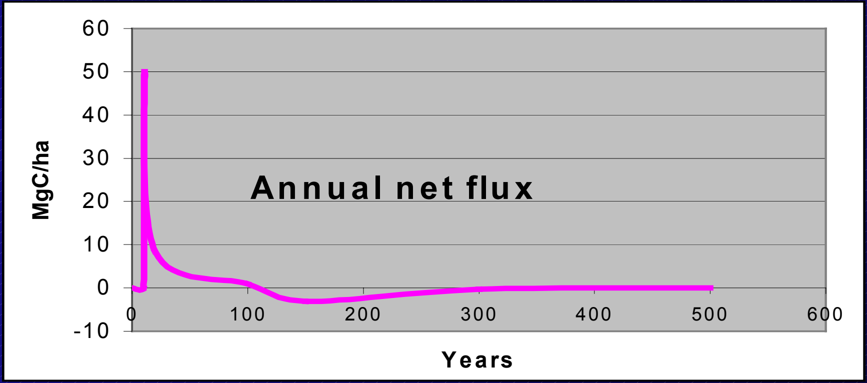
- Changes in area (emphasis on forests)
  - Croplands (clearing and abandonment)
  - Pastures
  - Shifting cultivation
- Changes in carbon stocks (C/ha)
  - Wood harvest & recovery
  - Fire management
- [Not environmentally-induced change]

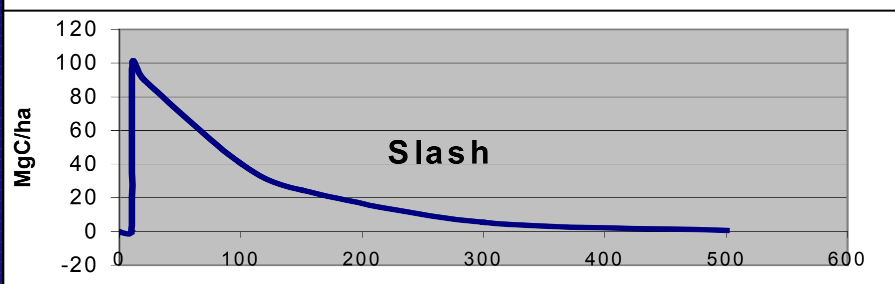
Response Curves

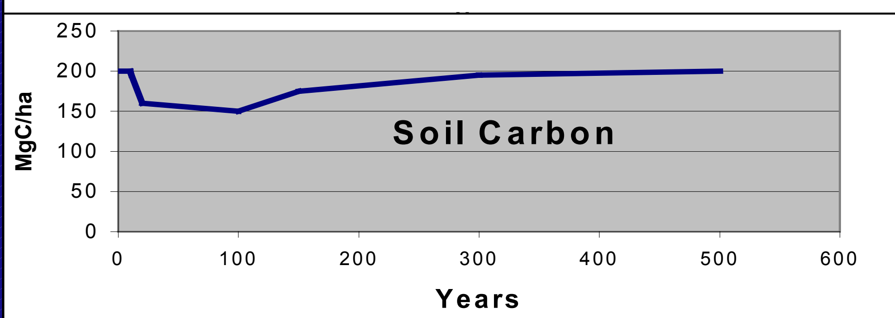




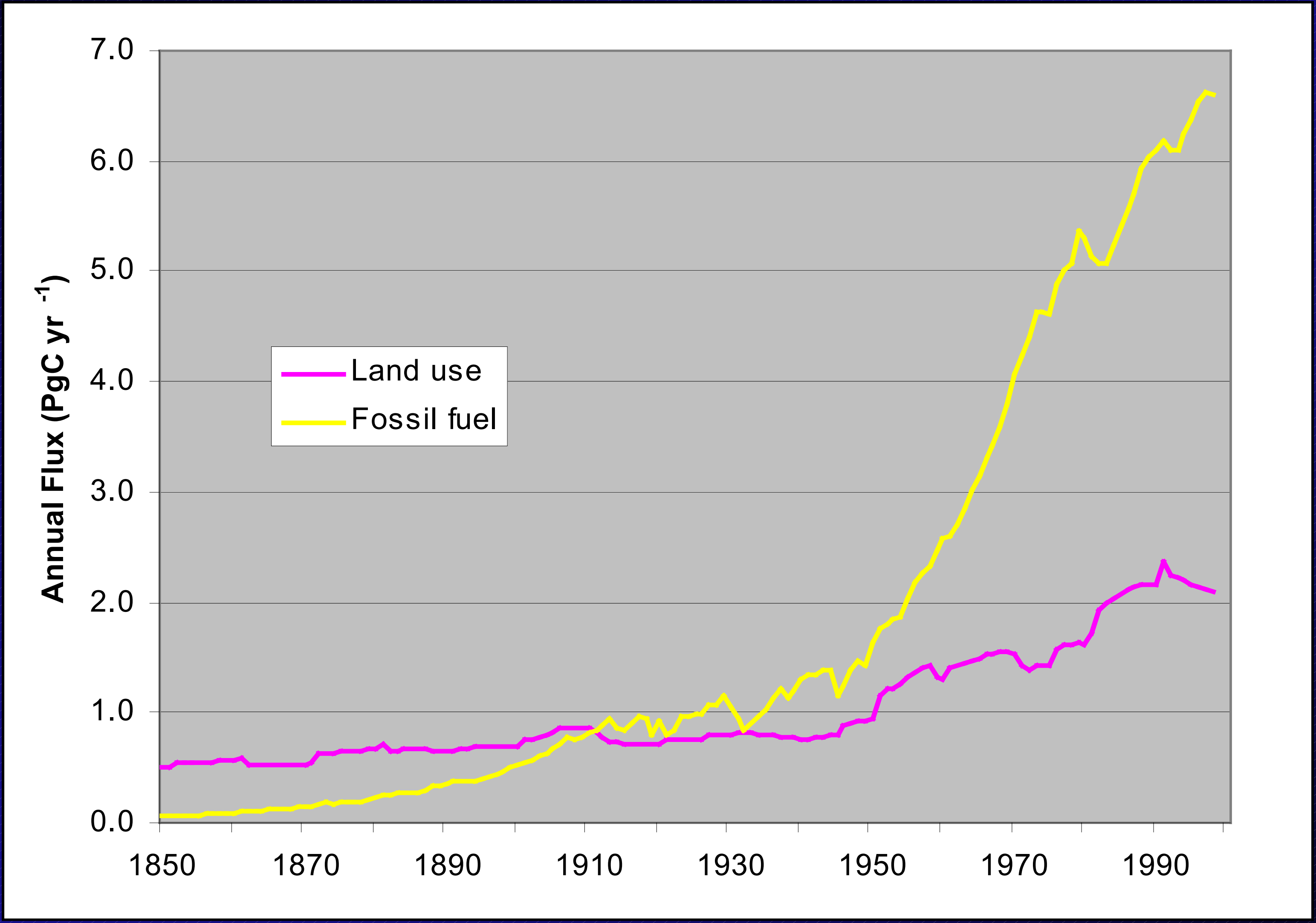








Annual Emissions of Carbon



Global Carbon Budget

	1980s	1990s
Fossil fuel emissions	5.4 ± 0.3	6.3 ± 0.4
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.2
Oceanic uptake	-1.9 ± 0.6	-1.7 ± 0.5
Net terrestrial flux	-0.2 ± 0.7	-1.4 ± 0.7
Land-use change	2.0 ± 0.8	2.2 ± 0.8
Residual terrestrial flux	-2.2 ± 1.1	-3.6 ± 1.1

Factors affecting carbon storage

Changes in land use

- Croplands
- Pastures
- Shifting cultivation
- Degradation
- Wood harvest
- Fire management

- REGROWTH

Other factors

- CO_2 fertilization
- N deposition
- Climate

- ENHANCED GROWTH

- Natural disturbances

Question

Terrestrial sources and sinks of carbon:

- Are they explained by changes in land use?

or

- Are other factors important?

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Annual terrestrial flux of carbon in the 1990s ($PgC\ yr^{-1}$)

	O_2 and CO_2	Inverse calculations CO_2, $^{13}CO_2$, O_2	Forest inventories	Land-use change
Globe	-1.4	-1.4	-	2.2
Northern mid-latitudes	-	-2.4	-0.7	-0.03
Tropics	-	1.2	-	2.2

Methods used to estimate terrestrial carbon sinks

- Top-down methods
  - Atmospheric concentrations of O_2 and CO_2
  - Inverse modeling: atmospheric data with models of atmospheric transport
- Bottom-up methods
  - Forest inventories
  - Land-use analyses

Global Carbon Budget

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	-1.7 ± 0.6	-2.4 ± 0.7
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	-0.4 ± 0.7	-0.7 ± 0.8
Land-use change	**2.0 ± 0.8**	**2.2 ± 0.8**
Residual	**-2.2 ± 1.1**	**-3.6 ± 1.1**
terrestrial flux	**-2.4 ± 1.1**	**-2.9 ± 1.1**

IPCC
Plattner

Inverse calculations with atmospheric data and transport models

Global net terrestrial flux -1.4 (±0.8)

adjusted for rivers -0.4 to -0.8

Gurney et al. (2002)
Sarmiento & Sundquist (1992)
Aumont et al. (2002)

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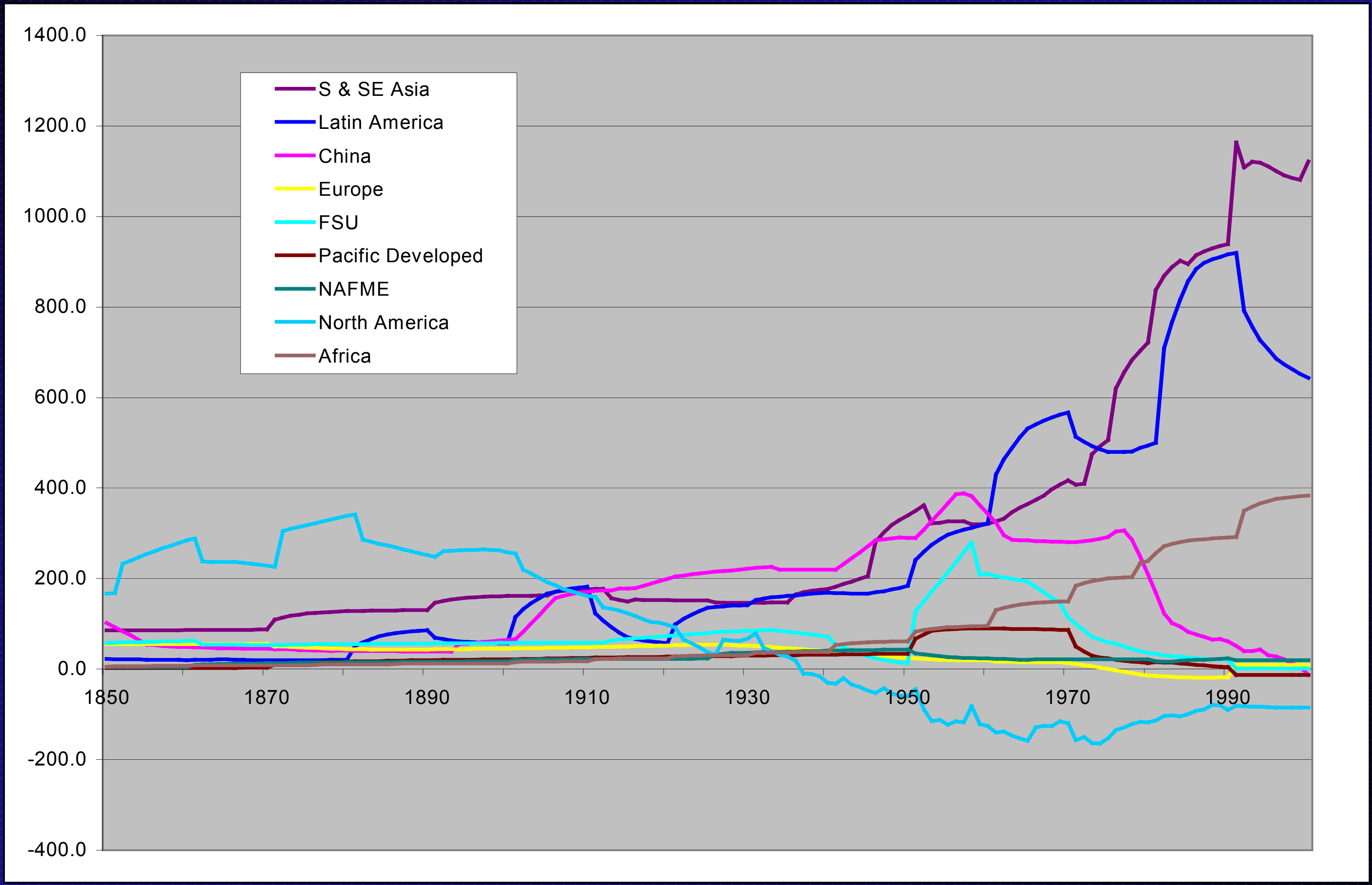
Emissions from Land-Use Change



Terrestrial sources (+) and sinks (-) of carbon estimated by different methods ($PgC\ yr^{-1}$)

Region	Inversions based on atmospheric data and models (Gurney et al. 2002)	Analysis of land-use change (Houghton, in press)	Forest inventories (Goodale et al., 2002)
Globe	-1.4 (±0.8)	2.2 (±0.8)	
Tropics	1.2 (±1.2)	2.2 (±0.8)	
North	-2.4 (±0.8)	-0.03 (±0.5)	-0.65 (±0.05)
South	-0.2 (±0.6)	0.02 (+0.2)	

Non-Forests:

What's happening outside of forests?

Carbon accumulation in the U.S. (PgC yr^{-1} in 1990)

	Pacala et al. (2001) low	Pacala et al. (2001) high	Houghton et al. (1999)	Houghton (in press)	Goodale et al. (2002)
Forest trees	0.11	0.15	0.072	0.046	0.11
Forest organic matter	0.03	0.15	-0.010	-0.010	0.11
Cropland soils	0.00	0.04	0.138	0.00	…
Woody encroachment	0.12	0.13	0.122	0.061	…
Wood products	0.03	0.07	0.027	0.027	0.06
Sediments	0.01	0.04	…	…	…
Total sink	0.30	0.58	0.35	0.12	0.28
	43%	36%	74%	51%	

Annual terrestrial flux of carbon in the 1990s (PgC yr^{-1})

	O_2 and CO_2	Inverse calculations CO_2, $^{13}CO_2$, O_2	"Forest" inventories	Land-use change
Globe	-0.7	-0.6 to -1.0	-	2.2
Northern mid-latitudes	-	-1.8	-1.4	-0.03

Change in forest vegetation (TgC yr^{-1}) in northern mid-latitude regions around the year 1990

Region	Land-Use Change	Forest Inventory*	Difference
Canada	-25	40	65 (larger)
Russia	-55	40	95 (larger)
U.S.A.	-45	-110	65 (smaller)
Europe	-20	-90	70 (smaller)
China	30	-40	70 (smaller)
Total	-115	-160	45 (smaller)

* From Goodale et al. (2002)

Is the difference the result of…

…growth enhancement?

or

…errors and omissions in analyses of land-use change?

Growth enhancement?

- Caspersen et al. (2000)
  - 98% of growth attributed to age structure
  - 2% attributed to growth enhancement
    - (0.001-0.01% per year)
- Joos et al. (2002)
  - 0.1% per year also fits data
  - a growth enhancement of 0.1% per year yields a 25% increase in growth for a doubling of CO_2

Terrestrial fluxes of carbon (PgC yr^{-1} for the period 1980-1989)

	McGuire et al.	Houghton
Croplands	0.8	1.21
Pastures	…	0.44
Shifting cultivation	…	0.24
Logging	…	0.29
Afforestation	…	-0.10
Other (fire suppr.)	…	-0.11
CO_2 fertilization	-1.9	…
Climatic variation	0.4	…
Total	-0.7	2.0

Have analyses of land-use change missed a sink?

- Growth enhancement ignored
- Natural disturbances ignored
- Gross rates of clearing and abandonment underestimated
- Management largely ignored

Summary for the northern temperate zone

Changes in land use yield a smaller sink than other estimates.

- Are the analyses incomplete?
- Or is there enhanced growth?

Annual terrestrial flux of carbon in the 1990s (PgC yr^{-1})

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Northern mid-latitudes	-	-1.8	-1.4	-0.03
Tropics	-	0.6 to 1.2	0 to -7	0.9 to 2.4

The Tropics

Either

- A large source from land-use change is offset by a large sink in undisturbed forests

or

- A more moderate source from land-use change accounts for the net flux

A large carbon sink in undisturbed (Amazonian) forests?

Measurements of CO_2 flux

(Grace et al. 1995, Malhi et al. 1998 vs. Wofsy, Goulden, others)

30-year sampling of small permanent plots

(Phillips et al. 1998, 2002 vs. Clark 2002)

Large emissions of CO_2 from waters

(Richey et al. 2002)

A smaller carbon source from tropical deforestation?

Lower rates of deforestation

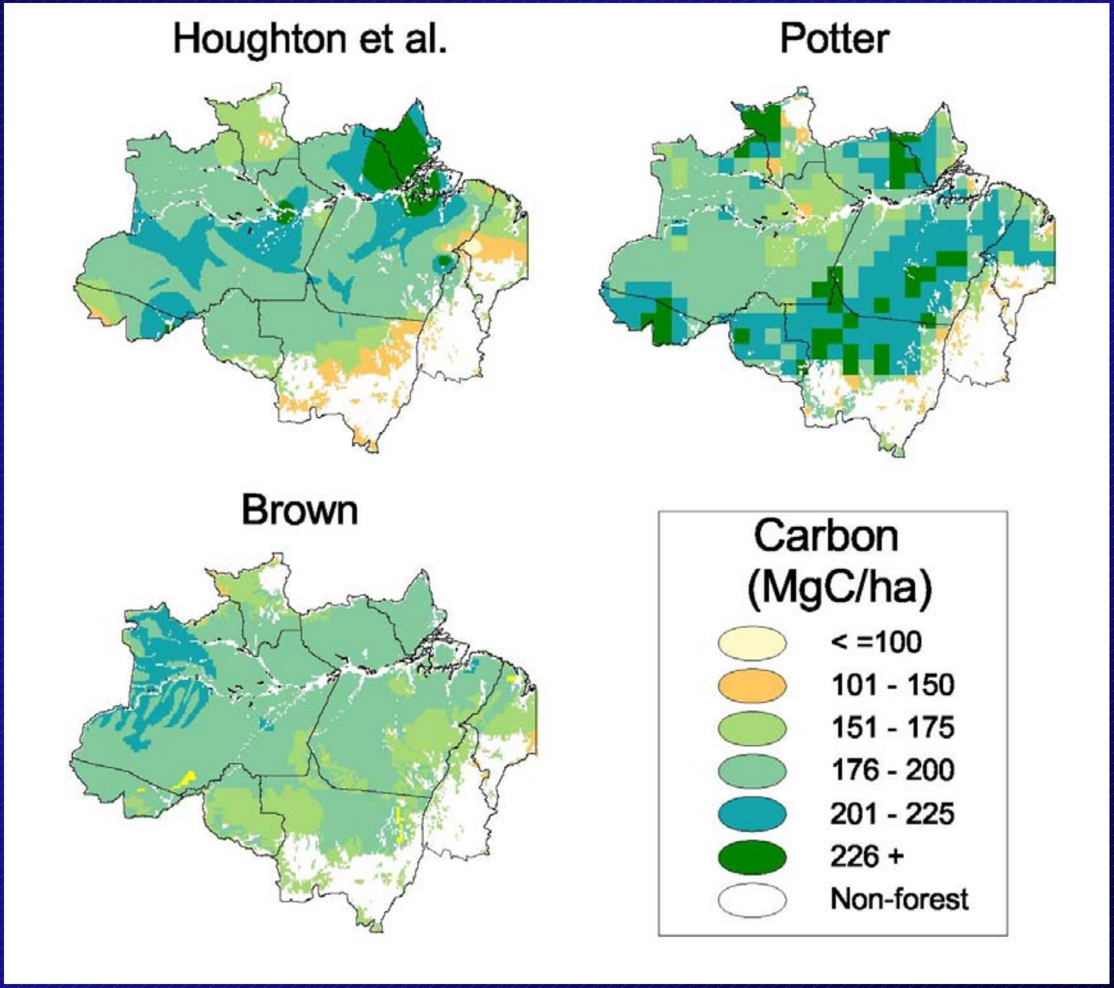
(Achard et al. 2002, DeFries et al 2002)

Lower estimates of biomass

Loss of tropical forest cover (percent lower than the FAO)

	Achard et al. (2002)	DeFries et al. (2002)
Tropical America	18	28
Tropical Asia	20	16
Tropical Africa	42	93
All tropics	23	54

Biomass in Amazonia



Conclusions

- Northern temperate zone
  - Changes in land use yield a smaller sink than other estimates
    - Are the analyses incomplete or is there enhanced growth?
- The Tropics
  - High rates of deforestation suggest enhanced growth
  - Low rates of deforestation suggest little enhanced growth

Priority Research Areas

Northern mid-latitudes

- Gross rates of clearing and abandonment
- Management, including fire suppression
- Woody encroachment
- Natural disturbances

Priority Research Areas

The Tropics

- Rates of deforestation and afforestation
- Aboveground biomass
- Links between land use and climate
  - Fires (Brazil, Indonesia)

The tropics should be easier

- The major changes in carbon involve changes in forest area
- The difference in carbon stocks (C/ha) between forests and non-forests is large

The northern mid-latitudes are more difficult

- The major changes in carbon involve changes in carbon stocks (C/ha)
  - Growth, management, enhanced growth
- And many sensors saturate at moderate levels of biomass
- But…

…What if we could measure changes in aboveground biomass from space?

- Could we see carbon sinks using multi-dates?
- Could we attribute the sinks to land-use change?
  - Yes, if we identified the history of land-use change, management, disturbance, etc.