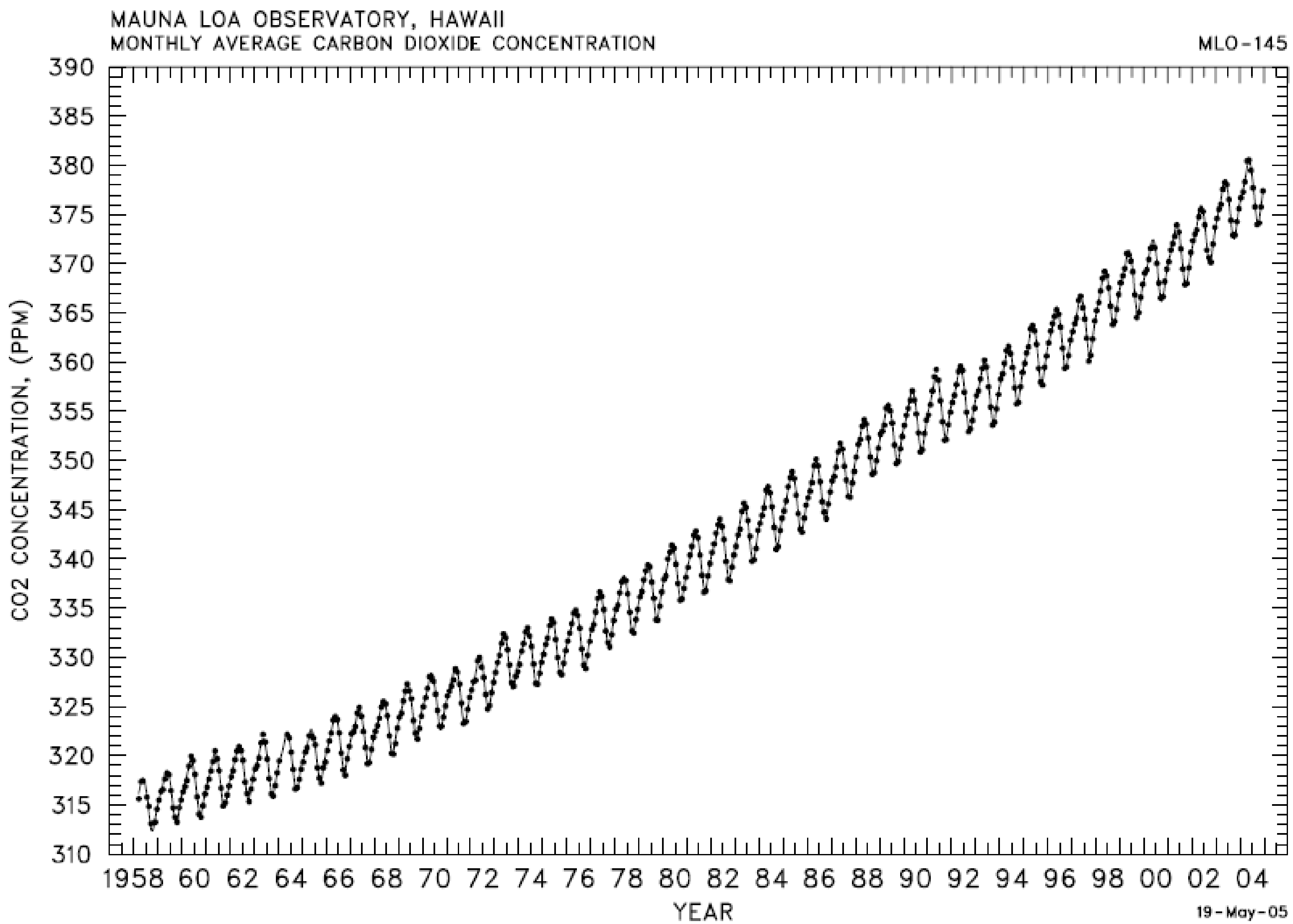
Introduction to Terrestrial Carbon Sequestration

Objectives

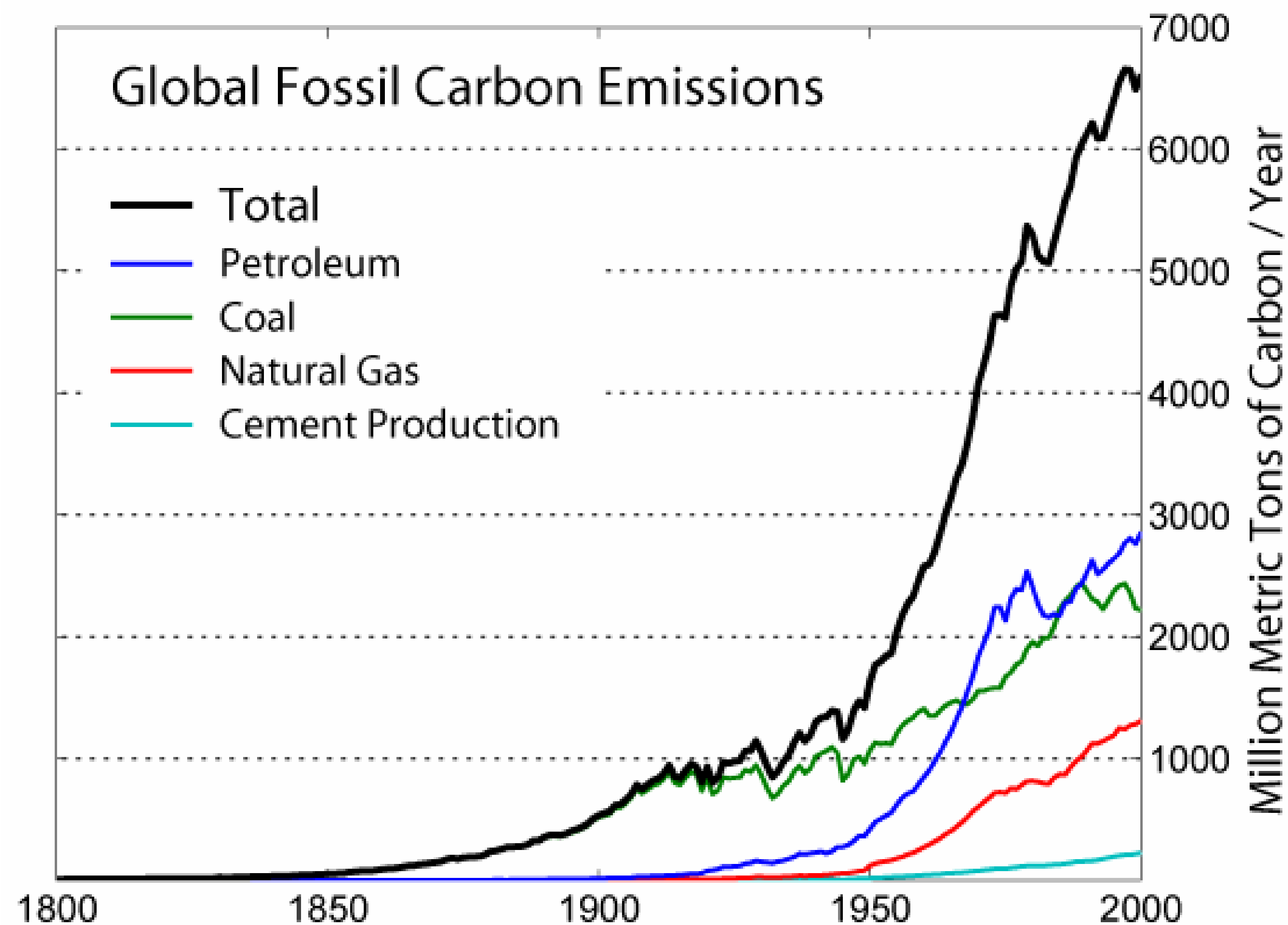
- The Carbon Conundrum
- The global carbon cycle
- The forest carbon cycle

CO_2 is increasing in the atmosphere



Keeling, CD and TP Whorf

Fossil Fuel combustion is the main source of CO_2



Marland et al., 2007

Why does rising CO_2 matter?

- Direct Plant Effects
- The Greenhouse Effect
- Global Warming

Increasing CO_2 can increase plant growth and decrease water use

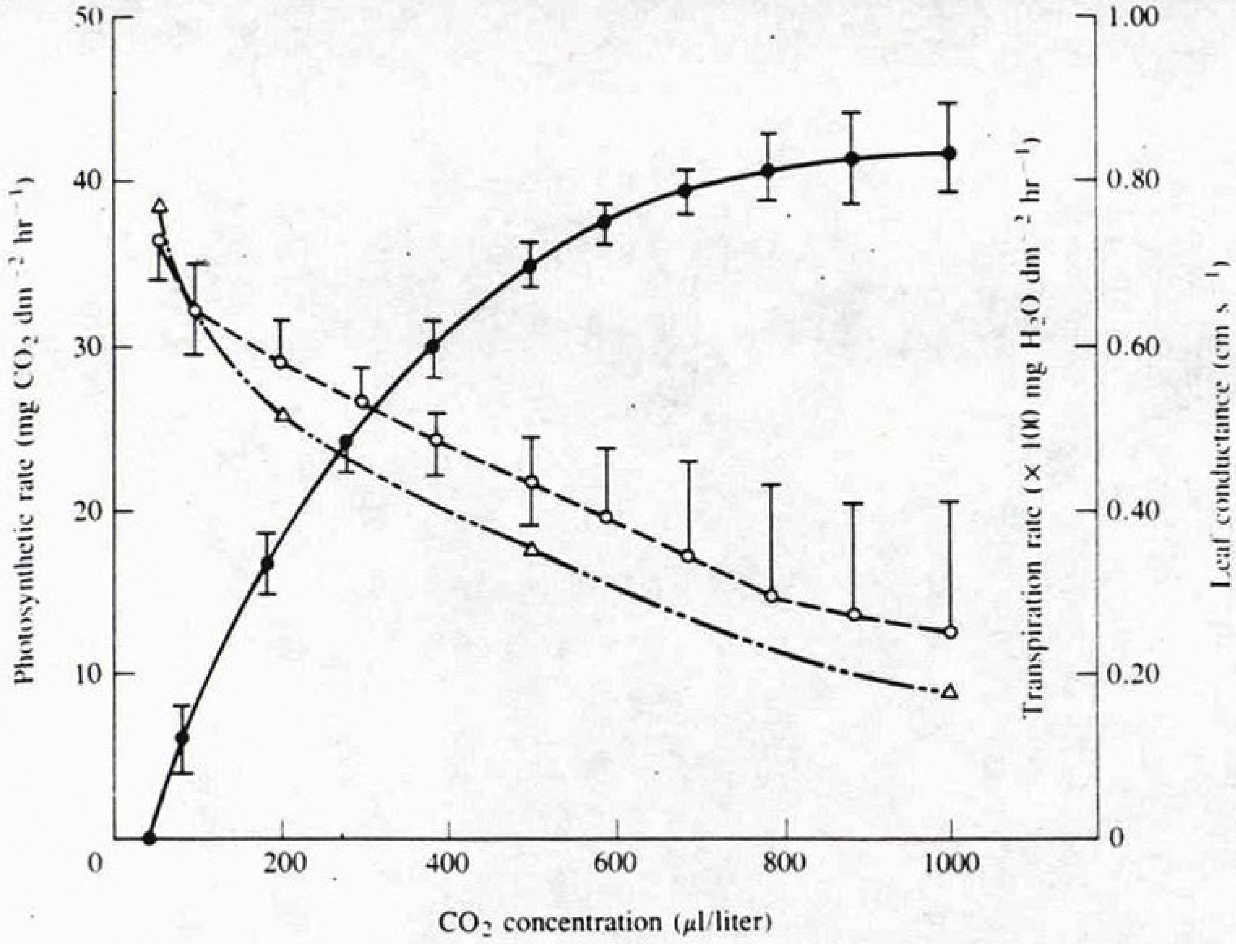
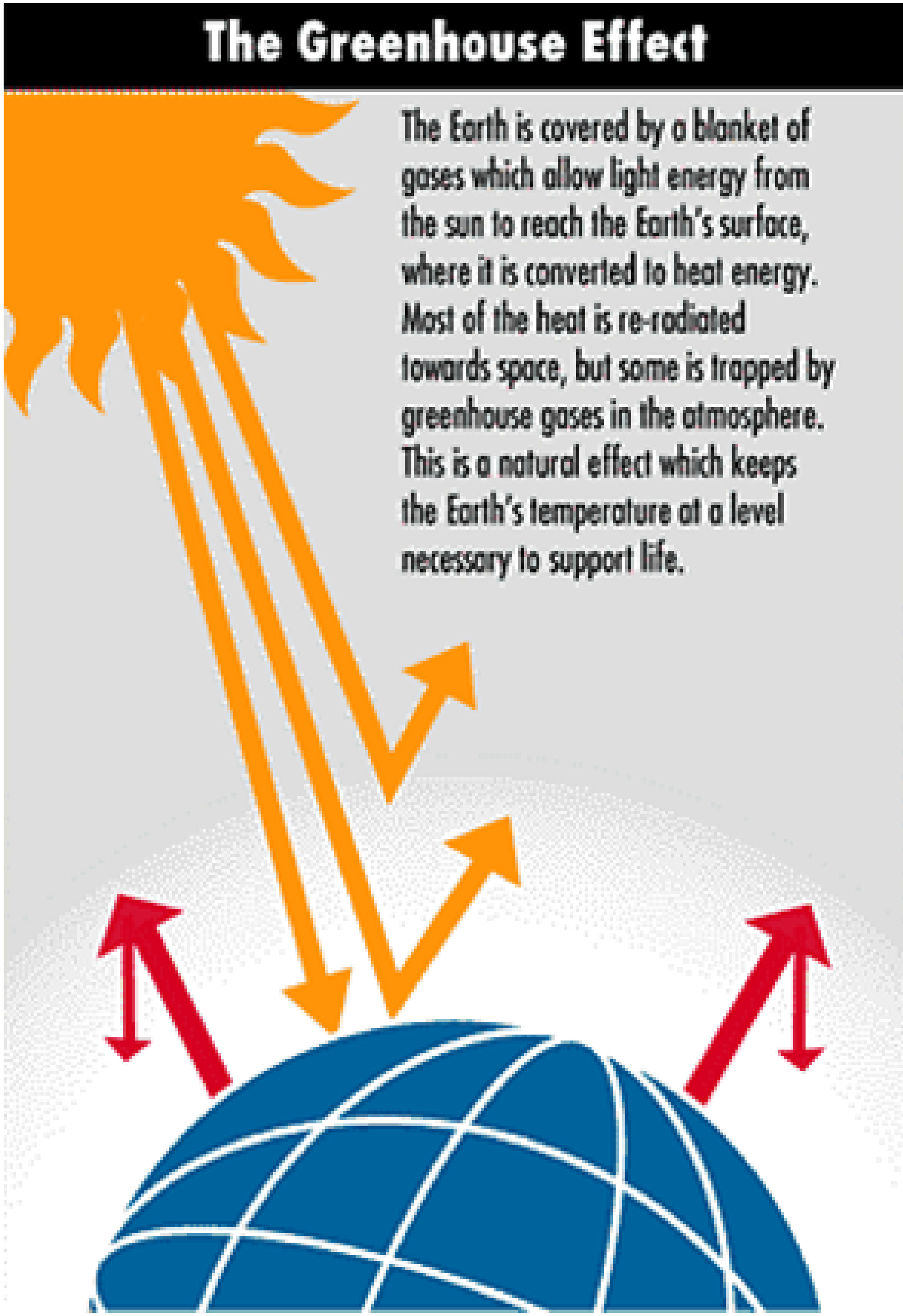


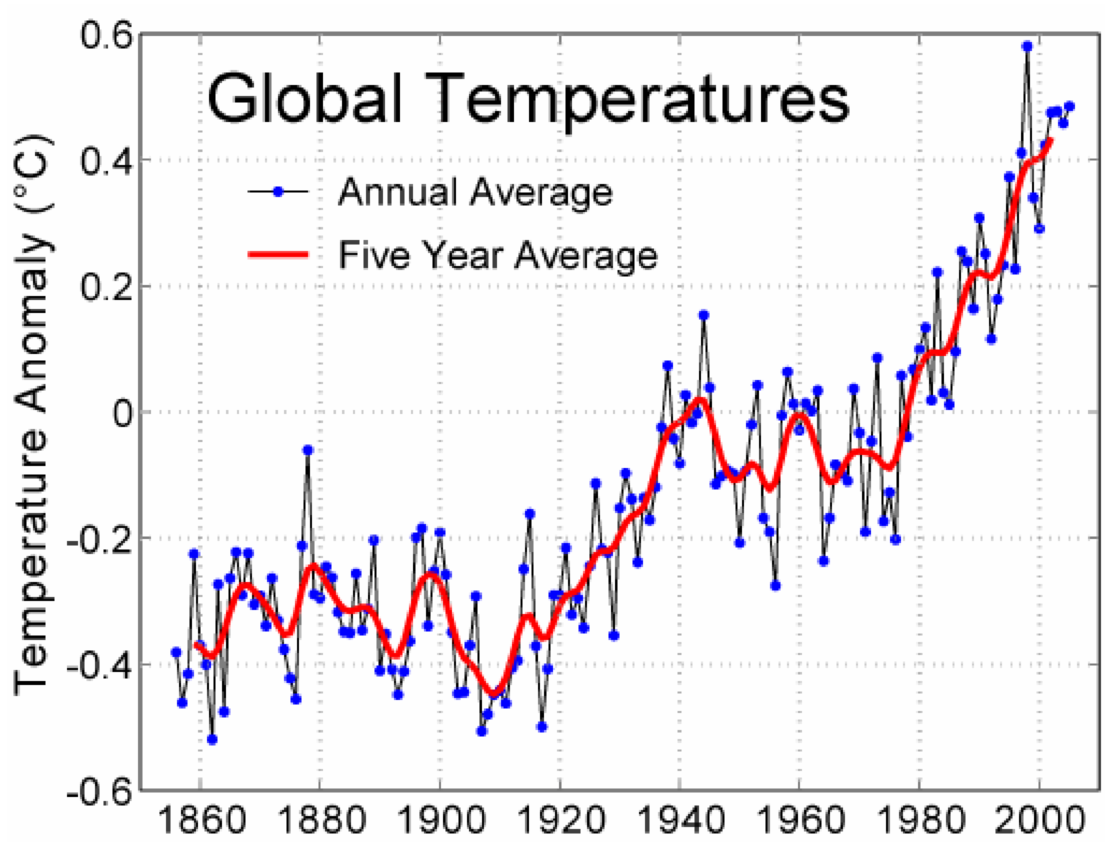
Figure 10.4 Effects of increasing CO_2 concentration on net photosynthesis (●), leaf conductance (△), and transpiration (○) of eastern cottonwood. (Adapted from Regehr *et al.*, 1975; from Sionit and Kramer, 1986; reprinted with permission from "Carbon Dioxide Enrichment of Greenhouse Crops," Volume II. Copyright © 1986 by CRC Press, Inc., Boca Raton, FL.)


The Greenhouse Effect
The Earth is covered by a blanket of gases which allow light energy from the sun to reach the Earth's surface, where it is converted to heat energy. Most of the heat is re-radiated towards space, but some is trapped by greenhouse gases in the atmosphere. This is a natural effect which keeps the Earth's temperature at a level necessary to support life.


The Enhanced Greenhouse Effect
Human activity - particularly burning fossil fuels (coal, oil and natural gas) and land clearing - is generating more of the greenhouse gases. Most scientists are convinced that this will trap more heat and raise the Earth's surface temperature.

Global Warming?

- The future is uncertain

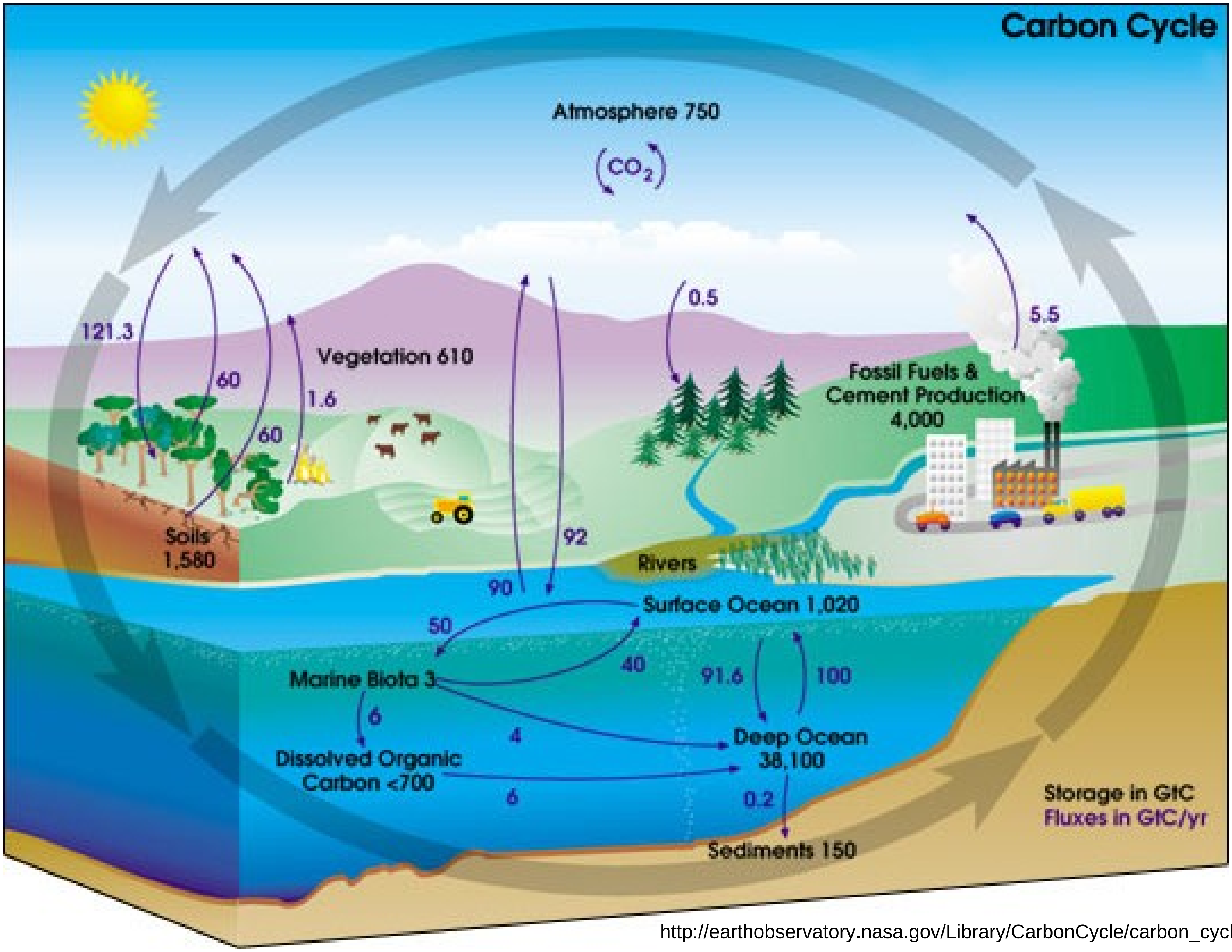


- Developing markets for C sequestration is a proactive action in the face of uncertainty

What is Carbon Sequestration?

- The long-term storage of carbon in:
  - The terrestrial biosphere
  - Deep Underground (Carbon Capture and Storage)
  - Oceans

The Global Carbon Cycle



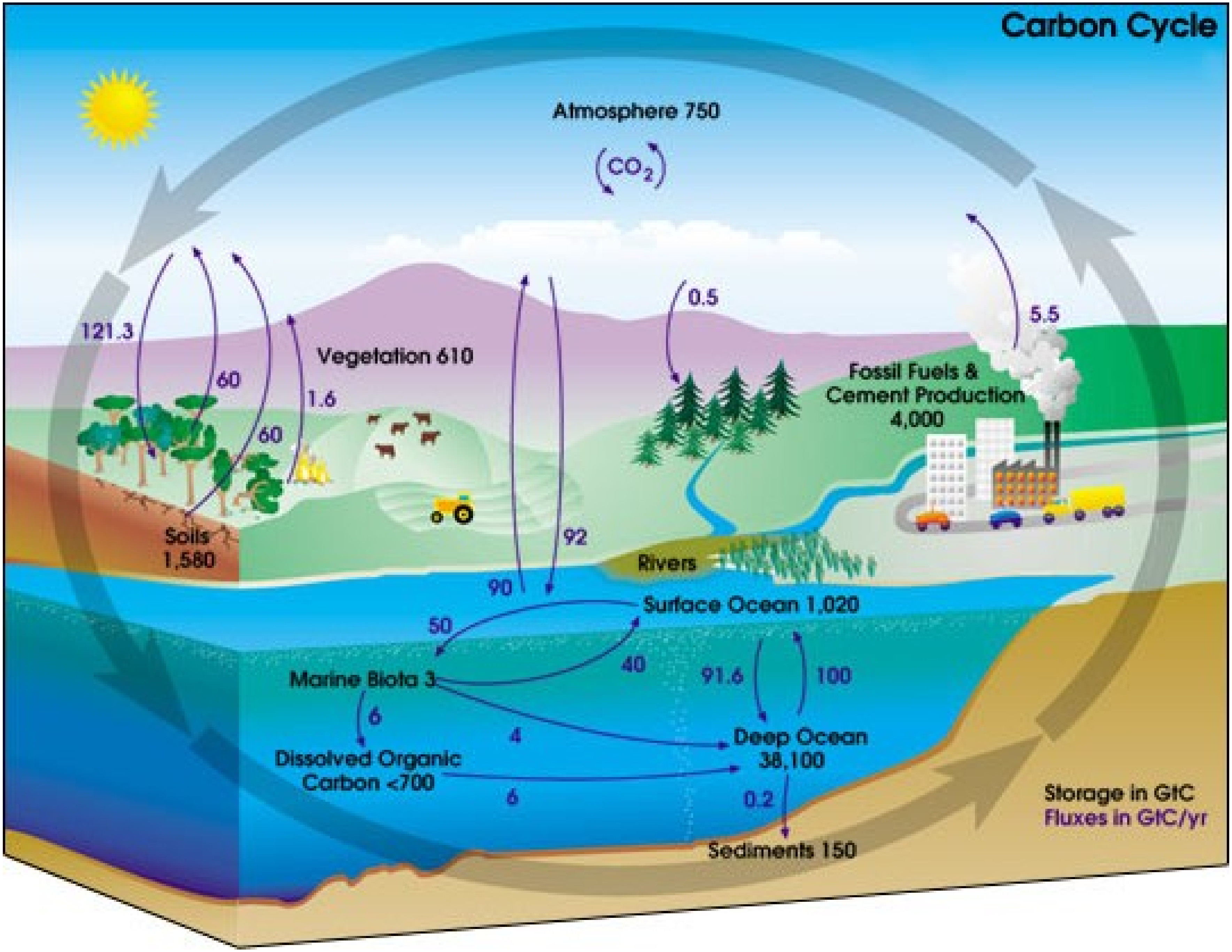
http://earthobservatory.nasa.gov/Library/CarbonCycle/carbon_cycle4.html

Where is C stored?

- Global total ~10^{23} g C
- Most is in Sedimentary rocks
  - 8 x 10^{22} g C (organic compounds and carbonates)
- In the near surface
  - ~40 x 10^{18} g C

Near Surface Carbon Stocks

Component	Gt C (10^{15})
Ocean	38100
Soil	1580
Atmosphere	750
Plant	610



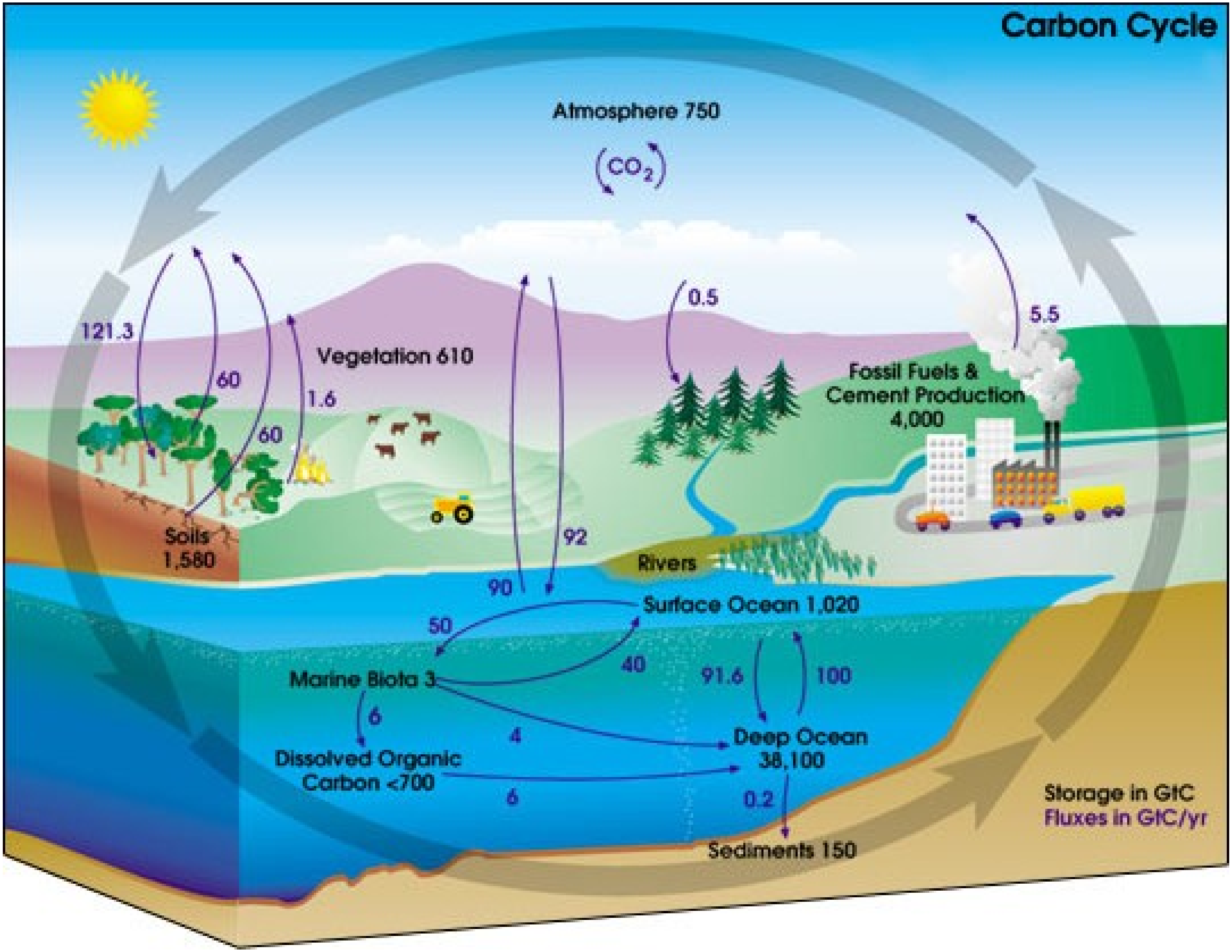
Carbon Cycle
Atmosphere 750
CO_2
121.3
60
60
1.6
Vegetation 610
90
92
0.5
5.5
Fossil Fuels & Cement Production 4,000
Soils 1,580
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean 38,100
Dissolved Organic Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr

Where is Carbon cycled?

- Terrestrial ecosystems (largely forests)
- Oceans

Near Surface Carbon Fluxes

Component	Gt C (10^{15})
Plant Uptake	121.3
Ocean Uptake	92
Plant Respiration	60
Soil Respiration	60
Ocean Release	90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Storage in GtC
Fluxes in GtC/yr

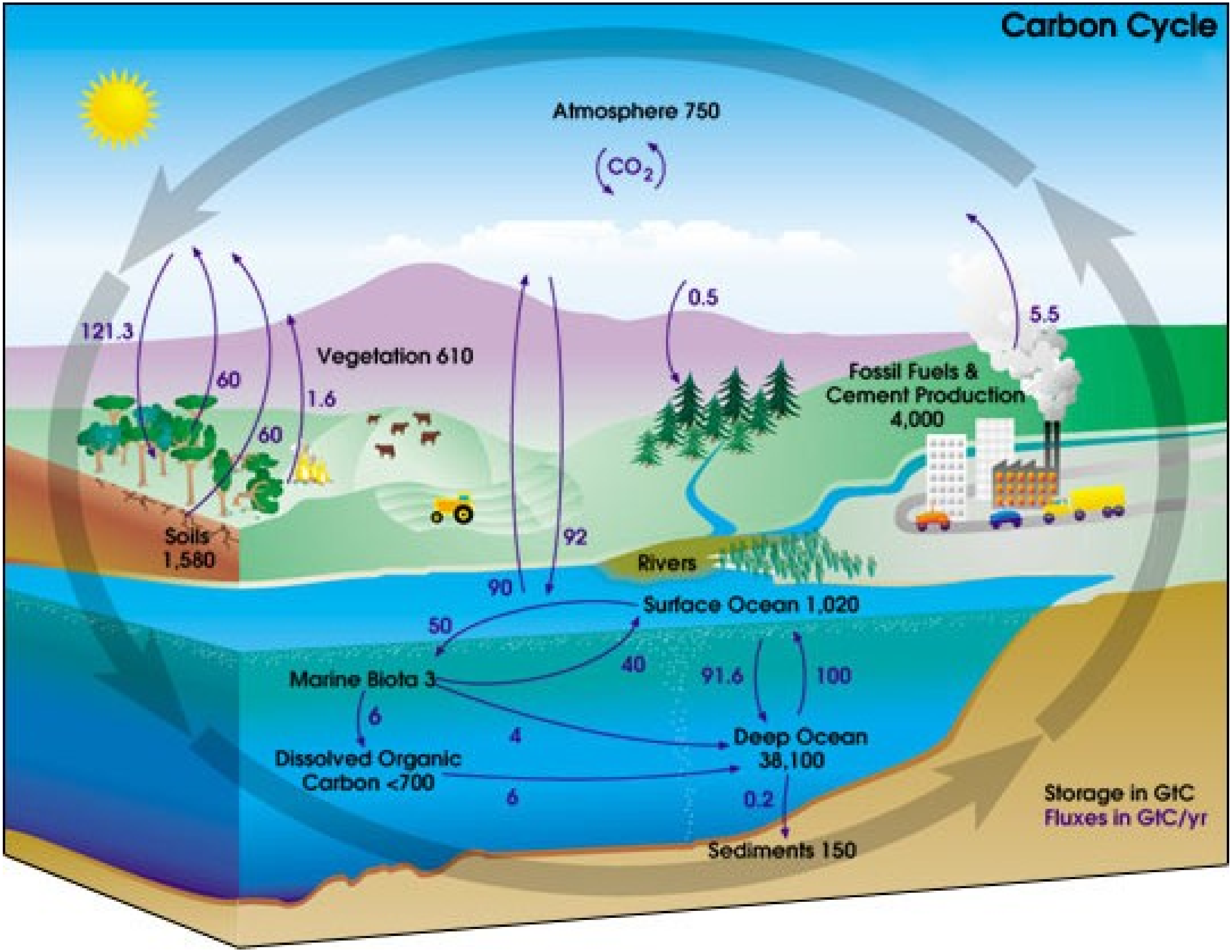
How are humans affecting the global carbon cycle?

Human perturbations to the global C cycle (sources)

CO_2 sources	1980-1989	1989-1998
	Gt C yr^{-1}	
Fossil fuel combustion and cement production	5.5 ± 0.5	6.3 ±0.6
Land-use change	1.6 ±0.8	1.6 ±0.8
Total emissions	7.1 ±1.3	7.9 ±1.4

Human perturbations to the global C cycle (sinks)

CO_2 sinks	Gt-C/yr
Storage in the atmosphere	3.3 ±0.2
Uptake by the ocean	2.2 ±0.8
Forest regrowth	0.7 ±0.5
Unknown sinks	1.7 ±1.5
Total sinks	7.9 ±3.0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Storage in GtC
Fluxes in GtC/yr

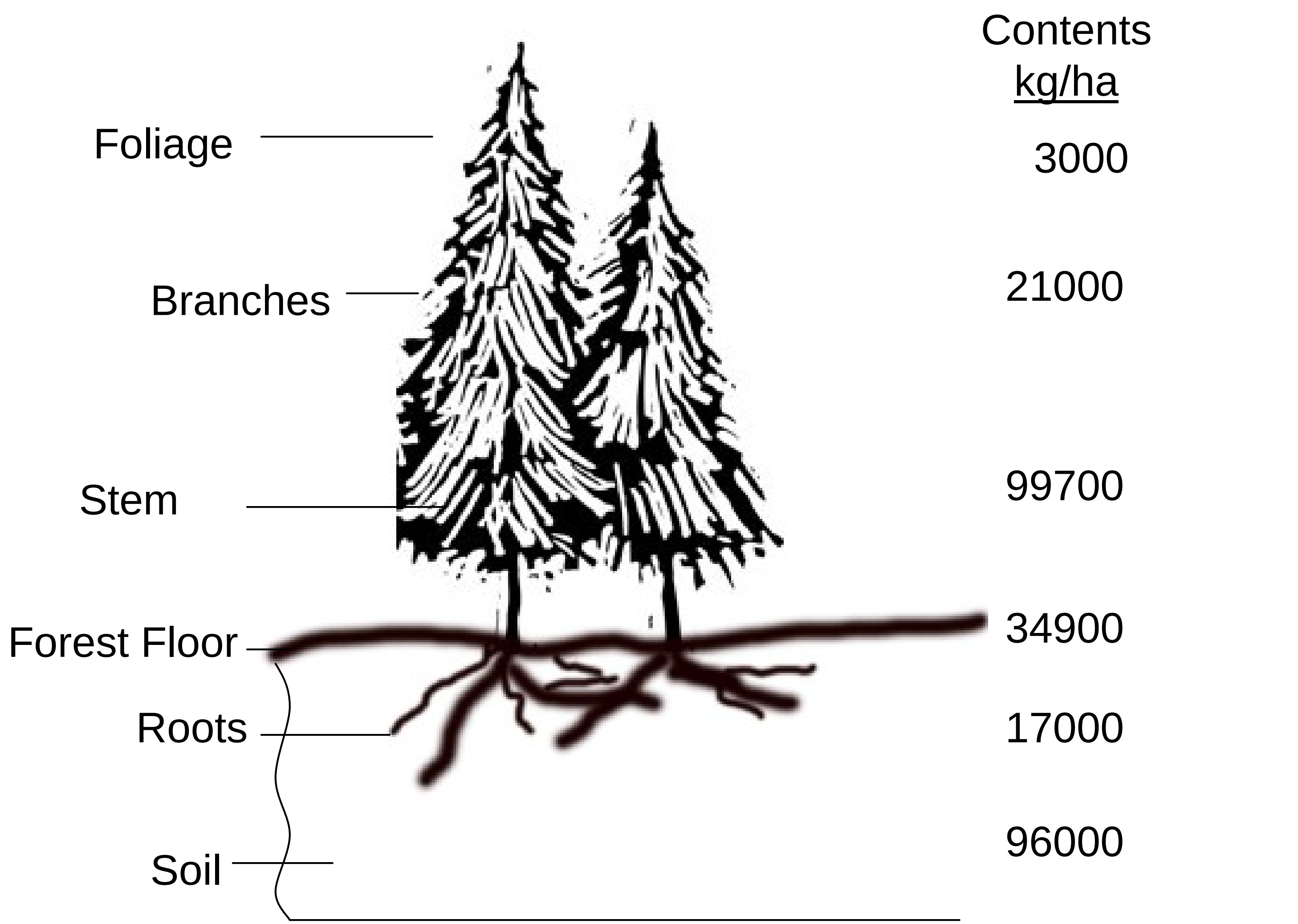
The Global C Cycle

- Emissions known well
- Atmospheric pool increasing
- Ocean sink critical but apparently limited
- Land-use change estimates continually improving
- Reforestation and unknown sinks, areas of high focus

The Forest Carbon Cycle

Where is carbon in the forest?

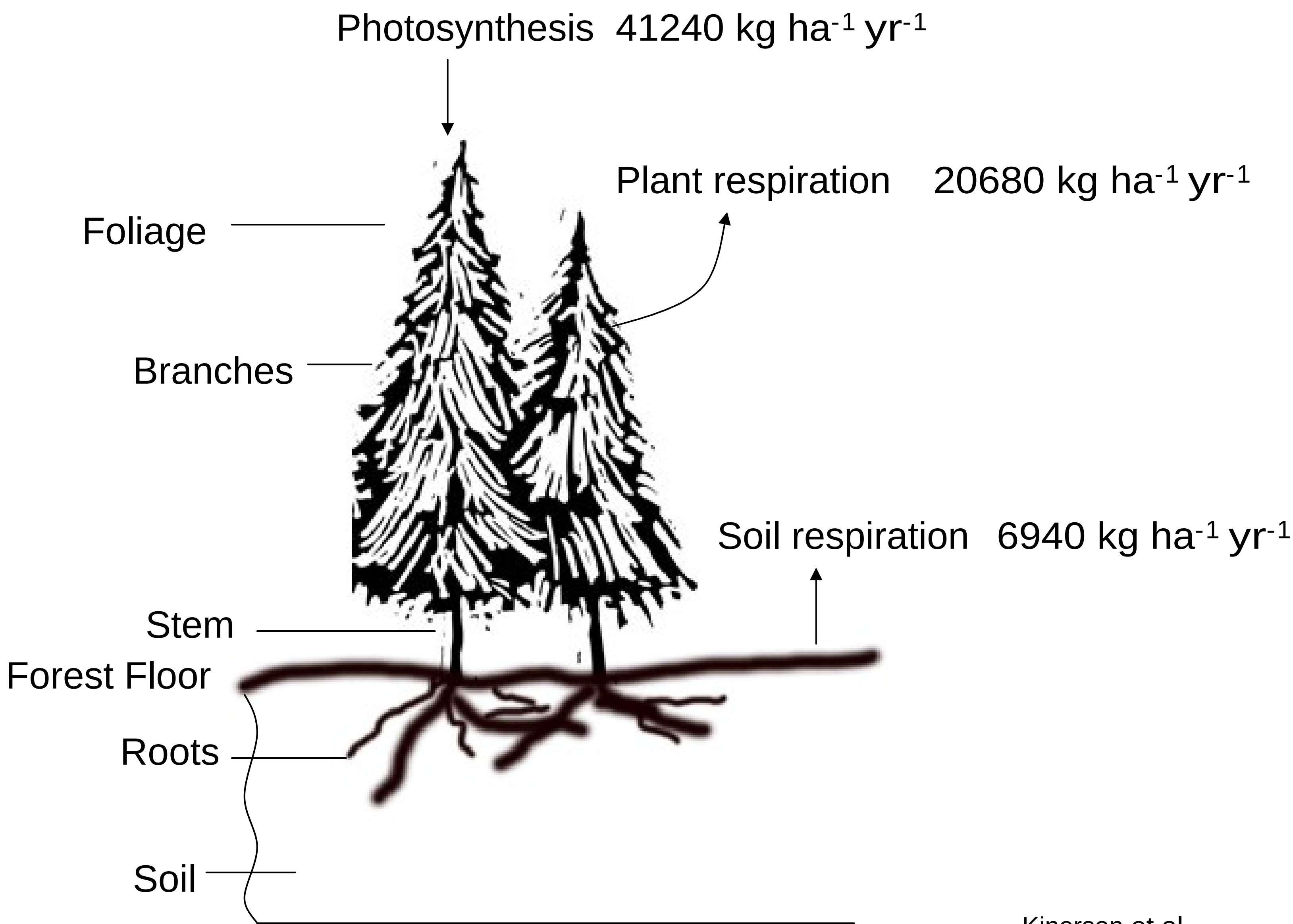
34-yr-old loblolly pine forest



Richter et al., 1995

What are the main carbon fluxes?

16 yr-old loblolly pine forest



Kinerson et al.

The Carbon balance of a forest ecosystem

- Gross Primary Productivity (GPP)
  - Photosynthesis: fixation of atmospheric C
  - $H_2O + CO_2 + \text{light energy} \rightarrow C_6H_{12}O_6 + O_2 + H_2O$

Net Primary Production (NPP)

- Some fixed C is used for respiration
  - $C_6H_{12}O_6 + O_2 + \text{enzyme} \rightarrow CO_2 + H_2O + \text{energy}$
  - Both Plant maintenance (Rm) and structural growth (Rs)

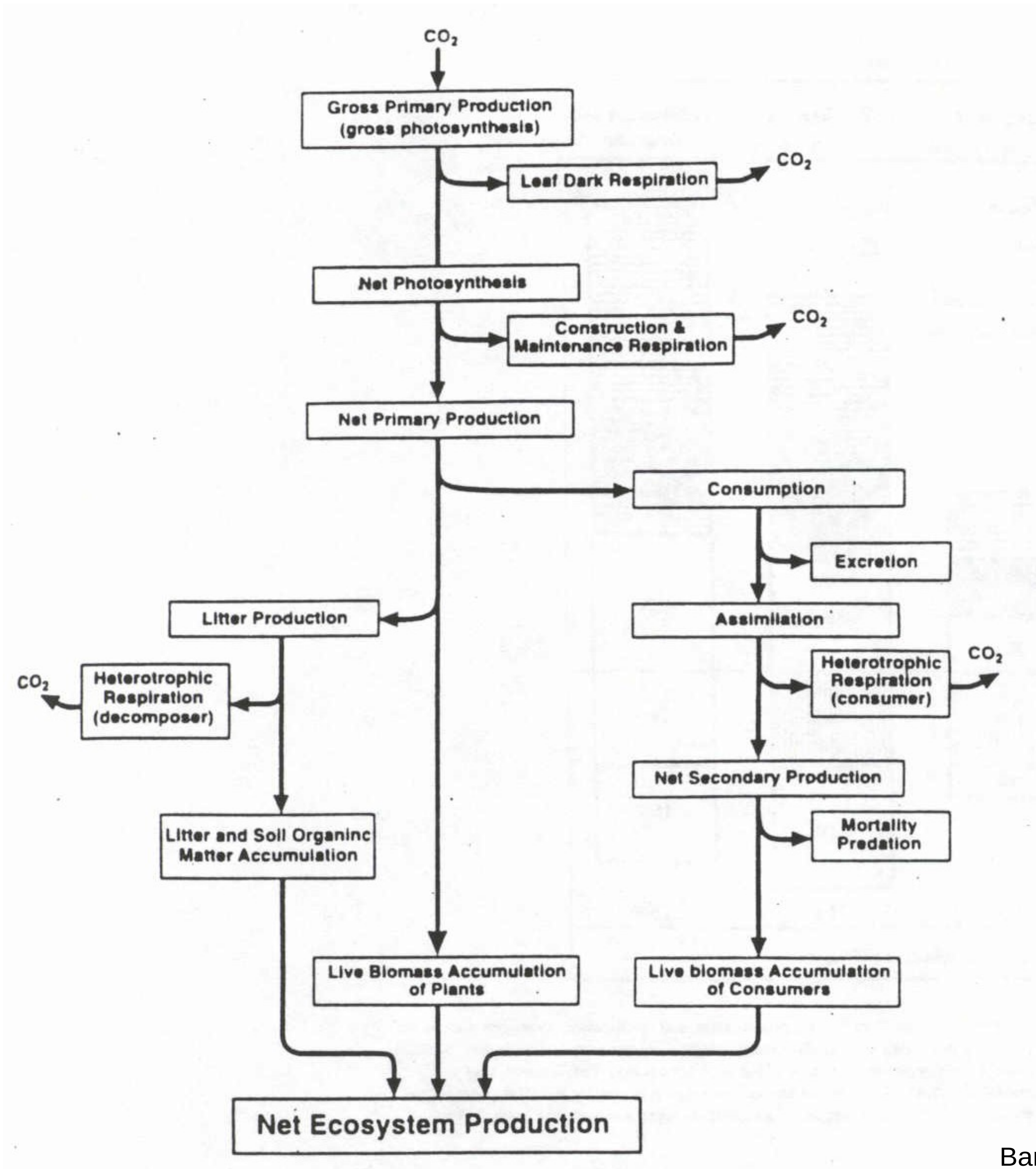
- NPP= GPP-(Rm + Rs)

Net Ecosystem Production (NEP)

- NEP is the amount of carbon gain in the ecosystem
  - NEP accounts for that C respired by secondary producers (i.e. heterotrophs: Rh)
  - NEP = NPP – Rh

- GPP= Pg (gross photosynthesis)
- NPP=GPP-Ra (autotrophic respiration)
- NEP=NPP-Rh (heterotrophic respiration)

- NEP defines annual (or long-term) carbon sequestration



CO_2
Gross Primary Production (gross photosynthesis)
Leaf Dark Respiration
CO_2
Net Photosynthesis
Construction & Maintenance Respiration
CO_2
Net Primary Production
Consumption
Excretion
Litter Production
Assimilation
Heterotrophic Respiration (consumer)
CO_2
CO_2
Heterotrophic Respiration (decomposer)
Net Secondary Production
Litter and Soil Organinc Matter Accumulation
Mortality Predation
Live Biomass Accumulation of Plants
Live biomass Accumulation of Consumers
Net Ecosystem Production

Barnes et al.

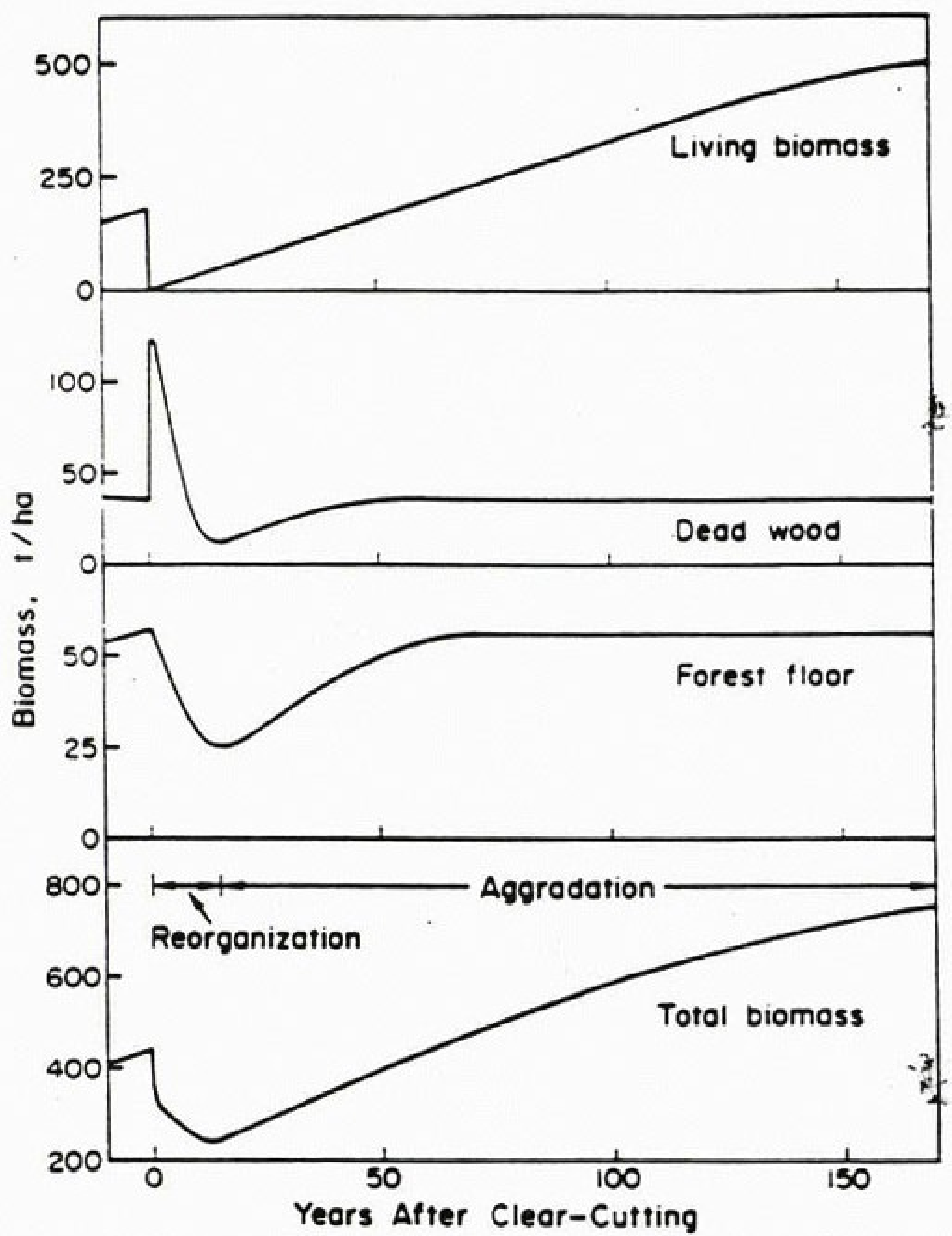
Carbon balance in two forests

Component	Immature Forest	Mature Forest
	kg/ha/yr	
GPP	12200	45000
Ra (plant respiration)	4700	32000
NPP	7500	13000
Rh (Heterotrophic respiration)	4600	13000
NEP	2900	0

Modified from Odum

Forest Carbon during Succession

- How do forest C pools change in response to forest disturbance?


500
250
0
Living biomass
100
50
0
Dead wood
50
25
0
Forest floor
800
600
400
200
Aggradation
Reorganization
Total biomass
Biomass, t/ha
0
50
100
150
Years After Clear-Cutting

Biomass (Carbon) accumulation

- Four phases of accumulation
  - Reorganization
  - Aggradation
  - Transition
  - Steady state

Re-organization

- Relatively brief period of time depending on climate (5-20 yr)

- Total C mass declines due to high decomposition although living biomass is accumulating
  - $GPP < R_A + R_H$

Aggradation

- Relatively long period in which total biomass accumulates and reaches a peak (~100 yr)

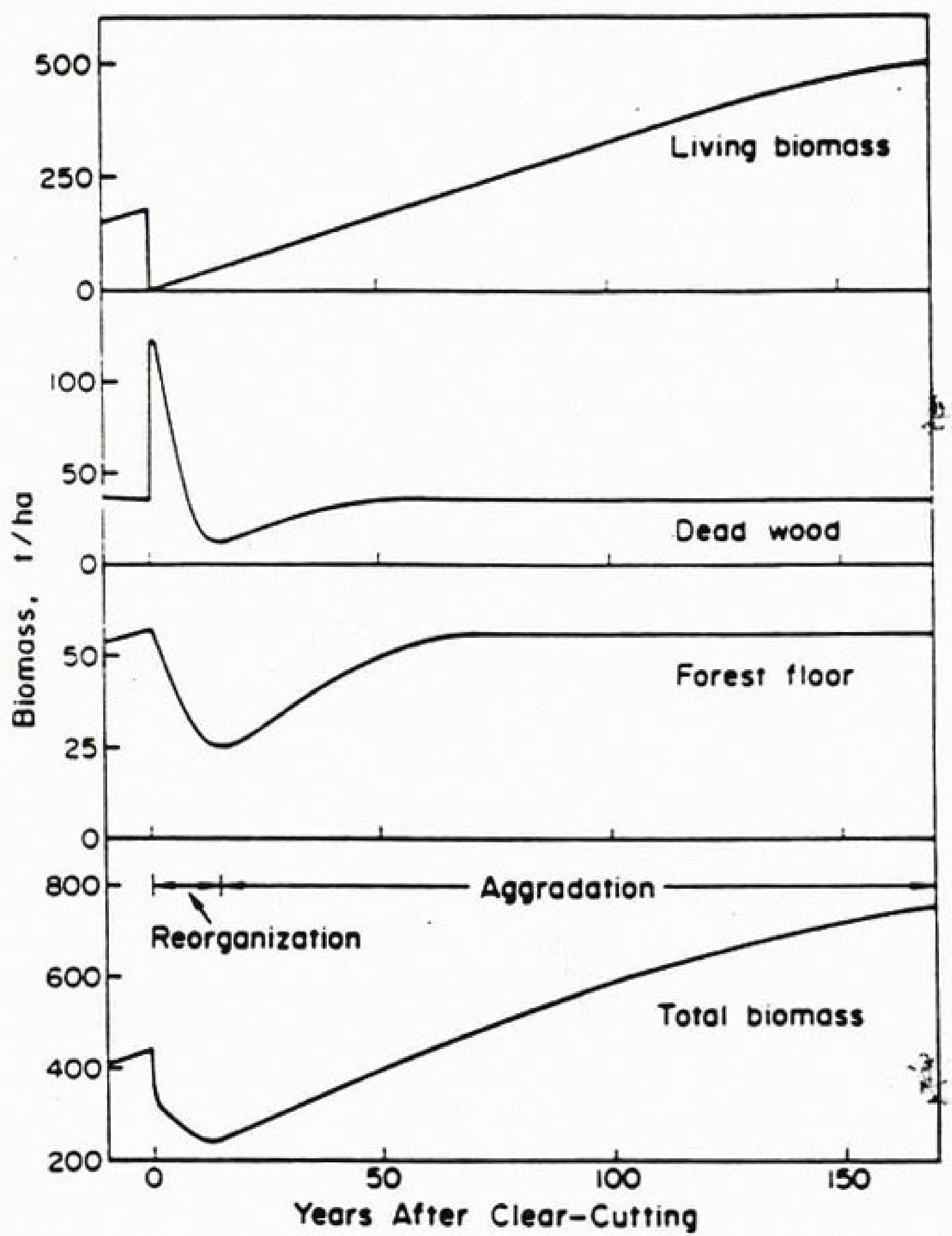
- Strong biotic control
  - $GPP > R_A + R_H$
  - In other words, NPP and NEP are high

Transition

- Variable in length of time
- Loss in overstory biomass as pioneers die off
- Structure shifts from even aged to uneven aged
- This transition period has not been well studied since globally we have a few old forests and many young forests but not many forests we have allowed to succeed to older age

Steady State

- Total carbon fluctuates about a relatively stable mean
- NEP=0



Living biomass
Dead wood
Forest floor
Total biomass
Aggradation
Reorganization
Biomass, t/ha
Years After Clear-Cutting
500
250
0
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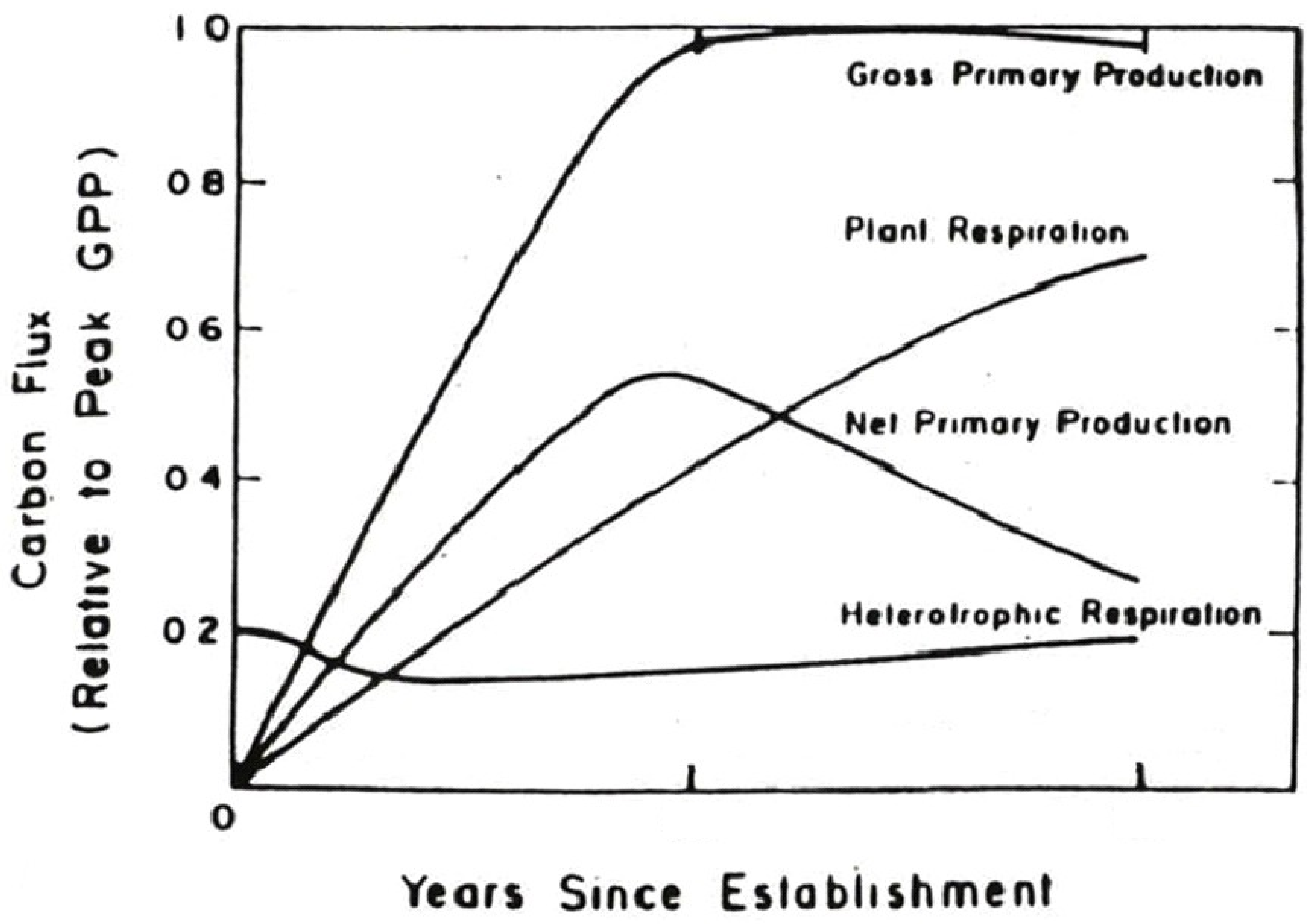
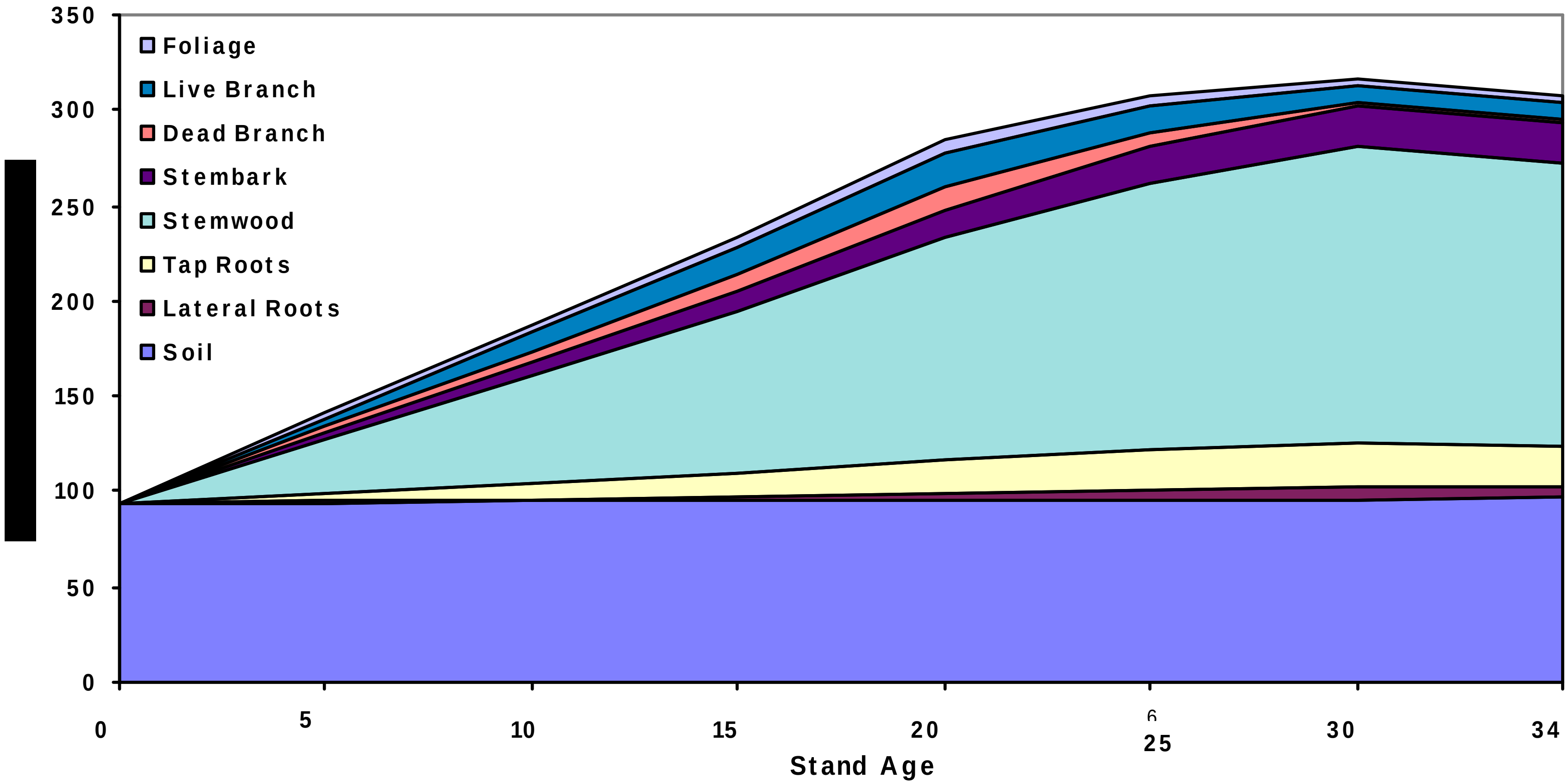
50
25
0
800
600
400
200
0
50
100
150



Waring and Schlesinger

Carbon Accumulation during Old Field Succession

34-yr-old loblolly pine stand



Richter and Markewitz

Forest Carbon Sequestration

- Focus on net balance of inputs and outputs
- In forests, focus on biomass and soil change

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