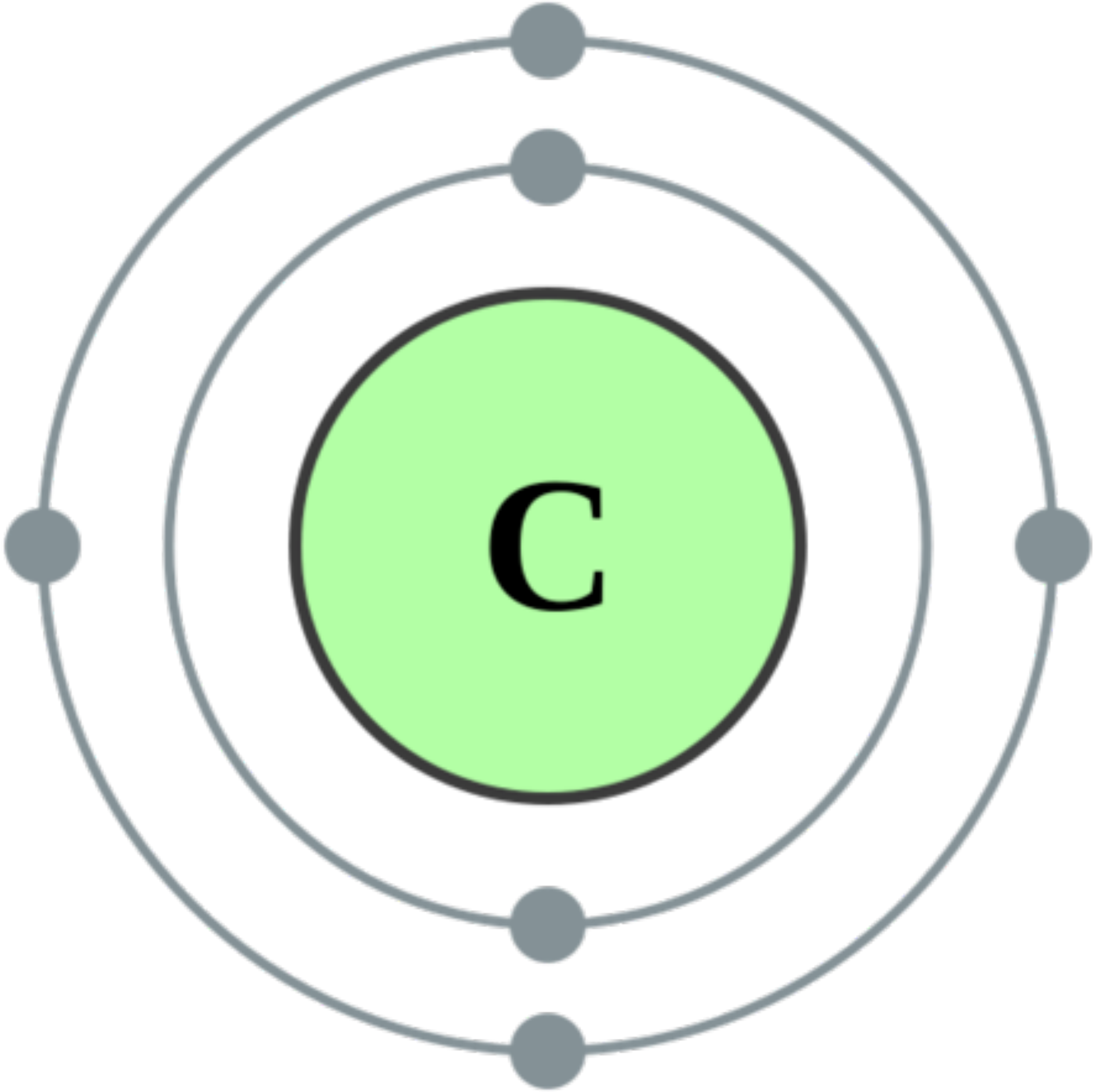
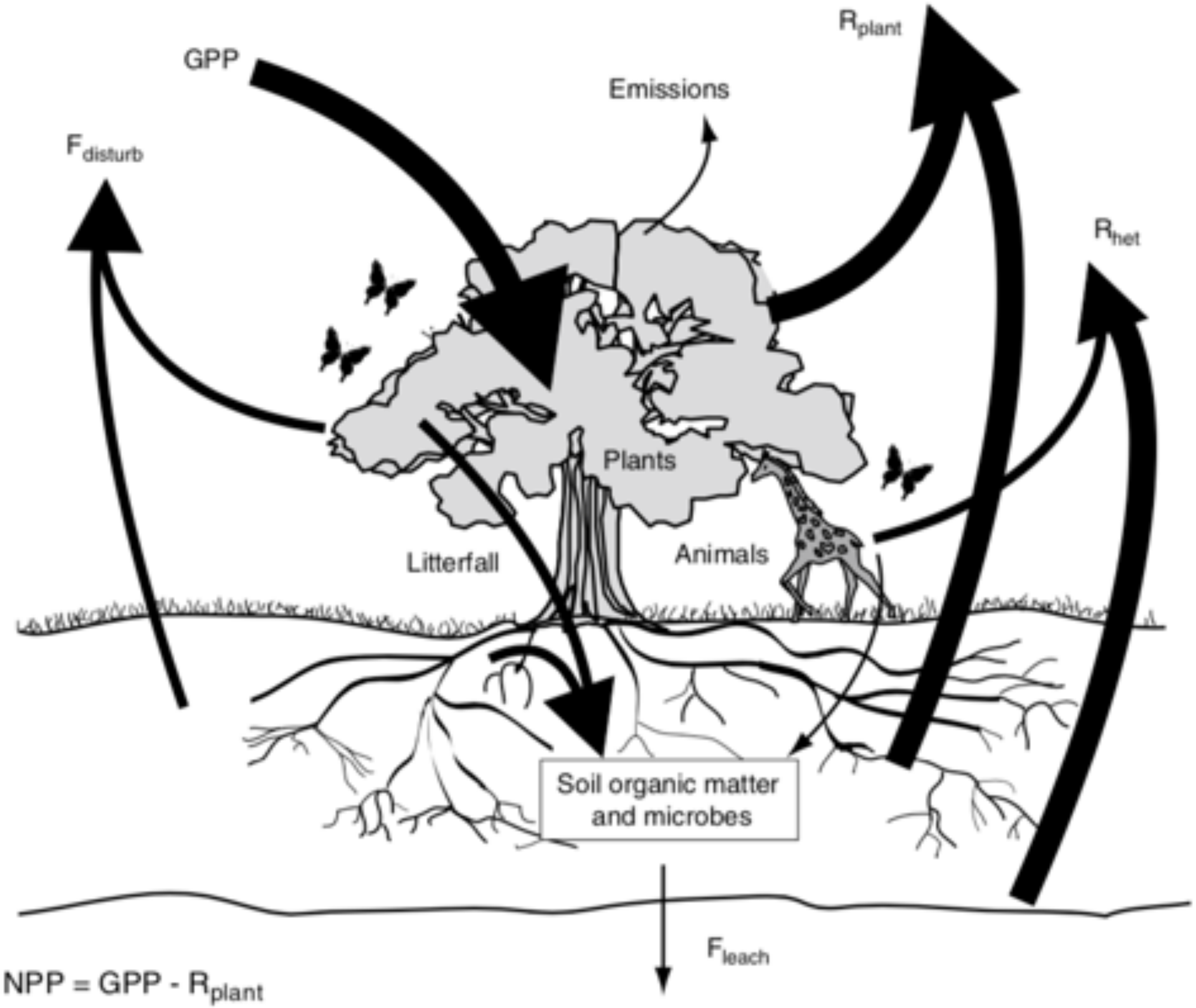


Carbon

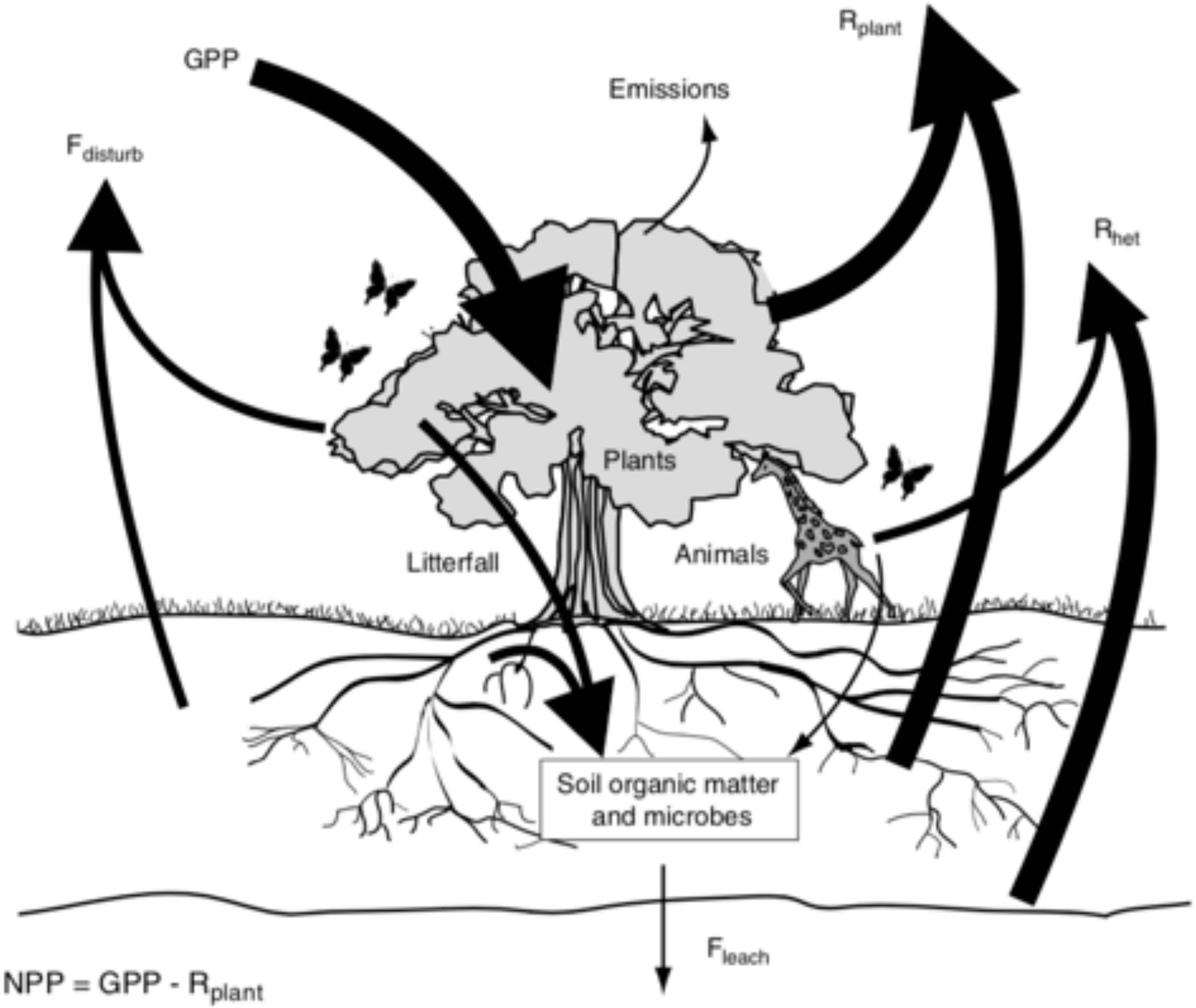
September 24, 2019

Terrestrial Ecosystem Carbon Cycle



$NPP = GPP - R_{plant}$

$NEP = GPP - (R_{plant} + R_{het})$



NPP = GPP - R_{plant}

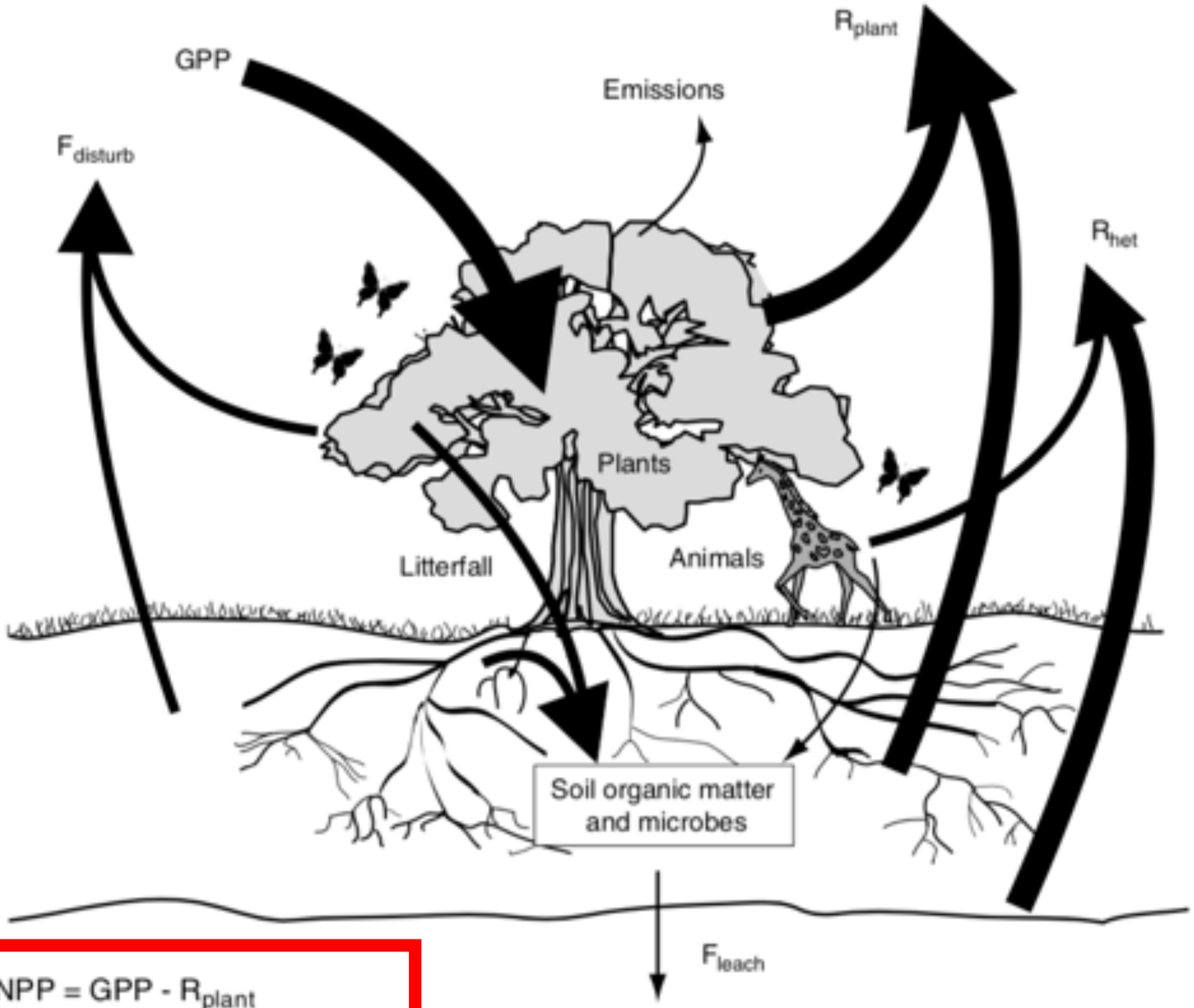
NEP = GPP - (R_{plant} + R_{het})

Terrestrial Ecosystem Carbon Cycle

Arrows represent fluxes

How do these compare to anthropogenic carbon fluxes?

Terrestrial Ecosystem Carbon Cycle



$$NPP = GPP - R_{plant}$$

$$NEP = GPP - (R_{plant} + R_{het})$$

$$NPP = GPP - R_{plant}$$

Net Primary Productivity (C into plants – C out of plants; per ground area)

$$\boxed{NPP} = GPP - R_{plant}$$

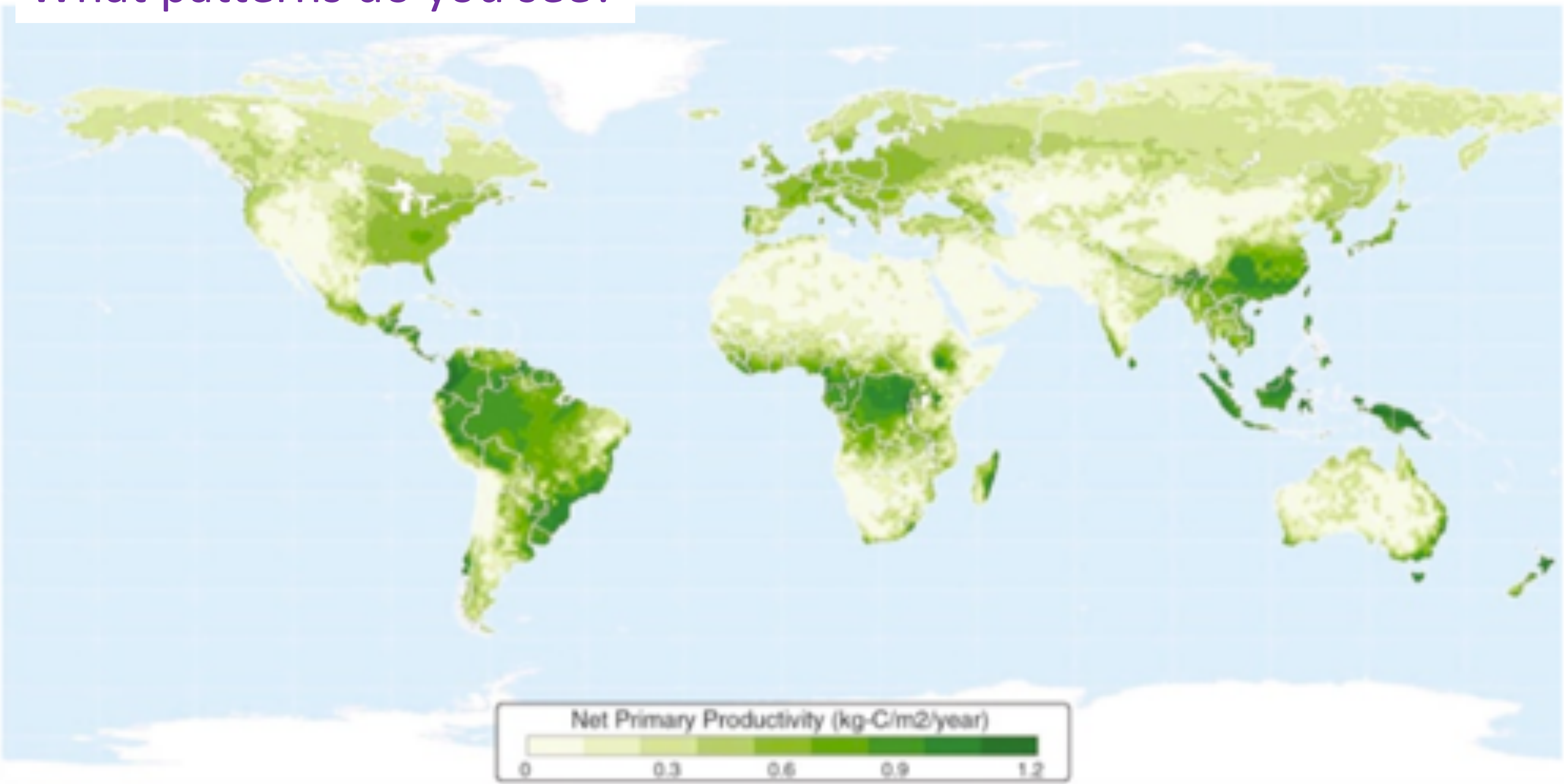
Gross Primary Productivity (total flux of C into plants; per ground area)

$$NPP = \boxed{GPP} - R_{plant}$$

Plant Respiration (total flux of C out of plants ; per ground area)

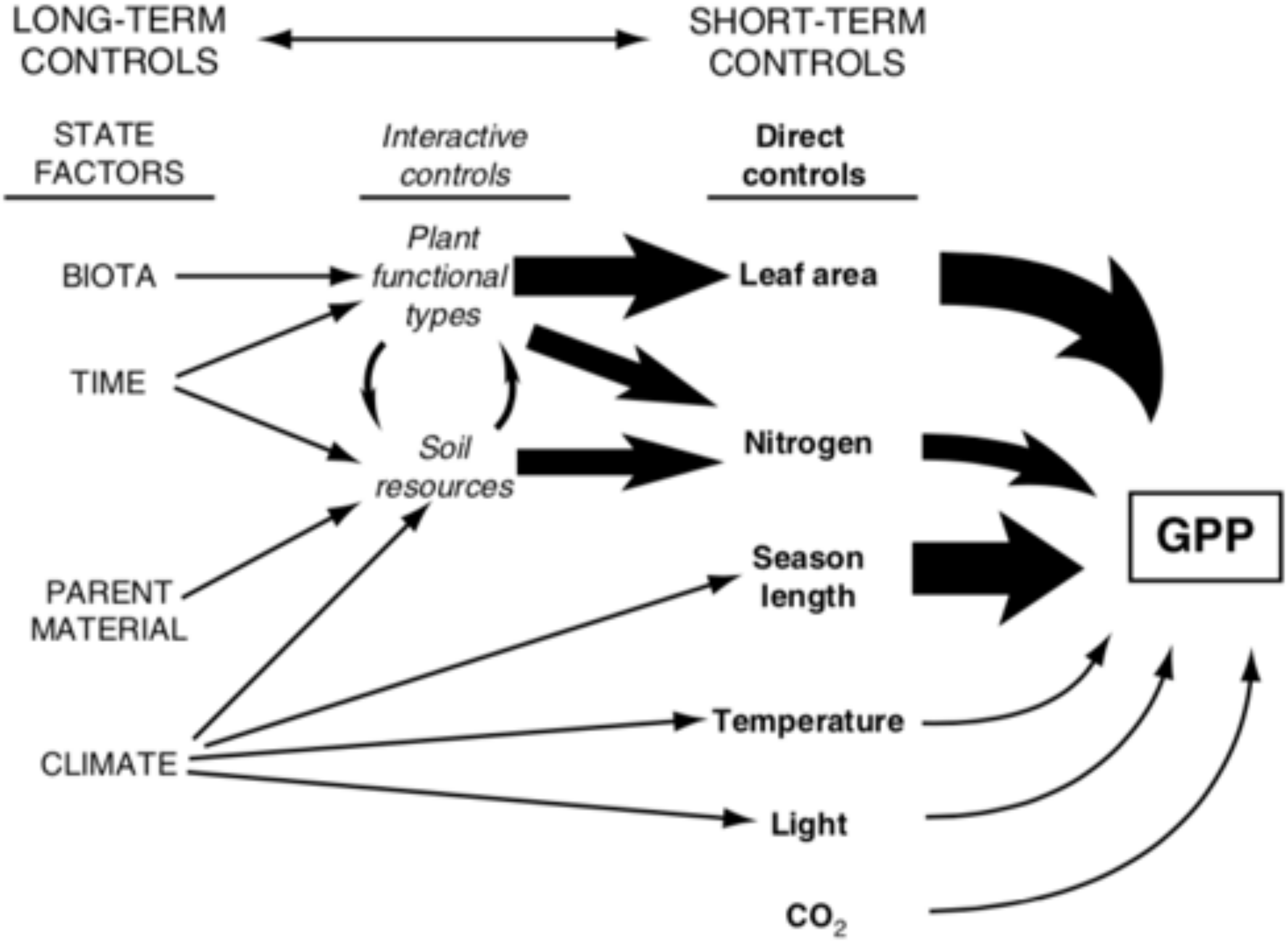
$$NPP = GPP - \boxed{R_{plant}}$$

What patterns do you see?



Gross Primary Productivity (total flux of C into plants; per ground area)

$$NPP = \boxed{GPP} - R_{plant}$$



LONG-TERM CONTROLS
SHORT-TERM CONTROLS
STATE FACTORS
Interactive controls
Direct controls
BIOTA
TIME
PARENT MATERIAL
CLIMATE
Plant functional types
Soil resources
Leaf area
Nitrogen
Season length
Temperature
Light
CO_2
GPP

$$GPP = photosynthesis * LAI$$

Carbon in to leaves (per leaf area)

$$GPP = \boxed{\text{photosynthesis}} * LAI$$

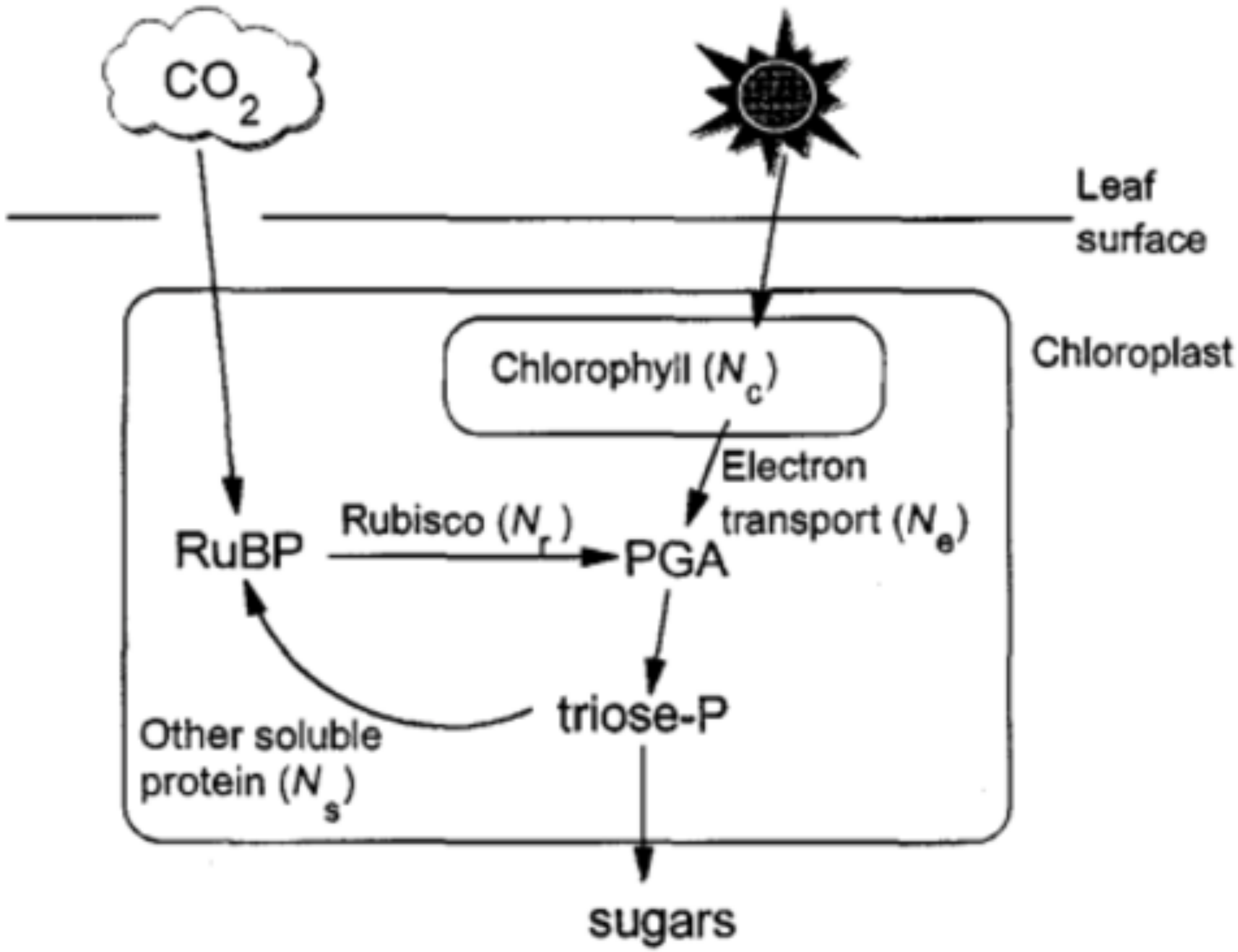
Leaf area index (leaf area per ground area)

$$GPP = photosynthesis * \boxed{LAI}$$

Carbon in to leaves (per leaf area)

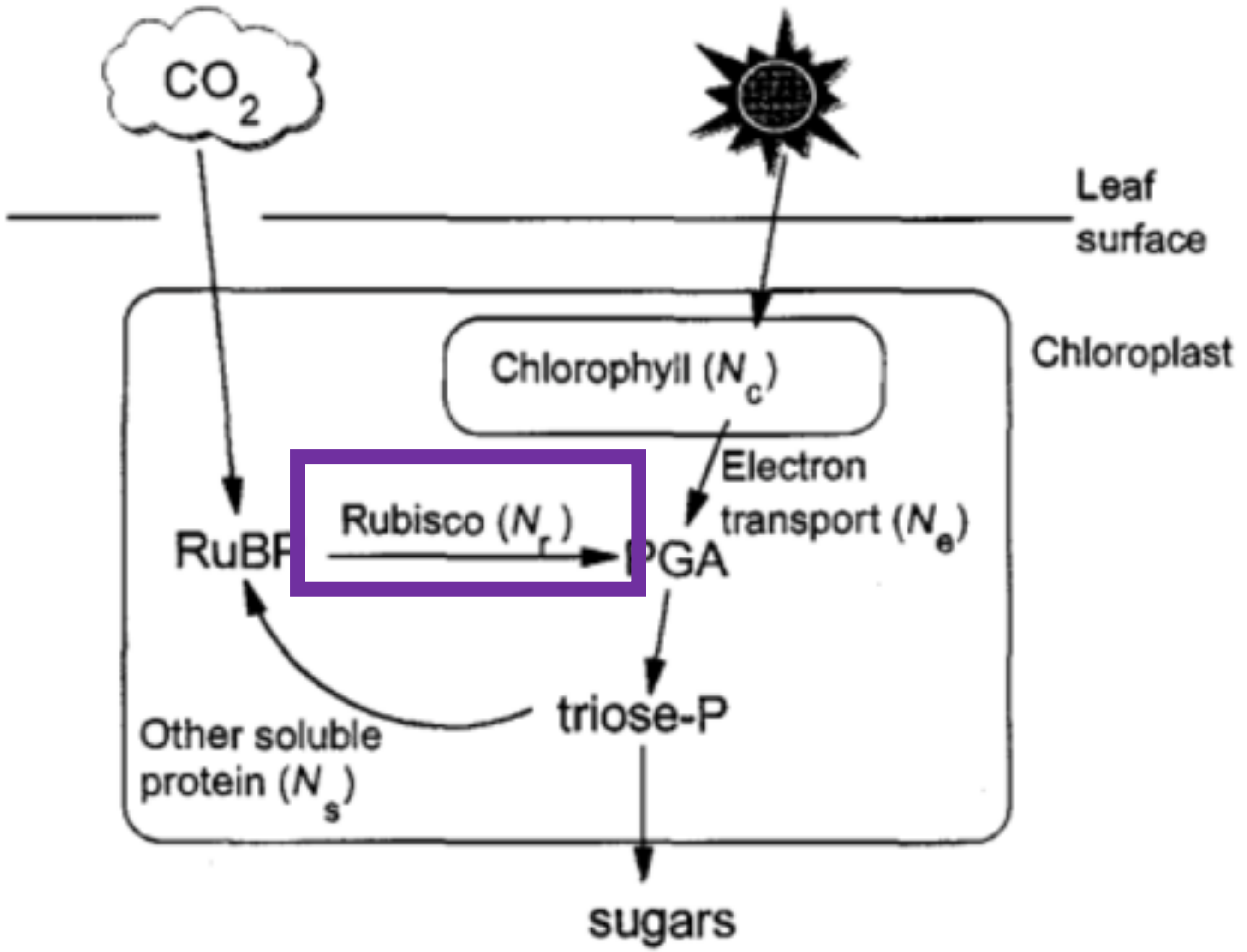
$$\text{GPP} = \boxed{\text{photosynthesis}} * \text{LAI}$$

Simple recap of photosynthesis



Medlyn 1996

Simple recap of photosynthesis



Medlyn 1996

Photorespiration

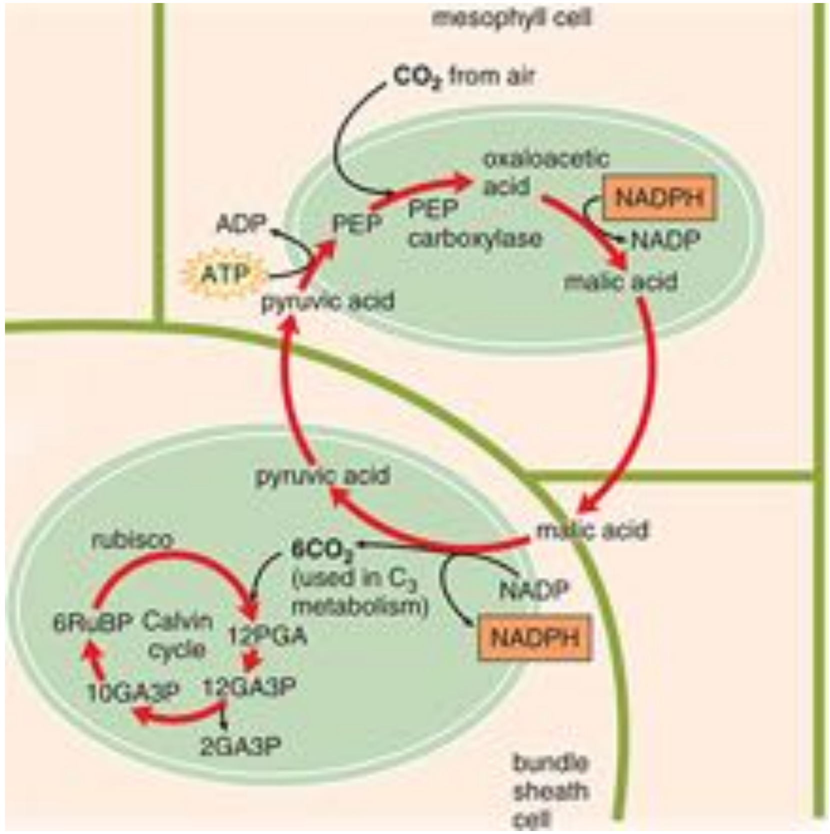
- Rubisco : RibUlose – 1,5 – BISphosphate Carboxylase and Oxygenase
- Catalyzes CO_2 and O_2
- Catalyzing O_2 leads to "wasteful" respiration (loss of CO_2)
- Increases as O_2 increases
- Increases with temperature

3 types of photosynthesis systems

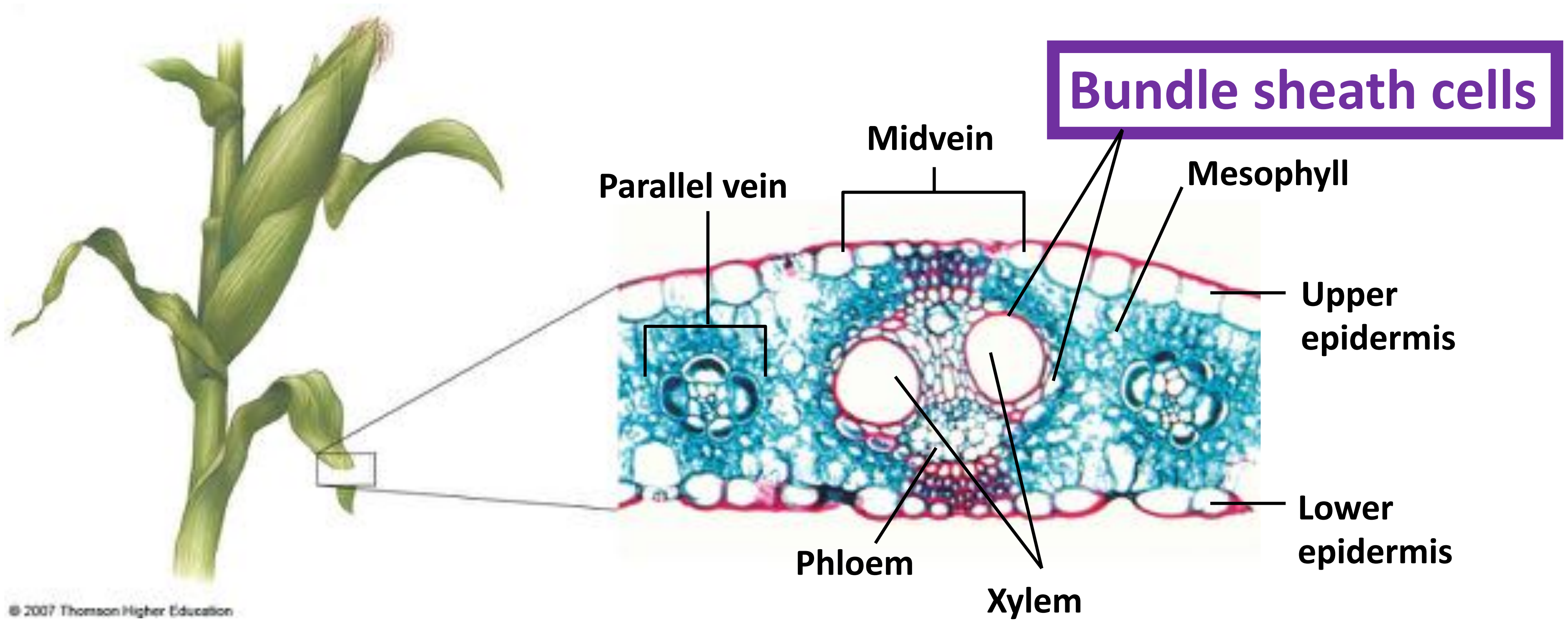
- C_3: what we already covered
  - Most plants
- C_4: Separate carbon acquisition and sugar creation in space
  - Typically grasses
- CAM: Separate carbon acquisition and sugar creation in time
  - E.g., Cacti

C4 photosynthesis

- PEP carboxylase captures CO_2 and creates a 4 carbon sugar in mesophyll
- Moves sugar to bundle sheath, where CO2 is removed
  - Bundle sheath cells surround veins
- Calvin cycle progresses as normal
- “Costs” two extra ATPs



C4 photosynthesis – why the bundle sheath?



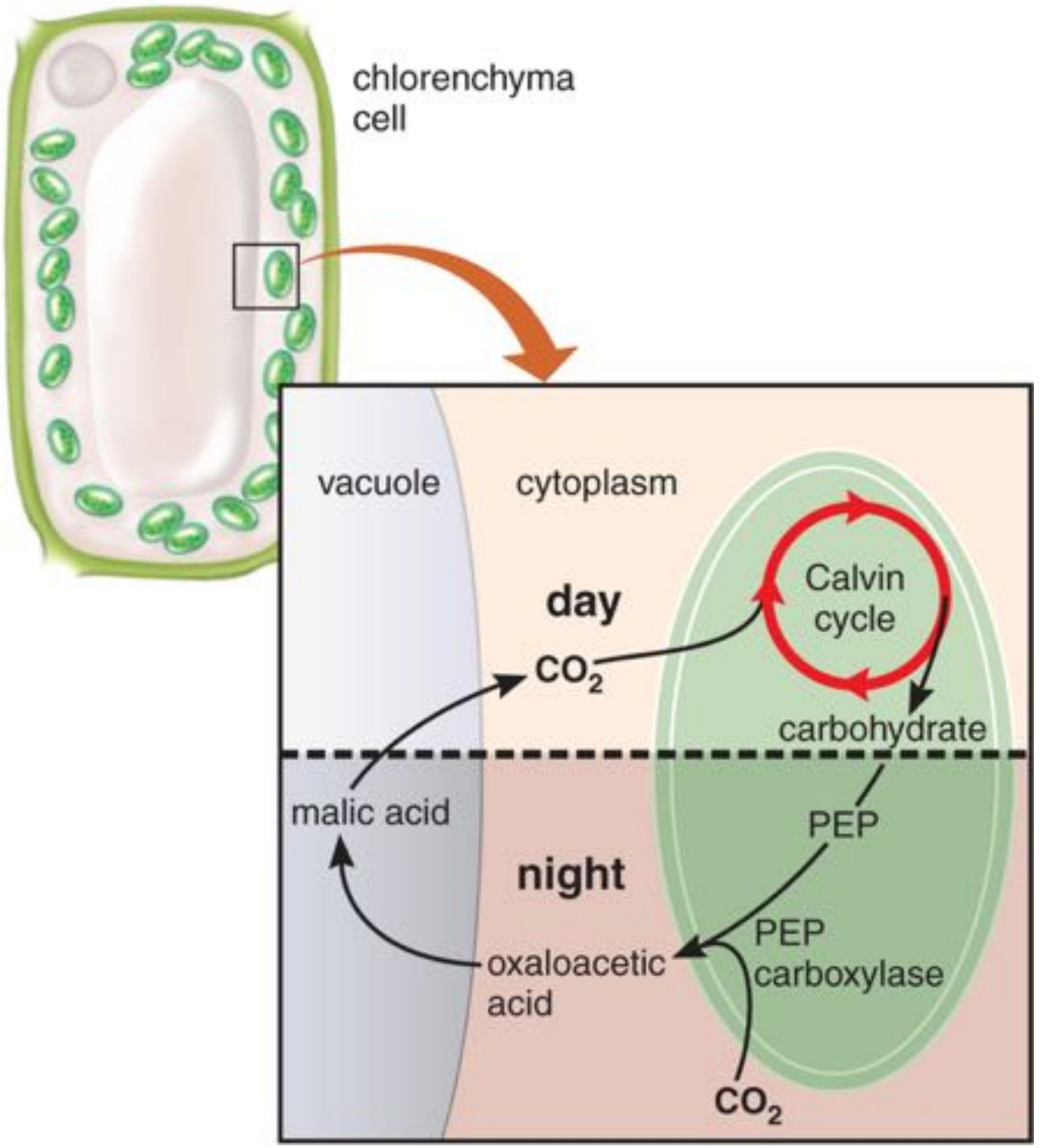
C4 photosynthesis - benefits

PEP carboxylase is not an oxygenase

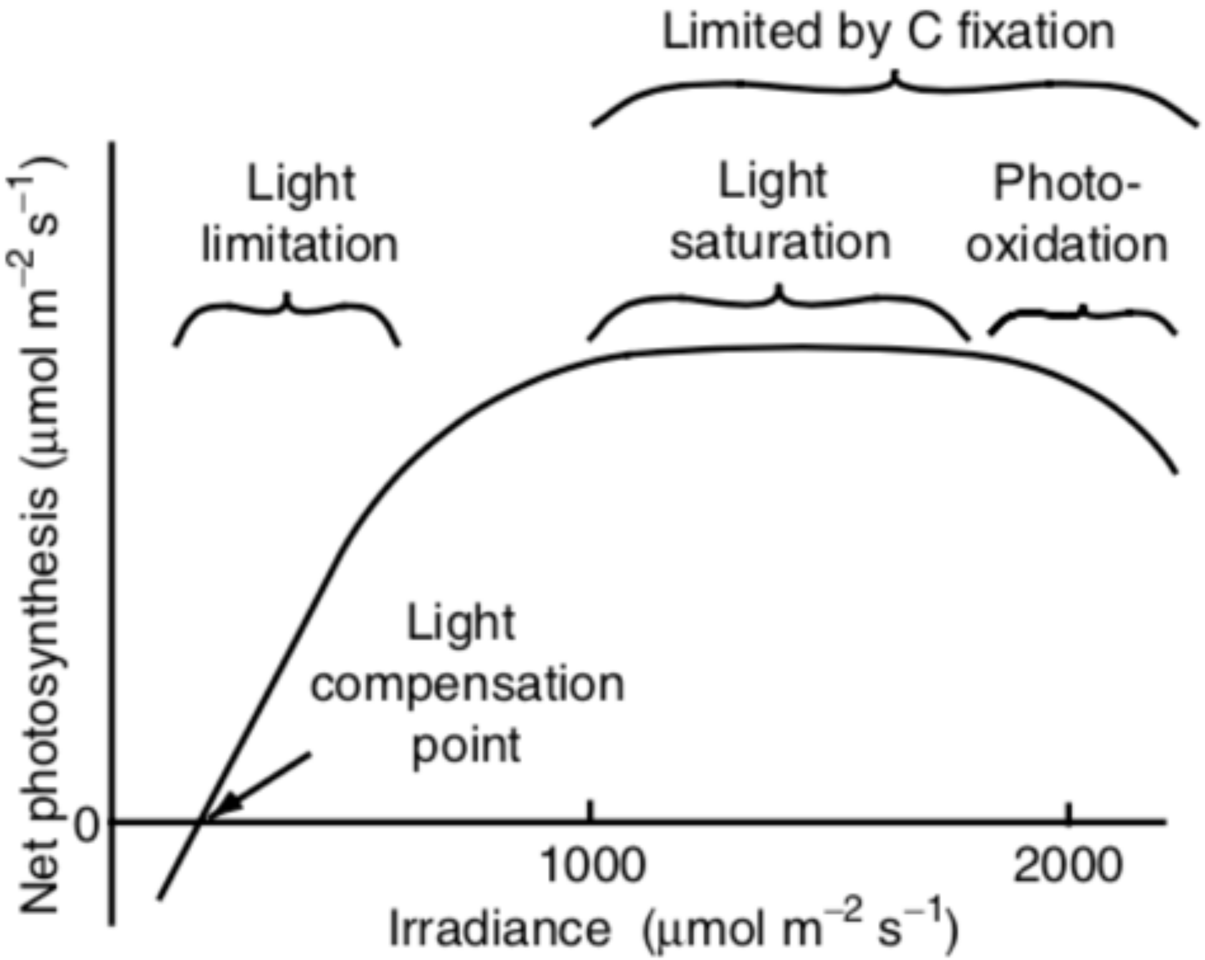
- Good at capturing CO_2
- Good in low CO_2 environments
- Good in hot, dry environments
  - Can close stomata

CAM photosynthesis

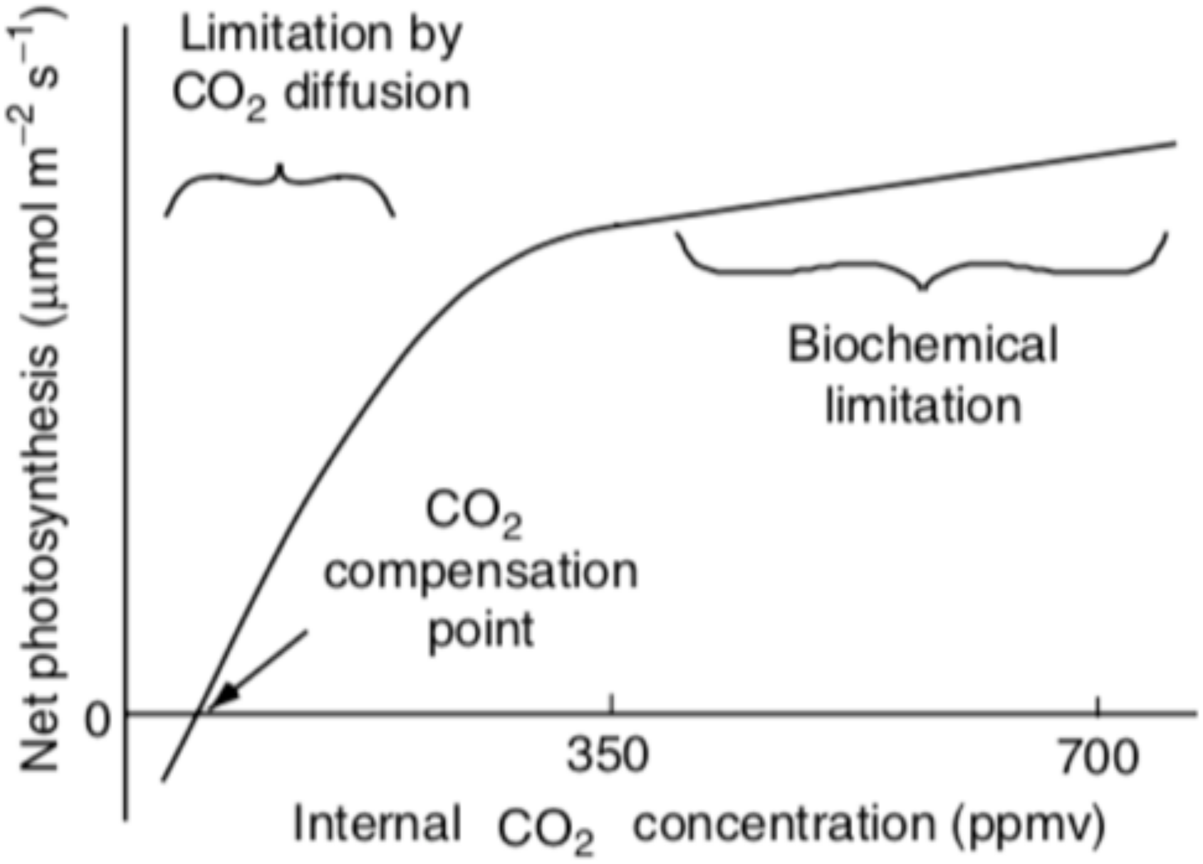
- Opens stomata during the night
  - PEP carboxylase captures CO_2 and creates a 4 carbon sugar
- Closes stomata during the day
  - Calvin cycle



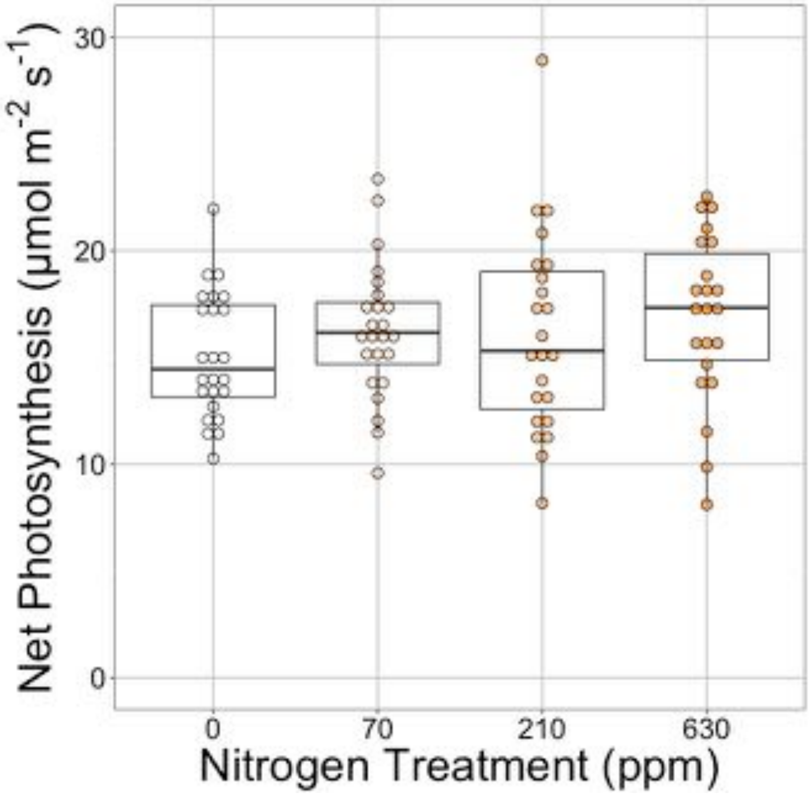
Environmental responses - light



Environmental responses – CO_2

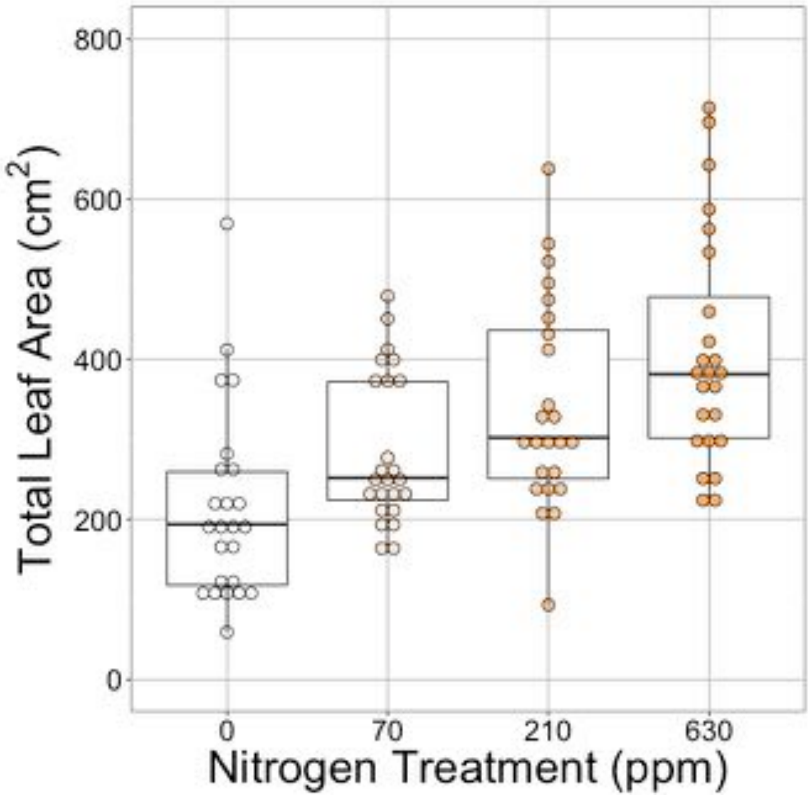


Photosynthesis is less responsive to soil resources (water and nutrients). Why?



Lizz Waring's postdoc work

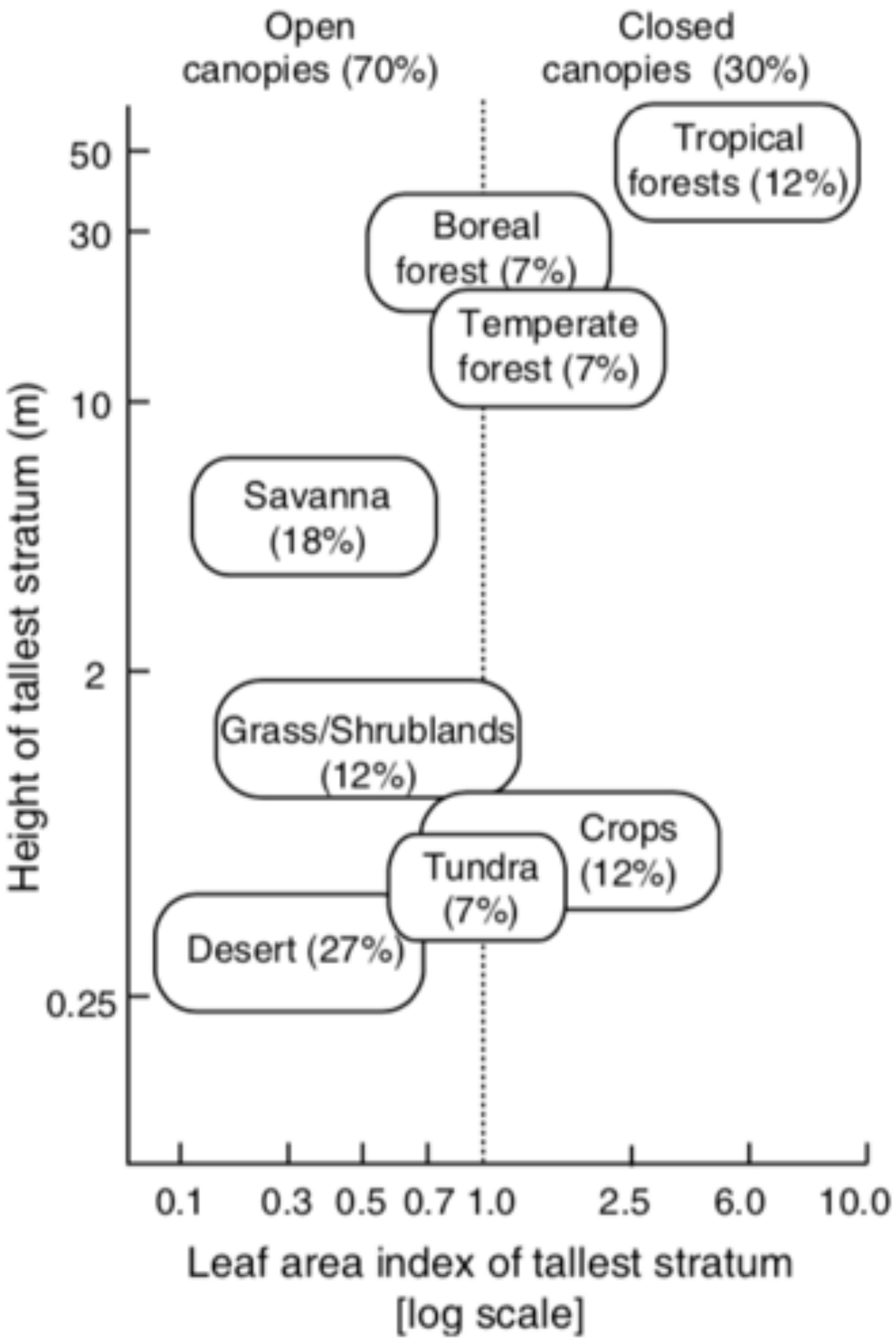
Photosynthesis is less responsive to soil resources (water and nutrients). Why?



Lizz Waring’s postdoc work

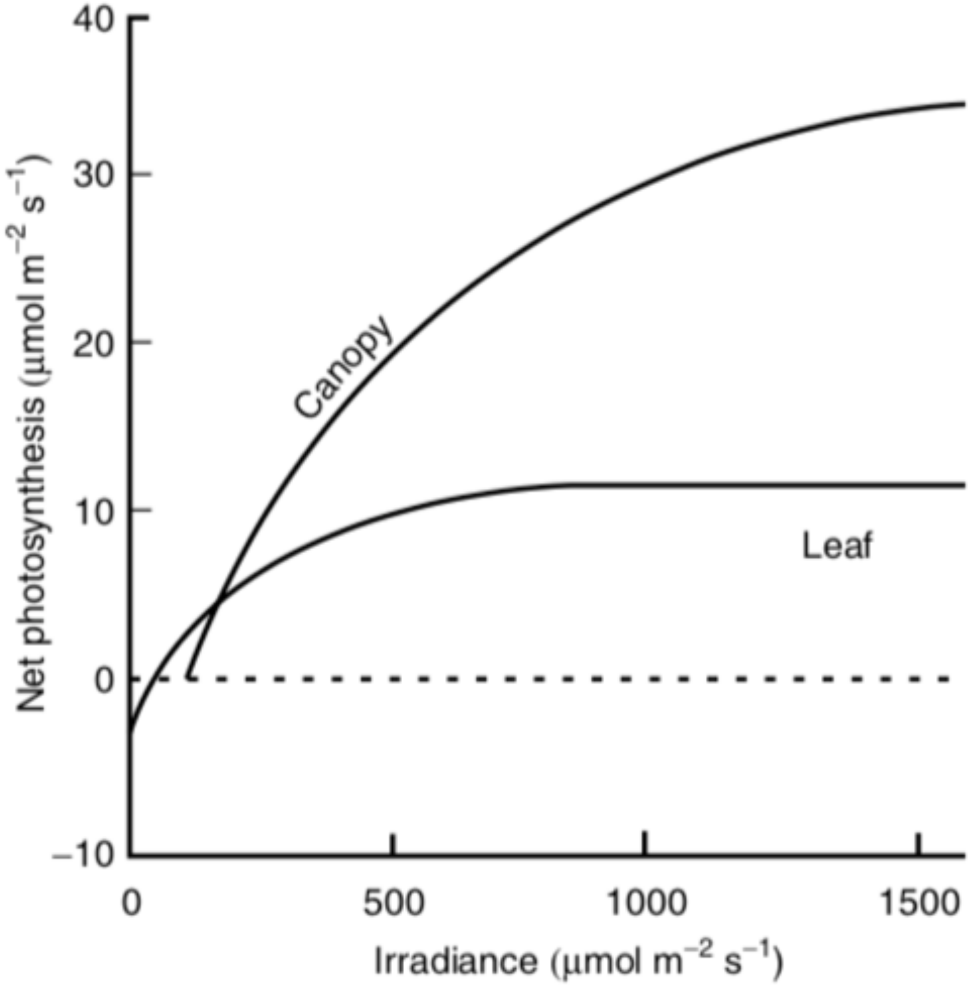
Leaf area index (leaf area per ground area)

$$GPP = \text{photosynthesis} * \boxed{LAI}$$



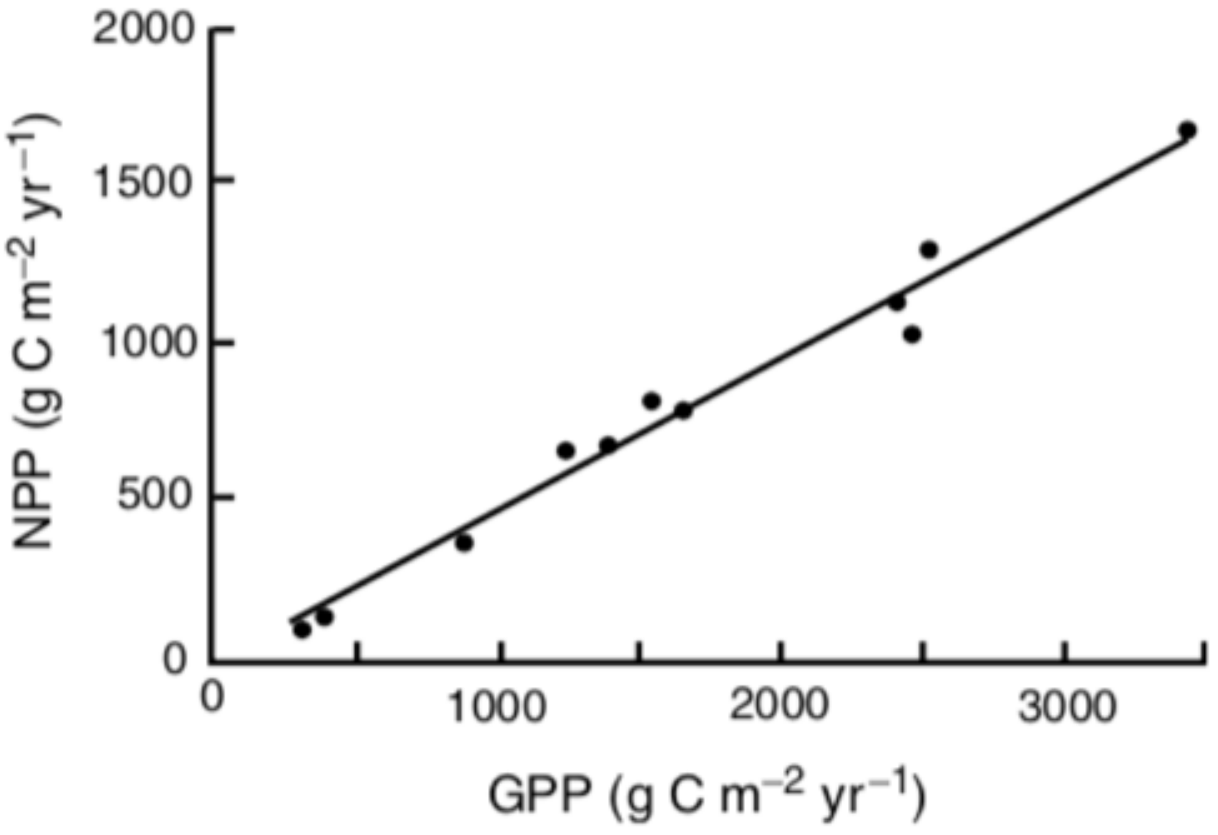
What's driving the x-axis distribution?

Canopies tend to have higher light use efficiency than leaves



Plant Respiration (total flux of C out of plants ; per ground area)

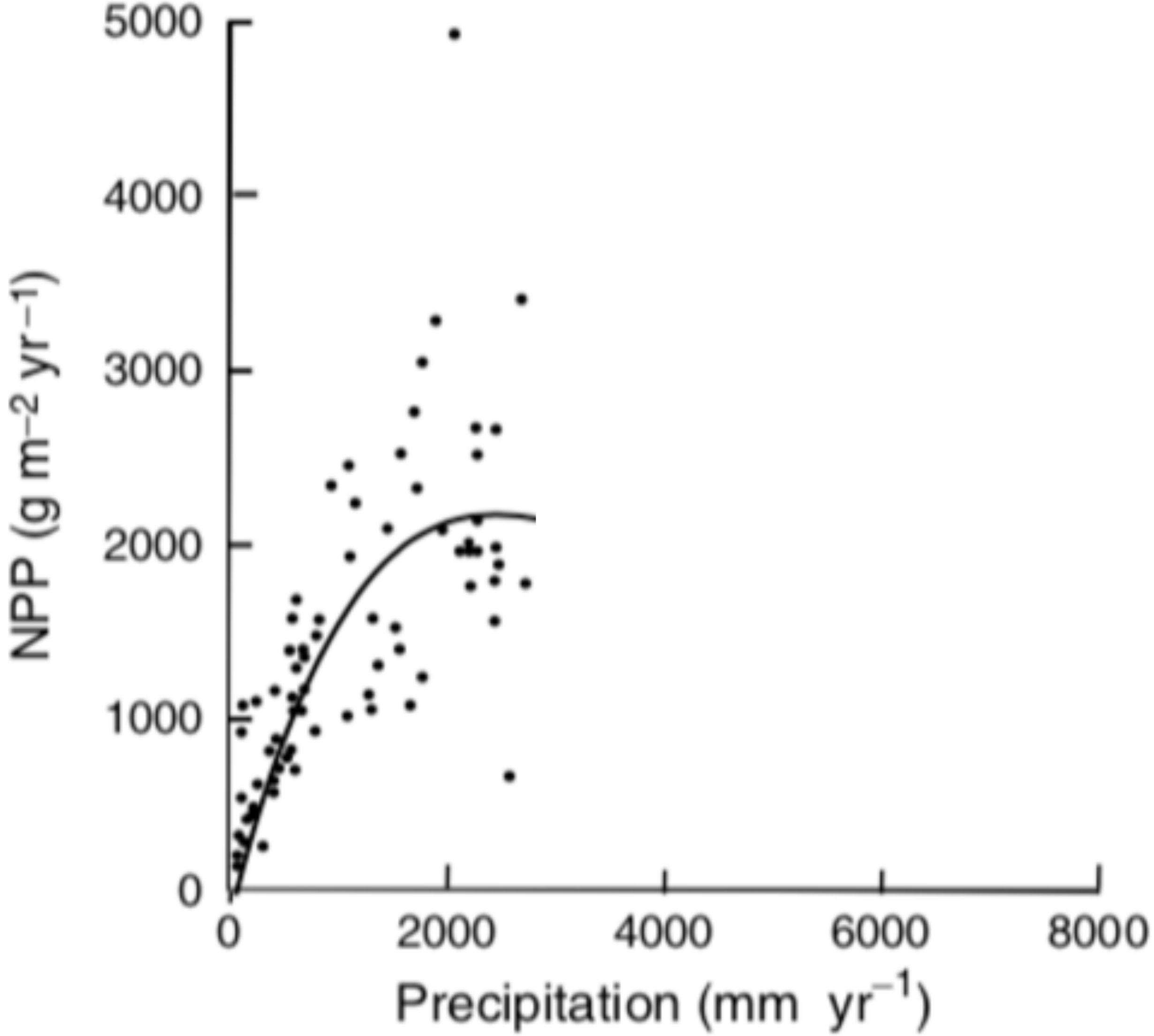
$$NPP = GPP - \boxed{R_{plant}}$$



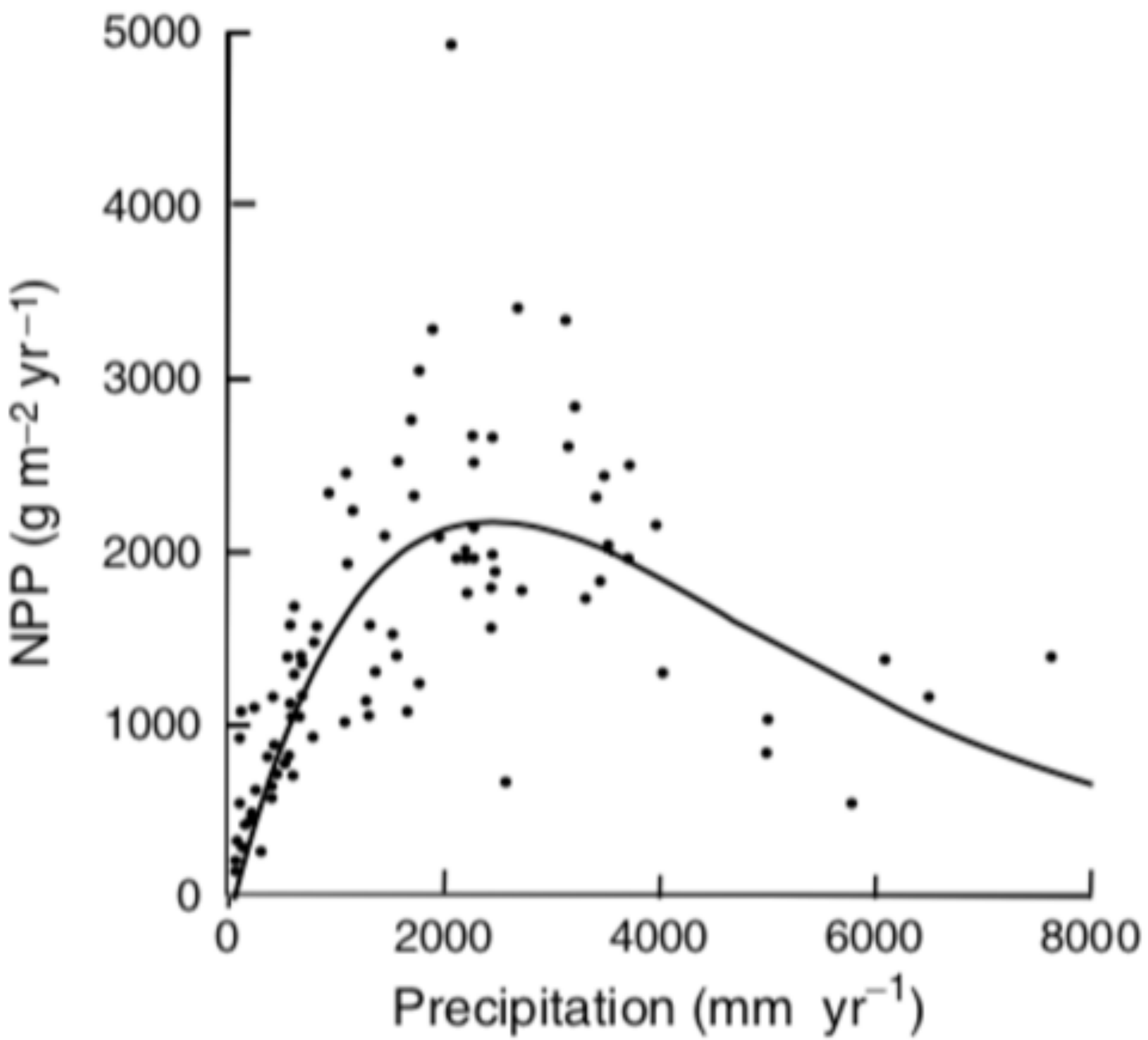
NPP = GPP – 0.5*GPP

What drives NPP?

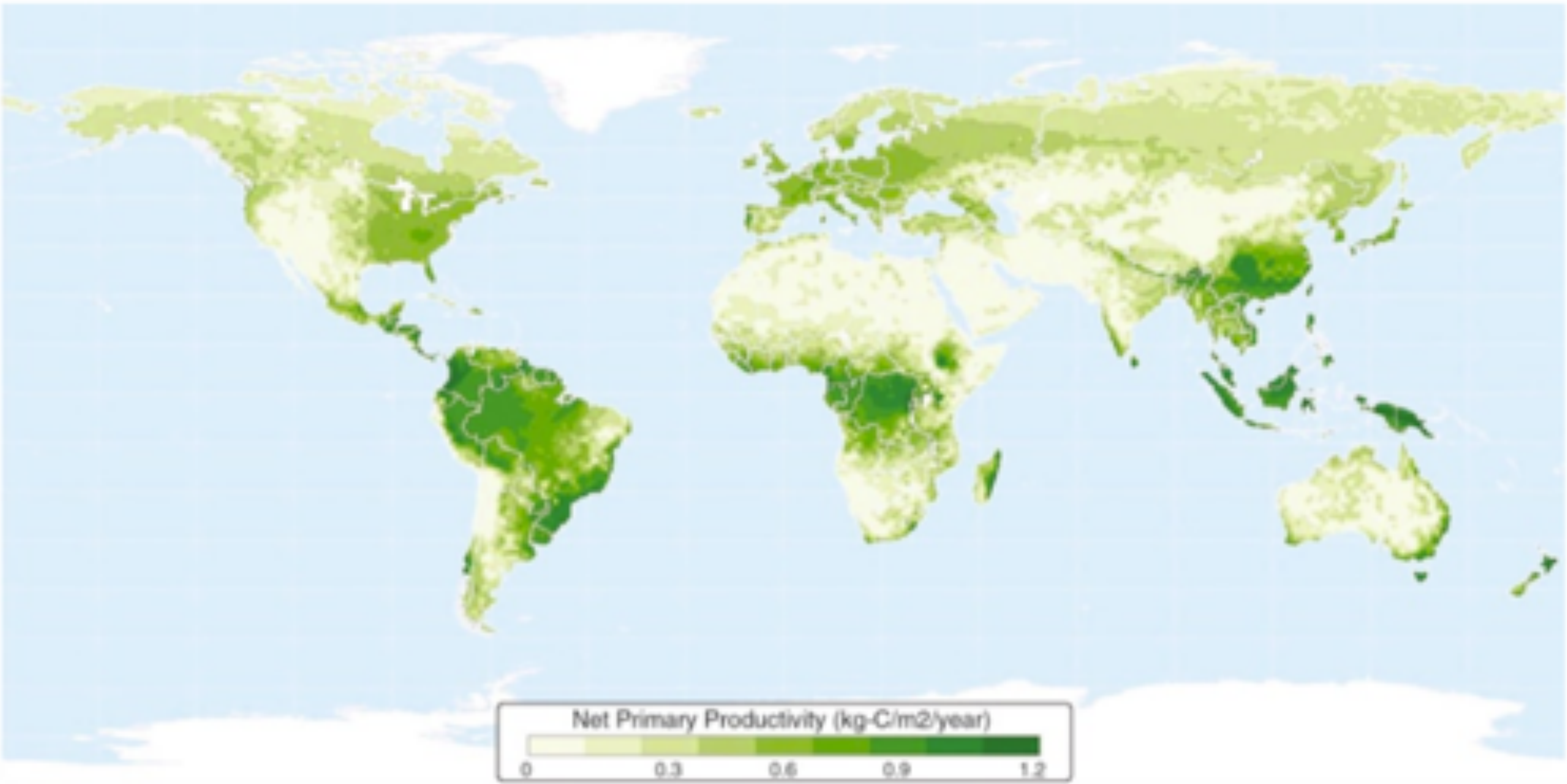
- Over short time scales (seconds to days)
  - Photosynthesis
  - Light, temperature, atmospheric conditions
- Over long time scales (weeks to months)
  - LAI
  - Growth demand
  - Soil resources



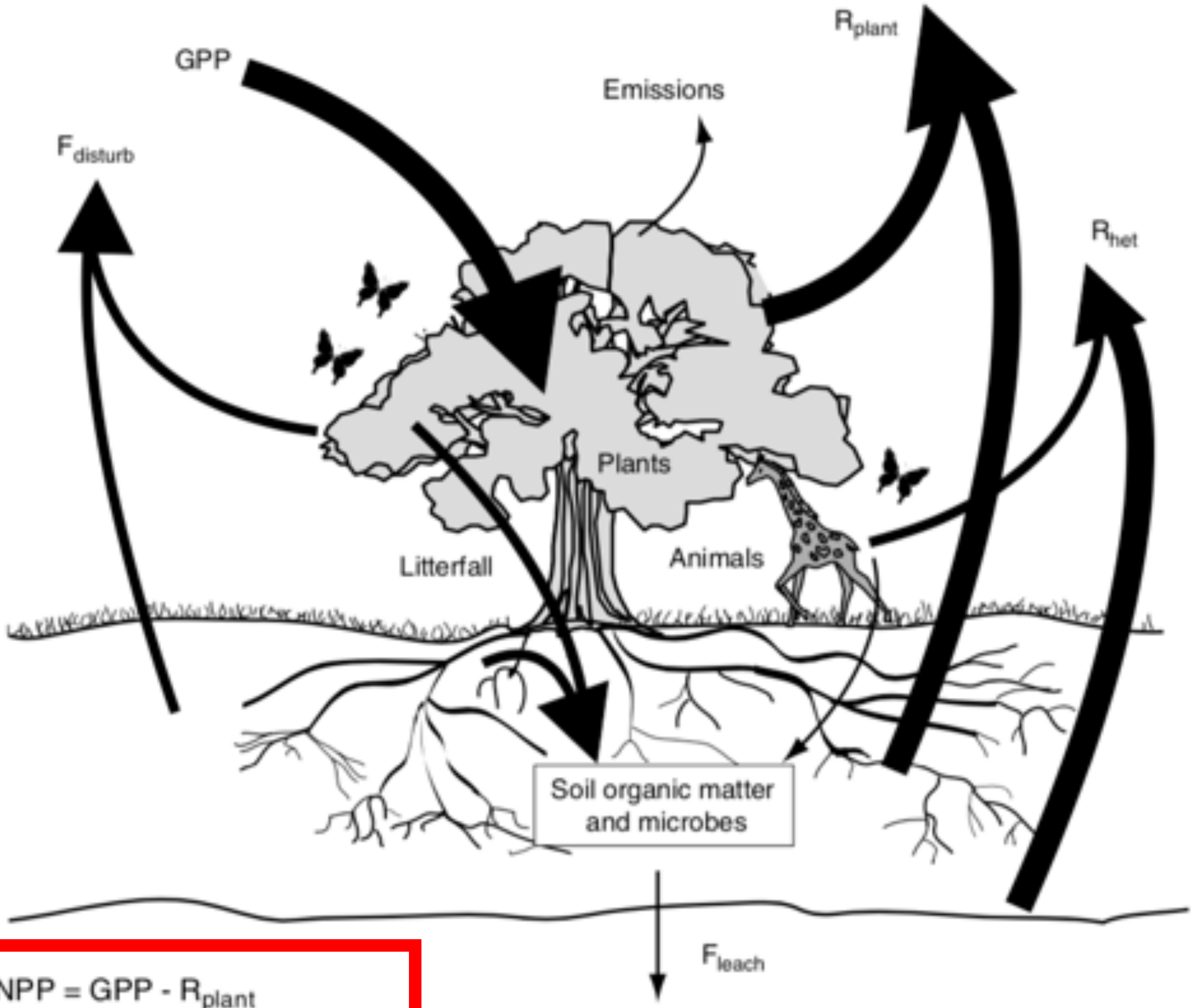
5000
4000
3000
2000
1000
0
NPP (g m−2 yr−1)
0
2000
4000
6000
8000
Precipitation (mm yr−1)



NPP (g m^{-2} yr^{-1})
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
Precipitation (mm yr^{-1})


Net Primary Productivity (kg-C/m2/year)
0
0.3
0.6
0.9
1.2

Terrestrial Ecosystem Carbon Cycle



$NPP = GPP - R_{plant}$

$NEP = GPP - (R_{plant} + R_{het})$

$$NEP = GPP - (R_{plant} + R_{heterotroph})$$

Net ecosystem production (total flux of C into ecosystem; per ground area)

$$\boxed{NEP} = GPP - (R_{plant} + R_{heterotroph})$$

Heterotrophic respiration (C flux out from heterotrophs; per ground area)

$$NEP = GPP - (R_{plant} + \boxed{R_{heterotroph}})$$

What stands out about this table?

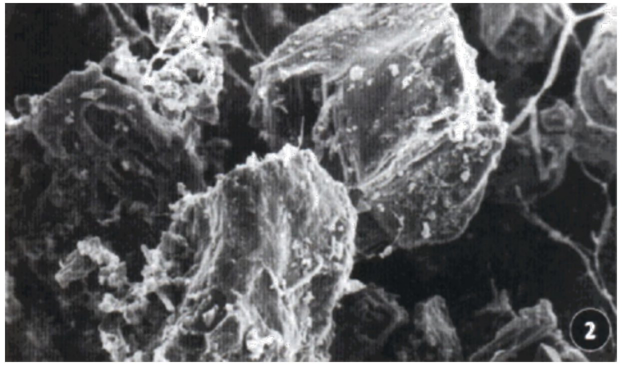
Nutrient	Source of plant nutrient (% of total)		
	Atmosphere	Weathering	Recycling
Temperate forest			
N	7	0	93
P	1	<10?	>89
K	2	10	88
Ca	4	31	65
Arctic tundra			
N	4	0	96
P	4	<1	96

Source: Chapin 1991.

Detritus

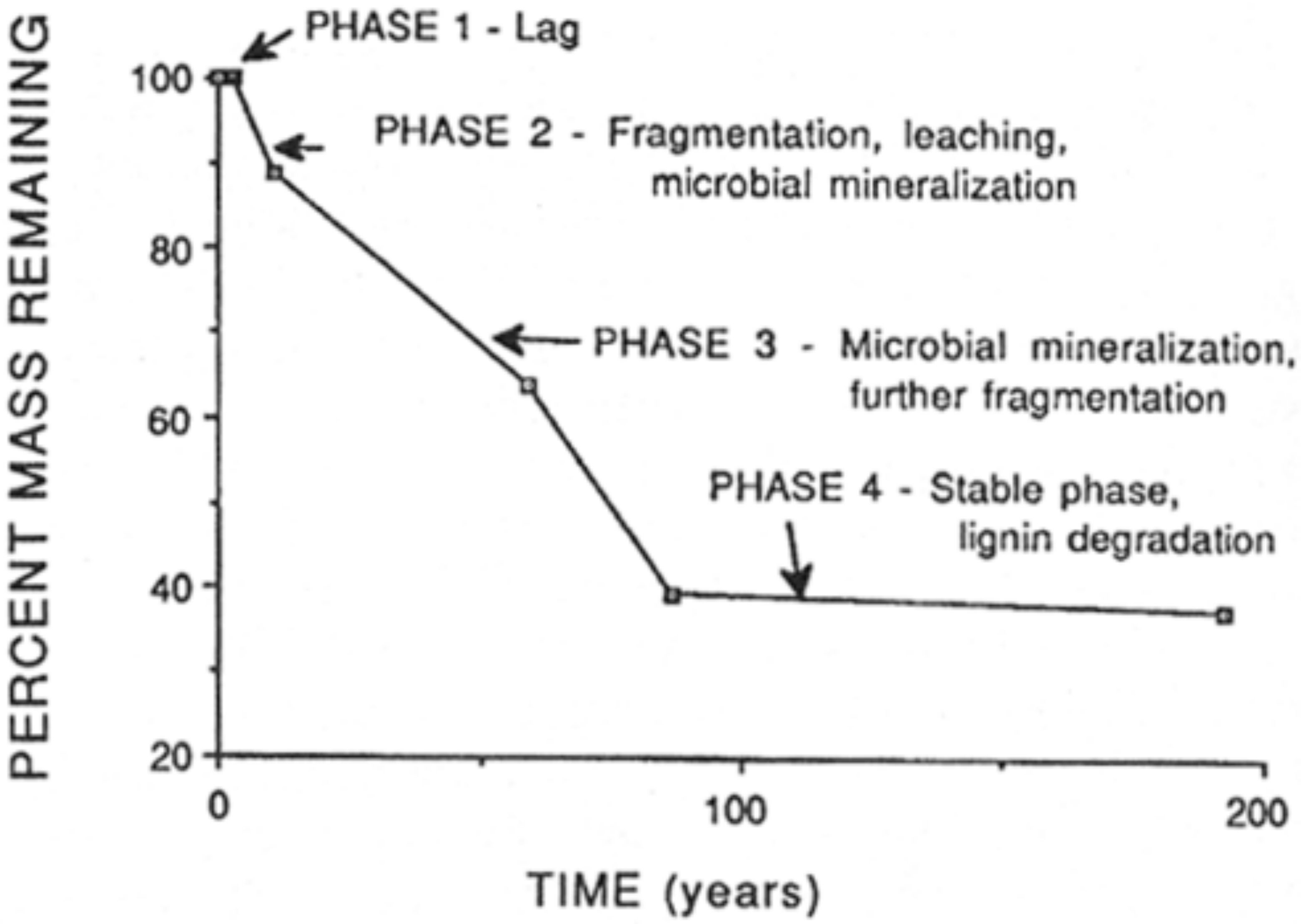
Decomposition of Organic Matter

Decomposition is a process that includes many different biochemical reactions that lead to loss of organic material as CO2 and the release of mineral nutrients and water

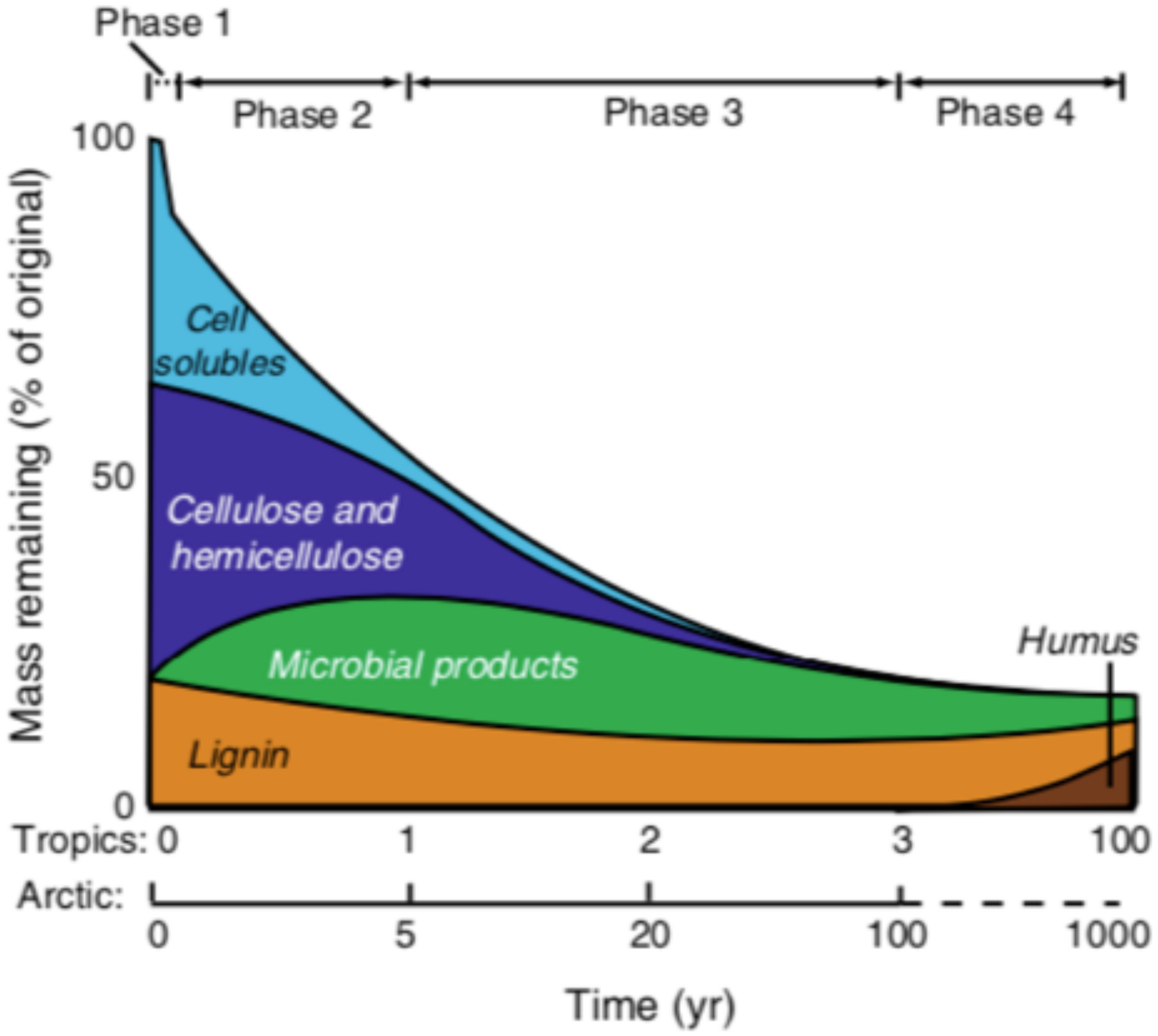


Decomposition results from:

1. **Leaching** – compounds out of detritus
2. **Fragmentation** – breakdown of protective coating
3. **Chemical alteration** of OM by bacterial and fungal enzymes

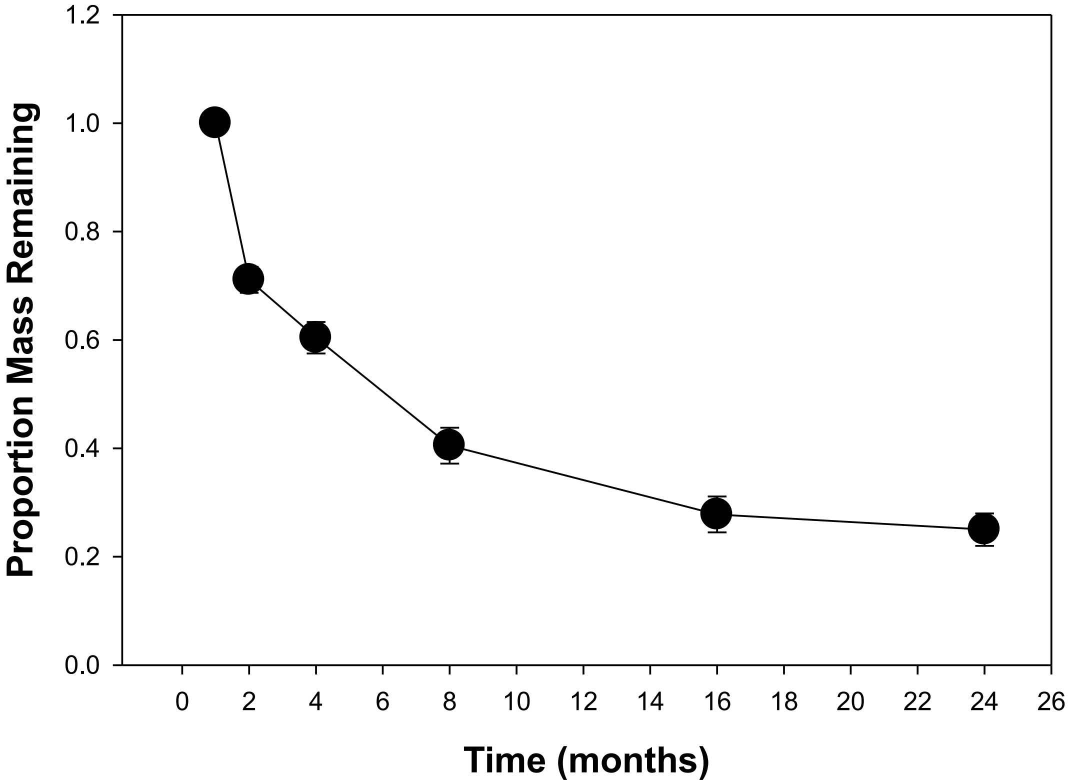


PERCENT MASS REMAINING
100
80
60
40
20
0
100
200
TIME (years)
PHASE 1 - Lag
PHASE 2 - Fragmentation, leaching, microbial mineralization
PHASE 3 - Microbial mineralization, further fragmentation
PHASE 4 - Stable phase, lignin degradation

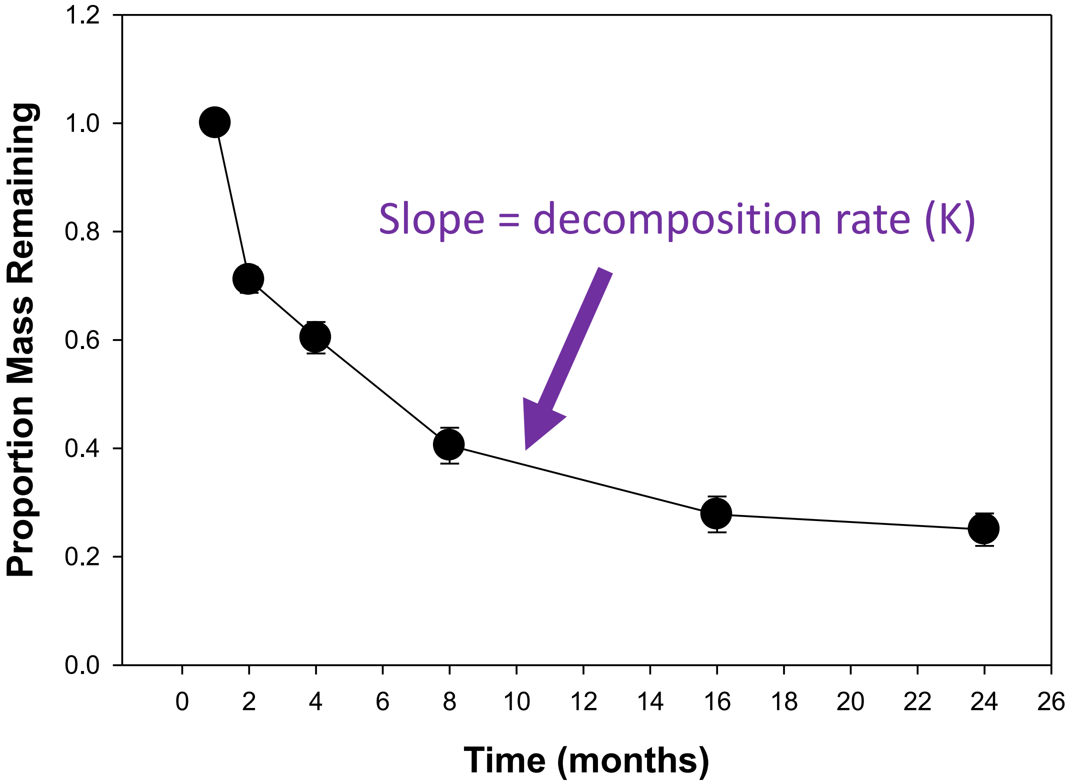


Microbes break down easy stuff before moving to more recalcitrant material

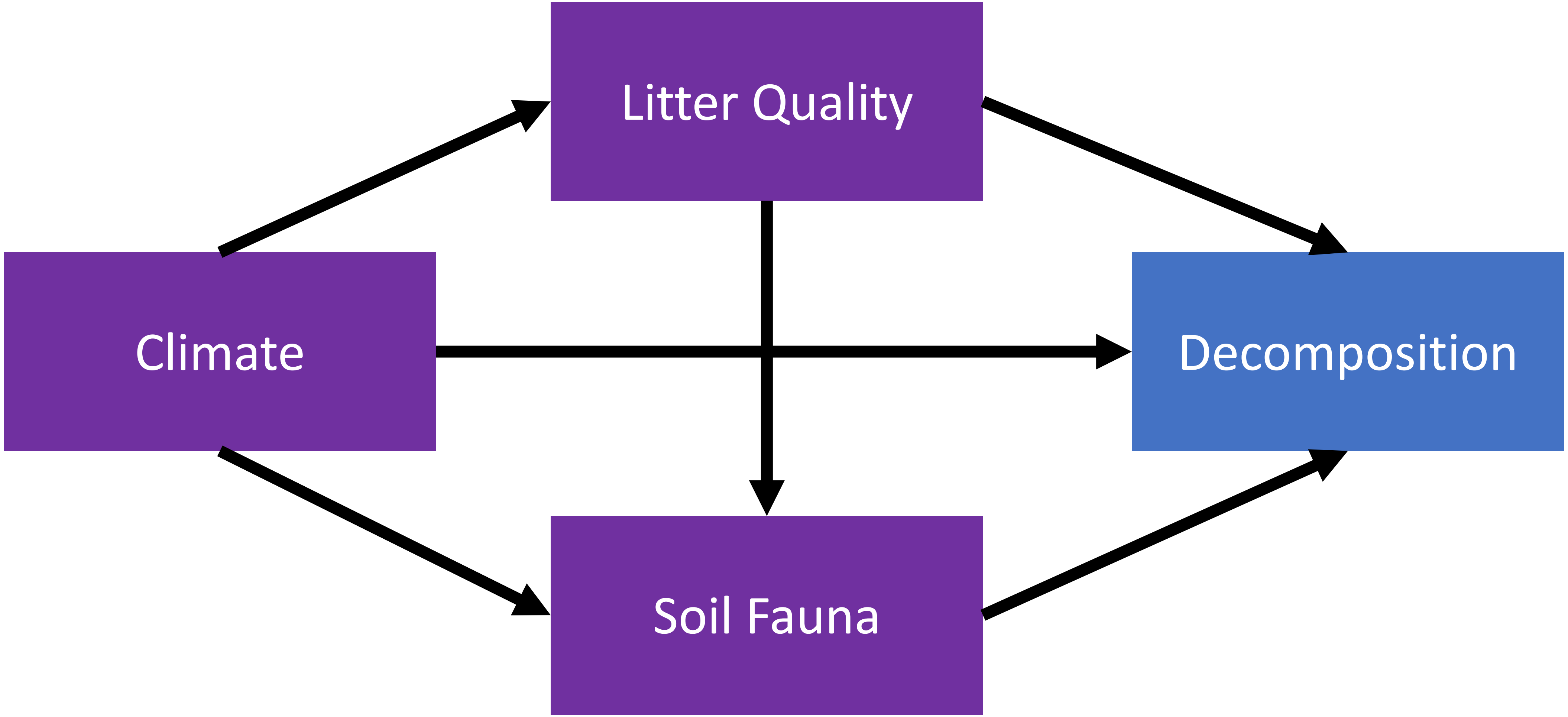
The rate of decomposition



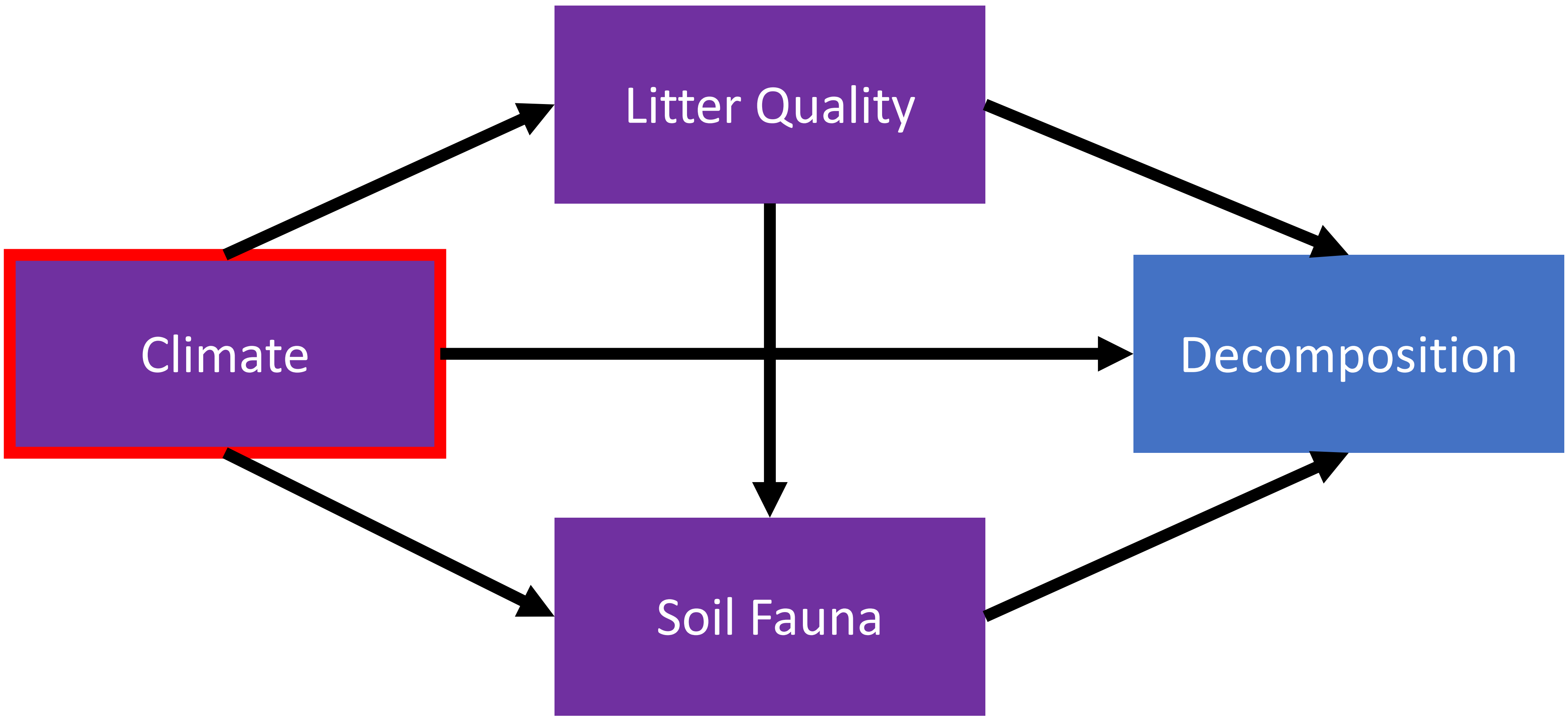
The rate of decomposition



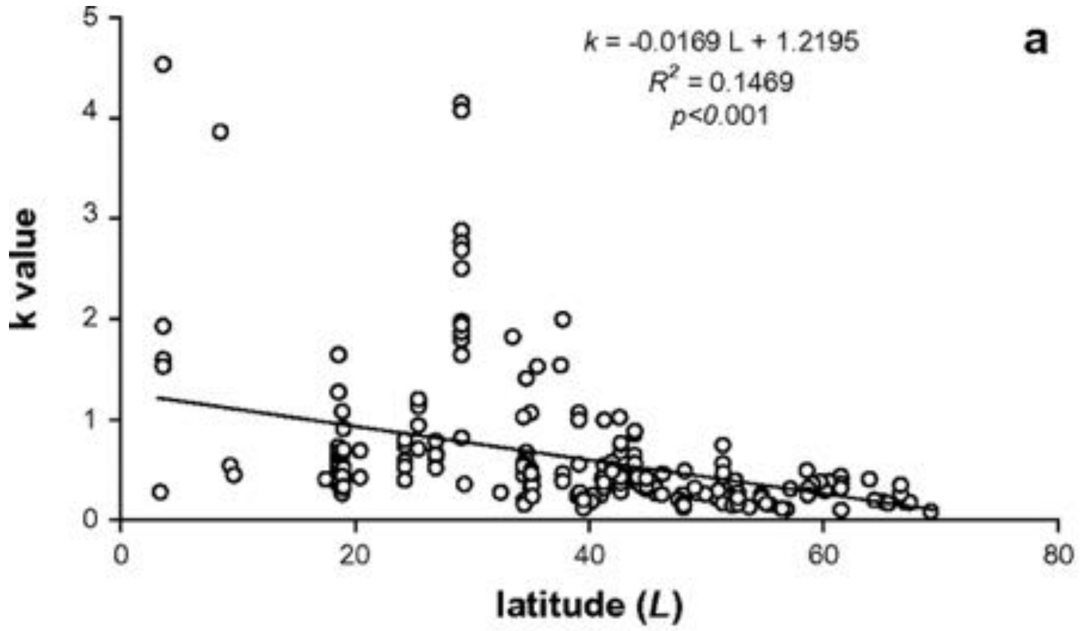
Major controls of decomposition



Major controls of decomposition

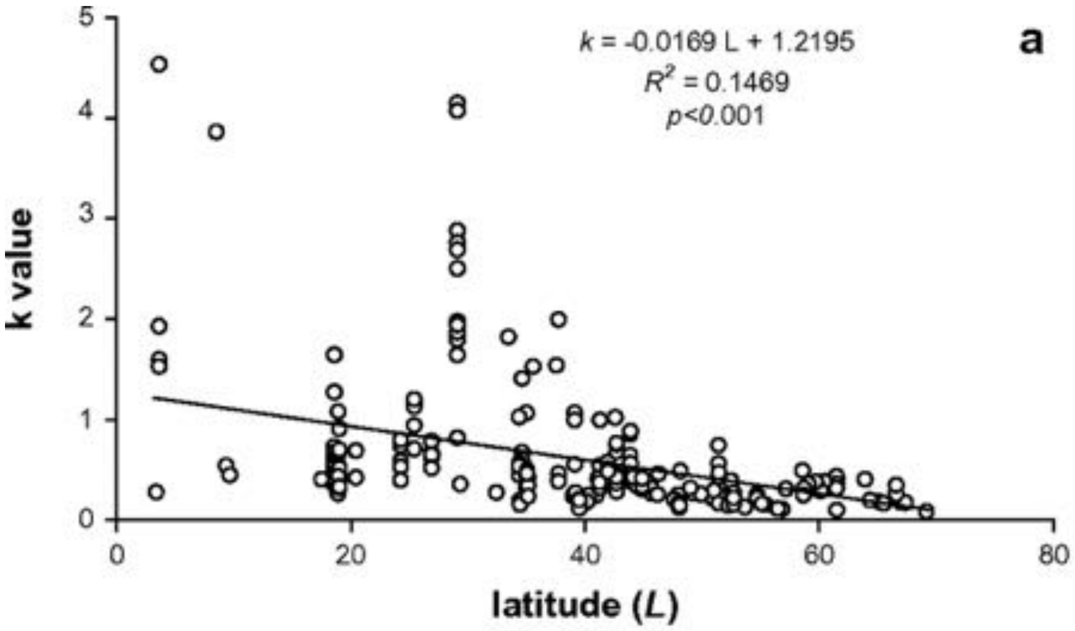


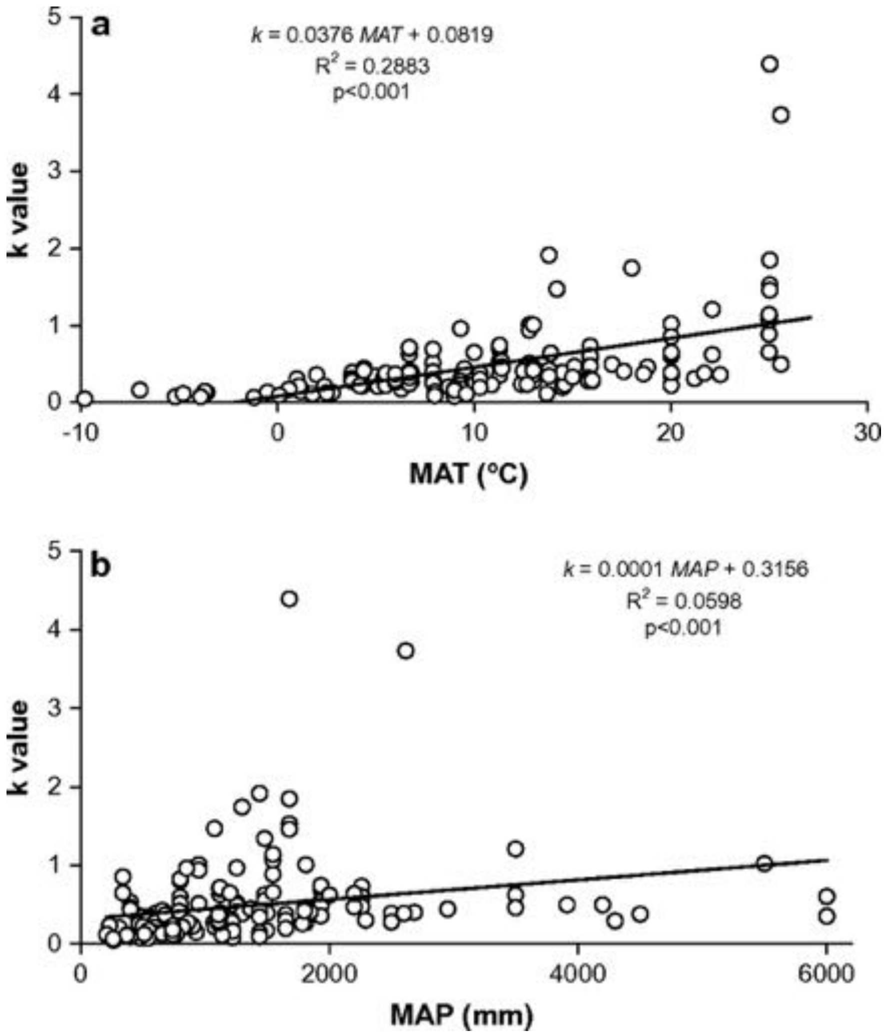
Climate and decomposition



Zhang et al. 2008

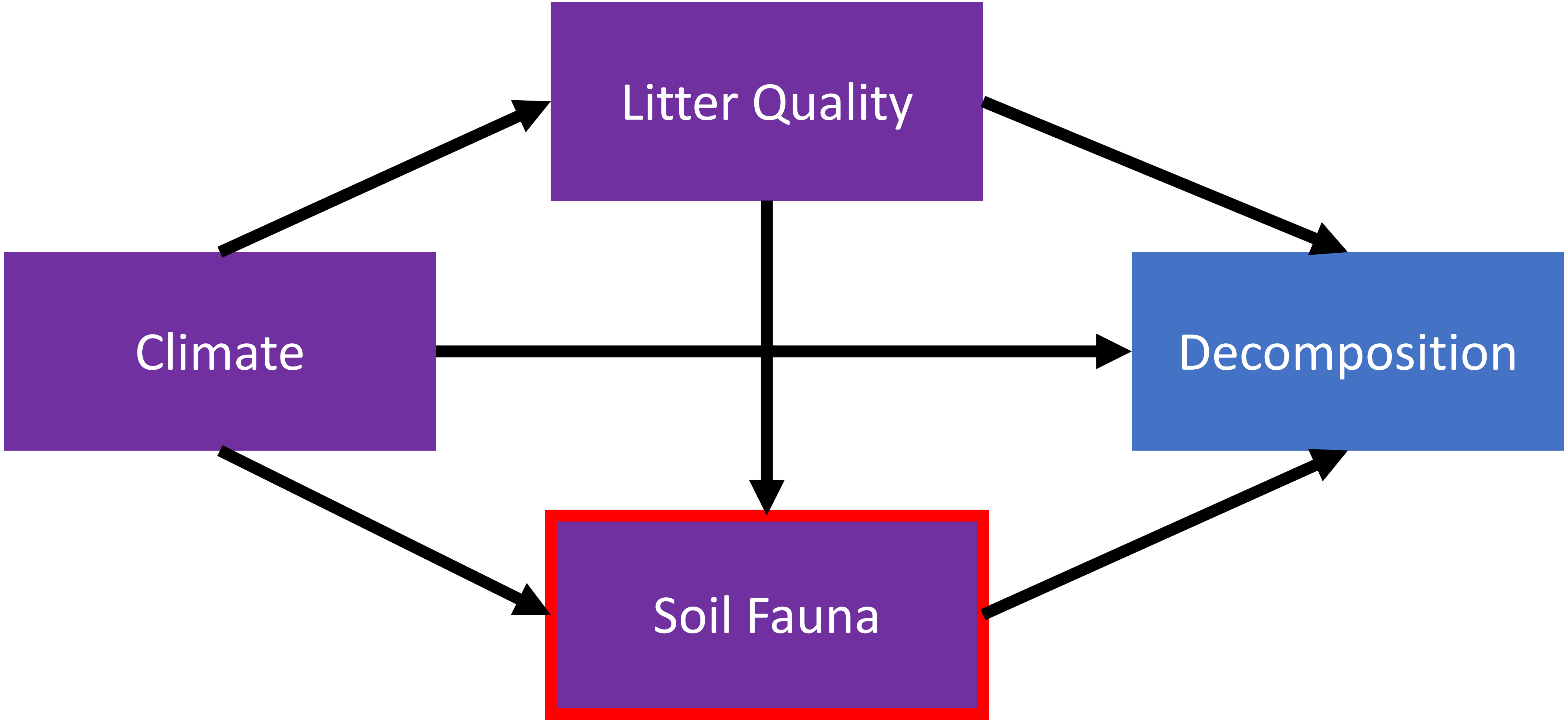
Climate and decomposition





Zhang et al. 2008

Major controls of decomposition

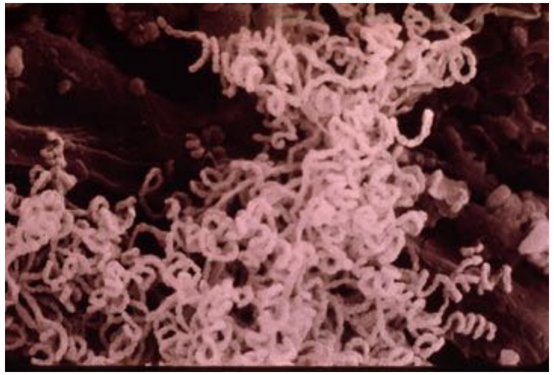


Soil organisms

- Breakdown organic material
  - Releases mineral nutrients
  - Stabilizes soil structure
  - Forms humus
- Inorganic transformations
  - Transforms N, P, S into plant available forms
- Nitrogen fixation
  - Fix N_2 from atmosphere

Microbial community characteristics determine litter decomposition

- Community composition
  - Who's there
- Enzyme activity – speed breakdown
- Most processes are mediated by enzymes secreted



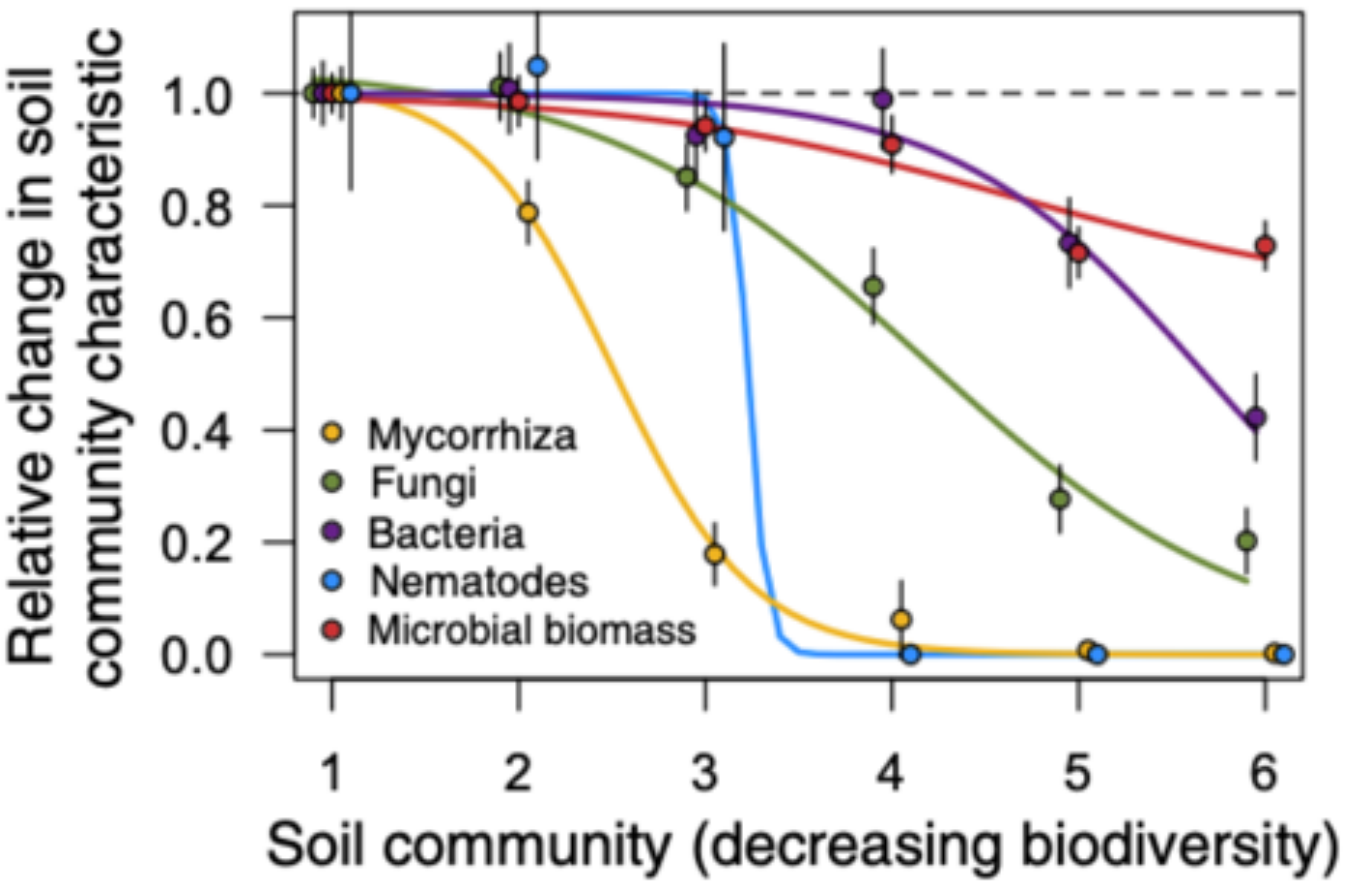
Extra-cellular enzymes in soils involved in C and N transformations:

Enzymes involved in C transformations

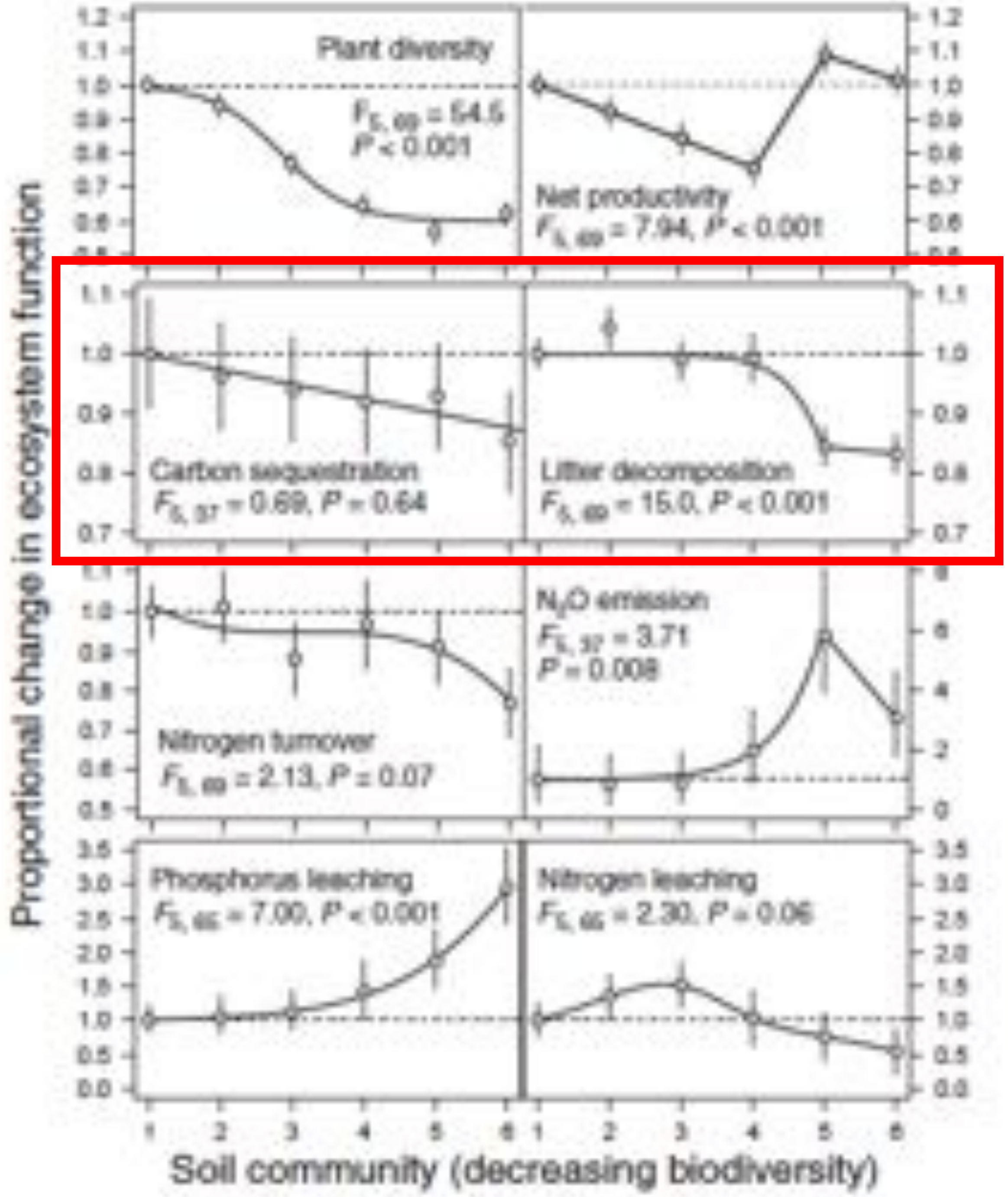
-glucosidase (1st step in cellulose degradation)	→	Microorganisms & plants (especially fungi & yeast)
-cellulase (cellulose to glucose)	→	Primarily fungi, some actinomycetes
-phenol oxidase (phenolic breakdown)	→	Primarily fungi

Enzymes involved in N transformations

-protease (proteins to polypeptides to amino acids)	→	Nearly all microorganisms
-urease (urea to ammonia)	→	Microorganisms & plants

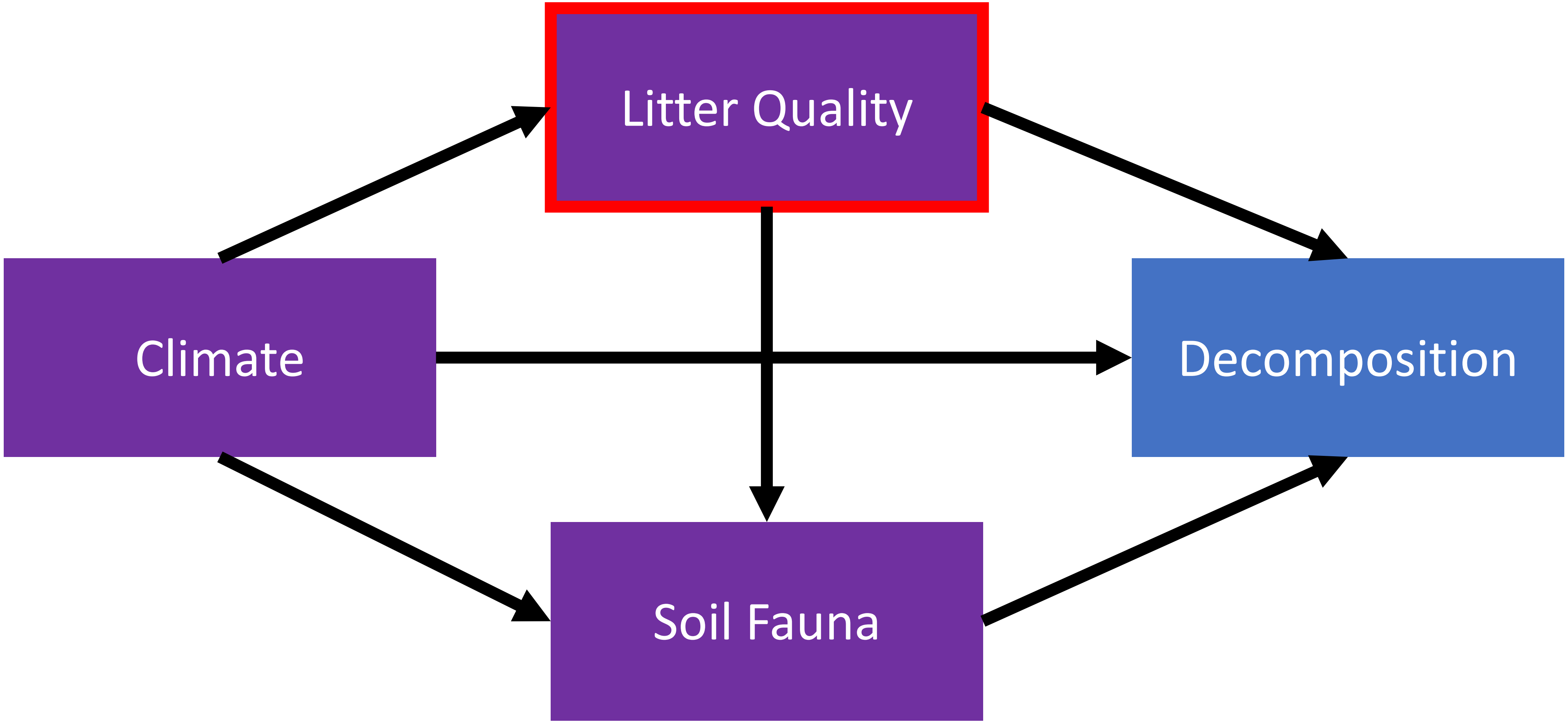


Wagg et al. 2014

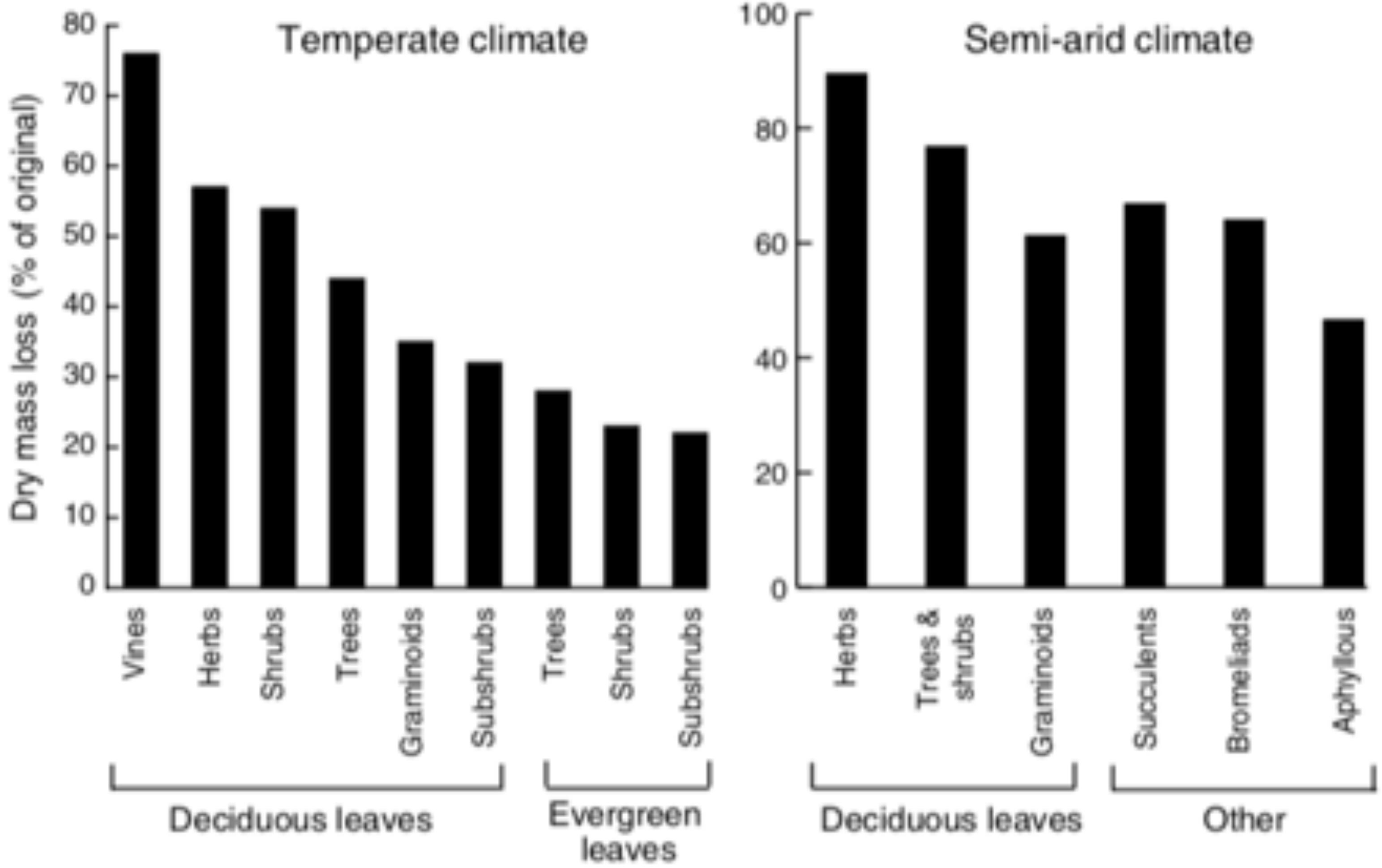


Wagg et al. 2014

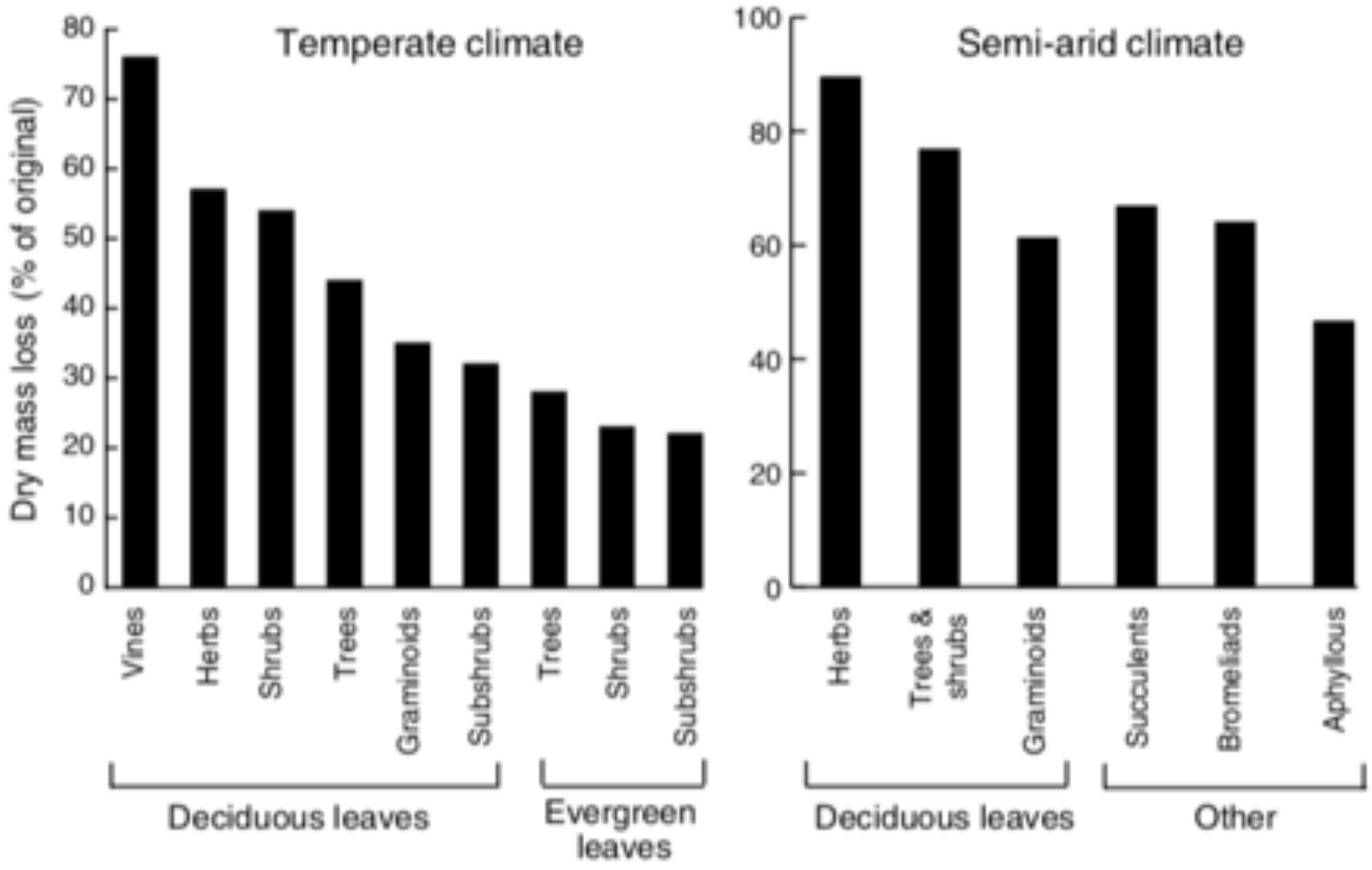
Major controls of decomposition



Litter quality varies with plant type

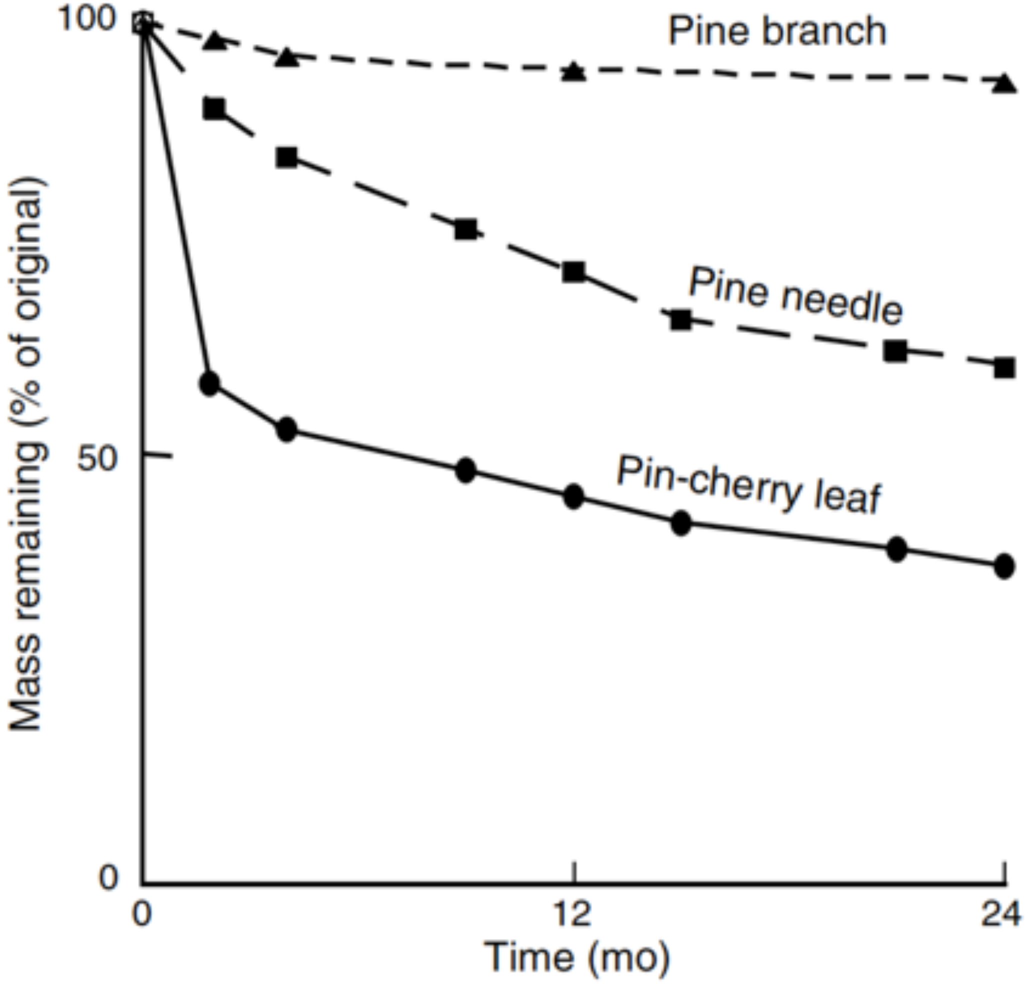


Litter quality varies with plant type

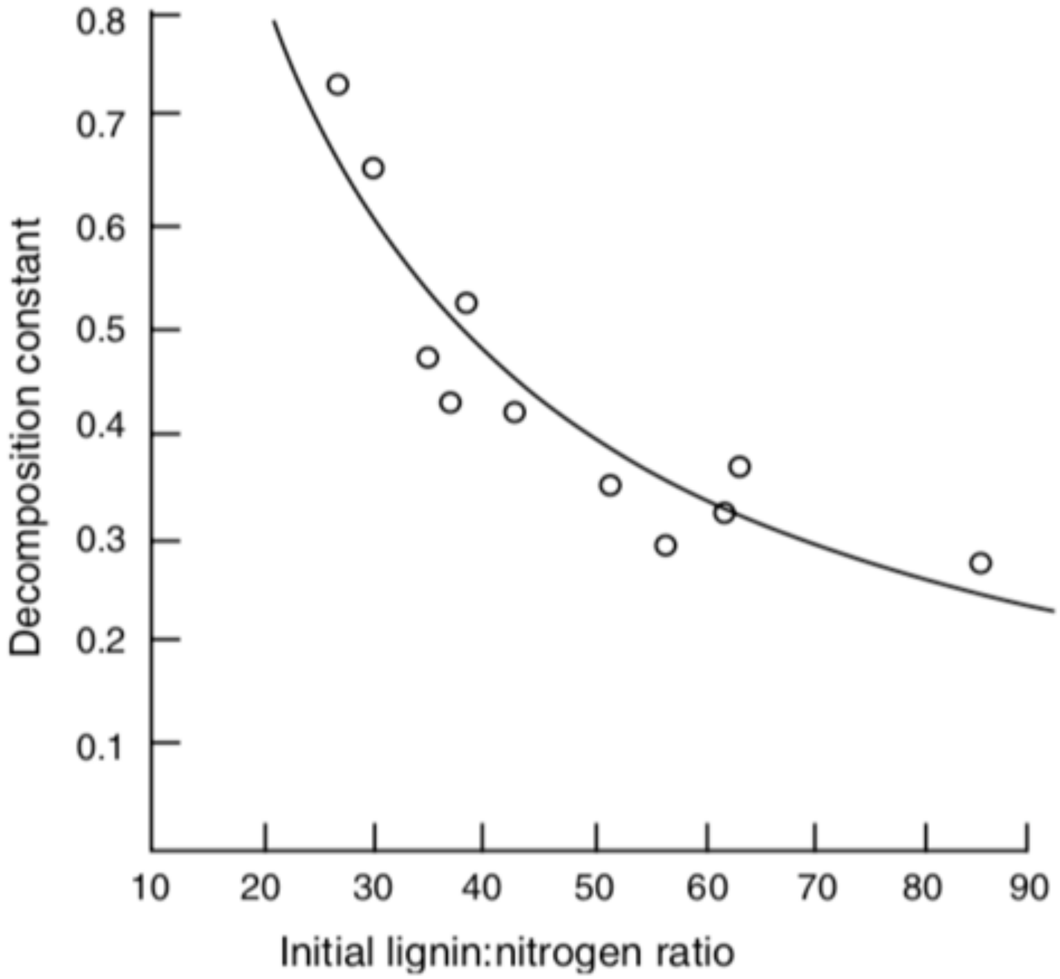


Why don't all decompose fast?

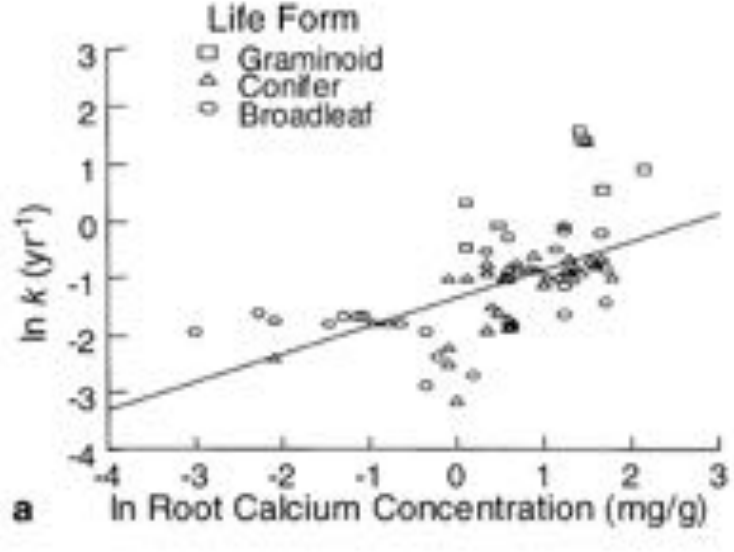
Leaves decompose faster than branches

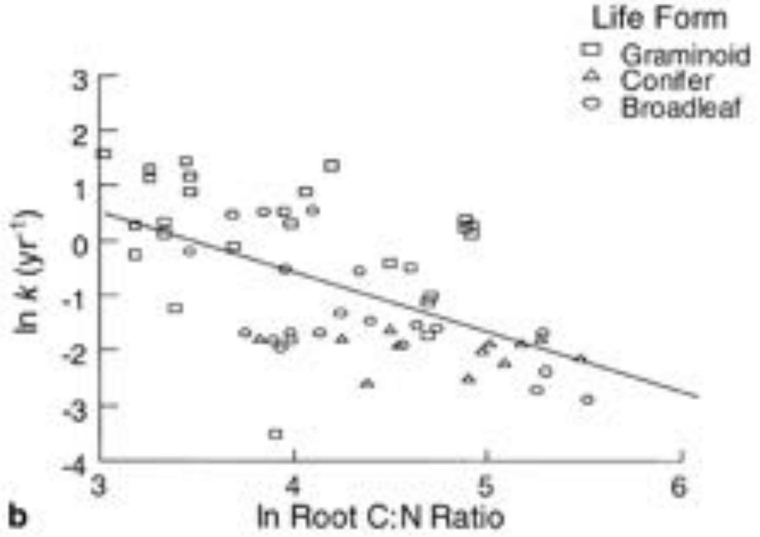


Higher nutrient litter decomposes faster



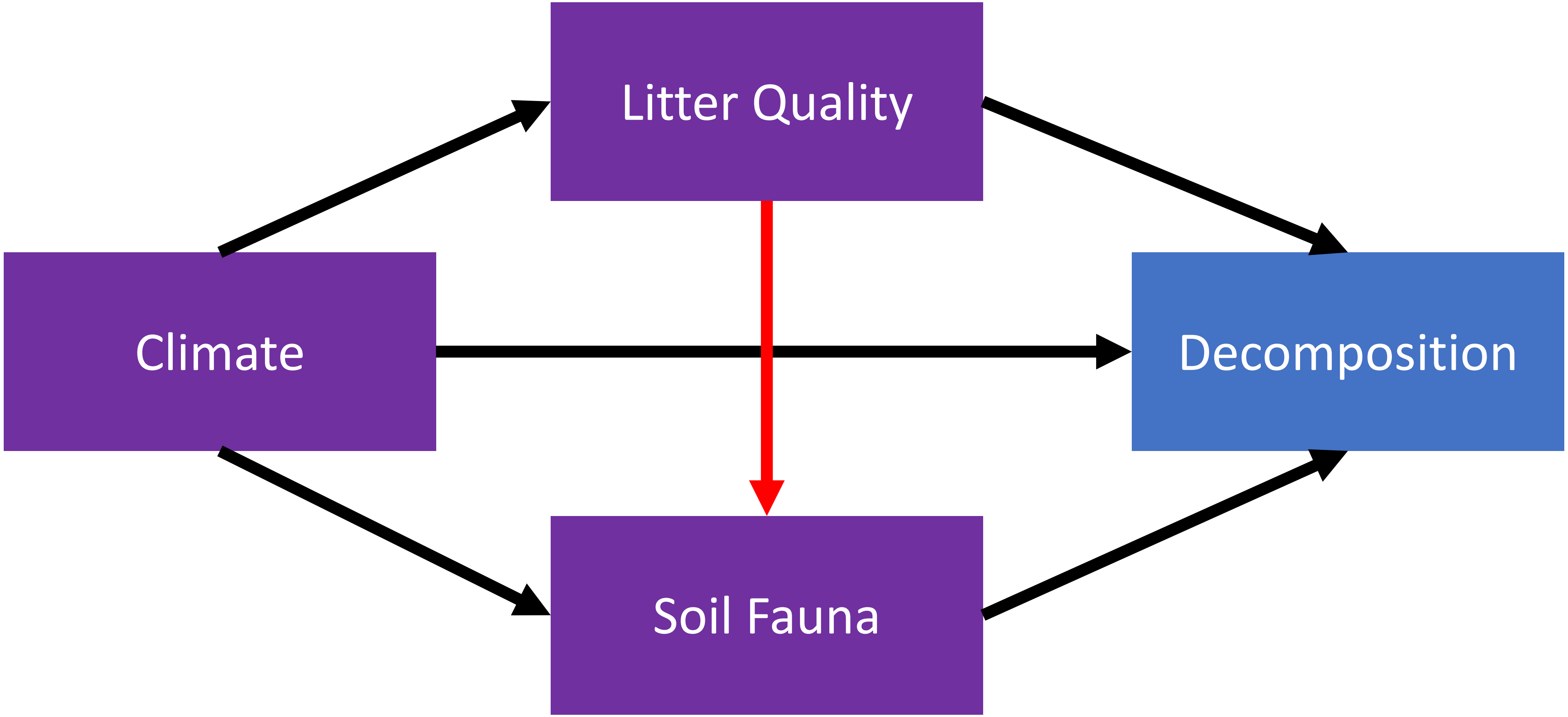
Higher nutrient litter decomposes faster





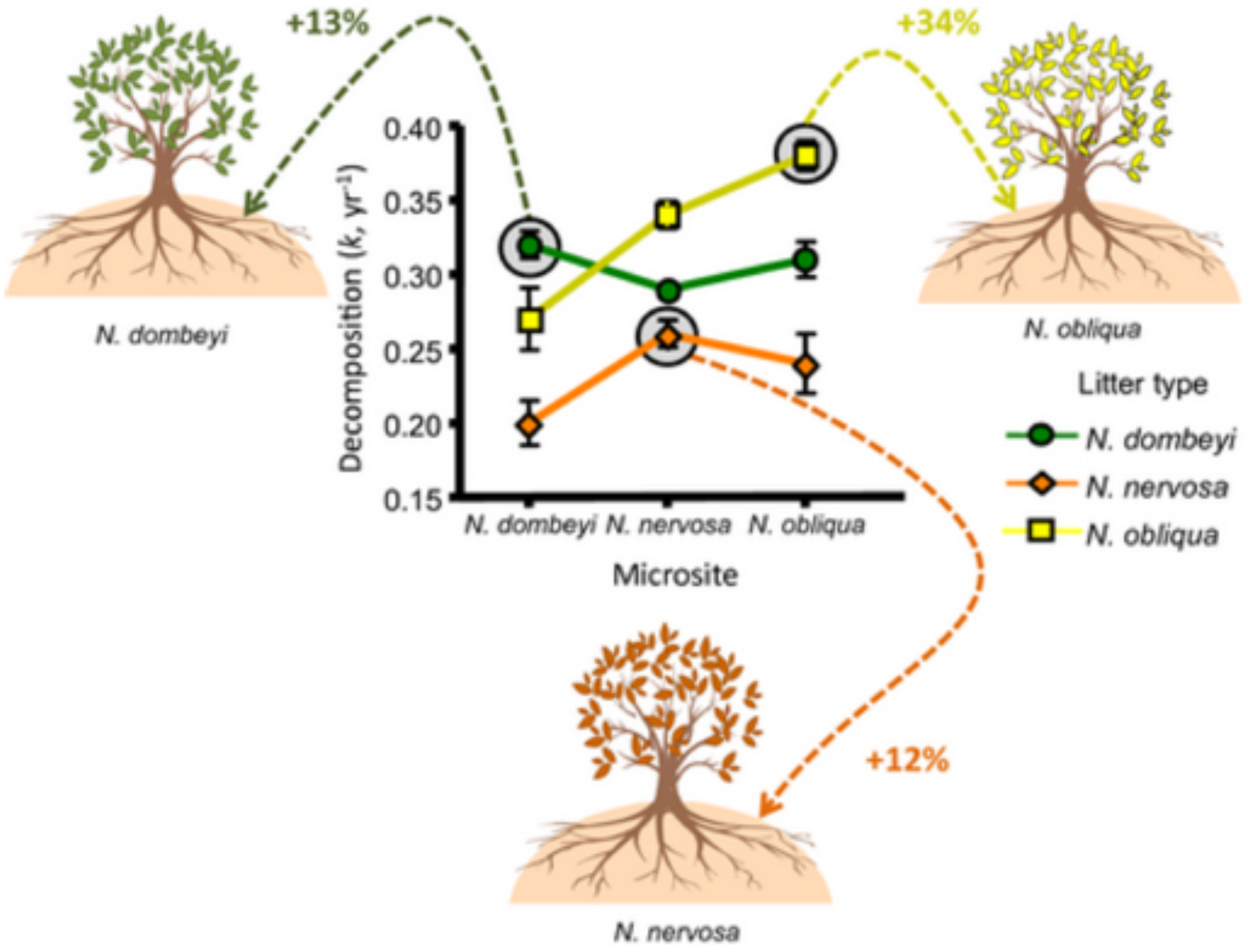
Silver & Miya 2001

Major controls of decomposition



Home Field Advantage

Do microbes decompose substrates that they've "seen" before better than naïve substrates?



Austin et al. 2014

Why is the ground brown?