The biology of the carbon cycle: a paradigm shift

- Carbon source-sink relations
- Carbon fluxes and carbon pools
- Elevated CO_2
- Species range limits and phenology

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16th Swiss Global Change Day, Bern, 1 April 2015

In Geneva 210 years ago:

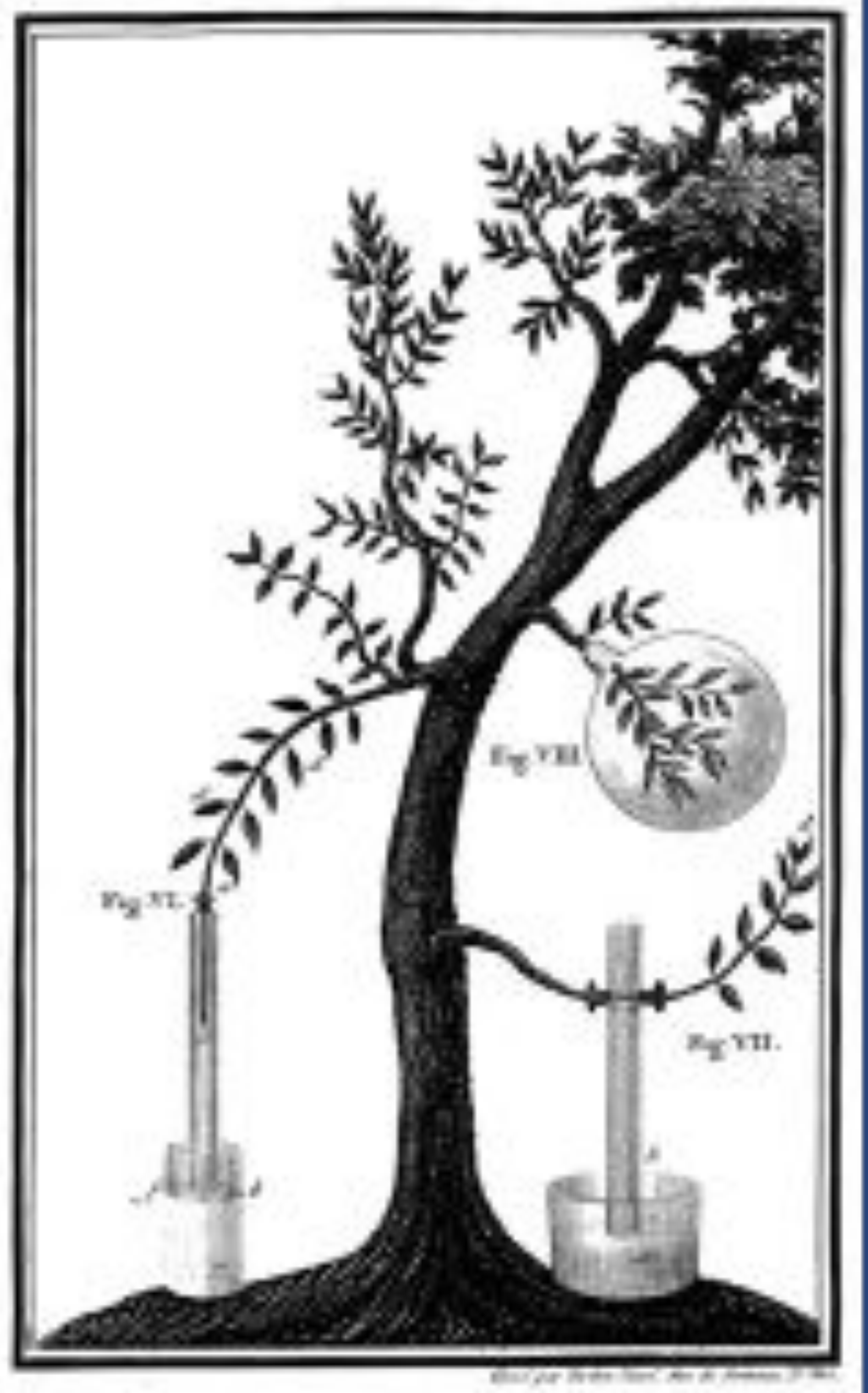
‘The primary plant food comes from air‘

- Nicolas-Théodore de Saussure (1804)
  Recherches chimiques sur la Végétation. Paris.

Paving the road:

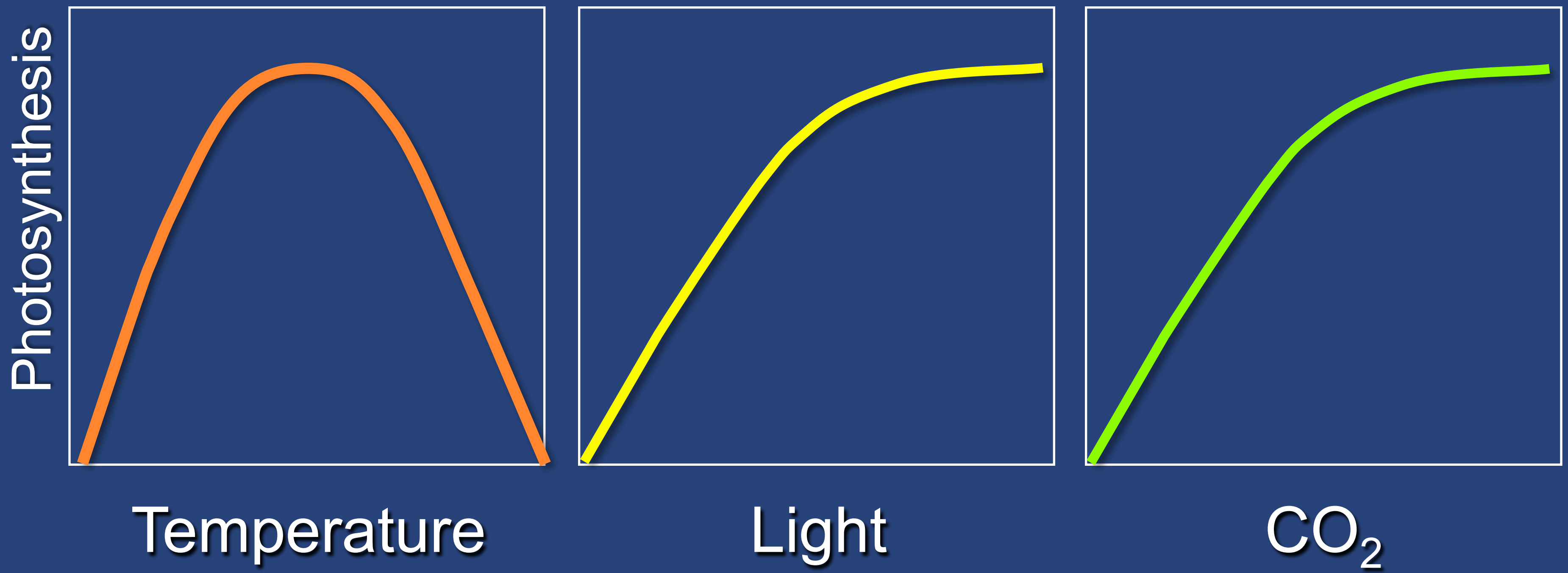
- Jan Ingenhousz (1779)
  Experiments upon vegetables, discovering their great power of purifying thecommon air in the sun-shine, and of injuring it in the shade and at night. P. Elmsly and H. Payne, London, UK.

- Jean Senebier (1783)
  Recherches sur l’nfluence de la lumière solaire pour métamorphoser l’air fixe en airpur par la vegetation. Barthelemi Chirol, Geneva, Switzerland.



The carbon centric view starts here ...

A f(T, PFD, CO_2)

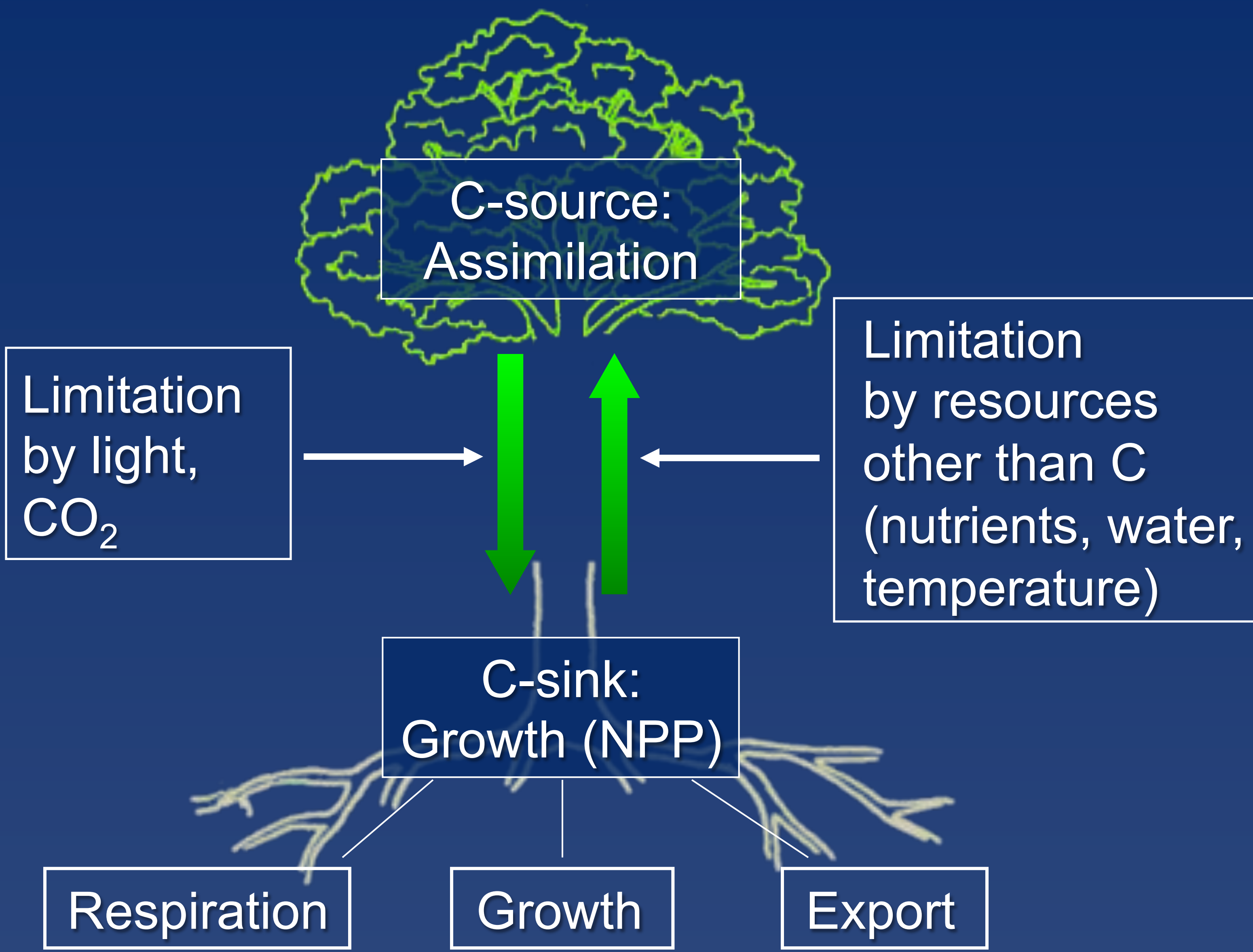


Sources rarely control sinks

Körner C (2012) Biologie in unserer Zeit 4:238
Körner C (2013) Nova Acta Leopoldina NF 114, 391:273

Hierarchy of controls

Carbon uptake and carbon use by plants



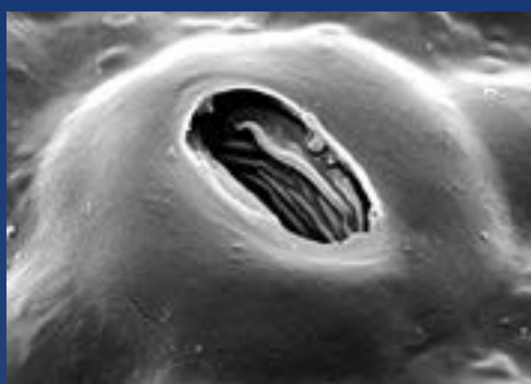
For instance, drought and low temperature affect sinks first, source activity follows

Drought: sinks affected first

Water shortage:

Old

Stomatal closure and inhibition of photosynthesis

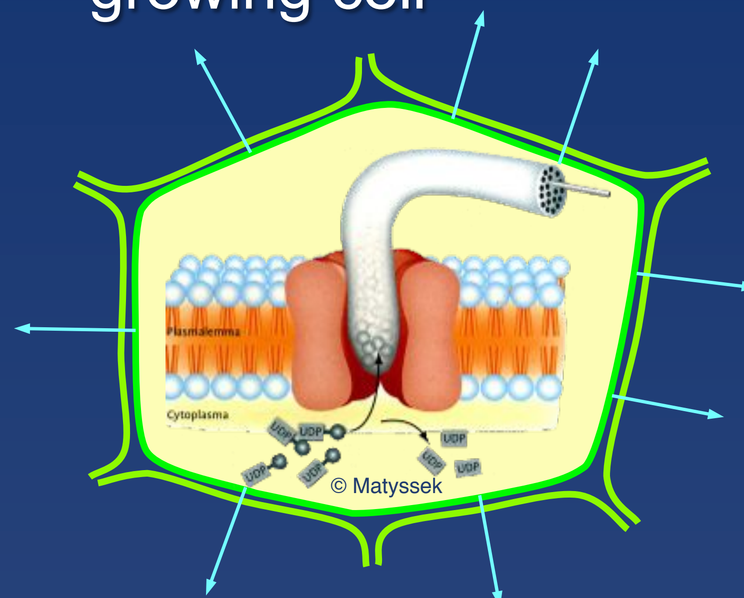


-1.2 to -2.0 MPa

Source

New

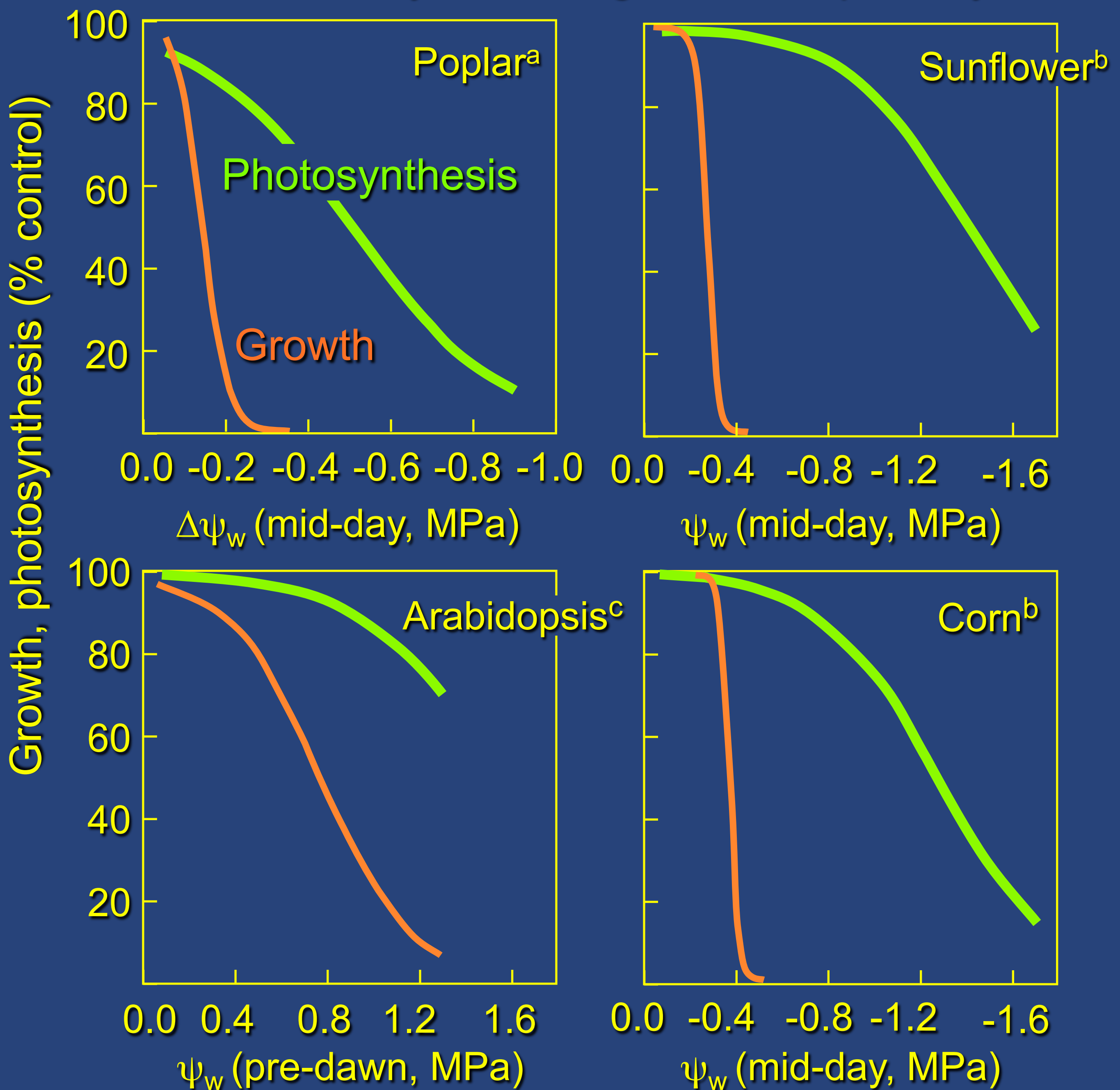
Turgor driven yielding of the cell wall in a growing cell



-0.5 to -1.0 MPa

Sink

Differential sensitivity of shoot growth and photosynthesis to soil water deficit.



!

Muller B *et al* (2011)
J Exp Bot 62:1715

Data from :

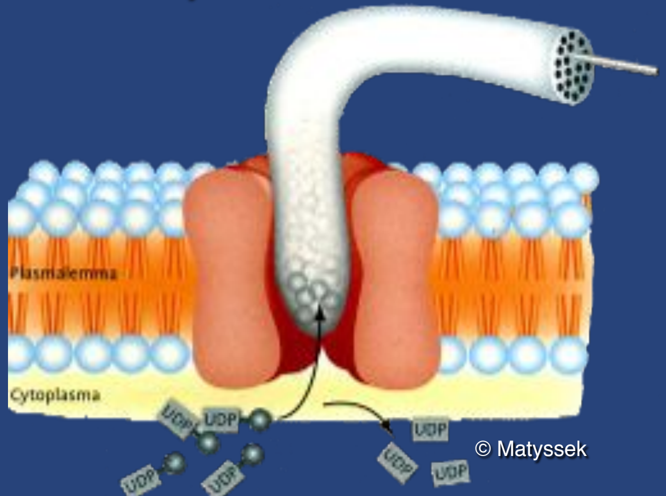
[a]Bogeat-Triboullot *et al* (2007)

[b]Boyer (1970), Tardieu *et al* (1999)

[c]Granier *et al* (2006), Hummel *et al* (2010)

Water shortage acts on sinks first

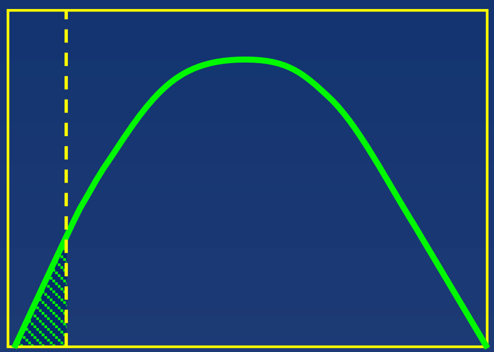
- Turgor controls tissue formation.
- Carbohydrate transport is not constrained, hence distant stores are filled.
- Carbohydrate downloading and storage are ensuring an operative photosynthetic machinery (no endproduct inhibition).



Low temperature: sinks stop first

Old

Photosynthesis



zero at -6 °C

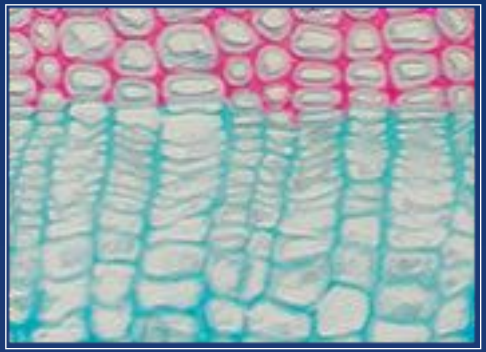
30-40 % at 0 °C

50-70 % at +5 °C

Source

New

Cambium

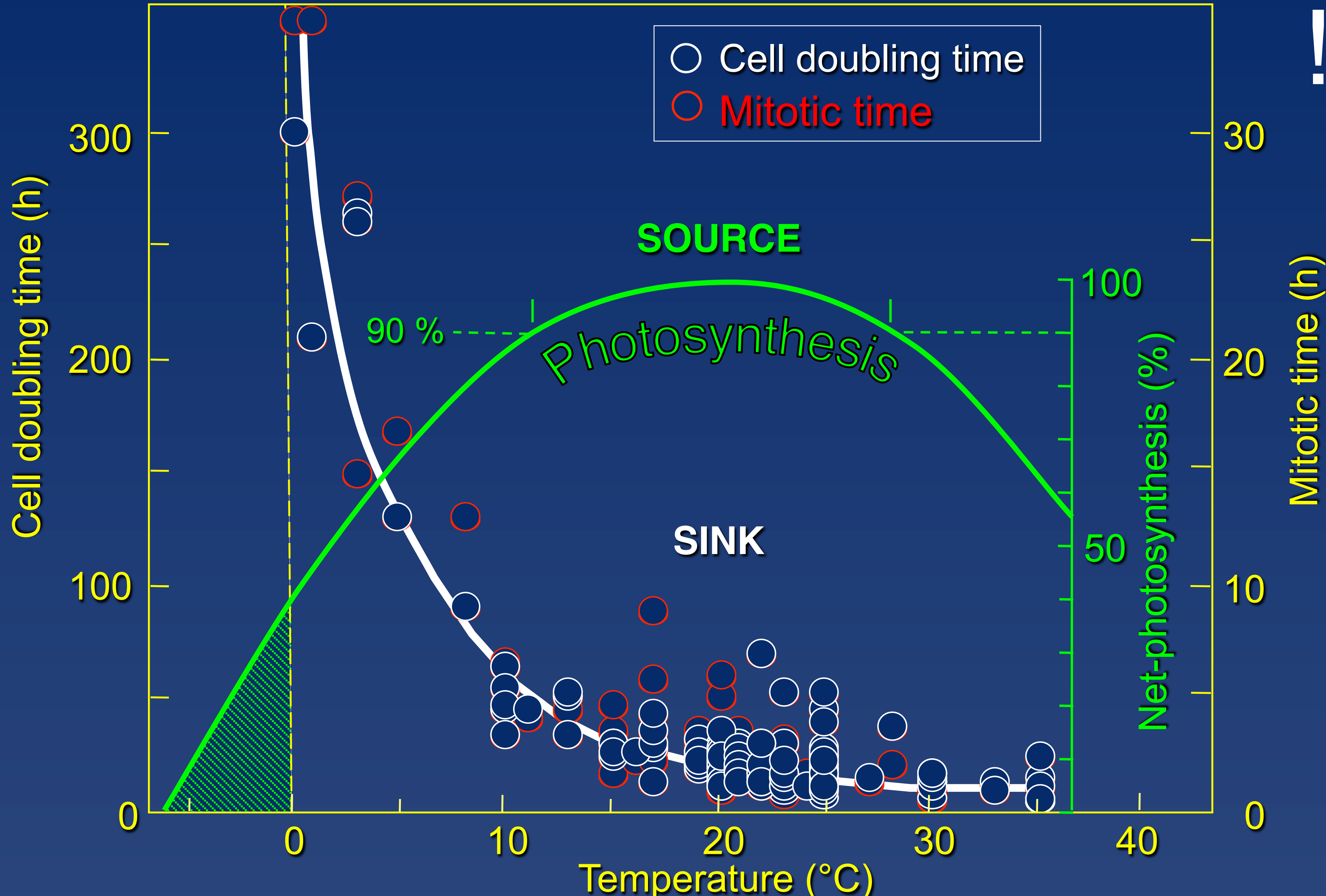


No cell differentiation < +5 °C

(Cell division is robust)

Sink

Different processes have different T sensitivity

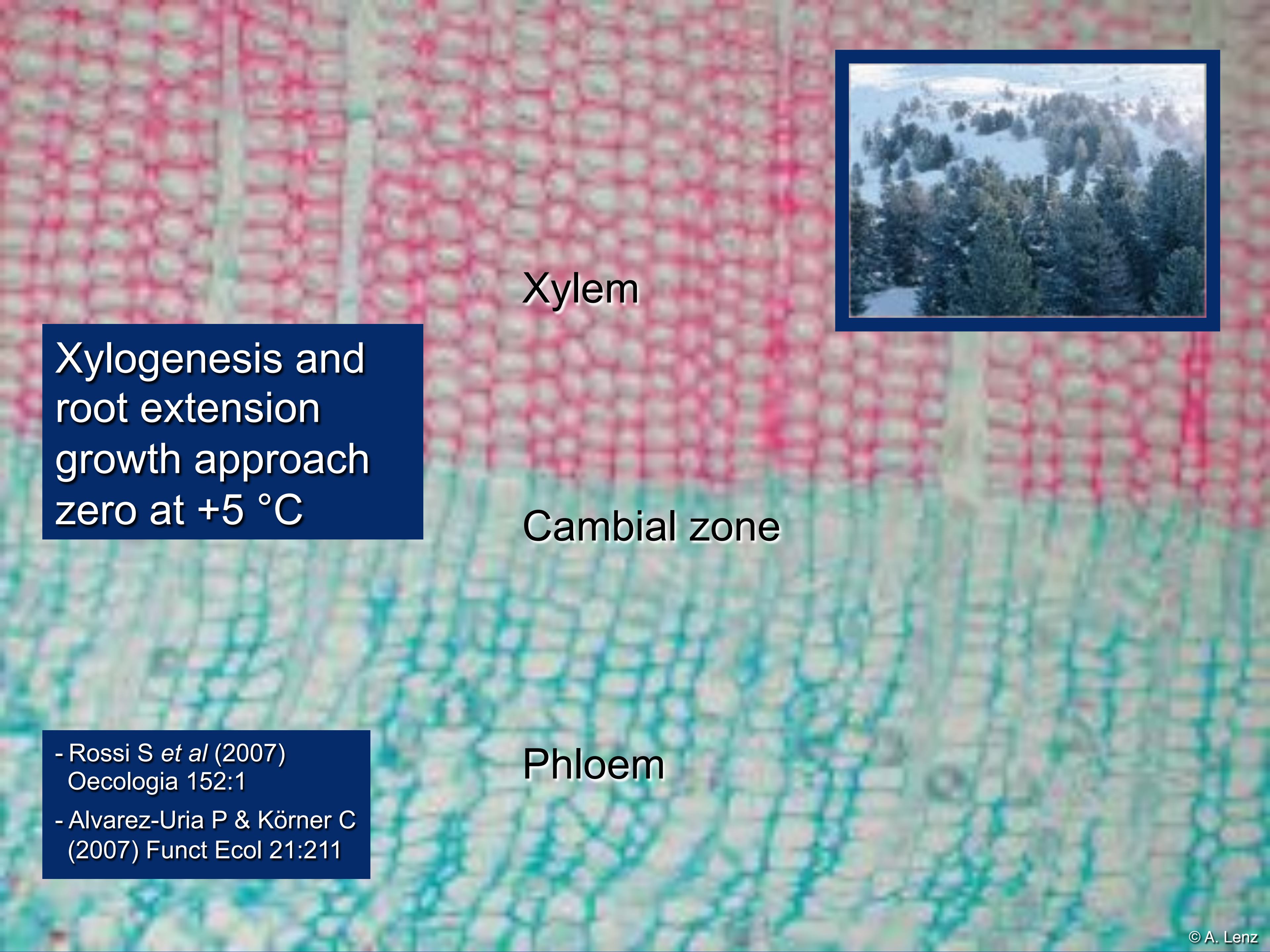


Körner C (2003) Alpine Plant Life. Springer, Berlin

Treelines will move sooner or later ...

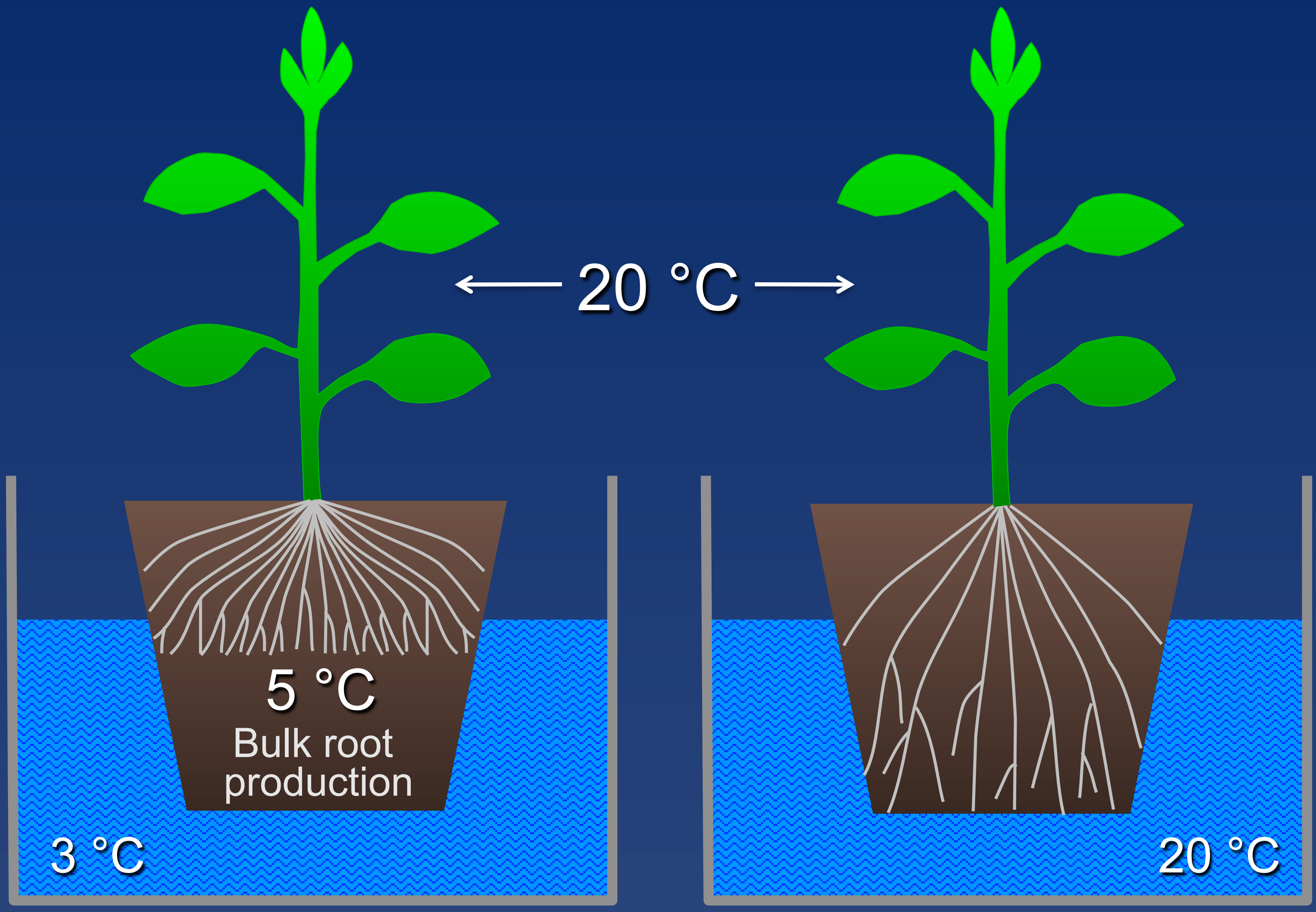
The cold edge

Xylogenesis and root extension growth approach zero at +5 °C



- Rossi S *et al* (2007) Oecologia 152:1
- Alvarez-Uria P & Körner C (2007) Funct Ecol 21:211

C-limitation or shutdown of tissue formation at low temperature?



Alvarez Uria P & C Körner C (2007) Funct Ecol 21:211
Schenker G *et al* (2014) Tree Physiol 34:302

Nutrient limitation: stoichiometry of C sinks controls C incorporation

→ Healthy life needs 25 essential chemical elements

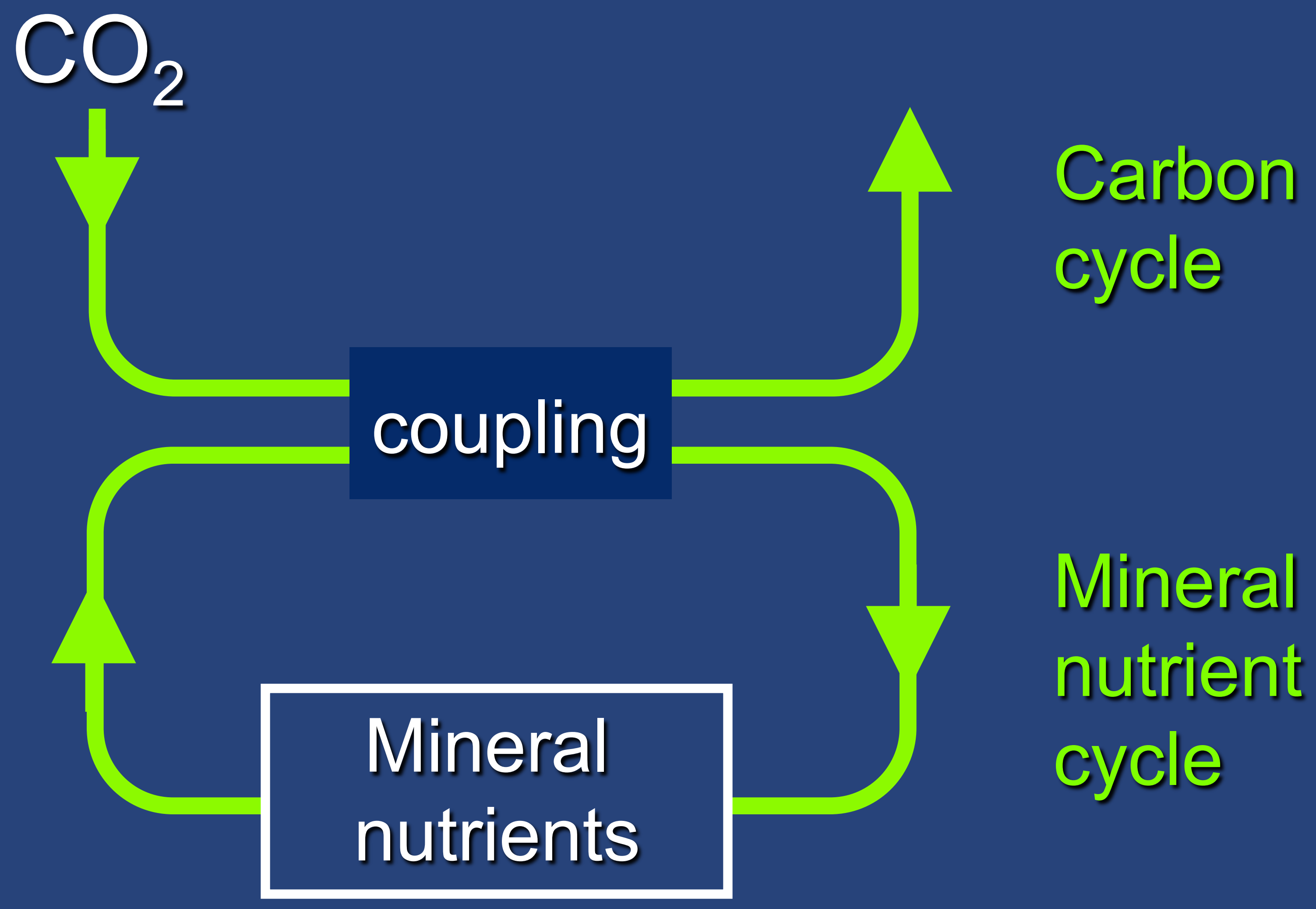
Old	New
More photosynthates permit capturing elements other than C	Nutrients control the amount of C that can be taken up

34 chemical elements for the life of bacteria, plants and animals

... a few are redundant, but >25 are essential (not just N!)

In: Sterner RW & Elser JJ (2002) Ecological Stoichiometry. Princeton Univ Press, Princeton

The mineral cycle controls the carbon cycle



Priority in theory and modeling of plant growth or NPP

Old model
(carbon centric)

C-uptake

↓

Other controls

Per unit leaf area CO_2 acquisition has priority over any other growth control

New model
(sinks control sources)

Other controls

↓

C-uptake

Meristem activity determines C-demand

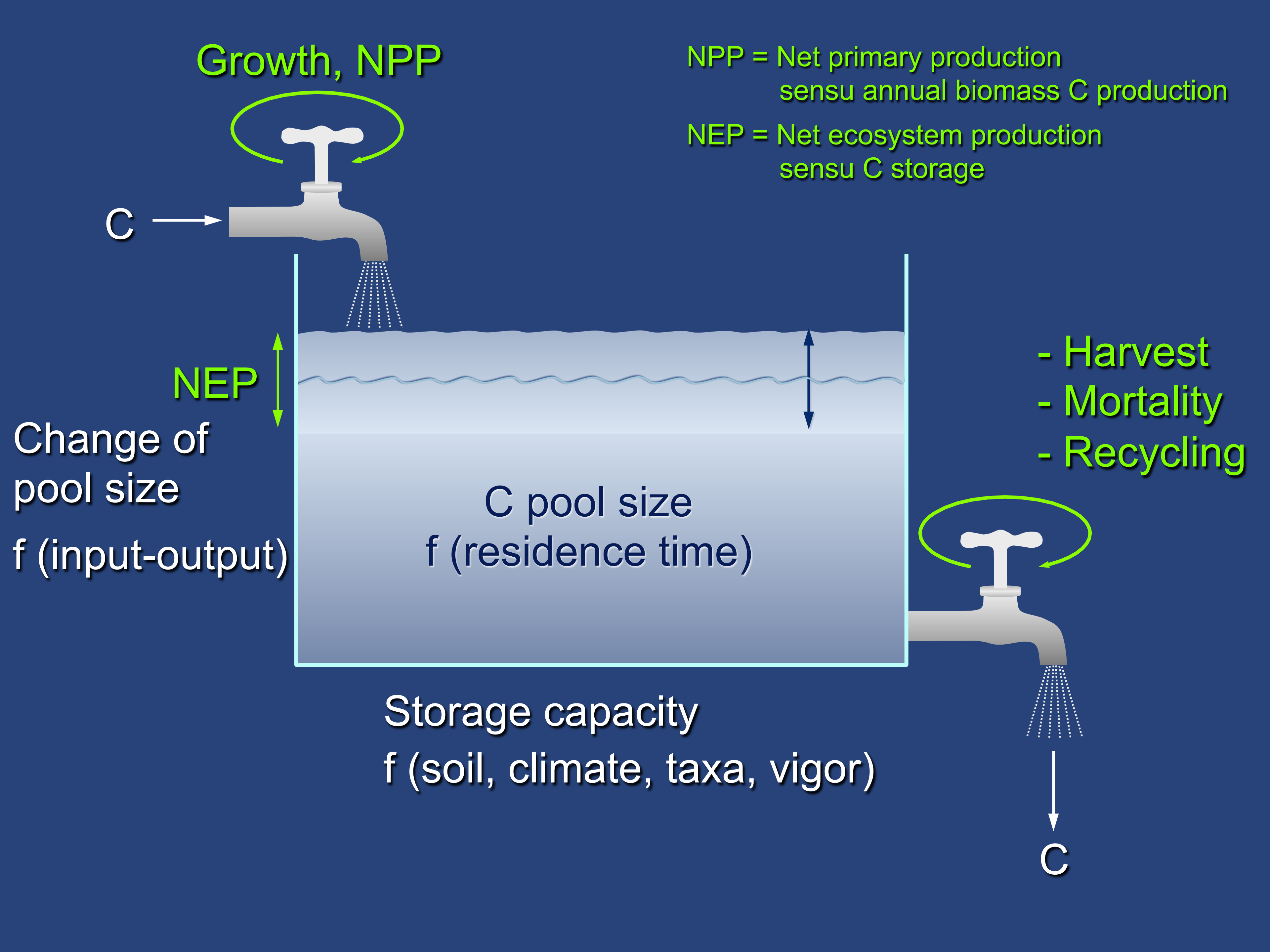
Fatichi S *et al* (2014) New Phytol 201:1086

Summary on source-sink relationships

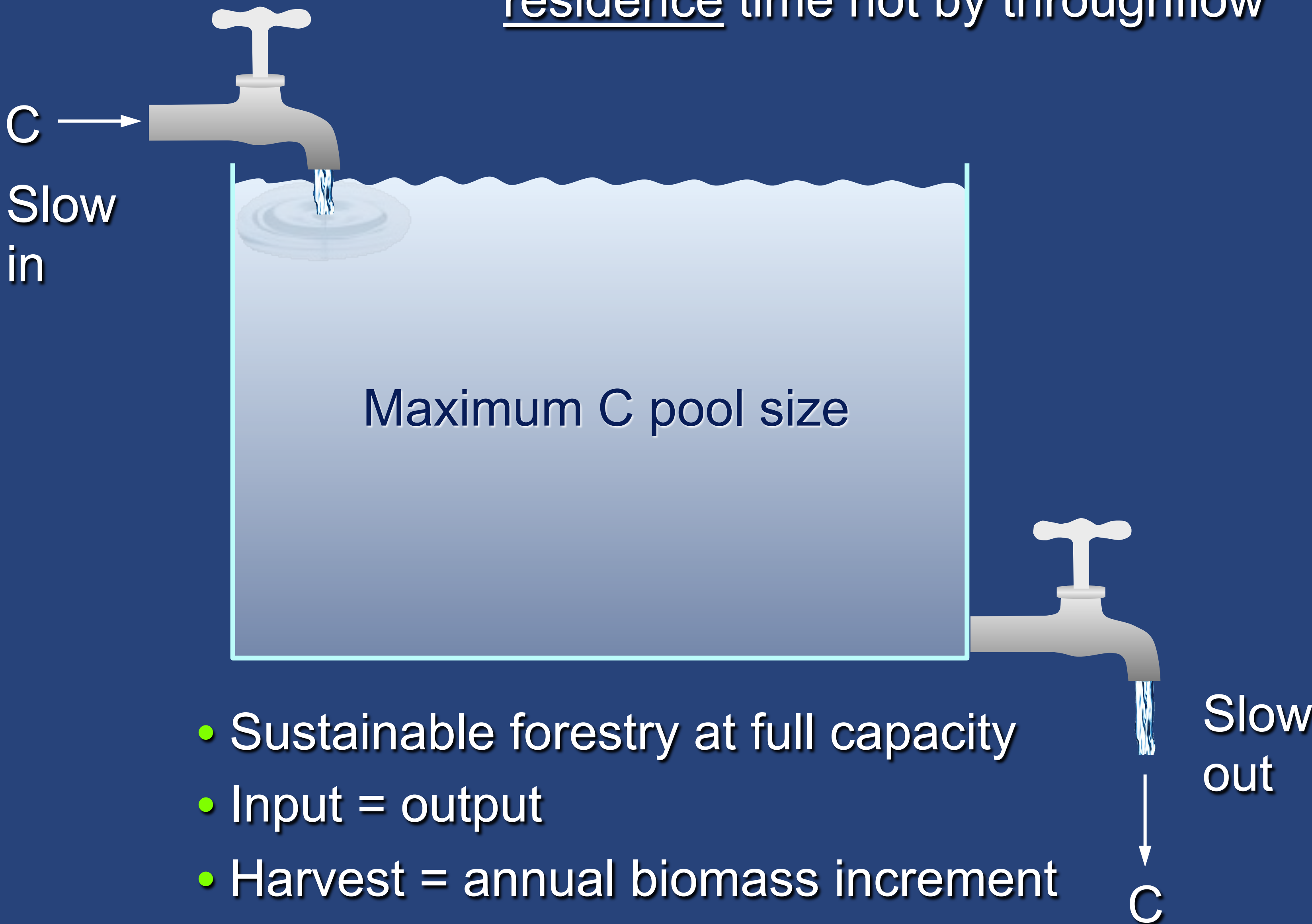
- Carbon uptake is largely controlled by C-sinks.
- Drought and low temperature act upon sink activity first (meristems).
- CO_2-saturation because sinks control source activity and because soil resources (nutrients) are finite.

Source driven growth models yield plausible results for the wrong reason.

Fatichi S *et al* (2014) New Phytol 201:1086

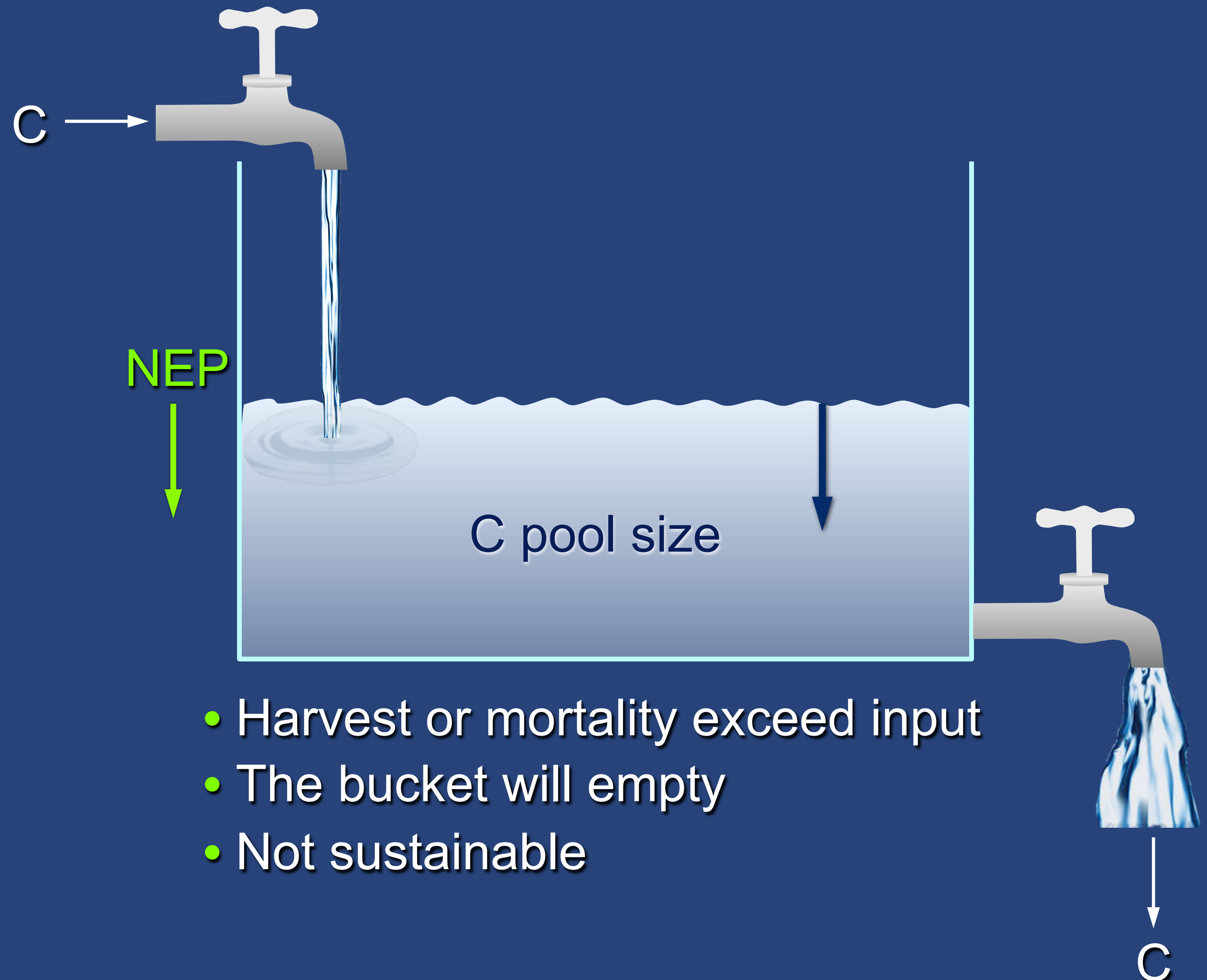

Growth, NPP
NPP = Net primary production
sensu annual biomass C production
NEP = Net ecosystem production
sensu C storage
C
NEP
Change of
pool size
f (input-output)
C pool size
f (residence time)
- Harvest
- Mortality
- Recycling
Storage capacity
f (soil, climate, taxa, vigor)
C

Storage is determined by <u>residence</u> time not by throughflow



- Sustainable forestry at full capacity
- Input = output
- Harvest = annual biomass increment

Negative C-balance

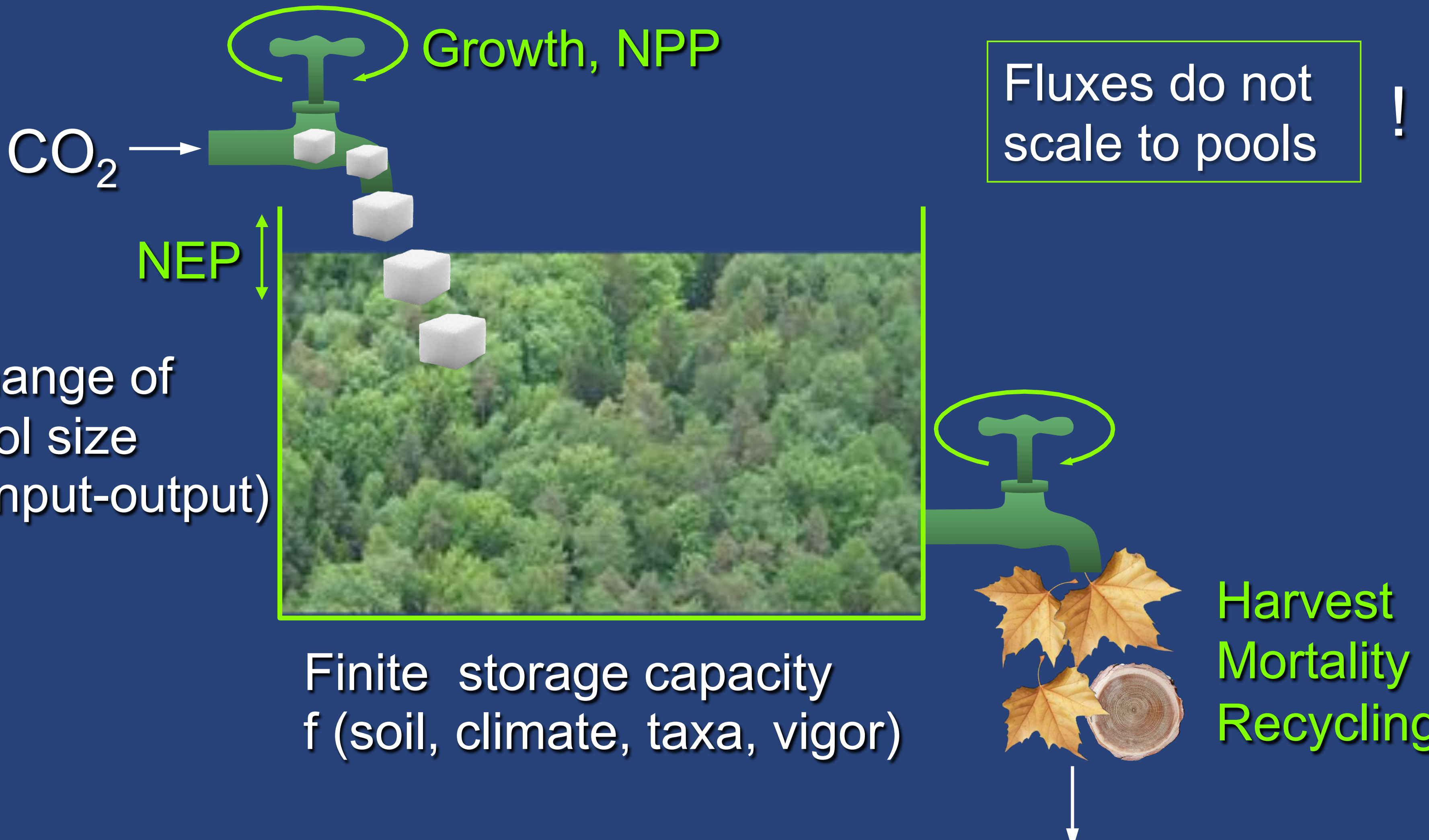


- Harvest or mortality exceed input
- The bucket will empty
- Not sustainable

Productivity and storage are correlated <u>negatively</u>

- High vigor, fast growth
- Fast rotation plantation
- Low storage

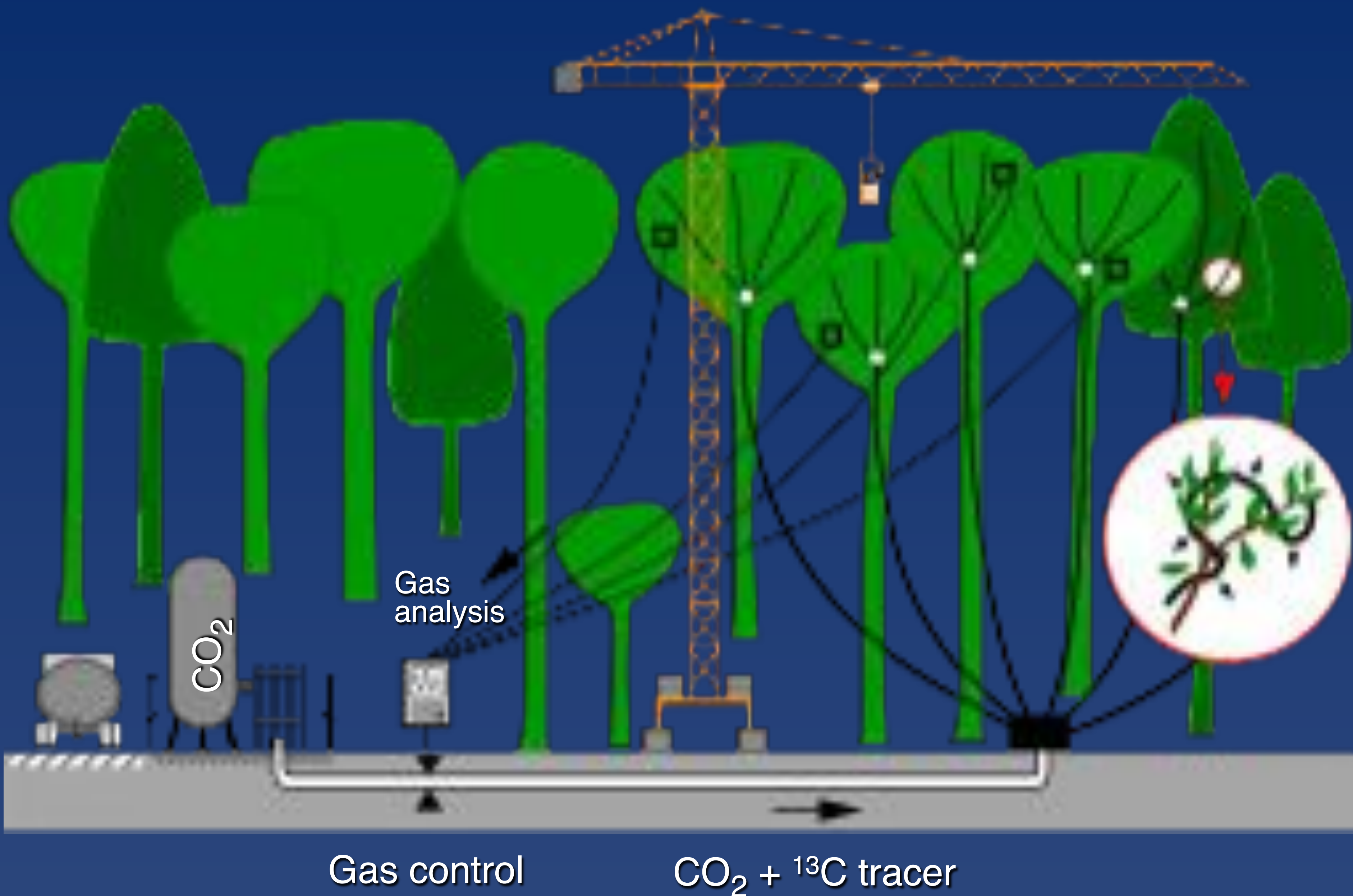
The C-capital (storage) is controlled by tree demography (residence time of C)



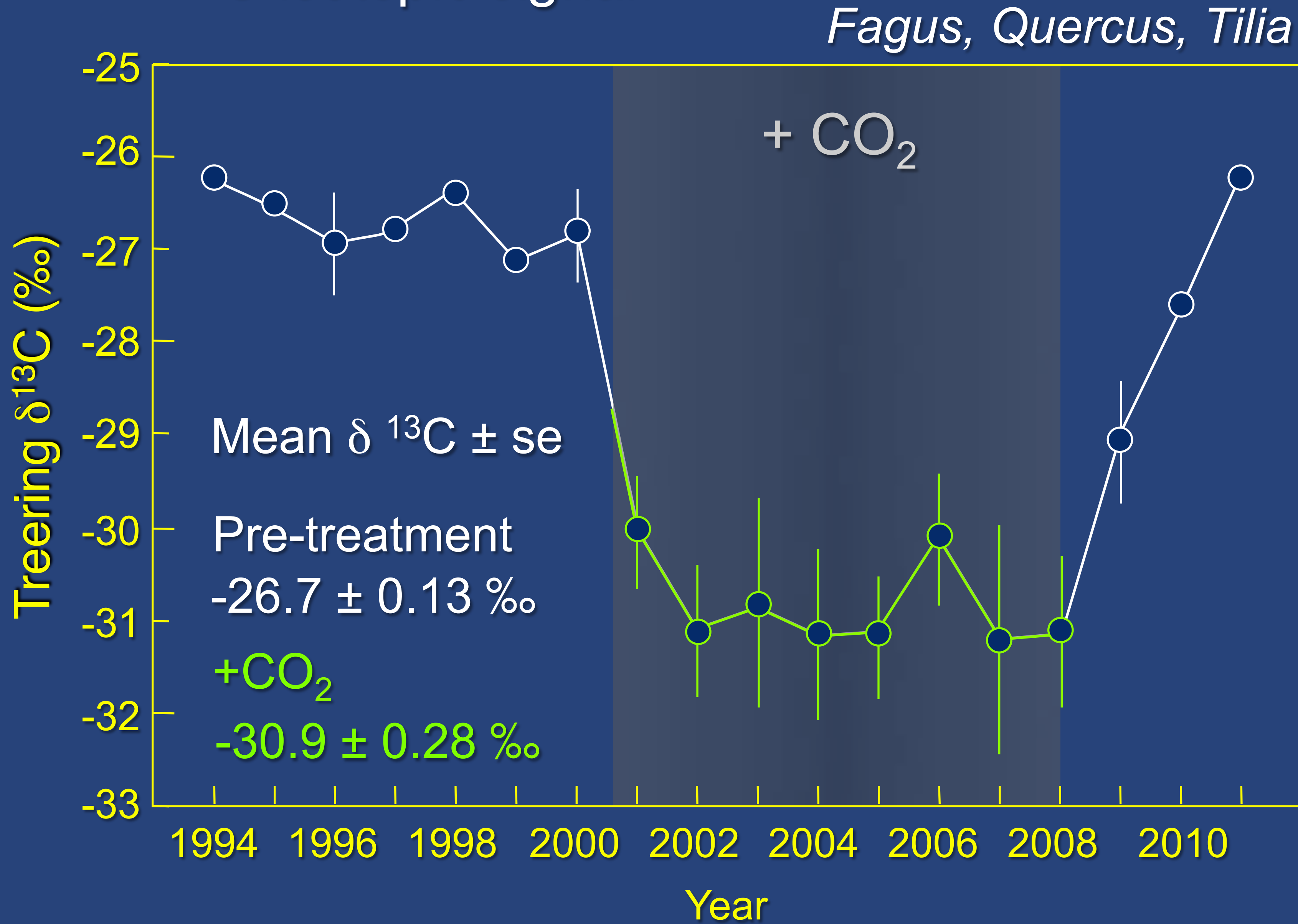
Körner C (2006) New Phytol 172:393
Bugmann H, Bigler C (2011) Oecologia 165:533

Is carbon a limiting resource?

web-FACE at the Swiss Canopy Crane site

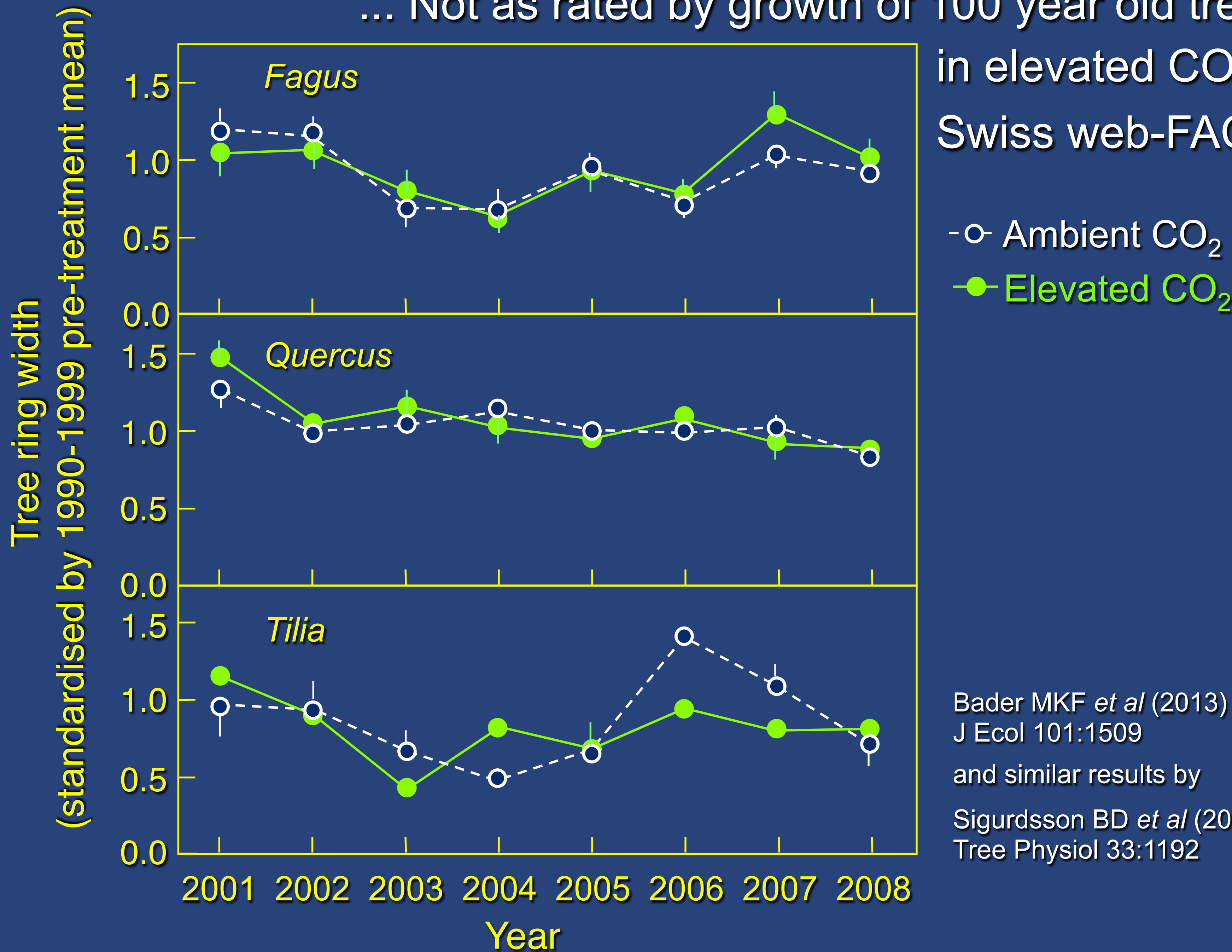


^{13}C isotopic signal



Bader MKF *et al* (2013) J Ecol 101:1509

... Not as rated by growth of 100 year old trees in elevated CO_2, Swiss web-FACE

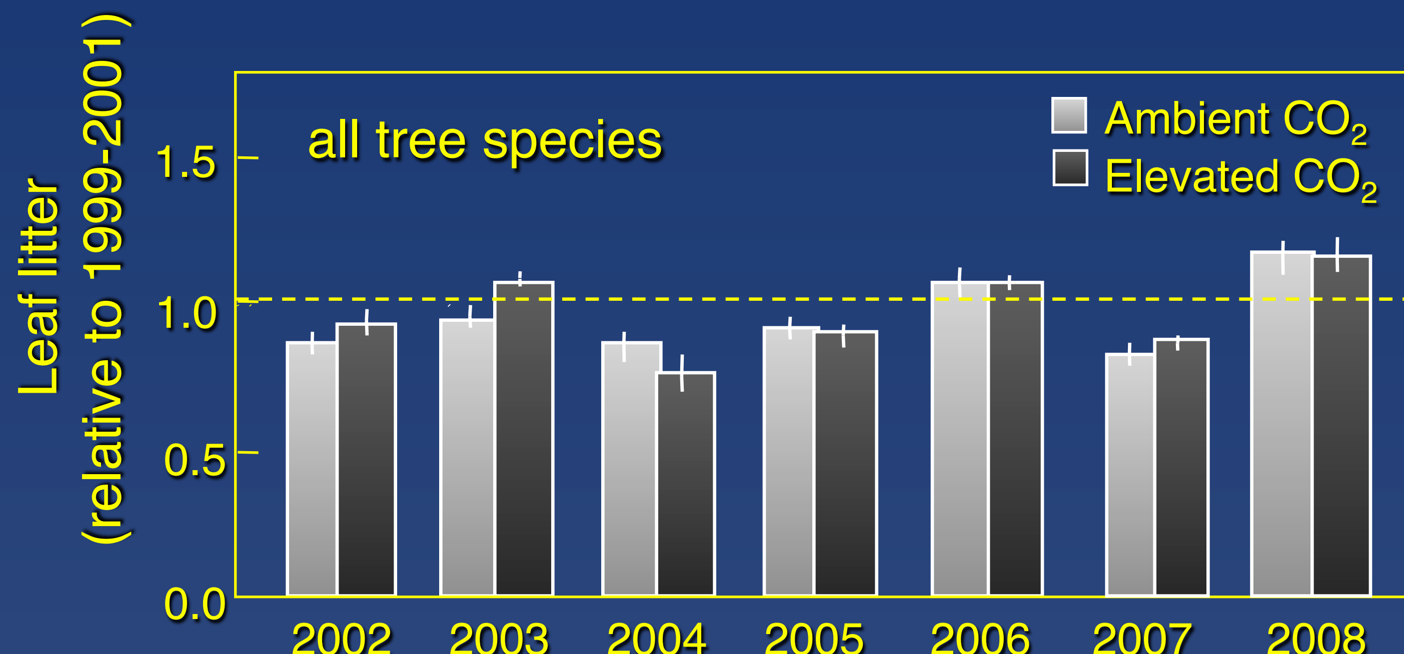


Bader MKF *et al* (2013)
J Ecol 101:1509

and similar results by

Sigurdsson BD *et al* (2013)
Tree Physiol 33:1192

... not as rated by leaf litter production



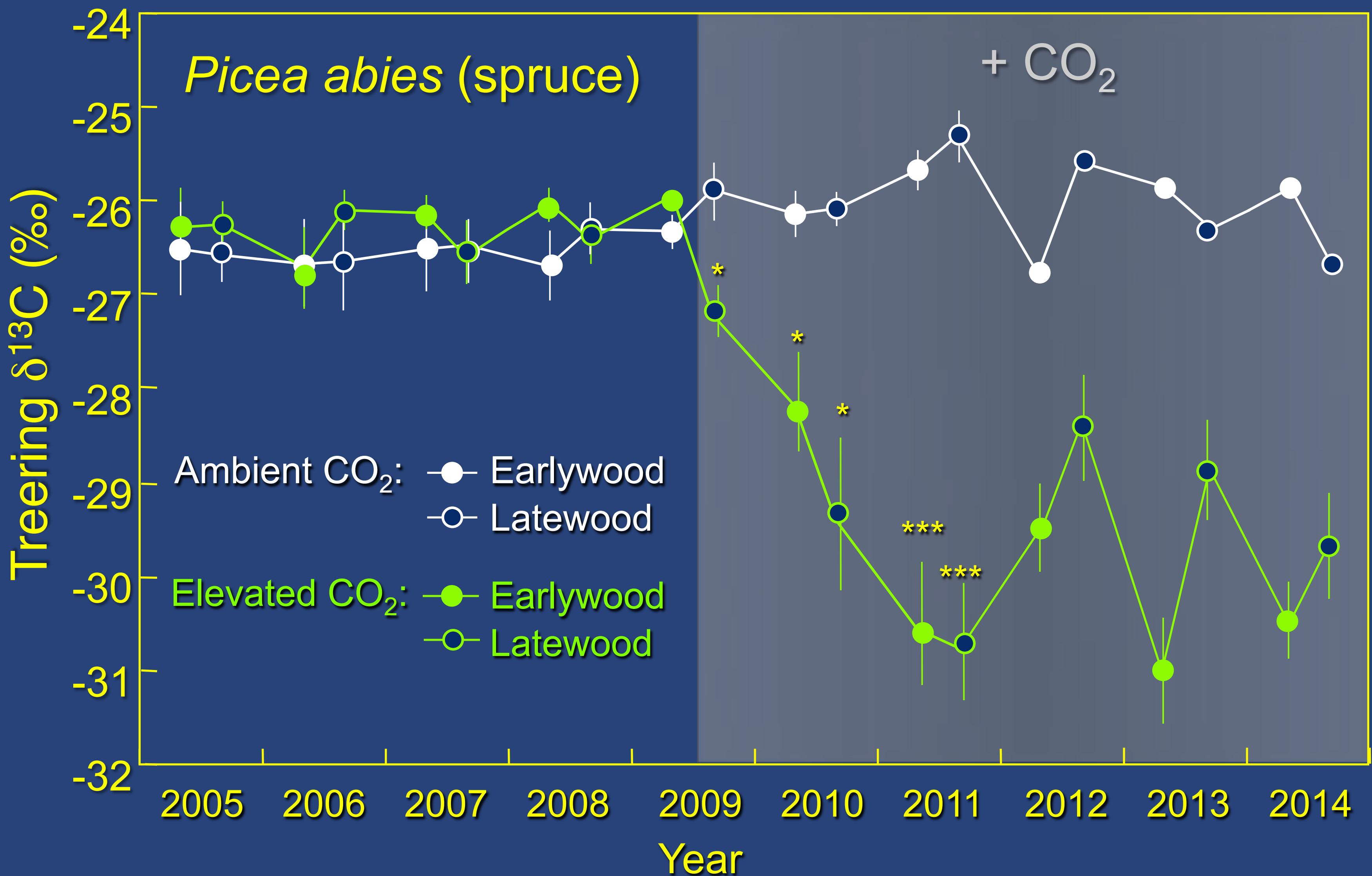
No change in allocation to leaves (and fine roots)

Körner C *et al* (2005) Science 309:1360

Bader MKF *et al* (2013) J Ecol 101:1509

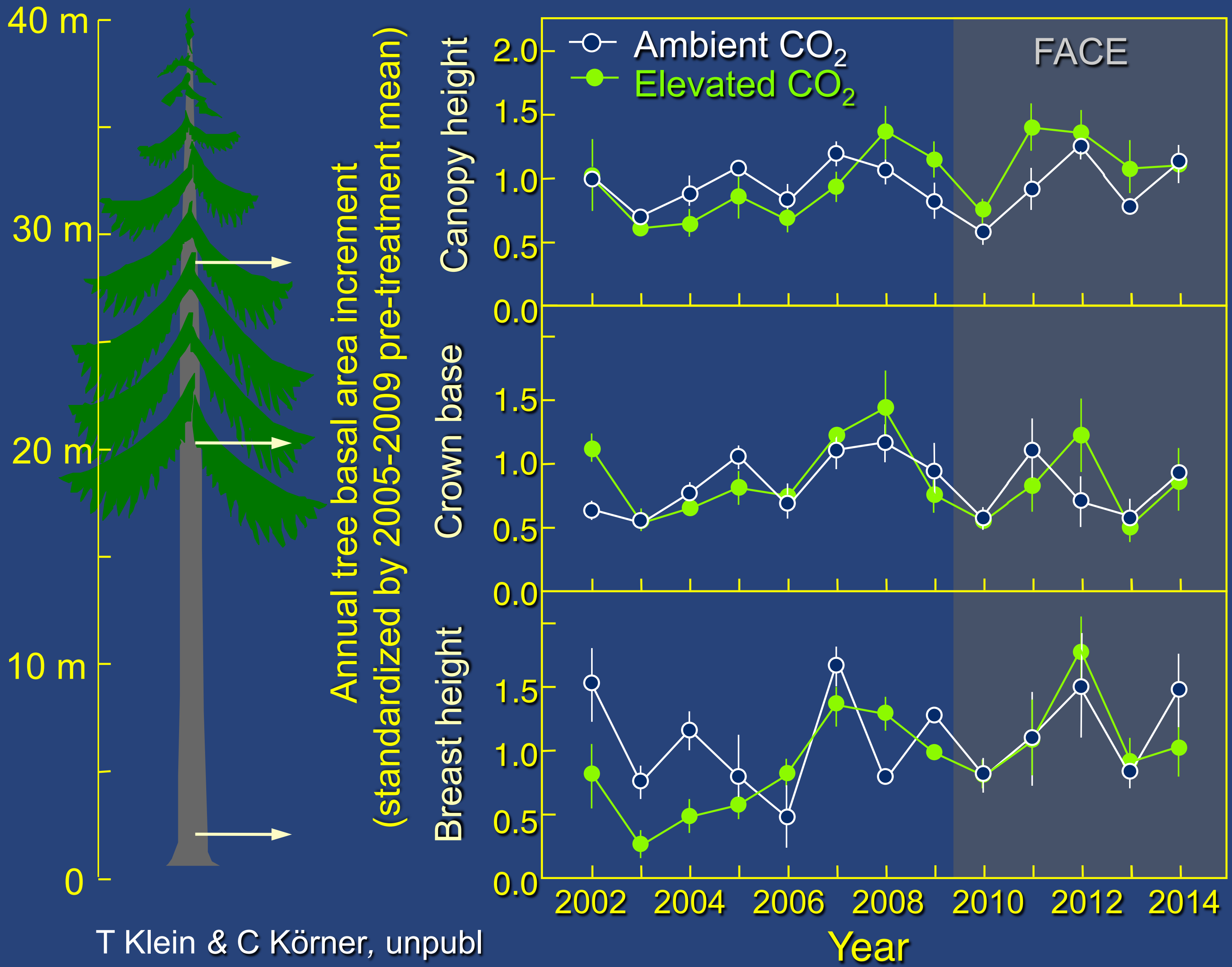

37 m tall spruce trees near Basel
CO_2
CO_2
CO_2
CO_2
CO_2
CO_2
CO_2
CO_2
CO_2

^{13}C isotopic signal



Mildner M *et al* (2014) Oecologia 175:747, and new data by T Klein, unpubl

Growth effects of elevated CO_2 on *Picea abies*



T Klein & C Körner, unpubl

Summary on elevated CO_2

- Commonly, assumed first principle responses (e.g. photosynthetic, respiratory or stomatal responses) don‘t scale.
- The rate of tissue formation controls the rate of carbon capture.
- Tissue formation is controlled by the most limiting resource which commonly is not C in a 400 ppm world.

Climate driven range limits of trees

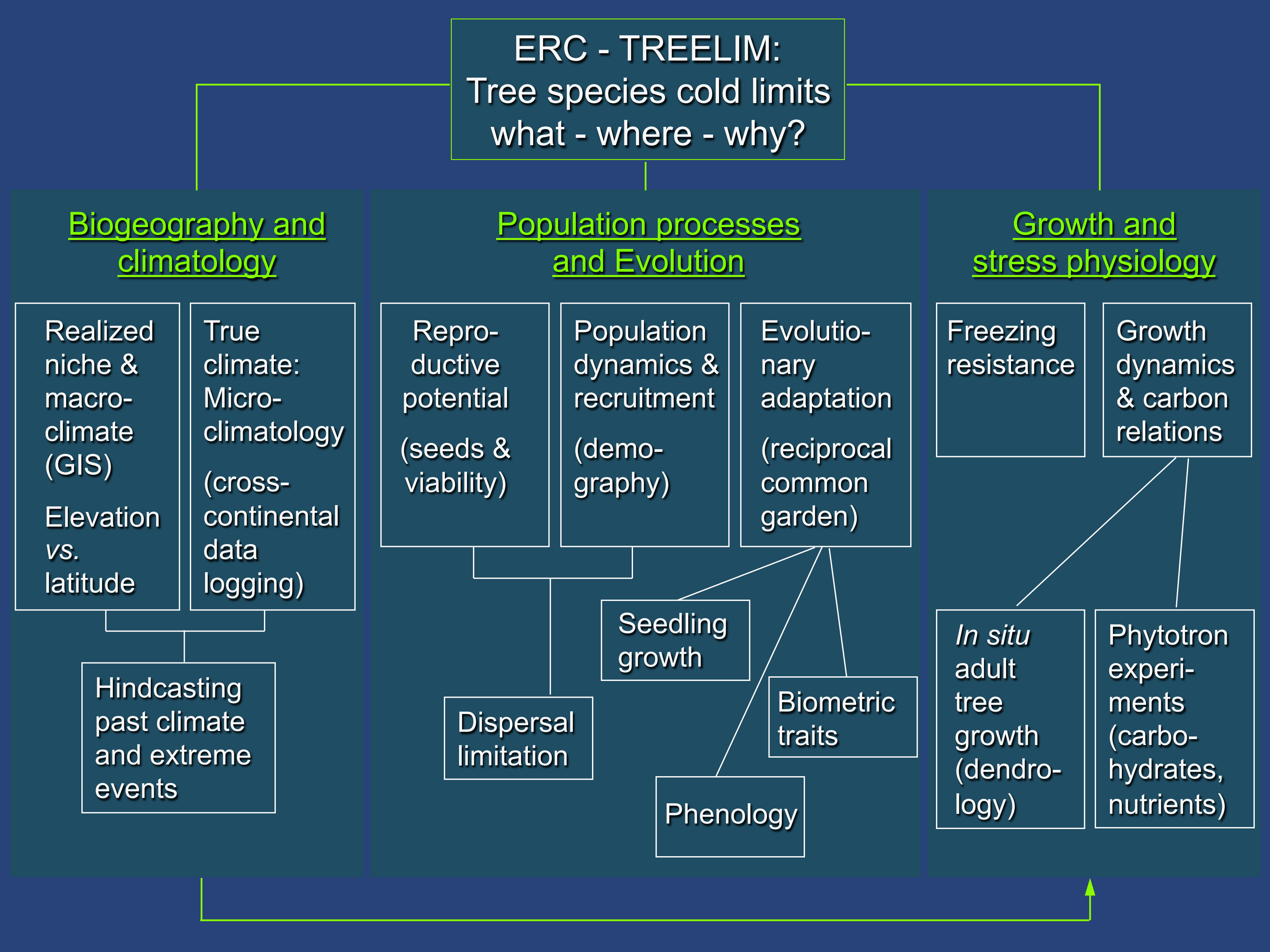
Treeline

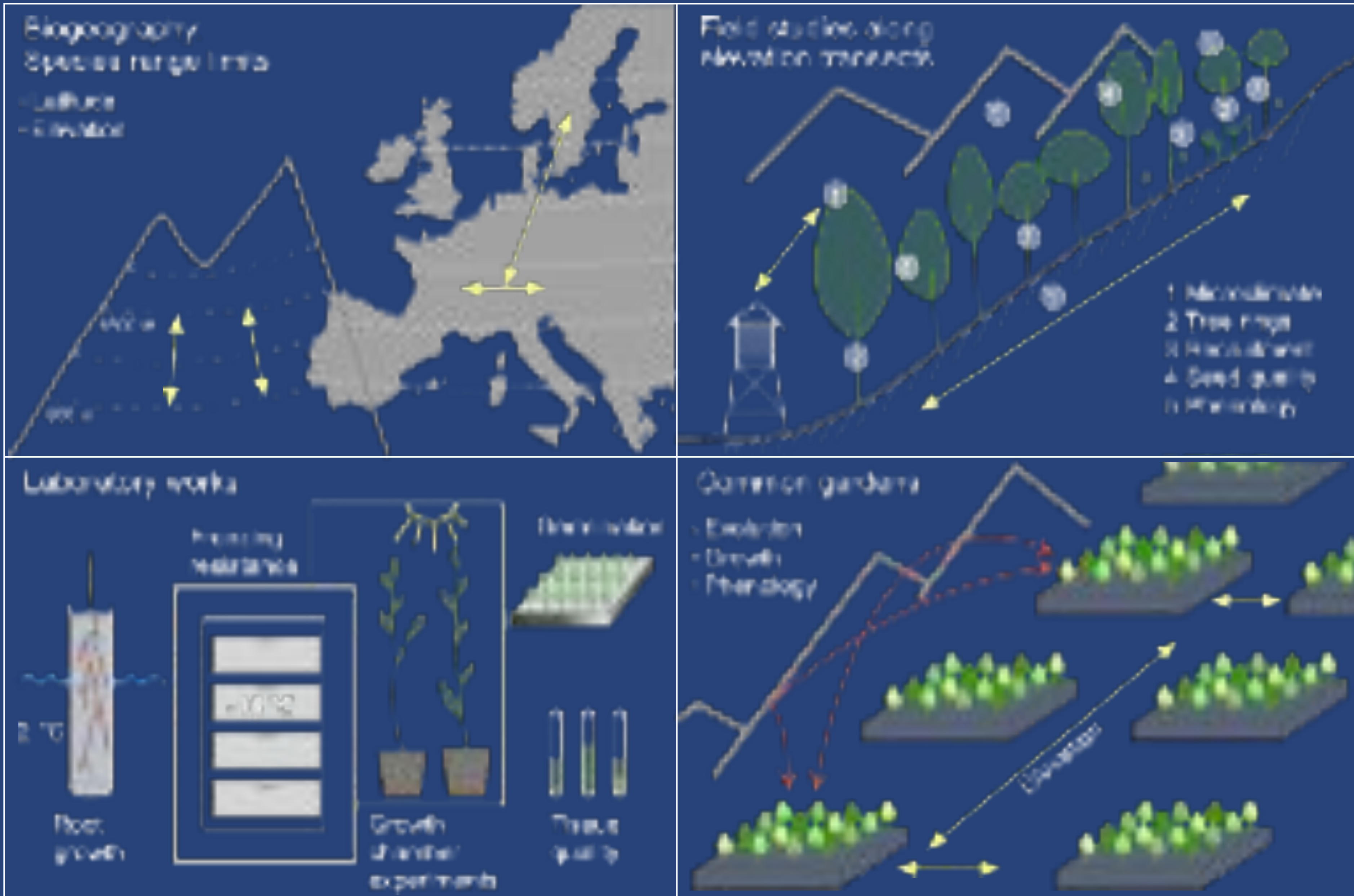
- The high elevation and high latitude tree limit, the treeline, is a lifeform limit.
- Several species may occupy it.

Tree species limit

- All species have a species specific low temperature limit.
- Each species has its own limit.

Warming affects both.


ERC - TREELIM:
Tree species cold limits
what - where - why?
Biogeography and climatology
Realized niche & macro-climate (GIS)
Elevation *vs.* latitude
True climate: Micro-climatology
(cross-continental data logging)
Hindcasting past climate and extreme events
Population processes and Evolution
Repro-ductive potential
(seeds & viability)
Population dynamics & recruitment
(demo-graphy)
Evolutio-nary adaptation
(reciprocal common garden)
Seedling growth
Dispersal limitation
Biometric traits
Phenology
Growth and stress physiology
Freezing resistance
Growth dynamics & carbon relations
In situ adult tree growth (dendro-logy)
Phytotron experi-ments (carbo-hydrates, nutrients)



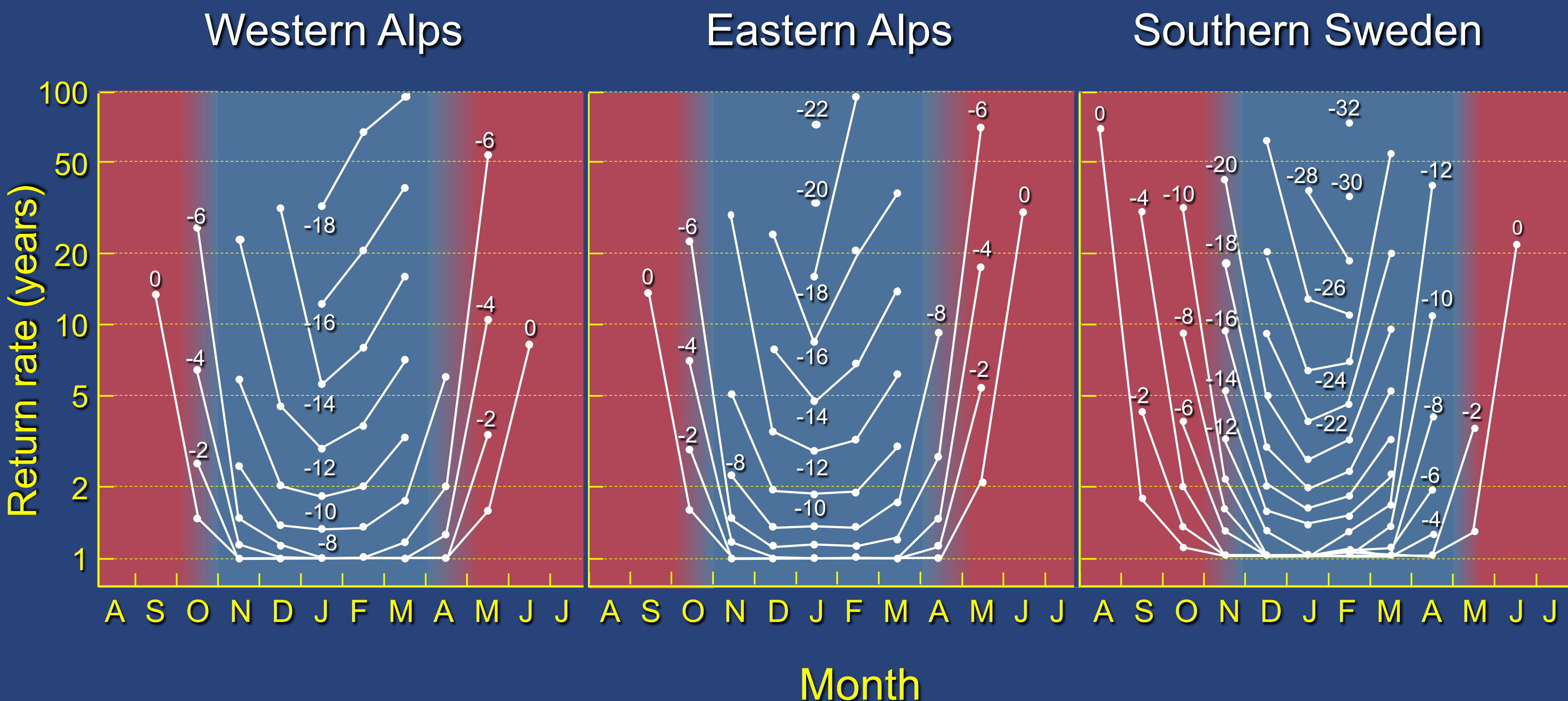
Biogeography
Species range limits
Field studies along elevation transects
2 Tree rings
4 Seed quality
Laboratory works
Freezing resistance
Root growth
Growth chamber experiments
Tissue quality
Common gardens
- Growth
- Phenology

Night time minima of temperature in the top of tree crowns

... match weather station records by 0.5 K

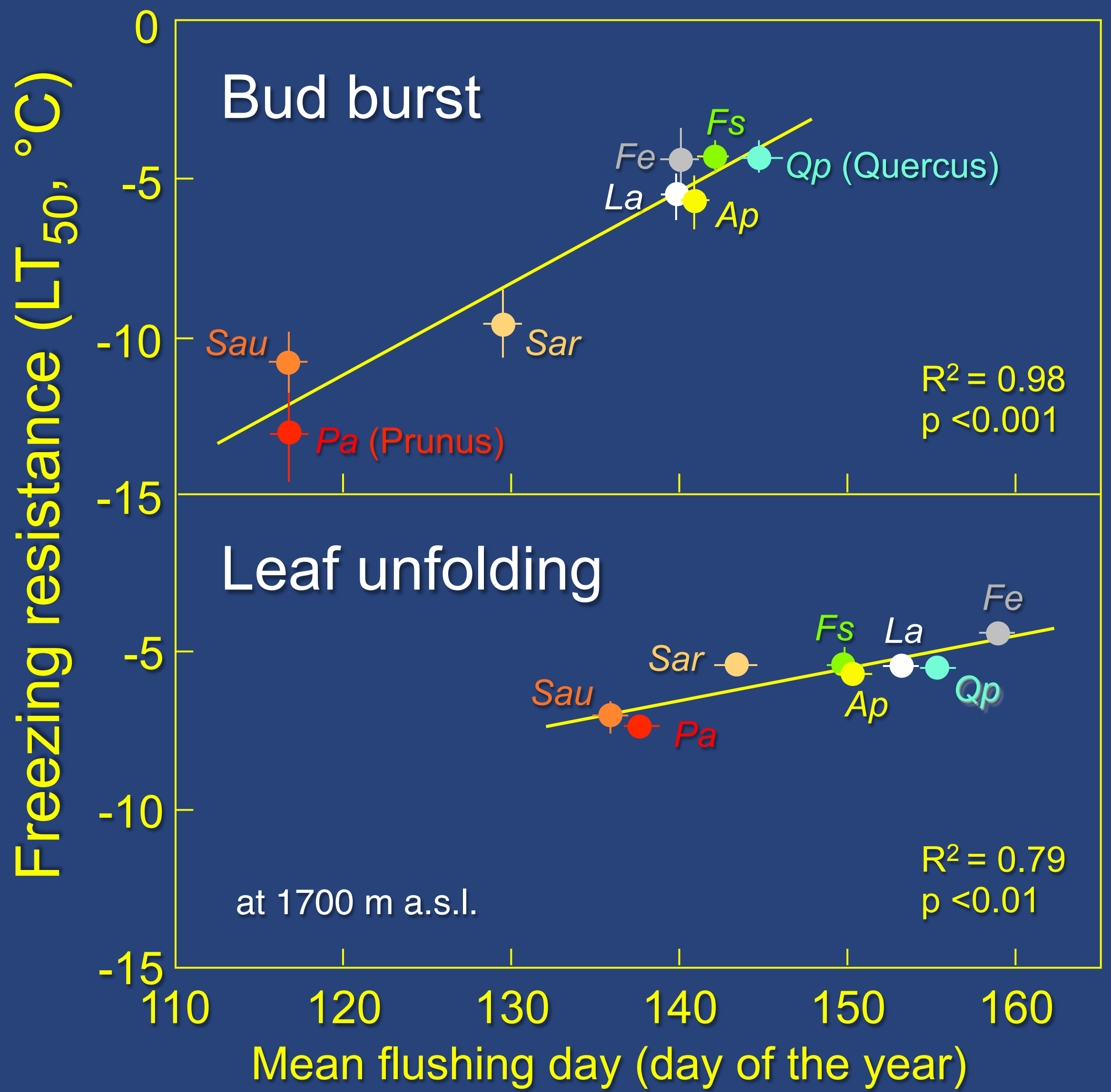
Return rates of extreme temperatures

Lowest temperatures (°C) predicted to occur during 100 years at the species limit of *Prunus avium,* as an example



From Kollas C *et al* (2014) J Biogeogr 41:773

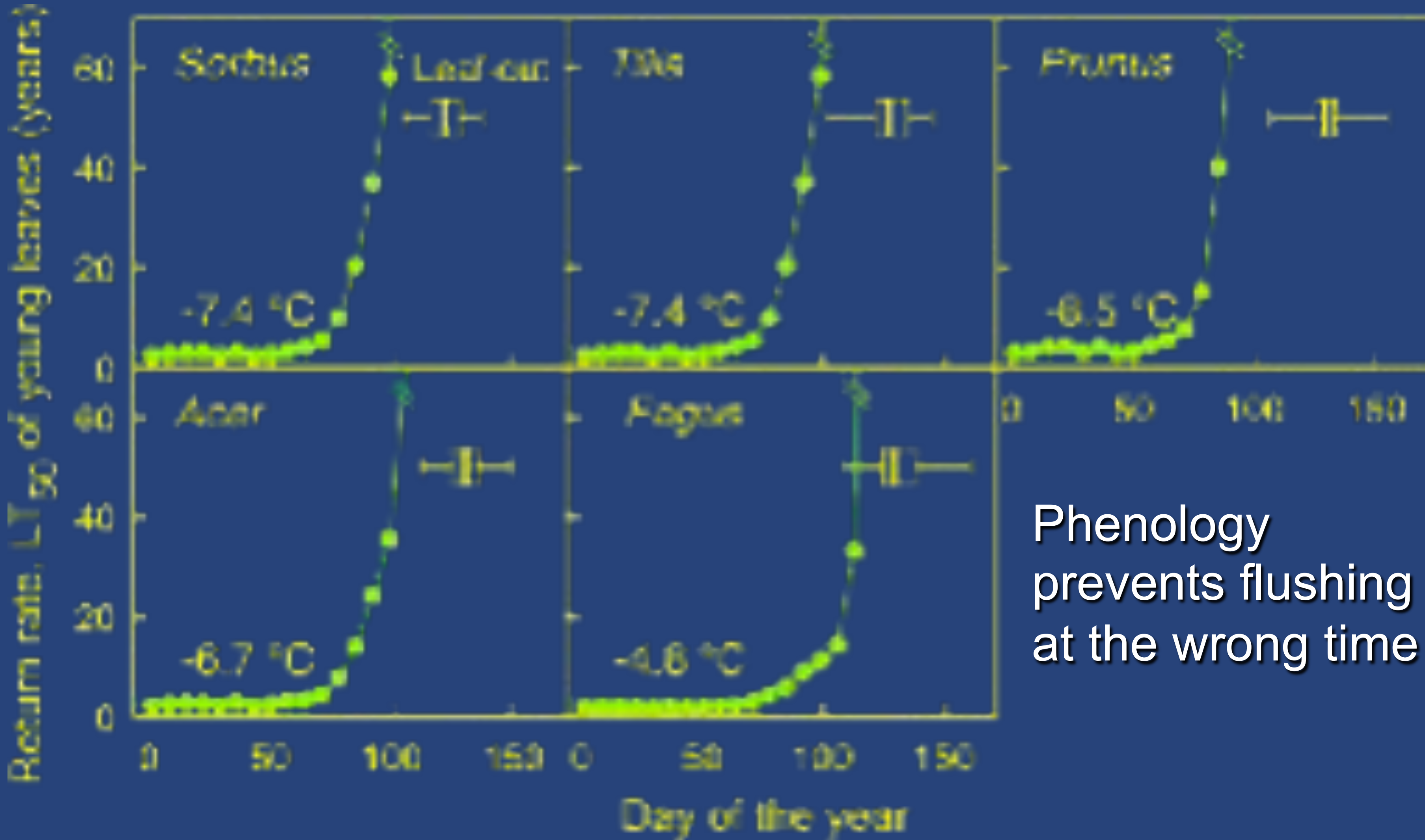
Freezing resistance during dehardening in spring



Early flushing species are more resistant than late flushing species

Lenz A *et al* (2013) New Phytol 200:1166

Risk of freezing damage in young leaves



Phenology prevents flushing at the wrong time

Lenz A *et al* (2013) New Phytol 200:1166

Controls of tree phenology in spring

- Opportunistic (T-only)

- Chilling
- Temperature

- Chilling
- Photoperiod
- Temperature

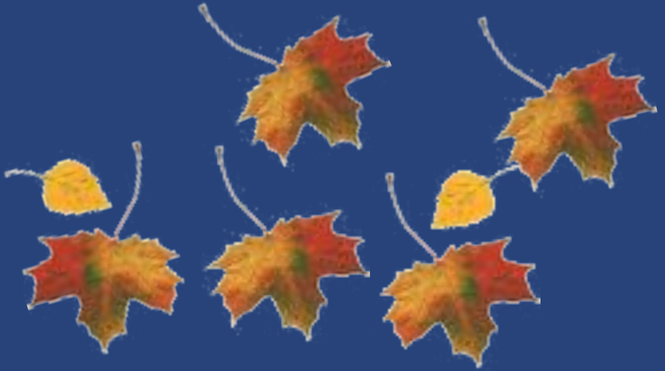
Syringa

Carpinus

Fagus

Körner C & Basler D (2010) Science 327:1461

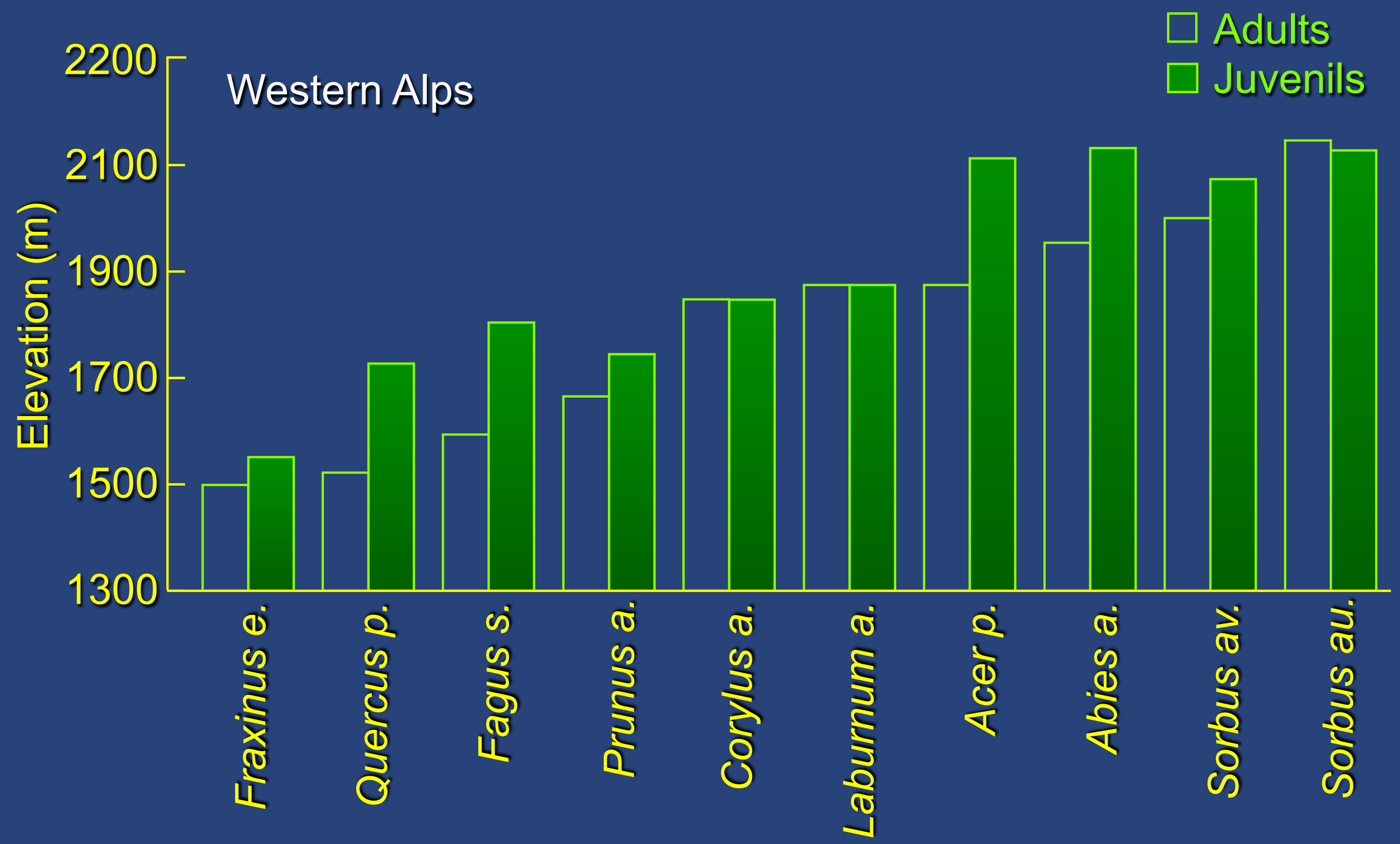
End of season phenology



Leaf coloration is misleading

- A longer season as rated by eye (phenology), should not be mistaken as an expression of the plant's internal state.
- The plant internal controls set developmental limits (time constraints).
- A longer greenness would only matter if there is C-limitation (no evidence).
- Autumnal phenology is driven by photoperiod.

Elevational limits of trees in the Alps: Juvenile (seedlings and saplings) were found at and beyond the adult elevational limits



Kollas C *et al* (2012) Ann Bot 109:473

Vitasse Y *et al* (2012) J Biogeogr 39:1439

Summary on range limits of trees and phenology

Tree species limits below treeline are set by

- Phylogenetic maximum freezing tolerance in spring
- Phenology is the way to escape dangerous freezing events but this constrains the length of the growing season.
- Phylogenetic life history traits define a minimum season length (e.g. tissue maturation, seed ripening).


Short term
Spring effects
Losses of immature tissue
Damage
Long term
Micro-evolution
Phenology of bud break
Minimum season length
Maximum freezing resistance in spring
Tissue maturation + life history
Macro-evolution Phylogeny
Short term
Winter effects
Losses of immature tissue
Damage
Tree success

The 'Treelim core team'

European Research Council

From left to right:
Christian Körner, Chris Kollas, Christophe Randin, Armando Lenz, Günter Hoch, Yann Vitasse

Overall conclusions

- Carbon sinks control C sources (mostly).
- Forest productivity is not C limited.
- C sequestration in forests requires a longer residence time of C in biota (tree turnover, tree demography).
- Tree phenology is an issue of stress tolerance in interaction with developmental constraints (not related to carbon relations).


... the more older trees the more carbon