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Title Stable isotopes in dendroecology

Module

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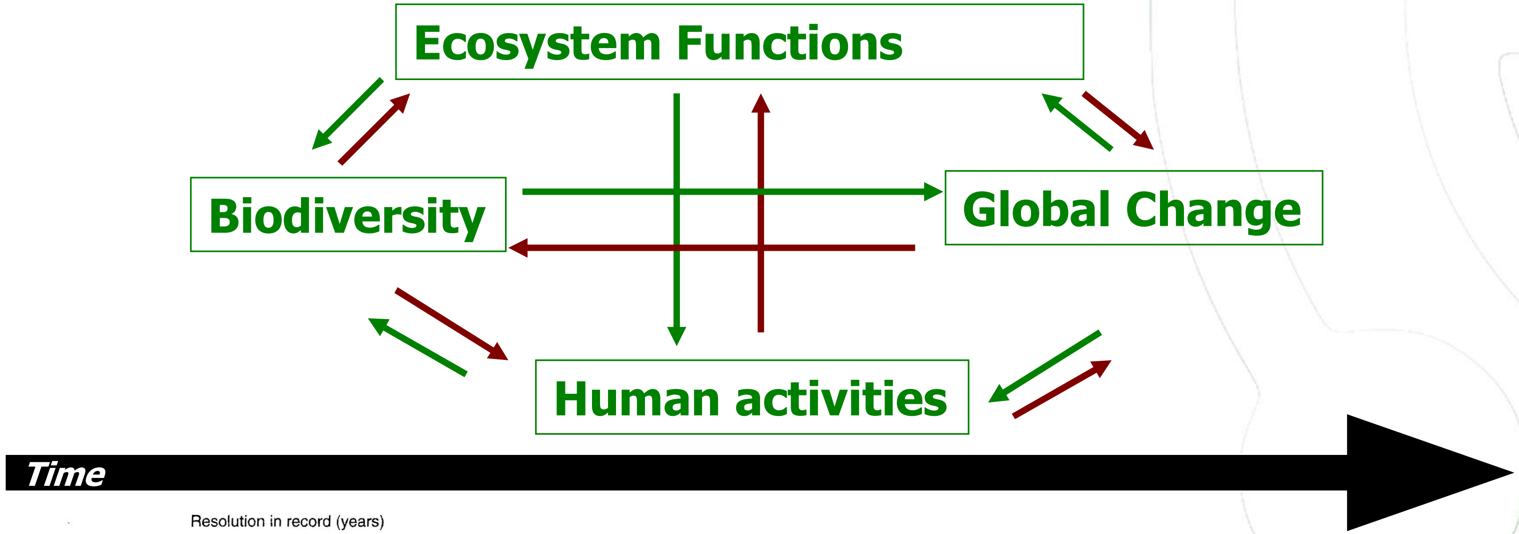
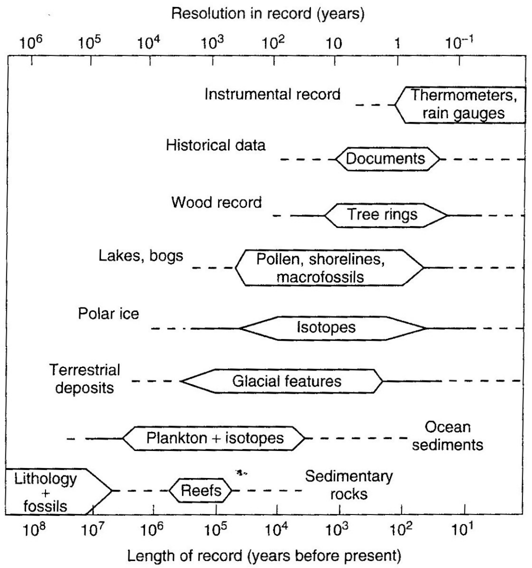
Outline

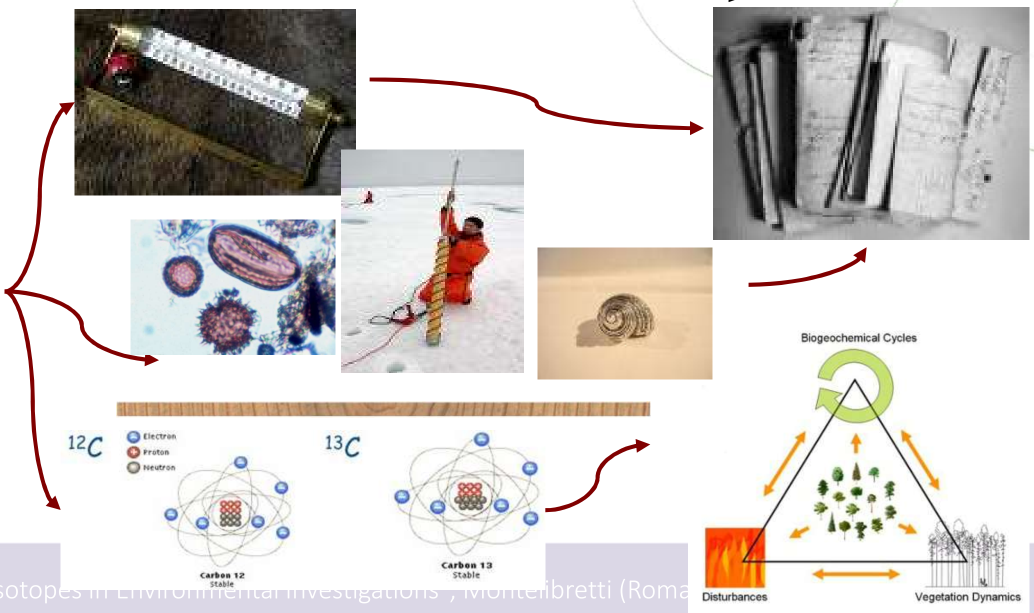
- ↓ Stable isotope: why we should use them?
- ↓ $\delta^{13}C$ $\delta^{18}O$
- ↓ Applications: global changes and disturbances
- ↓ Effects of CO_2 enrichment on forest
- ↓ Mediterranean species and Drought effect
- ↓ Fire
- ↓ Prospectives

Historical perspective





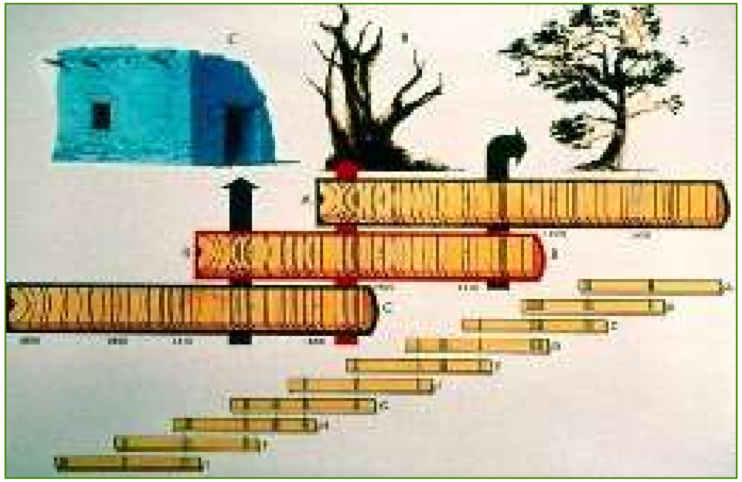
(Webb et al., 1985)



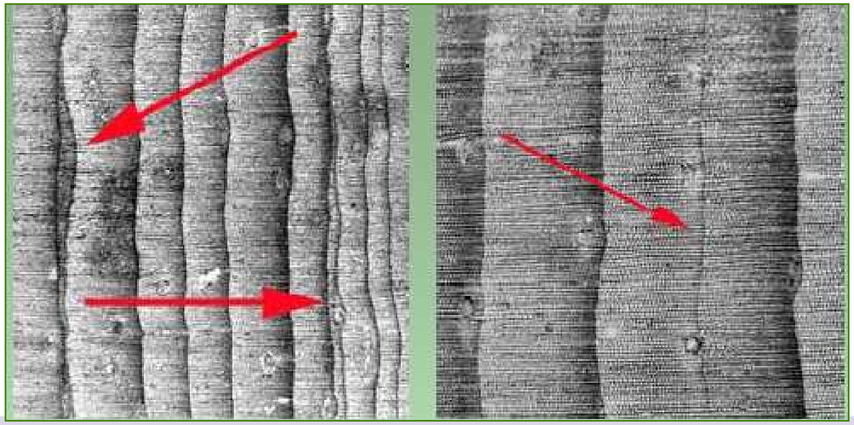
Dendrochronology

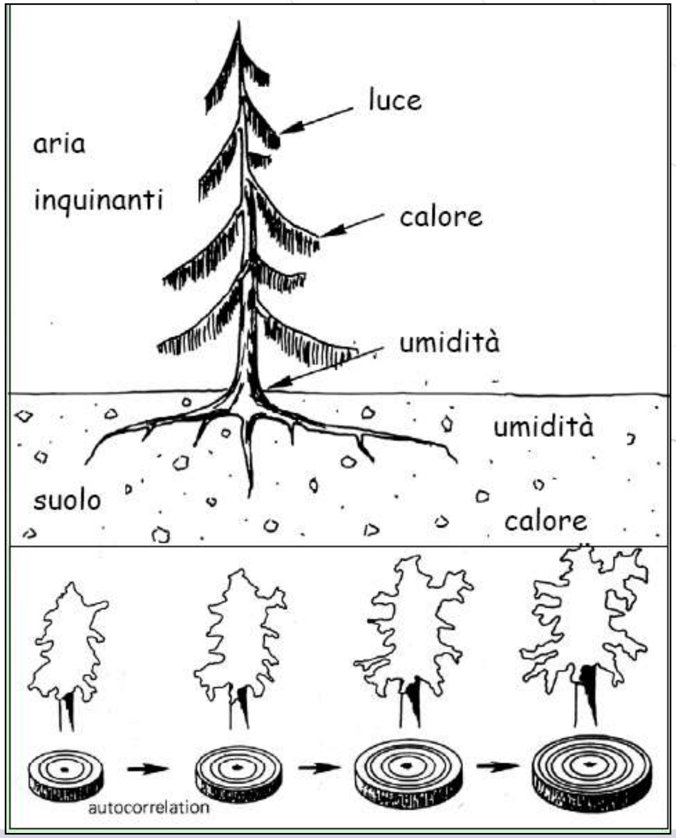
The science that deals with the dating and the study of annual growth layers in wood.

Fritts, 1976

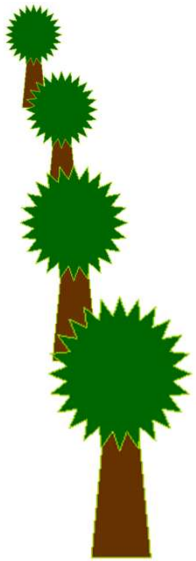


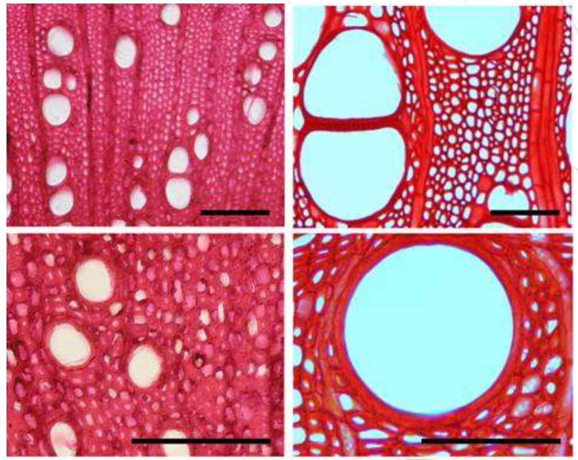
- Quantitative variations (ring-width, density)
- Visible signs (scars, callous tissue,resin ducts)
- Changes in chemical composition of wood





Quantative wood anatomy





Stable features

Variable features

Vessel size

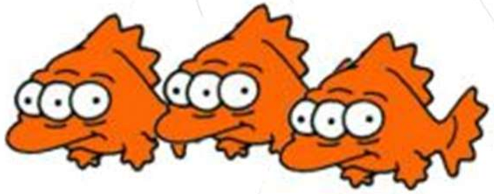
▼

Environmental influence

"A methodological approach based on the measurement of wood cell anatomical characteristics, analyzed through time and used to characterize the relationships between tree growth and various environmental factors"
2nd Workshop on QWA, Birmensdorf, Switzerland, May 2007

I'm a dendrochronologist, so...

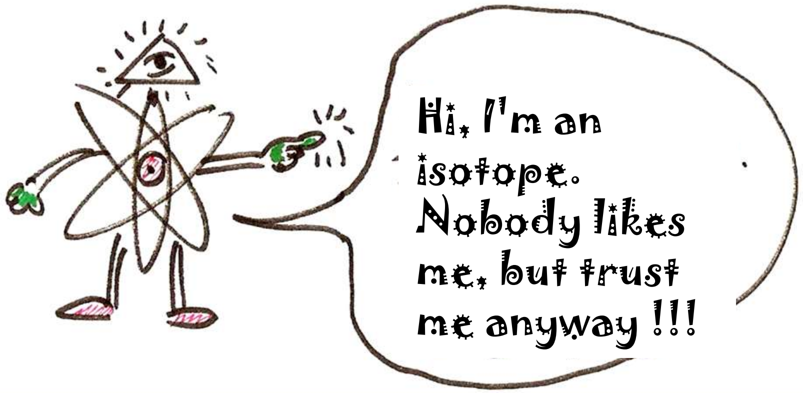
WHY SHOULD I CARE ABOUT (STABLE) ISOTOPES?



- *they are (quite) expensive*

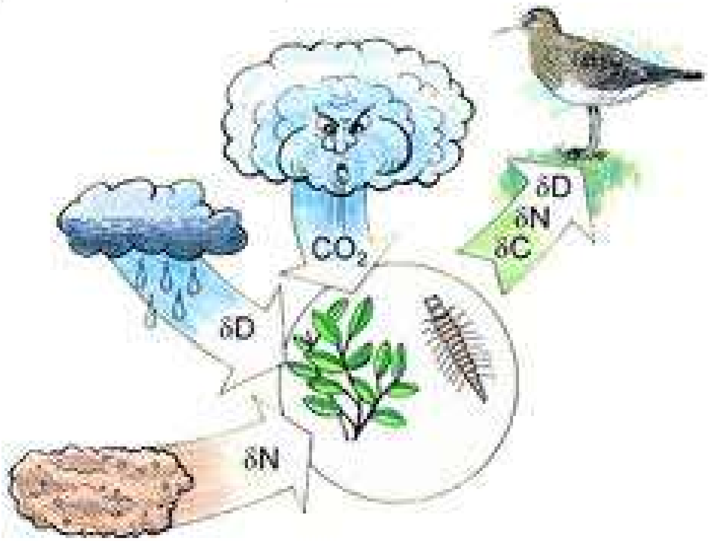
- *they imply destructive sampling*

- *I can't see them …*

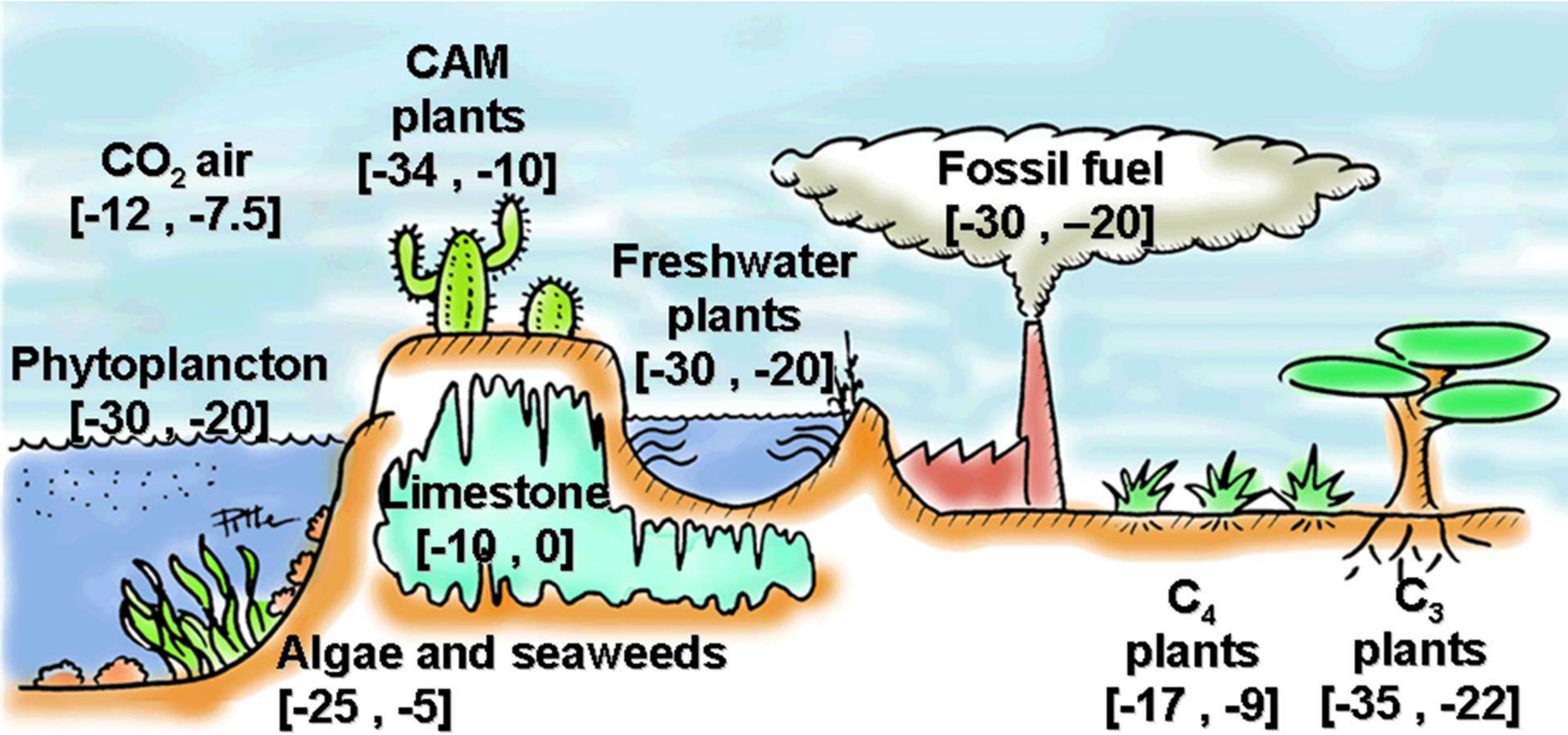


Stable Isotopes a ValuableTool in Ecological and Physiological Research

- ➔ The isotope abundance is specifically changed in environmental and physiological processes leaving its specific „fingerprint“
- ➔ The signal given by the above mentioned processes are well preserved in organic matter, sediments and fossiled materials
- ➔ Isotope ratios represent an integrative information over time and space
- ➔ Isotopes are ideal tracers

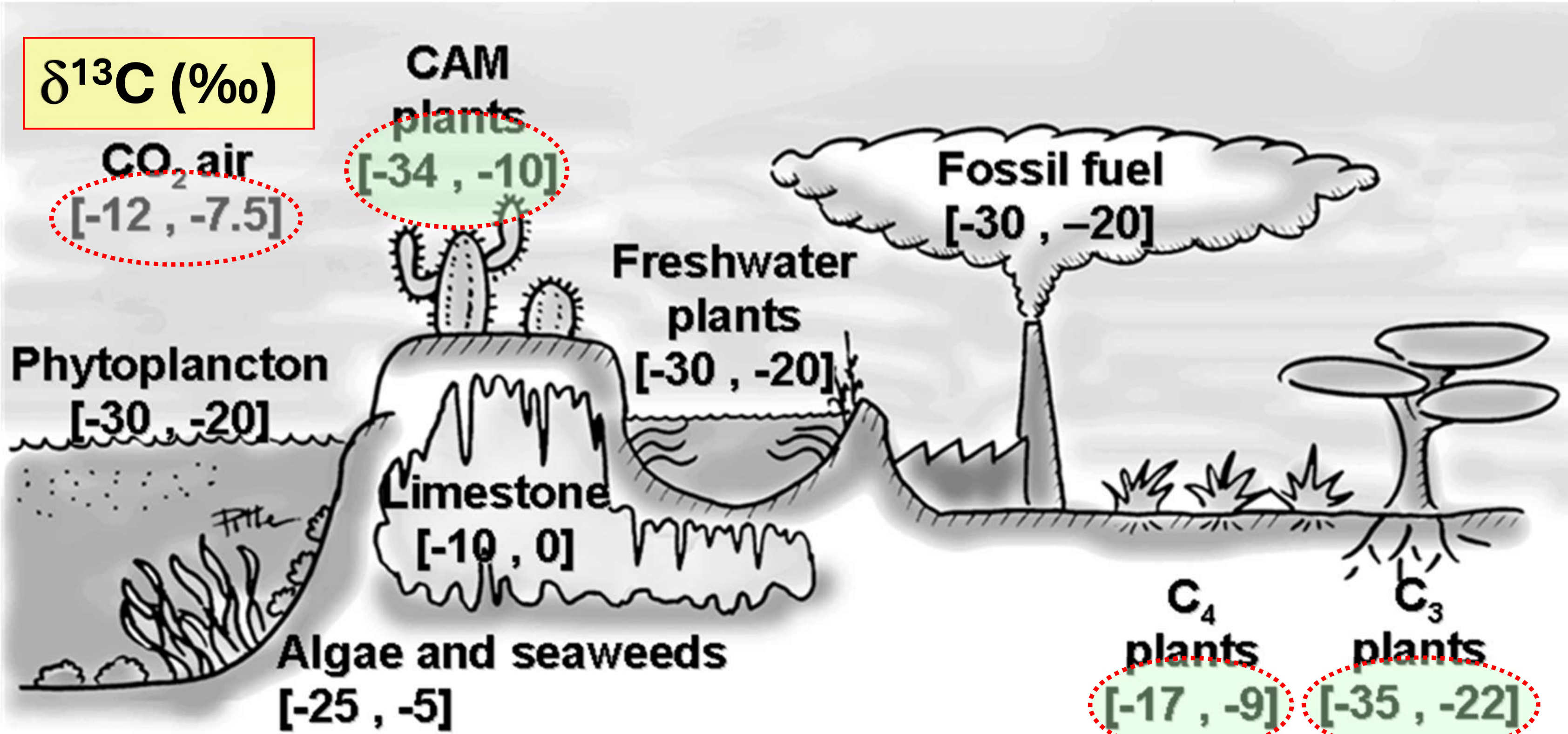


Carbon isotopes in the biosphere



Ferrio et al., 2005

What is the range of d values for plant tissues:



- $\delta^{13}C$ (‰) in plants is lower than in fixed CO_2
  →Carbon isotope discrimination ($\Delta^{13}C$)
- Discrimination is variable→Phot. pathway

Basis for ^{13}C variations in plants

There are……

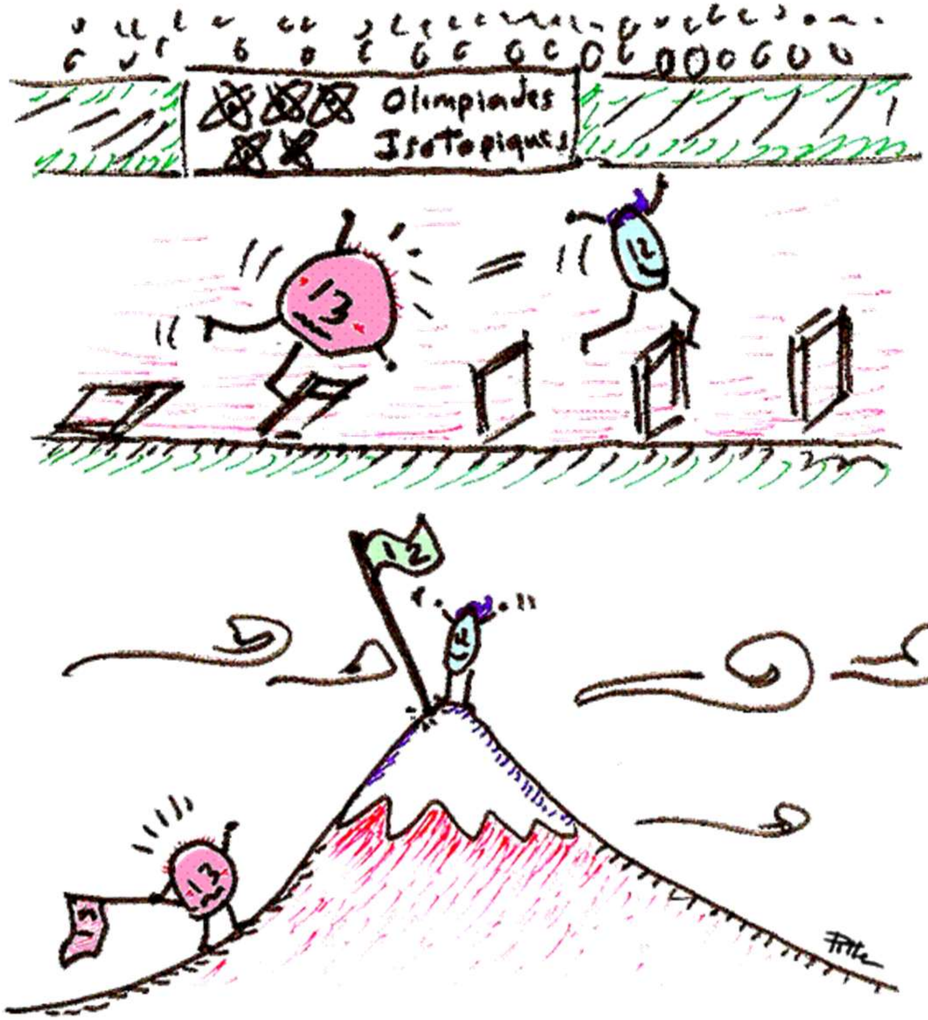
- ❖ Irreversible steps in the metabolic process, where not all of the substrate is consumed
- ❖ Metabolic branch points
- ❖ Opportunities where diffusion is a fundamental step in the pocess
- ❖ Secondary fractionation events associated with common pools

Table 1 Isotope effects of steps leading to CO_2 fixation in plants.

Process	Isotope effect (α)	Discrimination (‰)	Symbol	Reference
Diffusion of CO_2 in air through the stomatal pore[a]	1.0044	4.4	a	Craig (16)
Diffusion of CO_2 in air through the boundary layer to the stomata[a]	1.0029	2.9	a_b	Farquhar (33)
Diffusion of dissolved CO_2 through water	1.0007	0.7	a_l	O'Leary (98)
Net C_3 fixation with respect to p_i	1.027	27	b	Farquhar & Richards (39)
Fixation of gaseous CO_2 by	1.030 (pH = 8)	30	b_3	Roeske & O'Leary (119)[b]
Rubisco from higher plants	1.029 (pH = 8.5)	20	b_3	Guy et al (50)
Fixation of HCO_3^- by PEP	1.0020	2.0	b_4^*	O'Leary et al (101)
carboxylase	1.0020	2.0		Reibach & Benedict (117)
Fixation of gaseous CO_2 (in equilibrium with HCO_3^- at 25°C) by PEP carboxylase	0.9943	−5.7	b_4	Farquhar (33)
Equilibrium hydration of CO_2	0.991	−9.0	e_b	Emrich et al (31)
at 25°C	0.991	−9.0		Mook et al (91)
Equilibrium dissolution of CO_2	1.0011	1.1	e_s	Mook et al (91)
into water	1.0011	1.1		O'Leary (98)

[a] Theoretical value
[b] Data corrected for dissolution of CO_2

Carbon isotope discrimination (C_3)



^{13}C is heavier and less reactive:

- diffuses more slowly through stomata →Physical fractionation

- *RuBisCo* fixes preferentially ^{12}C during photosynthesis →Chemical fractionation

Carbon isotope discrimination

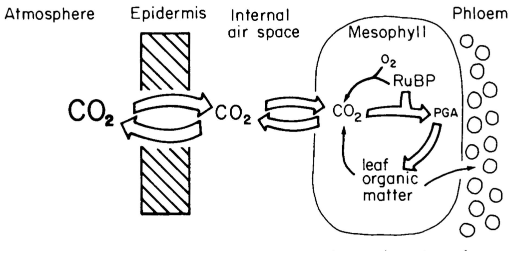
Why do plants contain less ^{13}C in their leaves than the CO^2 in the air?

1. $^{13}CO_2$ diffuses into leaves more slowly than $^{12}CO_2$
2. Rubisco preferentially binds $^{12}CO_2$

$$\delta^{13}C \text{ plant} = \delta^{13}C \text{ atm} - (\text{diffusion effect} + \text{enzyme effect})$$

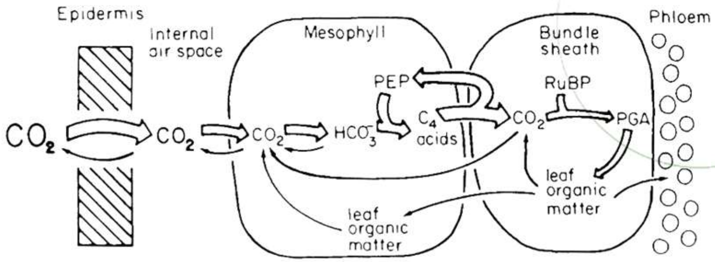
DISCRIMINATION

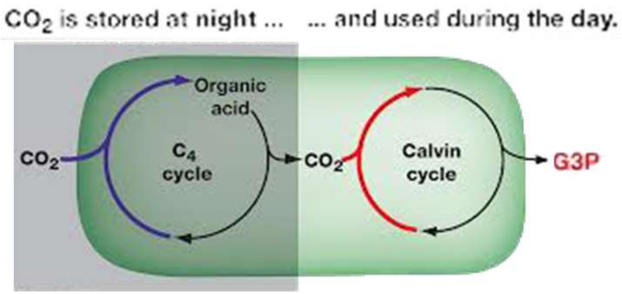
Different Types of Photosynthesis



C_3 pathway: First step in photosynthesis converts CO_2 into 3 carbon sugar

C_4 pathway: First step in photosynthesis converts CO_2 into four carbon sugar. Spatial separation of light and dark reactions



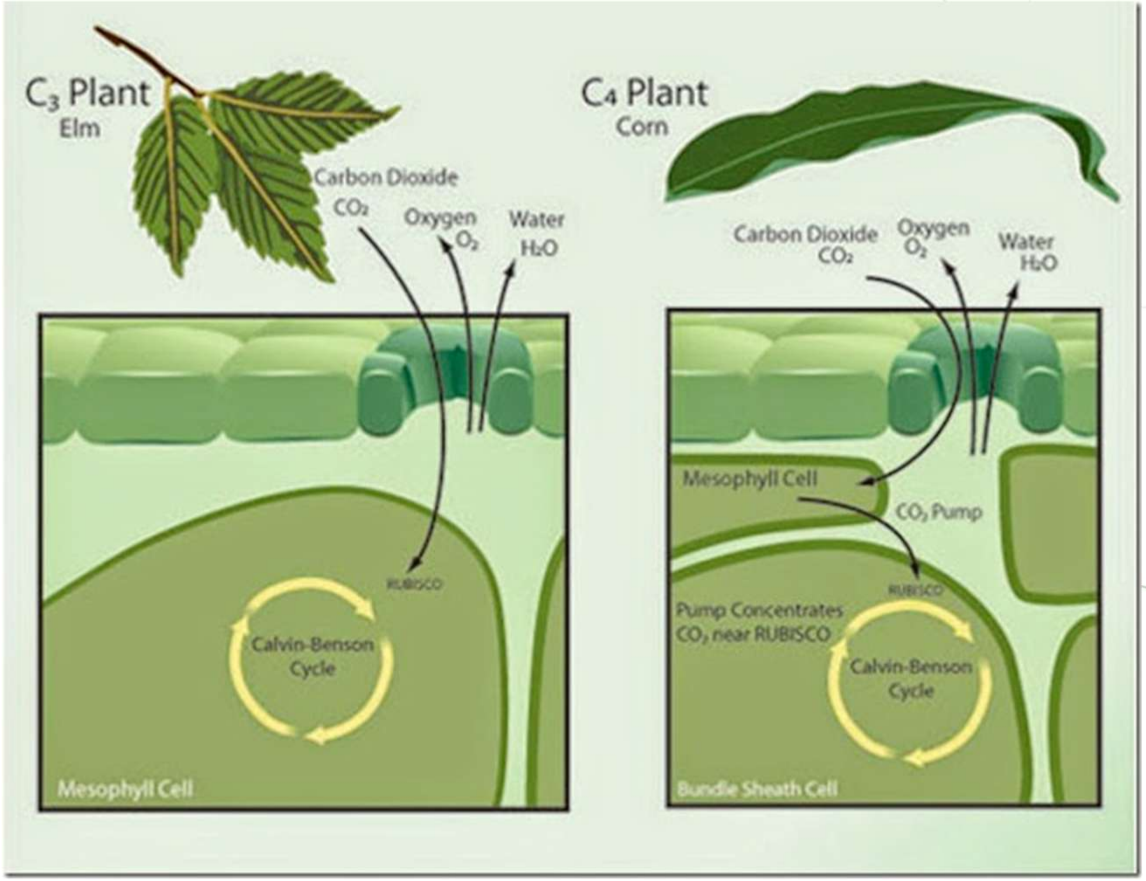


www.uic.edu

CAM pathway: First step in photosynthesis converts CO_2 into 4 carbon sugar
temporal separation of light and dark reactions

Variation in ^{13}C are associated with photosynthetic pathway

C3

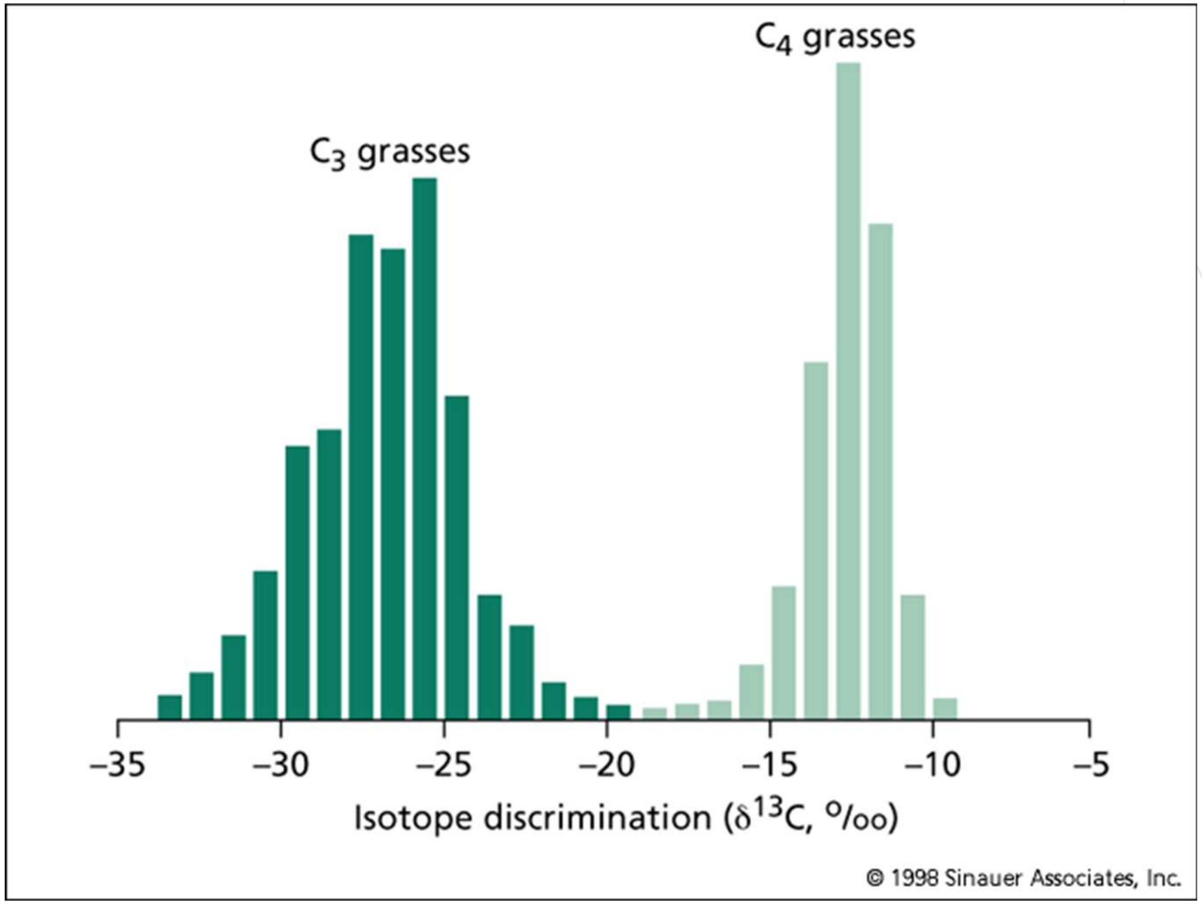


C4

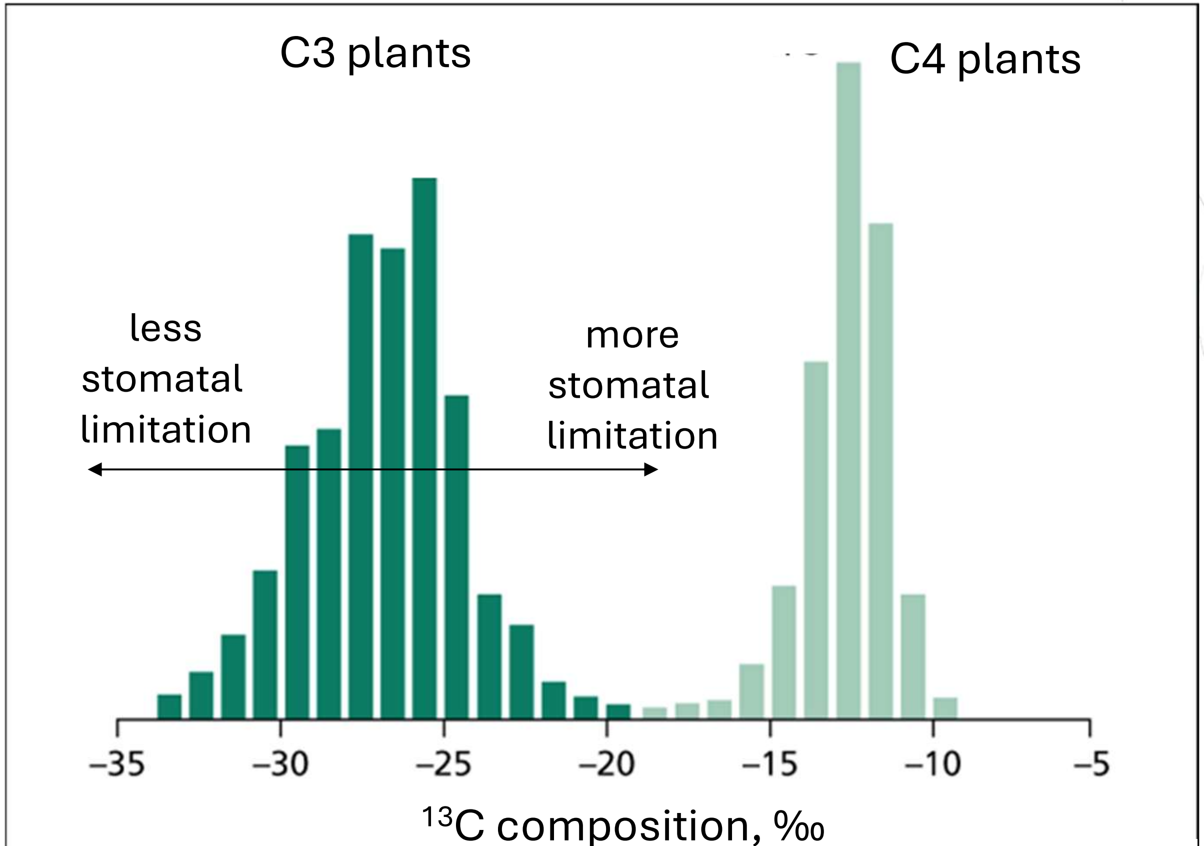
> 95% of all plant species
70-75% of all productivity (today)

> 5% of all plant species
25-30% of all productivity (today)
)

Why the wide range of δ13C values in C3 plants?

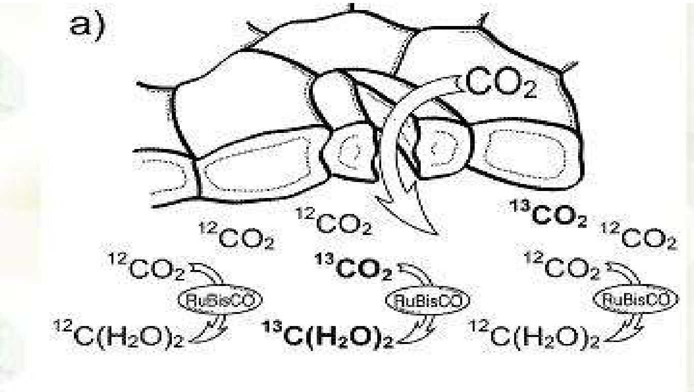


The $\delta^{13}C$ of C3 plants reflects how much stomatal conductance limits photosynthesis.



From Cerling et al., ‘97

Relation between C isotope composition and stomatal conductance



High stomatal conductance

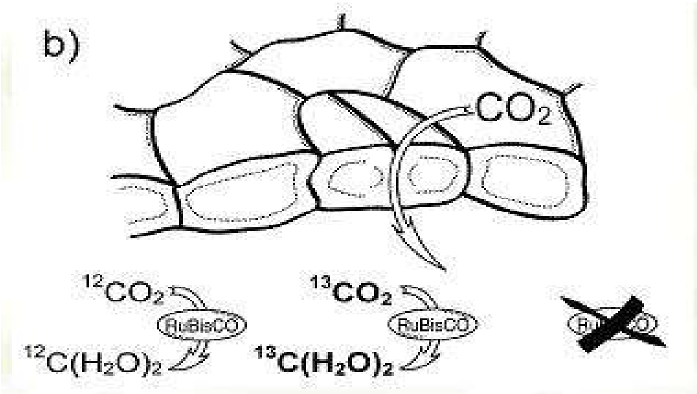
⇩

High discrimination

⇩

Decrease in $\delta^{13}C$

$\delta^{13}C$ reflects the amount in which the heavier isotope ^{13}C is discriminated respect the lighter ^{12}C during the physical and chemical processes involved in the synthesis of plant organic matter (*Farquhar et al. 1989*).



Low stomatal conductance

⇩

Low discrimination

⇩

Increase in $\delta^{13}C$

$\delta^{13}C$ as environmental proxy

$$\delta^{13}C_{plant} = \delta^{13}C_{atm} - a - (b - a) \bullet c_i/c_a$$ (Farquhar *et al.*, 1989)

- $\delta^{13}C_{plant}$ ↓ -27‰
- $\delta^{13}C_{atm}$ ↓ -8‰
- a ↓ 4,4‰
- b ↓ 27‰
- c_i/c_a ↓ 0,4/0,9

- $\delta^{13}C_{plant}$= plant $^{13}CO_2$
- $\delta^{13}C_{atm}$= atmospheric $^{13}CO_2$
- a = fractionation in the gaseous phase
- b = fractionation by RuBisCO
- c_i = CO_2 concentration in the leaf intercellular spaces
- c_a = CO_2 concentration of the ambient air

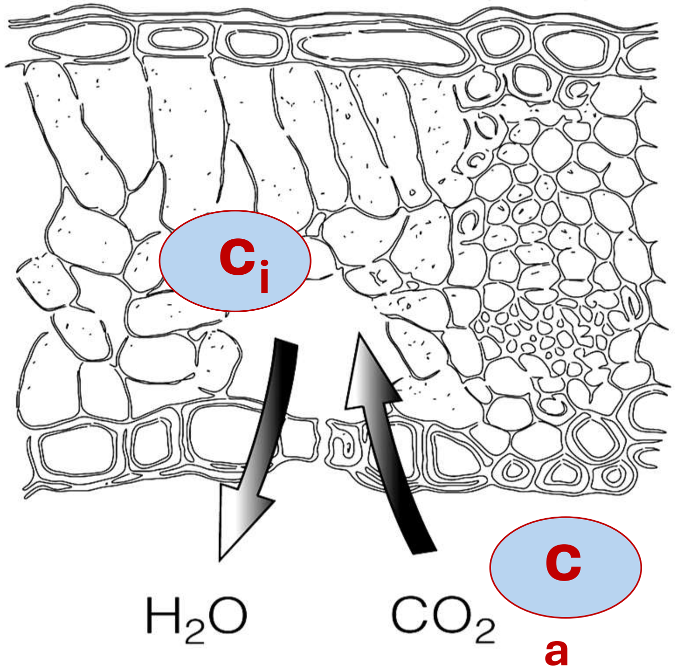
^{13}C Discrimination

↓

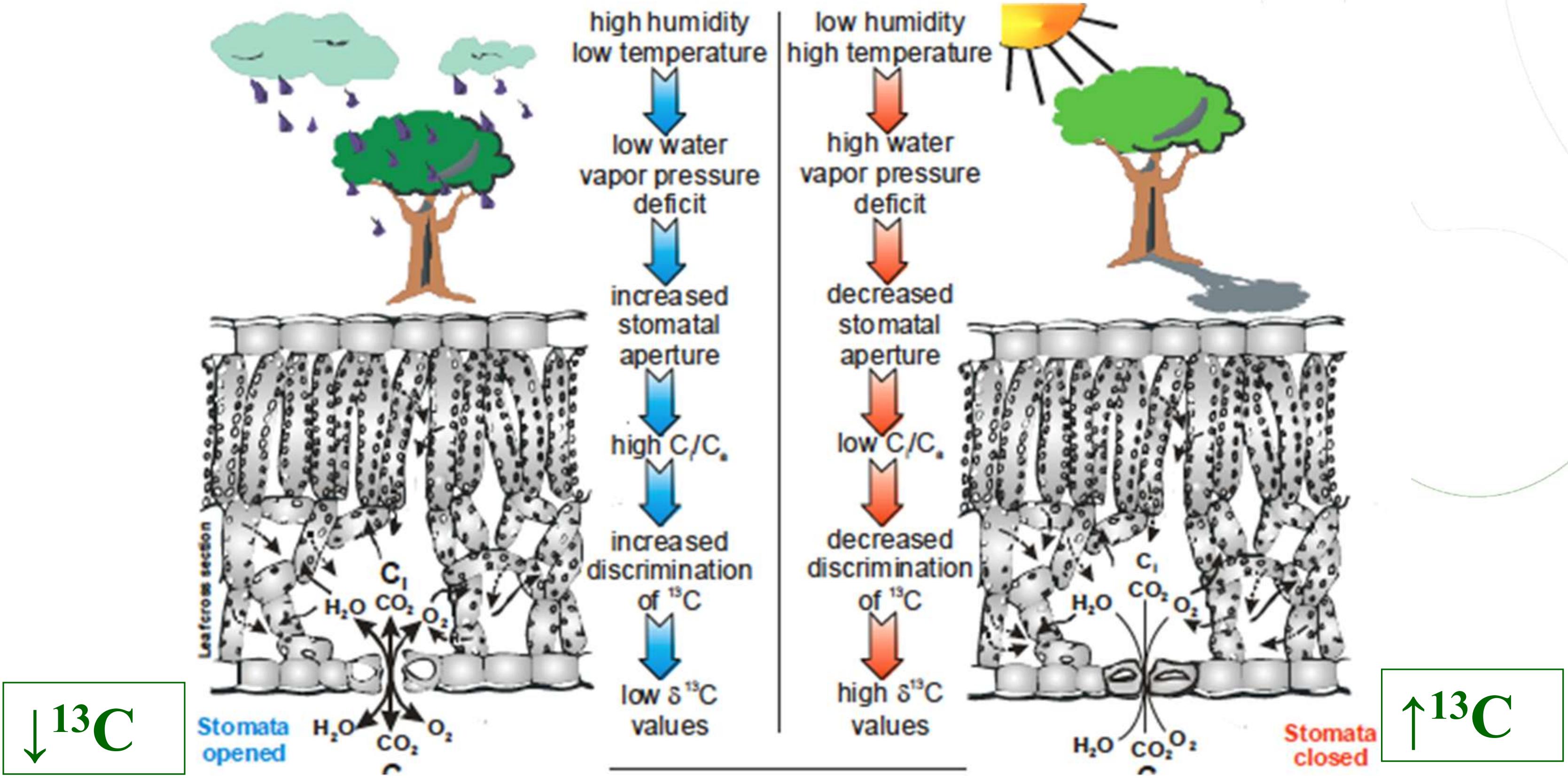
c_i/c_a

↙ ↘

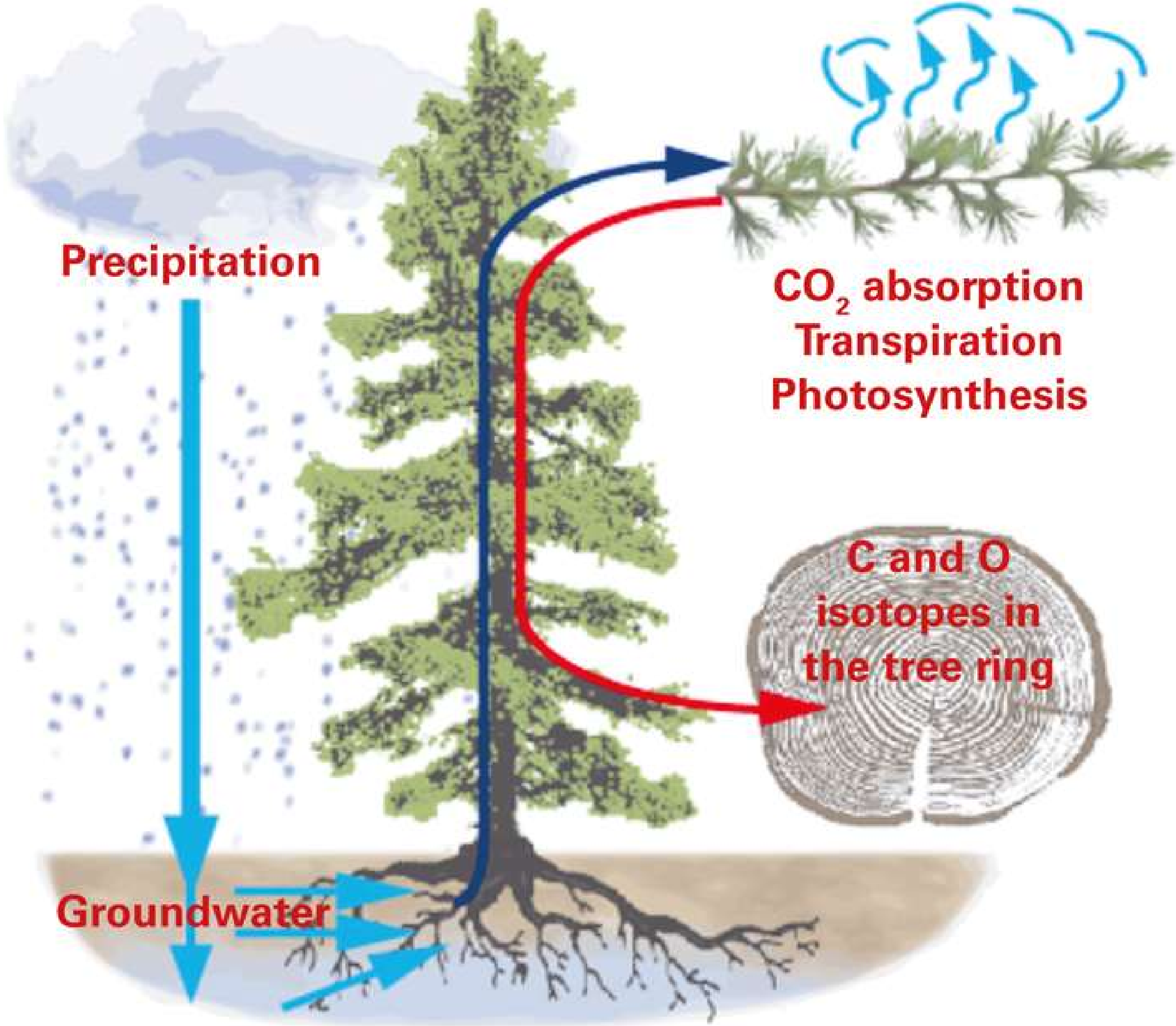
Stomatal conductance | **Photosynthetic activity**



Environmental conditions reflected in δ¹³C



The determination of δ¹³C in plant tissue is widely used to integrate the influence of a range of environmental factors on plant performance (*Leavitt & Long, 1991*).


Precipitation
Groundwater
CO_2 absorption
Transpiration
Photosynthesis
C and O
isotopes in
the tree ring

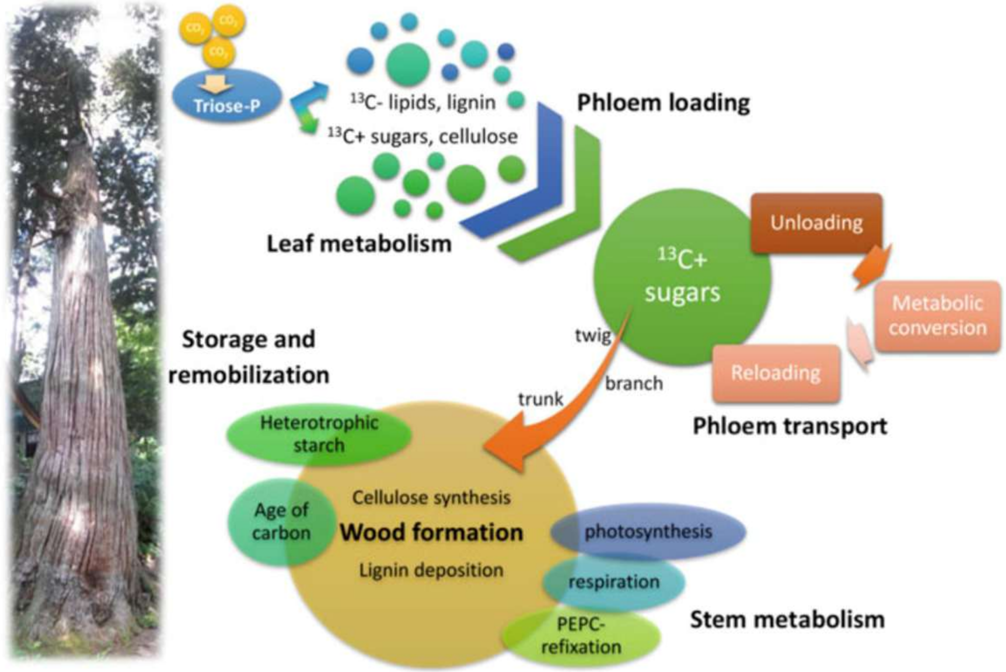
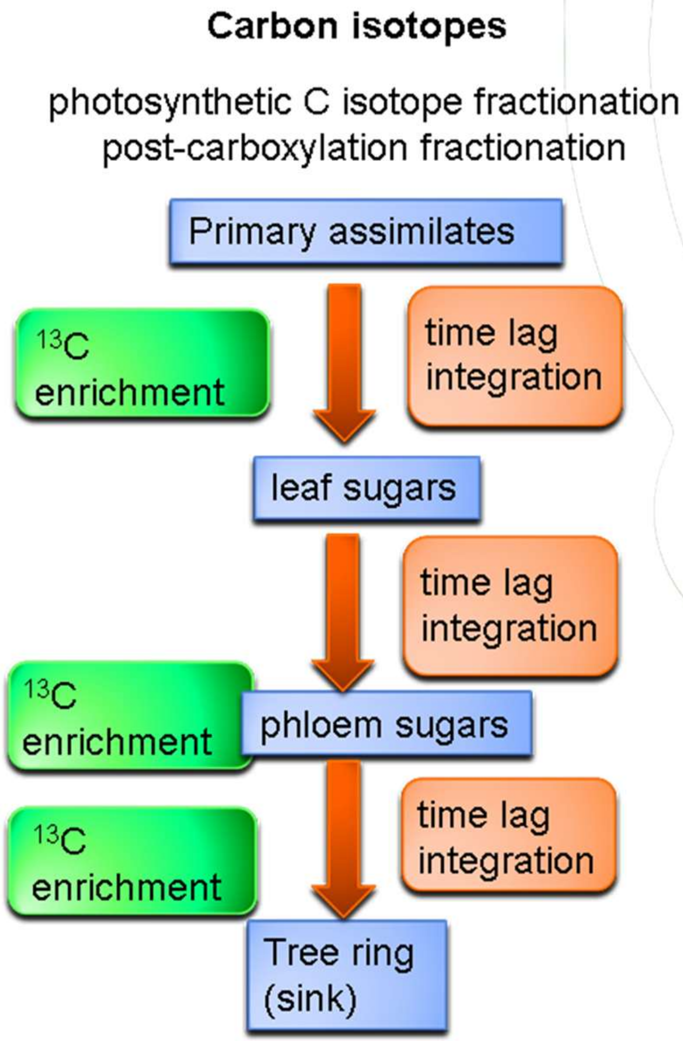


Fig. 13.1 Conceptual scheme summarizing the main processes in the way from primary assimilates (triose-P) to the wood that may cause fractionation at time scales relevant to tree-ring archives. The first fractionation processes occur already within the leaf, where various isotopic effects during metabolic pathways and phloem loading cause lipids and lignin to be depleted, and sugars and cellulose to be enriched in ^{13}C. For some species, a basipetal enrichment in phloem sap from twigs to basal stem has been described, potentially associated with the continuous unloading and reloading of sugars during phloem transport. This sugar would be partially exposed to metabolic reactions (e.g. production of lignin) in stem tissues, causing an enrichment of the fraction that is reloaded in the phloem. Wood formation could also be affected by fractionations occurring during stem metabolism. Bark photosynthesis, respiratory fractionation, or PEPC CO_2 refixation processes are known to produce fractionations, but their direct effect on tree rings is not clear. Finally, the source of carbon used for wood formation could show seasonal and inter-annual variations. In particular, remobilization of stored carbon is crucial for leaf development and early stem growth in deciduous trees but could also play a key role during stress episodes. See text for further details

Temporal integration



Carbon Fractionation *within* Individual Plants

C^{13} *within* Plants

- Does C^{13} vary within individual plants?

- Is there a difference in internal fractionation between C3 and C4 plants?

Does C^{13} vary *within* plants?

- YES!

- Carbon fractionation within plants can be described by differences in:
  - Plant organs
  - Plant compounds

Fractionation in Plant Organs

- Differences in bulk $\delta^{13}C$ of different plant parts (leaves, roots) are common.
- Since most $\delta^{13}C$ measurements are made on leaves, it is important to indicate the plant part measured.
- Fractionation in plant organs differs among C3 and C4 plants .

Table 3 Isotopic differences between leaves and other plant components

Species	Value (‰)	Reference
Grain – leaves (C_3)		
Oats	3.3, 3.6	Winkler *et al.* (1978)
Wheat	1.2, 2.0	Yoneyama *et al.* (1997)
Wheat	2.9, 4.6	Winkler *et al.* (1978)
Legumes (7 species)	0.9 ± 0.2	Yoneyama & Ohtani (1983)
Grain – leaves (C_4)		
Maize	1.5	Lowdon (1969)
Maize	1.4	Gleixner *et al.* (1993)
Roots – leaves, woody vegetation (C_3)		
Citrus	2.4	Syvertsen *et al.* (1997)
Eucalyptus	0.9	Handley *et al.* (1993)
Fagus	1.5	Fotelli *et al.* (2003)
Pinus	1.5	E. Hobbie & J. Colpaert (unpublished)
Populus	2.5	Ineson *et al.* (1996)
Pseudotsuga	1.8	Hobbie *et al.* (2002)
Roots – leaves, nonwoody vegetation (C_3)		
Barley	0.4 ± 0.2	Hubick & Farquhar (1989)
Barley – stressed	0.5 ± 0.3	Hubick & Farquhar (1989)
Beta (sugar beet)	1.2	Gleixner *et al.* (1993)
Desmodium	1.5	Schweizer *et al.* (1999)
Legumes (seven species)	1.0 ± 0.1	Yoneyama & Ohtani (1983)
Peanut	0.5	Hubick *et al.* (1986)
Plantago	1	Staddon *et al.* (1999)
Ricinus	0.6	Handley *et al.* (1993)
Tomato	1.1	Bradford *et al.* (1983)
Wheat	1.2 to 1.4	Cheng & Johnson (1998)
Wheat	1.8	Lichtfouse *et al.* (1995)
Roots – leaves (C_4)		
Four species	−0.2 to 0.2	Trouve *et al.* (1994)
Brachiaria	−0.5	Schweizer *et al.* (1999)
Pennisetum	−1.8	Desjardins *et al.* (1994)
Saccharum	0.4	Spain & Le Feuvre (1997)
Zea	−1.4	Qian & Doran (1996)

Organs: C3 versus C4

C3 Plants

- Roots are typically enriched by 1–3‰ relative to leaves.
- Grains enriched by 1–4‰ relative to leaves.

C4 Plants

- Roots similar or slightly lower in $\delta^{13}C$ relative to leaves.
- Grains enriched by ≈ 1.5‰ relative to leaves in maize.

(Hobbie and Werner, 2003)

Compounds: C3 versus C4

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C3 Plants

- Alkanes and lipids 4–6‰ depleted (Collister et al., 1994).

C4 Plants

- Alkanes and lipids 8–10‰ depleted (Collister et al., 1994).
- In C4 plants, lipid concentration was found to be about half that in C3 plants (Chikaraishi and Naraoka, 2001).
- Isotopic enrichment of cellulose relative to lignin is slightly greater in leaves of C4 plants.

Conclusions

- Isotopic composition can vary by:
  - Plant organ measured
  - Plant organic compound measured
- Degree of fractionation variable among C3 and C4 plants
- Variations in plant organ $\delta^{13}C$ correspond to isotopic variations in plant organic compounds (metabolites).

Gessler et al. 2014.
Tree Physiology 34: 796-818

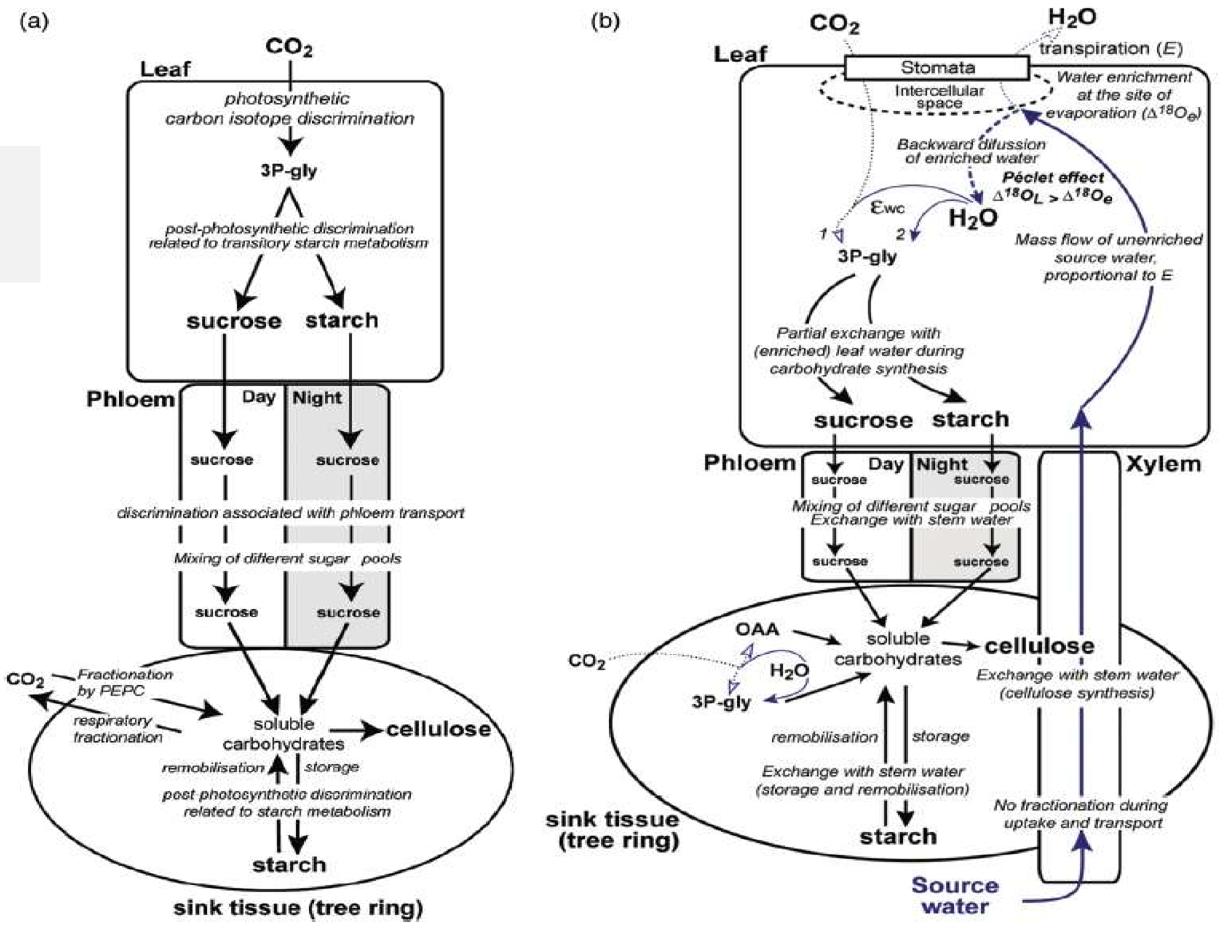


Figure 1. Overview of the different processes influencing the carbon (a) and oxygen (b) isotope signature, from primary sources (CO_2 and H_2O, respectively) to tree-ring cellulose, going through different organic and inorganic pools. PEPC, phosphoenolpyruvate carboxylase; $\Delta^{18}O_e$ and $\Delta^{18}O_L$, isotopic enrichment of water at the site of evaporation and of mean lamina leaf water, respectively; ε_{wc}, equilibrium fractionation factor between oxygen in water and carbonyl groups; OAA, oxaloacetate; 3P-gly, 3-phosphoglycerate.

Oxygen (and hydrogen) isotopes in tree rings

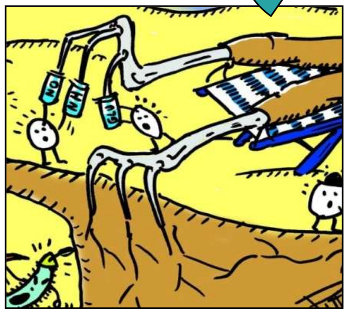
- The primary source: stable isotopes of water in the biosphere
- Sources of variability for stable isotopes in trees
  - ✓ From soil moisture to xylem transport through water uptake
  - ✓ Leaf evaporative enrichment
  - ✓ Transfer of the isotopic signal of leaf water into organic matter and tree-ring cellulose
- Link between isotopic fractionation and long-term tree-ring archive

Oxygen and hydrogen isotopes in tree rings

H_2O

STEP 2. Leaf water evaporative enrichment

Organic Matter

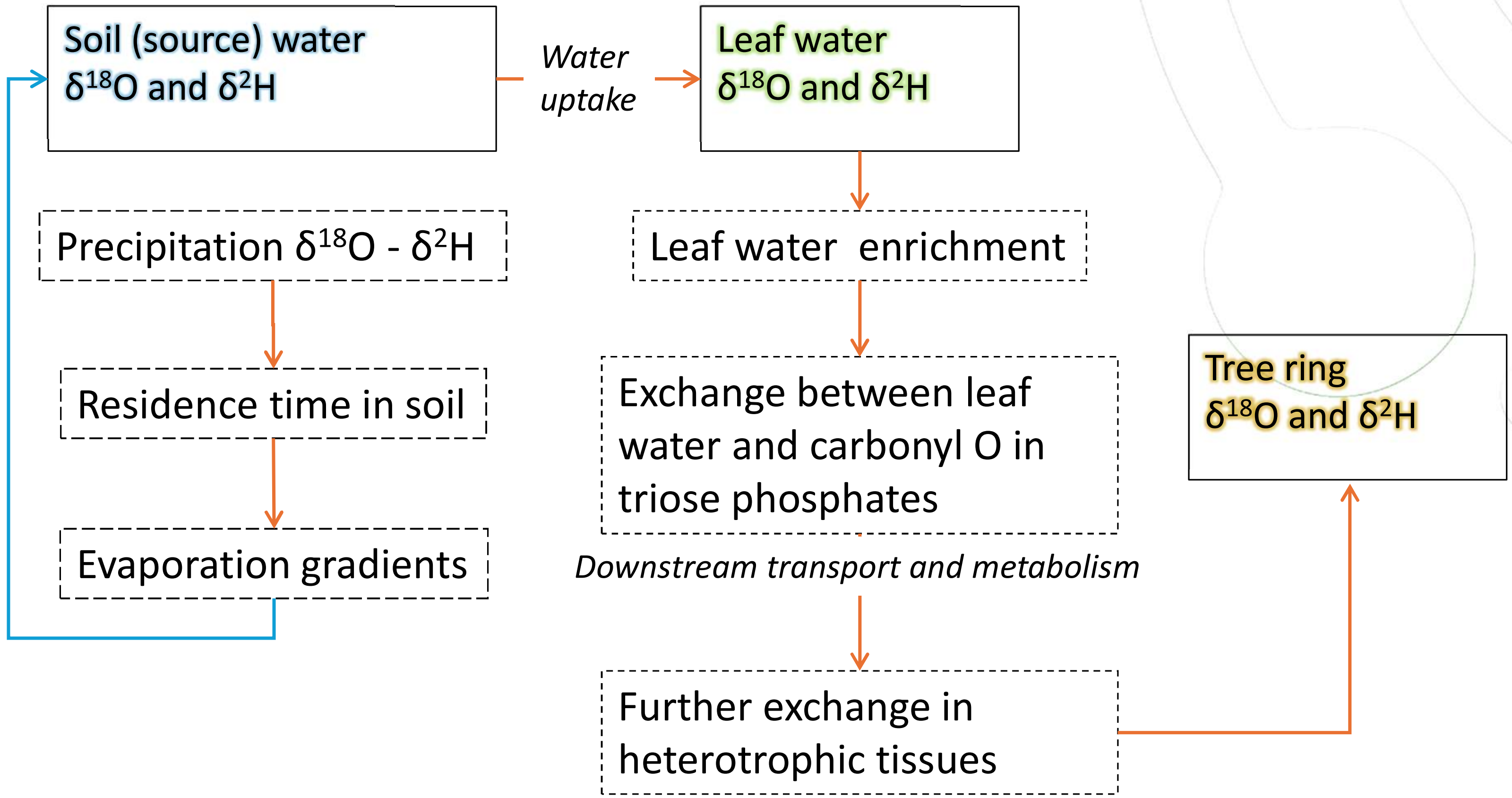


STEP 1. From soil to xylem water

STEP 3. From leaf to phloem and tree rings

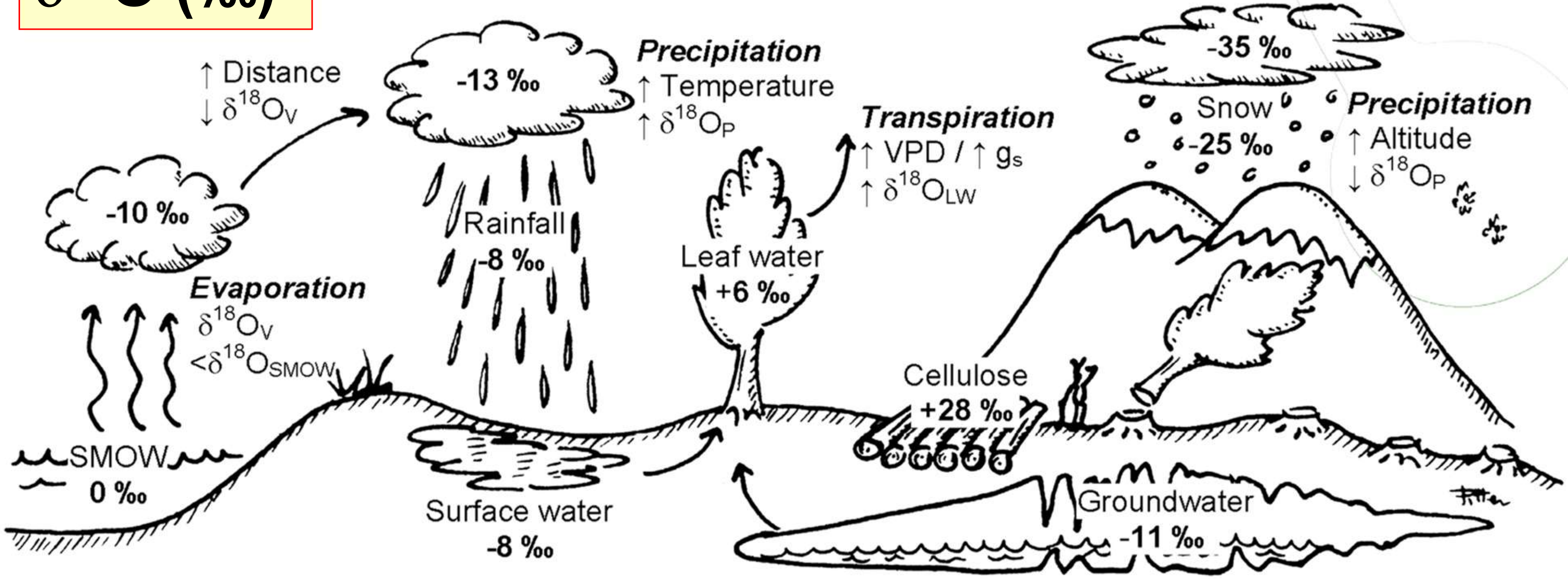
Increasing time integration from hours (leaf water)
to days (phloem), weeks (tree-ring slices), years (tree rings)

Oxygen and hydrogen isotopes in tree rings



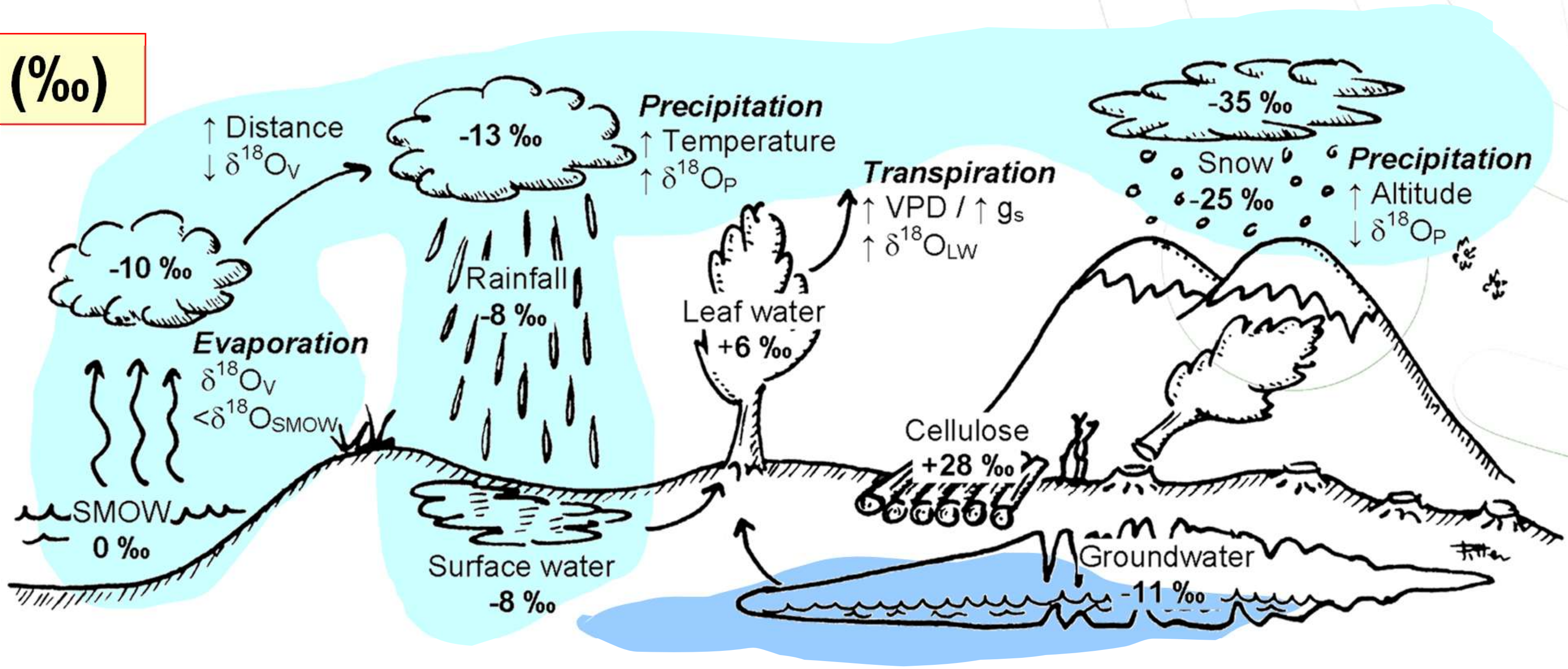
STEP 1. From soil to xylem water

$\delta^{18}O$ (‰)



STEP 1. From soil to xylem water

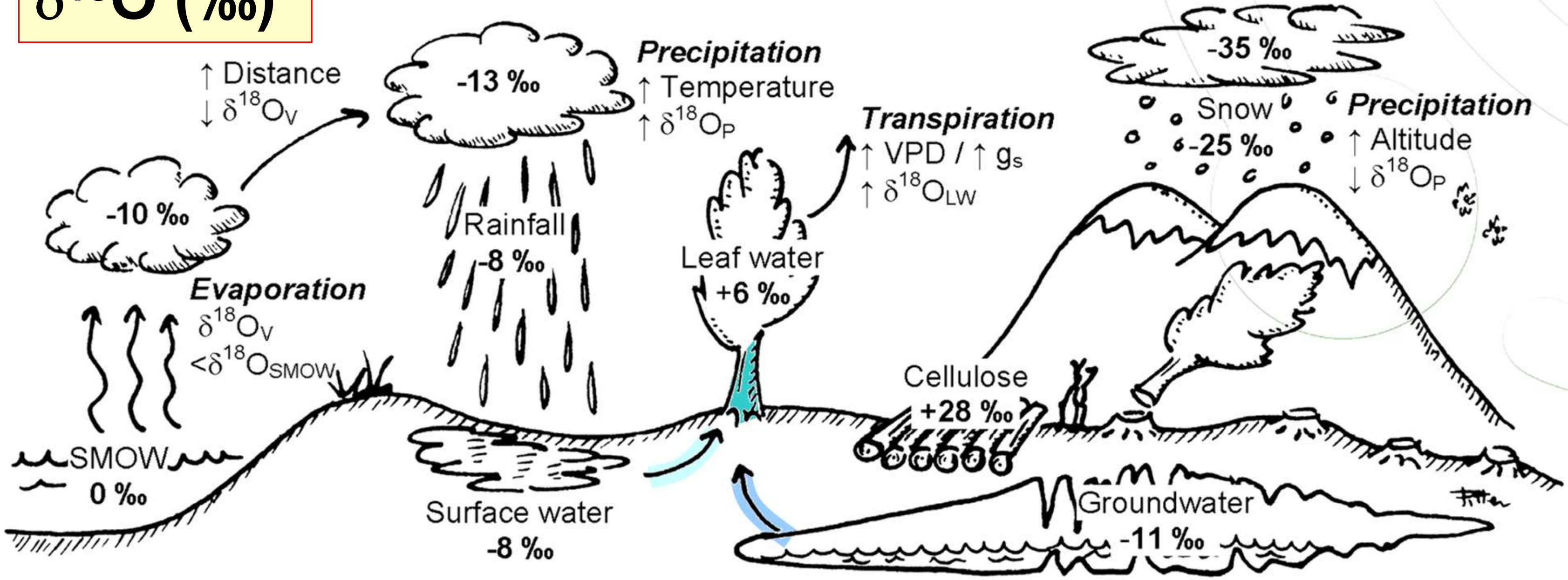
δ18O (‰)



$\delta^{18}O$ and $\delta^{2}H$ (‰) change in the hydrological cycle owing to a number of fractionation processes

STEP 1. From soil to xylem water

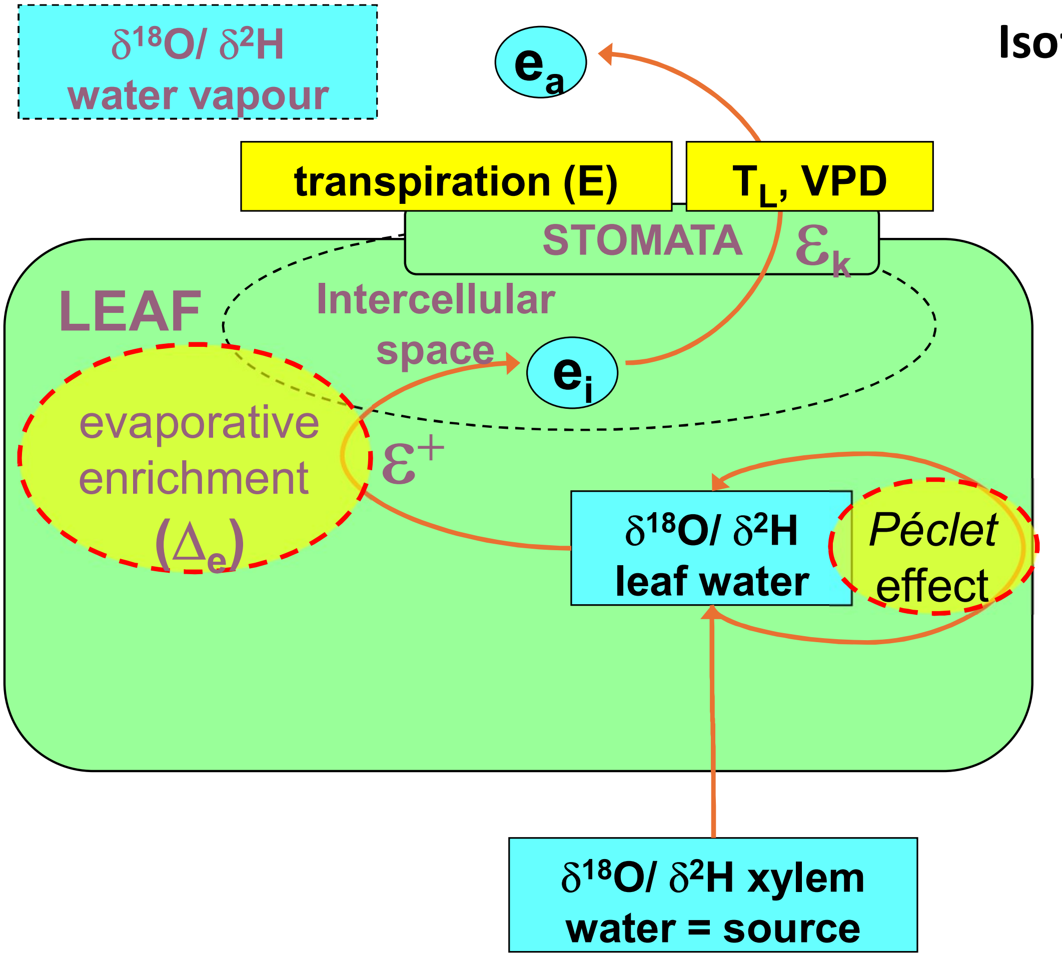
δ18O (‰)



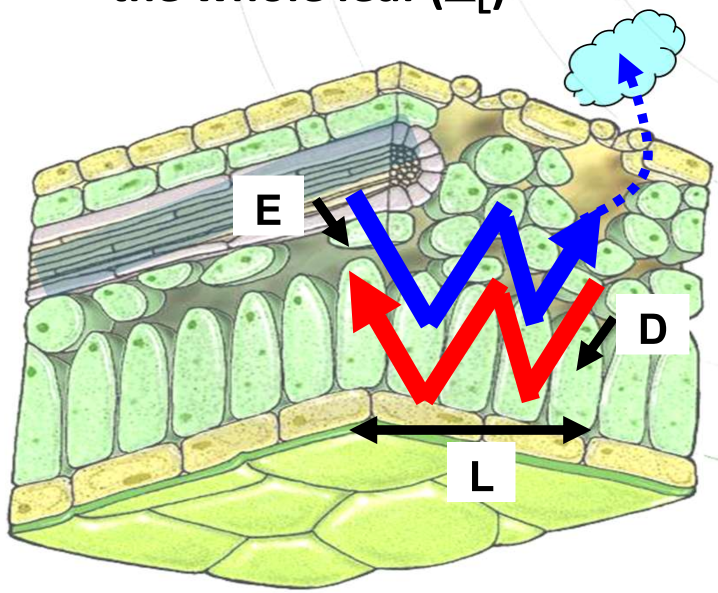
$\delta^{18}O$ (‰) changes in the hydrological cycle

$\delta^{18}O$ (‰) in xylem water reflects the origin of source water

Step 2. Leaf water evaporative enrichment



Isotopic enrichment above source water at the whole leaf (Δ_L)*



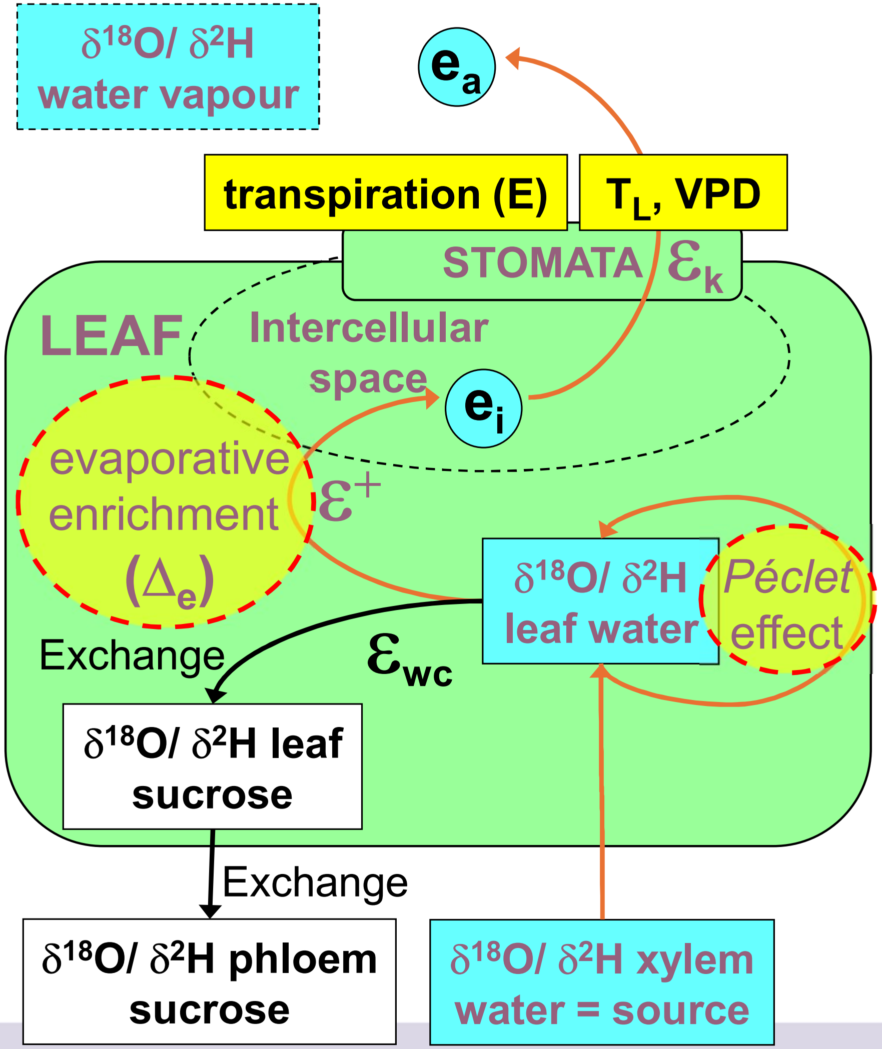
E= transpiration

L = effective pathlength

D = self-diffusivity

*Farquhar and Lloyd, 1993

Step 3. From leaf to phloem and tree rings



In the case of cellulose, which is the main component of wood, about 50% of the enrichment signal is further exchanged with xylem water

The $\delta^{18}O$ signal in wood is a mixture, in varying proportions, of source water $\delta^{18}O$ and evaporative enrichment at the leaf level (≈ evaporative demand modulated by stomatal conductance)

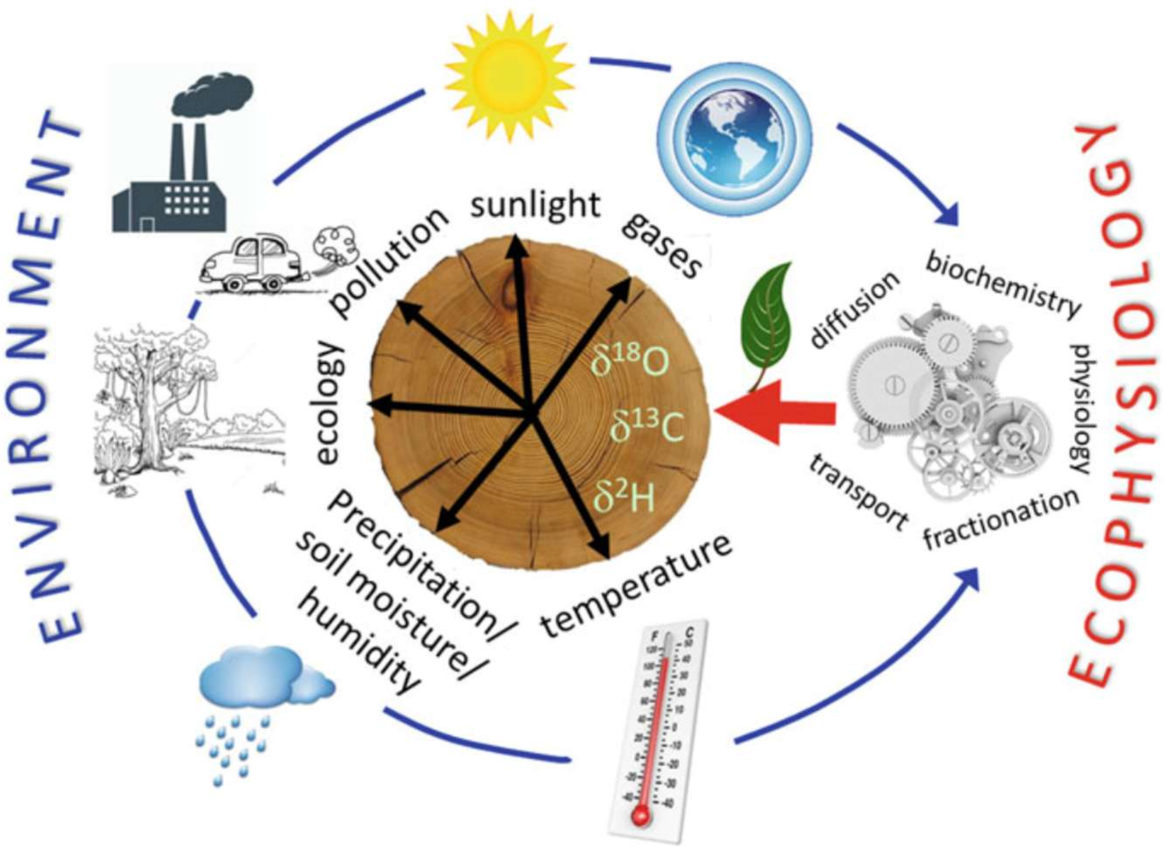
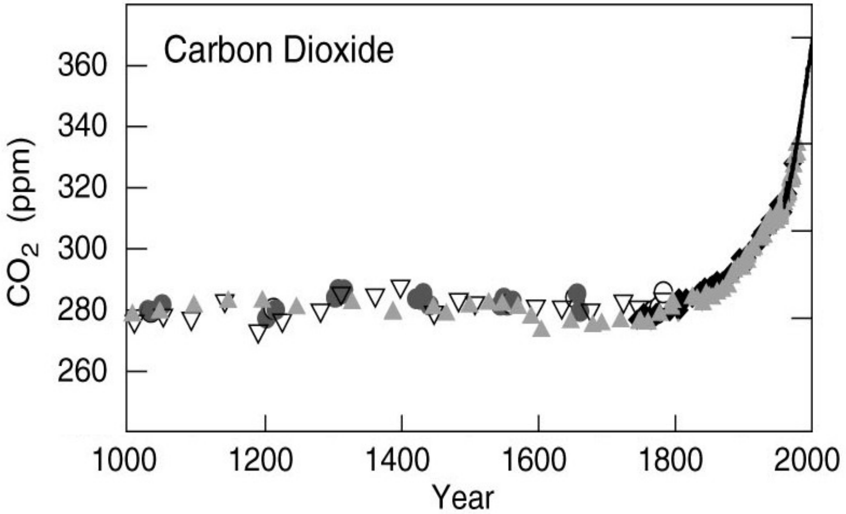


Fig. 1.1 Schematic representation of interplay between environmental factors and ecophysiology that produces tree-ring C-H-O isotope composition. Environment can influence the ecophysiological, biochemical, and physicochemical mechanisms responsible for producing the isotope composition and consequently isotope dendrochronology can be used to infer environment and ecological events affecting ecophysiology (e.g., insect outbreaks). Tree rings allow identification of changes through time, but if a network of sites is sampled, the tree-ring isotope results can also reveal changes in space (isoscapes)

Effects of CO_2 enrichment on forest

For over a millennium these old trees grew in an atmosphere with nearly unchanging [CO_2] (~280 ppm)



Photosynthetic assimilation of CO_2 is central to the metabolism of plants. As atmospheric concentrations of CO_2 rise, how will this affect the plants we depend on? And how this will affect Carbon sequestration?

Working hyphotheses

CO_2 Increase

1. Increase of Productivity
Increase in WUE_i (A/gs)
→ Due to an increase in A (Assimilation)
→ Increase in carbon sequestration

2. Increase or no change of productivity
Increase in WUE_i (A/gs)
→ Due to a decrease in stomatal conductance gs
→ No variation or reduction in carbon sequestration

3. Decrease of productivity
Negative effect on WUE_i
→ Reduction of C sequestration in the long- term trend

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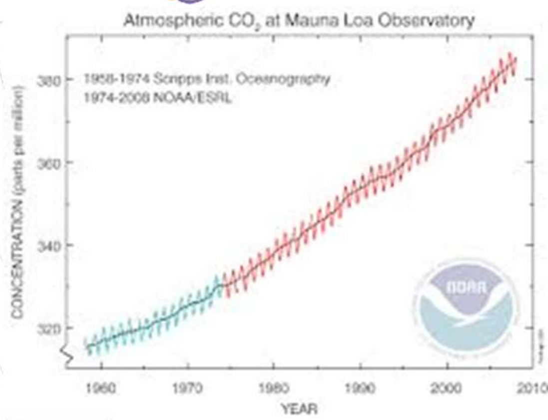


CO_2 productivity and C sequestration

CARBON FIXATION CO_2 TOMATA

Photosynthate assimilation

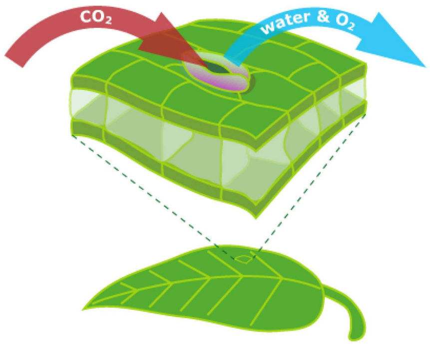
⬇

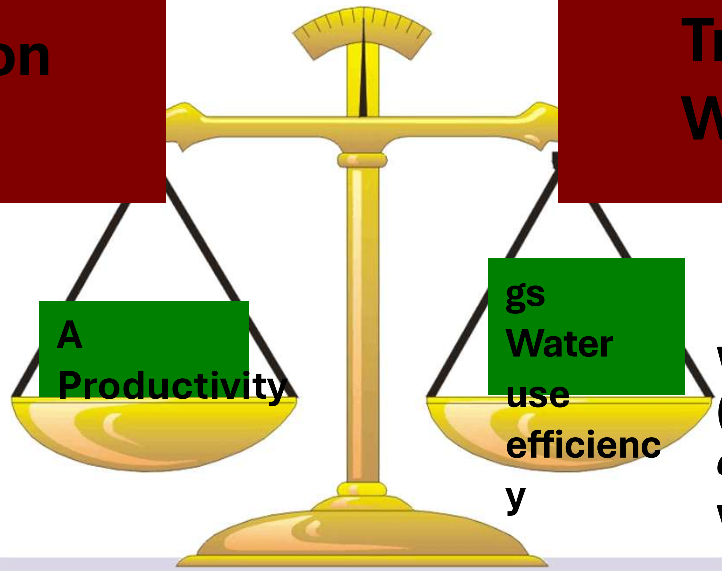
C allocation

Stomata conductance

⬇

Transpiration
Water losses





Water use efficiency (WUE)=the amount of *carbon* acquired *per* unit of water lost = A/gs

Intrinsic Water use efficiency

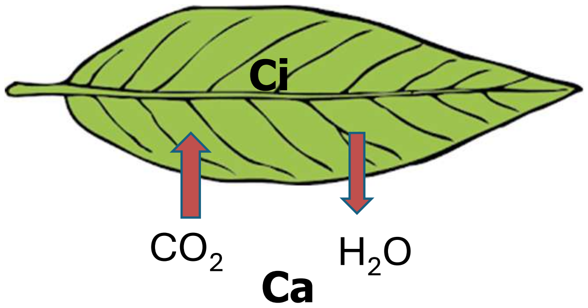
Carbon isotope discrimination is a measure of Intrinsic water-use efficiency (WUE_i)

WUE_i is the ratio of carbon assimilation to stomatal conductance A/gs

$$WUE_i = A/gs = \frac{(ca - ci)}{1.6}$$

1.6= the ratio of diffusivity of water and CO_2 in air

$$\delta^{13}C_{plant} = \delta^{13}C_{air} - a - (b-a)\frac{ci}{ca} \quad \Rightarrow \quad ci = ca\,\frac{\delta^{13}C_{air} - \delta^{13}C_{plant} - a}{b-a}$$



$$WUE_i = \frac{ca}{1.6}\,\frac{b - \delta^{13}C_{air} + \delta^{13}C_{plant}}{b-a}$$

Forest FACE Synthesis Project

Research
New Phytologist

Elevated CO_2 increases tree-level intrinsic water use efficiency: insights from carbon and oxygen isotope analyses in tree rings across three forest FACE sites

Giovanna Battipaglia[1,2], Matthias Saurer[3], Paolo Cherubini[4], Carlo Calfapietra[5], Heather R. McCarthy[6], Richard J. Norby[7] and M. Francesca Cotrufo[8]

[1]Environmental Science Department, Second University of Naples, 81100, Caserta, Italy; [2]Centre for Bio-Archeology and Ecology, Ecole Pratique des Hautes Etudes (PALECO EPHE), Institut de Botanique, University of Montpellier 2, F-34090, Montpellier, France; [3]PSI Paul Scherrer Institute, 5232, Villigen, Switzerland; [4]WSL Swiss Federal Institute for Forest, Snow and Landscape Research, 8903, Birmensdorf, Switzerland; [5]IBAF-Institute of agro-environmental and Forest Biology, CNR, Porano, Italy; [6]Department of Microbiology and Plant Biology, University of Oklahoma, Norman, OK, USA; [7]Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, USA; [8]Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO, USA

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Received: *25 July 2012*
Accepted: *4 October 2012*

New Phytologist (2013) **197**: 544–554
doi: 10.1111/nph.12044

Key words: climate change, dendro-ecology, *Liquidambar styraciflua*, *Pinus taeda*, *Populus alba*, *Populus nigra*, *Populus × euramericana*.

Summary

- Elevated CO_2 increases intrinsic water use efficiency (WUE_i) of forests, but the magnitude of this effect and its interaction with climate is still poorly understood.
- We combined tree ring analysis with isotope measurements at three Free Air CO_2 Enrichment (FACE, POP-EUROFACE, in Italy; Duke FACE in North Carolina and ORNL in Tennessee, USA) sites, to cover the entire life of the trees. We used $\delta^{13}C$ to assess carbon isotope discrimination and changes in water-use efficiency, while direct CO_2 effects on stomatal conductance were explored using $\delta^{18}O$ as a proxy.
- Across all the sites, elevated CO_2 increased ^{13}C-derived water-use efficiency on average by 73% for *Liquidambar styraciflua*, 77% for *Pinus taeda* and 75% for *Populus sp.*, but through different ecophysiological mechanisms.
- Our findings provide a robust means of predicting water-use efficiency responses from a variety of tree species exposed to variable environmental conditions over time, and species-specific relationships that can help modelling elevated CO_2 and climate impacts on forest productivity, carbon and water balances.

ITINERIS

Ibimet

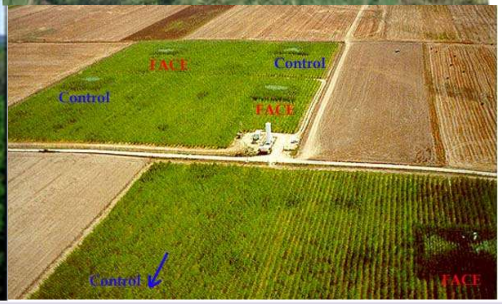
PAUL SCHERRER INSTITUT PSI

FACTS-I

WSL

Duke FACE, USA
P. taeda
L. styraciflua

Oak Ridge FACE, USA
L. styraciflua

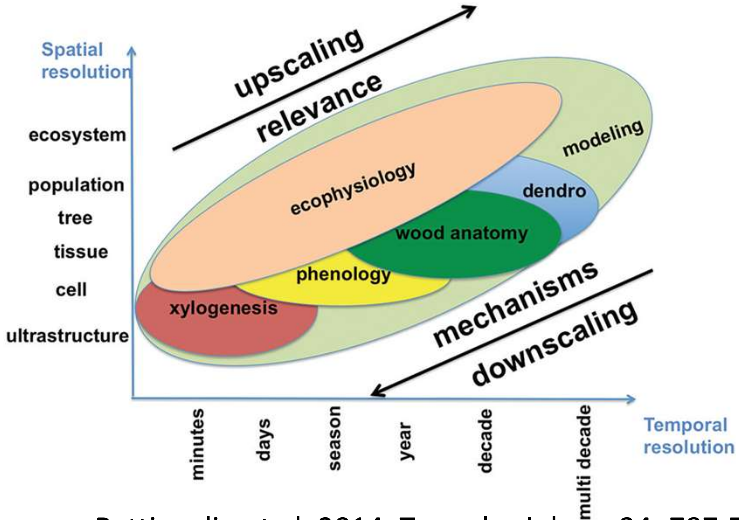


POP_EUROFACE, I _P. alba, P. nigra. P. x. euramericana

AIMS:

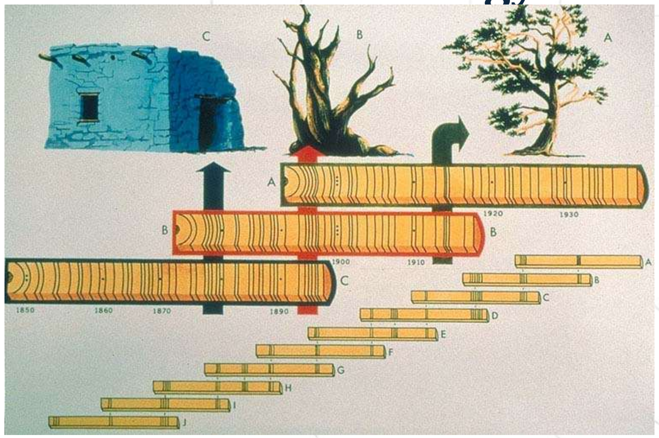
How the elevated CO_2 will affect forest productivity and WUE in 5 species across 3 forest stands exposed to ~550 ppm CO_2 for 3-8 years

Methods

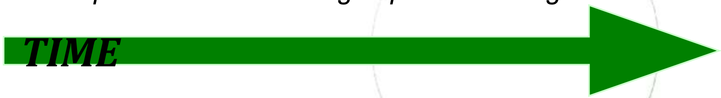


Battipaglia et al. 2014, Tree physiology, 34: 787-791.

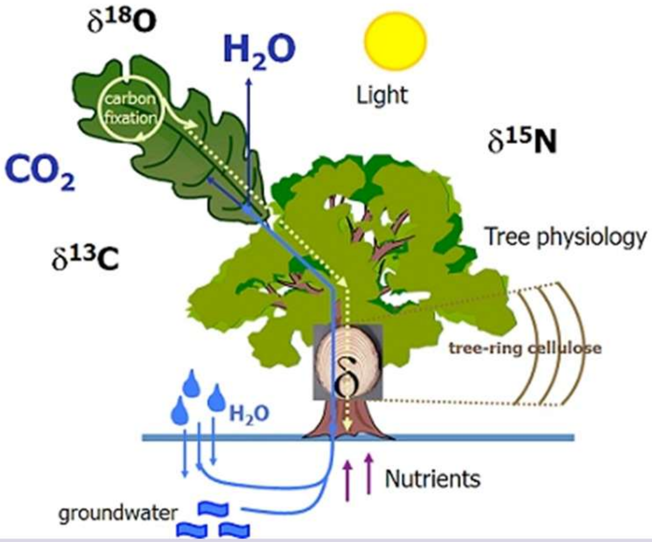
➢Dendrochronology

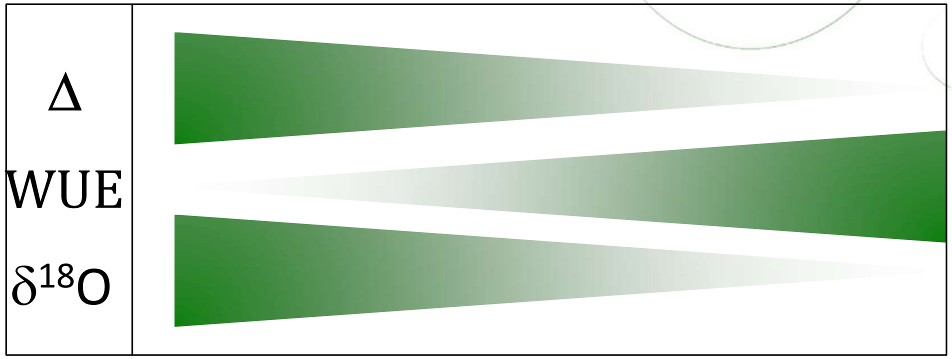


http://www.ncdc.noaa.gov/paleo/treering.html



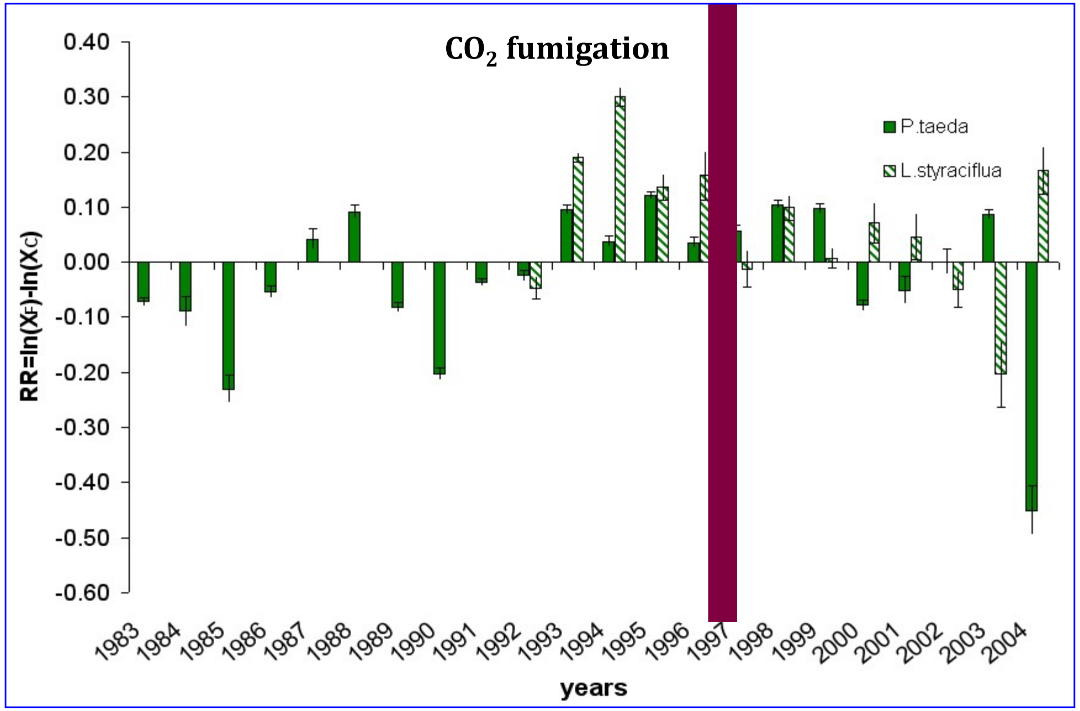
➢Stable isotopes





$\Delta^{13}C$ as proxy of Water use efficiency
$\delta^{18}O$ as proxy of stomatal conductance

Productivity: CO_2 fertilization effect?

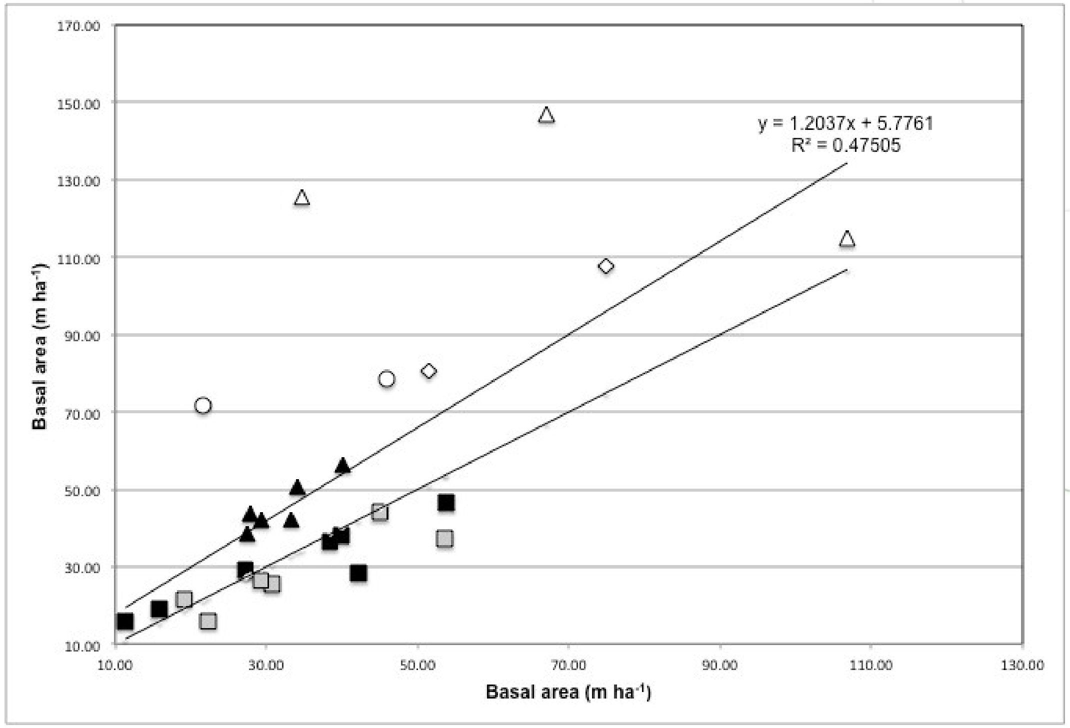


Before the fumigation, the growth of the species were quite variable

No clear BA increase in the fumigated plots

Productivity: CO_2 fertilization effect?

Regression is significantly different from 1:1 line



P. nigra

P. alba

P. euro

P. taeda

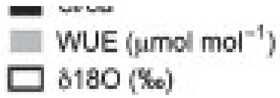
L. styraciflua duke

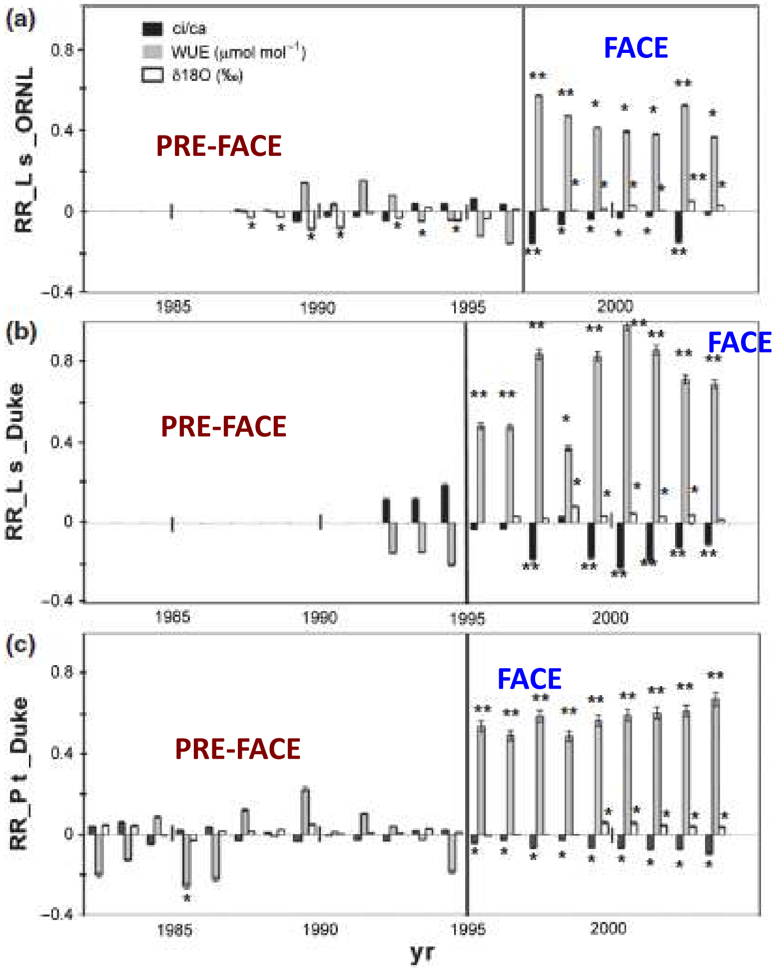
L. styraciflua ORNL

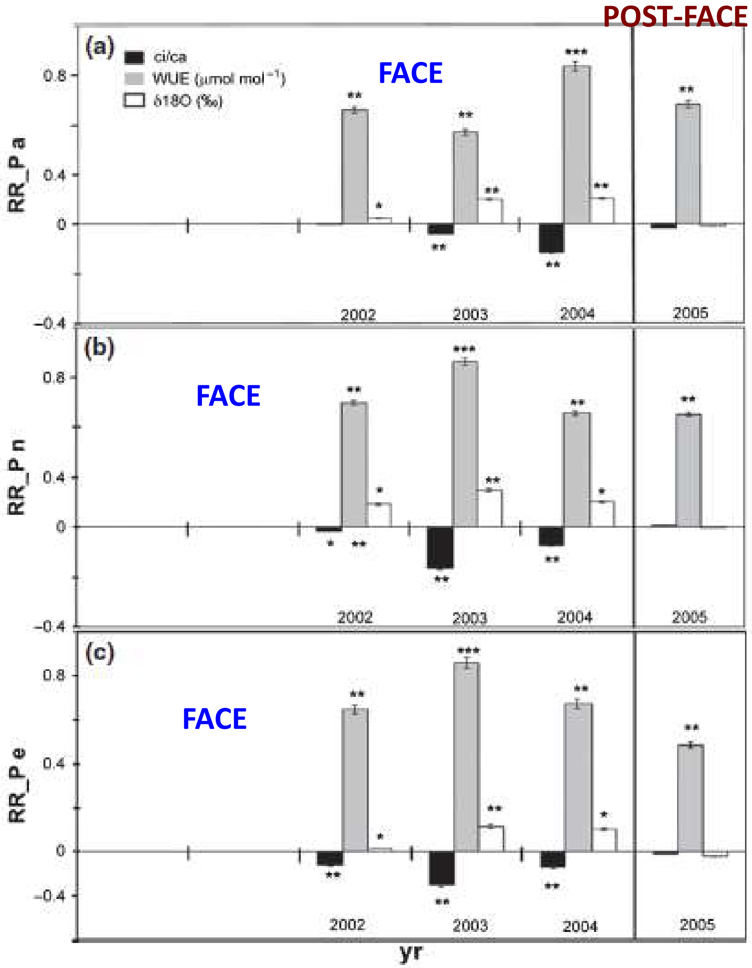
Growth Response is species specific!!

WUEi: the amount of carbon acquired per unit of water lost

$$WUE_i \cong A/g_s$$



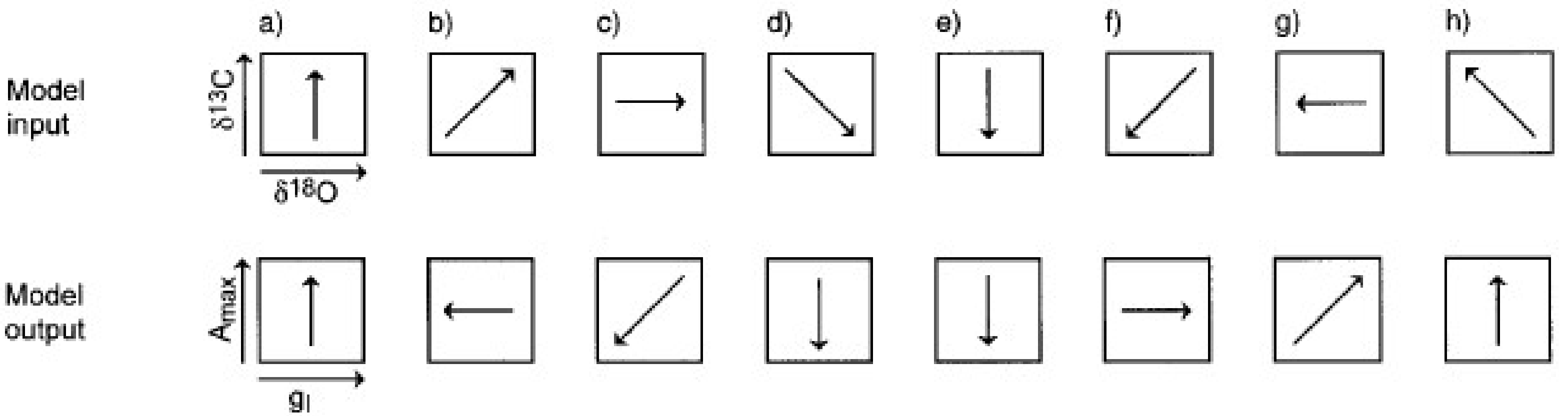




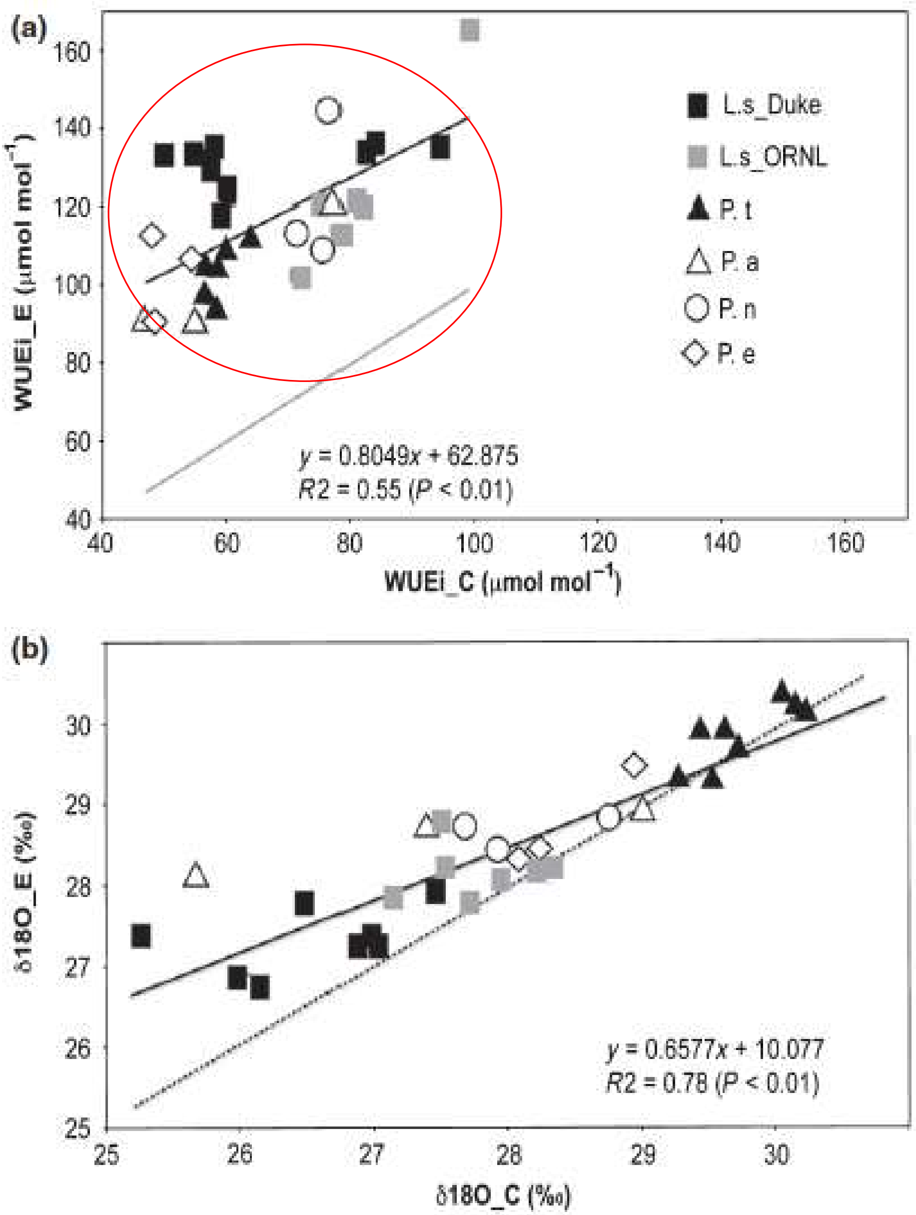
The dual isotope approach

- Described in: **Scheidegger *et al*.** (2000) Linking stable oxygen and carbon isotopes with stomatal conductance and photosynthetic capacity: a conceptual model. *Oecologia* 125: 350-357
- The model attempts at distinguishing whether differences in intercellular CO_2 concentration are caused by a response of *gs* or *A.*

Changes between two treatments are shown by arrows



Regression is significantly different from 1:1 line



Response of WUE_i to elevated CO_2 is consistent across a wide range of species

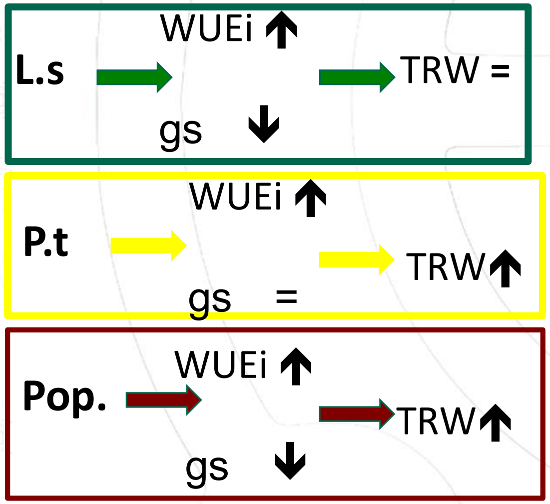
WUEi increases in all species

Variations of $\delta^{18}O$ are different in the different species

Variation in stomatal conductance (g_s)

Parameter	Site	Species	$\delta^{18}O$ r^2	b	BAI r^2	b
WUE_i	ORNL	L. s	0.65*	0.59	0.003	0.50
WUE_i	Duke	L. s	0.68*	0.48	0.10	0.26
WUE_i	Duke	P. t	0.12	0.08	0.30*	0.80
WUE_i	POPEUROFACE	P. a	0.45*	0.53	0.38*	0.55
WUE_i	POPEUROFACE	P. n	0.48*	0.35	0.74**	0.27
WUE_i	POPEUROFACE	P. e	0.38*	0.51	0.91***	0.70

Battipaglia et al_2013_NPH



Across all the sites, elevated CO_2 increased ^{13}C-derived water-use efficiency on average by **73%** for *Liquidambar styraciflua*, **77%** for *Pinus taeda* and 75% for *Populus* sp., but through different ecophysiological mechanisms:

➔ In ***L. styraciflua***, warmer conditions seemed to be coupled with a **reduction of stomatal conductance (gs)**, increasing **WUEi** but without a parallel stimulation of **tree growth**.

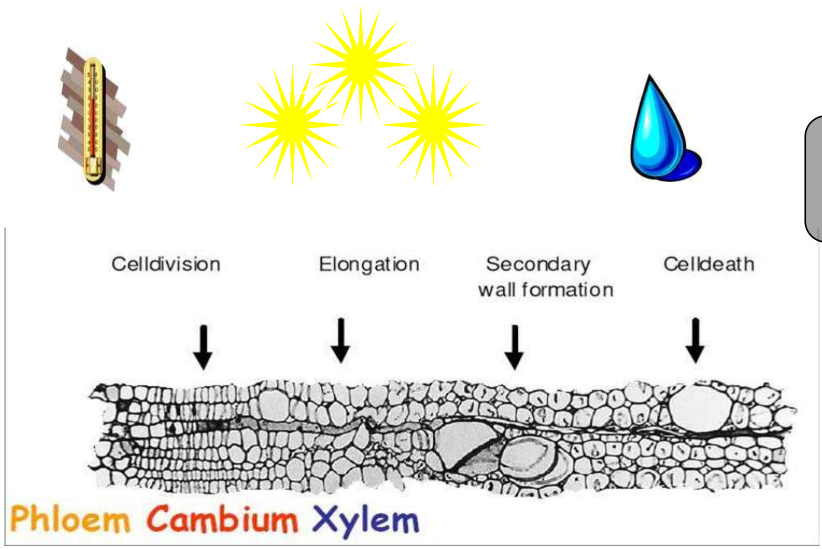
➔ A reduction of **gs** was also observed in the fast-growing ***Populus*** sp., accompanied by **positive tree growth** responses, and was partially limited by high temperature during 2003 and 2004.

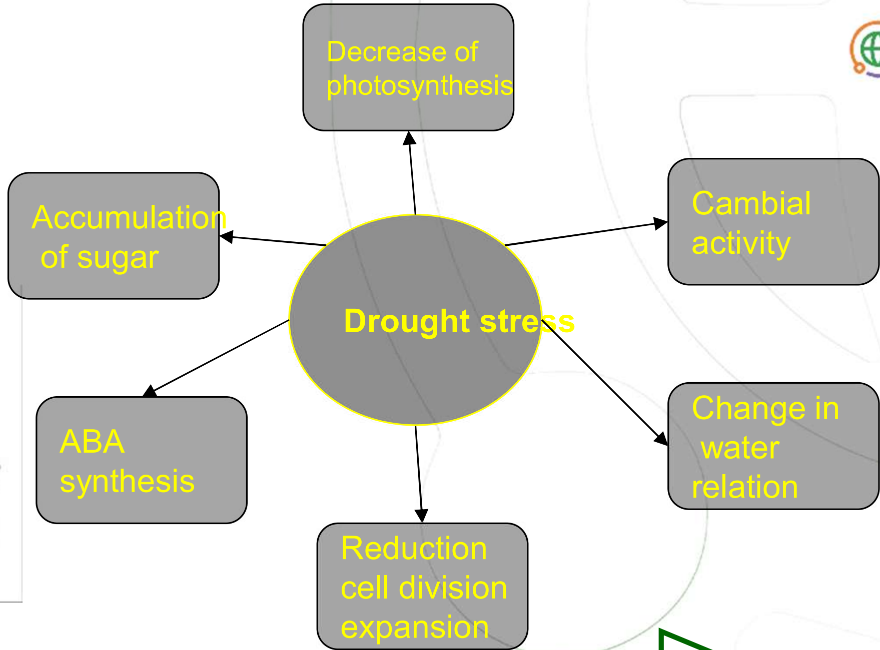
➔ Finally the rise of **WUEi** in ***P. taeda*** was mainly related to soil moisture increases under elevated CO_2 and opens new questions about the ability of this isohydric species (with tight stomatal control) to withstand the expected reduction in soil water in combination with an increase in drought.

Mediterranean species and Drought effect

Plant strategies to cope with drought..

Wood formation



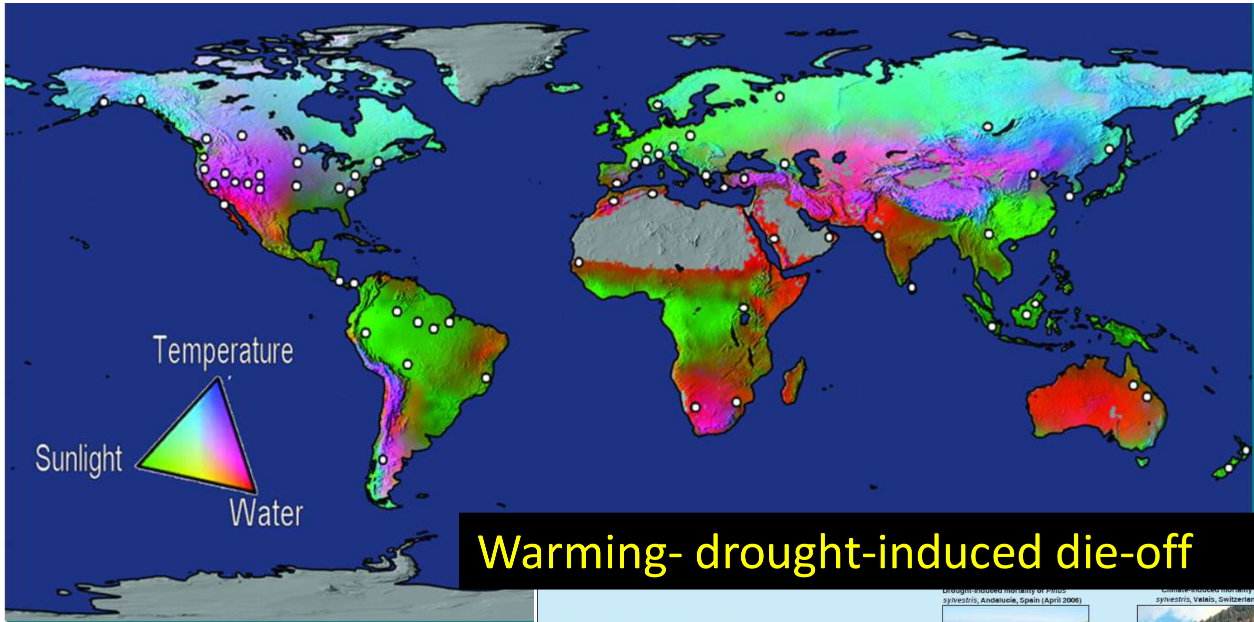


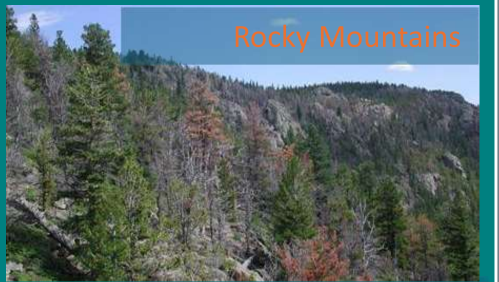
Time

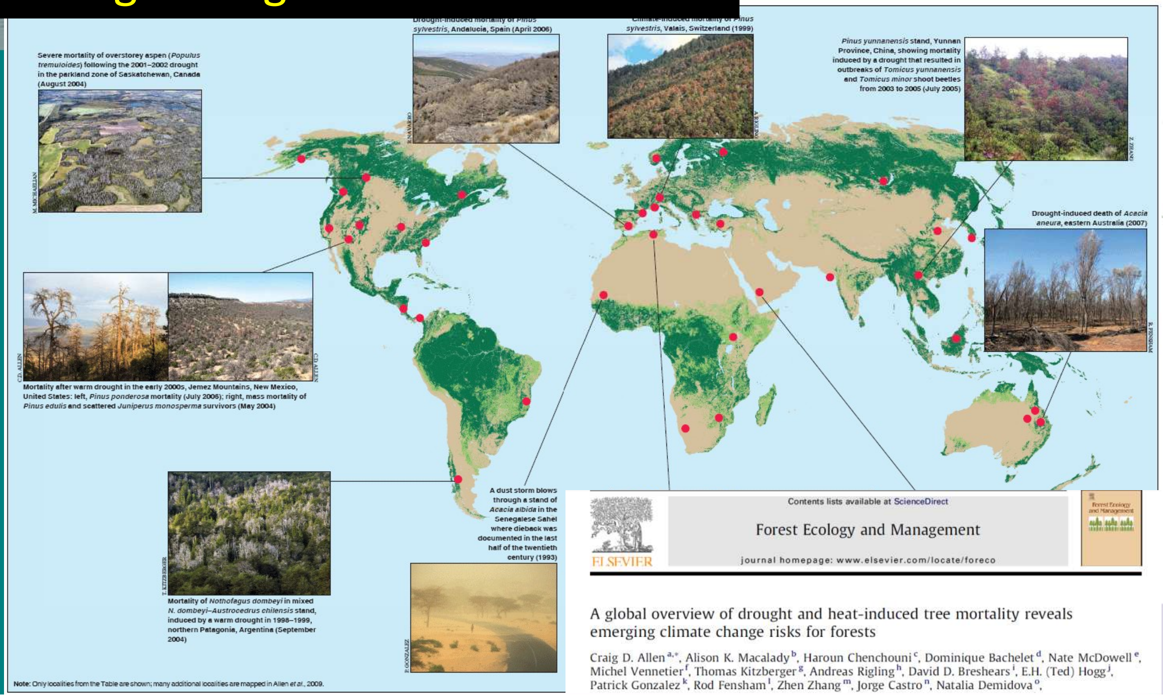
Retrospective analysis

Forecasting analysis

Warming- drought-induced die-off







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A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests

Craig D. Allen[a,*], Alison K. Macalady[b], Haroun Chenchouni[c], Dominique Bachelet[d], Nate McDowell[e], Michel Vennetier[f], Thomas Kitzberger[g], Andreas Rigling[h], David D. Breshears[i], E.H. (Ted) Hogg[j], Patrick Gonzalez[k], Rod Fensham[l], Zhen Zhang[m], Jorge Castro[n], Natalia Demidova[o],

Which physiological mechanisms drive tree mortality under drought?

Three possible, not mutually exclusive, mechanisms:

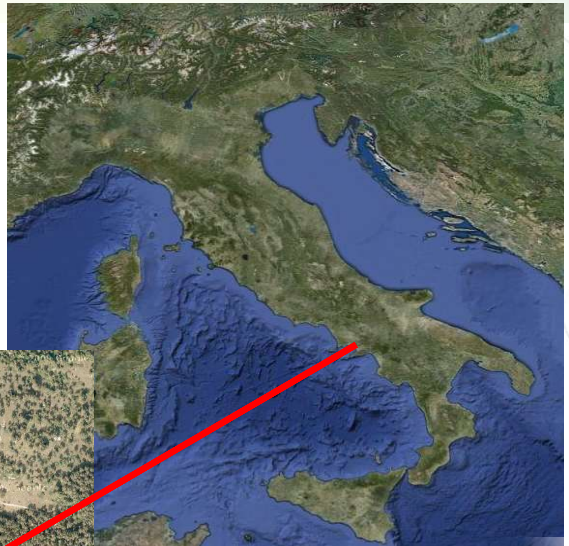
1. Hydraulic failure

2. Carbon starvation

3. Biotic attacks

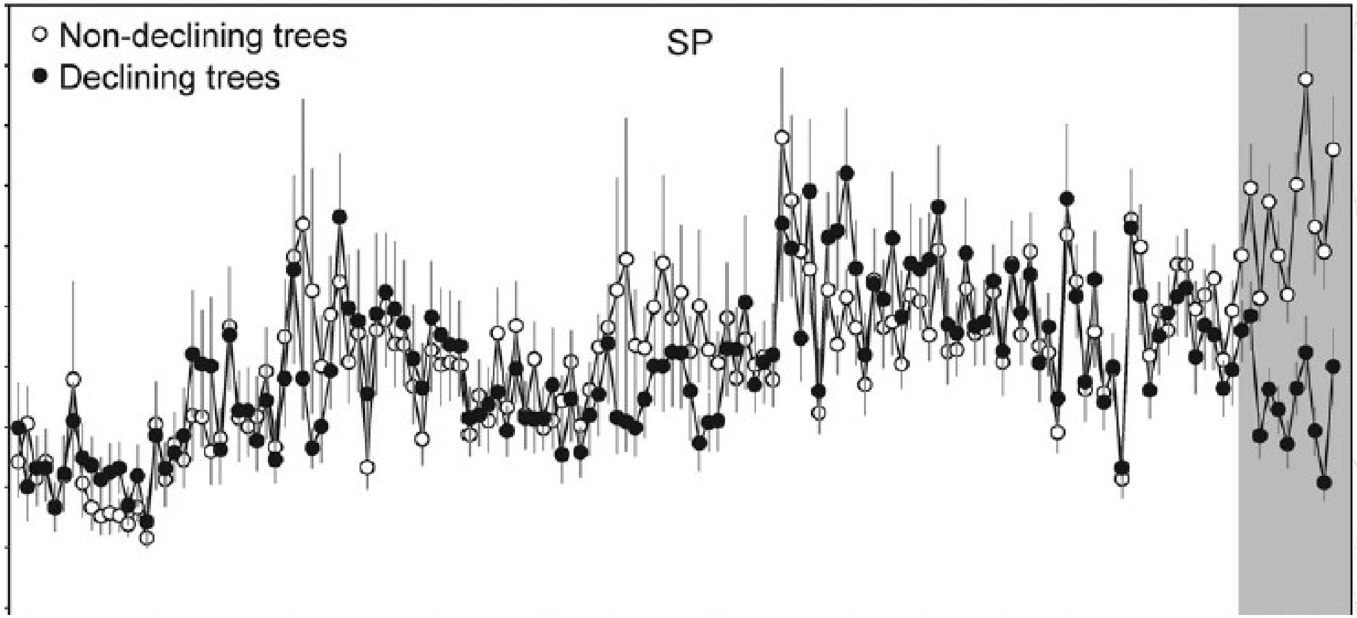
A multi-proxy assessment of dieback causes in a Mediterranean oak species

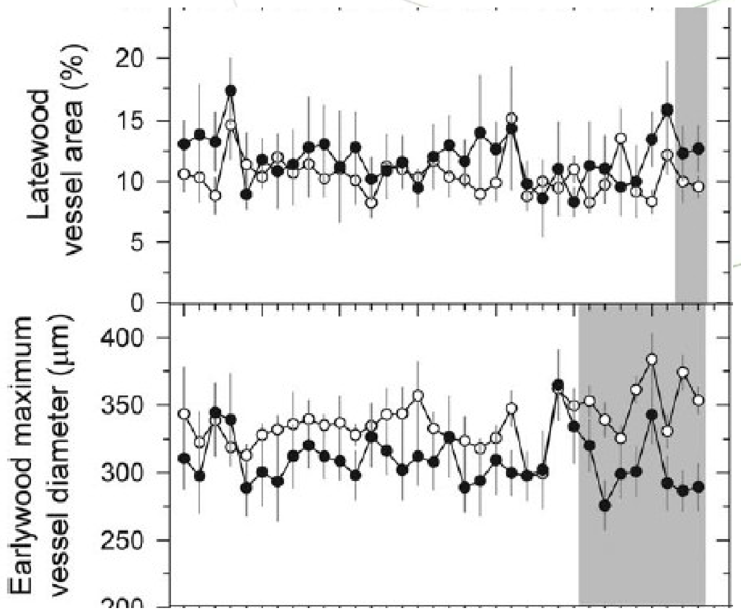
Michele Colangelo[1], J. Julio Camarero[2], Giovanna Battipaglia[3,4], Marco Borghetti[1], Veronica De Micco[5], Tiziana Gentilesca[1] and Francesco Ripullone[1,6]

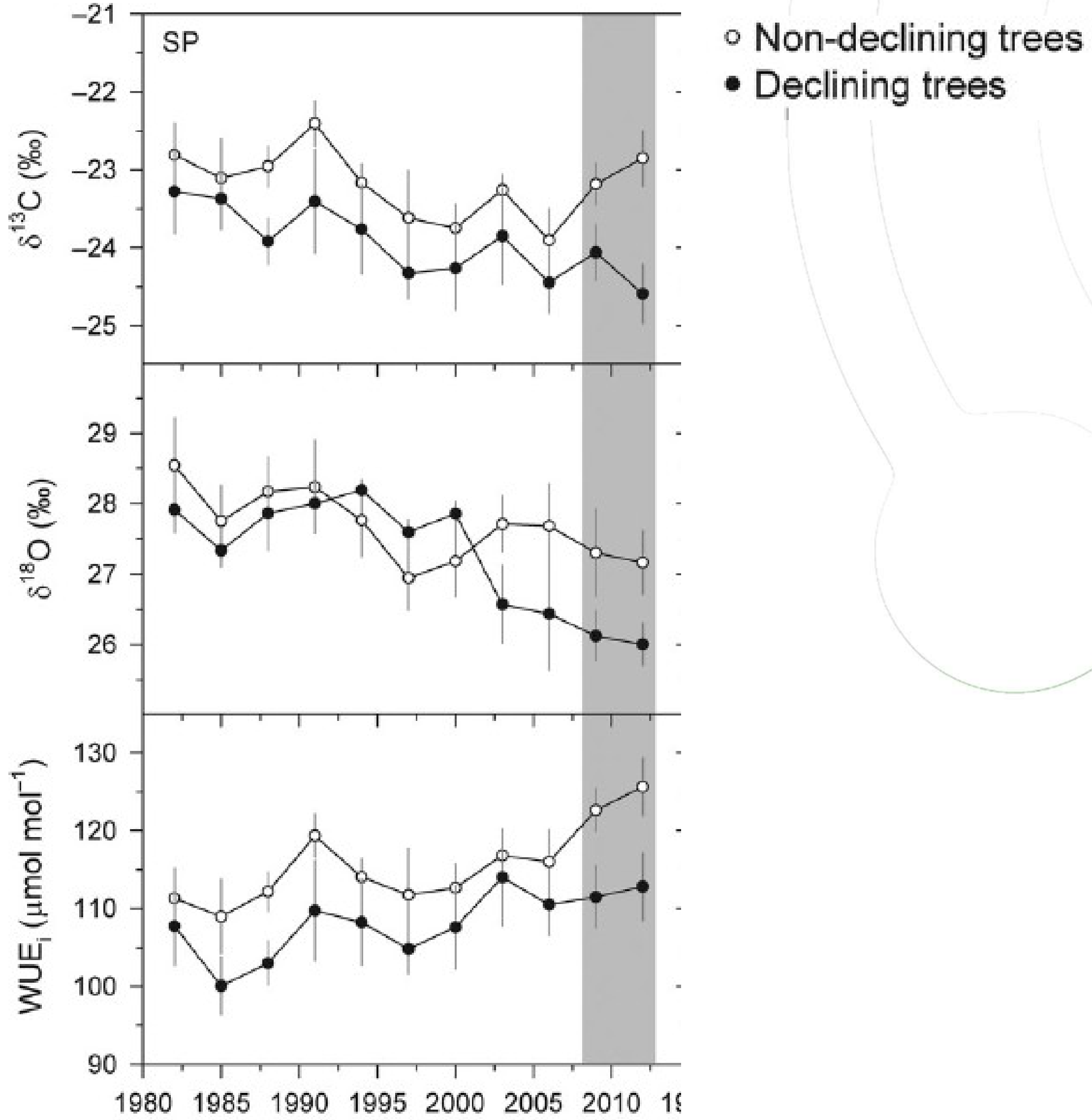


Q. cerris

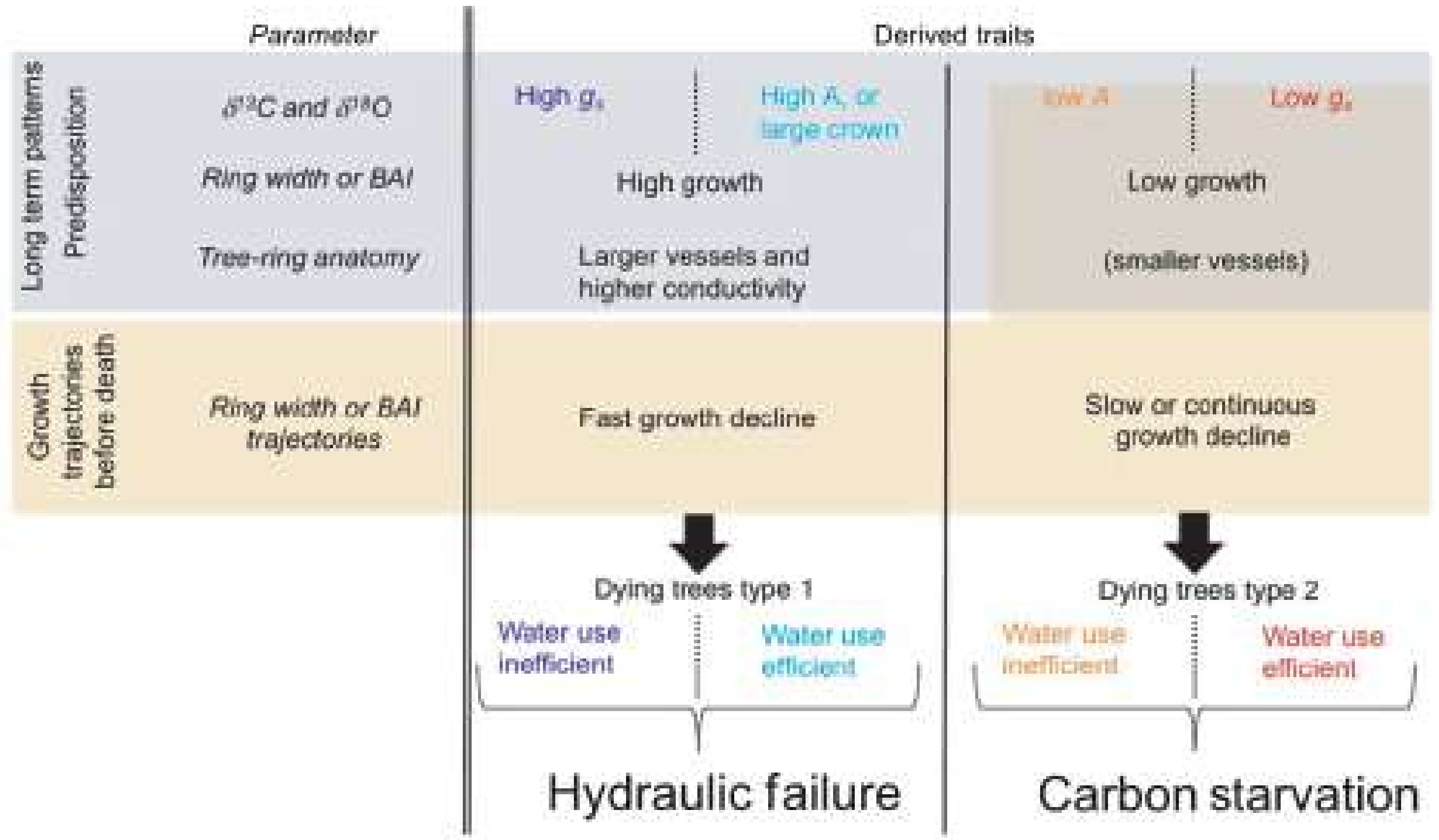
BASAL AREA MM²







SP
Non-declining trees
Declining trees
δ13C (‰)
δ18O (‰)
WUEi (μmol mol−1)
−21
−22
−23
−24
−25
29
28
27
26
130
120
110
100
90
1980
1985
1990
1995
2000
2005
2010



Gessler et al. 2018, *New Phytologist 219:485-490*

most vulnerable to drought are characterized by:

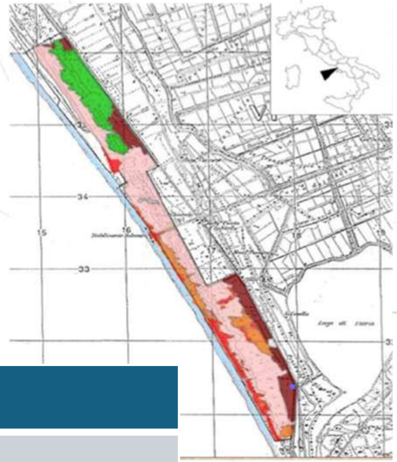
- - lower wood density
- Low WUEi

Fire Effect on plants

Study sites and PB conditions

P. halepensis- National Park of Cilento
(NPC) PB May 2009

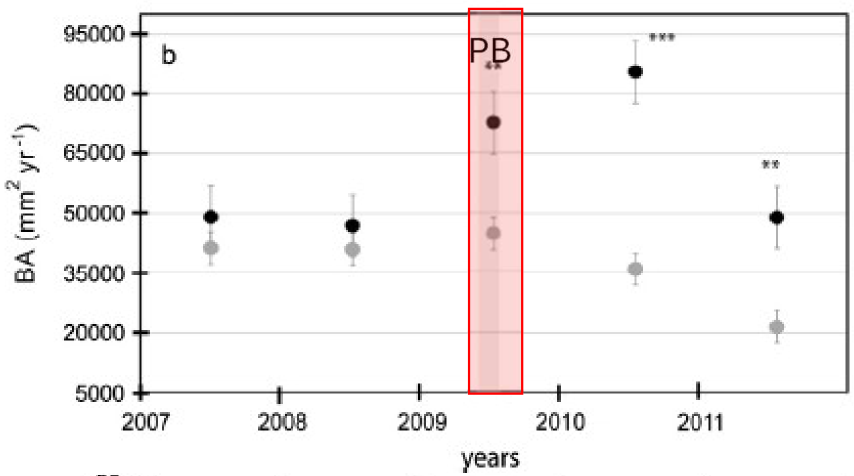
P. pinea- National Reserve of Castelvolturno
(NRC) PB March 2014

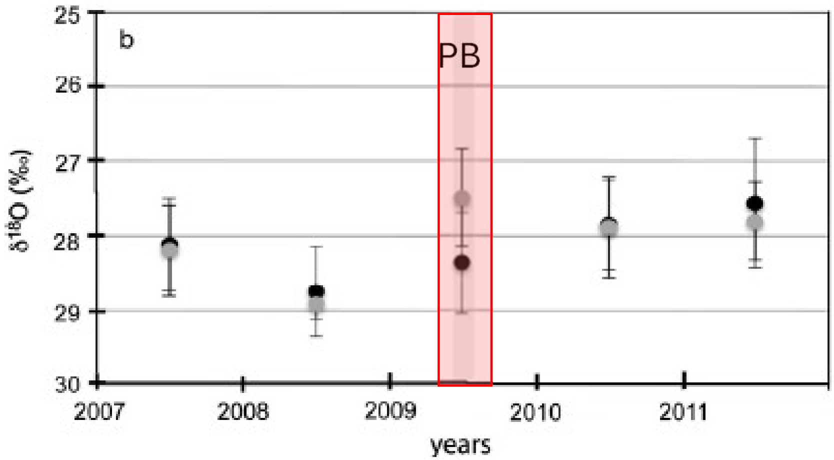


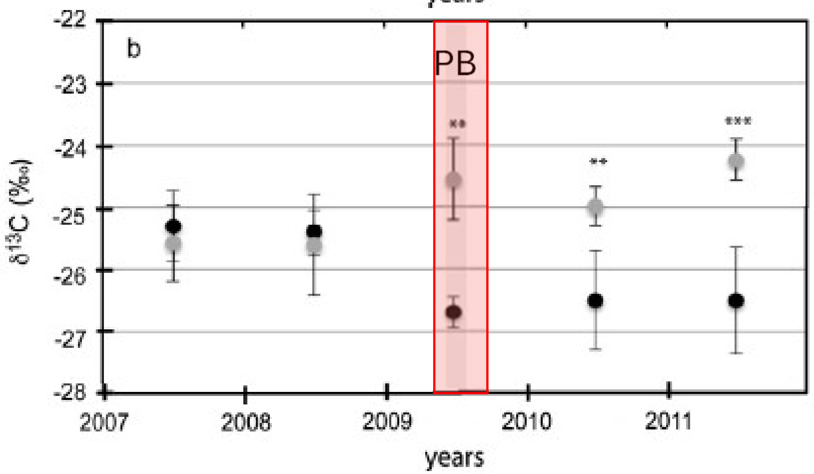
PRESCRIBING BURNING CONDITIONS		
	NPC	**NRC**
AIR TEMPERATURE (ºC)	23	18
RELATIVE AIR HUMIDITY (%)	53	54
WIND SPEED (km/h)	4	1-3 Km/h
FLAME HEIGHT (m)	<1	<1
SURFACE TMAX (ºC)	737	851
FIRE INTENSITY (kW/m)	62	<200

- burned
- control

Old stand



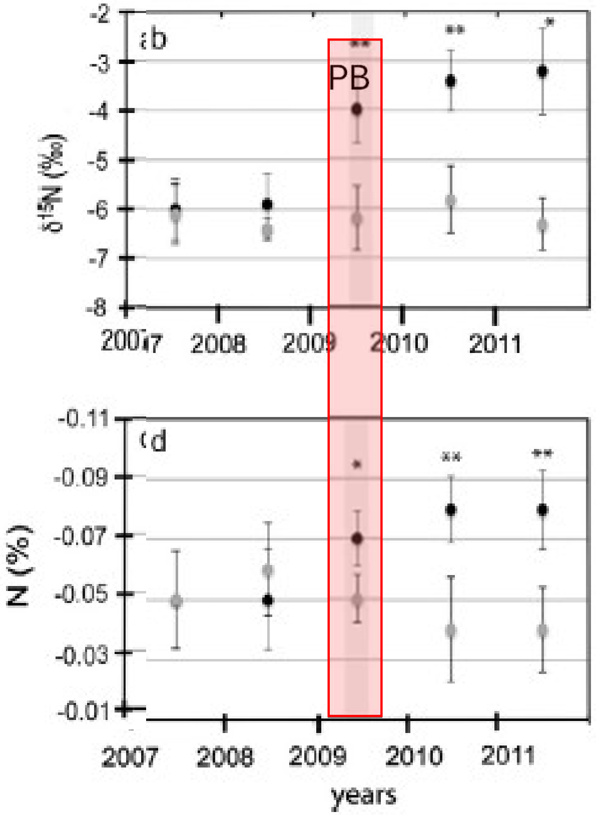




Battipaglia et al 2014 For Ecol Manage

- Increase in BA in the short and mid term
- Decrease in $\delta^{13}C$ in short and mid term
- No change in $\delta^{18}O$ in short and mid term

Variation in productivity and ^{13}C derived WUE_i related to an increase of photosynthetic activity



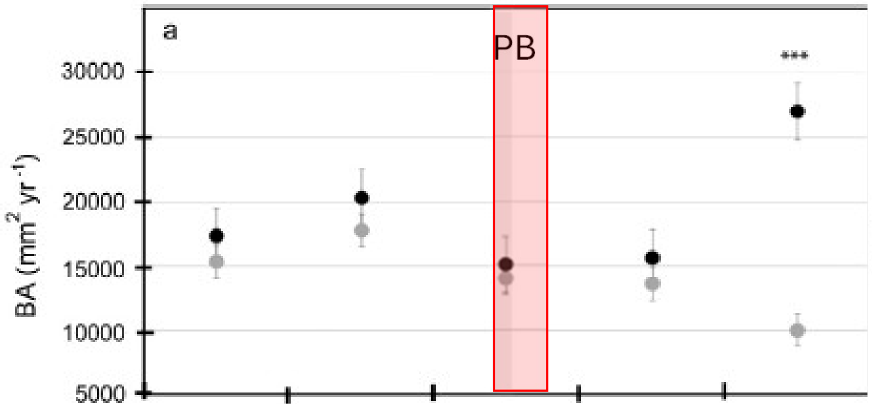
- Increase in $\delta^{15}N$ in the short and mid term
- Increase in N% in the short and mid term

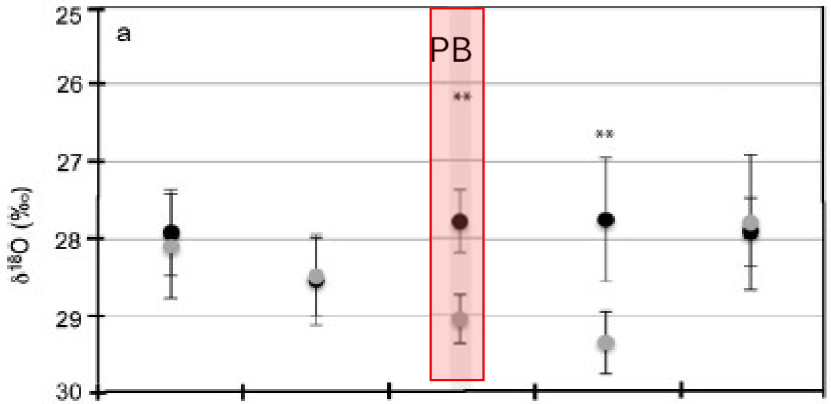
Prescribed fire has a positive effect on old individuals of *P.halepensis* for reduction of competition and the fertilizer effect of nitrogen and water

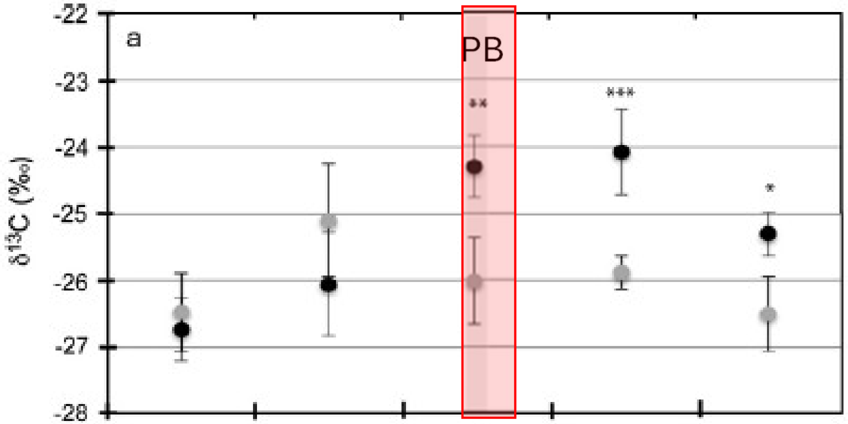
Battipaglia et al 2014 For Ecol Manage

Young stand

- burned
- control



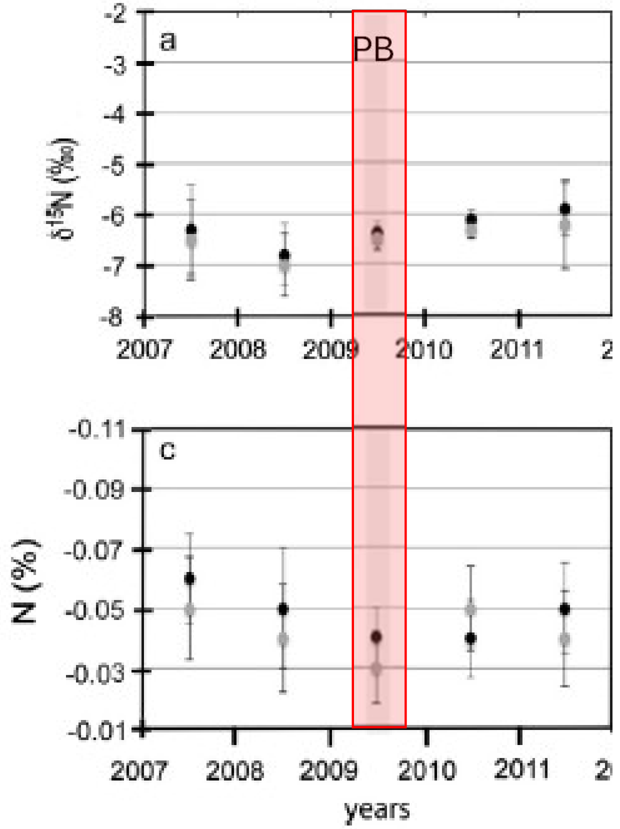




- No change BA in the short term
- Increase in $\delta^{13}C$ in short and mid term
- Increase in $\delta^{18}O$ in short term

Stomatal conductance is the dominant limitation to photosynthesis

Battipaglia et al 2014 For Ecol Manage



Battipaglia et al 2014 For Ecol Manage

- No change in $\delta^{15}N$ in the short and mid term
- No change in N% in the short and mid term

Young trees do not benefit from prescribed burning, but they suffer from an increase of competition with the older individuals.

Take home message

- Prescribed fire effects depend on tree’s age
- Need to extend the study to PB with different burning conditions and different species


Tree Physiology 36, 1019–1031
doi:10.1093/treephys/tpw034

Research paper

Effects of prescribed burning on ecophysiological, anatomical and stem hydraulic properties in *Pinus pinea* L.

Giovanna Battipaglia[1,2,3,8], Tadeja Savi[4], Davide Ascoli[5], Daniele Castagneri[6], Assunta Esposito[1], Stefan Mayr[7] and Andrea Nardini[4]

Pinus pinea stand

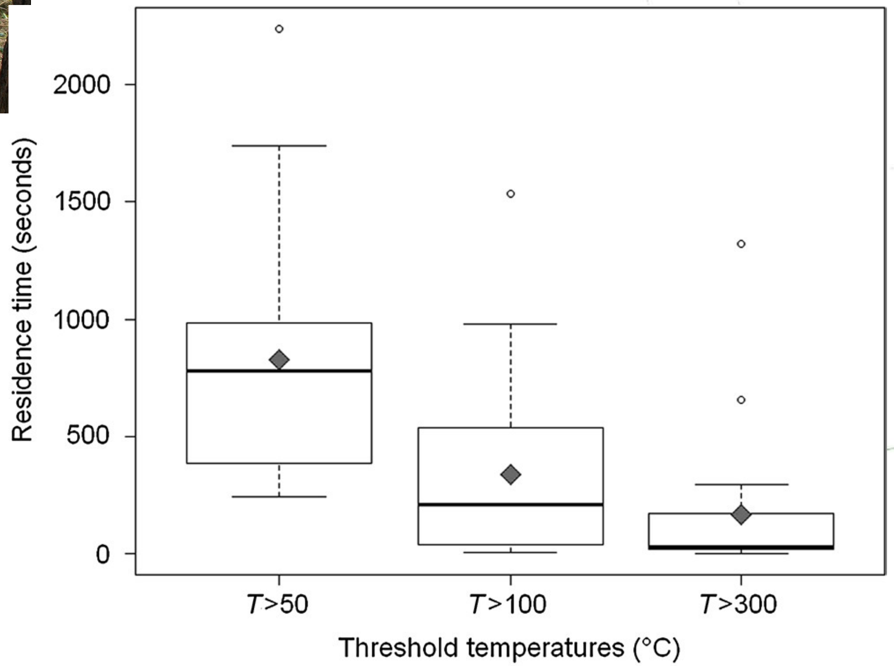
- Two areas: burned area and control area.
- litter fuels added around the trunk of ten trees to produce a gradient of heat treatment
- Thermocouples placed at the stem base, as a proxy of fire heating.
- 20 trees sampled in each area

- Three cores were collected with a 5 mm diameter borer (Suunto, Finland) per each trees: two for dendro-isotopic measurements and one for anatomical analyses
- Trunk sampled for hydraulic measurements, two weeks after PB

Burned area

Trunk sampled

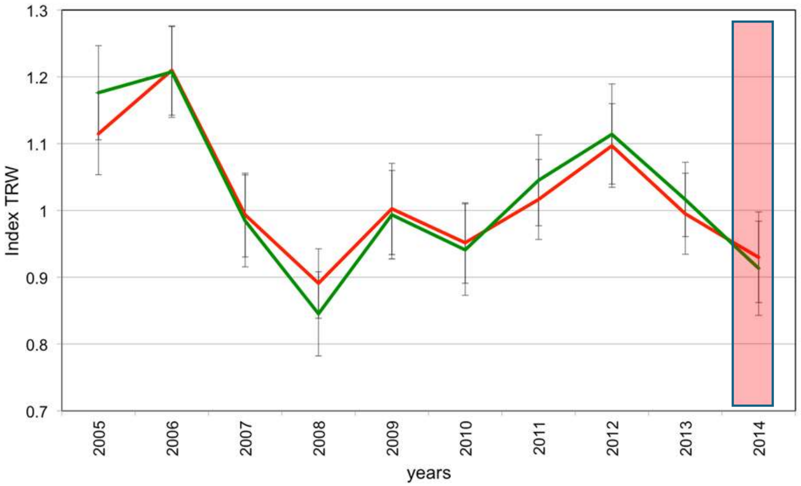
Temperature distribution

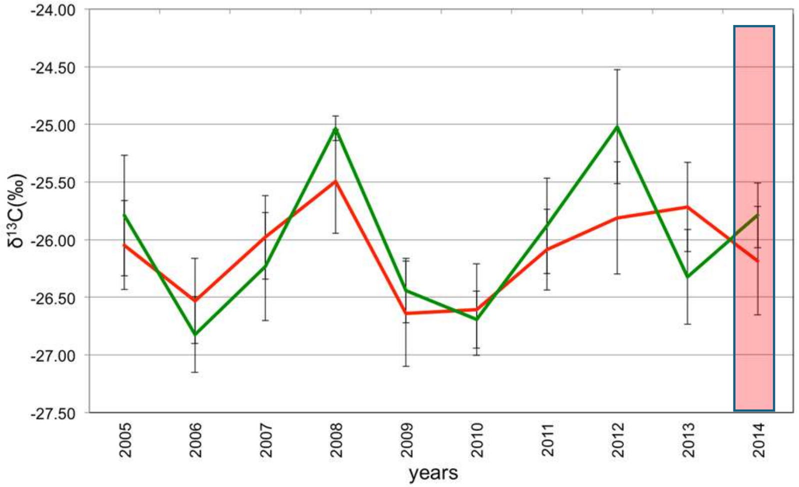


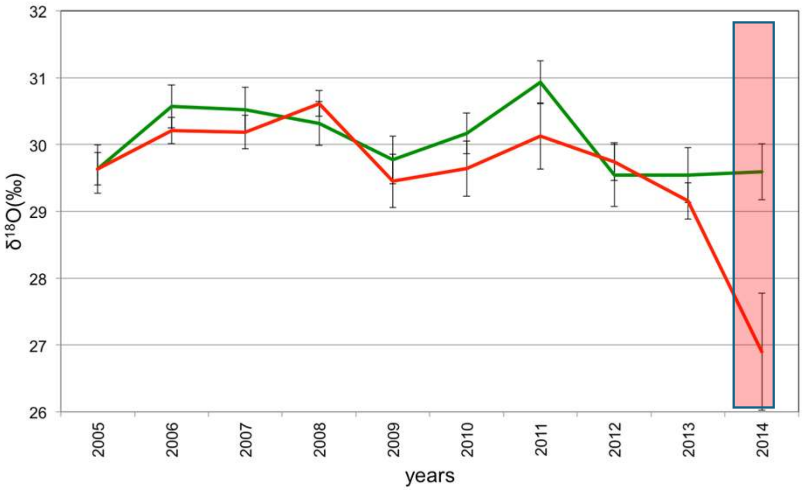
The time–temperature integration above 50°C ranged between 27,825 and 595,948 s °C. The maximum temperature range was 361–851 °C, but peaks were reached only for few seconds. The residence time of temperatures above 50 and 300 °C ranged between 242–2239 and 0–1323 s, and on average was 826 and 165 s, respectively.

Dendro-isotopic analyses

- burned
- control







-No differences in TRW
-No differences in $\delta^{13}C$
-Decrease in $\delta^{18}O$ in 2014

Increase in photosynthetic activity and stomatal conductance. But too dense stand for an increase in productivity in the short term

Take home message

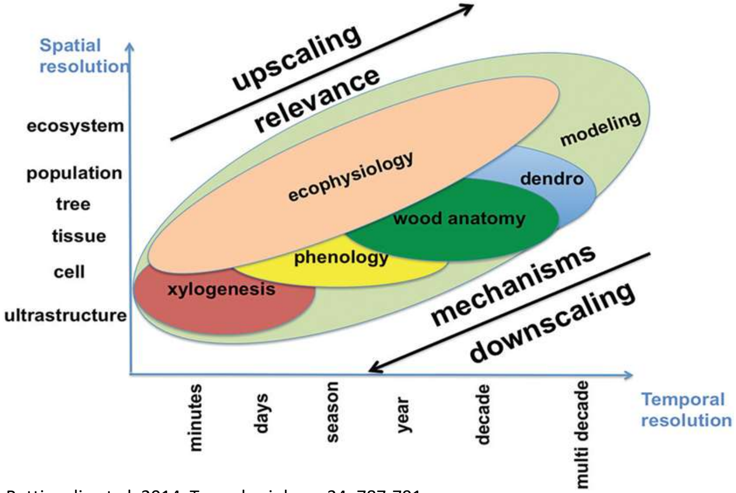
- PB have minor impacts on the ecophysiology of *P. pinea*
- No redaction in radial growth
- No alteration of xylem characteristics
- PB doesn’t have major effect on hydraulic functionality and safety

PB effects on plants are different from wildfire effects

Ecophysiological effects of PB depend on species

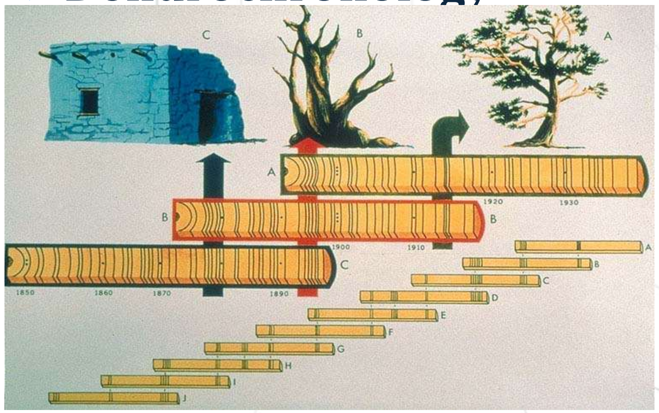
July 2017
Southern Italy struck by wildfire!

Methods



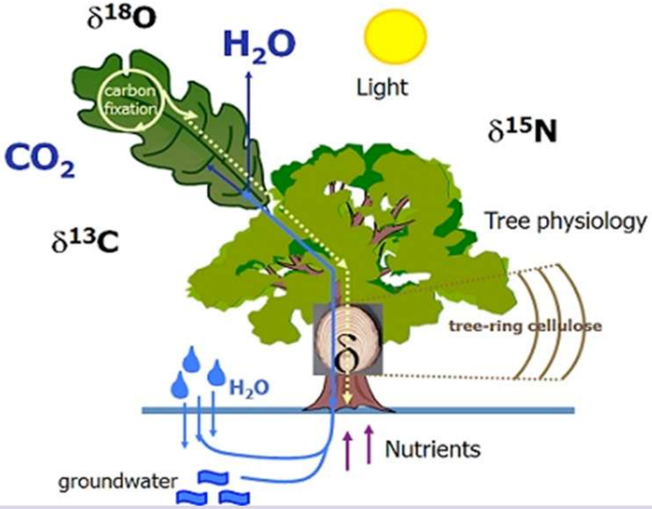
Battipaglia et al. 2014, Tree physiology, 34: 787-791.

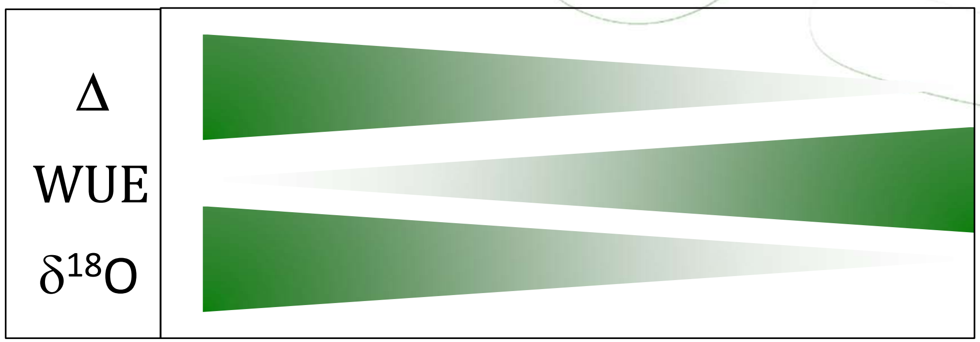
➢Dendrochronology



http://www.ncdc.noaa.gov/paleo/treering.html

➢Stable isotopes





$\Delta^{13}C$ as proxy of Water use efficiency
$\delta^{18}O$ as proxy of stomatal conductance

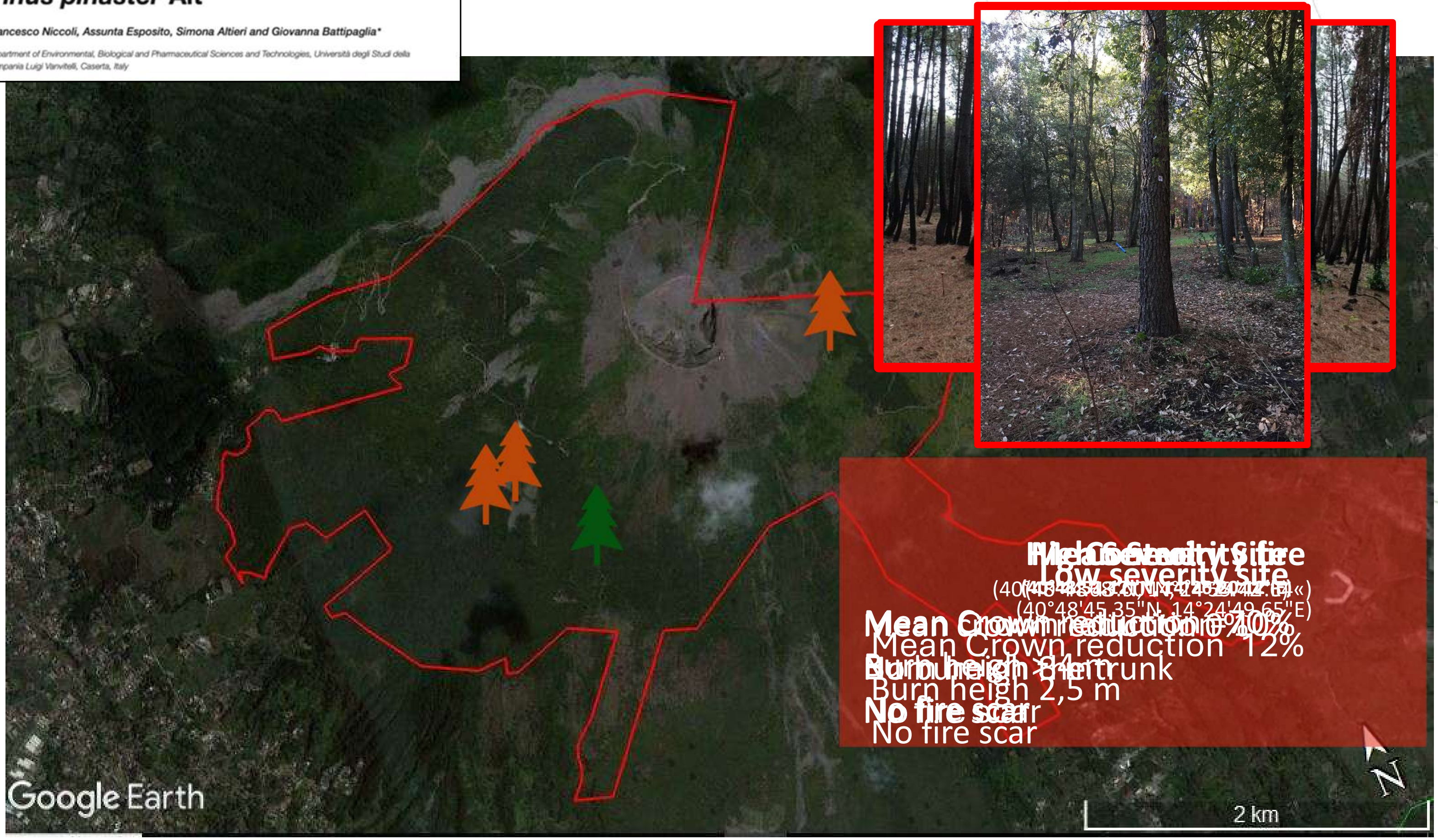
frontiers in Plant Science

ORIGINAL RESEARCH
published: 26 April 2019
doi: 10.3389/fpls.2019.00539

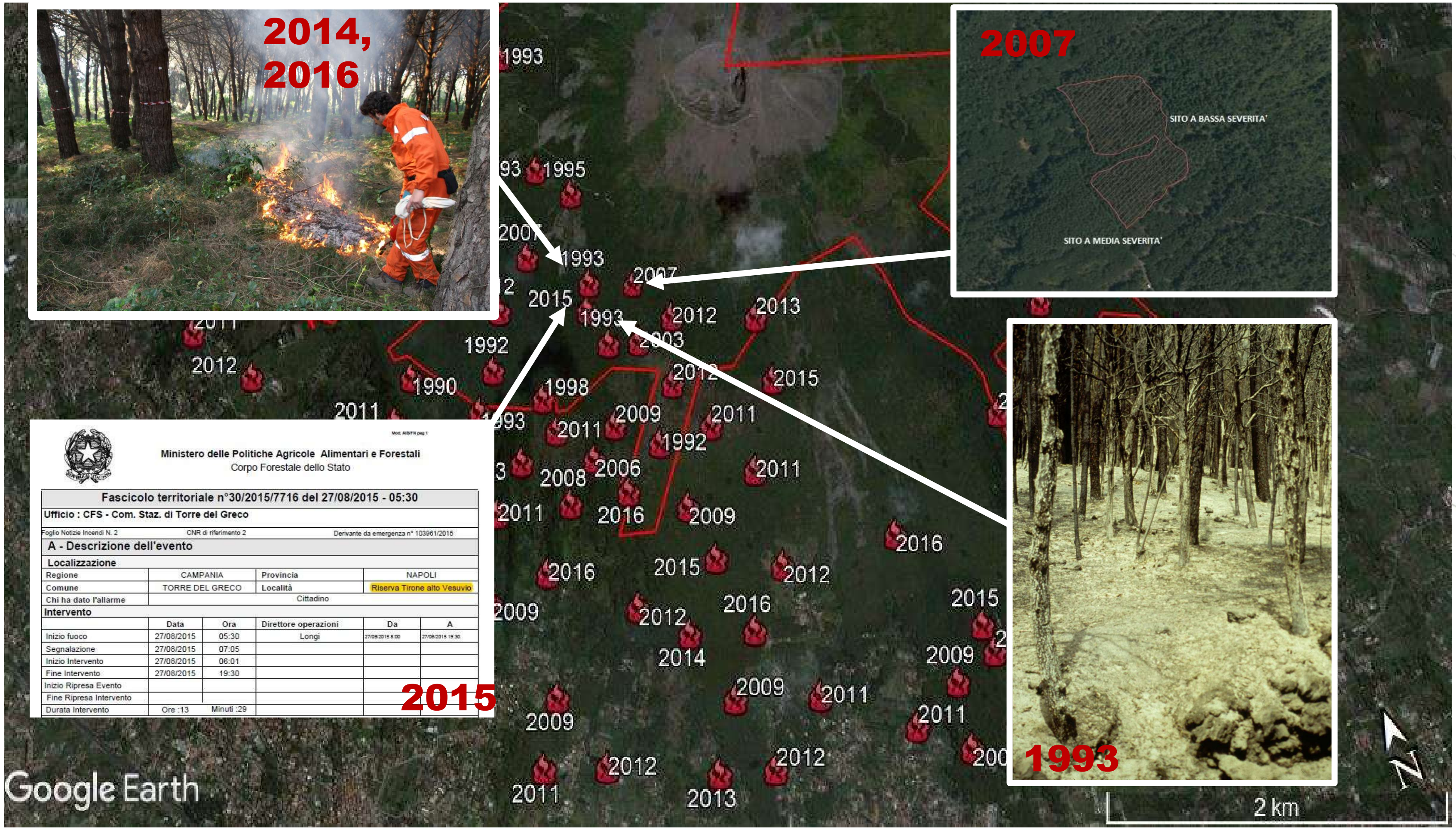
Fire Severity Influences Ecophysiological Responses of *Pinus pinaster* Ait

Francesco Niccoli, Assunta Esposito, Simona Altieri and Giovanna Battipaglia*

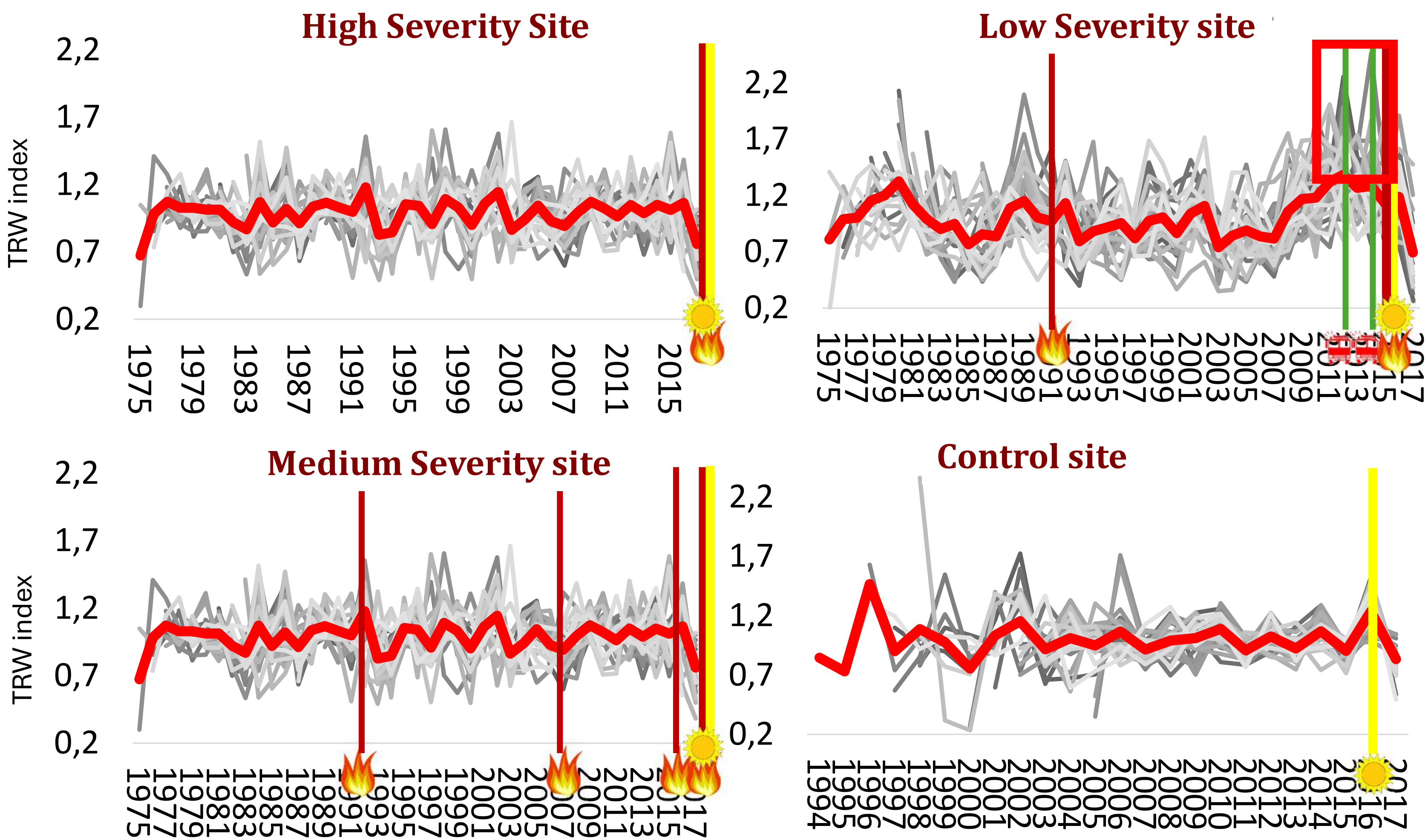
Department of Environmental, Biological and Pharmaceutical Sciences and Technologies, Università degli Studi della Campania Luigi Vanvitelli, Caserta, Italy



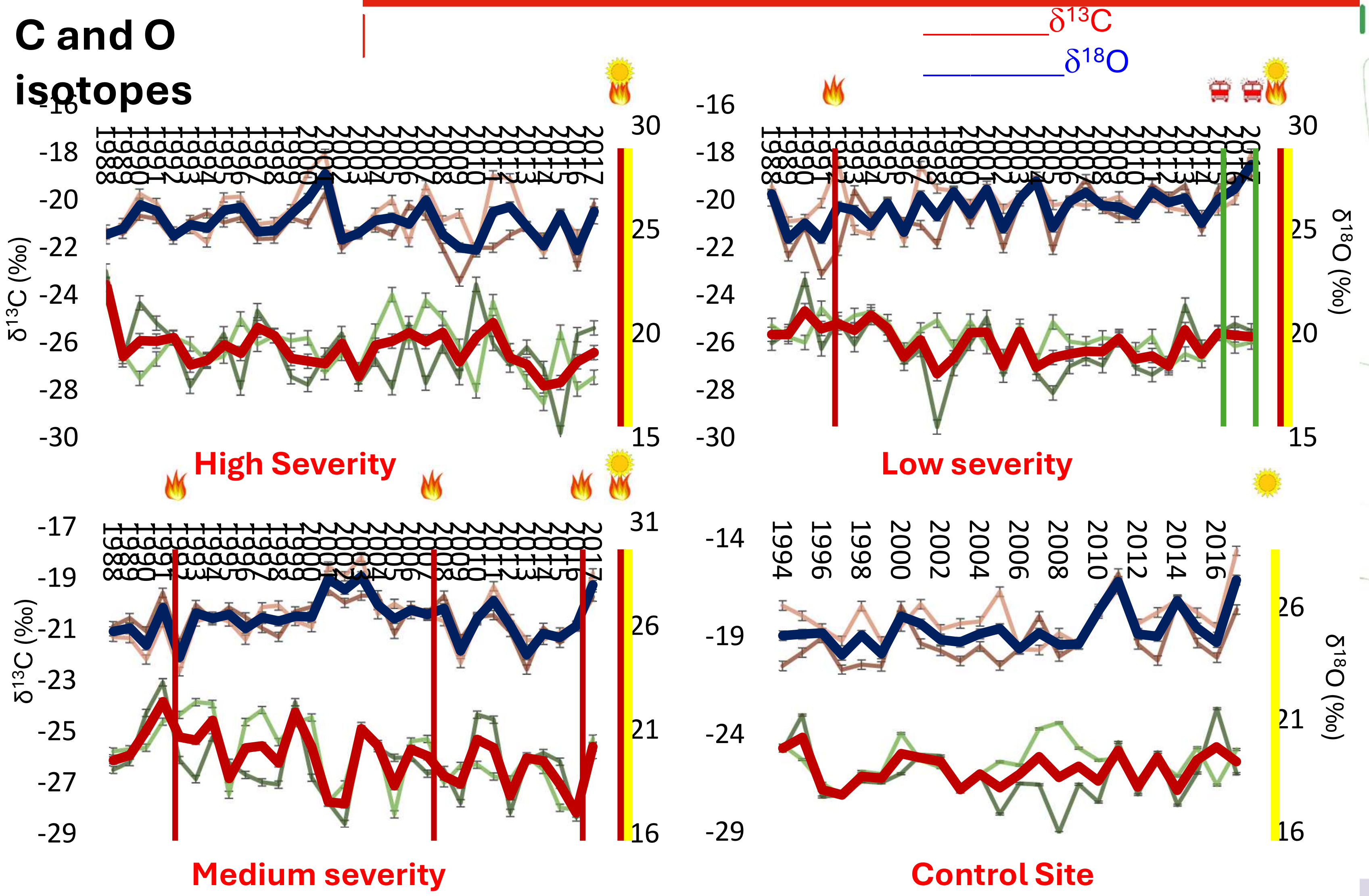
HISTORICAL RECONSTRUCTION OF PAST WILDFIRES



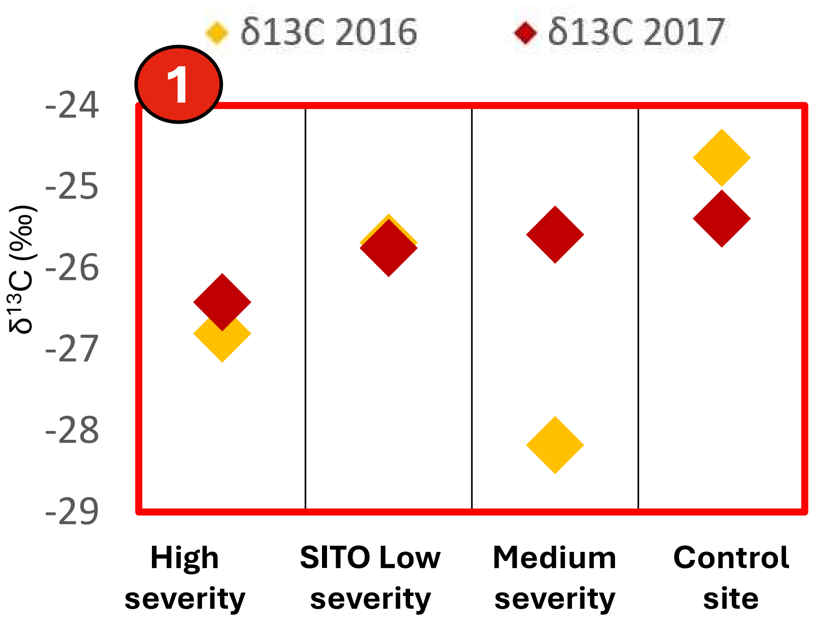
TREE GROWTH

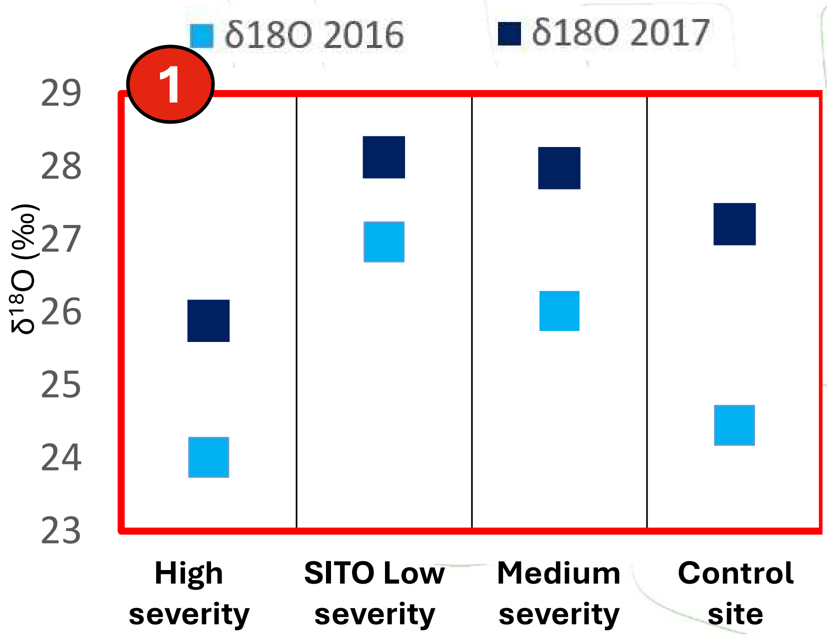

High Severity Site
Low Severity site
Medium Severity site
Control site
TRW index
2,2
1,7
1,2
0,7
0,2

C and O isotopes



What the isotopes tell us?



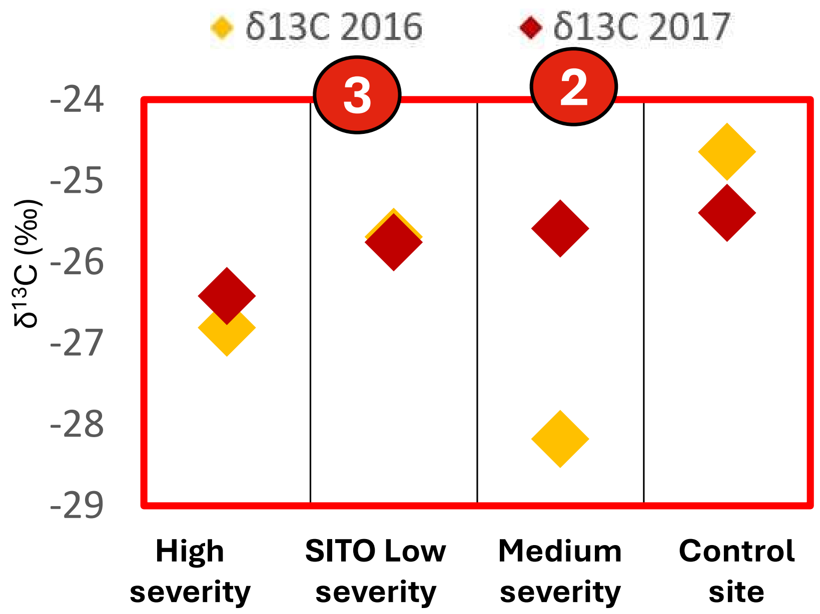


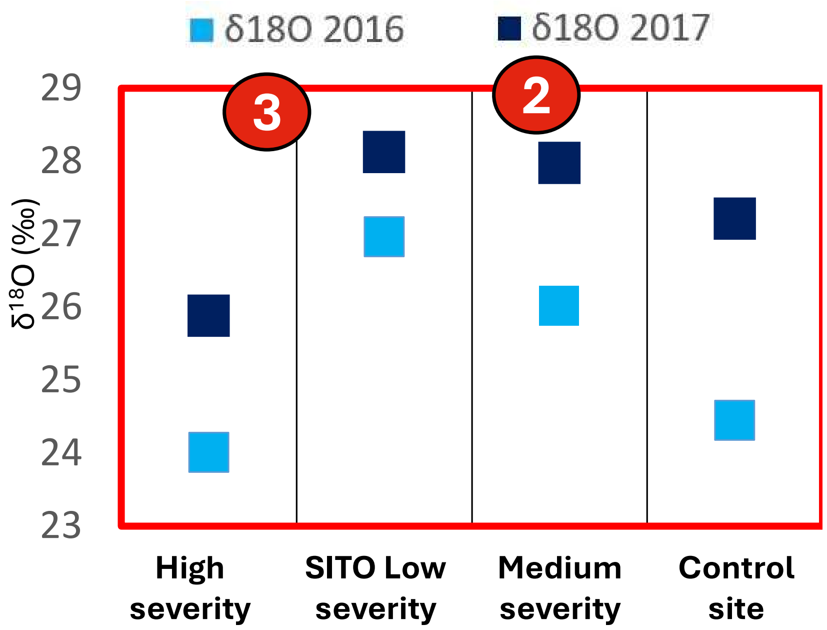
1

High severity site ↑δ^{13} ↑$\delta^{18}O$

we could hypothesize that the plants to protect themselves from strong stress condition, due to fire, and as a consequences of the serious observed crown damage, closed their stomata and lowered their photosynthetic activity. These conditions explain the observed reduction in growth of 2017 tree ring.

What the isotopes tell us?



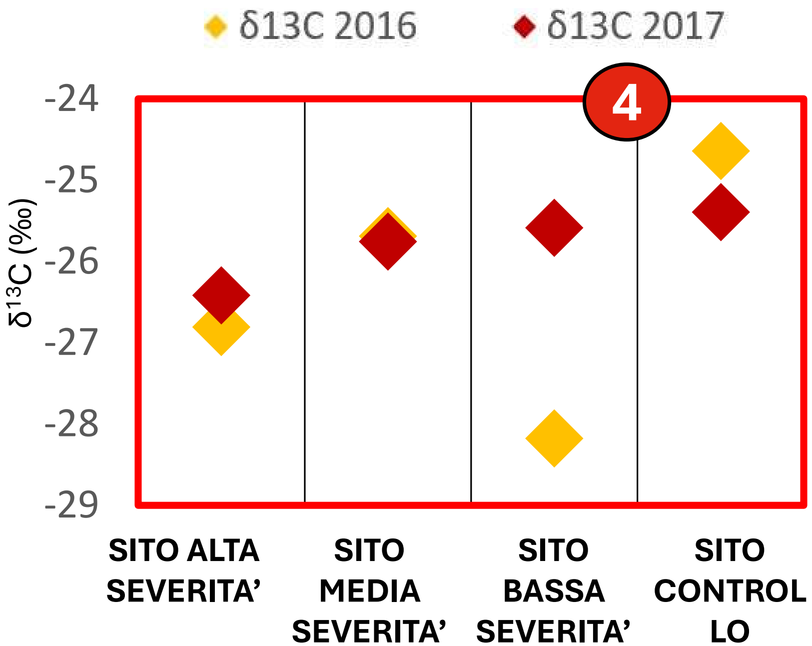


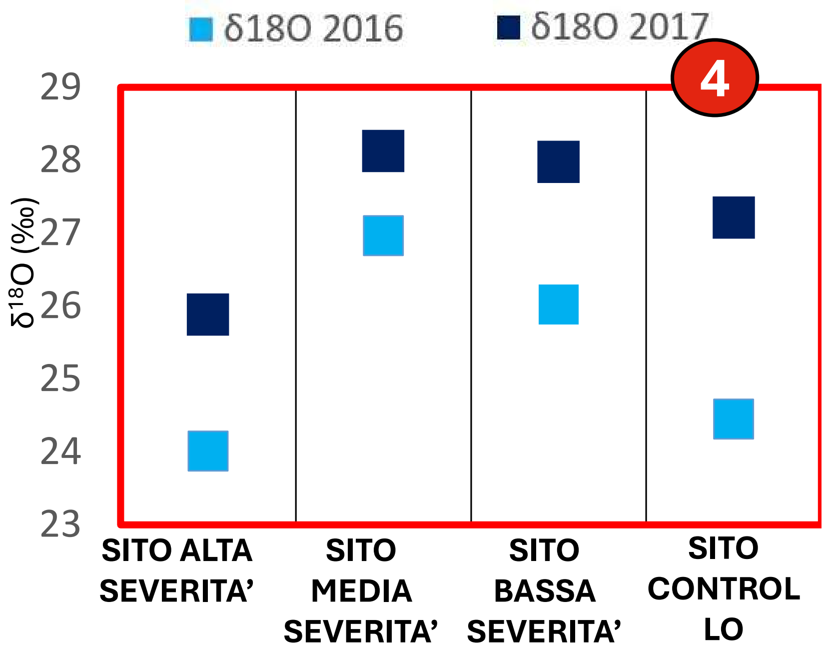
3

Medium severity site ↑δ^{13} ↑$\delta^{18}O$; Low severity ≈ δ^{13} ↑$\delta^{18}O$

Slow Stomatal conductance and photosynthetic activity

What the isotopes tell us?





4

Control site ↓δ^{13} ↑δ^{18}O

This variation, compared to the previous year, can indicate a lower photosynthetic activity and an unchanged stomatal conductance (Scheidegger et al., 2000) probably related to the extreme hot conditions experienced in that summer by all the plants.

All the sampled trees in the burned sites showed a decrease in tree growth in 2017, in particular in the latewood at high-severity site. In all the sites the high temperatures and the time of exposure to the flames were not sufficient to determine the death of the cambium and all the trees, even if reduced their stomatal conductance and photosynthetic activity, were able to complete the 2017 seasonal wood formation.

Our findings demonstrated that *P. pinaster* growth reduction is strictly linked to the percentage of crown scorch and that even trees with high level of crown scorched could survive.

Further, the dendrochronology analyses showed that several individuals experienced and endured higher fire severity than the 2017 wildfire.

Università degli Studi della Campania *Luigi Vanvitelli*

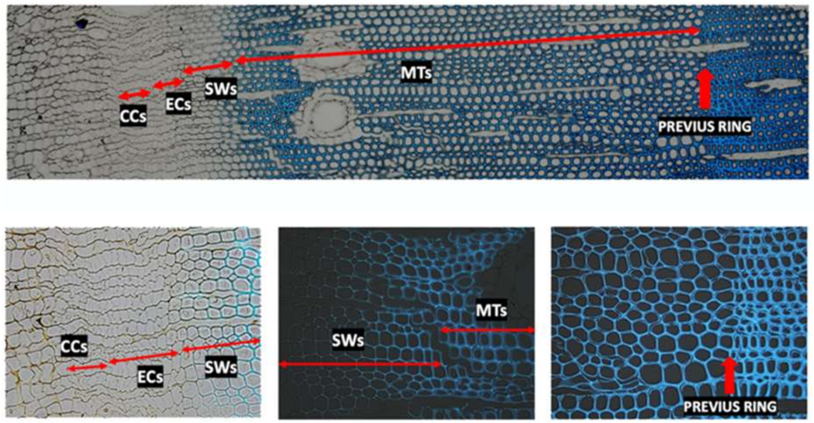
ITT-Net

DENDROLAB

ITINERIS

Medium long-term study

From 2019 to 2020



Xylogenesis monitoring

Contents lists available at ScienceDirect

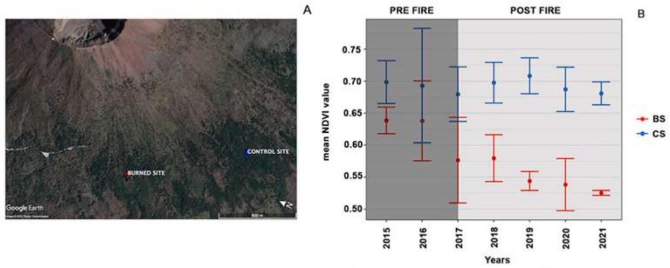
Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

Fire affects wood formation dynamics and ecophysiology of *Pinus pinaster* Aiton growing in a dry Mediterranean area

F. Niccoli [a,*], A. Pacheco-Solana [a,b], V. De Micco [c], G. Battipaglia [a]

[a] *Department of Environmental, Biological, Pharmaceutical Sciences and Technologies, University of Campania "Luigi Vanvitelli", Via Vivaldi 43, 81100 Caserta, Italy*
[b] *The Earth Institute, Tree-ring Laboratory, Lamont-Doherty Earth Observatory of Columbia University, New York 10964, United States of America*
[c] *Department of Agricultural Sciences, University of Naples Federico II, via Università 100, 80055, Portici, Italy*



Dendrochronologia 79 (2023) 126086

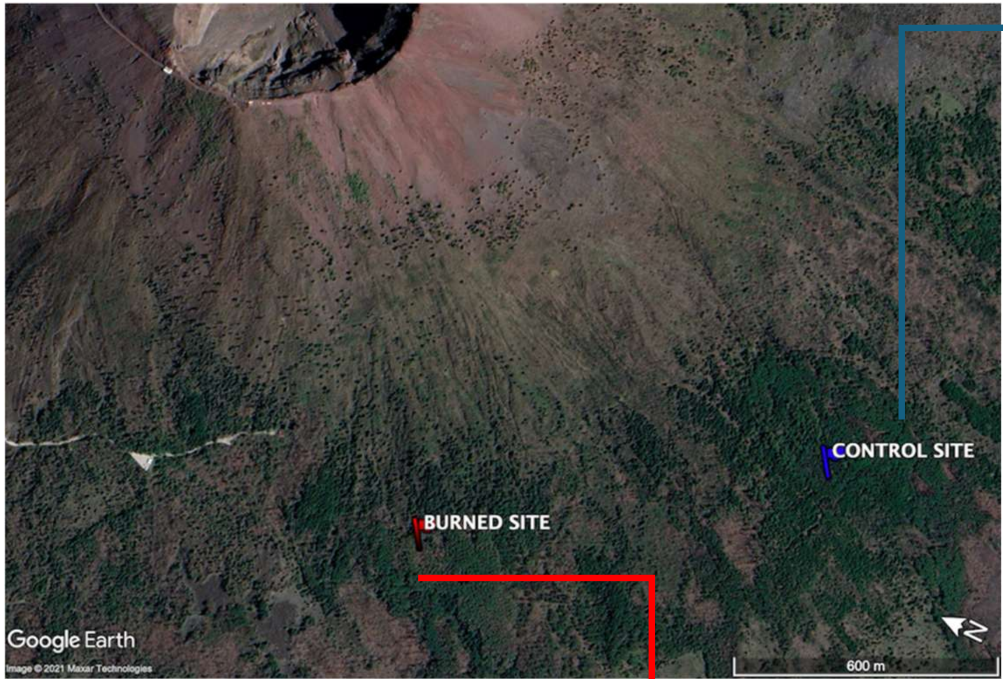
Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

Effects of wildfire on growth, transpiration and hydraulic properties of *Pinus pinaster* Aiton forest

Francesco Niccoli [a,*], Arturo Pacheco-Solana [a,b], Sylvain Delzon [c], Jerzy Piotr Kabala [a], Shahla Asgharinia [d], Simona Castaldi [a], Riccardo Valentini [d], Giovanna Battipaglia [a]



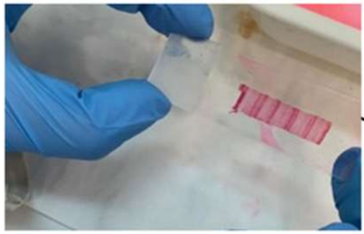
Unburned trees not defoliated

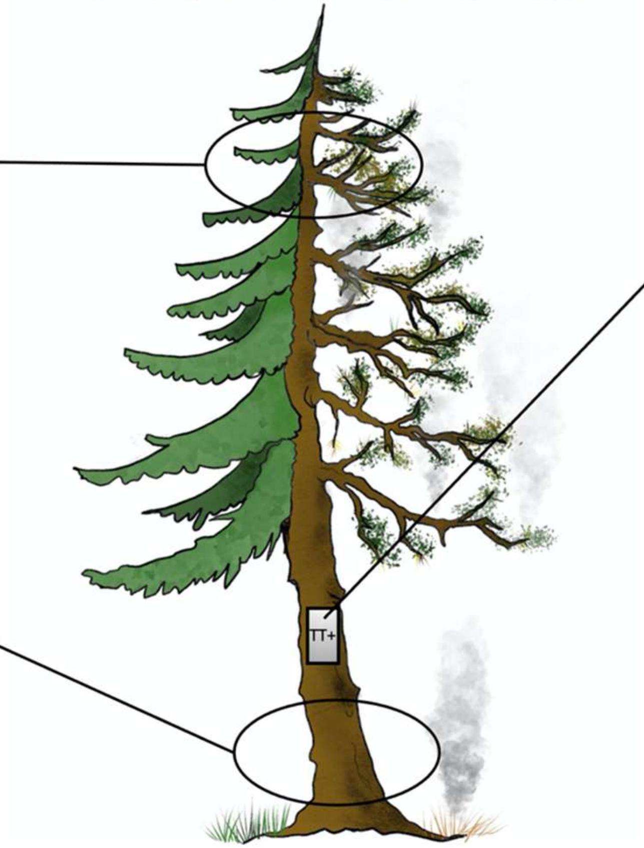
Burned trees with crown damage (50% of defoliation)

CONTROL TREES vs BURNED TREES

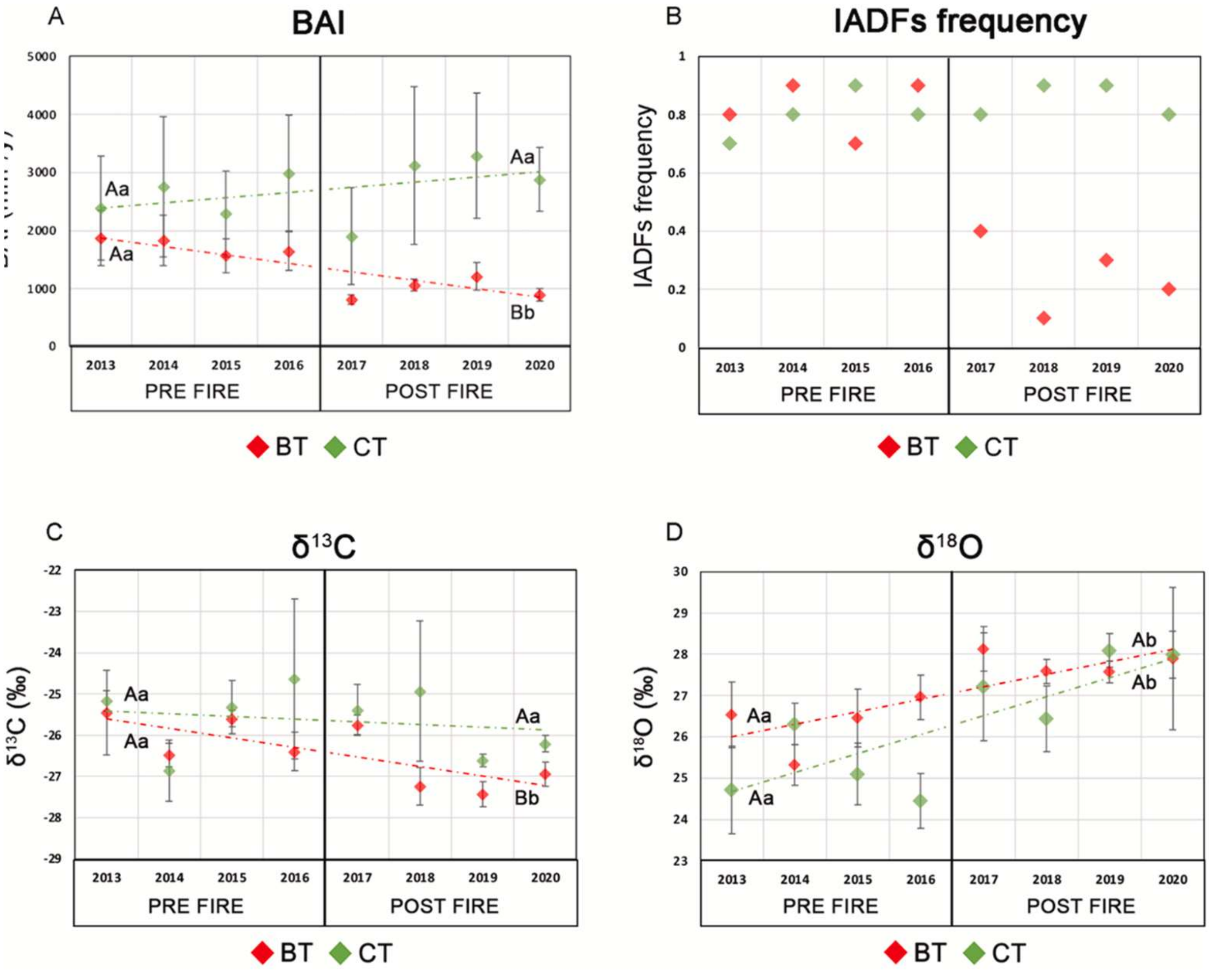
Cavitation test

Dendro-anatomy analysis





TreeTalker monitoring


A
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4000
3000
2000
1000
0
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Aa
Aa
Bb
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2014
2015
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2017
2018
2019
2020
PRE FIRE
POST FIRE
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IADFs frequency
IADFs frequency
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0.6
0.4
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PRE FIRE
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PRE FIRE
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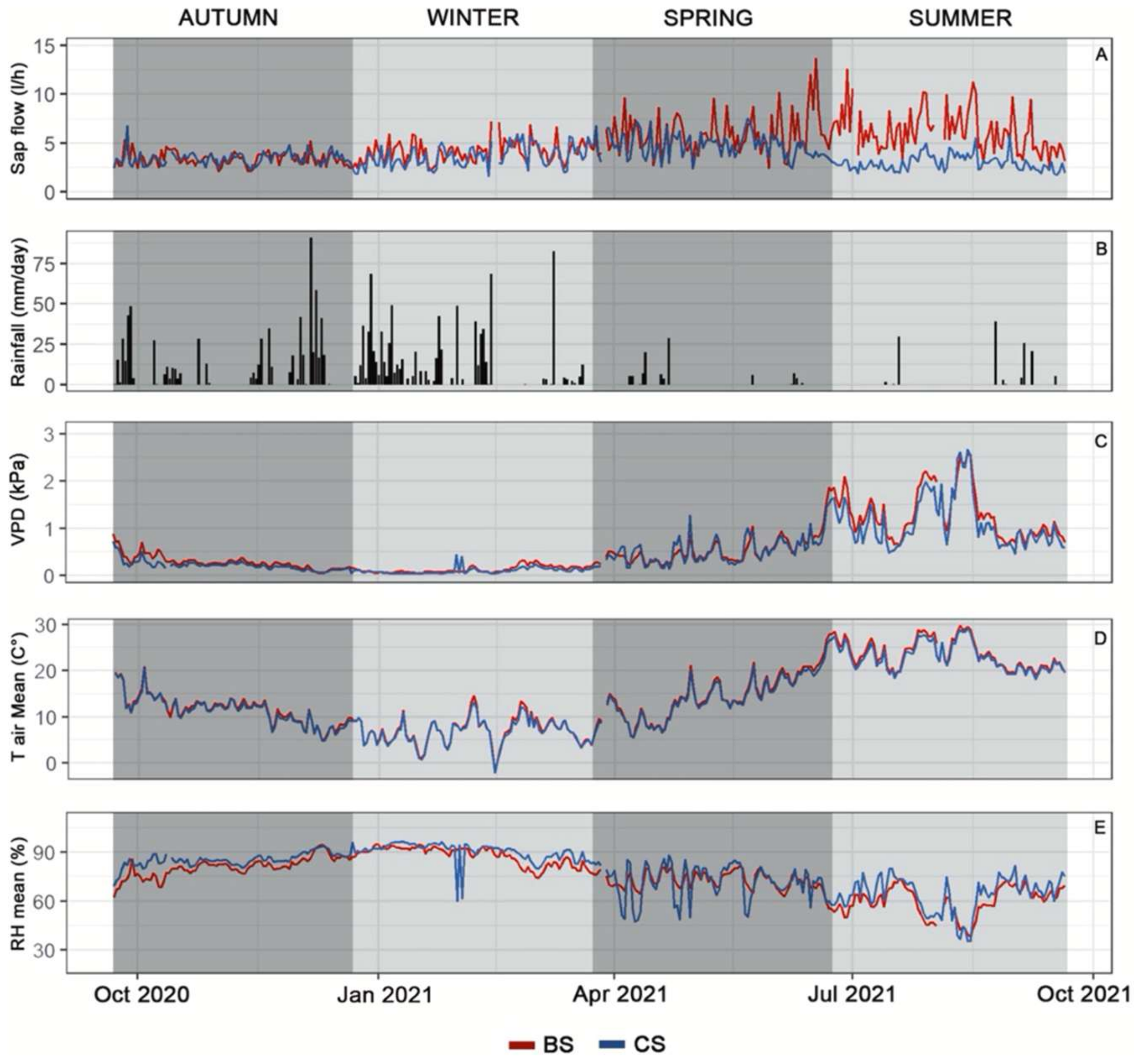
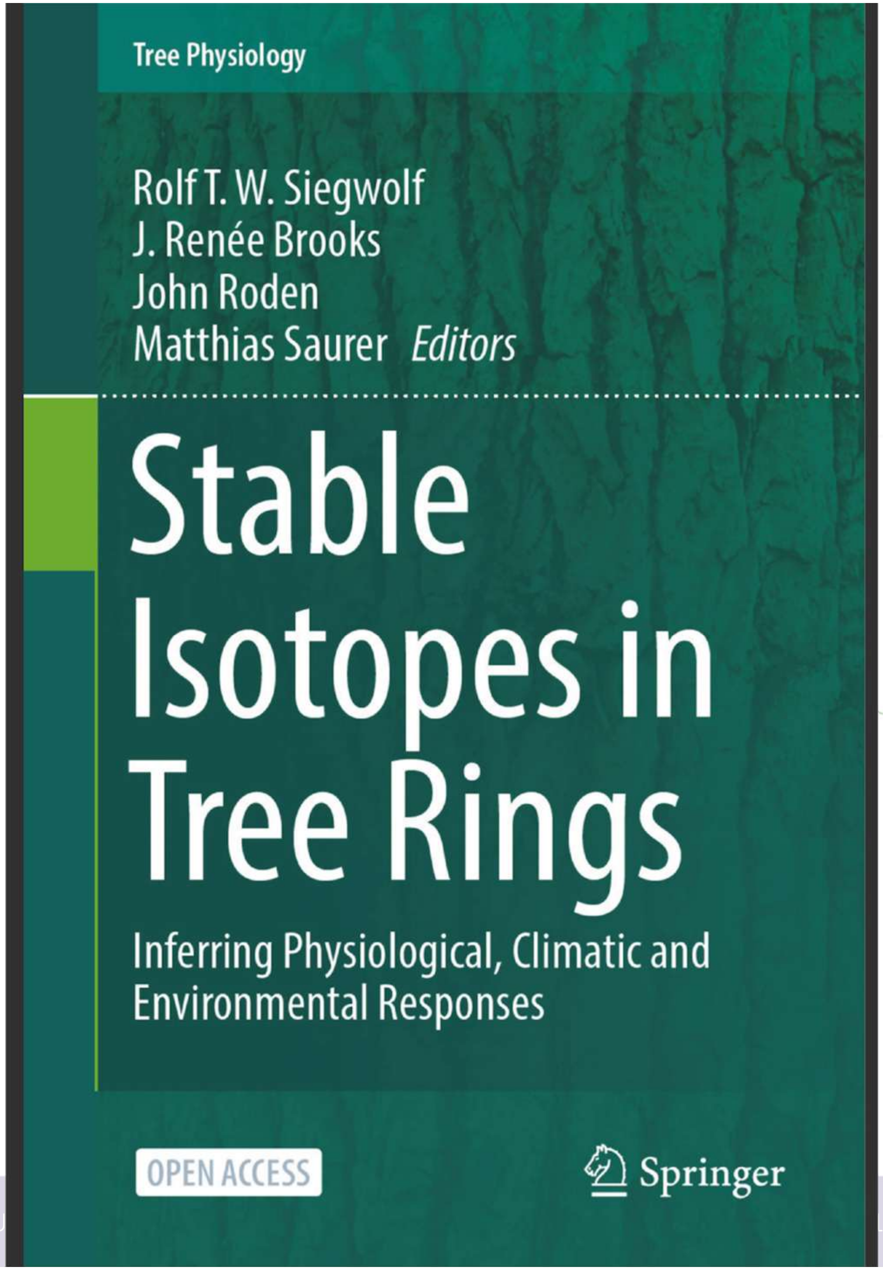

AUTUMN
WINTER
SPRING
SUMMER
Sap flow (l/h)
Rainfall (mm/day)
VPD (kPa)
T air Mean (C°)
RH mean (%)
A
B
C
D
E
Oct 2020
Jan 2021
Apr 2021
Jul 2021
Oct 2021
BS
CS

ITINERIS


Tree Physiology
Rolf T. W. Siegwolf
J. Renée Brooks
John Roden
Matthias Saurer *Editors*
Stable Isotopes in Tree Rings
Inferring Physiological, Climatic and Environmental Responses
OPEN ACCESS
Springer

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THANKS!

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