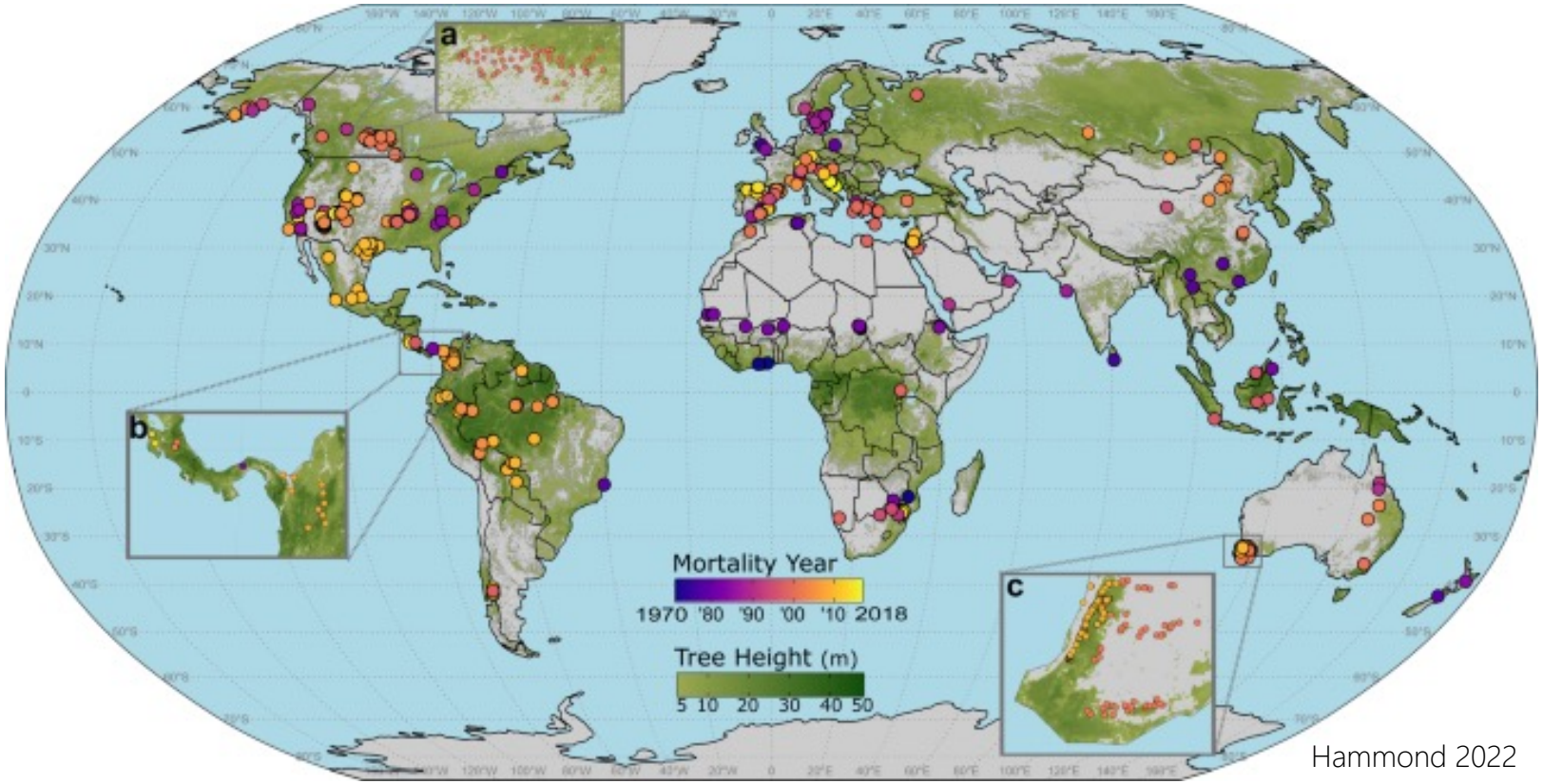
Understanding Forest Acclimation Dynamics Using Stable Isotopes

Dr. Valentina Vitali

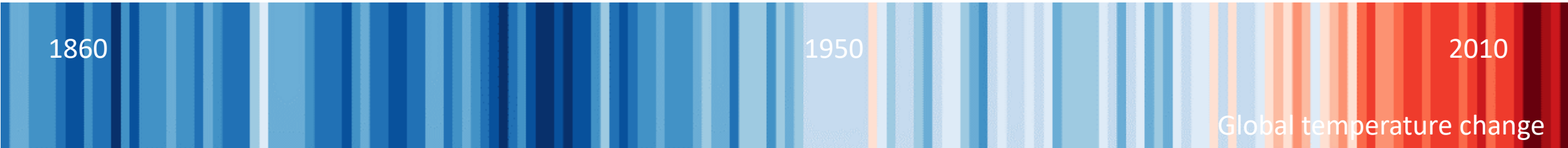
WSL

Impact of climate change on forest ecosystems



Hammond 2022

Locations of substantial drought- and heat-induced tree mortality around the globe.



Acclimation to new environmental conditions

Understanding tree acclimation to drought is important for forest ecosystem resilience.

Acclimation occurs through

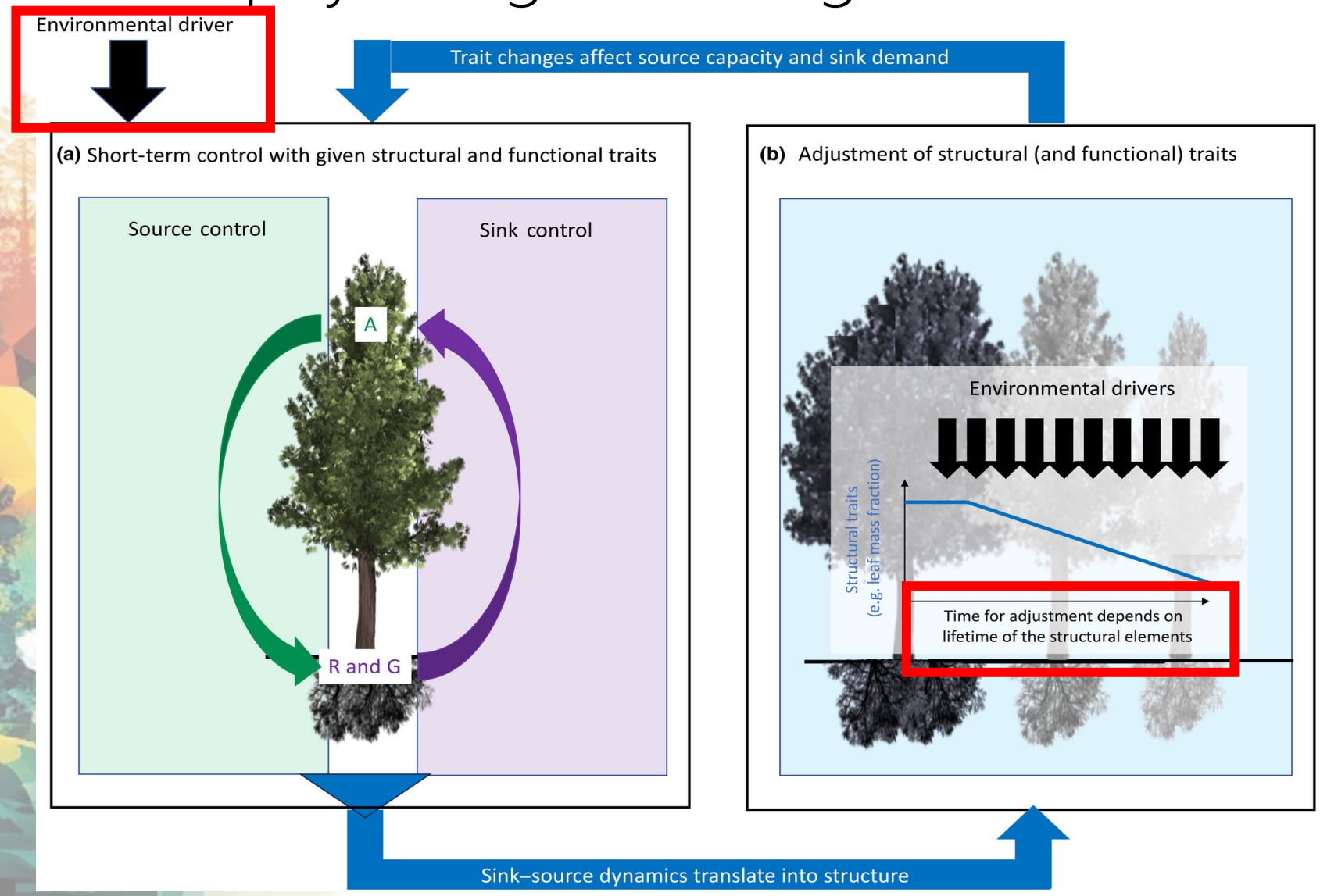
physiological,

biochemical,

and structural changes.

- Physiological adjustments reduce water loss.
- Biochemical changes balance reduced CO2 uptake.
- Structural alterations include morphological adjustments.

Structural and physiological changes

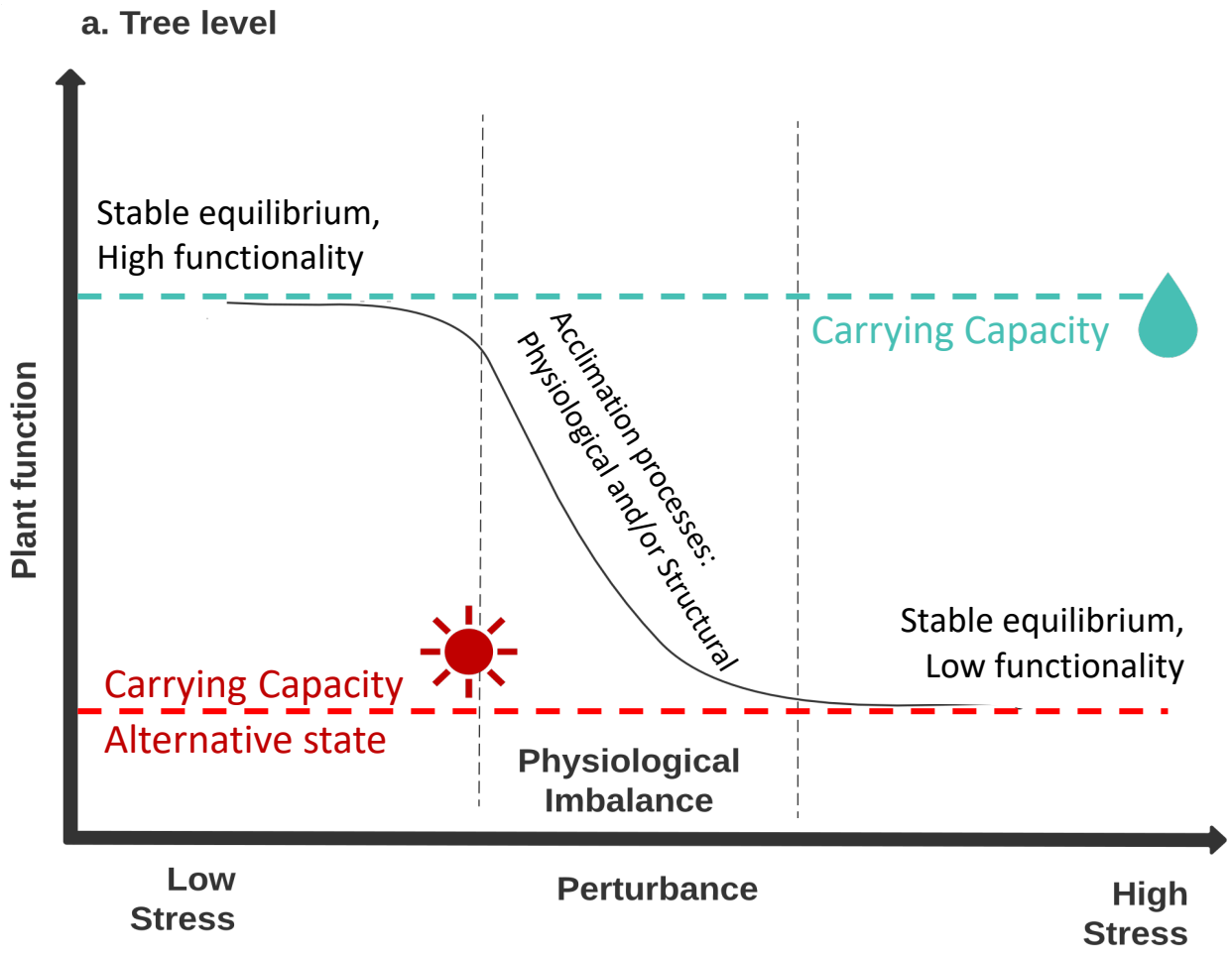


Gessler A & Zweifel R 2024

Acclimation to new environmental conditions

Carrying capacity is a term used in ecology to define the maximum load that an environment can support.

The environment's physical characteristics, such as resources, and competition, act as limiting factors. Therefore, the population's growth will depend on these factors.

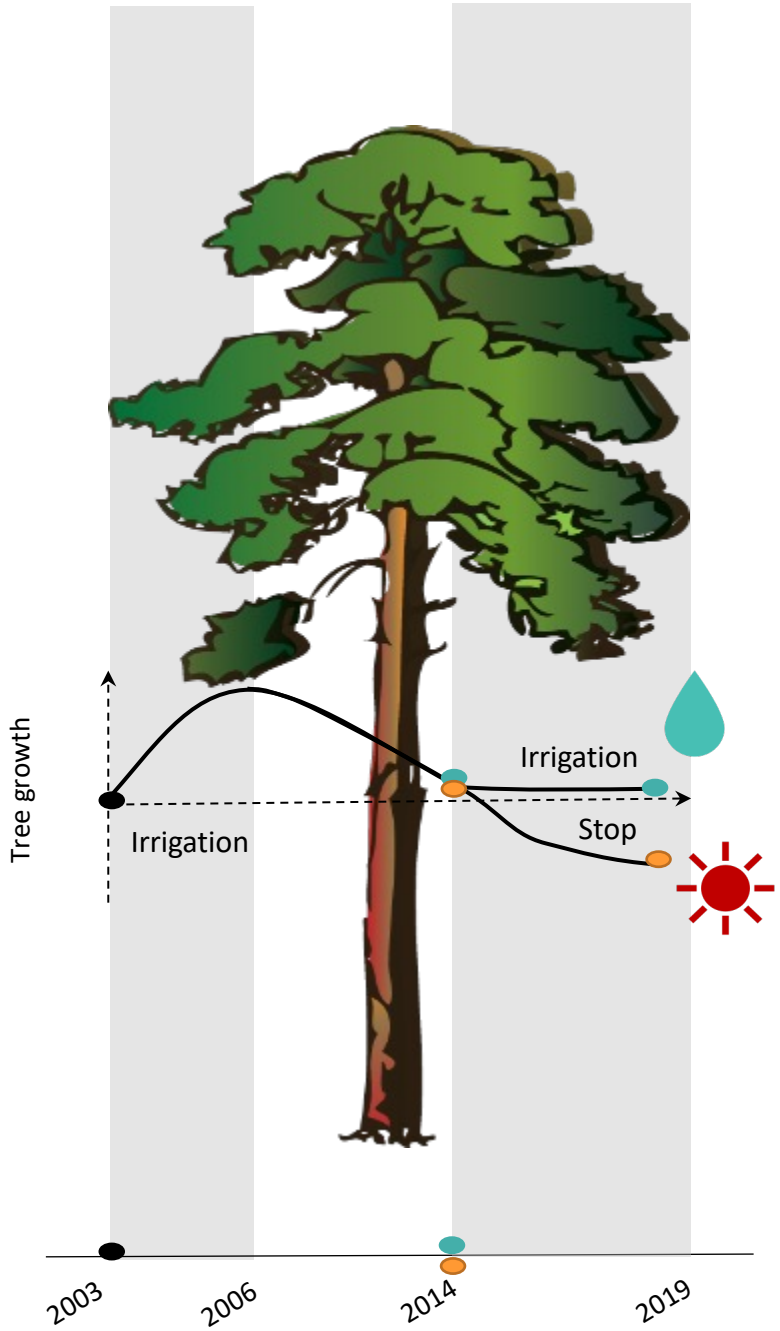


Vitali et al. 2024 GCB

Long-term irrigation experiment: Pfynwald

Pfynwald forest used for a 17-year irrigation experiment is ideal for assessing tree acclimation to water availability changes.

Testing a multiproxy approach to identify the reaching of an “acclimation equilibrium” or “physiological imbalance”.



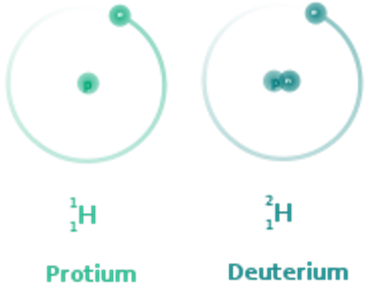
Multiproxy approach

Combining proxies provides an overview of tree functioning which can quantify the **physiological and structural acclimation** responses of trees to altered environmental conditions.

Proxy	TRW	QWA	$\delta^{13}C$-$\delta^{18}O$	O–H relationship
Inferred variables	Climate	Water transport	Photosynthetic activity	**Hydrological signature**
	Carbon allocation	Timing of cell formation	Stomatal conductance	**Metabolic impact**
Tree functioning	Growth	Hydraulic capacity	Canopy functioning	**Acclimation status**

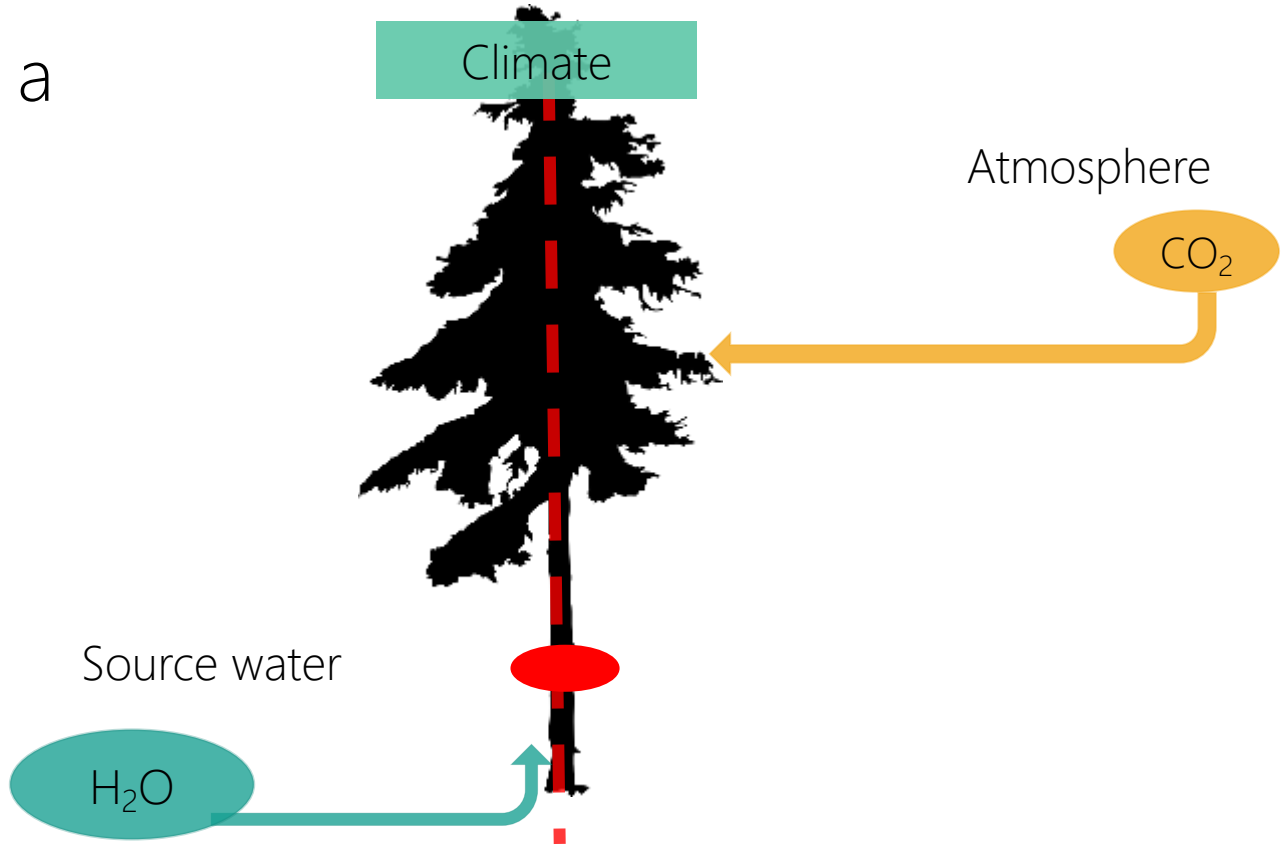
How can isotopes can be used to study acclimation?

Using isotopes as a proxy for tree physiology



Relative abundance of stable Isotopes

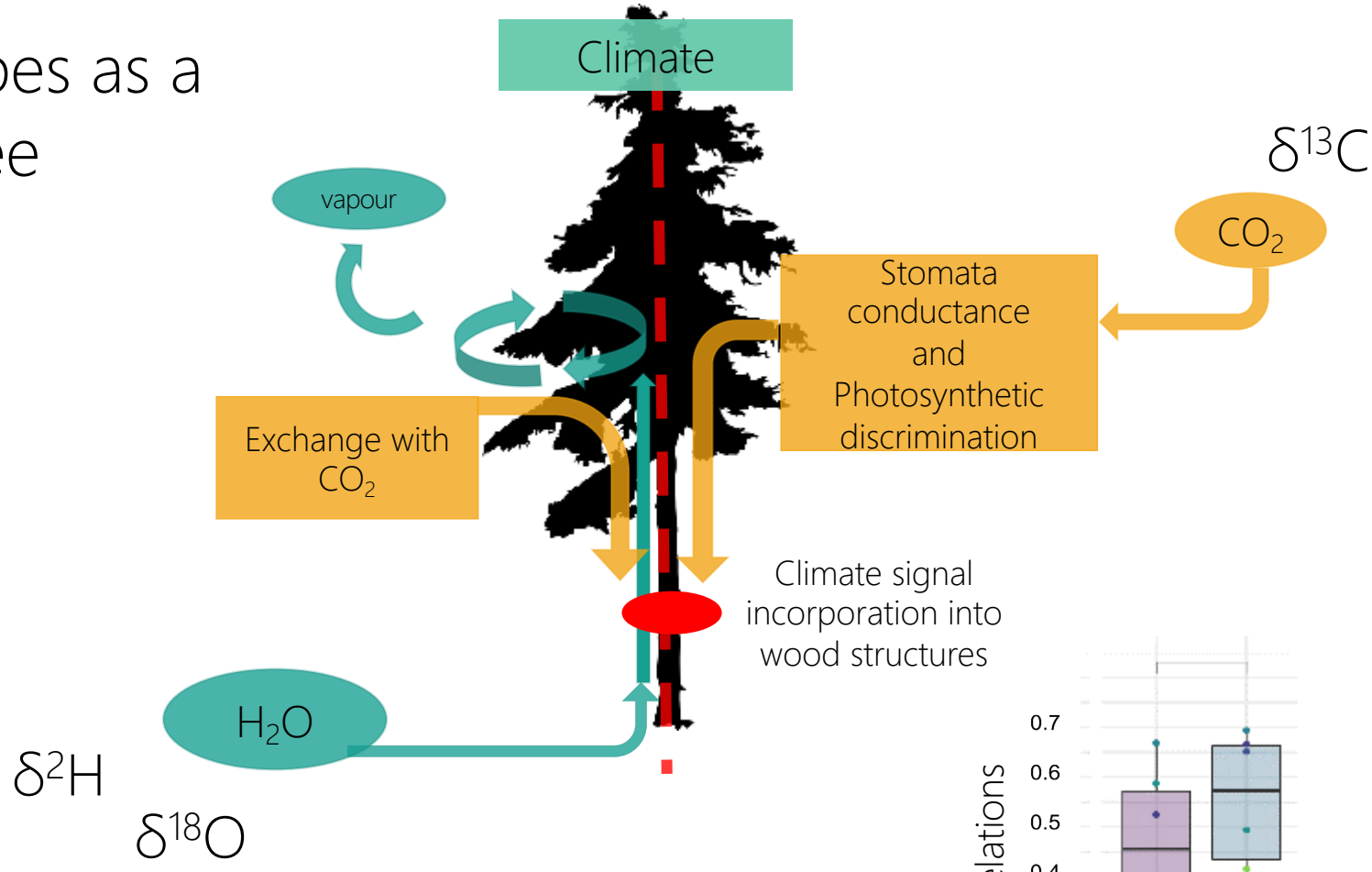
$$\delta^2H(‰) = {}^{2}H/_{1}H$$



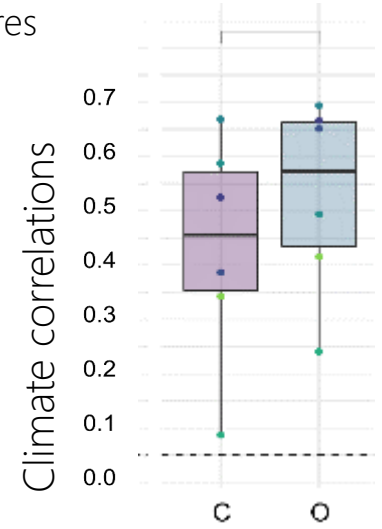
Relative abundance is affected by physical (evaporation) and biochemical (photosynthesis) processes.

The change between source and product creates a **unique fingerprint that allows us to "reverse engineer" these processes**.

Using isotopes as a proxy for tree physiology

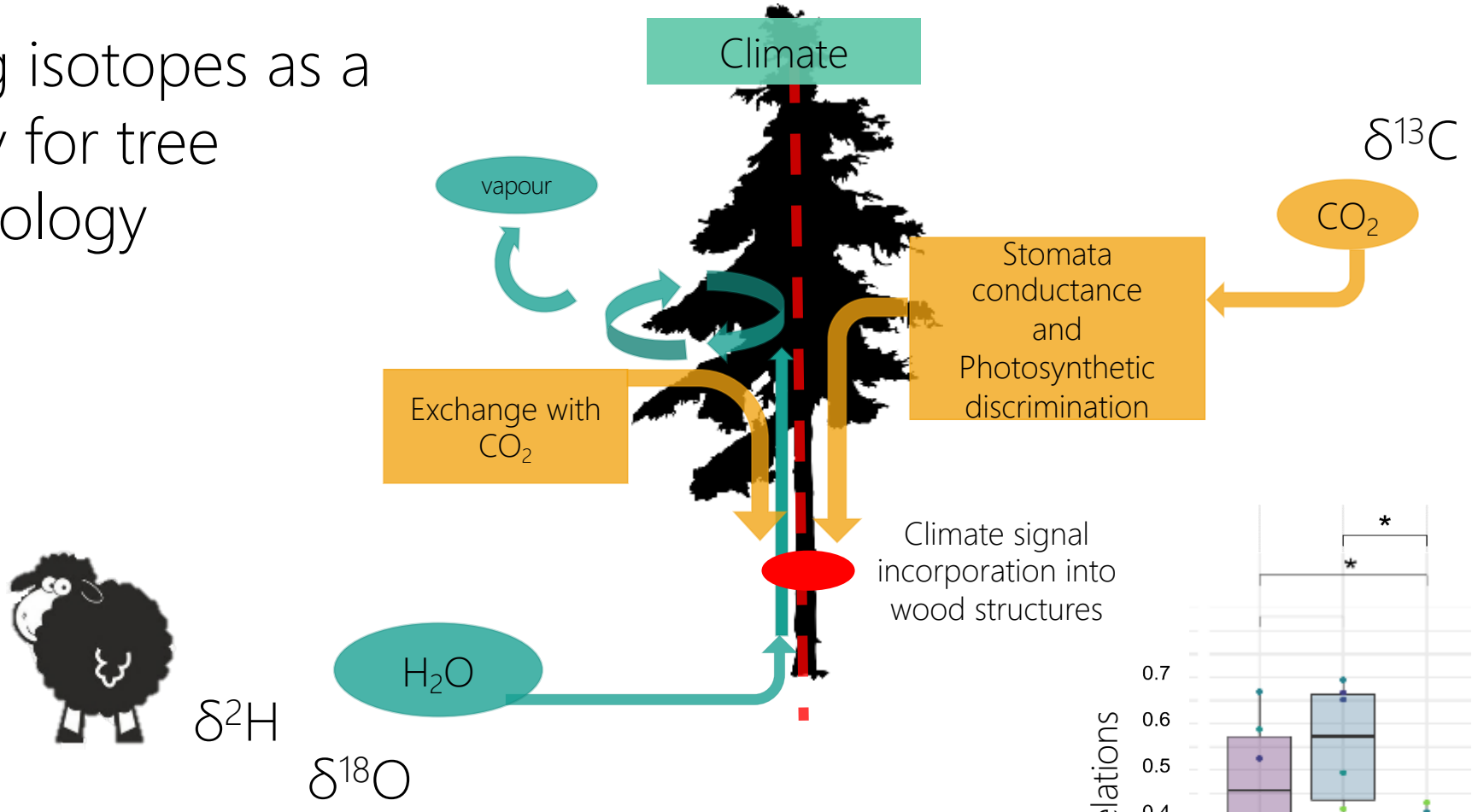


Tree-ring cellulose isotopes can be used as proxies for climate reconstruction.



Vitali et al. 2022 STOTEN

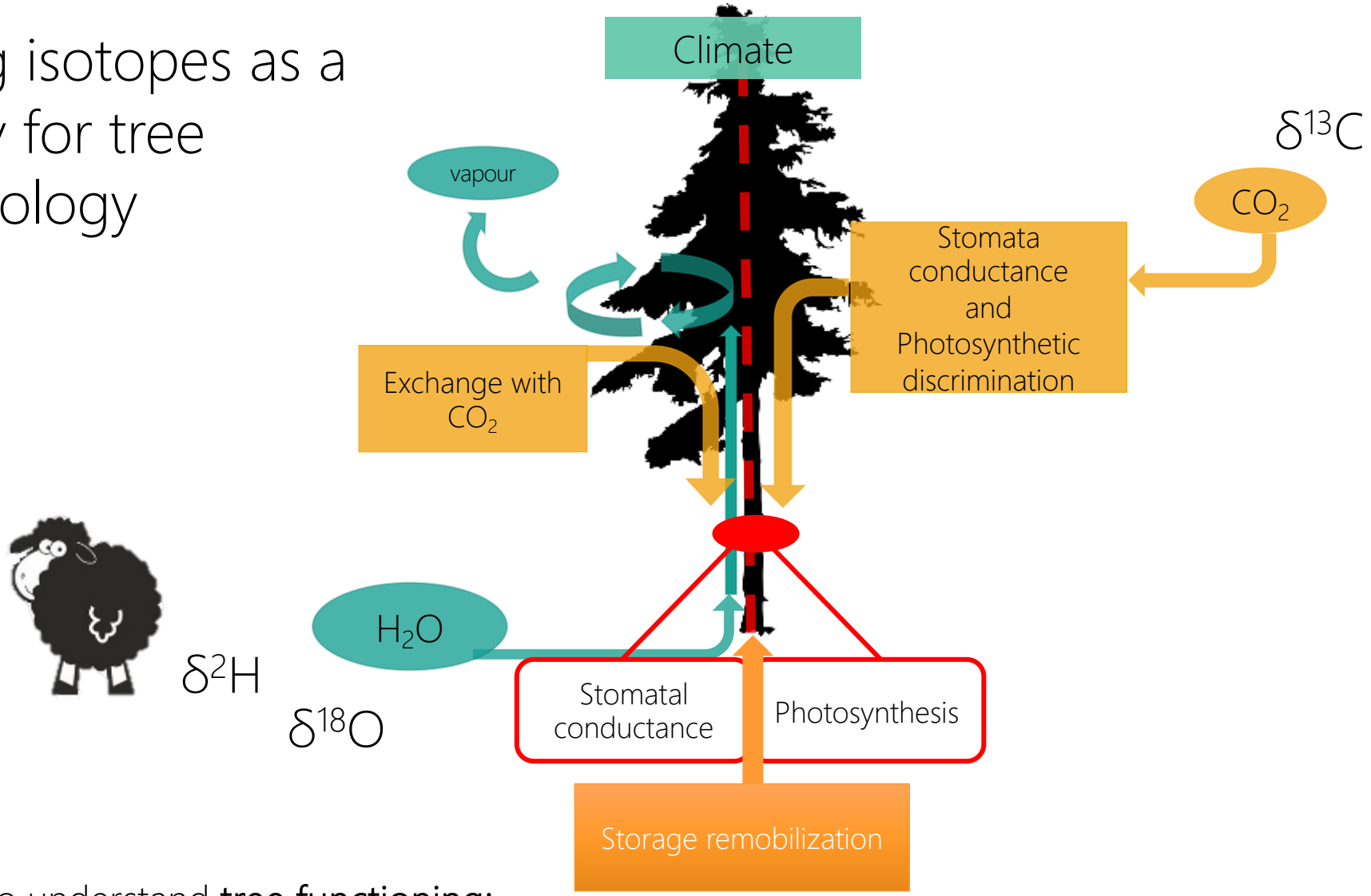
Using isotopes as a proxy for tree physiology



The O and H isotopes should hold a source water "signal".
However, the H climatic signal was significantly weaker than O.

Vitali et al. 2022 STOTEN

Using isotopes as a proxy for tree physiology



But also to understand **tree functioning:**

Tree-ring cellulose $\delta^{18}O$ $\delta^{13}C$ are proxies for stomata conductance and photosynthetic rates.

$\delta^{2}H$ records shifts in autotrophic versus heterotrophic processes.

Vitali et al. 2022 STOTEN
Vitali et al. 2023 Tree Phys.

The O-H hypothesis

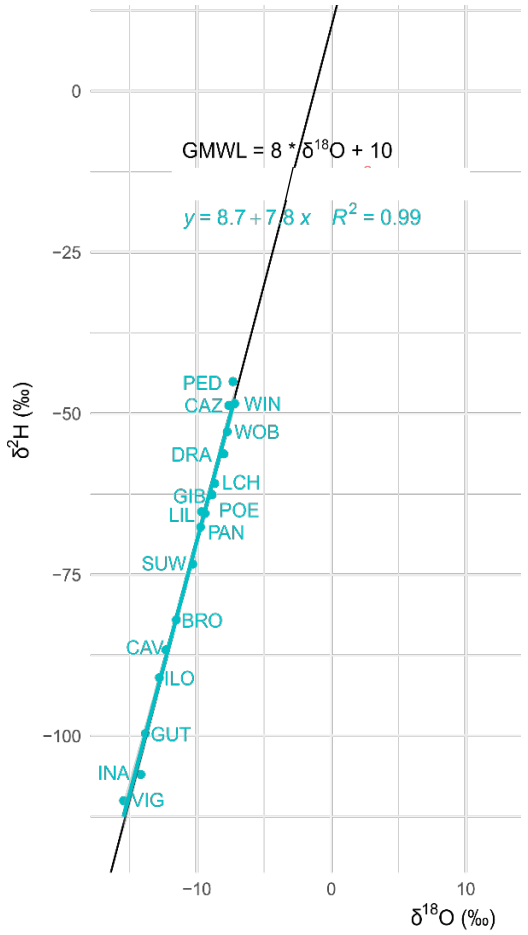
The $\delta^{18}O$-$\delta^{2}H$ relationship in precipitation follows the Global Meteoric Water Line.

However, in tree-rings cellulose, this relationship becomes site and species-specific due to changes related to plant metabolism.

The OH relationship indicates how tree physiology modifies the hydrological signal.

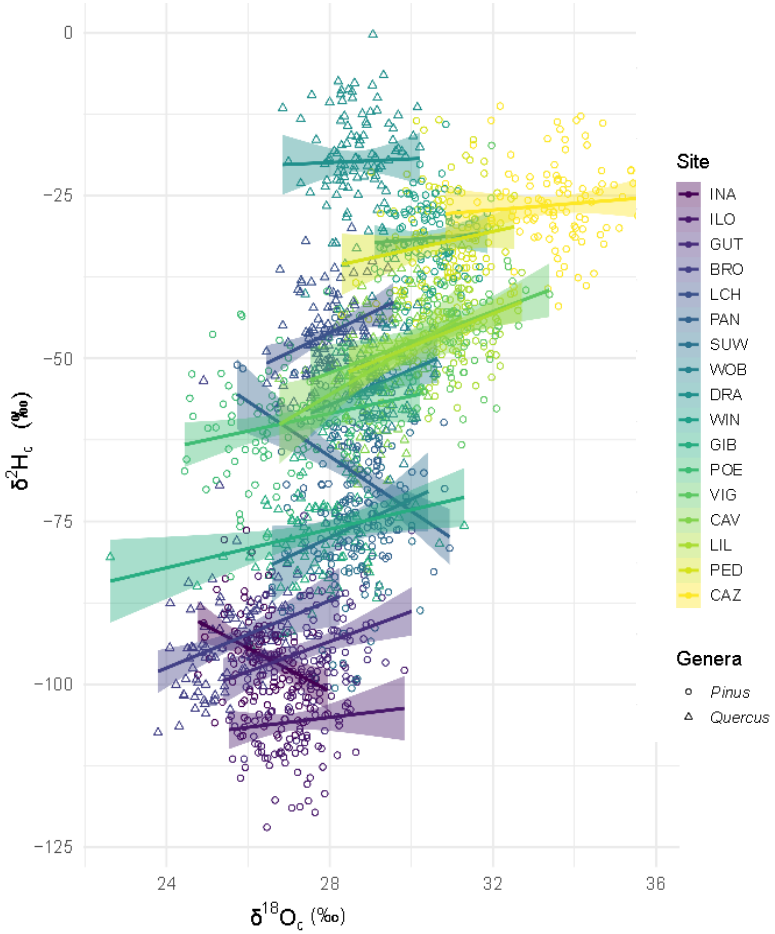
The $\delta^{18}O$ - $\delta^{2}H$ relationship

Site-level precipitation



Hydrological signal

Tree-ring cellulose



Mix of physiological, hydrological and climatic signal

Vitali et al. 2022

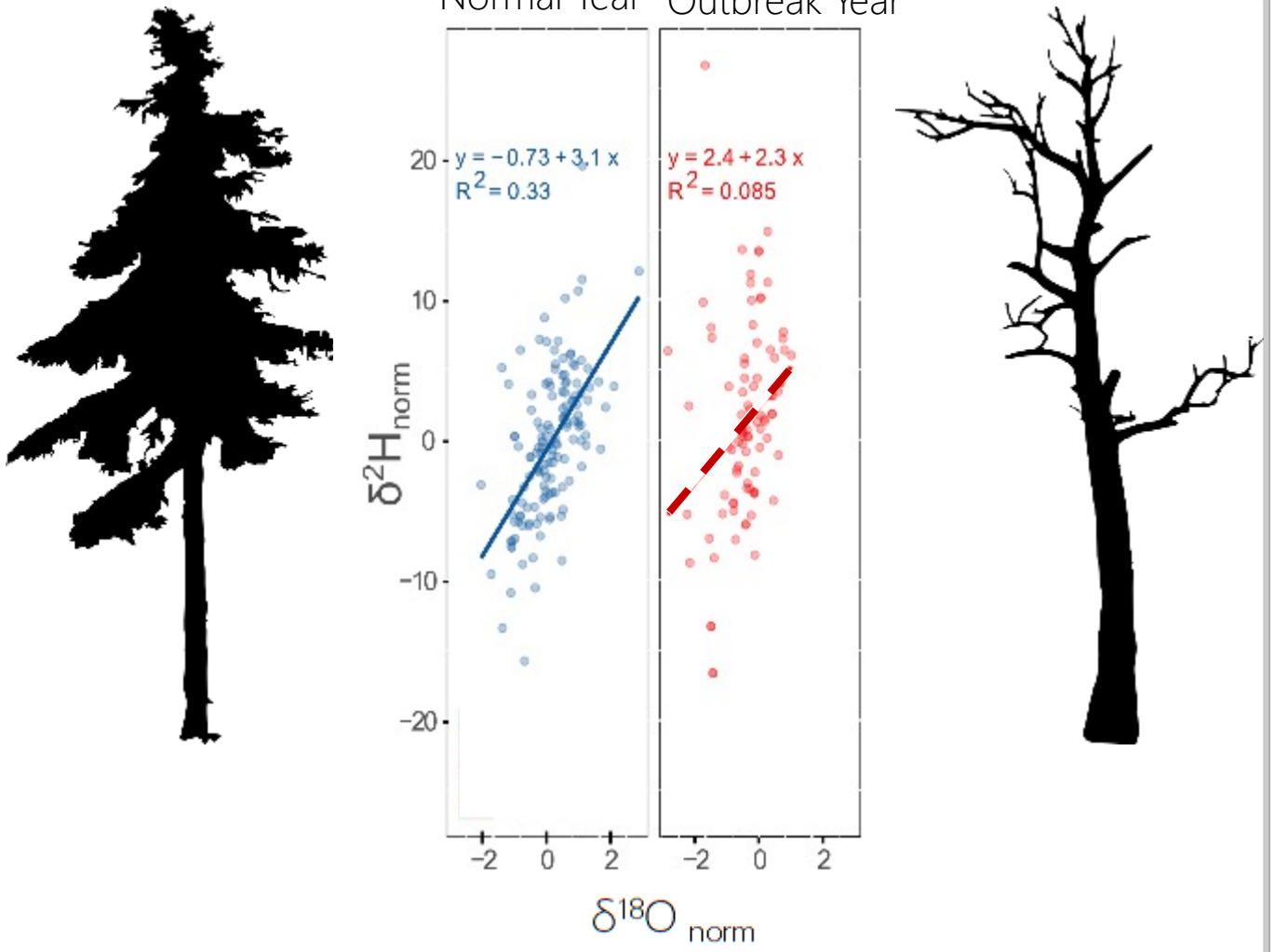
The O-H hypothesis

A decoupling between δ^2H $\delta^{18}O$ is found in cases of "physiological imbalance".

In the case of LBM, indicated an imprinting of resource remobilization.

Can we see imbalance

Defoliation fingerprint in larch budmoth outbreaks

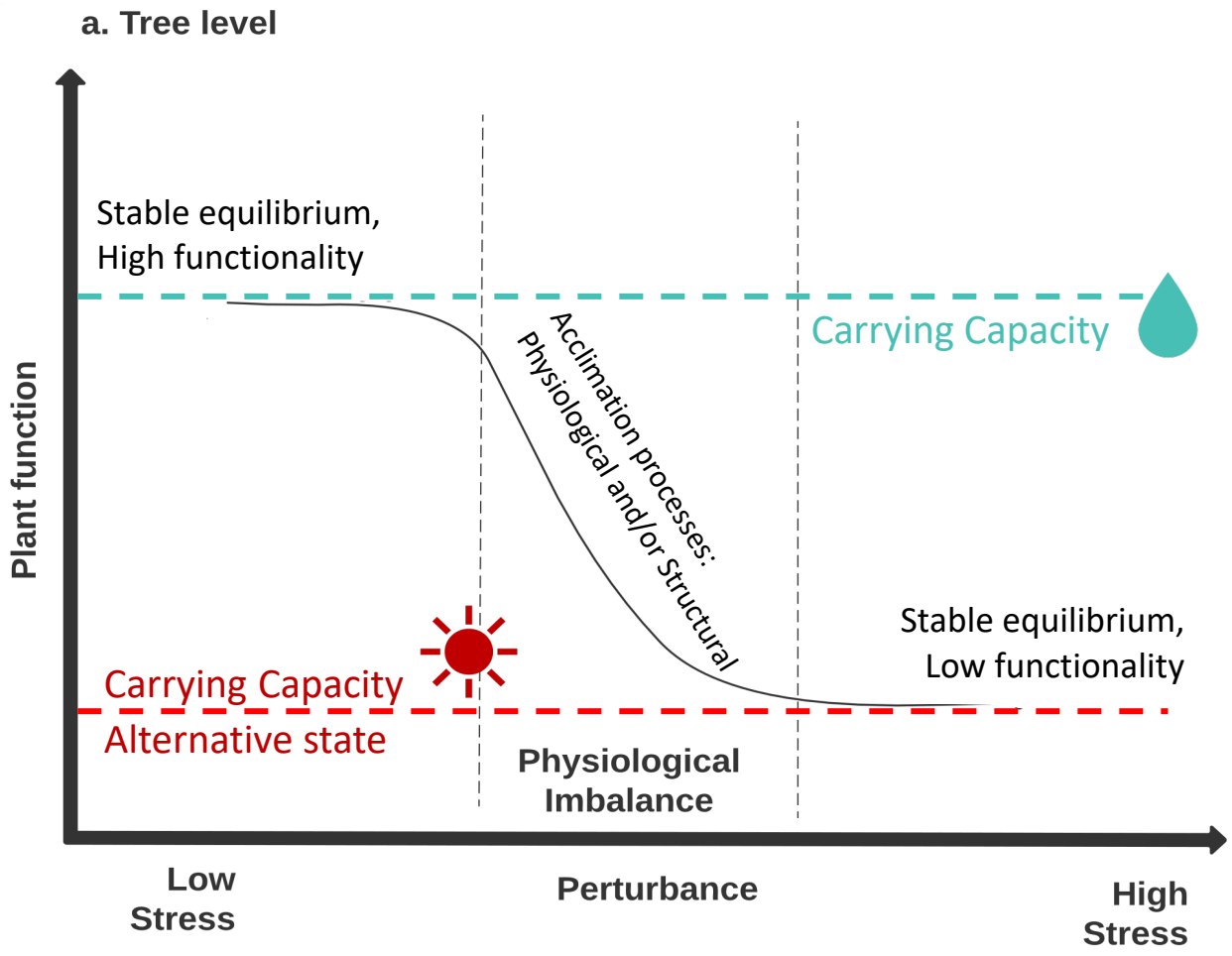


Hydrological signal vs. Physiological signal

Vitali et al. 2023.

Acclimation to new environmental conditions

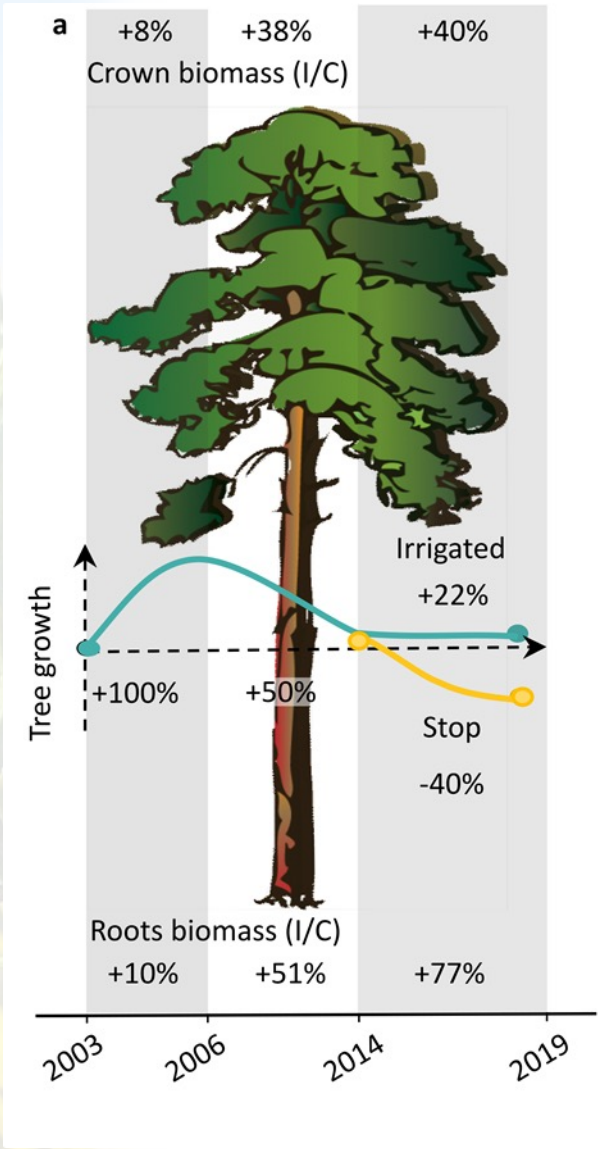
Can we use the OH relationship to identify an "imbalance" in growth?

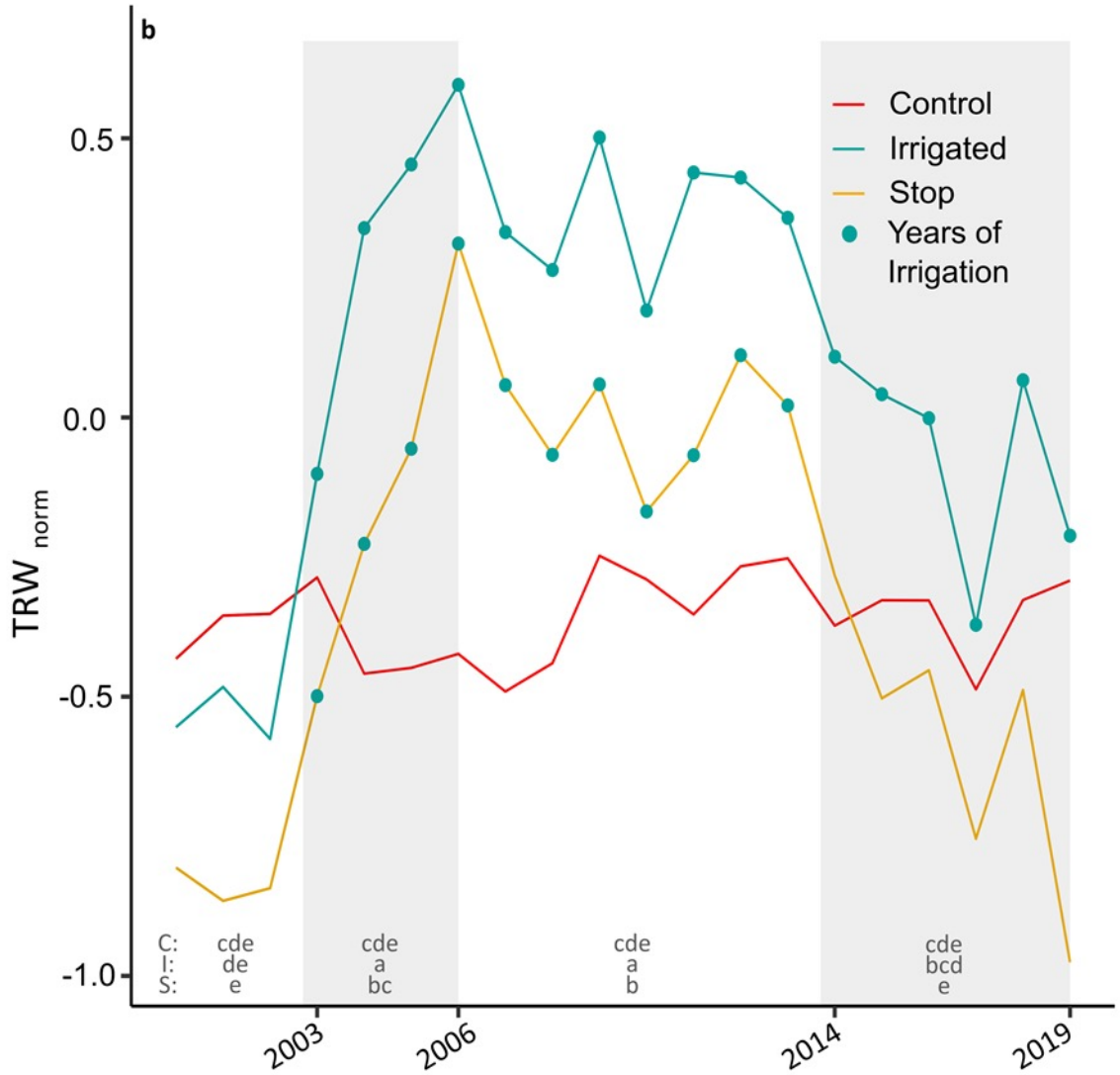


Vitali et al. 2024 GCB

Long-term treatment effects

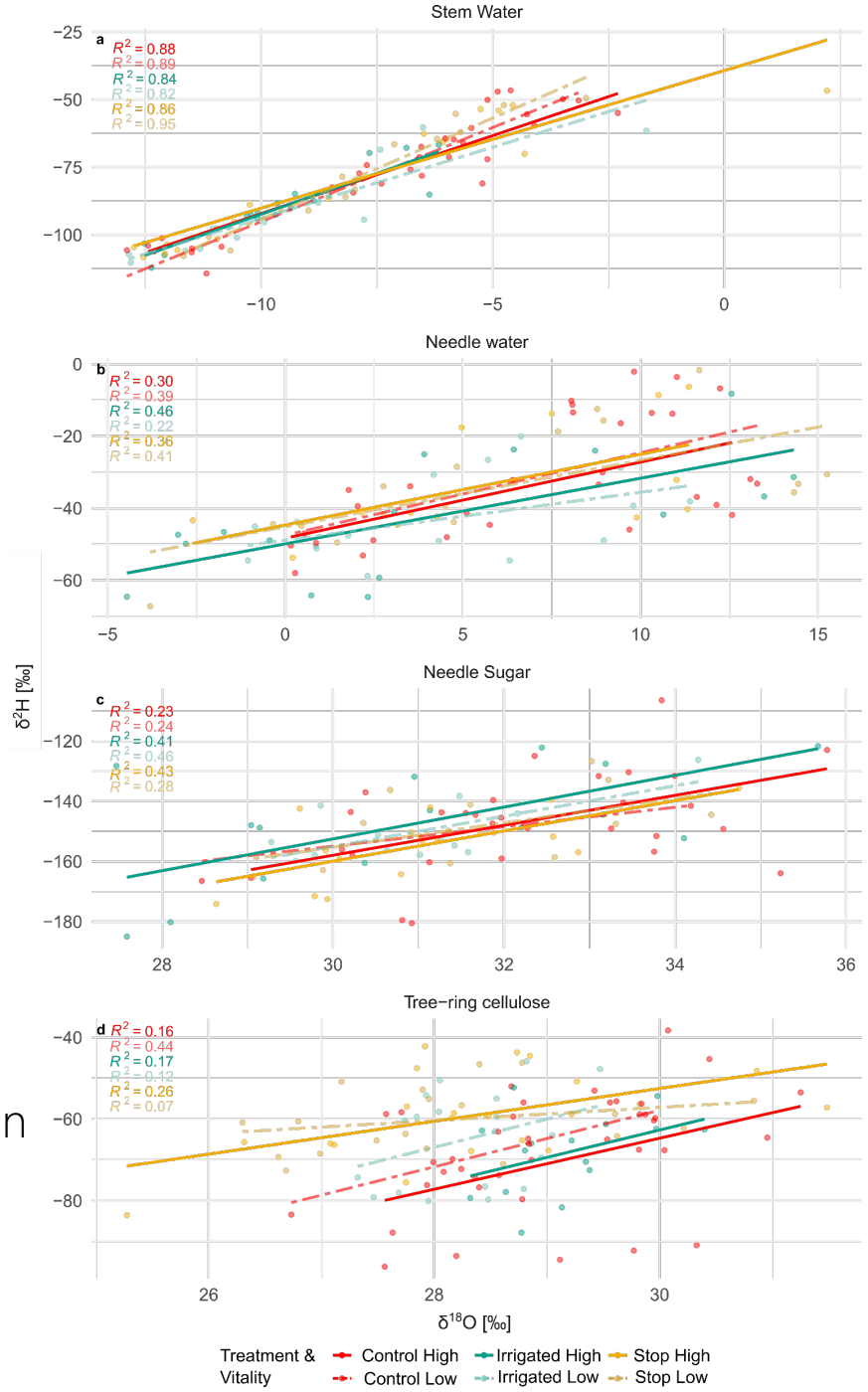
We observed changes in growth patterns during the Pfynwald experiment, which reflected changes in isotopic composition of tree ring cellulose



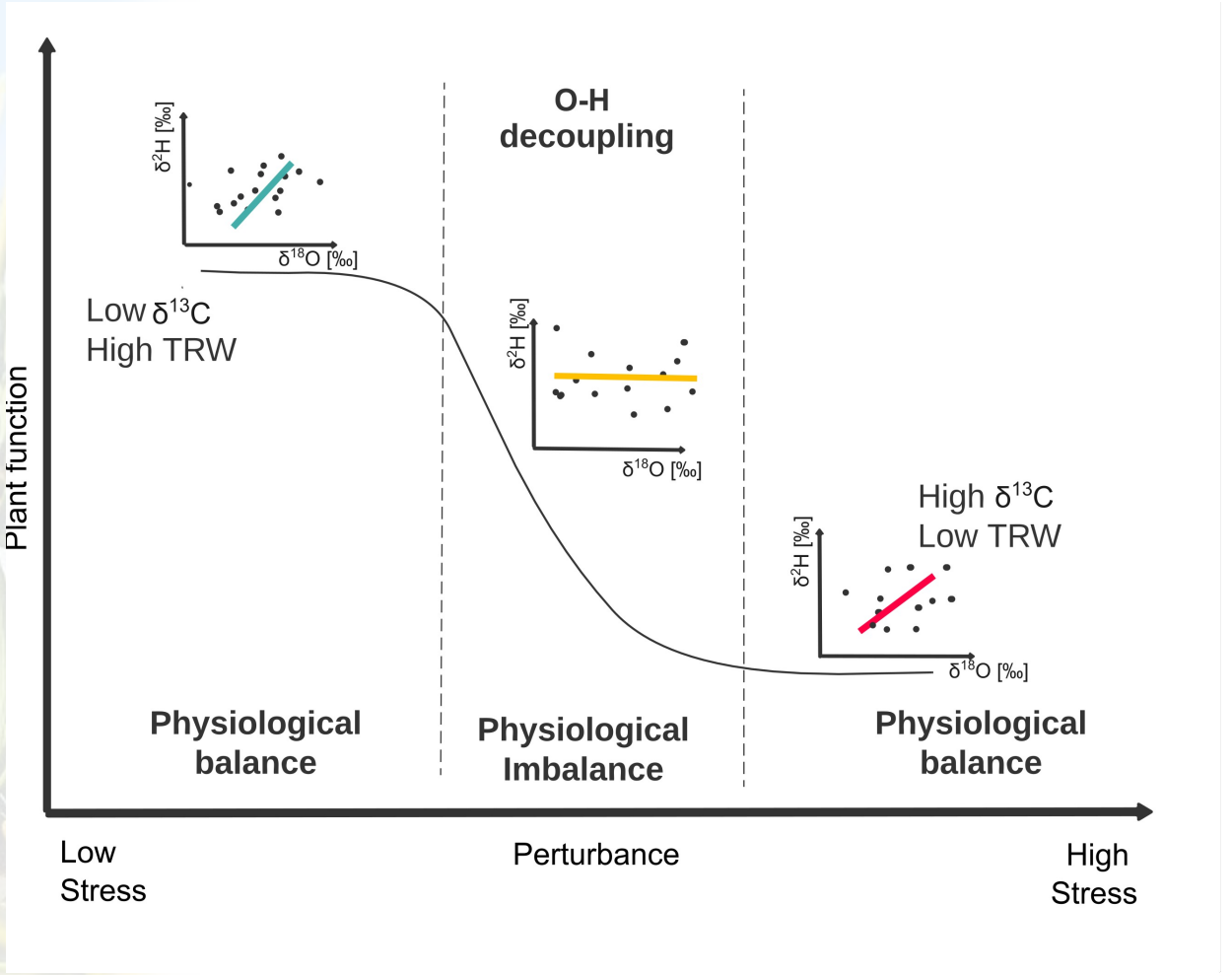


The O-H relationship across plant tissues

Changes of the O-H relationship between treatment become evident in the tree-ring cellulose

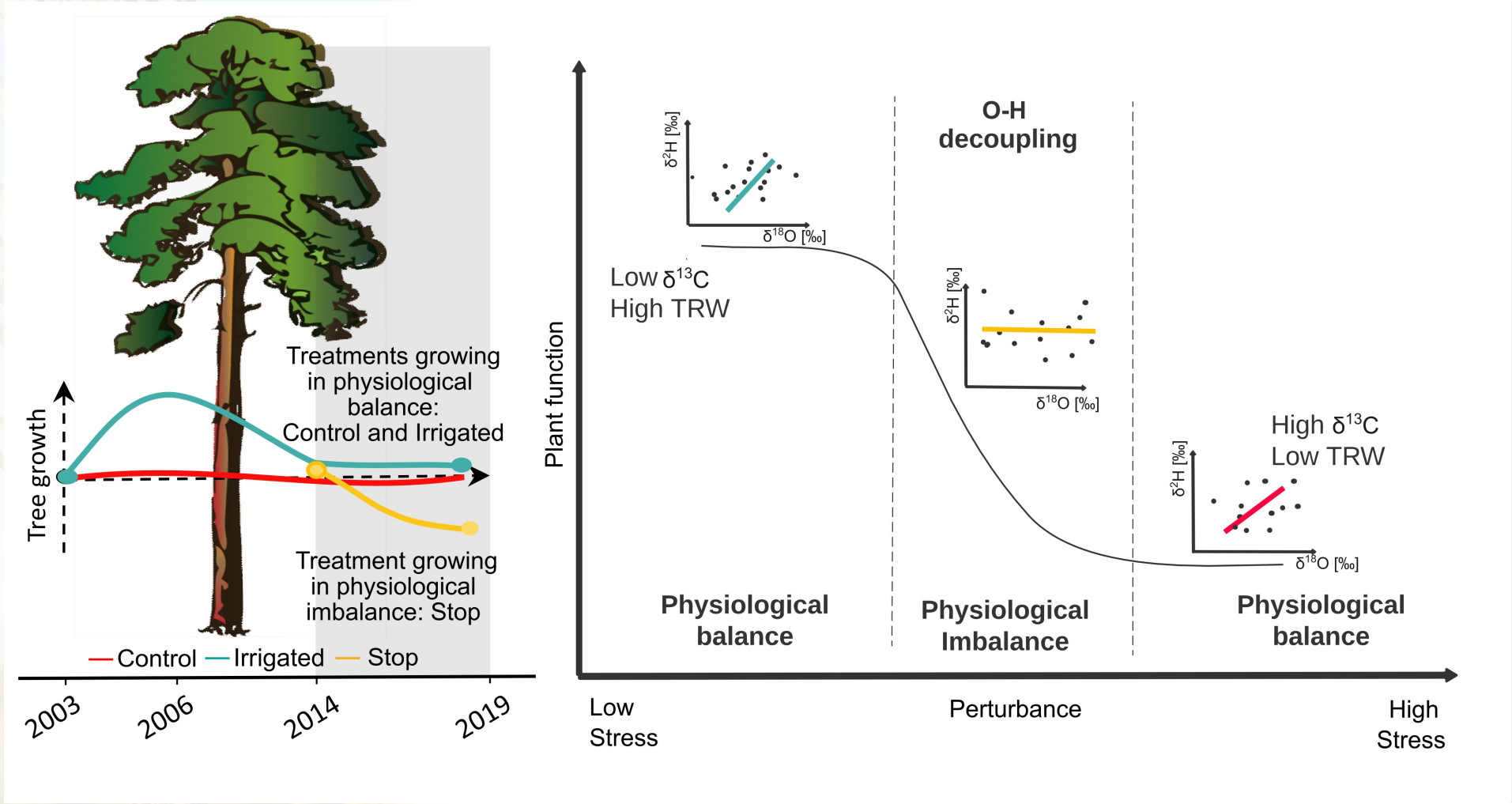


The acclimation slope and the multi-proxy measures



By using a multiproxy approach, which combines data from different parts of trees and different time resolutions, we can gain a better understanding of the tree's physiology, stages of acclimation, or shifts between steady states.

Take home message



This information can be used as an early warning sign of an unbalanced ecosystem, which could lead to lower functioning states and potentially mortality if the acclimation processes are insufficient.

Thank you for your attention

Questions @ valentina.vitali@wsl.ch

References

Vitali, V. , Martínez-Sancho E., Treydte, K., Andreu-Hayles L., Dorado-Liñán, I., Gutierrez, E., Helle, G., Leuenberger, M., Loader, N., Rinne-Garmston K.T., Schleser, G.H., Allen, S., Waterhouse J.S., Saurer, M., Lehmann, M. M. (2022) The unknown third – Hydrogen isotopes in tree-ring cellulose across Europe. Science of The Total Environment.

Vitali V, Peters RL, Lehmann MM, Leuenberger M, Treydte K, Büntgen U, Schuler P, Saurer M (2023) Tree-ring isotopes from the Swiss Alps reveal non-climatic fingerprints of cyclic insect population outbreaks over the past 700 years. Tree physiology.

Vitali, Valentina; Schuler, Philipp; D'Odorico, Petra; Guidi, Claudia; Klesse, Stefan; Lehmann, Marco M. et al.(2024): Finding balance: Tree ring isotopes differentiate between acclimation and stress-induced imbalance in a long-term irrigation experiment. In preprint.

Art from kittl.com

Isotopes-Team @WSL

Matthias Saurer

Marco Lehmann

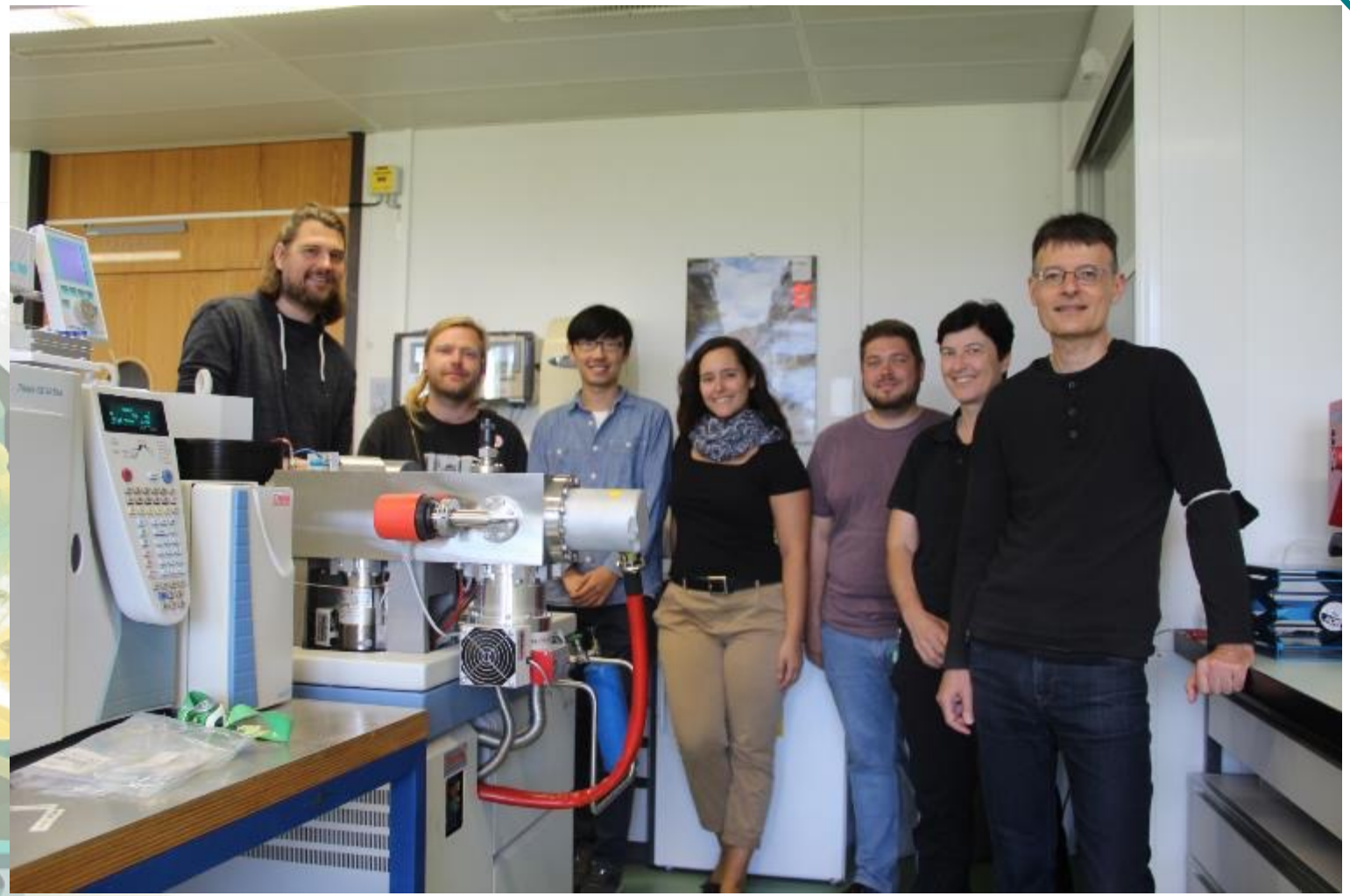
Manuela Oettli

Haoyu Diao

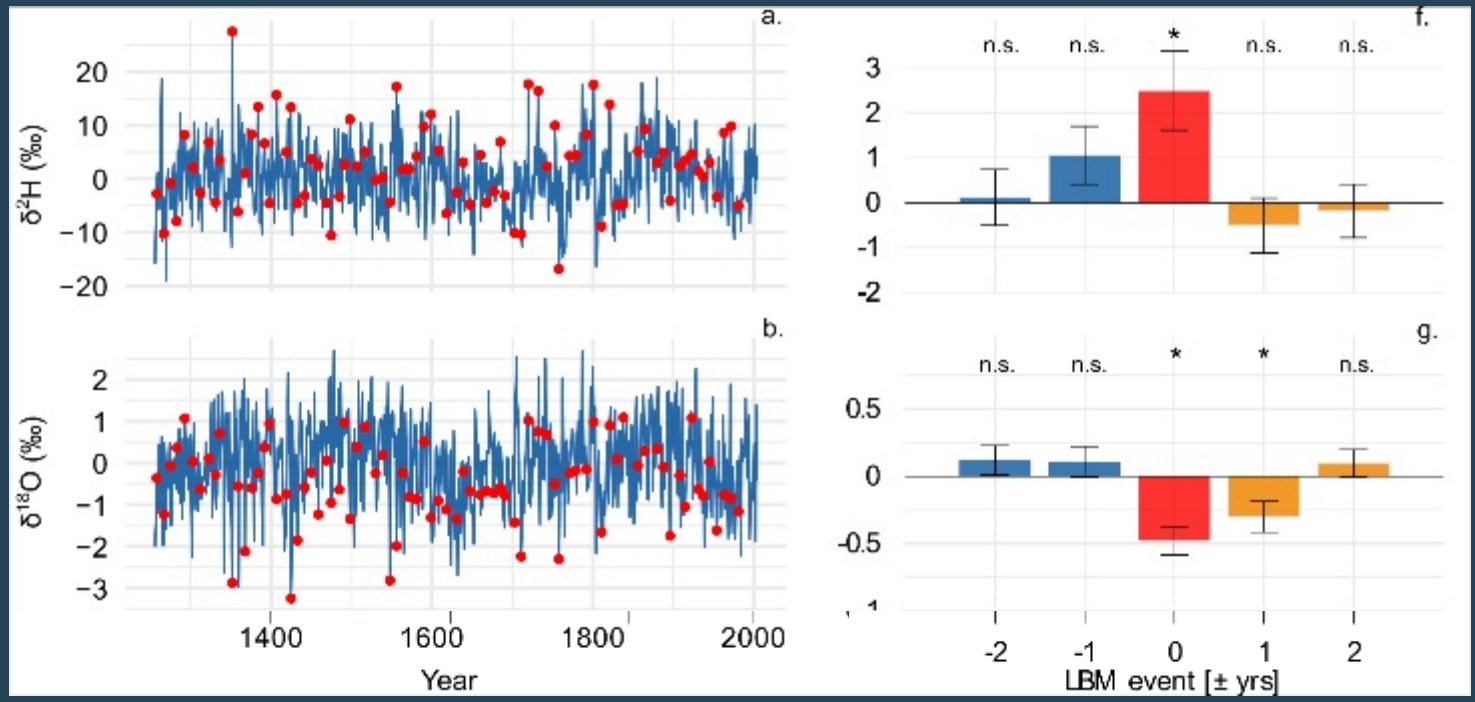
Philiph Schuler

Oliver Rehmann

Vitali Valentina



"O-H-decoupling" observed during LBM-outbreaks



In defoliation years δ^2H are significantly enriched and $\delta^{18}O$ depleted, compared to normal years.

Older NSCs isotope signal is modified by post-photosynthetic isotope fractionations:

^{18}O-depletion during the transport of sugars to sink tissues and tree-ring cellulose synthesis (Gessler et al., 2014),

^{2}H-enrichment is connected to the use of C reserves, and heterotrophic metabolism (Kimak et al., 2015).

(Vitali V., et al 2023)