Water and forests
in the Mediterranean: what future?

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Experimental sites


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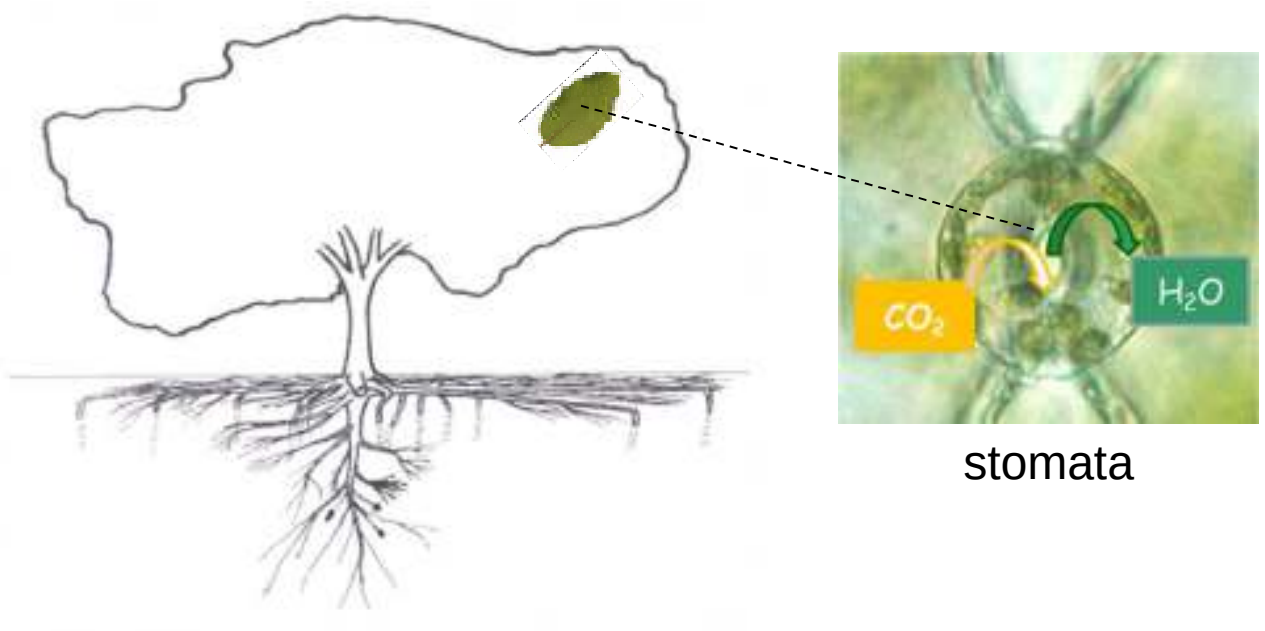
Background

Water is considered as the most limiting factor for tree survival, forest productivity and ecosystem diversity worldwide (Choat *et al*., 2012; Engelbrecht, 2012).

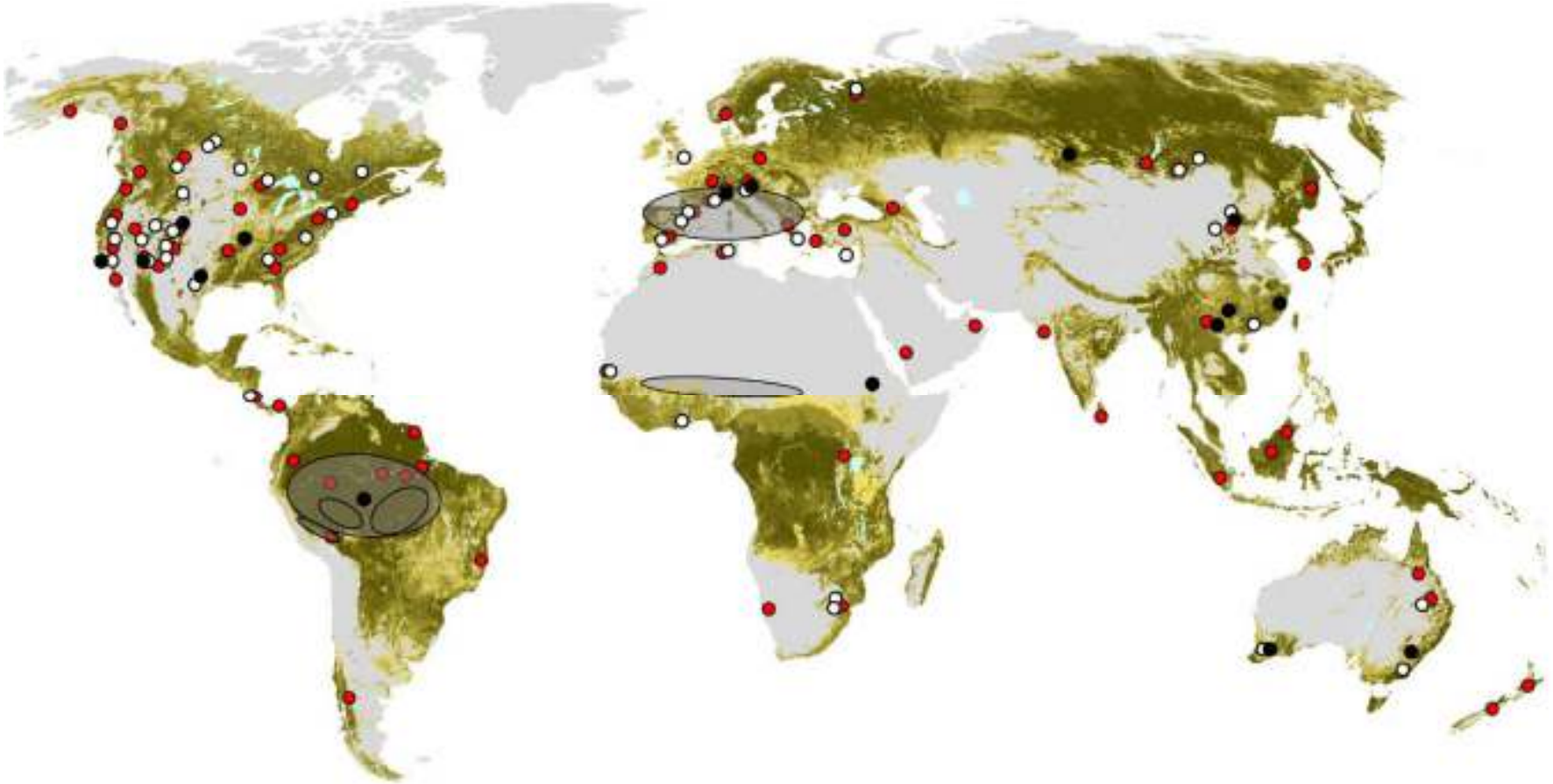


stomata

The trade-off of water for carbon

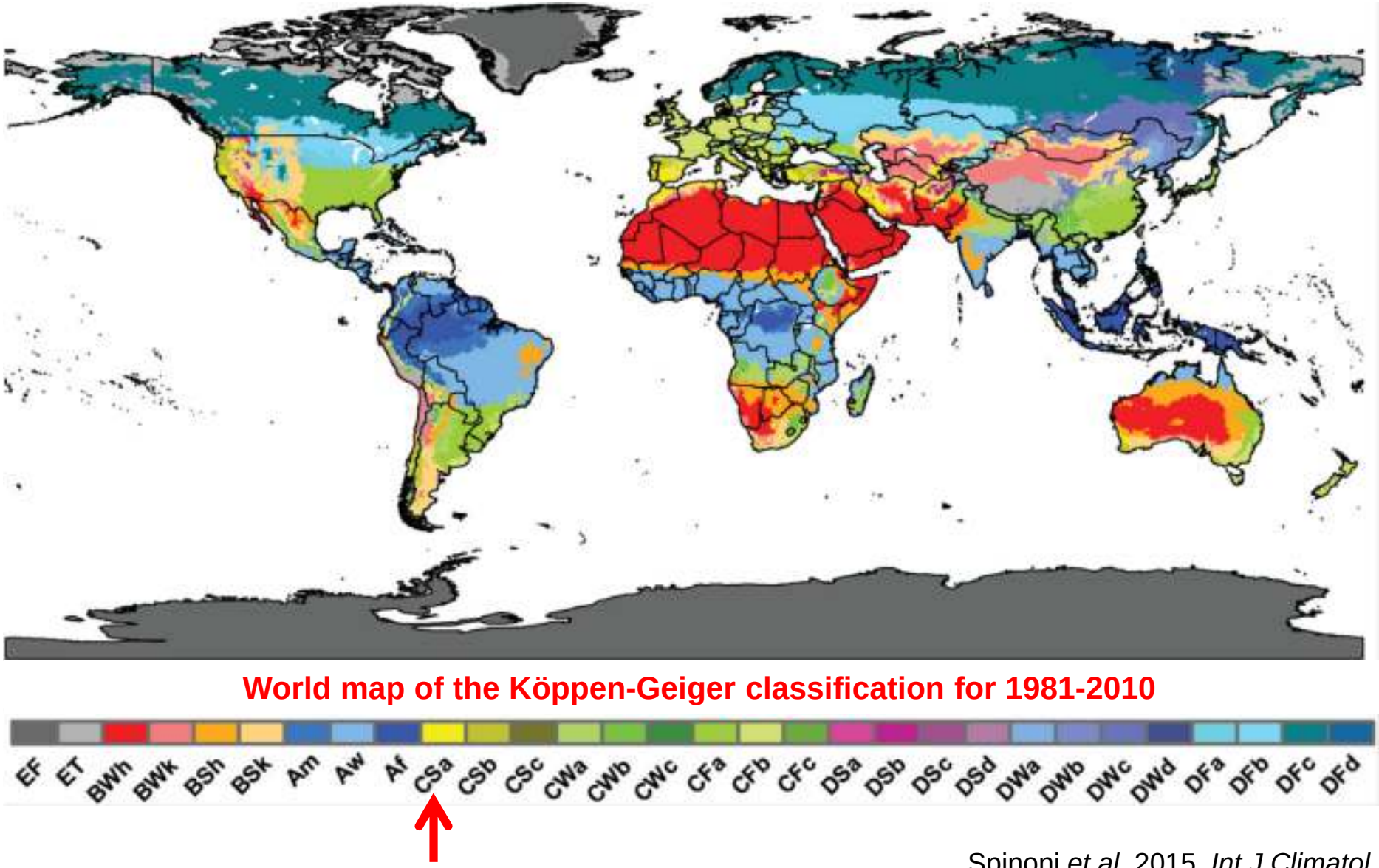
Transpiration is the cost of photosynthesis

Reported locations of enhanced tree mortality (drought-induced and heat-induced) across the globe



Allen *et al*. 2015, *Ecosphere*

In the Mediterranean hot climate zones aridity is increasing



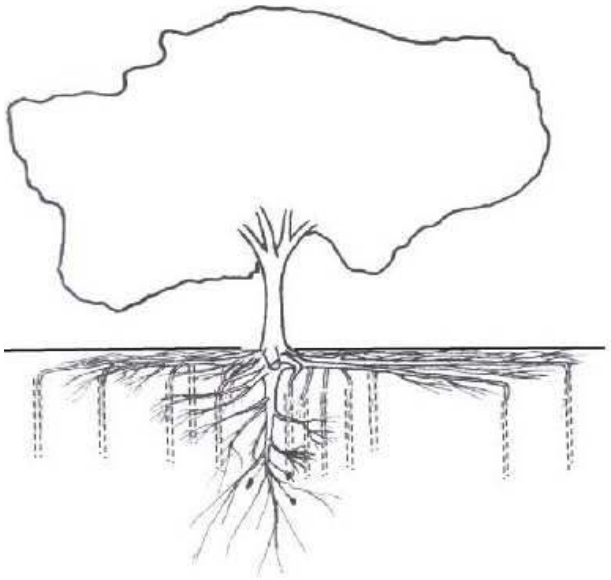
World map of the Köppen-Geiger classification for 1981-2010

Spinoni *et al*. 2015, *Int J Climatol*

Water and Mediterranean evergreen trees

- In these areas annual evapotranspiration largely exceeds rainfall
- Summer periods are hot and dry
- Soils are often shallow and/or with low water retention capacity
- Evergreen trees are prone to suffer some degree of water and heat summer stress

To cope with drought trees developed structural and physiological atributes (Baldocchi & Xu, 2007; David *et al*., 2007; Sardans & Peñuelas, 2013)

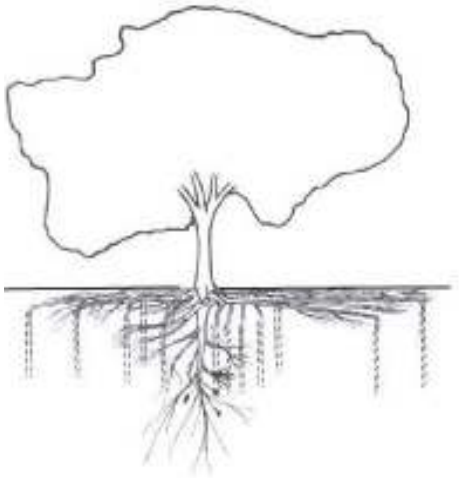


- **restricting water losses**
- **maximizing water uptake**
- **xylem resistant to cavitation**

Water and Mediterranean evergreen trees

- Cork oak (*Q. suber* L.) is an evergreen tree native to the western Mediterranean Basin, occupying large areas in the Iberian Peninsula.

- Portugal and Spain contribute to about 80% of the world cork production and exports (APCOR, 2014).



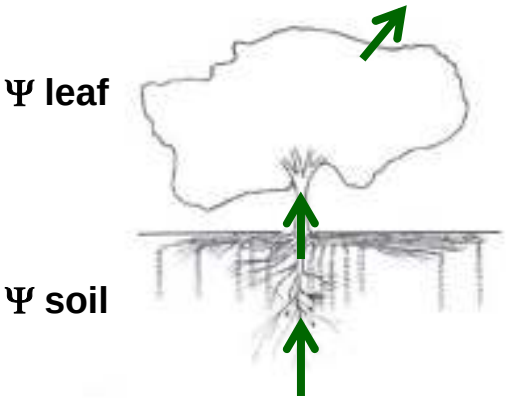
Based on a hydraulic interpretation of tree functioning, drought adaptive strategies of cork oak trees are presented for 2 experimental sites under different edaphic and climatic conditions (southern of Tagus river)

Site 1 - no summer water stress
Site 2 - some degree of summer water stress

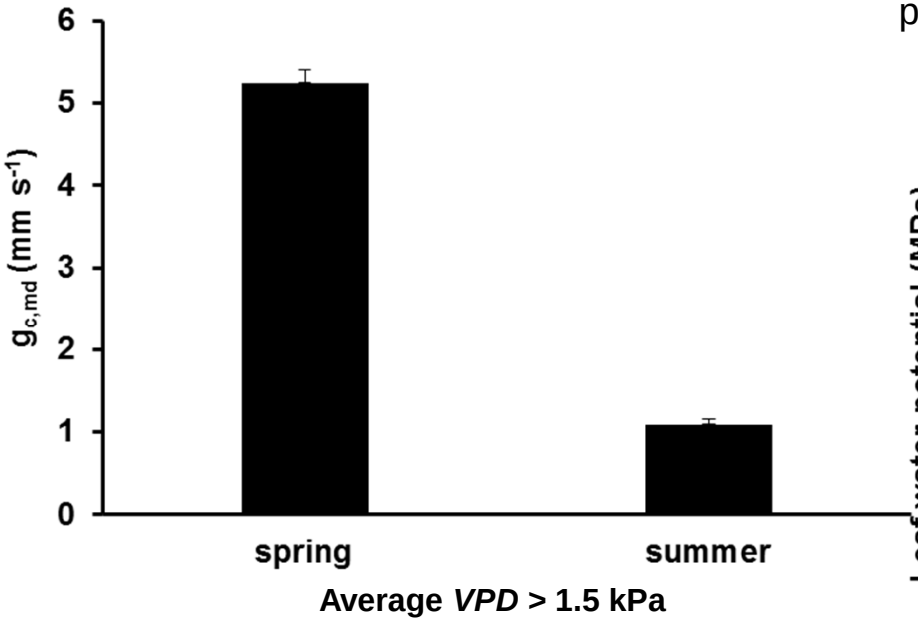
Restricting water losses – stomatal control

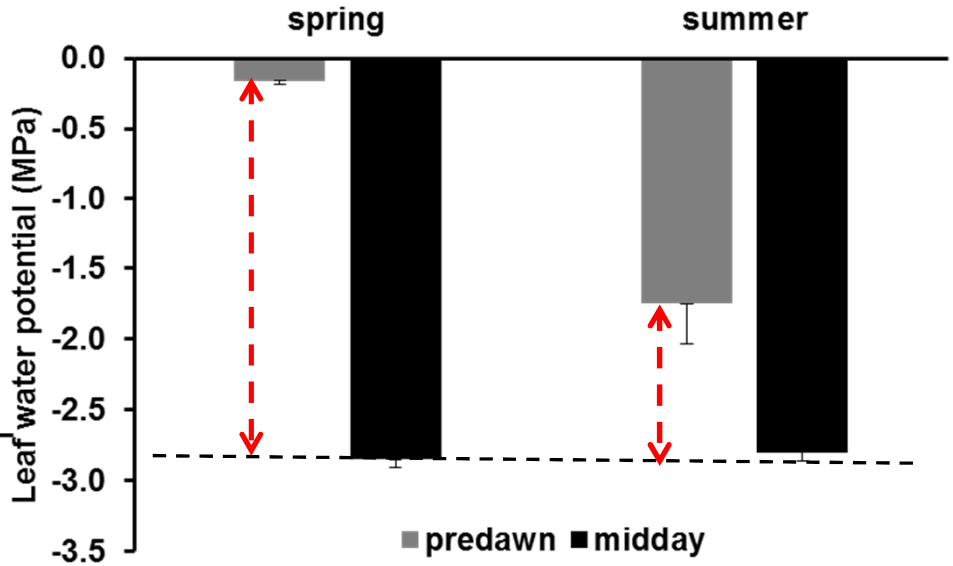
$$T = - k_{sl} (\Psi_{soil} - \Psi_{leaf})$$ Darcy Law

Sap flow driving force



Midday stomatal conductance ($g_{c,md}$) decreased from spring to summer in response to increased vapour pressure deficit *(VPD)* (stomata act as pressure regulators preventing midday leaf water potential from decreasing below a critical threshold)

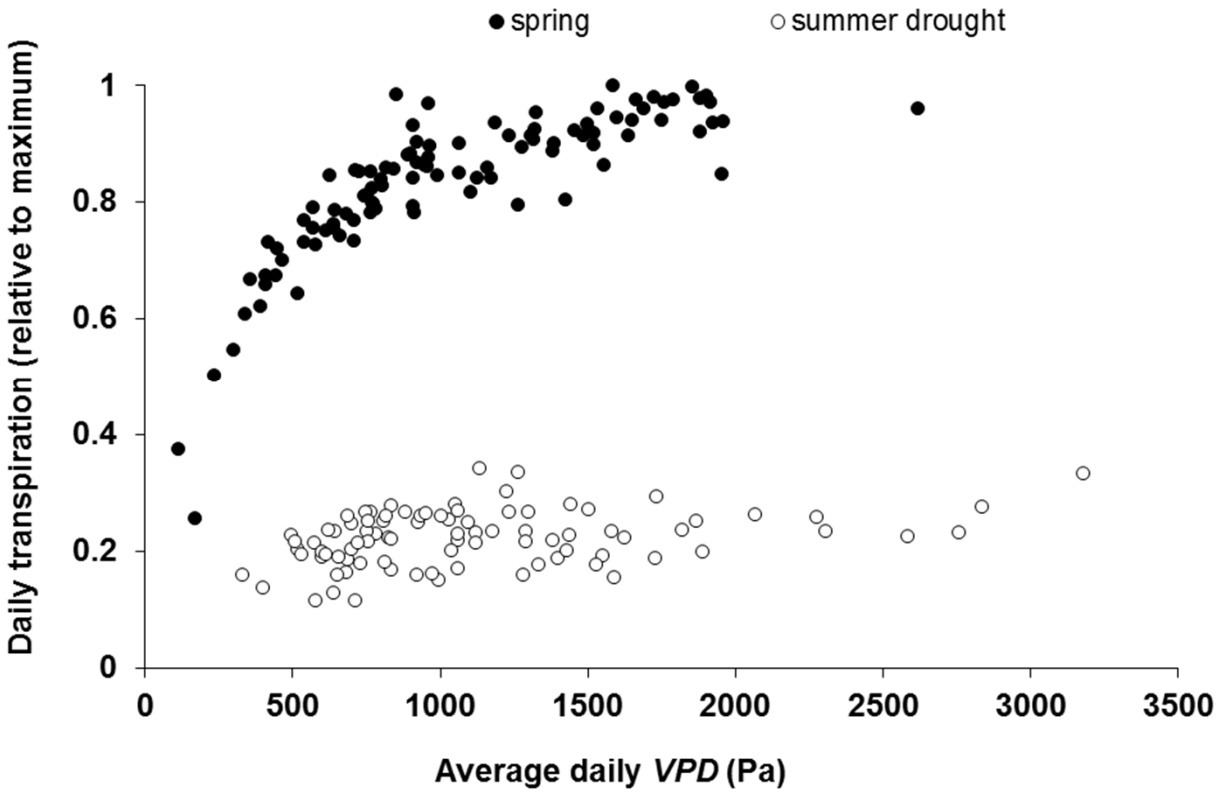




Cork oak trees
Site 2: summer water stress

Adapted from David *et al*. 2007, *Tree Physiol*

Restricting water losses – stomatal control



Distinct transpiration plateaus
(sap flow driving force decreased from spring to summer: midday leaf water potential remained stable, while predawn leaf water potential decreased due to restrictions in water availability)

Cork oak trees
Site 2: summer water stress

Maximizing water uptake – root structure

- Environmental conditions
  - Water availability
  - Shallow soils/compact horizons
  - Soils with prolonged waterlogging
  - Consolidated/fractured bedrock
- Tree age
- Coexistance with other species

Water and Mediterranean evergreen trees

Maximizing water uptake – root structure

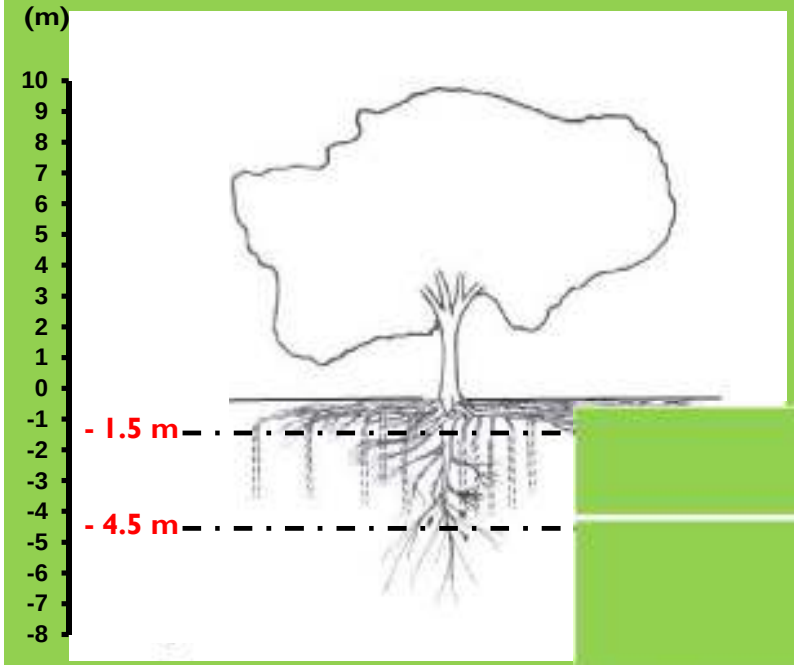
David *et al*. 2004, Agr For Met; David *et al*. 2007, Tree Physiol

Maximizing water uptake – root structure

Cork oak trees
Site 1: no summer water stress

David *et al*. 2013, *Forest Ecol Manag*

Maximizing root water uptake – water sources



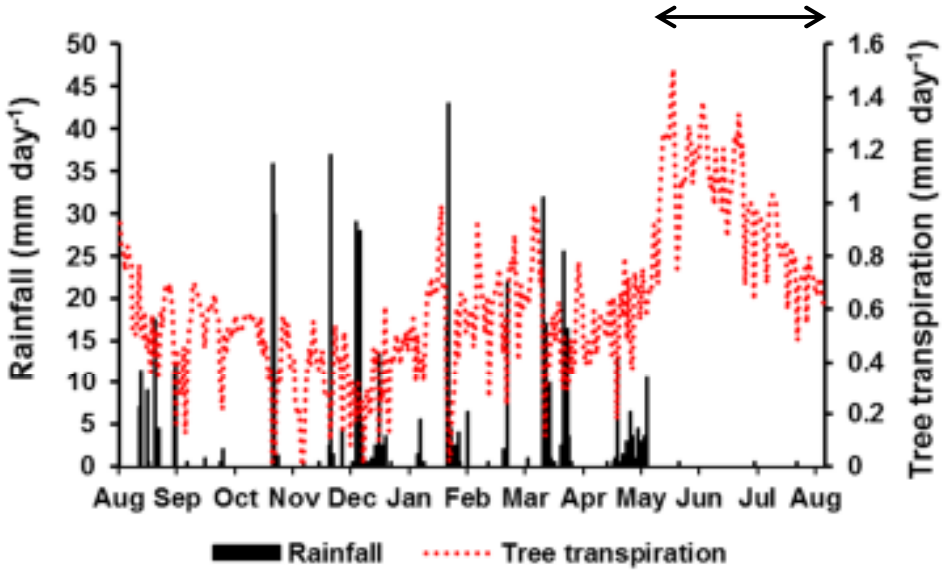
During summer trees used preferentially groundwater
(isotopic composition of twig xylem water is closer to that of groundwater than to that of unsaturated soil water)

Isotopic signature ($\delta^{18}O$)			
	Xylem water	Groundwater	Unsaturated soil water
26 Jun	**-4.06 (0.31) a**	**-4.50 (0.05) a**	**0.97 (0.33) b**
14 Aug	**-4.78 (0.19) a**	**-4.03 (0.07) a**	**-2.49 (0.51) b**
13 Aug	**-4.75 (0.15) a**	**-4.98 (0.51) a**	**1.96 (0.70) b**
10 Sept	**-4.84 (0.21) a**	**-5.44 (0.46) a**	**-1.86 (0.67) b**

Cork oak trees
Site 1: no summer water stress

David *et al*. 2013, *Forest Ecol Manag*

Maximizing water uptake – root water uptake dynamics

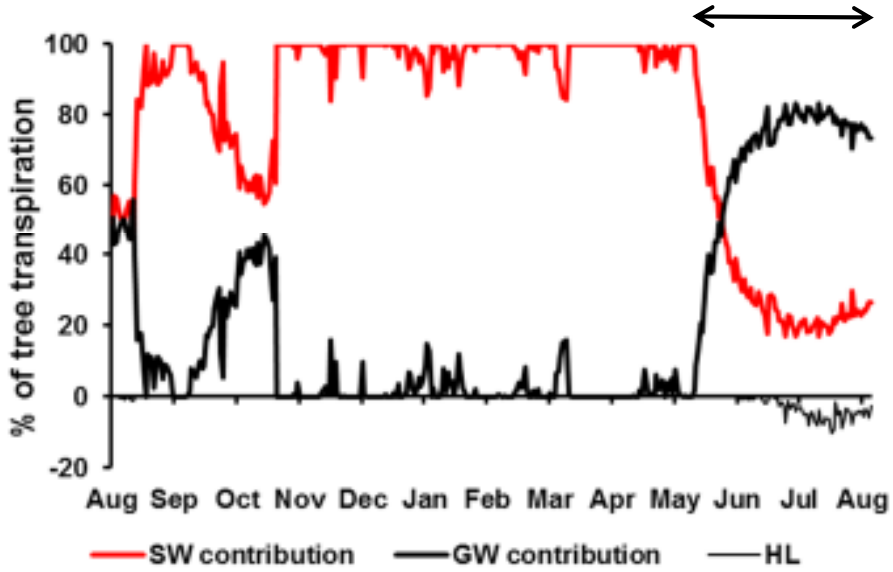


Transpiration rates remained high in summer (lack of rainfall in summer; root access to groundwater)

Trees used preferentially unsaturated soil water (SW) during most of the year and groundwater (GW) during the dry summer (root sap flow data)

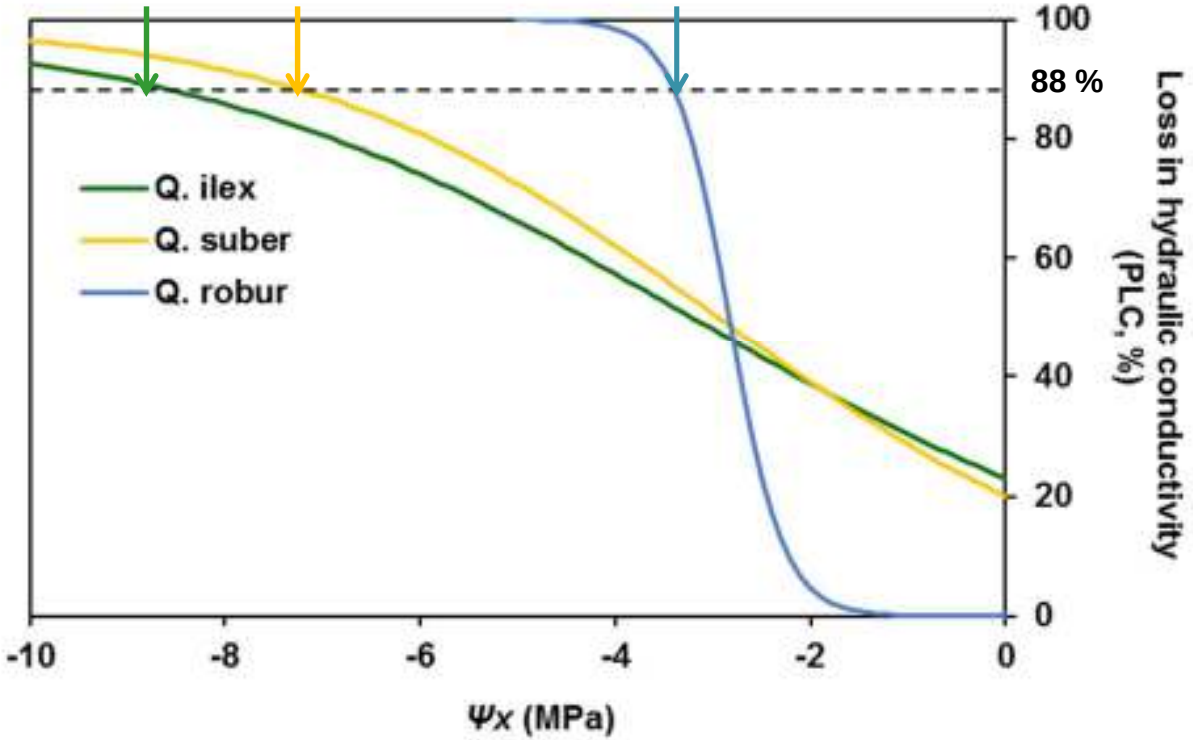
Trees performed hydraulic lift (HL) in summer

Cork oak trees
Site 1: no summer water stress



Adapted from David *et al*. 2013, *Forest Ecol Manag*

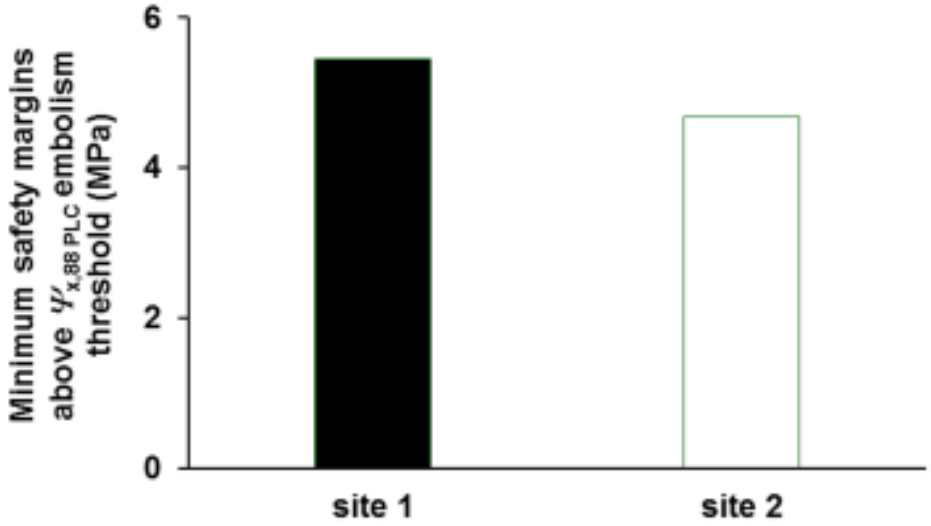
Xylem vulnerability to drought-induced embolism



Current-year shoots in Mediterranean evergreen oaks (*Q. suber* and *Q. ilex*) are more tolerant to drought-induced embolism than in deciduous temperate oaks (*Q. robur*)

Adapted from Cochard *et al*. 1992, Pinto *et al*. 2012, *Ulri et a*l. *2013*

Hydraulic safety margins above $\Psi_{x,\ 88\ PLC}$ embolism threshold



Comfortable hydraulic safety margins in the studied years, though smaller at the driest site
Hydraulic failure might occur when Ψ_x drops below the embolism threshold

Cork oak trees
Site 1: no summer water stress
Site 2: some degree of summer water stress

Adapted from Pinto *et al*. 2012, Forest Ecol Manag

Adaptation measures for managing forests under enhanced drought

Science-based knowledge should support management measures.

Adaptation measures should rely on the evaluation of the risks that Mediterranean forests face, through improved drought monitoring, early warning systems, and mapping of areas representing different levels of risk.

- Recommendations should be tailored to spatial scales and site-specific conditions;

- Reforestation programs should consider the available sources and storages of water supply to roots: tree density and selection of species should be balanced with local water availability;

- When an understory layer is present, water use by both strata should be evaluated as competition for water might impact on tree water status and health;

Adaptation measures for managing forests under enhanced drought

- Soil conservation practices to improve soil surface infiltration and maintain high water holding capacities are of paramount relevance;

- Management practices (e.g. tillage) should not damage/destroy roots to prevent decoupling the trees from the sources of water and nutrient supply;

- Genetic breeding is needed to improve drought resistance;

- Irrigation of intensive forest plantations, in specific sites within existing irrigation project areas or in their vicinity, should be evaluated.

Water resources planning – simplified catchment water balance

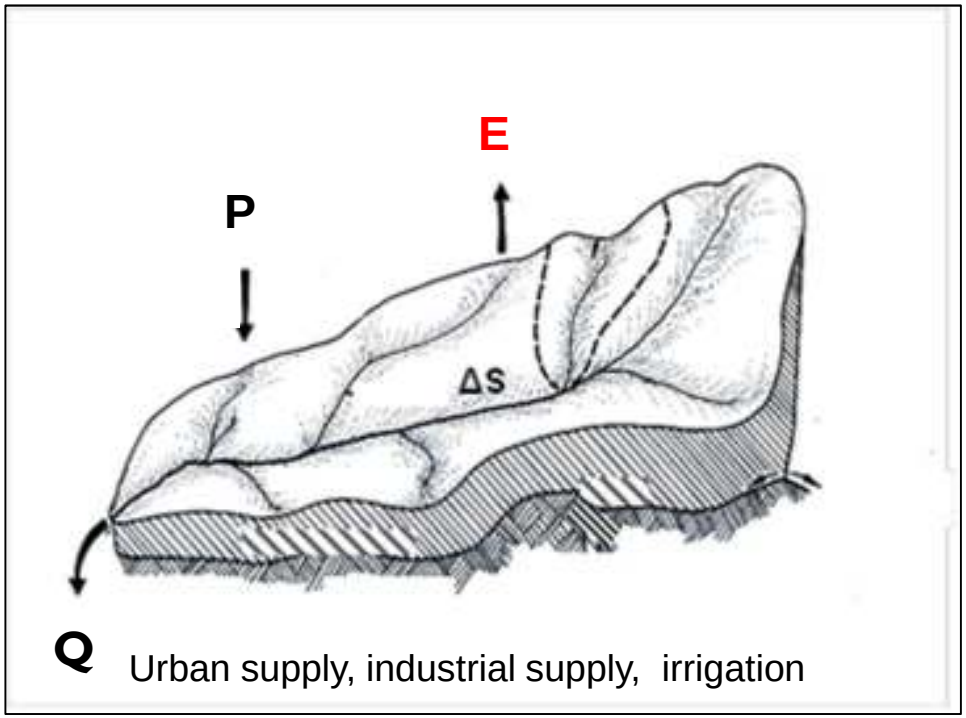
Inputs = Outputs ± Δ Storage

$P = E + Q \pm \Delta S$

Annual scale: $\Delta S \approx 0$

$P \approx E + Q$

$E = Ic + T + E_{soil}$



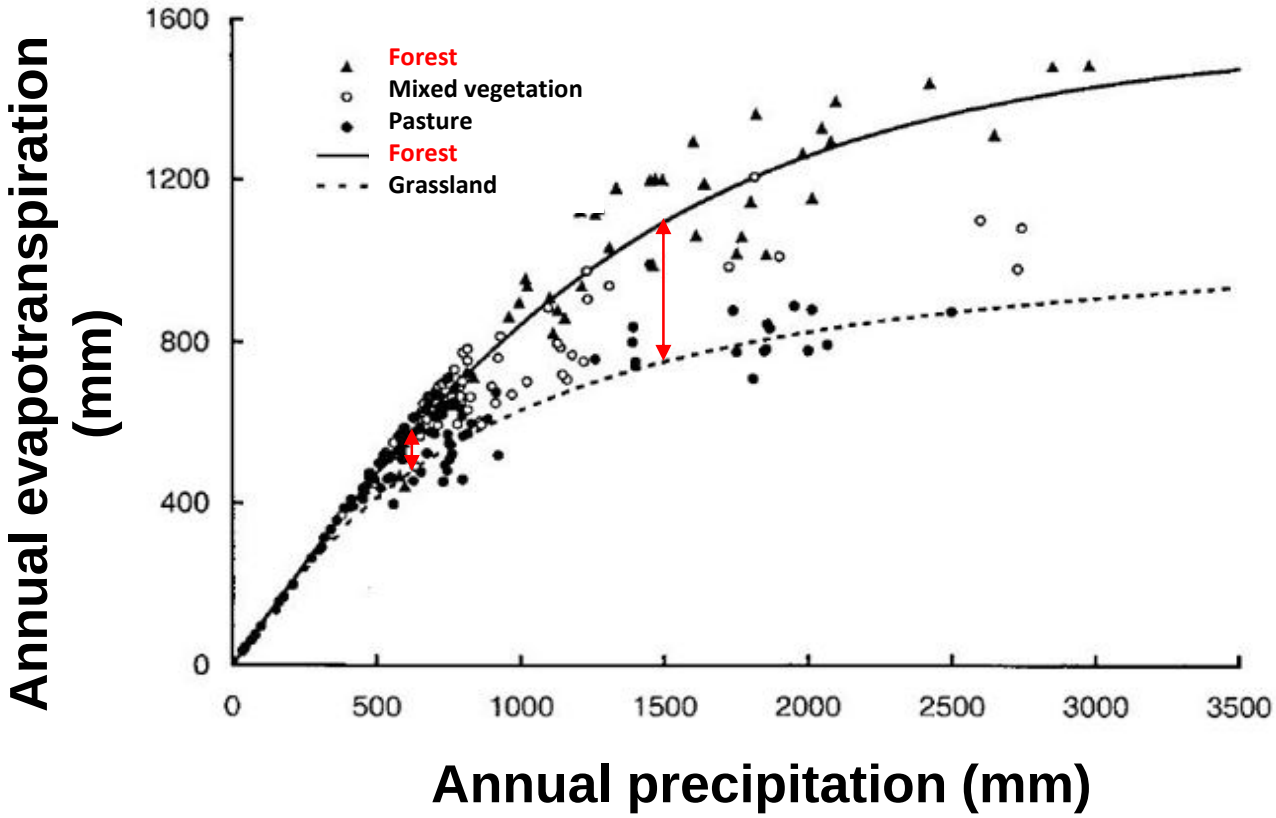
Forest density and forest composition may affect E and therefore Q.

In water-limited environments (P is limiting) → conflicts may arise between ecosystem productivity (water for carbon trade-off) and downstream water uses (Q): planning is important.

Adapted from Hewlett, 1982

Forests and Water

Tendency - data from different experimental catchments



Forests use more water than grassland but the difference decreases with decreasing precipitation.

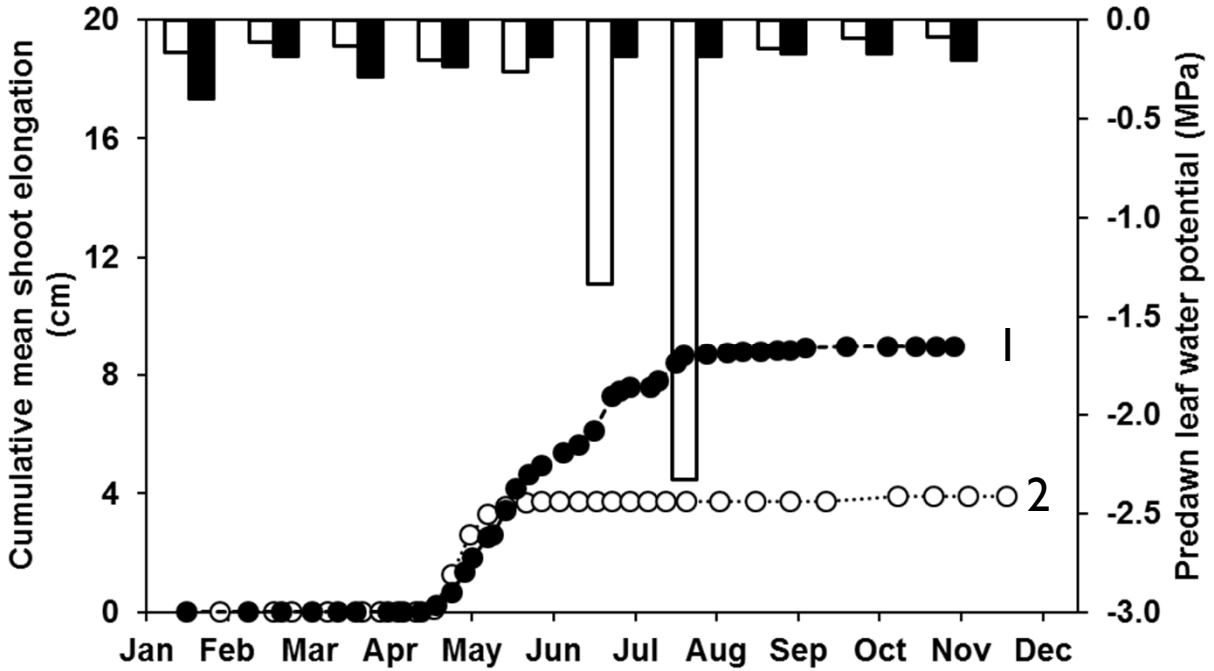
When annual rainfall is less than 500 mm, annual evapotranspiration is about the same irrespective of vegetation type.

Zhang *et al*. 2001, Water Resour Res

Trade-off water for carbon

Growth depends on water use

(lower at the site 2; at site 1 shoot elongation continues through part of summer)



Cork oak trees
Site 1: no summer water stress
Site 2: some degree of summer water stress

Adapted from Pinto *et al*. 2011, *Forest Ecol Manag*

In water limited environmets, a close colaboration between forest and water resource managers is needed

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