



View Mediterranean oak woodlands through an ecohydrological lens

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• Why studying vegetation cover and its relationships with climate and soil?

- Most of water within the hydrological cycle is used by vegetation cover.
- For MT climate areas with a rain amount of 800 mm yr⁻¹ 600 mm were evapotranspirated.
- The vegetation compartment is the only compartment that may be modified to change your water ressources.

- The ecohydrological optimality hypothesis ⇒ Understand how does "vegetation canopy density" equilibrate with climate and soil?
- And, how this equilibrium state may be modified by experimental drought or climate changes?

"It is the control of leaf area index and morphology which is often the most powerful means a mesophytic plant has for influencing its fate when subject to long term water stress in the field." **Passioura** 1976

"Where water may be limiting, trees appear to adjust to potential water stress through leaf morphology adaptations and minimum canopy development". **Brown** 1981

"The main response of the shrubs to different precipitation regimes in the chaparral range is to change leaf-area index, not physiological parameters". **Poole & Miller** 1979 Early works in arid zones related shrub density to rainfall (e.g. **Woodell & Mooney** 1969 for creosote bush *Larrea tridentata* 12 sites Mojave desert) Rain amount (<200mm) as a surrogate of AET (deep drainage & runoff = 0)

Grier & Running 1977 Gholz 1982 site water balance?

Specht R. 1972 (with AET/PET as the key explaining variable)

Woodward 1987 simulated the soil water balance with a "big leaf" approach of canopy AET and derived biome *LAI*

Among others







Evaporative coefficient (k)

Eagleson (1982) is the first author to have derived a onedimensional, statistical-dynamic model for the equilibrium between the hydrological and the biological components of an ecosystem.

He traced back the underlying hypothesis of optimality in Rosenzweig 1968.

He assumed that in water-limited environments, ecosystems develop a stable canopy density, which maximized biomass and minimized drought stress.

Ecohydrology

Darwinian expression of vegetation form and function

Peter S. Eagleson Massachusetts Institute of Technology Optimal bioclimate

(8.40)

availability of light and water while the climate range becomes more restricted. The inverse is true in resource-poor climates.

It is perhaps easier to examine this space by reducing its dimensionality through the use of dimensionless variables. Dividing Eq. 8.37 by \widehat{I}_{SL} and inverting each term we have

 $1 \geq \Pi_L \geq \Pi_W,$

in which the dimensionless habitat variables are each a ratio of species-to-climate parameters according to their prior definitions for light:

$$\Pi_{\rm L} \equiv \frac{\widehat{I_{\rm SL}}}{\widehat{I_l}} = \frac{P_{\rm sm}/\varepsilon}{f_I(\beta L_{\rm t})I_0},\tag{8.41}$$

and for water:

$$\Pi_{\rm W} \equiv \frac{\widehat{I_{\rm SL}}}{\widehat{I_{\rm SW}}} = \frac{I_{\rm SL}}{f_I(\beta L_{\rm t})I_{\rm SW}} = \frac{P_{\rm sm}/\varepsilon}{\frac{f_I(\beta L_{\rm t})}{1 - \rho_{\rm T}} \left[(1 \pm R_{\rm b})\frac{\lambda V_{\rm e}}{m_{t_b^{\otimes}}M} + q_{\rm b} \right]}.$$
(8.42)

The feasible canopy bioclimatic space of Fig. 8.18a is shown in these dimensionless coordinates in Fig. 8.18b where the feasible prism transforms into a planar triangle, the stable surface called the climatic climax becomes the uppermost boundary, and the climatic optimum reduces to a point.

However the mathematical formulation is extremely complex and lacks of accessibility.

See also Hatton Salvucci Wu 1997 Eagleson's optimality theory of an ecohydrological equilibrium: quo vadis? Functional Ecology 11: 665-674



- *Quercus ilex* is a good plant model because it spreads across the Mediterranean Sea under climate conditions ranging from semi-arid to humid.
- It may be observed growing in dense forests or in open woodlands or even in savanna-type ecosystems.





As Nemani and Running did with Forest-BGC in "Testing a theoretical climate-soil-leaf area hydrologic equilibrium of forests", we simulated this model on the Puéchabon site

See Hoff C & Rambal S 2003. An examination of the interaction between climate, soil and leaf area index in a *Quercus ilex* ecosystem. Ann. For. Sci. 60 : 153–161.



Close assumptions in Rambal 1993 PCE



At low soil water storage capacity, reducing rain amounts induced a rather low change in equilibrium LAI





Figure 1. Regional Climate Change Index (RCCI) over 26 land regions of the World calculated from 20 coupled AOGCMs and 3 IPCC emission scenarios (A1B, A2, B1).

Table 2. Values of ΔP , $\Delta \sigma_B$ RWAF and $\Delta \sigma_T$ over the 26 Regions of Figure 1^a

Region	Season	ΔP , %	$\Delta \sigma_P, \%$	RWAF	$\Delta \sigma_T \%$	Season	ΔΡ, %	$\Delta \sigma_P, \%$	RWAF	$\Delta\sigma_T$, %
NEU	WS (May-Oct)	0.85 (0)	17 30 (2)	1.13 (1)	15.00 (4)	DS (Nov Apr)	14.40.(2)	6.60 (1)	1.43 (2)	_10.45 (4)
MED	WS (Oct-Mar)	-9.73 (1)	24.94 (4)	1.09 (0)	-3.43(0)	DS (Apr-Sep)	-21.58(4)	39.99 (4)	1.47 (2)	15.25 (4)
NEE	WS (May-Oct)	6.02 (1)	23.23 (4)	1.34 (2)	4.19(0)	DS (Nov-Apr)	20.07 (4)	16.71 (2)	1.93 (4)	-12.40(2)
NAS	WS (May-Oct)	11.40 (2)	14.69 (2)	1.39 (2)	3.39 (0)	DS (Nov-Apr)	27.27 (4)	9.41 (1)	1.96 (4)	5.28 (1)
CAS	WS (Nov-Apr)	-2.08(0)	21.89 (4)	1.29 (1)	2.02 (0)	DS (May-Oct)	-9.26(1)	16.13 (2)	1.55 (4)	4.31 (0)
TIB	WS (Apr-Sep)	7.94 (1)	3.15 (0)	1.42 (2)	3.00 (0)	DS (May-Oct)	15.93 (4)	12.62 (2)	1.54 (4)	3.61 (0)





		Control			Dry				
Year	P_g	P _n	Е	E/P _n	P _n	Е	E/P _n	E _{dry} /E _{control}	
2004	989	781	430	0.55	553	322	0.58	0.75	
2005	835	671	364	0.54	475	270	0.57	0.74	
2006	940	774	308	0.40	550	243	0.44	0.79	
2007	681	509	417	0.82	360	330	0.92	0.79	
Mean	861	684	(380)	0.58	(485)	(291)	0.63	0.77	
			F	net ↓		T	rans	oiration ↓	

















Figure 1. Annual water balance of tree/grass savanna.

The trees draw no moisture from the root zone of the grass. So, they use all the water percolated from the upper layer.

 $\partial \mathbf{s}_0 / \partial M_g = \mathbf{0}$

Time-and space-averaged soil moisture in the upper layer M_g fraction of surface covered by grass

The tree-grass mixture appears stable with respect to perturbations.

"Changes in savanna tree density may be considered as a visible indicator of climate change".

Tree density increased with annual rain amounts across southern Spain Dehesas (after Joffre R, Rambal S, Ratte JP. 1999. The dehesa system of southern Spain and Portugal as a natural ecosystem mimic. *Agrofor Sys 45: 57-79*)



	Location	Ecosystem type	Mean rainfall	
1	Central-W Spain	Oak savanna or Dehesas	480	
2	Central-W Spain	Oak savanna or Dehesas	506	
3	Central Italy	Mixed forest with deciduous trees	637	
4	NE Spain	Dense forest	658	
5	S France Mixed forest with <i>Pinus halepen</i>		663	
6	SE Portugal	Oak savanna or Dehesas	665	
7	NE Spain	Mixed forest with Pinus halepensis	714	
8	S Spain	Oak savanna or Dehesas	720	
9	Central Italy	Mixed forest with deciduous trees	750	
10	S France	Open forest	763	
11	S France	Plantation	770	
12	Central Italy	Woodland – shrubland mosaic	803	
13	S France	Dense forest	883	

	age		height	LAI	DBH
1	100	50	8.4	0.74	46
2	60-150	200	5.9-10.5		46
3	40-60	1435	15-18(?)	3.96	14.9
4	30	3491	10	5.3	
5	50	2150	5.4	2.7	6.9
6		35-45	6.8		48
7	18	660	3-4		3-3.5
8	80-100	50	7.7	0.7	33
9	15-25		6		11
10			4.4		16
11	24	2200	5.4	4	17.5
12			7		
13	42	9550	4.0	2.9	4.8

We need to understand the hydraulic stategy displayed by trees.



As proposed by Ritchie & Hinckley (1976) "It is tempting to compare species based upon these curves using both the slope α and intercept $\Delta \psi_{max}$ as indicators of species differences".



 $\Delta \psi_{max}$ / h = 1.18 DBH^{-0.32} with r² = 0.68 and s_{y.x} = 0.11 $\Delta \psi_{max}$ / h = 2.37 DBH^{-0.67} s_{y.x} = 0.18

$\Delta \psi \propto A_{\rm L} D g_{\rm s} I / A_{\rm S} k_{\rm s}$

 A_L/A_S leaf area to sapwood area ratio k_s is the specific conductivity, *I* the hydraulic path length, g_s is the stomatal conductance and *D* is the air saturation deficit.

The **hydraulic limitation hypothesis** predicts that the cost of pulling water from soil to leaves through larger stems eventually disadvantages the trees and may lead to their decline

So, taller trees must have relatively smaller leaf area/sapwood area ratio

At Puechabon, for a median DBH of 8 cm an A_{L} / A_{S} of c.a. 1400 (unitless)

However, values of $A_{\rm L}$ / $A_{\rm S}$ of c.a. 5300-4700 (unitless) for DBH ranging from 35 to 50 cm, largely greater than the one we observed for dense woodlands



We ask new questions among others:

Coordination mechanisms

Coupling hydraulic stategy with the one used for carbon and nutriment ressources

Understand tree vulnerability to drought