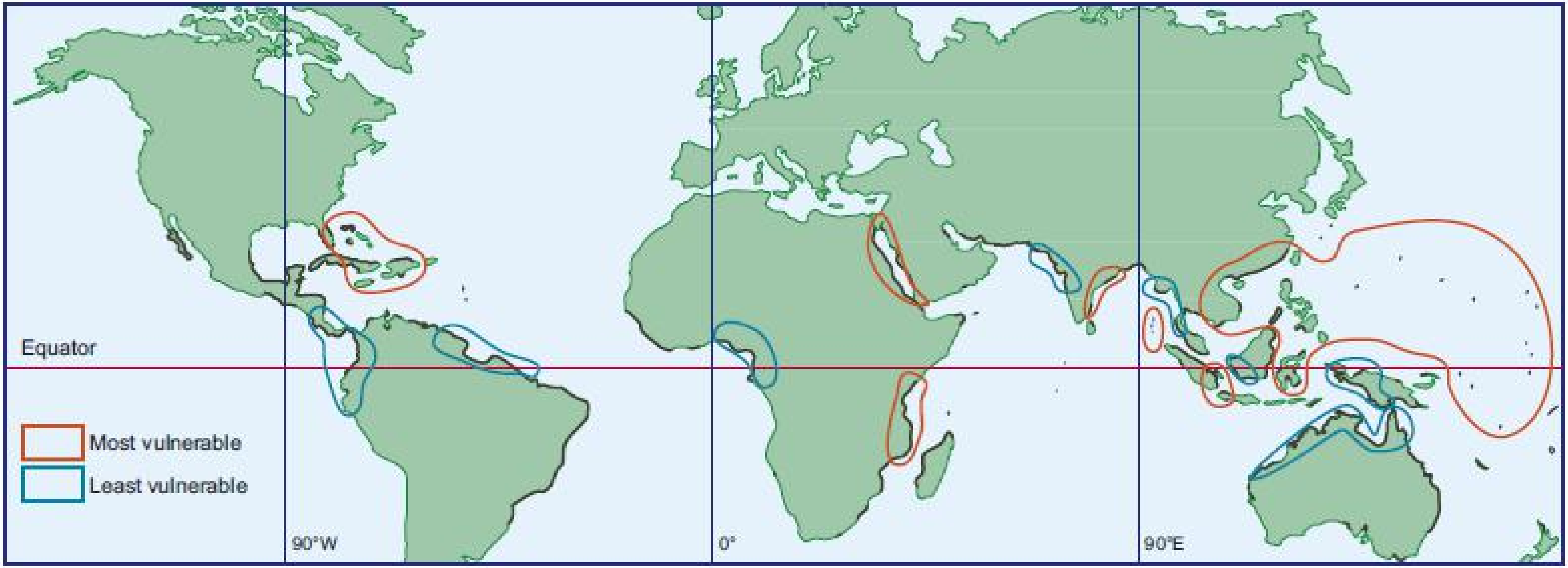
DEPARTMENT OF
EARTH SYSTEM SCIENCE
地球系统科学系

Stable water isotopes in halophyte plants

Jie Liang

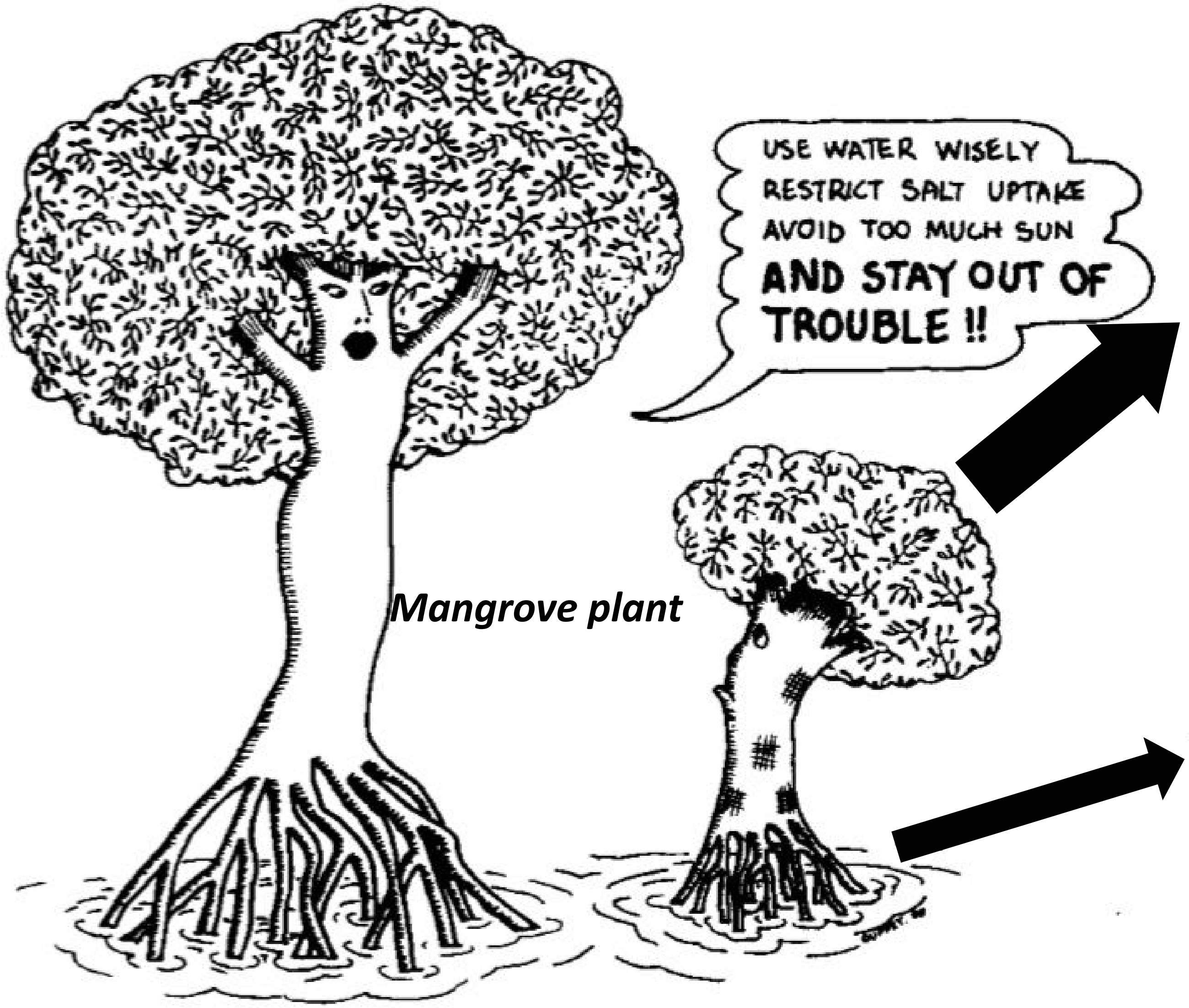
Department of Earth System Science, Tsinghua University

Mangroves

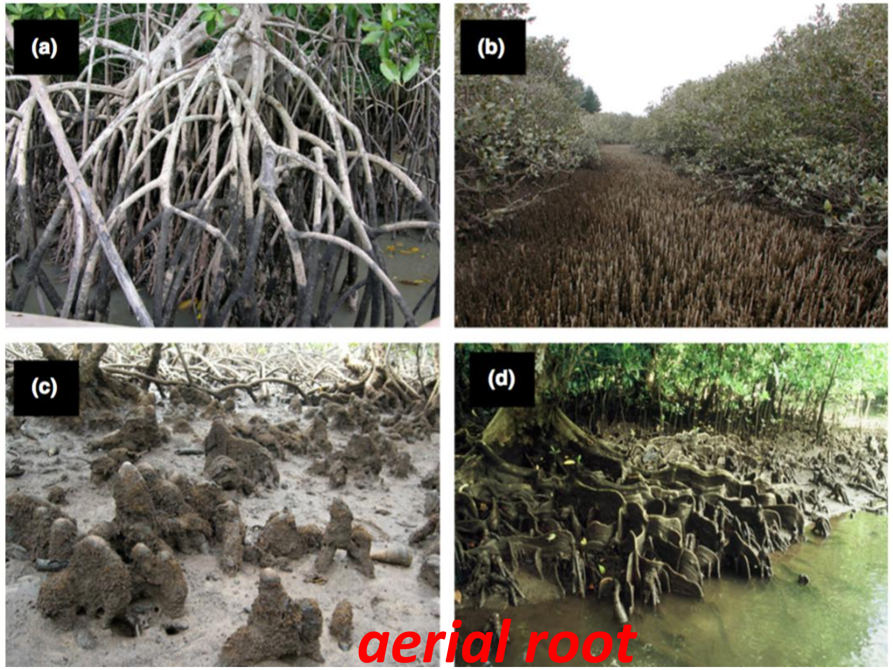


Alongi (2008)

Unique physiological structure for adapting to special habitats!



Marilyn C. Ball (1988)



Krauss et al. (2013)

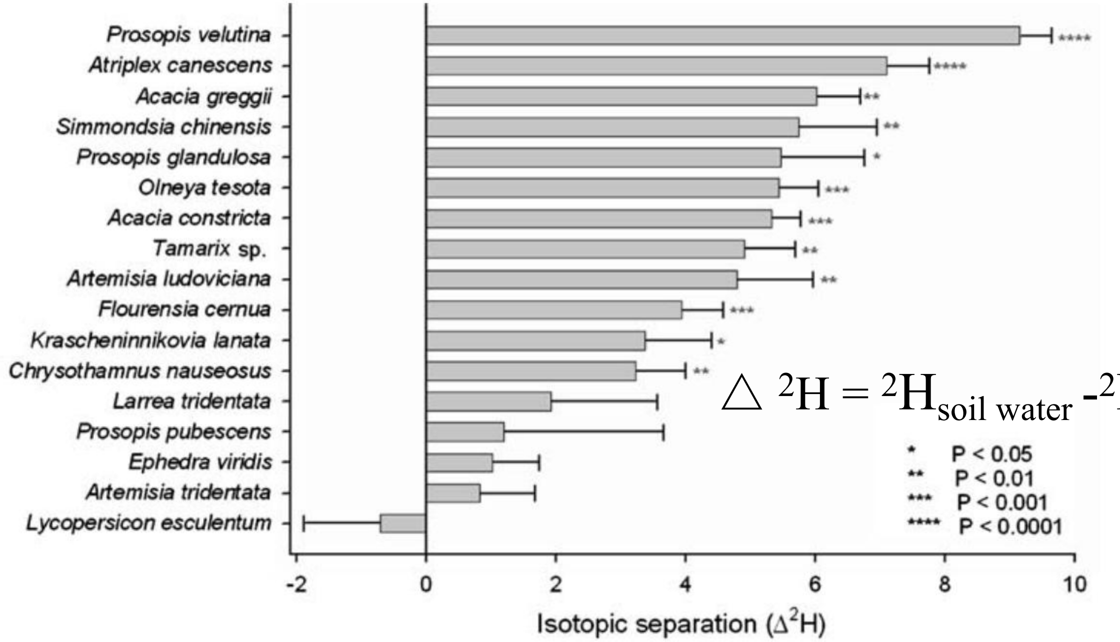
Special physiological structure with unusual water relations!

Stable Isotopes and Plant Carbon-water Relations

1993, Pages 497–510

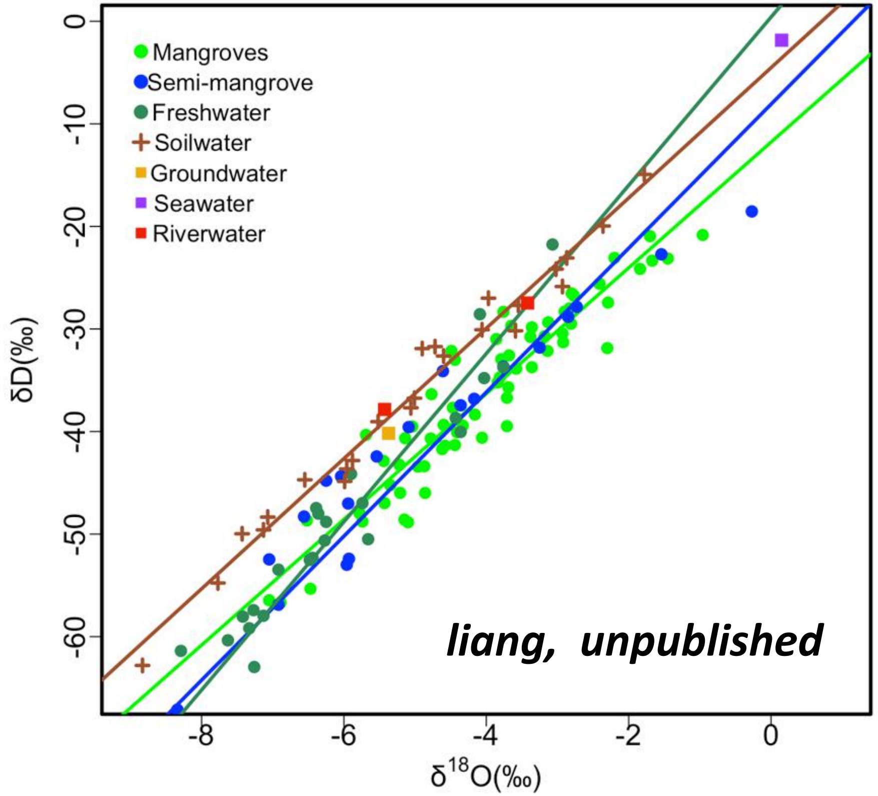
31 – Hydrogen Isotopic Fractionation by Plant Roots during Water Uptake in Coastal Wetland Plants

Guanghui Lin, Leonel da S. L. Sternberg

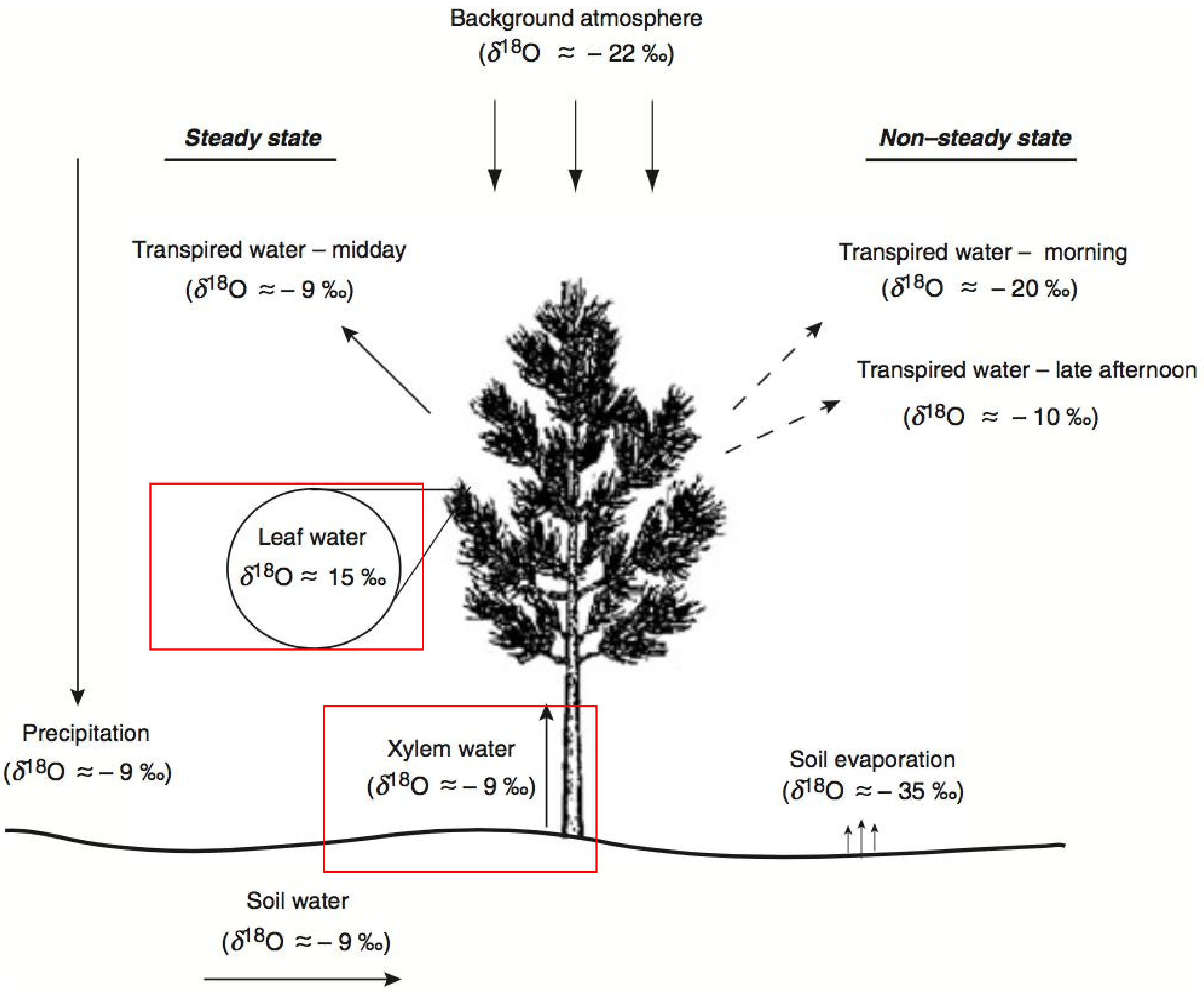


$\triangle\, ^2H = {}^2H_{soil\ water} - {}^2H_{xylem\ water}$

Ellsworth, 2007



liang, unpublished

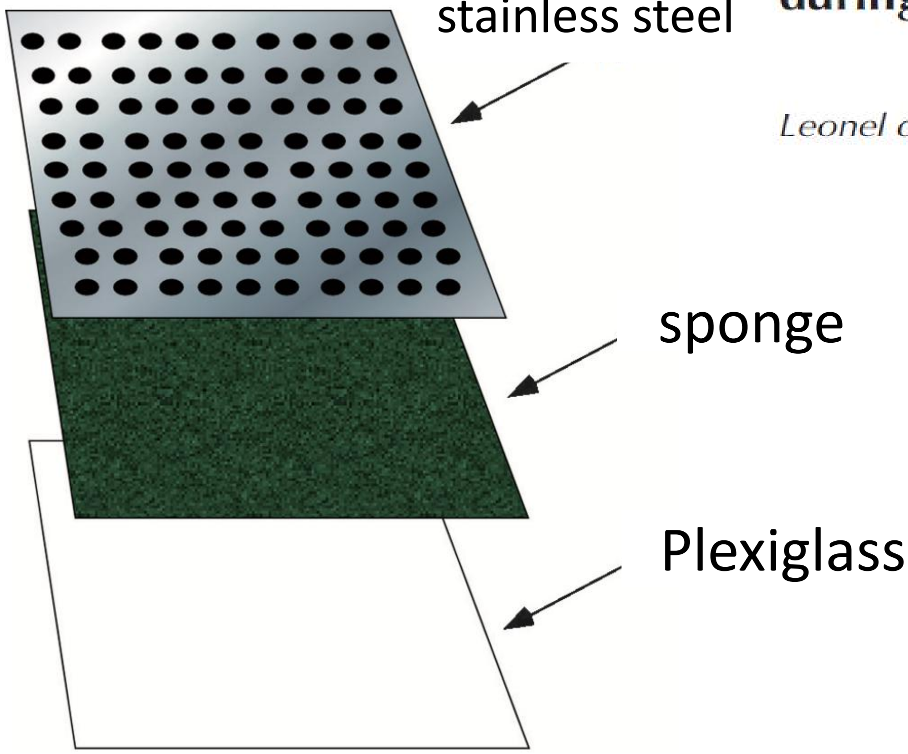

Background atmosphere
($\delta^{18}O \approx -22$ ‰)
Steady state
Non–steady state
Transpired water – midday
($\delta^{18}O \approx -9$ ‰)
Transpired water – morning
($\delta^{18}O \approx -20$ ‰)
Transpired water – late afternoon
($\delta^{18}O \approx -10$ ‰)
Leaf water
$\delta^{18}O \approx 15$ ‰
Precipitation
($\delta^{18}O \approx -9$ ‰)
Xylem water
($\delta^{18}O \approx -9$ ‰)
Soil evaporation
($\delta^{18}O \approx -35$ ‰)
Soil water
($\delta^{18}O \approx -9$ ‰)

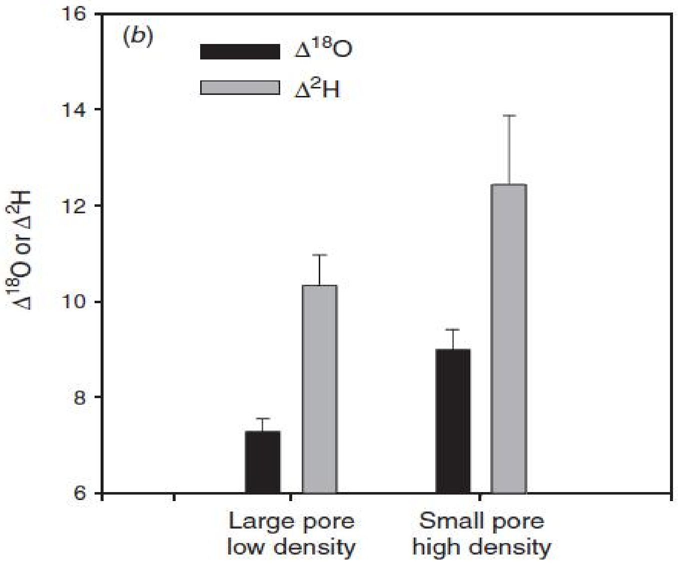
Isotopic enrichment of Leaf water ($\triangle^{18}O = {}^{18}O_{leaf\ water} - {}^{18}O_{xylem\ water}$)

CSIRO PUBLISHING
Functional Plant Biology, 2014, **41**, 648–658
http://dx.doi.org/10.1071/FP13235

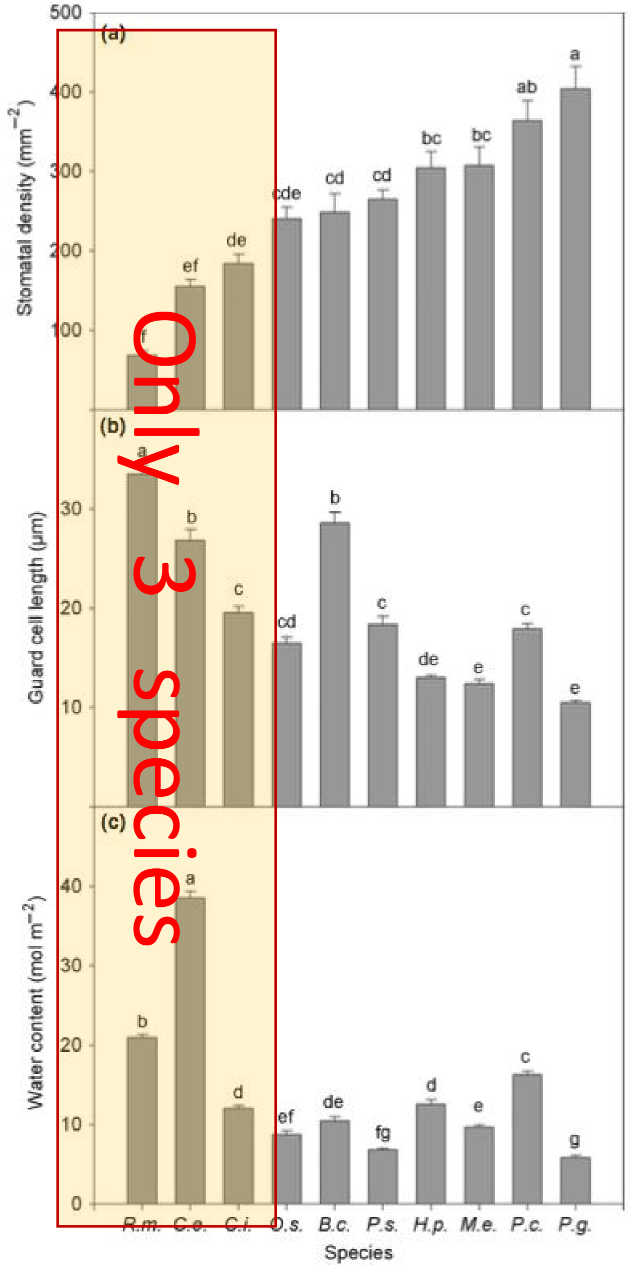
Stomatal pore size and density in mangrove leaves and artificial leaves: effects on leaf water isotopic enrichment during transpiration

Leonel da Silveira Lobo Sternberg[A,B] *and Lynn M. Manganiello*[A]





Isotopic enrichment of Leaf water ($\triangle^{18}O = {}^{18}O_{leaf\ water} - {}^{18}O_{xylem\ water}$)



New Phytologist
Research

Effects of stomatal density and leaf water content on the ^{18}O enrichment of leaf water

Leticia Larcher[1], Ikuko Hara-Nishimura[2] and Leonel Sternberg[3]

STOMAGEN Transgenic lines	Transpiration	Δ_L	Δ_L/Δ_e	℘
Low stomatal density (ST-RNAi)	2.32 ± 0.06c	6.2 ± 1.5a	0.45 ± 0.11a	1.97 ± 0.71a
Wild-type (CS60000)	3.00 ± 0.02b	6.7 ± 0.7a	0.51 ± 0.05a	1.55 ± 0.30a
High stomatal density (ST-OX)	3.50 ± 0.11a	6.5 ± 0.7a	0.55 ± 0.06a	1.38 ± 0.30a

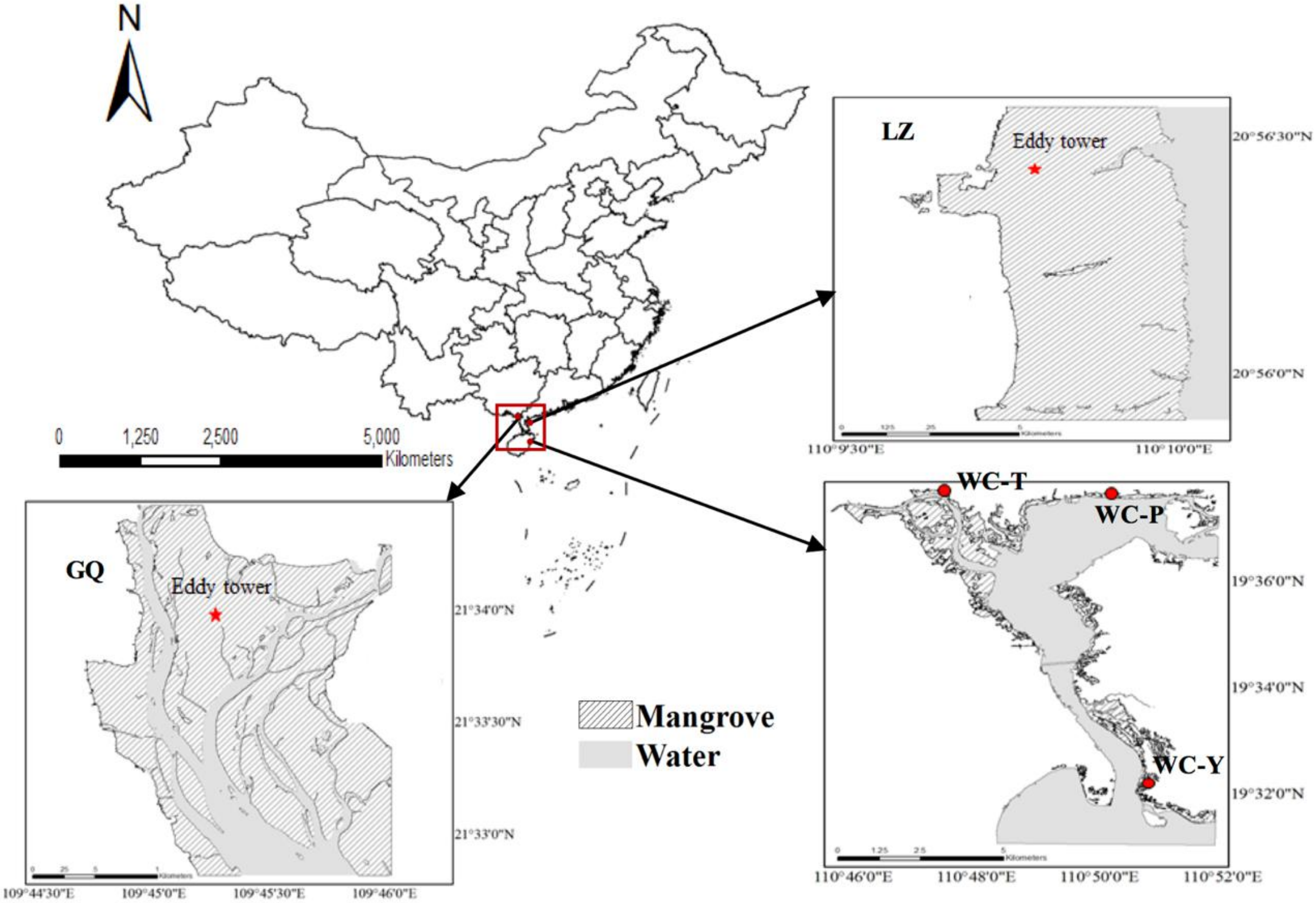
Cuntz et al. (2009):$\triangle_L$ is not influenced by habitats

♚ ***Is leaf isotopic enrichment in mangroves different from freshwater plants?***

♛ ***Is the difference common presence？***

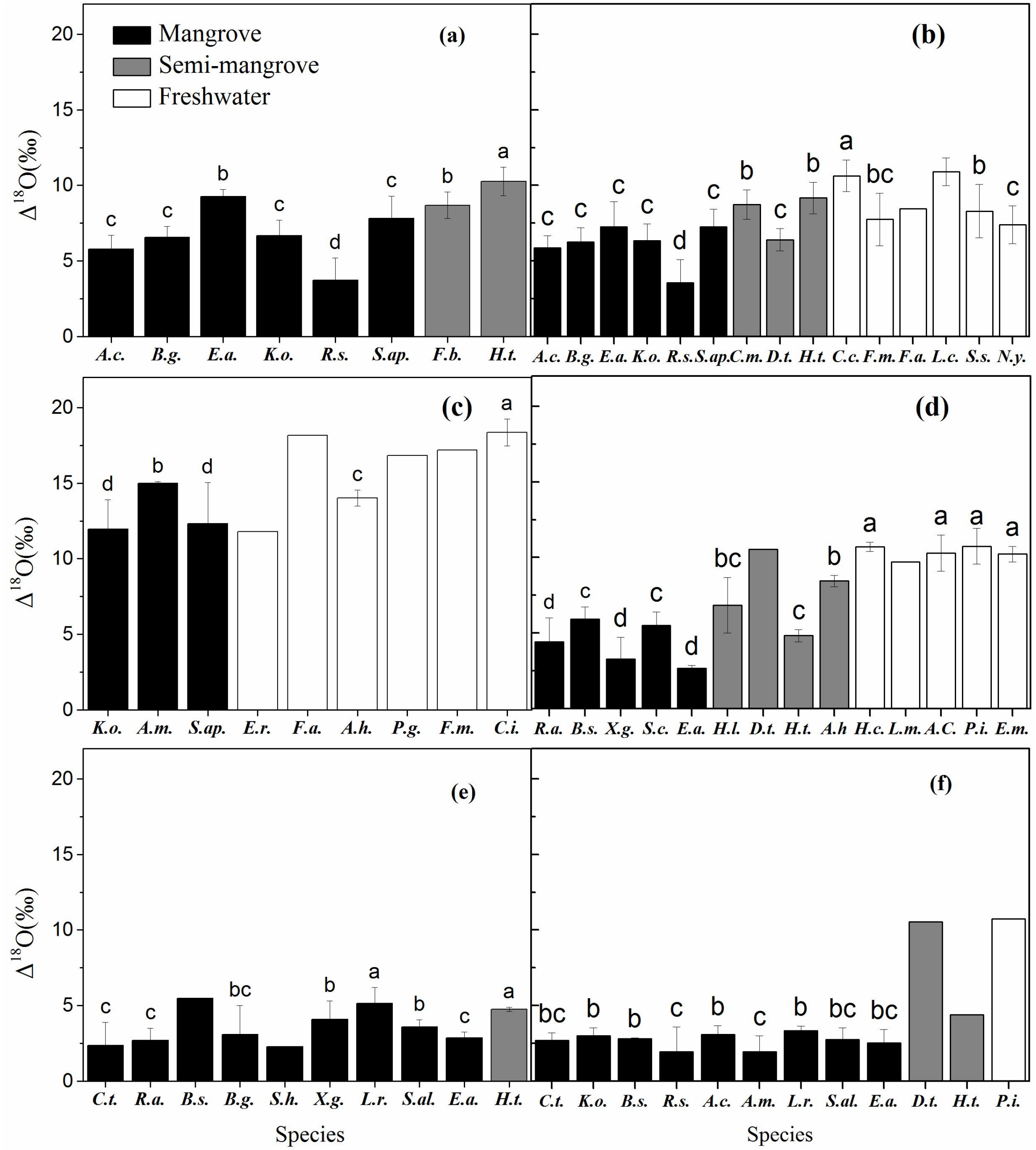
♝ ***Is the difference related to leaf traits?***

Isotopic enrichment of Leaf water ($\triangle^{18}O = {}^{18}O_{leaf\ water} - {}^{18}O_{xylem\ water}$)

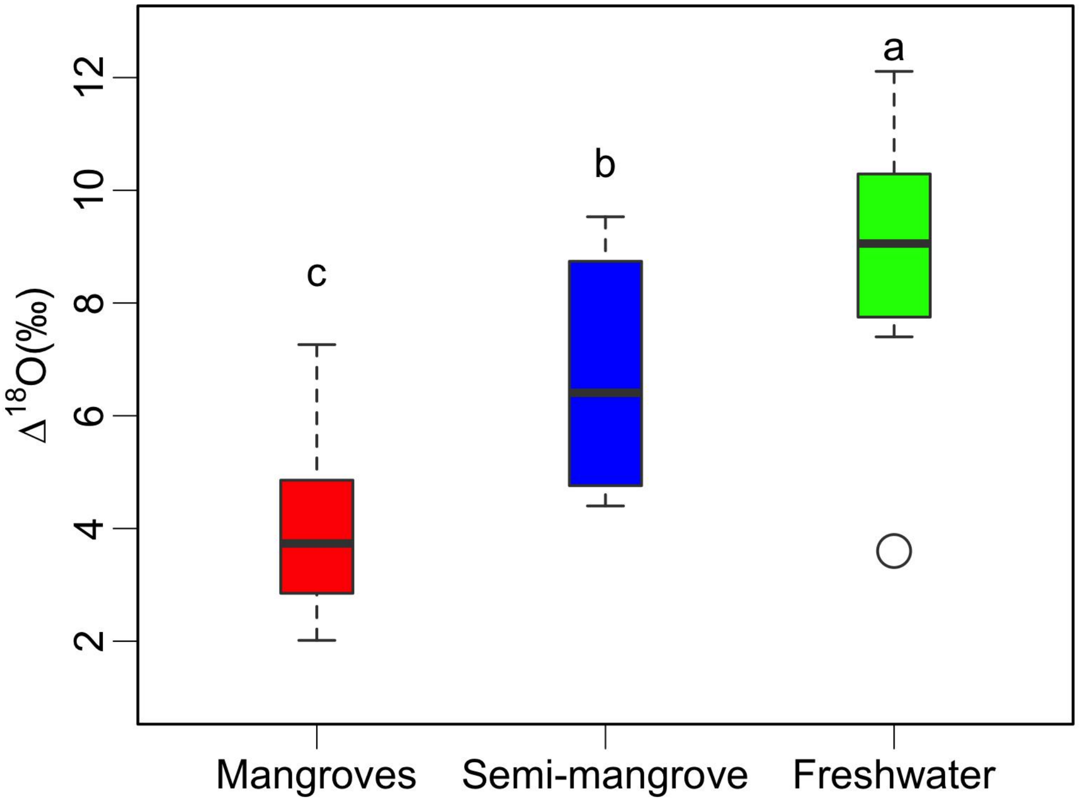


4 times for field campaign
5 sites in south of China
15 mangrove species(total 28)
16 land species

Isotopic enrichment of Leaf water ($\Delta^{18}O = {}^{18}O_{leaf\ water} - {}^{18}O_{xylem\ water}$)



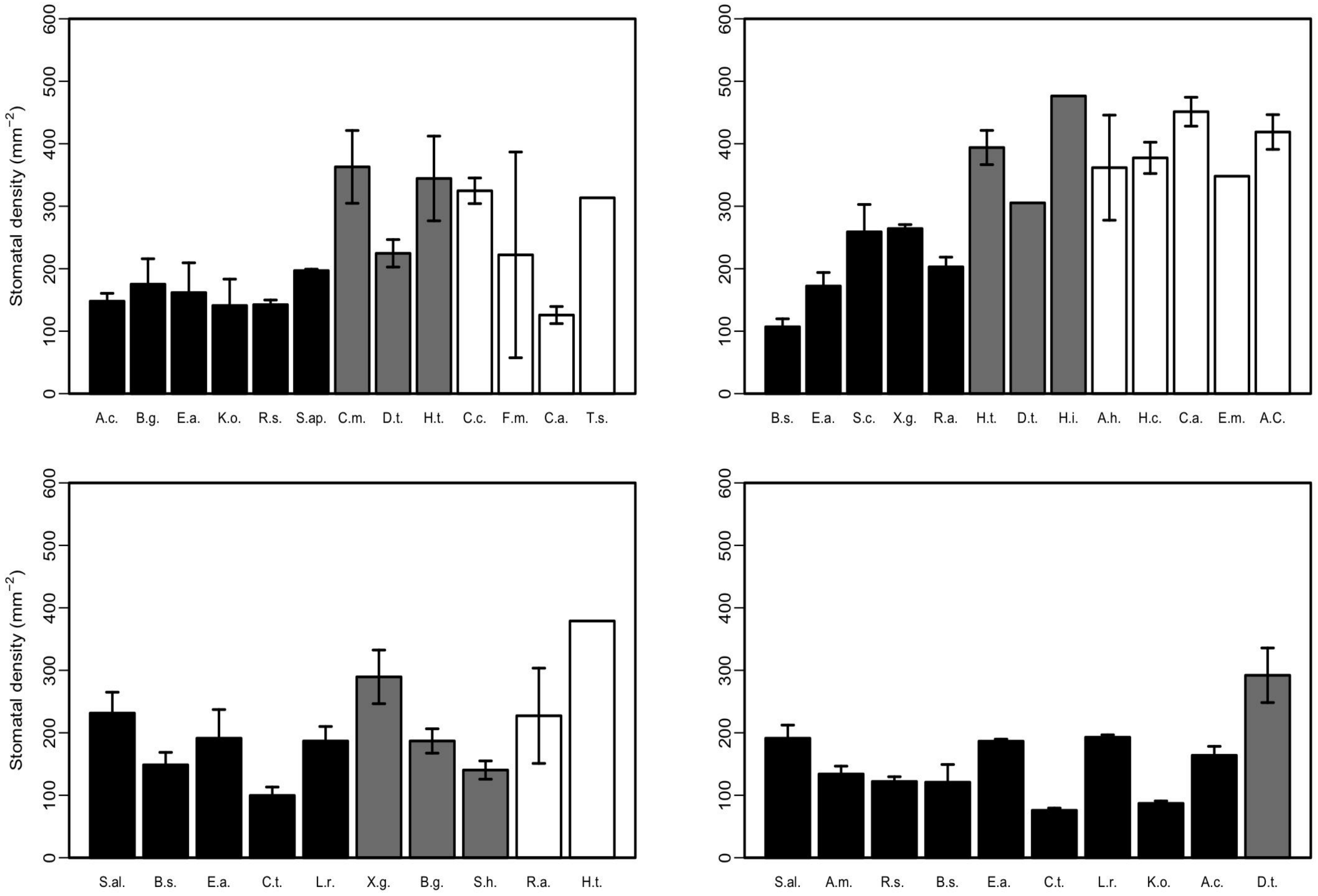
Water isotopic discrimination of mangrove leaves are very different from freshwater plants!



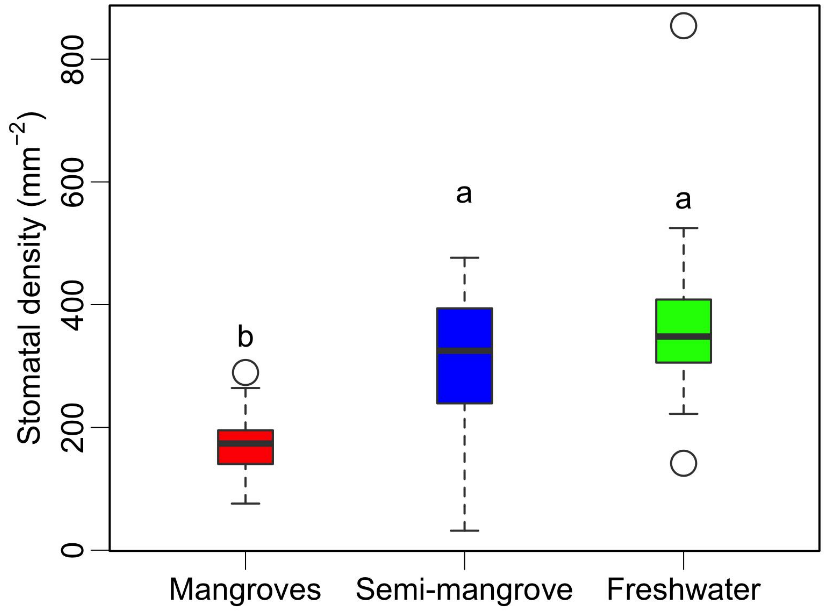
(Liang et al. 2017)

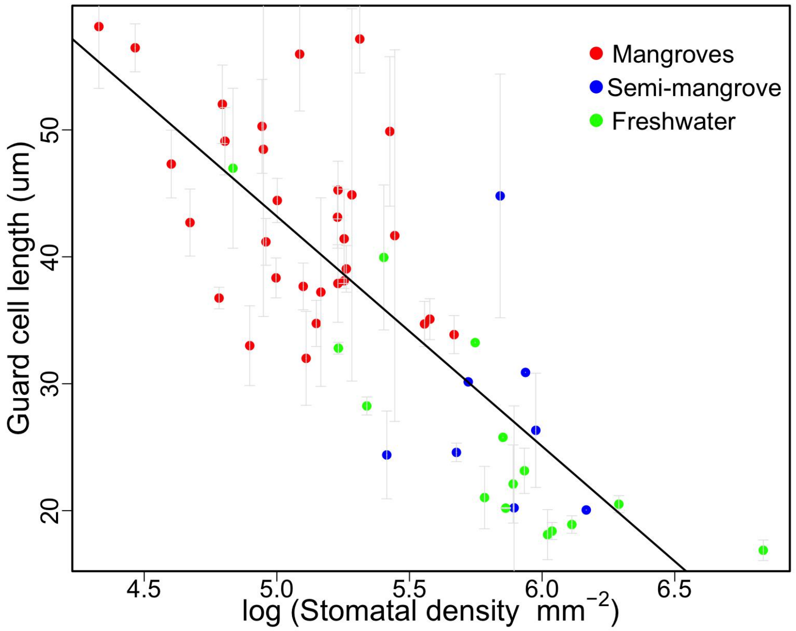
Stomata

Fewer stomata for mangroves

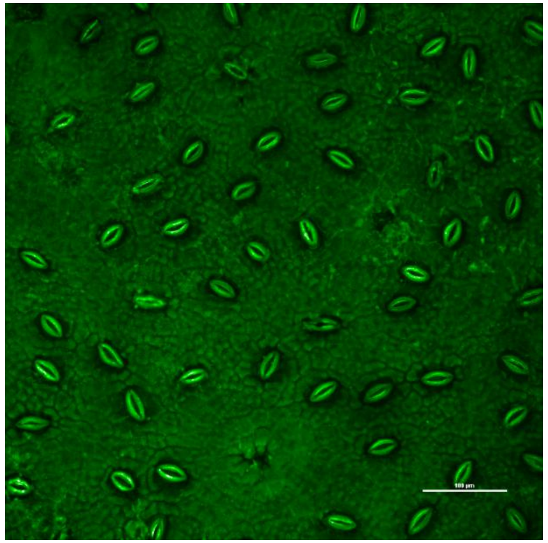


Stomata

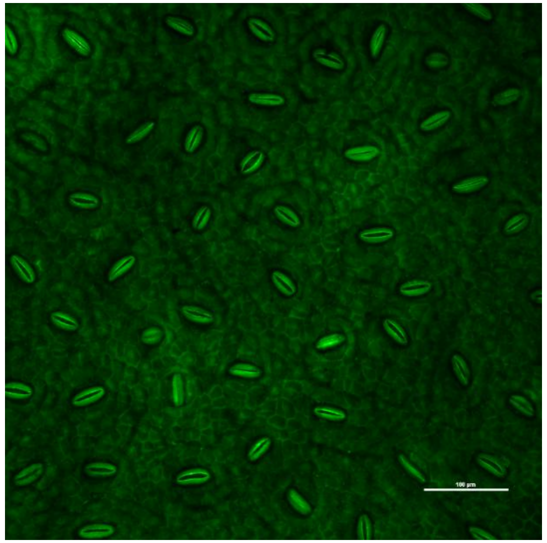




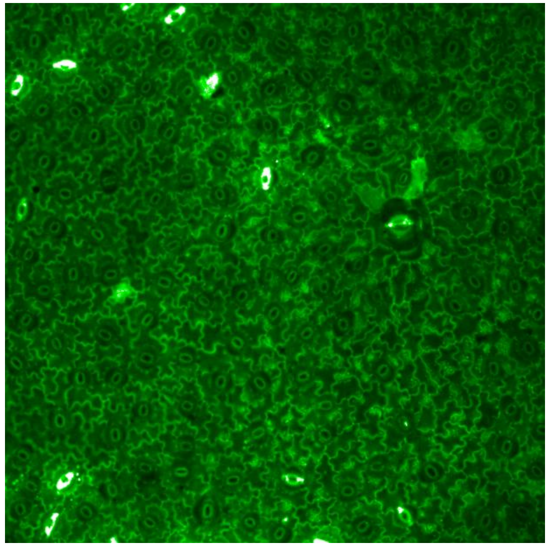
Fewer and lager stomata for mangroves



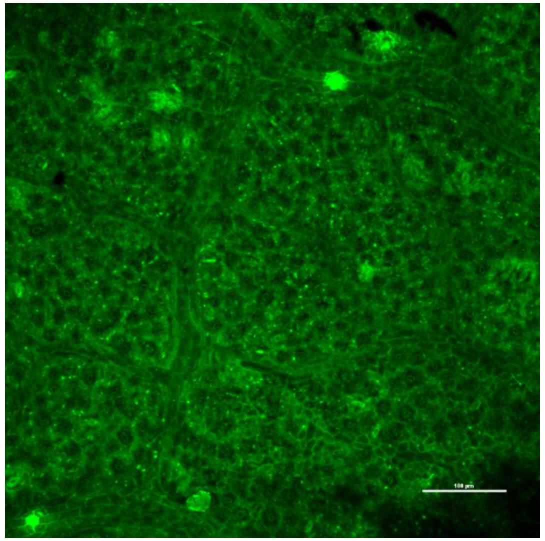
Aegiceras corniculatum



Kandelia obovata

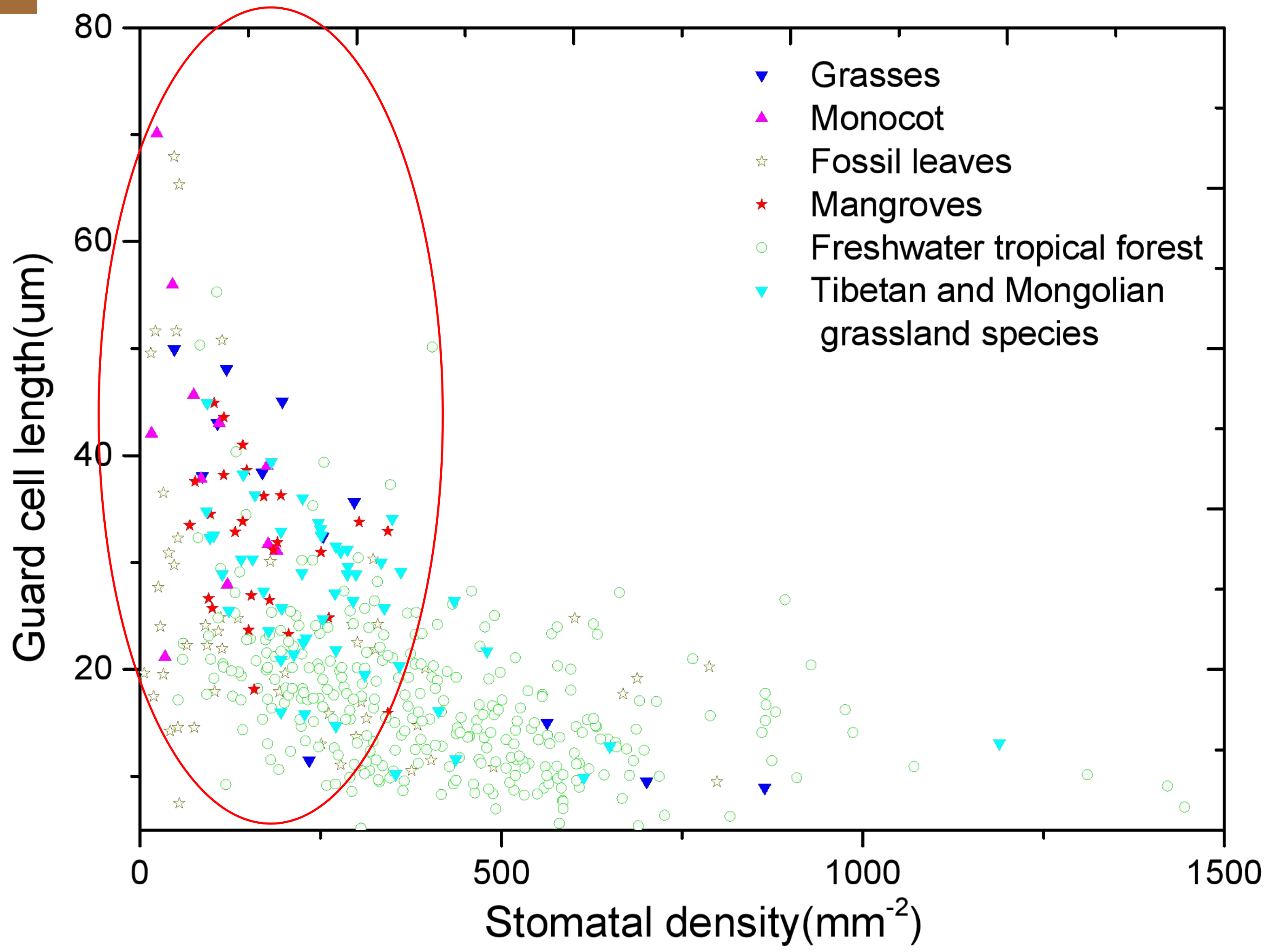


Melaleuca Viridiflora



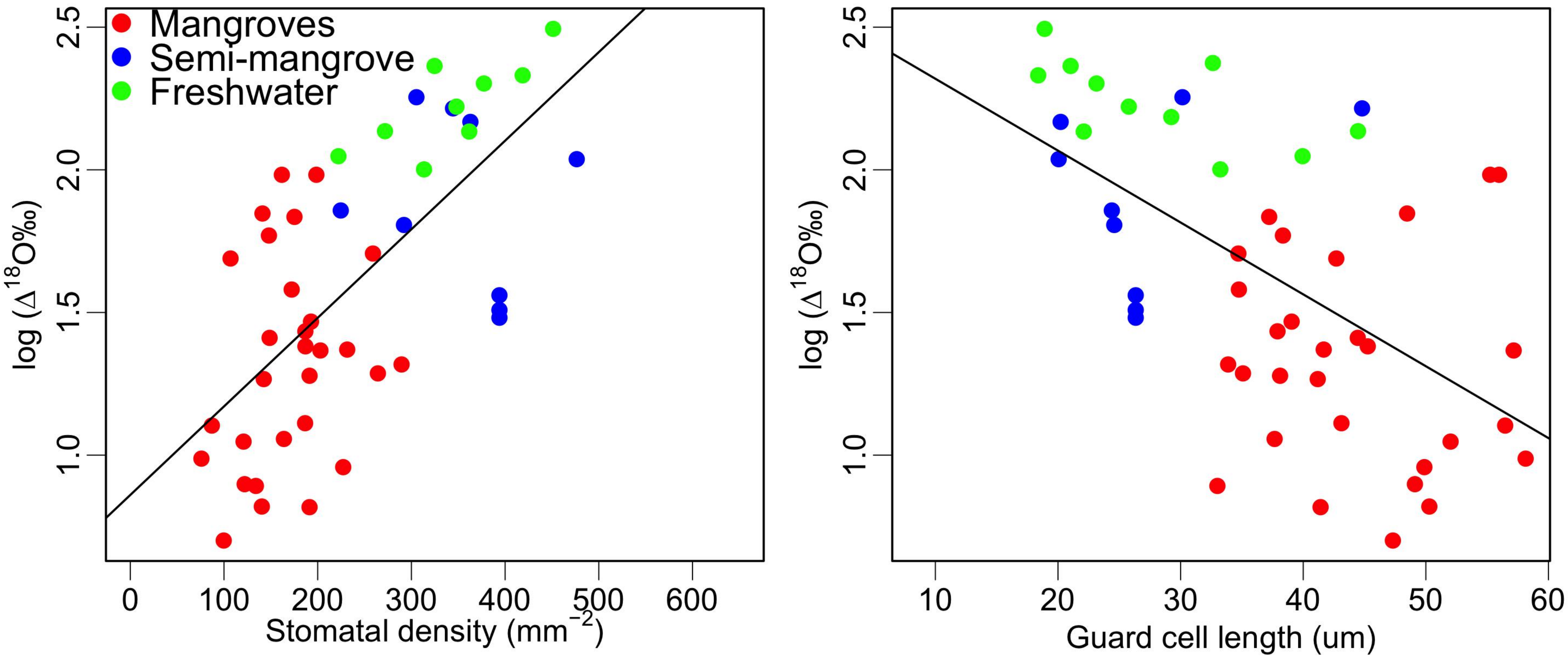
Streblus asper

Stomata



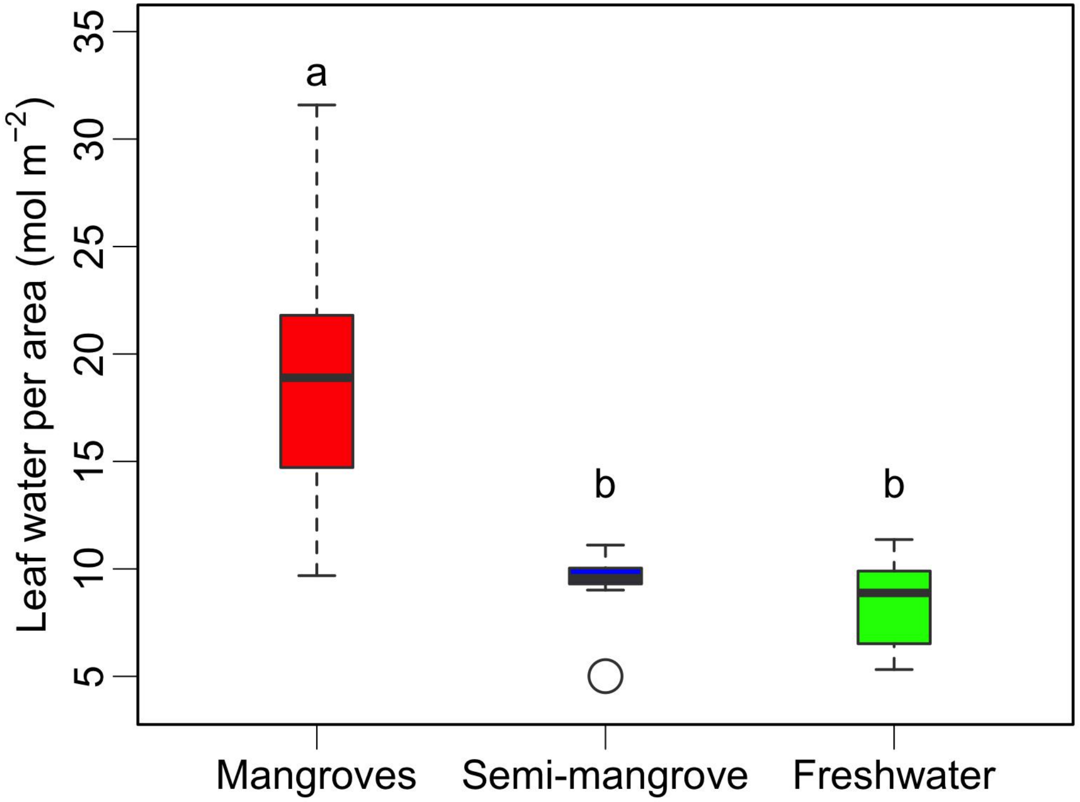
Grasses
Monocot
Fossil leaves
Mangroves
Freshwater tropical forest
Tibetan and Mongolian grassland species
Guard cell length(um)
Stomatal density(mm-2)
80
60
40
20
0
500
1000
1500

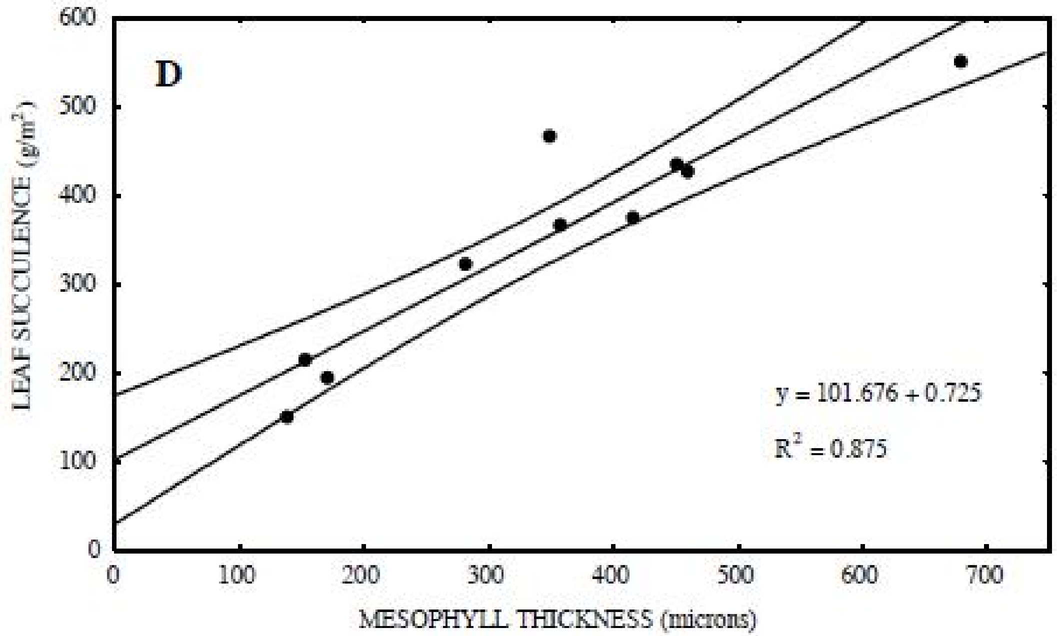
Stomata


Mangroves
Semi-mangrove
Freshwater
log (Δ18O‰)
2.5
2.0
1.5
1.0
0
100
200
300
400
500
600
Stomatal density (mm−2)
log (Δ18O‰)
2.5
2.0
1.5
1.0
10
20
30
40
50
60
Guard cell length (um)

Succulence

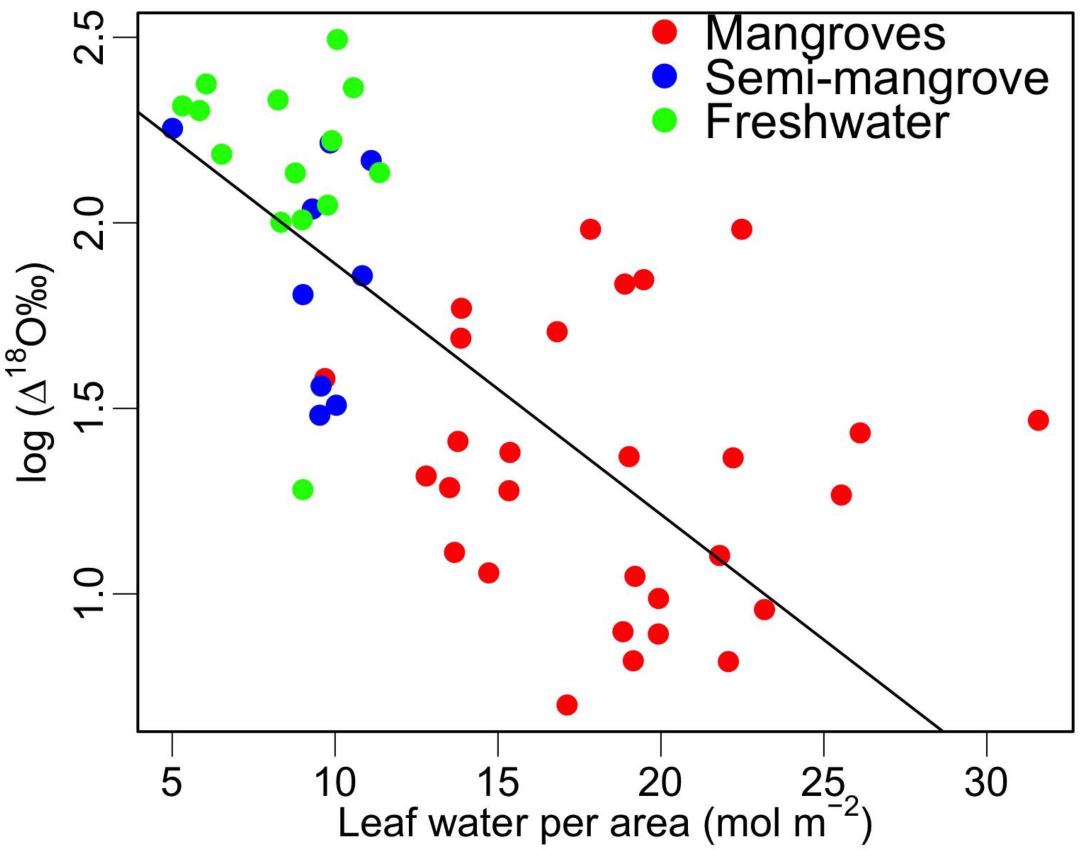
Higher water content

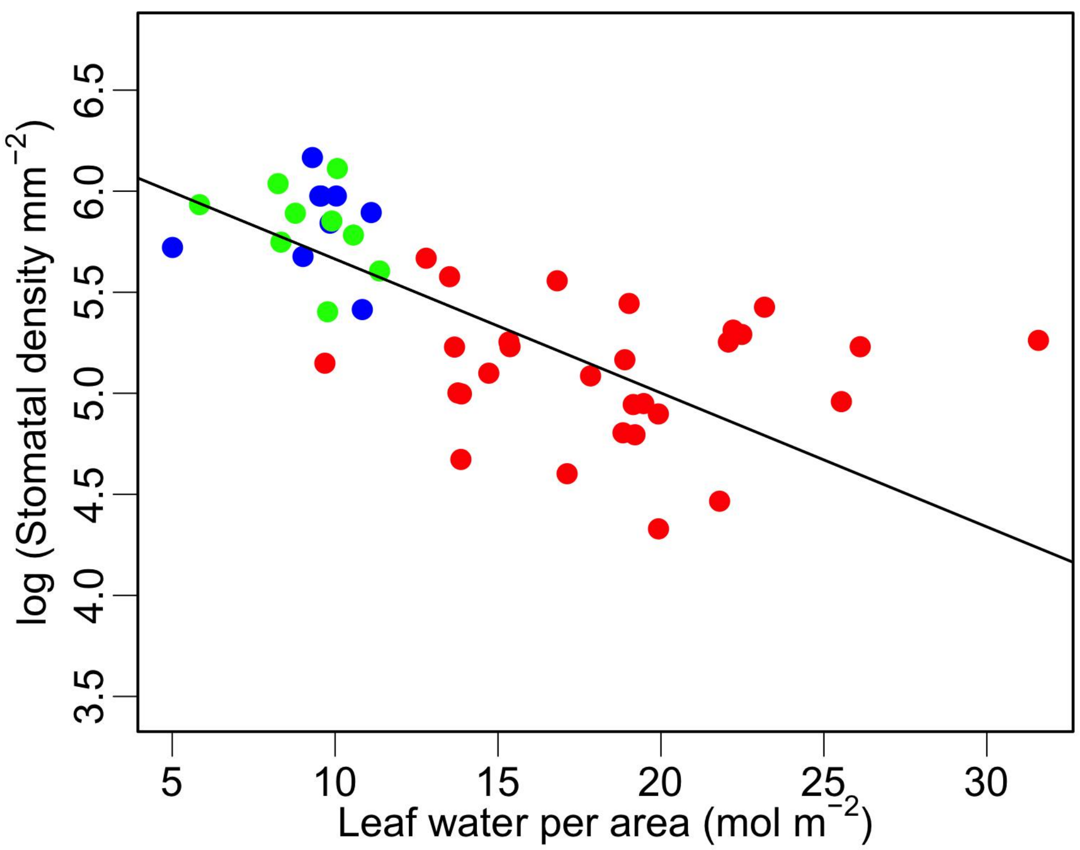




Mantovani (1998)

Succulence


Mangroves
Semi-mangrove
Freshwater
log (Δ18O‰)
2.5
2.0
1.5
1.0
5
10
15
20
25
30
Leaf water per area (mol m−2)


log (Stomatal density mm−2)
6.5
6.0
5.5
5.0
4.5
4.0
3.5
5
10
15
20
25
30
Leaf water per area (mol m−2)

Theory

Bulk leaf water / Evaporative water

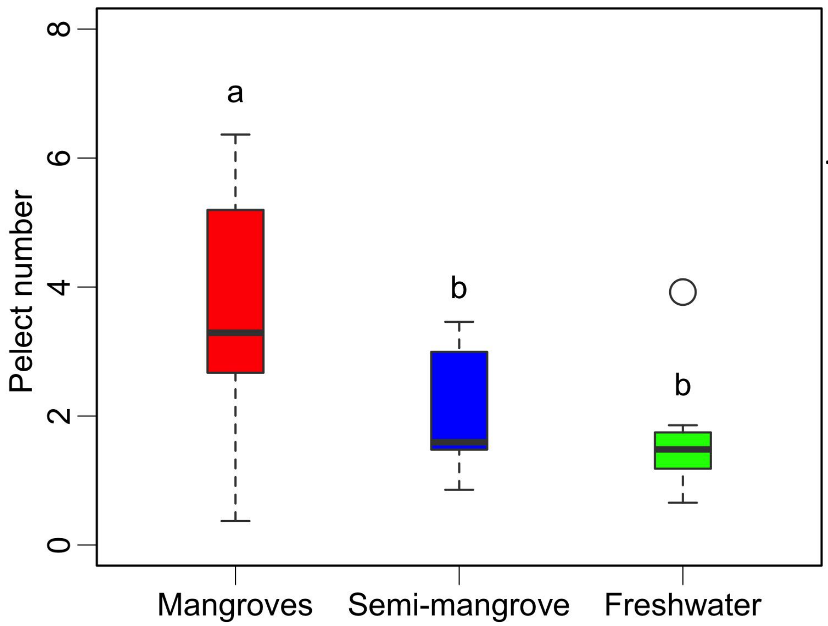
$$\frac{\Delta_{Ls}}{\Delta_{es}} = \frac{1-e^{-p}}{p} \quad (1)$$

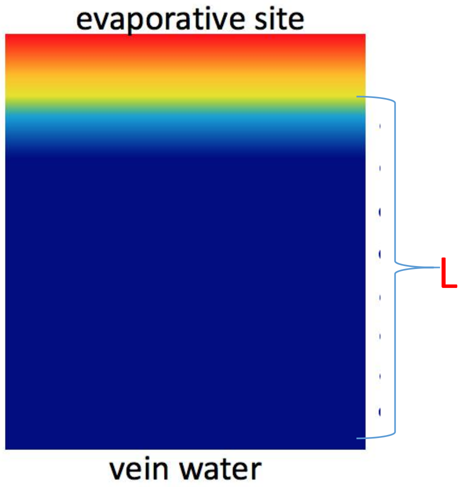
$$\Delta_{es} = \varepsilon^{+} + \varepsilon_k + (\Delta_v - \varepsilon_k)h_L \quad (2)$$

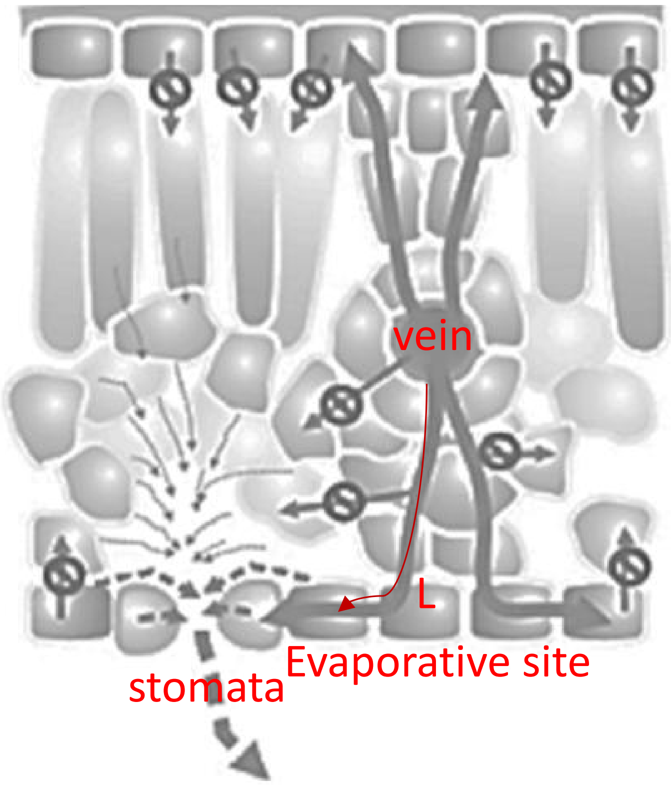
$$P = \frac{EL}{DC} \quad (3)$$

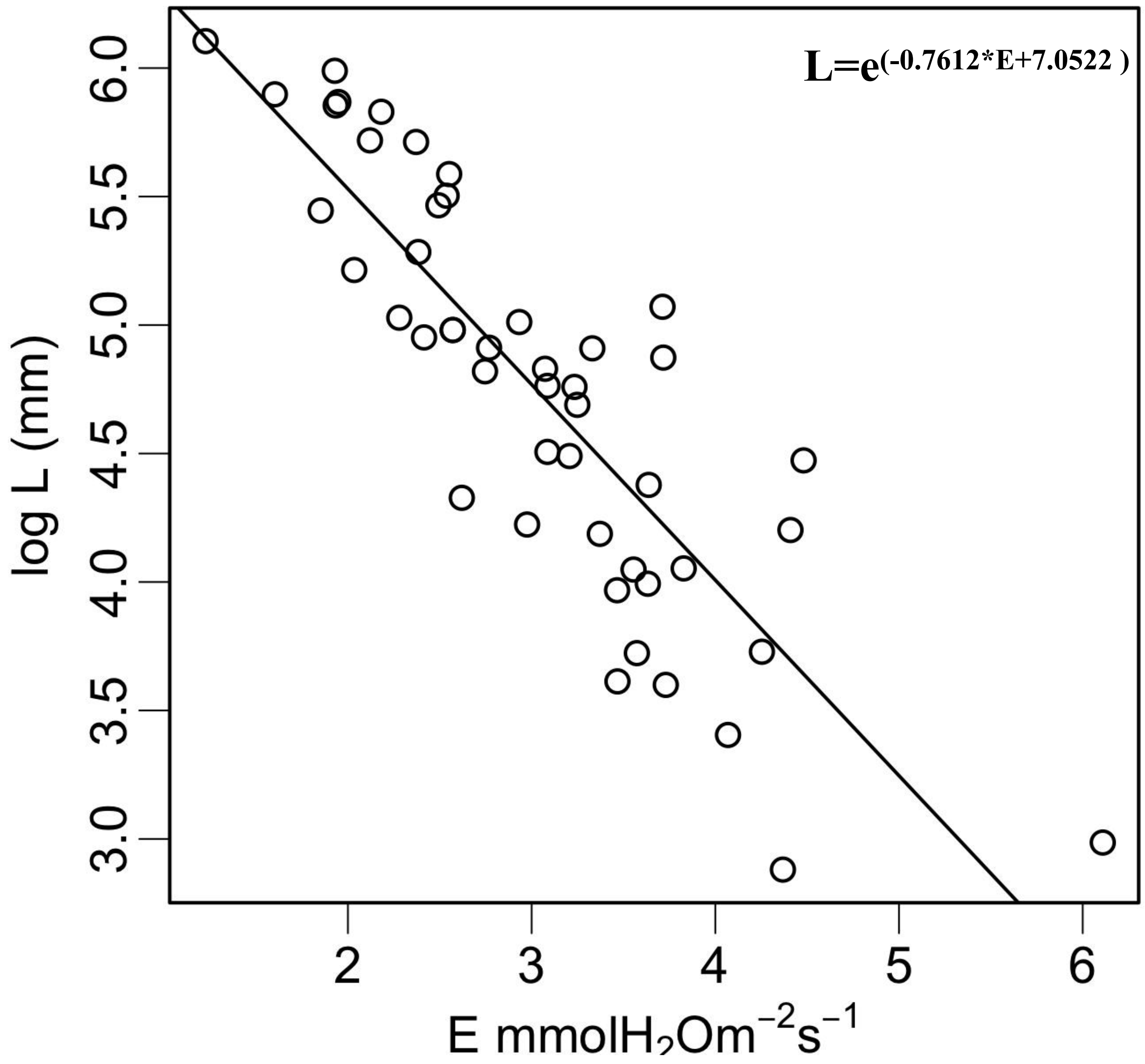
Transpiration

Efficient mixing path length



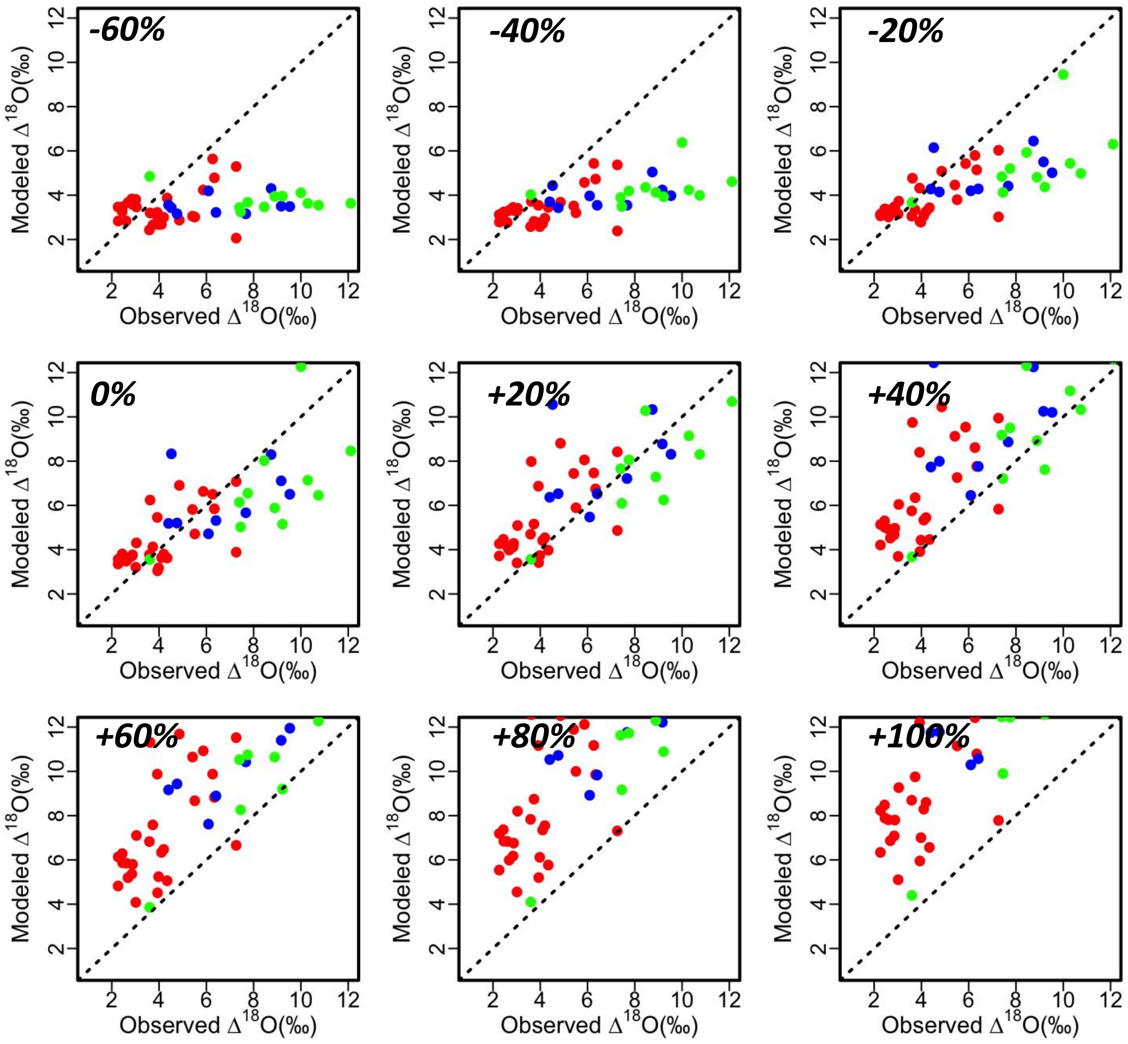




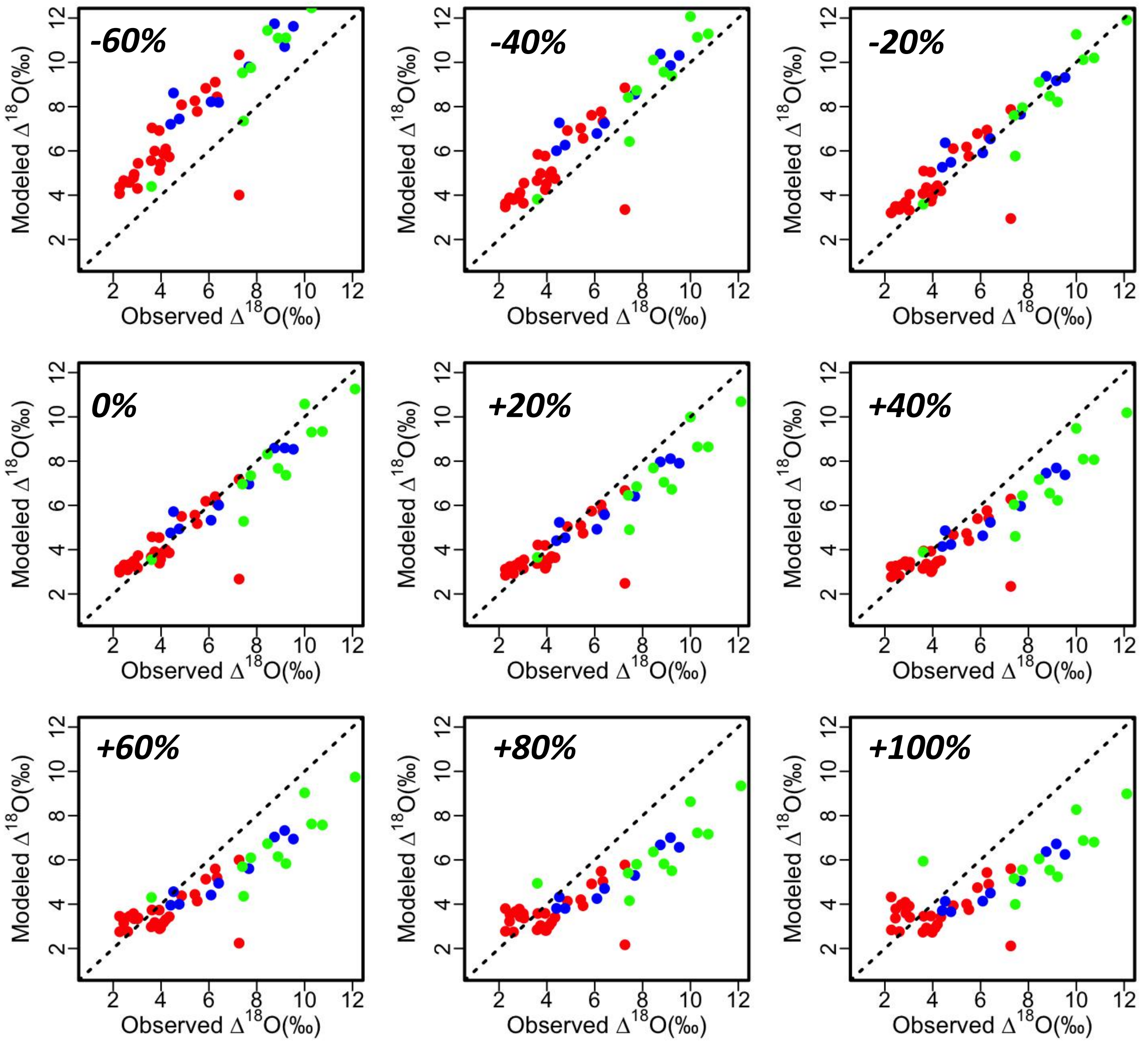

L=e(-0.7612*E+7.0522)
log L (mm)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2
3
4
5
6
E mmolH2Om−2s−1

Theory-sensitivity analysis

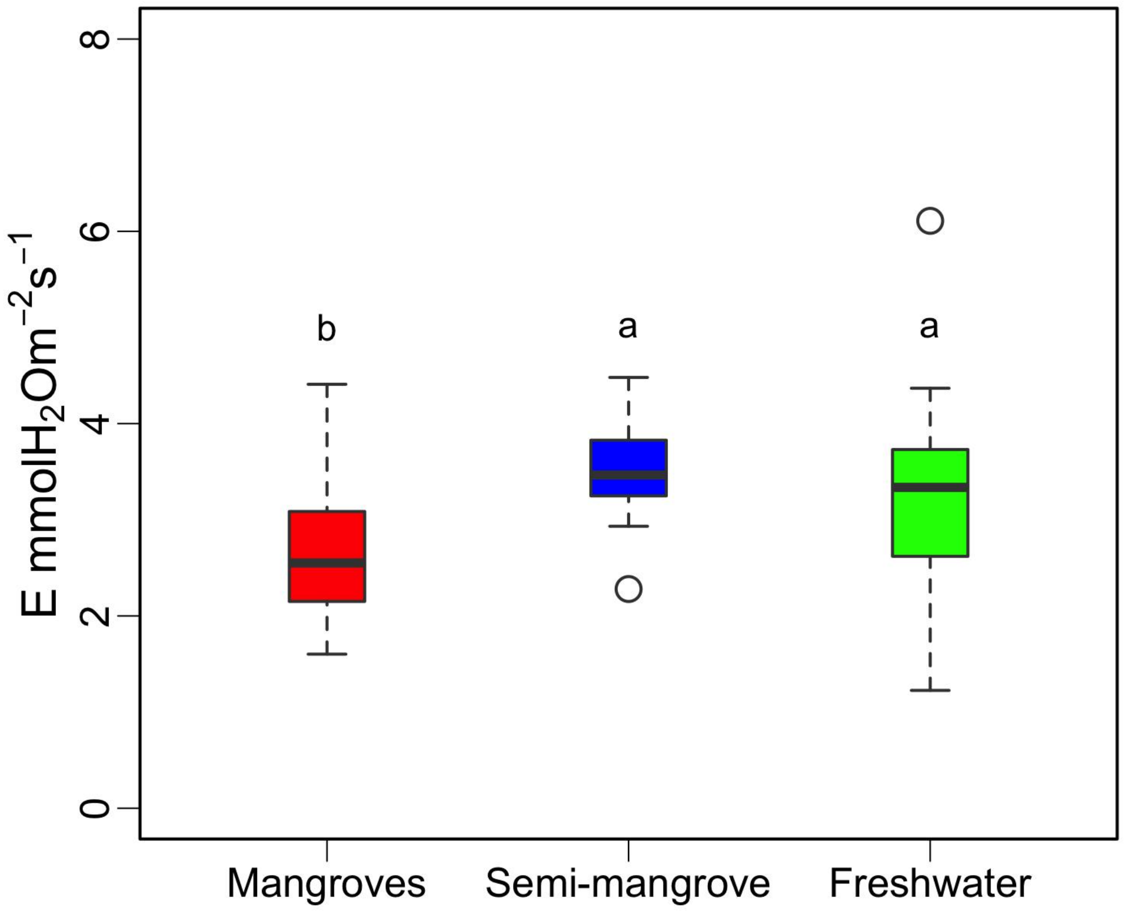
E variation



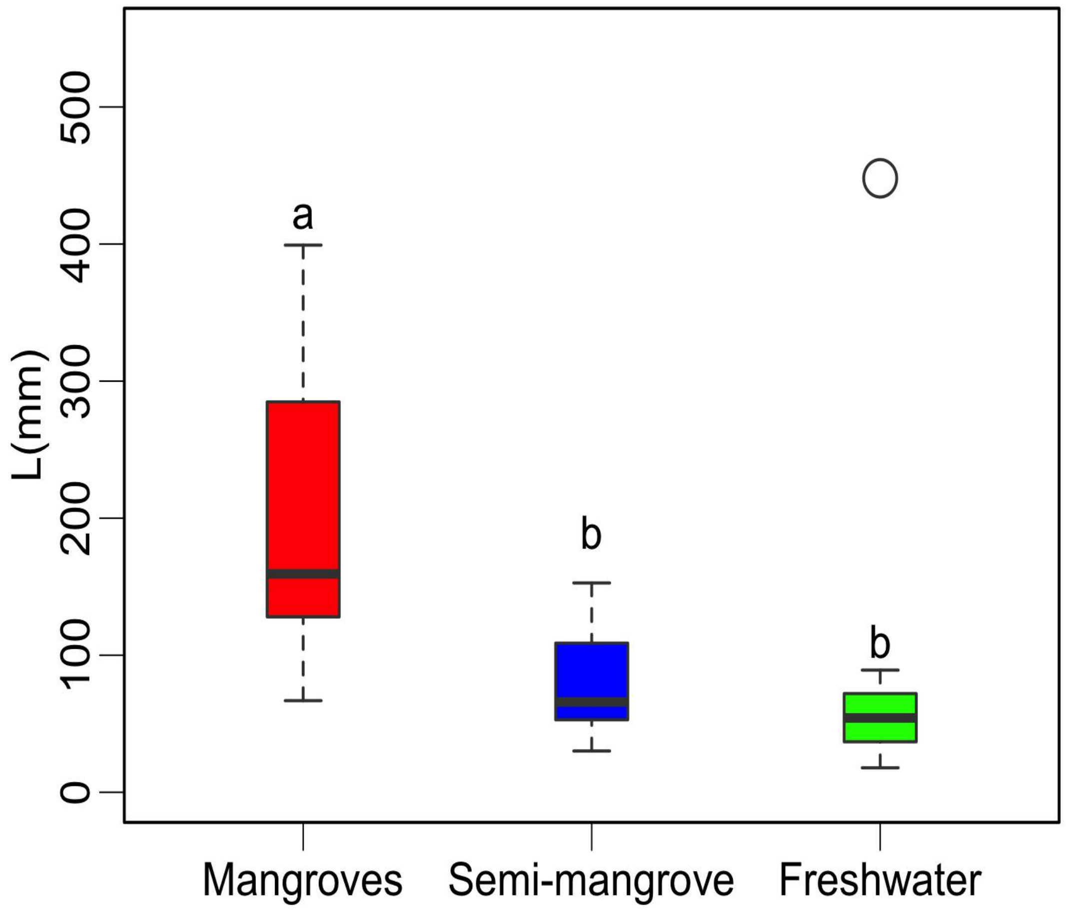
L variation



Lower transpiration

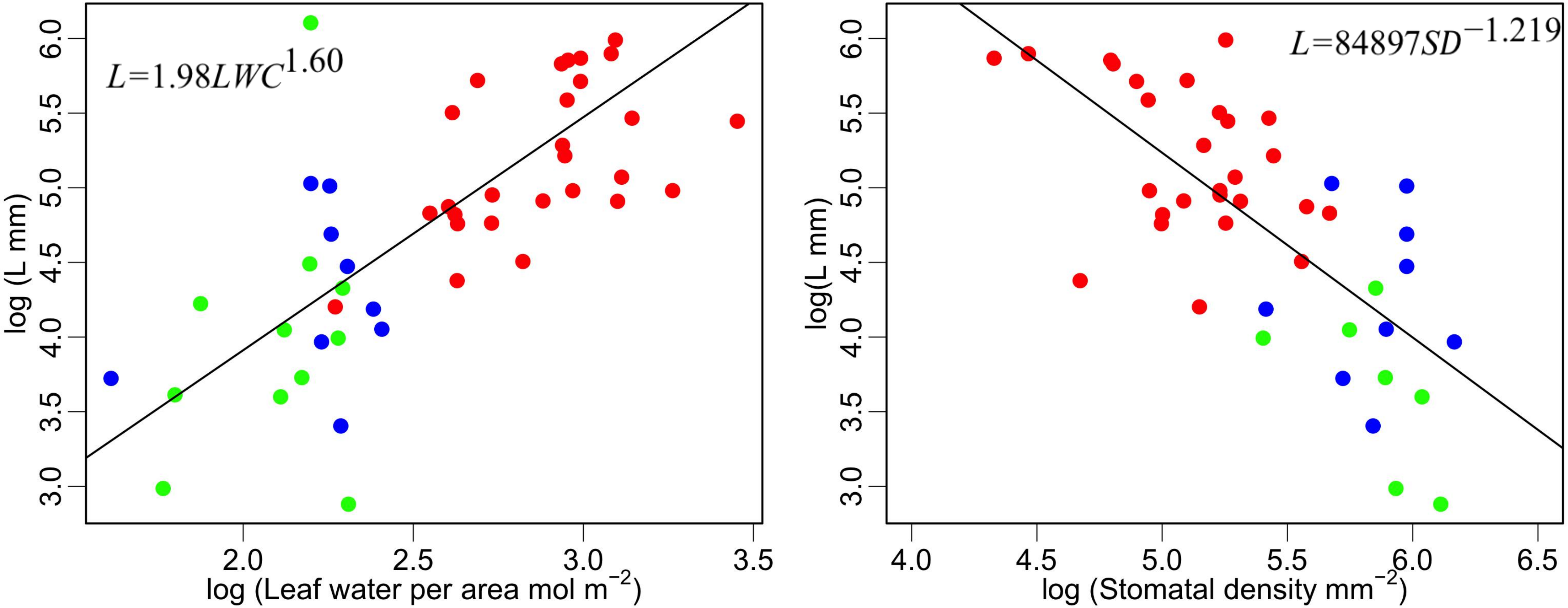


longer L



$$L = \left(\sum_{i=1}^{n} \frac{A_E}{A_{mi}} l_i \right) + \frac{A_E \bar{l}_S}{A_S} j^{-\varnothing}, \quad \text{Eqn 16}$$

Larcher, L., et al. (2015)



Theory-Correlation analysis

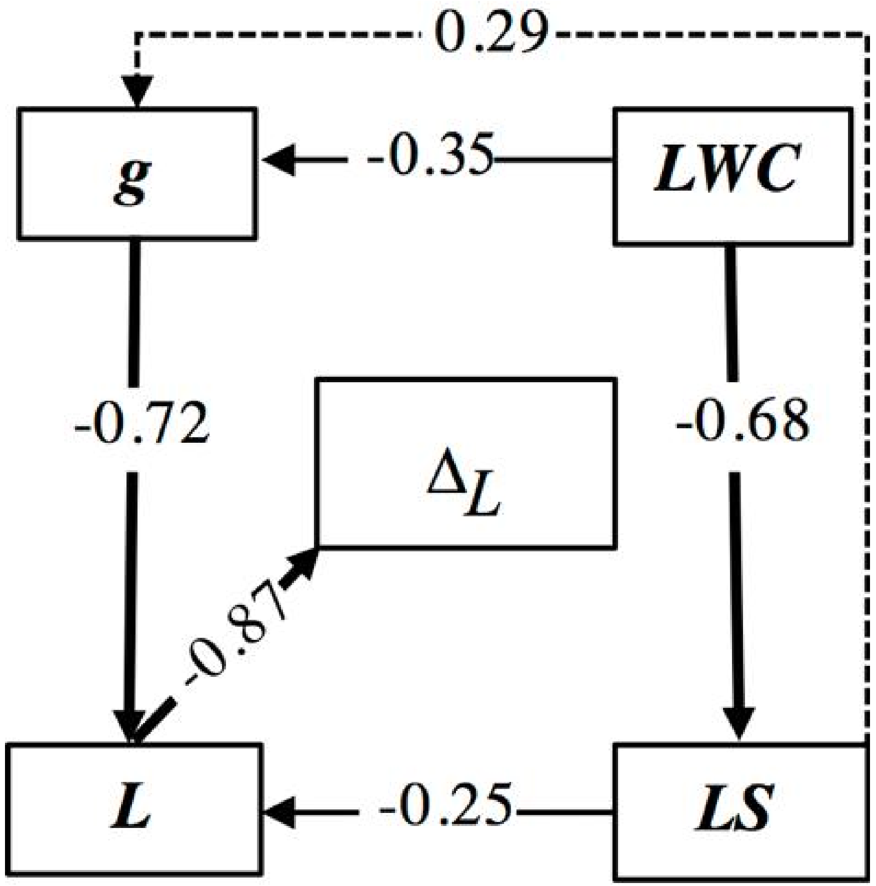
$E = gw_i(1-h_L)$

Table 2. Correlation coefficients of factors related to both leaf anatomical traits and leaf water enrichment

Item	*LWC*	*LMA*	*LS*	*SL*	*E*	h_L	w_i	*T*	*g*	Δ_L/Δ_e	*P*	*L*
Δ_L	**-0.64**	**-0.59**	**0.65**	**-0.55**	**0.63**	-0.07	-0.09	-0.09	**0.60**	**0.89**	**-0.87**	**-0.79**
LWC		**0.68**	**-0.67**	**0.66**	**-0.63**	-0.09	-0.11	-0.10	-0.45	-0.47	**0.53**	**0.63**
LMA			**-0.64**	**0.68**	**-0.62**	-0.25	-0.07	-0.07	-0.47	-0.53	**0.60**	**0.69**
LS				-0.69	**0.60**	0.15	0.22	0.23	**0.53**	**0.52**	**-0.55**	**-0.63**
SL					**-0.51**	-0.03	-0.26	-0.25	-0.37	-0.37	**0.45**	**0.54**
E						0.19	0.11	0.11	**0.86**	**0.65**	**-0.65**	**-0.79**
h_L							-0.09	-0.04	0.31	0.21	-0.13	-0.17
w_i								**0.99**	-0.26	-0.17	0.23	0.08
T									-0.26	-0.16	0.23	0.07
g										**0.71**	**-0.68**	**-0.73**
Δ_L/Δ_e											**-0.93**	**-0.84**
P												**0.93**

leaf water content per area (*LWC*), leaf mass (dry) per area (*LMA*), stomatal density (*LS*), transpiration (*E*), relative humidity (h_L), leaf temperature (*T*), stomatal conductance (*g*), the mole fraction of (light) water vapor in the intercellular (w_i), the ratio of the isotope enrichment of bulk leaf water to that of the evaporative water (Δ_L/Δ_e), *Péclet* number (*P*), effective mixing path length (*L*) with species-specific leaf water isotopic enrichment (Δ_L). Bold numbers indicated that the correlation coefficients reached the significance level at $p<0.05$.

Conclusions 1

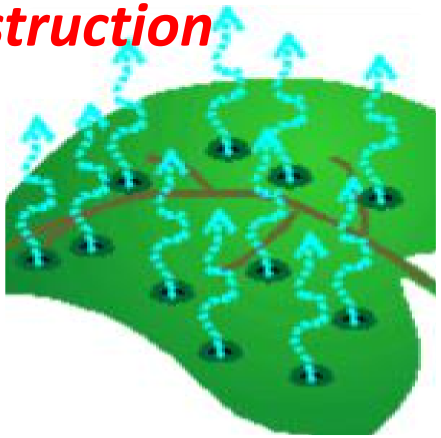


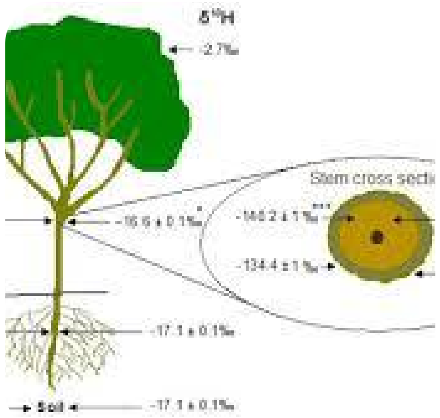
Schematic diagram of underlying mechanism lowering leaf water isotopic enrichment of mangroves than adjacent non-mangrove plants. *The values beside the paths were the standardized (0~1) path coefficients, which were only shown for the significant effects. (Note that logarithm of all variables was used).*

1.Our research built the relationship between leaf traits and L which is hardly measurable

2.Our research imply models involving leaf water enrichment models should cautiously be used in the plants with special leaf traits in other water-limited ecosystem.

3.Climate reconstruction





Leaf-scale isotope studies

(Farquhar and Cernusak 2005; Roden and Ehleringer1999)

Climate reconstruction

(Brunel et al. 1992)

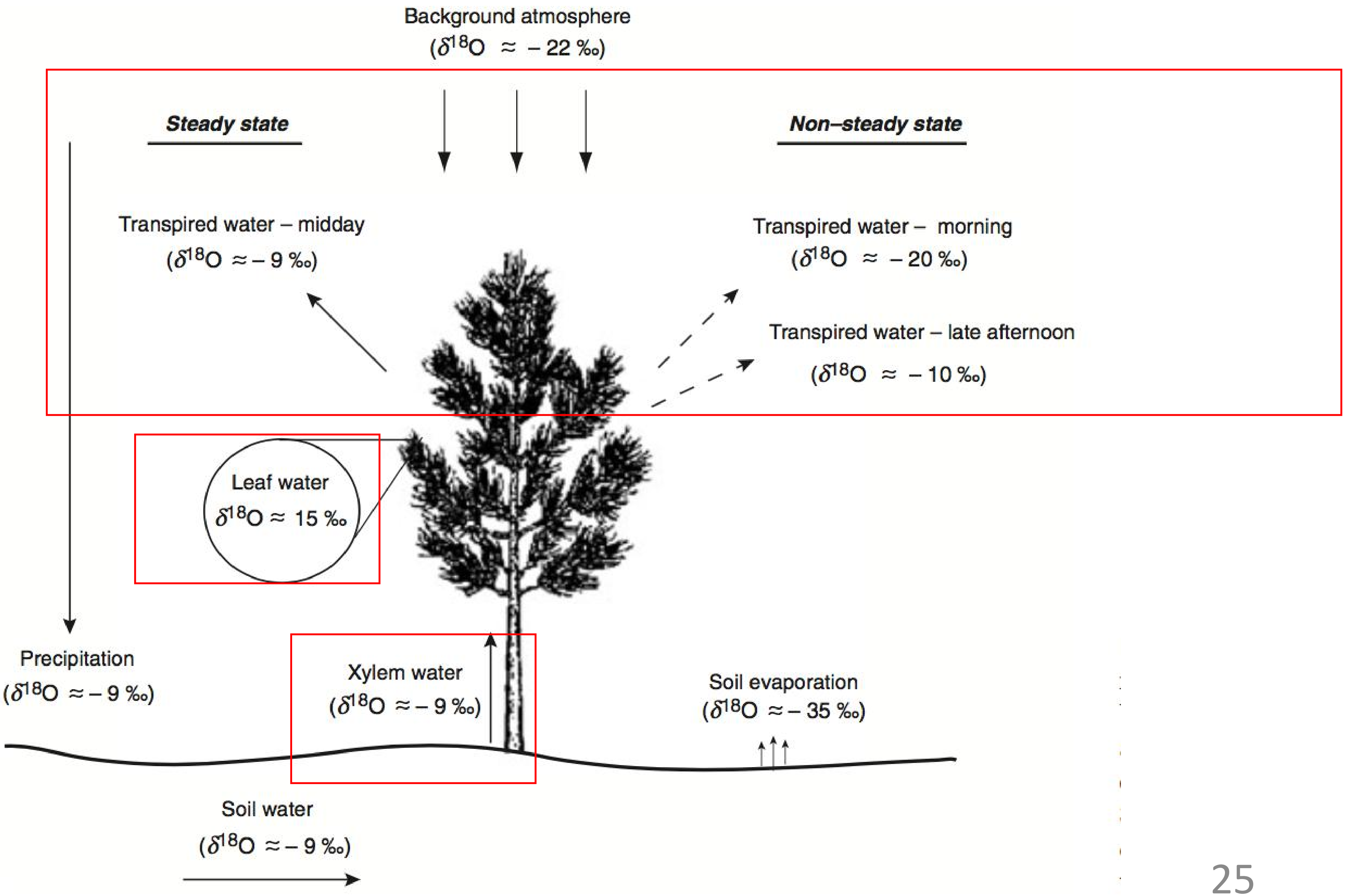
Global-scale estimates of productivity

(Ciais et al. 1997; Farquhar et al. 1993)

$$\Delta_{es} = \varepsilon^{+} + \varepsilon_k + (\Delta_v - \varepsilon_k)h_L$$

$$\Delta_{cx} = \Delta_L(1 - p_{ex}p_x) + \varepsilon_o$$

$$Mc_a \frac{d\delta_a}{dt} = F_{oa}(\delta_o - a_w - \delta_a) + F_{ao}a_w + \Re(\delta_r - \delta_a) + A\Delta_A + F_{an}(\delta_{an} - \delta_o)$$


Background atmosphere
(δ18O ≈ – 22 ‰)
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Non–steady state
Transpired water – midday
(δ18O ≈ – 9 ‰)
Transpired water – morning
(δ18O ≈ – 20 ‰)
Transpired water – late afternoon
(δ18O ≈ – 10 ‰)
Leaf water
δ18O ≈ 15 ‰
Precipitation
(δ18O ≈ – 9 ‰)
Xylem water
(δ18O ≈ – 9 ‰)
Soil evaporation
(δ18O ≈ – 35 ‰)
Soil water
(δ18O ≈ – 9 ‰)

Partitioning ET

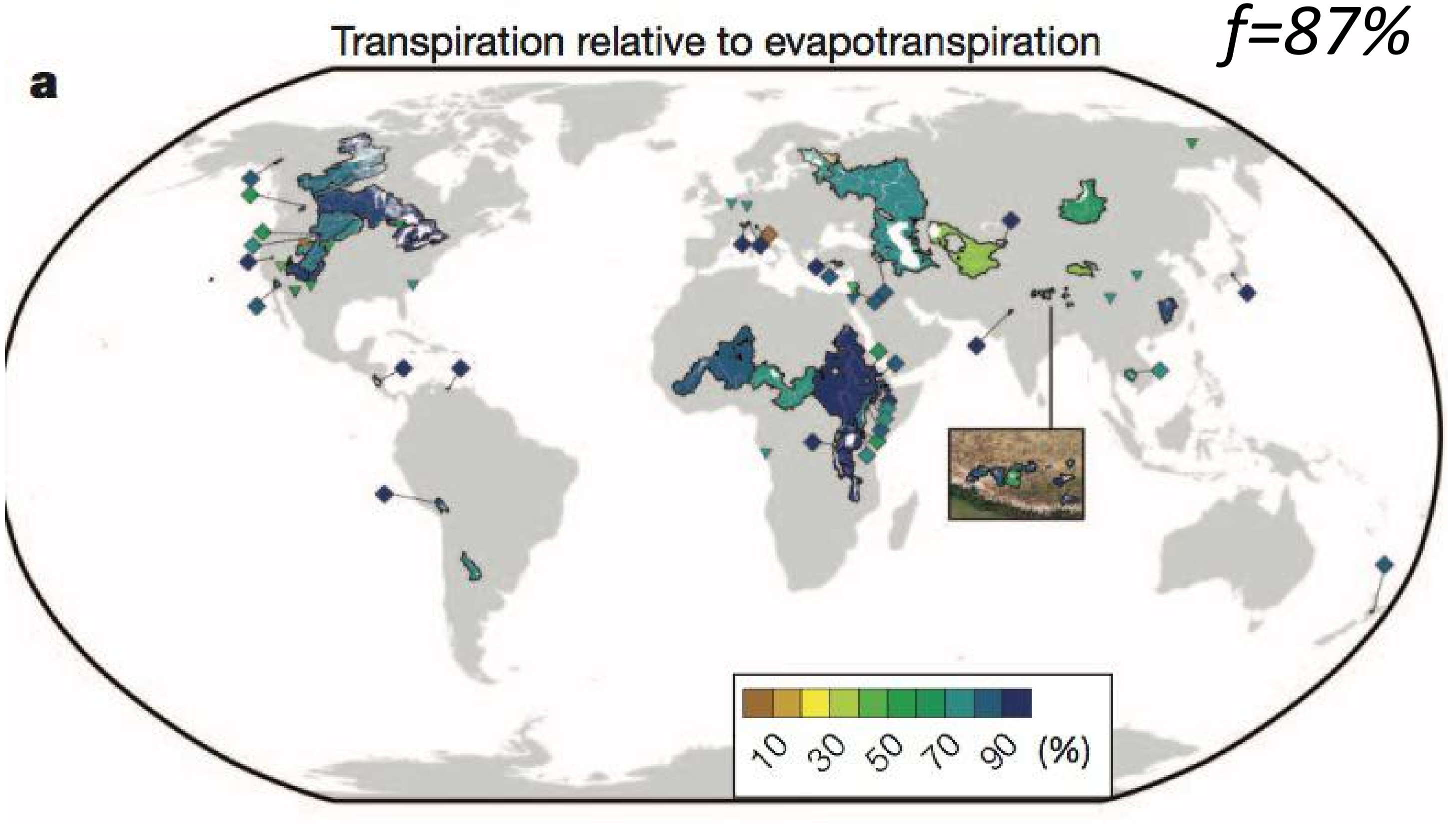
LETTER

doi:10.1038/nature11983

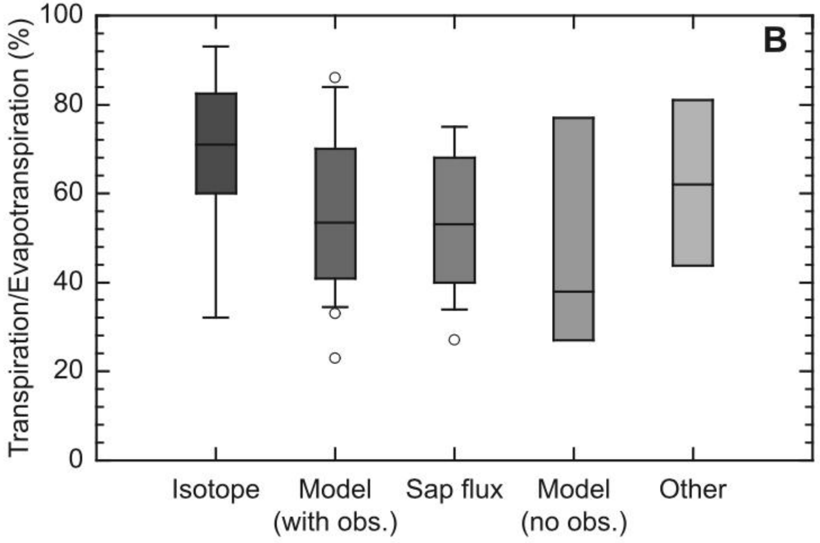
Terrestrial water fluxes dominated by transpiration

Scott Jasechko[1], Zachary D. Sharp[1], John J. Gibson[2,3], S. Jean Birks[2,4], Yi Yi[2,3] & Peter J. Fawcett[1]

f=87%



Jasechko, et al.,2013



Schlesinger& Jasechko ,2014

$$ET = T + E$$

+

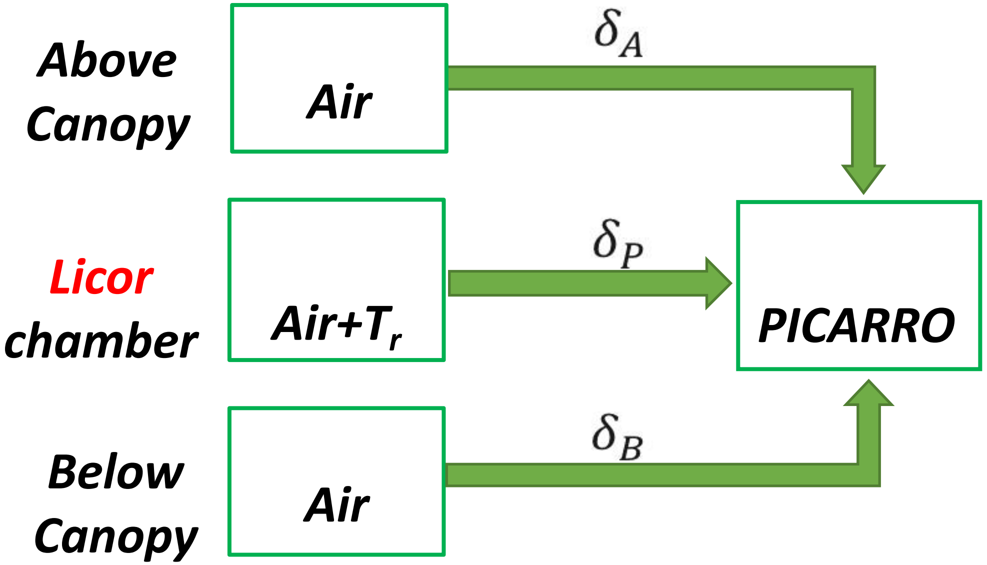
$$ET \times \delta_{ET} = T \times \delta_T + E \times \delta_E$$

$$f = \frac{T}{ET} = \frac{\delta_{ET} - \delta_E}{\delta_T - \delta_E}$$

♛ ***How to reduce the uncertity of caculating*** $\boldsymbol{\delta_T}$?

♛ ***Is the T/ET in mangrove ecosystem lower?***

LICOR-PCARRO measurement system(LPMS)

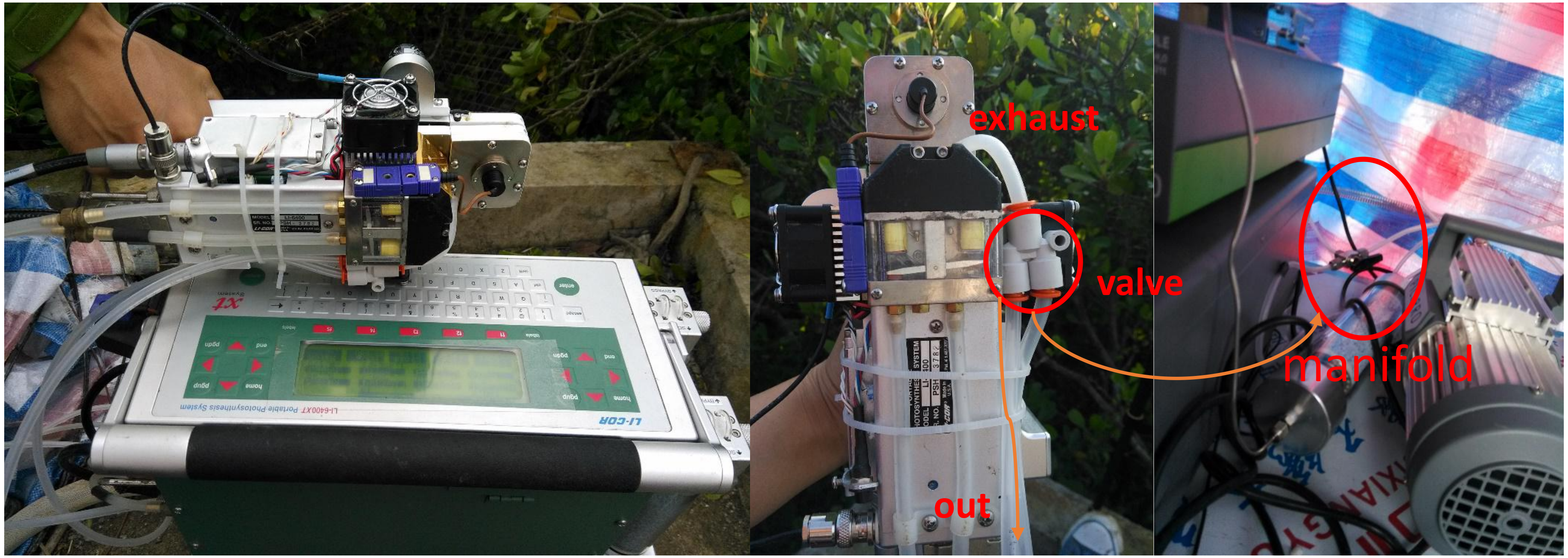


We monitored separately (every 10 mins) the isotope composition of

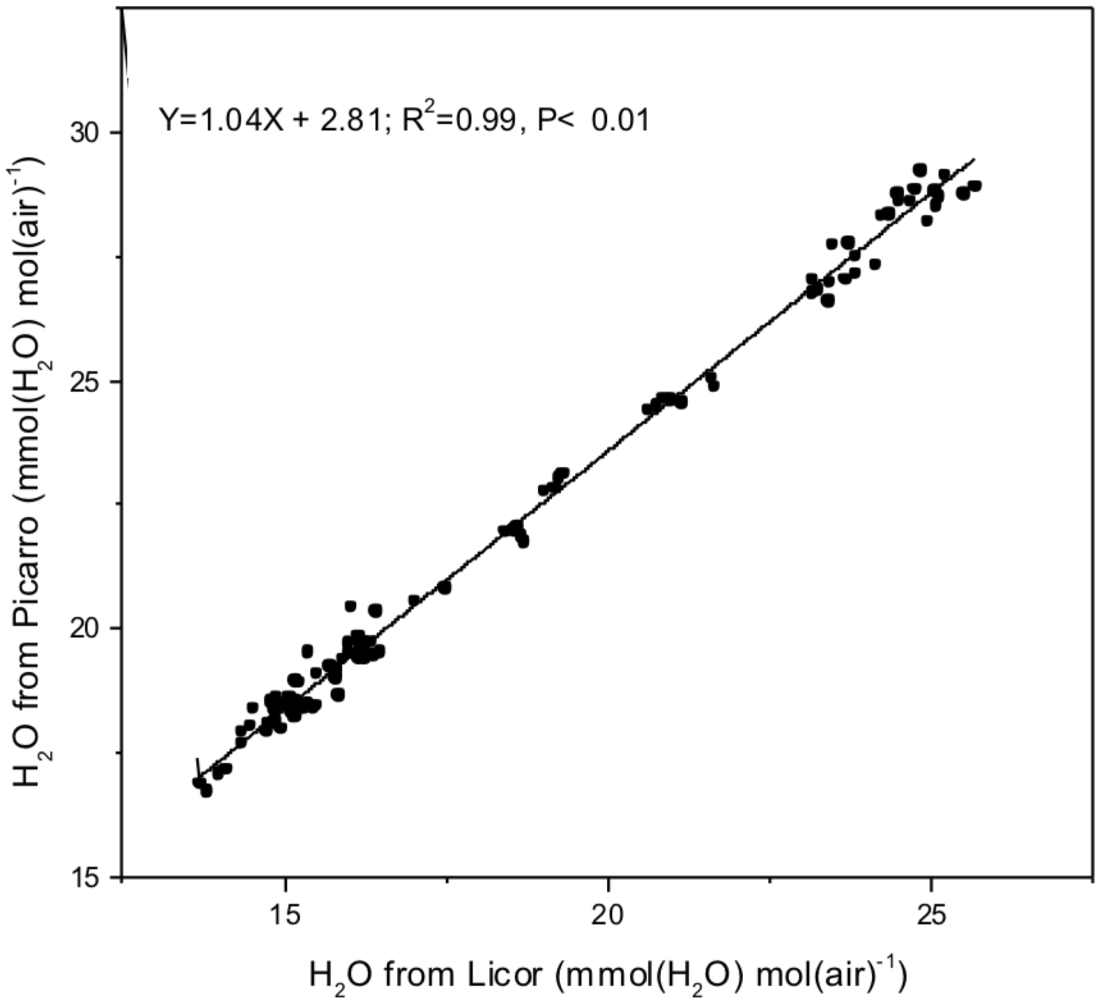
1. water vapor above canopy as reference air

2. licor6400 exhaust

3. water vapor below canopy

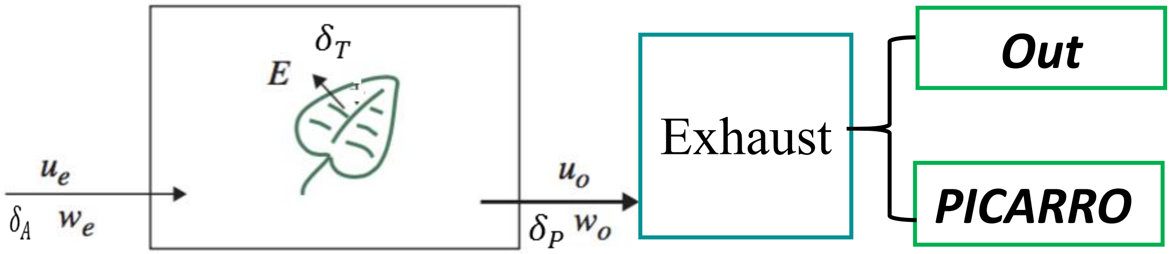


LPMS stability



δ_T caculation

Combining Licor _picarro



LICOR6400 Chamber

Theory

Mass conservation

$$sE = u_o w_o - u_e w_e \quad (1)$$

Flux conservation

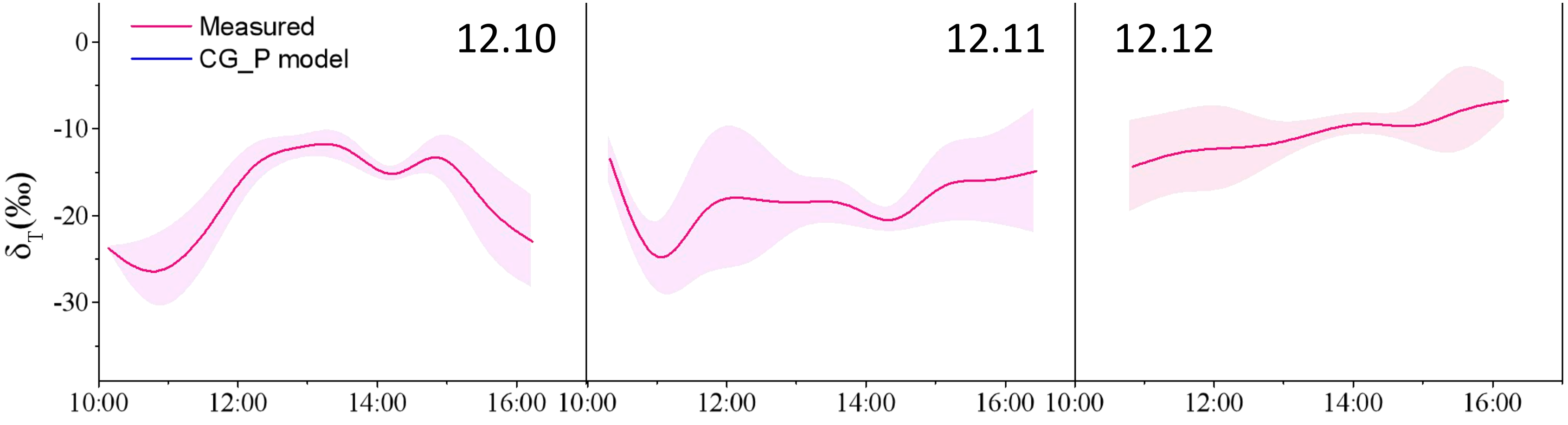
$$u_o = u_e + sE \quad (2)$$

Heavier isotope conservation

$$\delta_T sE = \delta_P u_o w_o - \delta_A u_e w_e \quad (3)$$

$$\delta_T = \frac{\delta_P w_o - \delta_A w_e + (\delta_A - \delta_p) w_o w_e}{w_o - w_e} \quad (4)$$

δ_T diurnal variation



1.$\delta^{18}O_T$ presented a bimodal pattern

2. caused by temporary stomatal closure

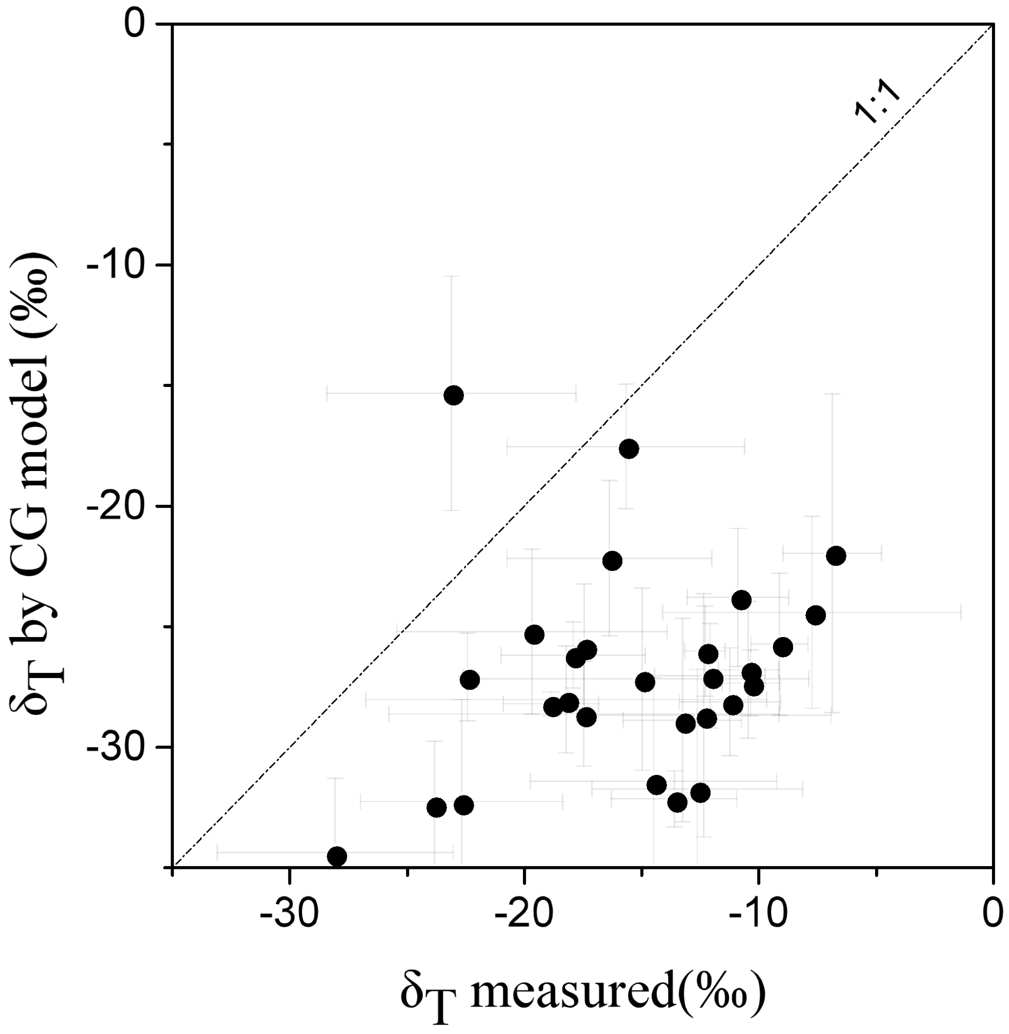
δ_T model

Method1: CG model

Assumption: Mixing uniform leaf water

$$\delta_T = \frac{\alpha^{+}\delta_B - h_L\delta_V - \varepsilon^{+} - (1-h_L)\varepsilon_k}{(1-h_L)(1+\varepsilon_k/1000)} \quad (6)$$

$$\delta_P$$



δ_T model

Method2: CG_P model (including peclect effect)

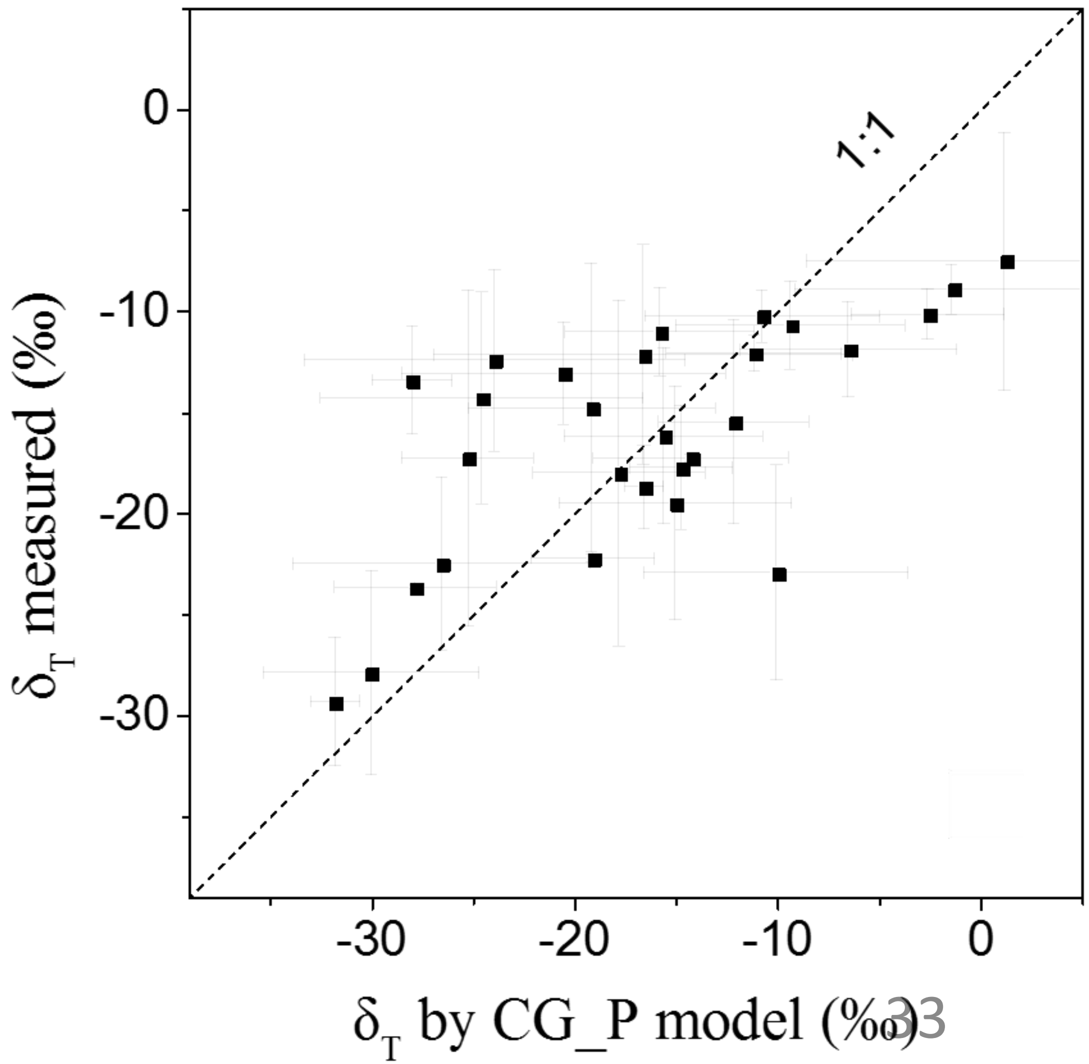
Assumption: leaf water is overwhelmed by evaporation site and source water

$$\delta_T = \frac{\alpha^+\delta_e - h_L\delta_V - \varepsilon^+ - (1-h_L)\varepsilon_k}{(1-h_L)(1+\varepsilon_k/1000)} \quad (14)$$

$$\frac{\Delta_L}{\Delta_e} = \frac{1-e^{-p}}{p} \quad (15)$$

$$P = \frac{EL}{DC} \quad (16)$$

$$L = e^{(-0.7612*E+7.0522)} \quad (17)$$



δ_T model

Method3: FC model

Assumption: leaf water excluding main vein

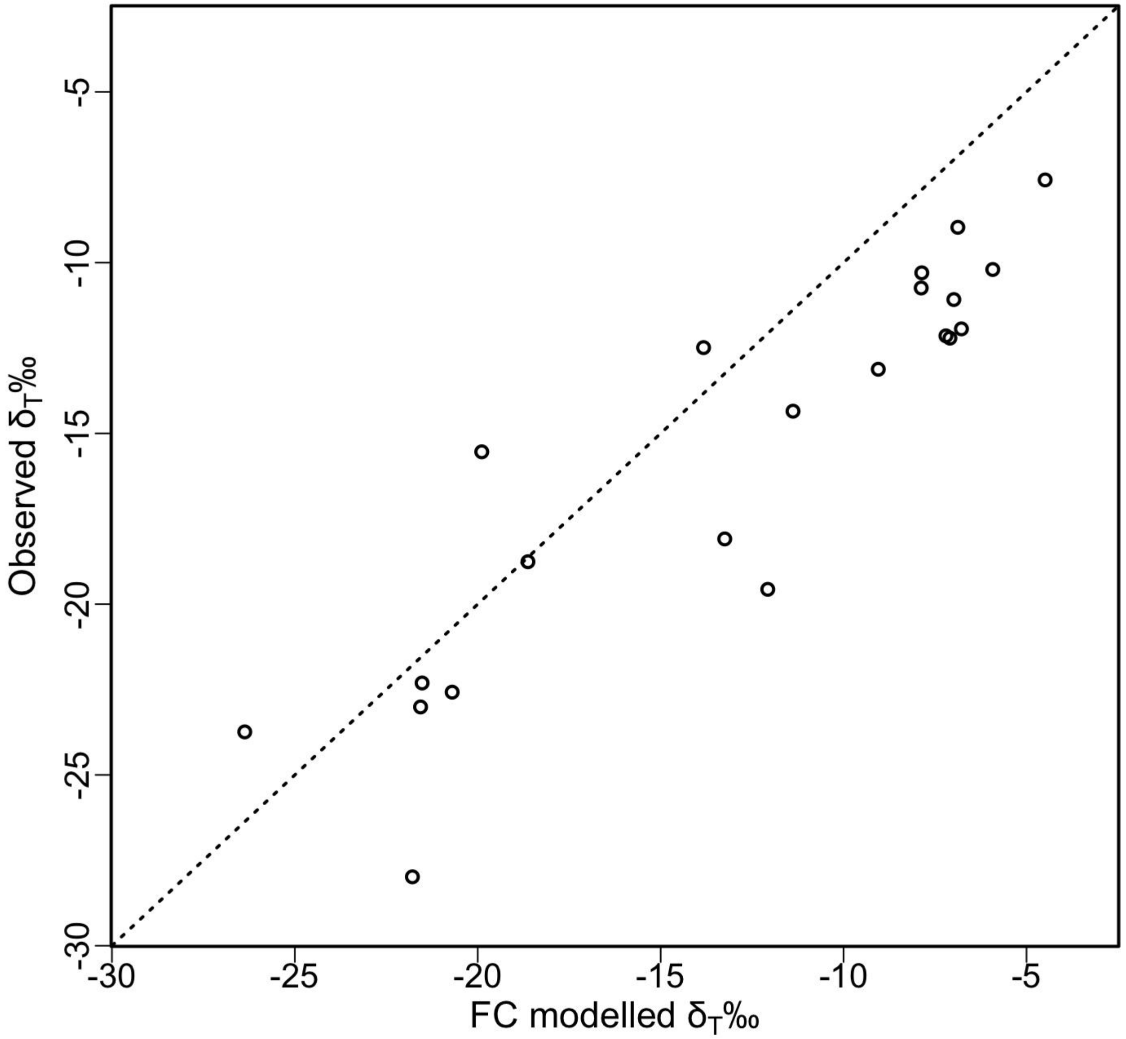
Leaf lamina water content (W $molm^{-2}$) balance

$$\frac{d(W)}{dt} = J - T_r \qquad (11)$$

Heavier isotope conservation

$$\frac{d(R_L W)}{dt} = R_X J - R_T T_r \qquad (12)$$

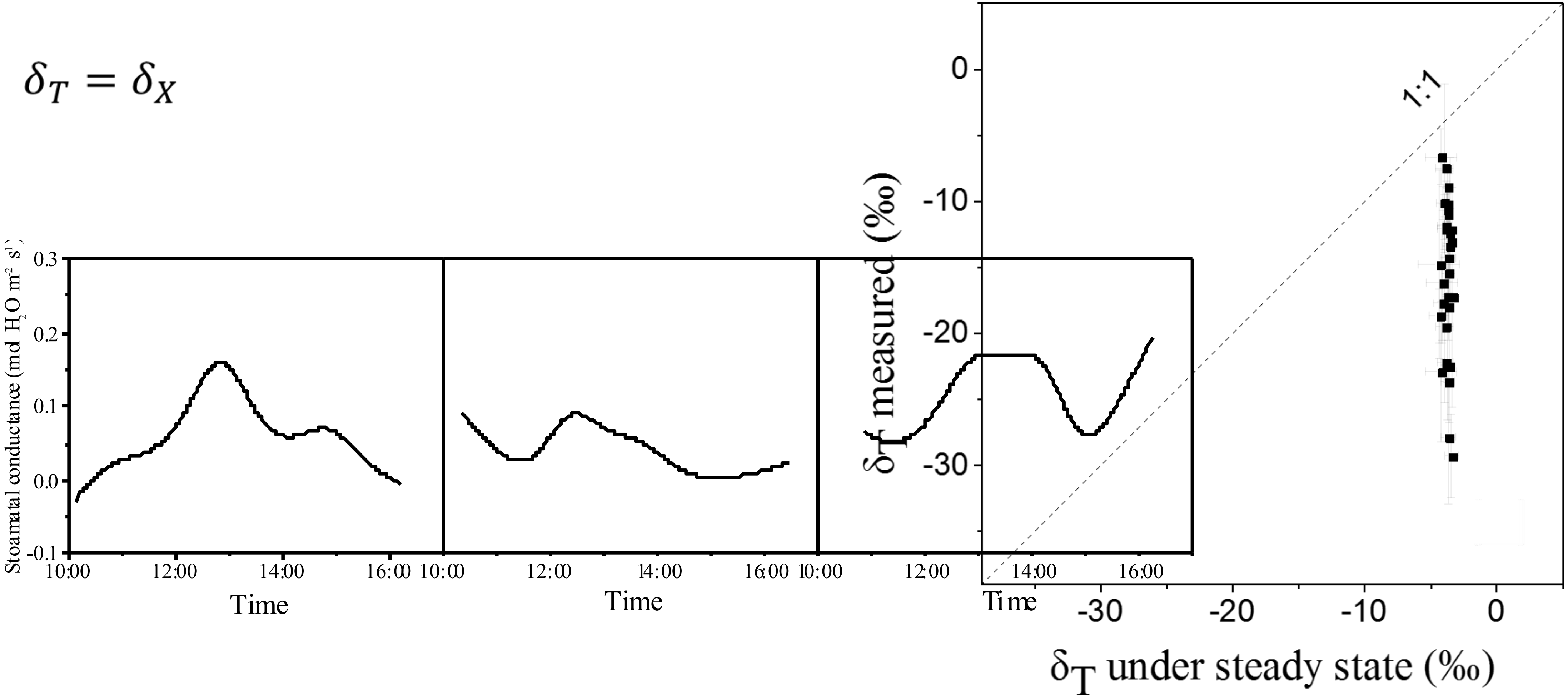
$$\delta_T = \delta_X - \frac{1}{T_r} * \frac{d(W * \Delta_L)}{dt} \qquad (13)$$



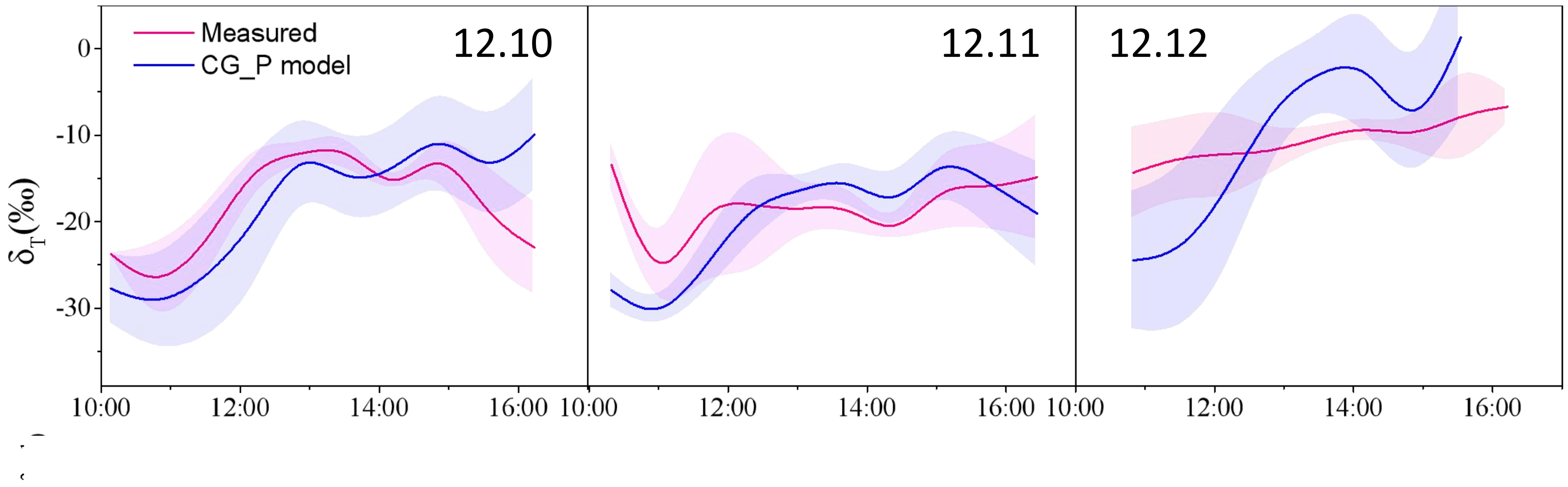
δ_T model

Method 4: steady-state assumption

$$\delta_T = \delta_X$$

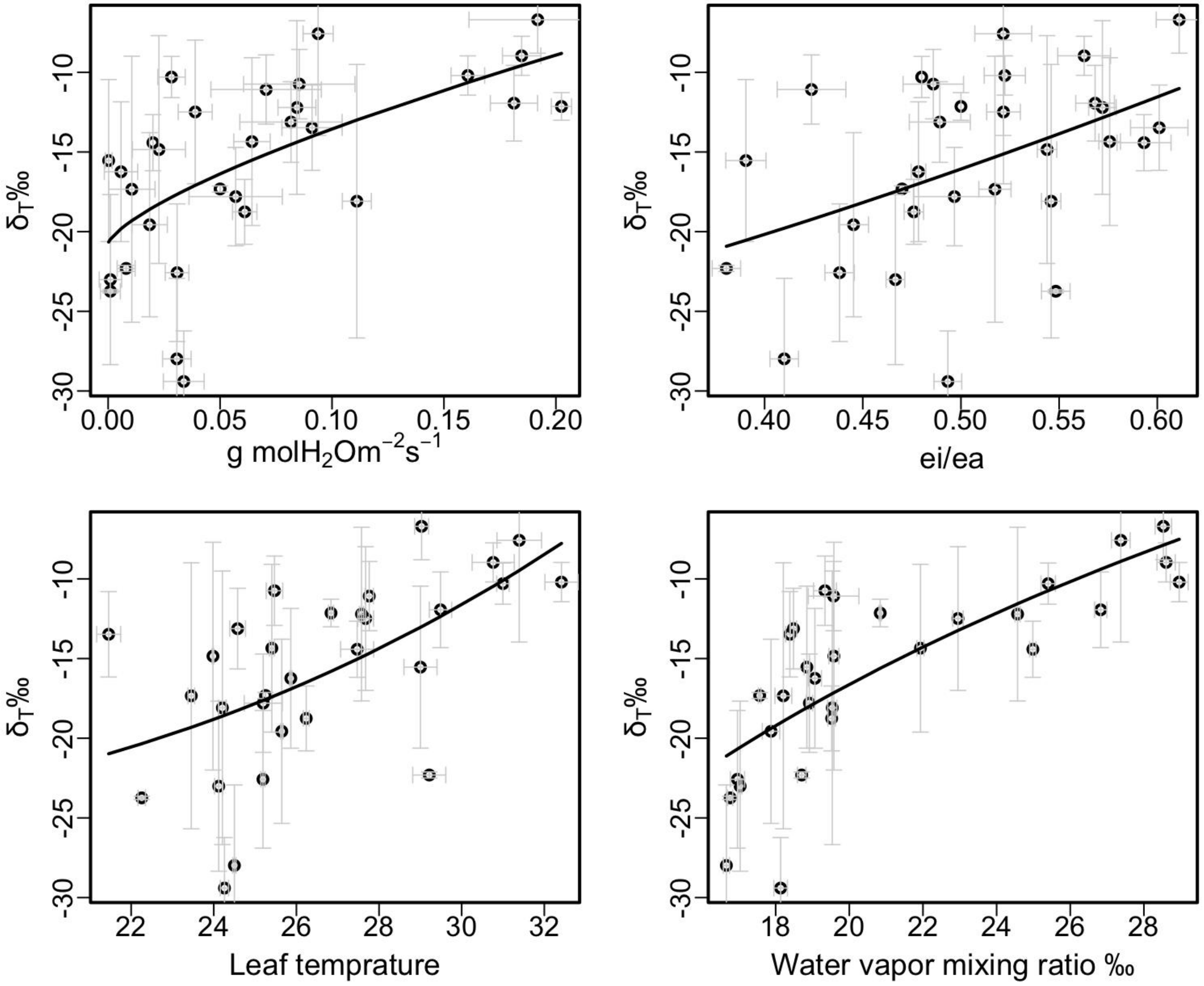


Modelling Results



What factors drive δ_T variation?

its variation mainly was drove by stomatal conductance ,leaf temperature and air humidity



Conclusions 2

1. The $\delta^{18}O_T$ presented a bimodal pattern caused by stomatal closure during 2:00~4:00 PM, and its variation mainly was drove by stomatal conductance and leaf temperature;

2. The $\delta^{18}O_T$ deviated from isotopic steady state throughout most of the days, when E is not high enough.

3. Modified CG model including peclet effect and FC model are both suitable to simulate $\delta^{18}O_T$ of mangrove leaves.