9th International Conference on Urban Climate

Weighing Whole Tree Transpiration Rate of Urban Trees and Analysis of Trees Morpho-physiological Effects

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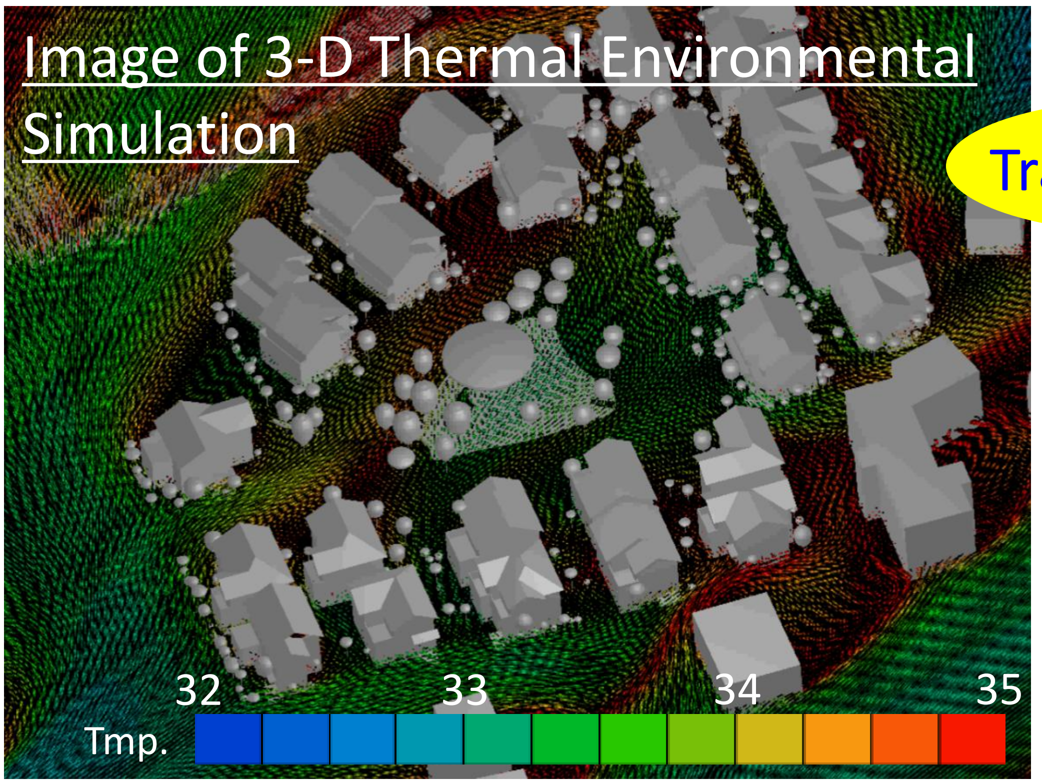
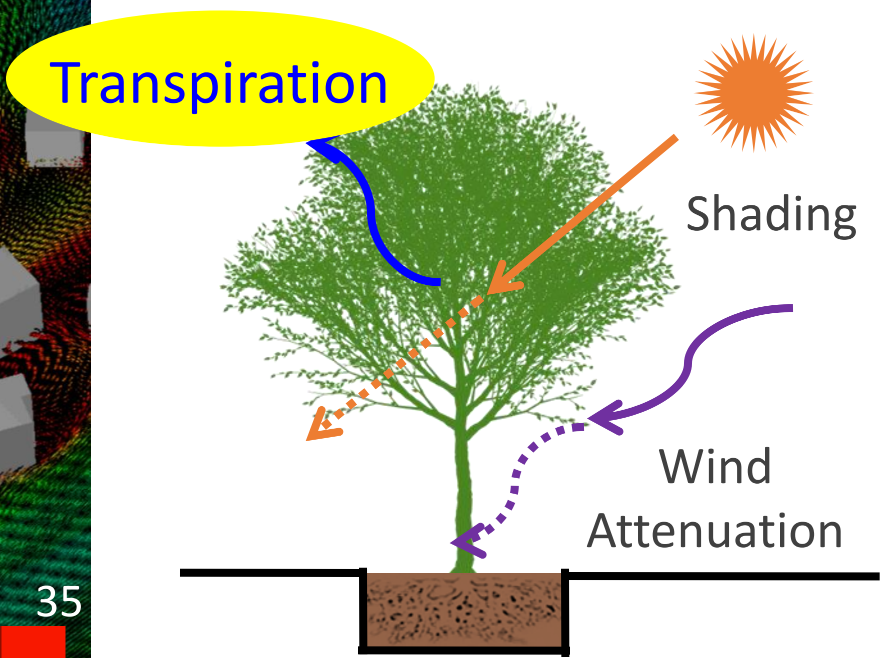
Background

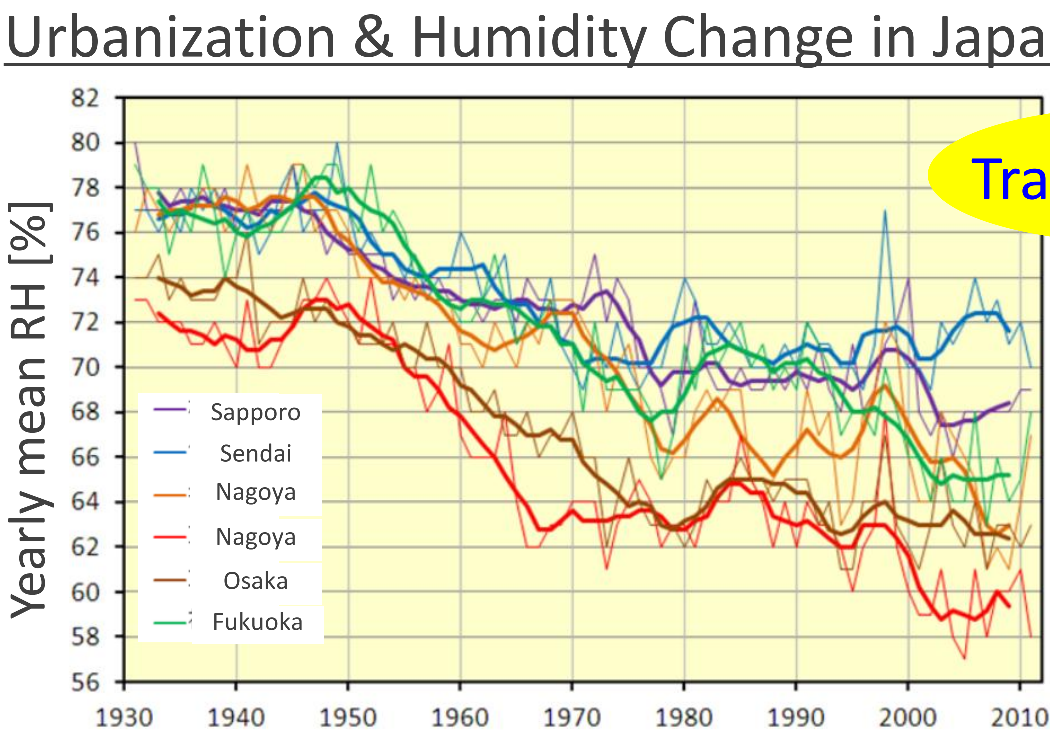
- ✓ Single-tree based model is promising to utilize urban tree's thermal effect for urban planning
- ✓ Transpiration model needs parameterization to represent physiological response (e.g. Jarvis: *Phil. Trans. Roy. Soc. Lond.* 1976)
- ✓ There is few data dealt with urban tree, esp. single-tree

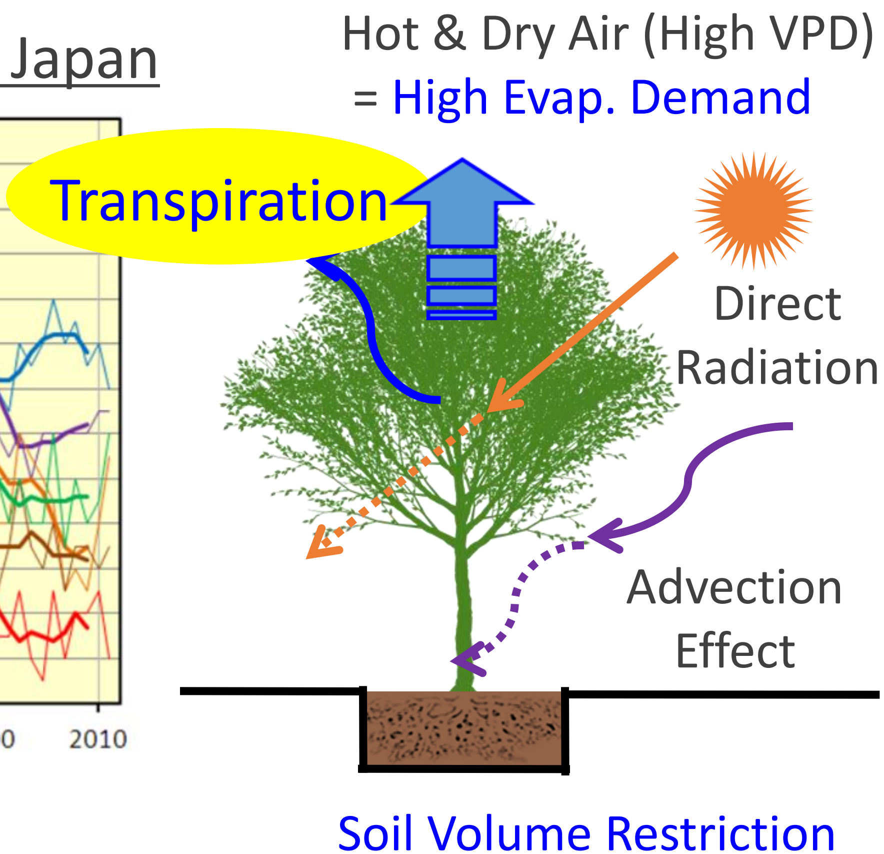




Do Urban Trees Use Much Water Than Forest?

- ✓ Some studies (e.g. Moriwaki et al.: *J. Jpn. Soc. Civil Eng.* 2002, Narita et al.: *Trans. AIJ* 2006) indicated garden/roadside trees can use much water than forest (1.5~2 times)
- ✓ Others indicated chronic drought due to water supply limitation



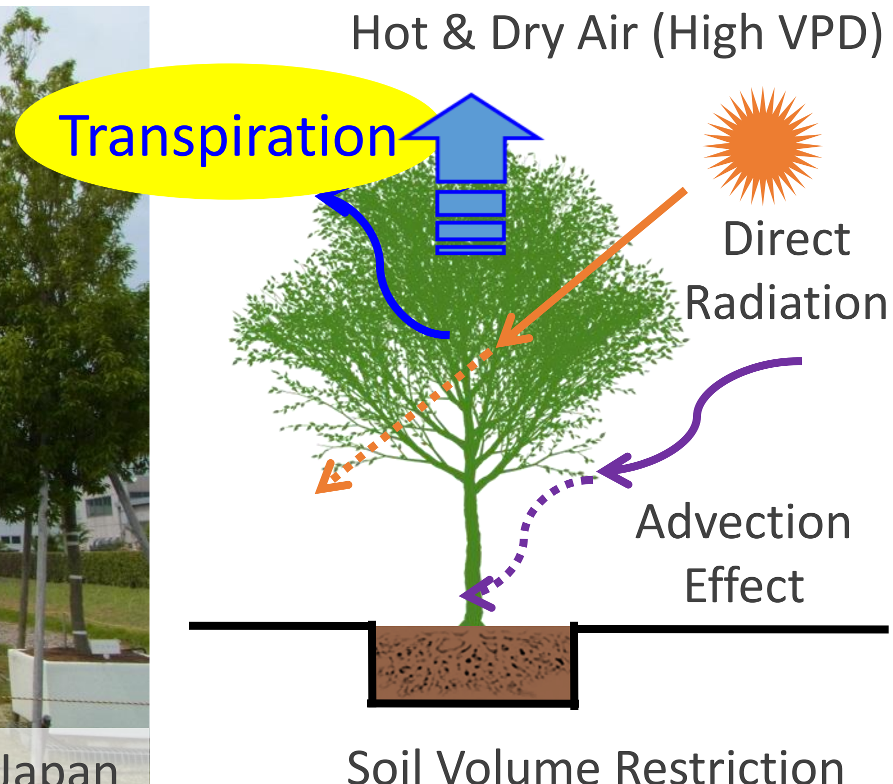


Purpose & Process of Study

1. Quantify whole-tree transpiration rate under isolated & soil restricted condition, sunny irrigation day

   cf. Asawa et al.: *J. Jpn. Soc. Reveget. Tech.* 2012･2014, Kiyono et al.: *Trans. AIJ* 2015

2. Parameterize hourly responses to light & humidity
3. Evaluate relative importance of parameters to reconcile model simplicity and species variation



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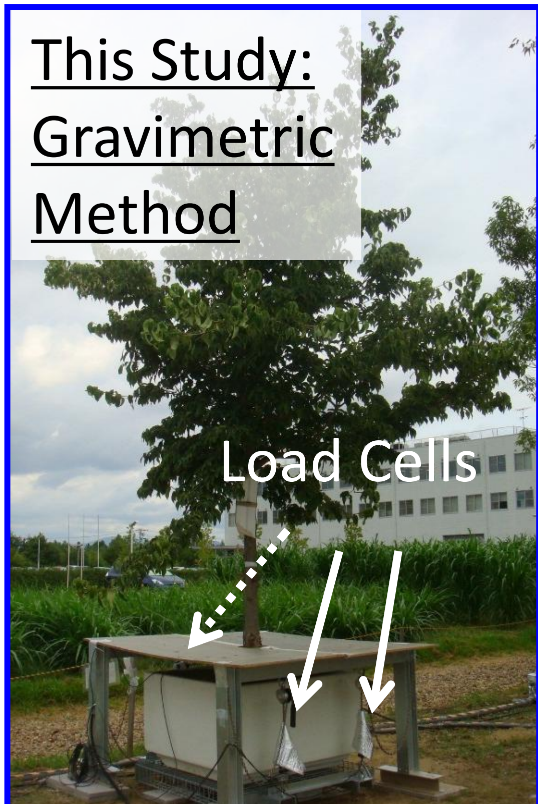
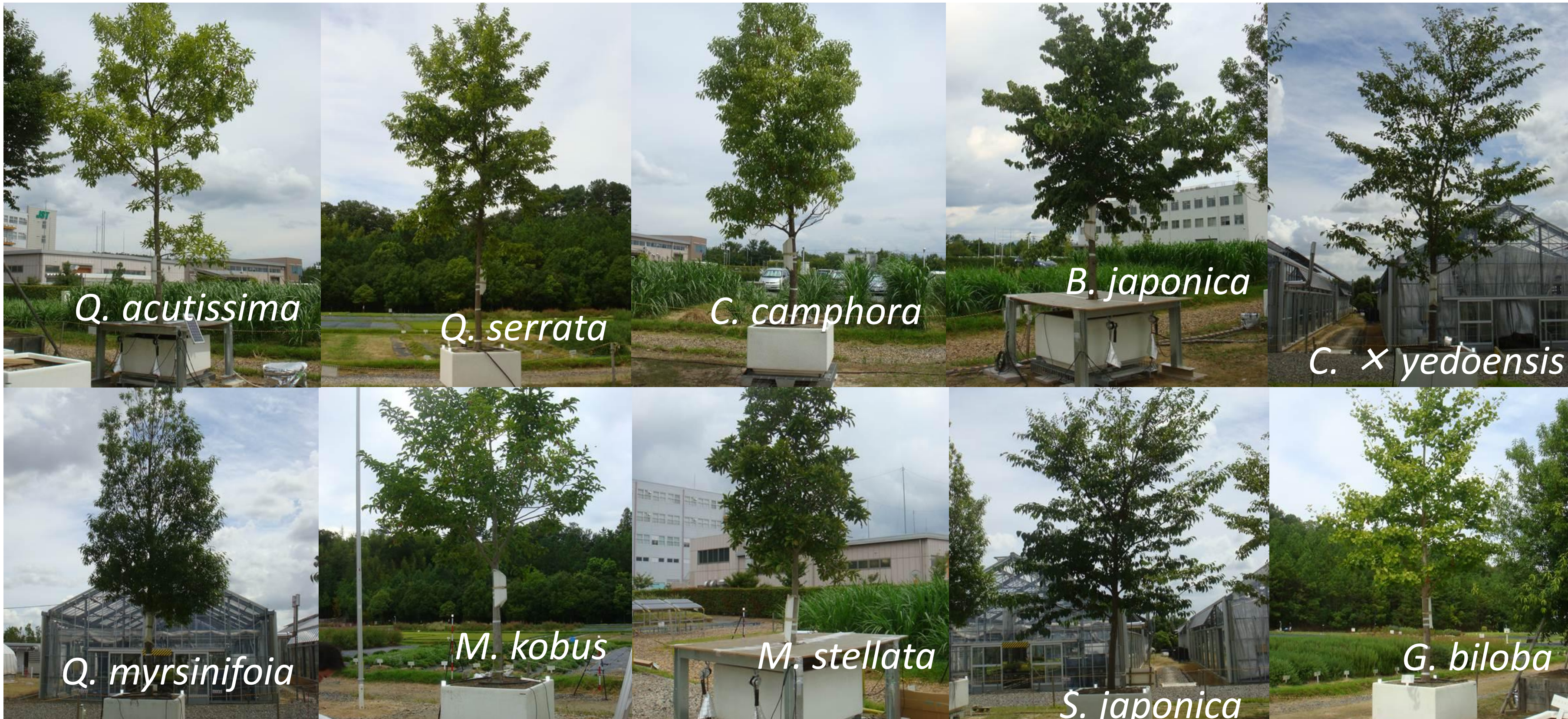


Advantages of Gravimetric Method:

- ✓ Hourly Temporal Resolution
- ✓ Comparison among Species (Xylem Type Difference)

cf. Saugier et al.: *Tree Physiol.* 1997, Steppe et al.: *Agric. For. Met.* 2010

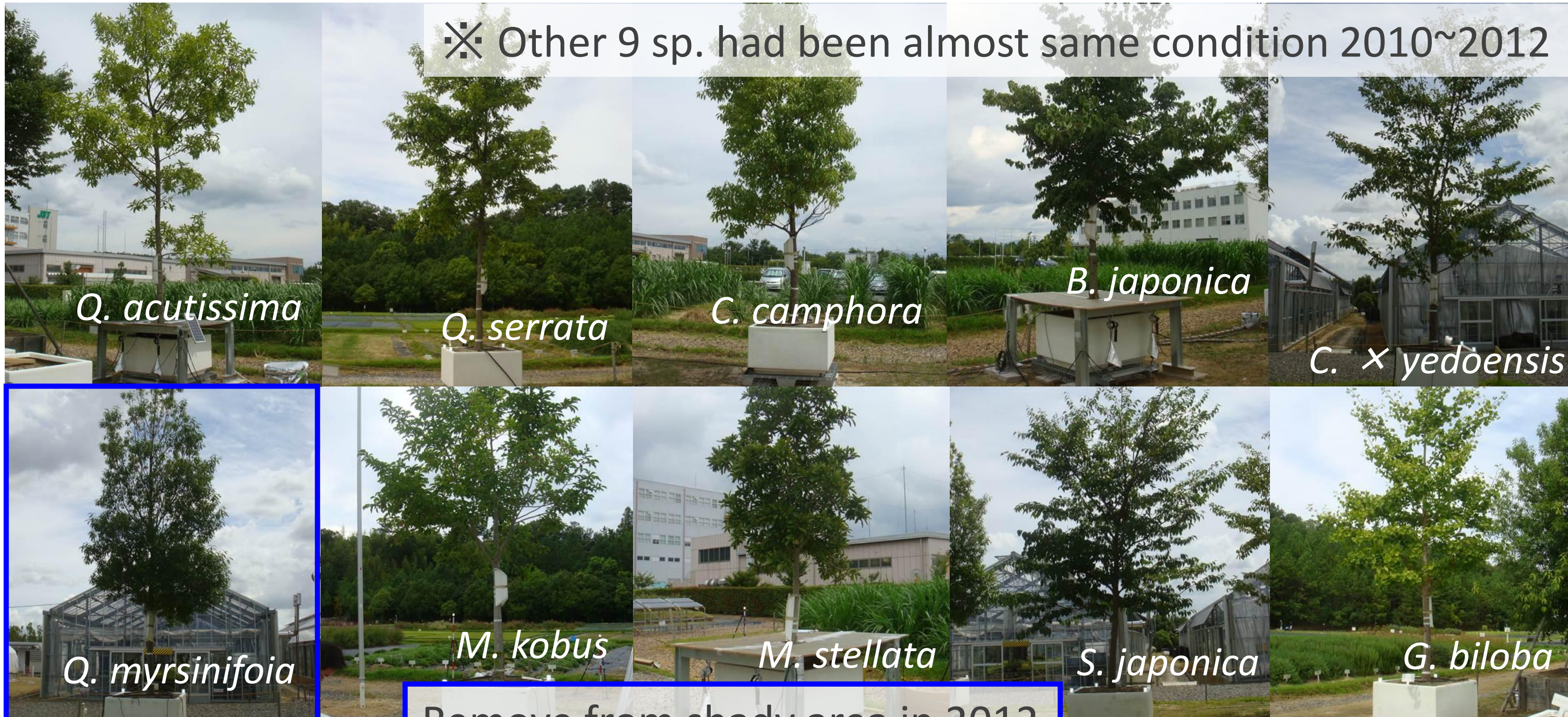
Sample Trees: 11 Popular Urban Tree Species in Japan



- ✓ Soil Volume: 0.5 m^3 (Trunk Diameter ≈ 10cm)
- ✓ Growing in farm field from 2010, everyday irrigation
- ✓ Measured in summer 2012 mainly
- ✓ Terrestrial laser scanning (VZ-400, RIEGLE) in 2012

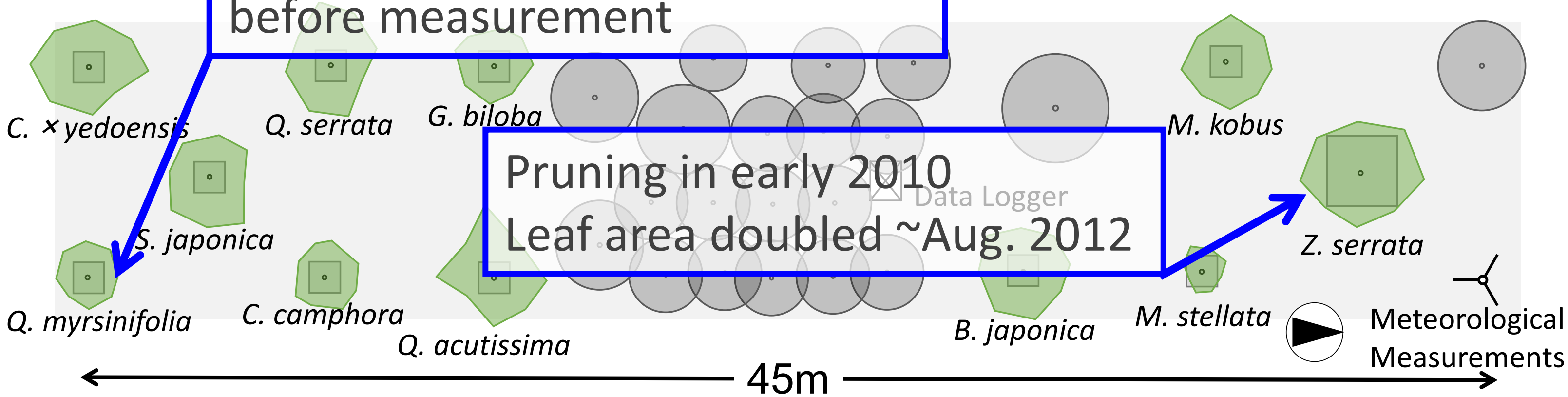
Condition Change of *Z. serrata* & *Q. myrsinifolia*

※ Other 9 sp. had been almost same condition 2010~2012



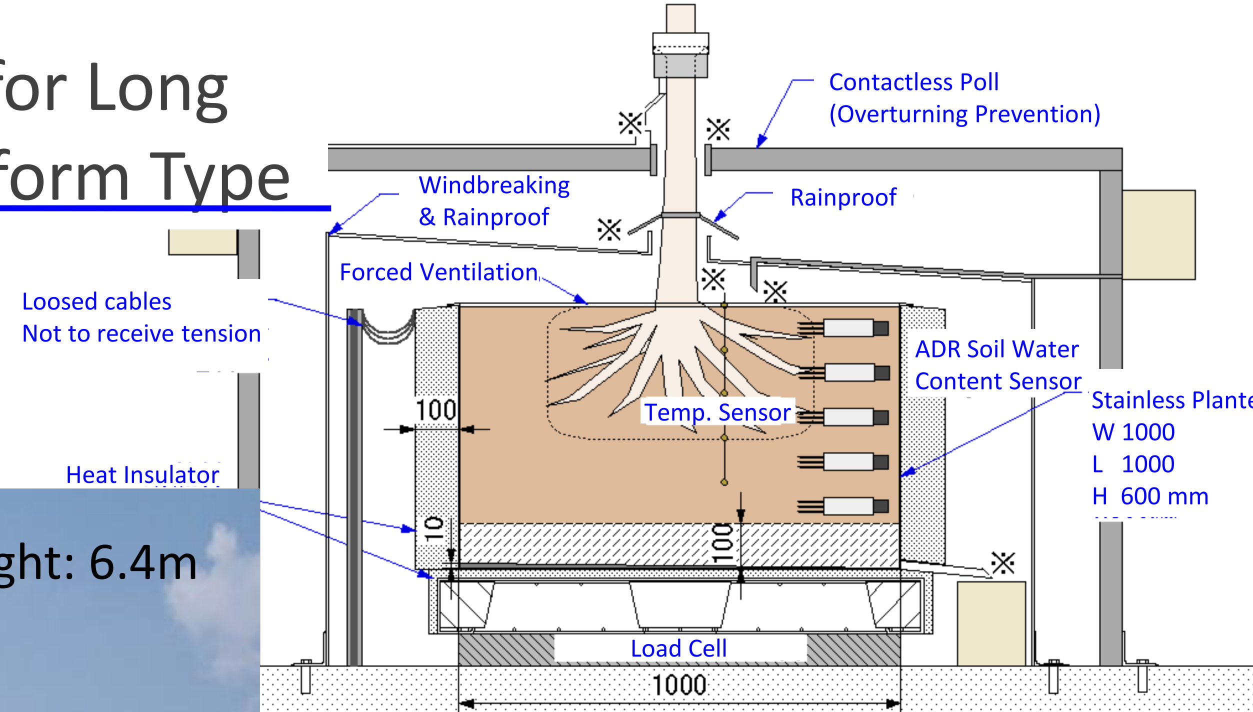
Remove from shady area in 2012 before measurement

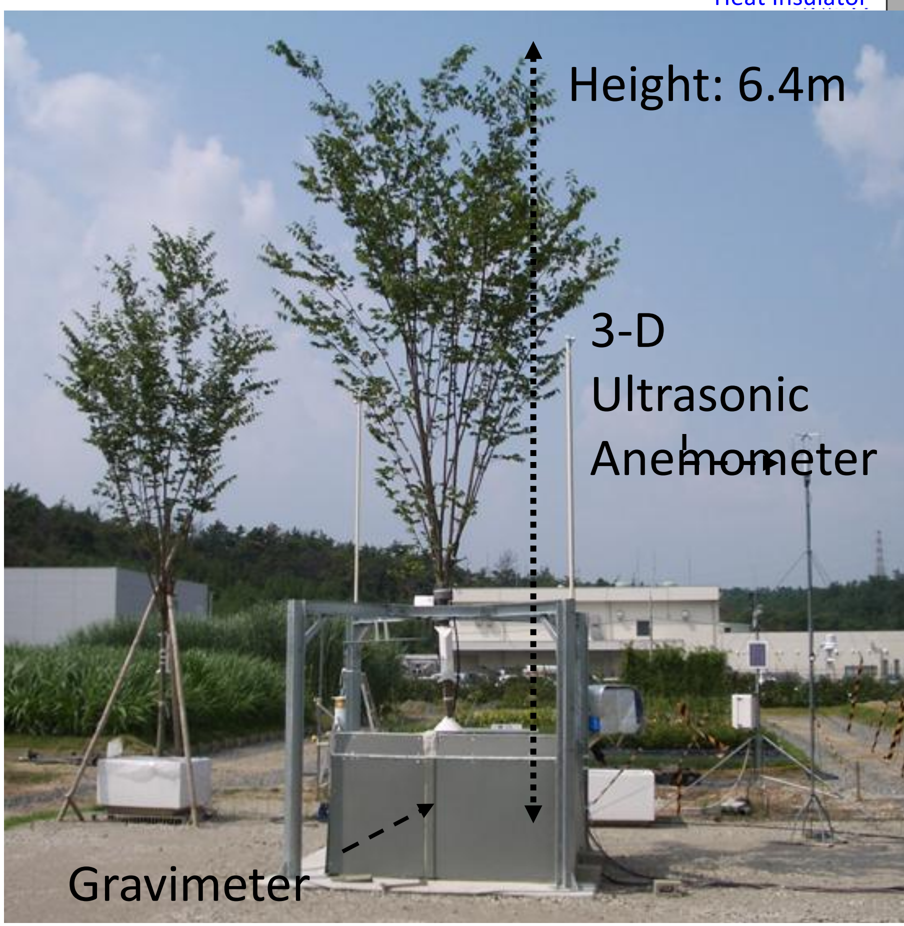
Pruning in early 2010
Leaf area doubled ~Aug. 2012



Weighing Method for Long Term Analysis: Platform Type

(cf. Asawa et al. 2012・2014)

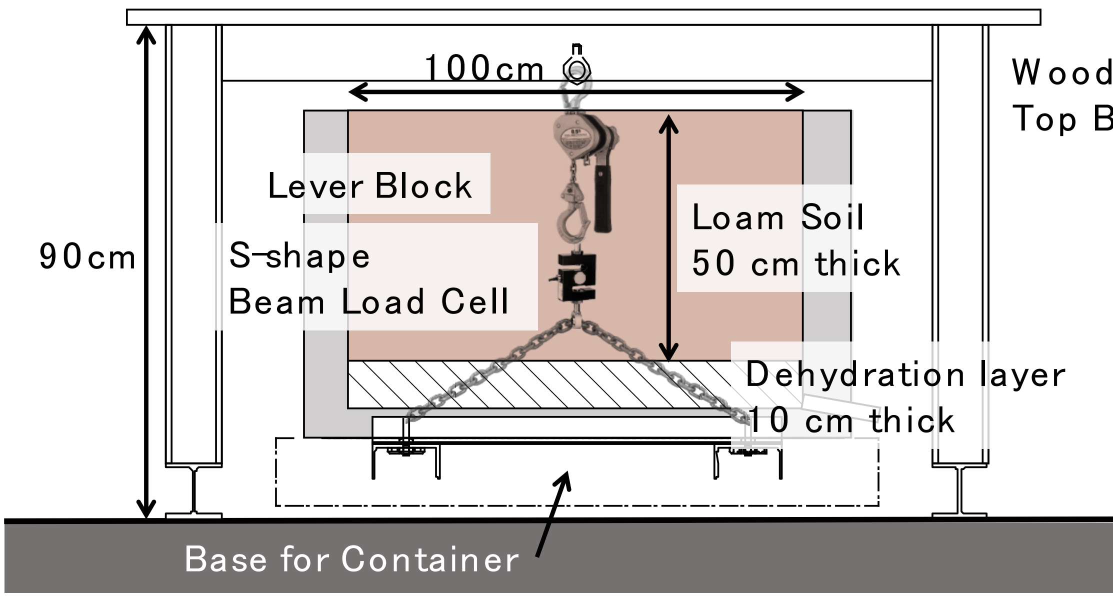


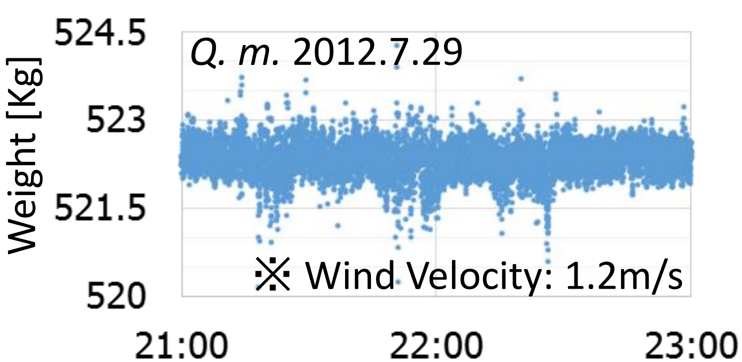


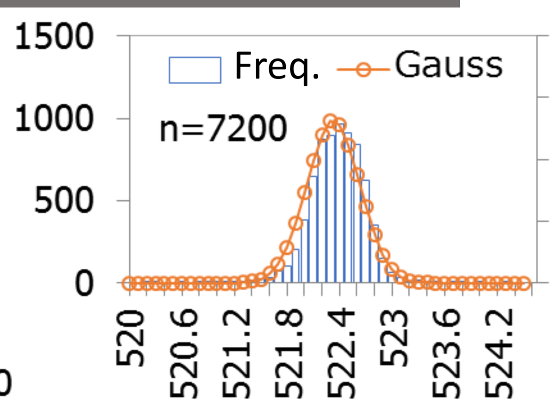
- ✓ Continuous measurement (2010 ~ 2012) of *Z. serrata*
- ✓ Stable platform type was adopted for long term measurement

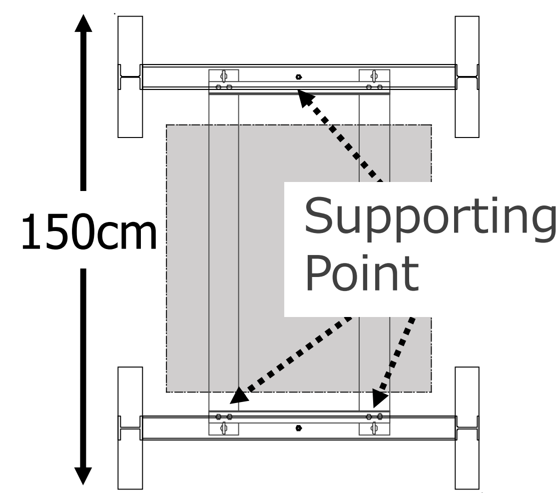
Weighing Method for Short Term Analysis: Hanging Type

- ✓ Hanging container using 3 beam type load cells (detachable & portable, 2.6kg), manually operation
- ✓ Top board covered soil surface completely

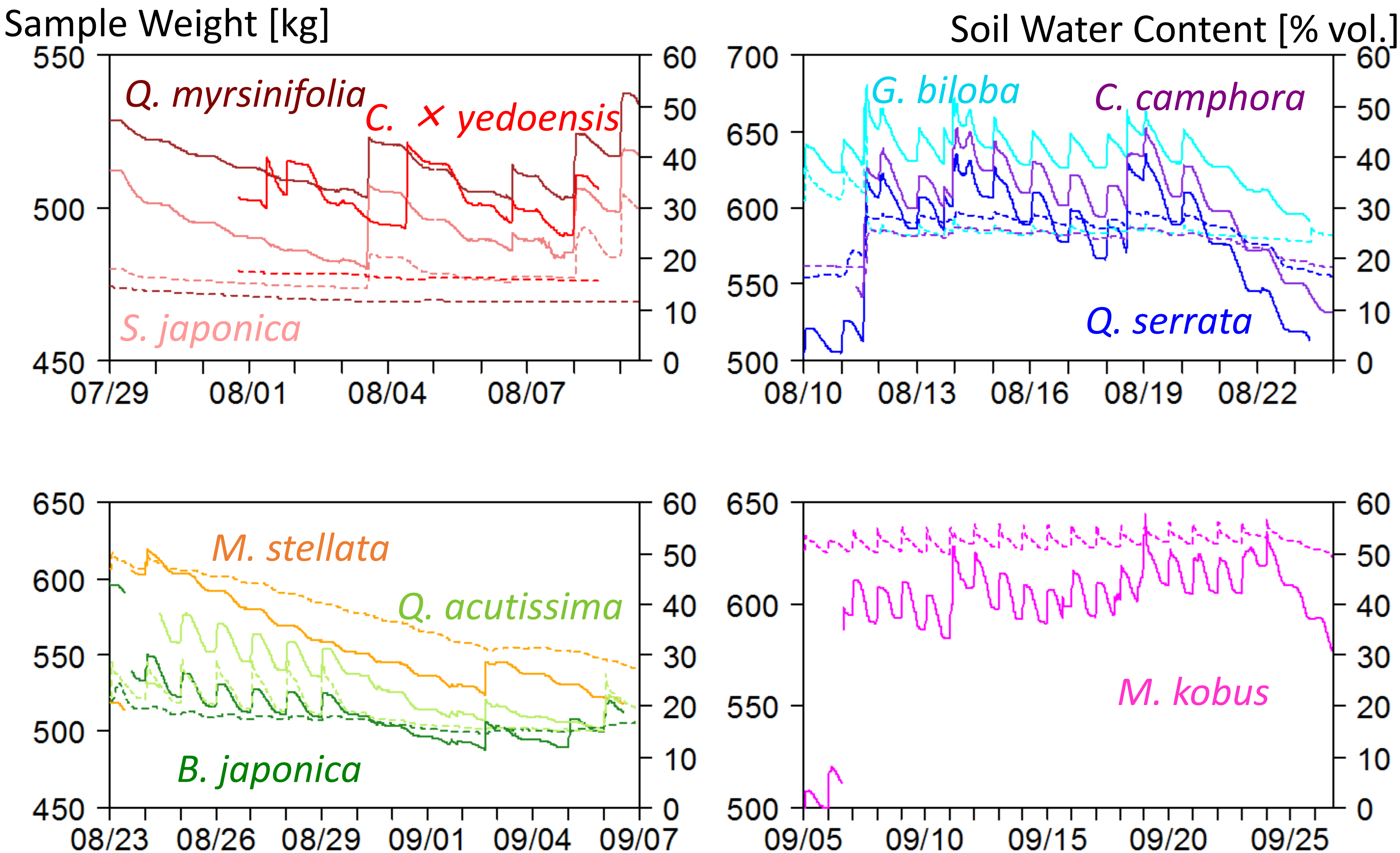






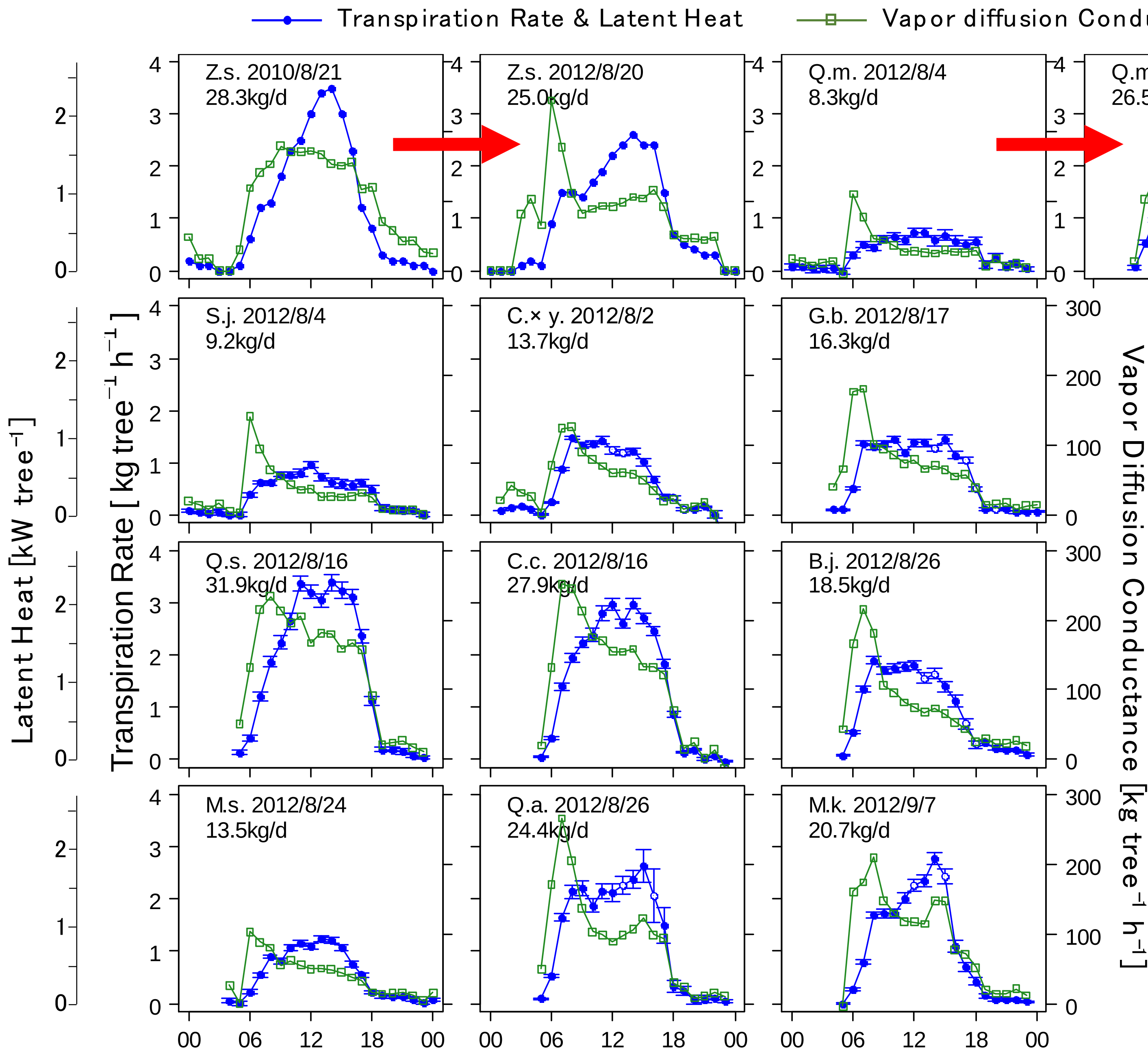


Sample Weight (hanging type, 10 min. moving avg.)



- ✓ Developed 3 hanging type gravimeter
- ✓ About 2 weeks continuous measurement for each tree

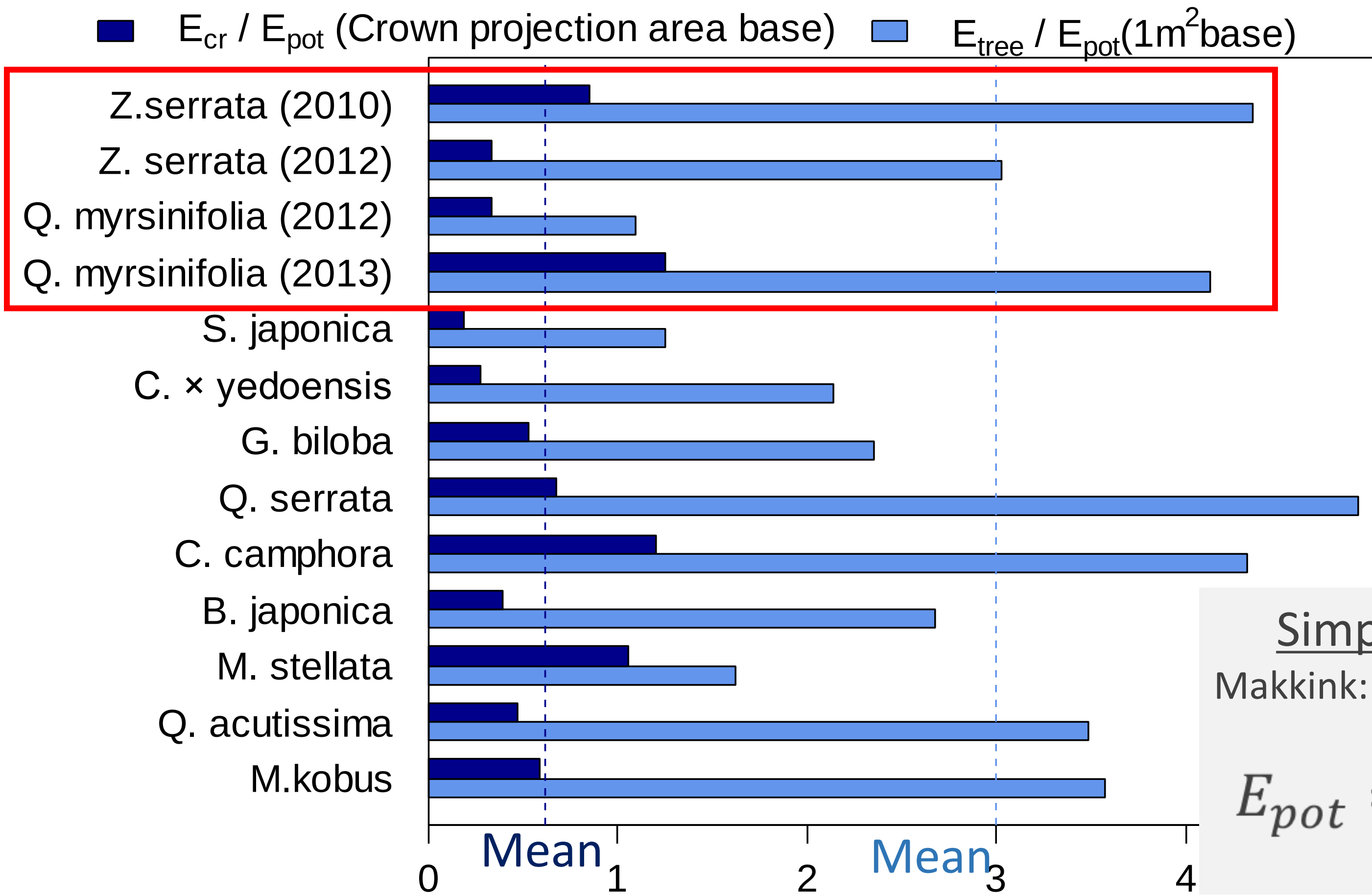
Diurnal Transpiration & Vapor Conductance



$$E = G_v \frac{VPD}{p_a}$$

- ✓ Max transpiration rate: 1~3 kg/h
- ✓ Midday depression of G_v was clear

Comparison of Daily Transpiration Capacity



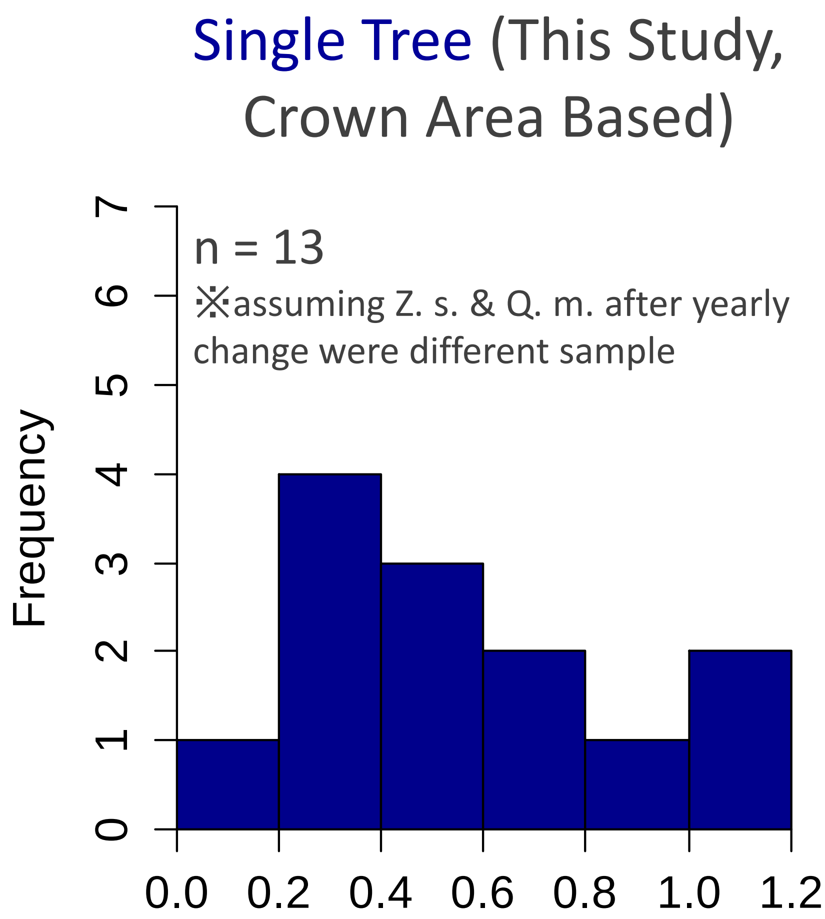
Simplified Penman Eq.

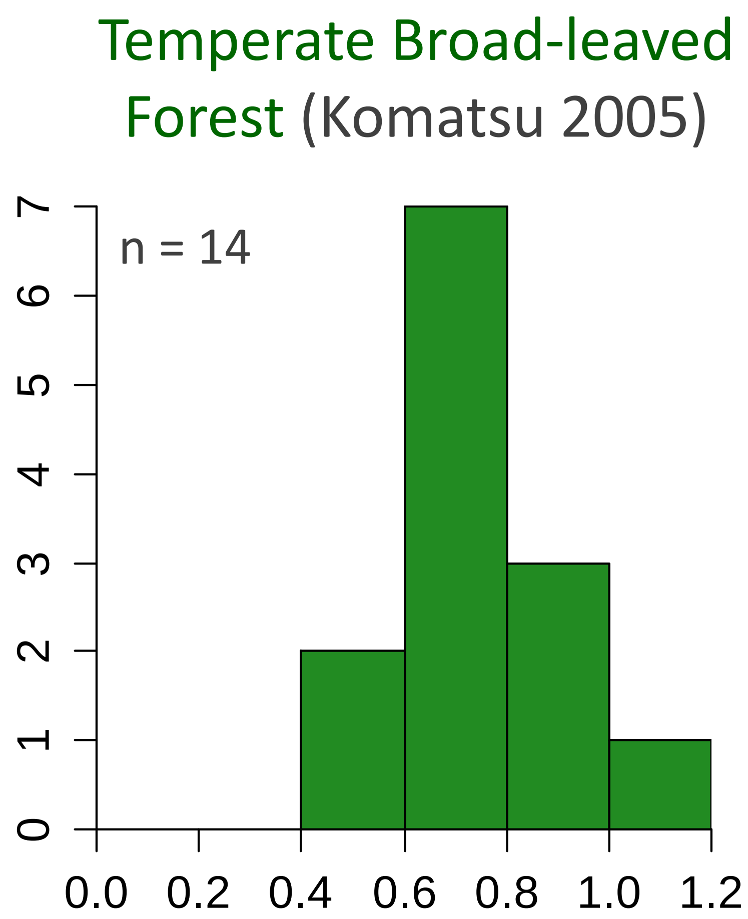
Makkink: *Netherl. J. Agric. Sci.* 1957

$$E_{pot} = a\frac{R_s}{\lambda}\frac{s}{s+\gamma} + b$$

- ✓ Normalized by E_{pot} (≈ Water Evap.) to remove atmospheric effect
- ✓ E_{cr}/E_{pot}= 0.62±0.36 (Mean±S.D.)
- ✓ *Z. s.* & *Q. m.* changed 2~3 fold over the years

Comparison of Daily Transpiration Capacity





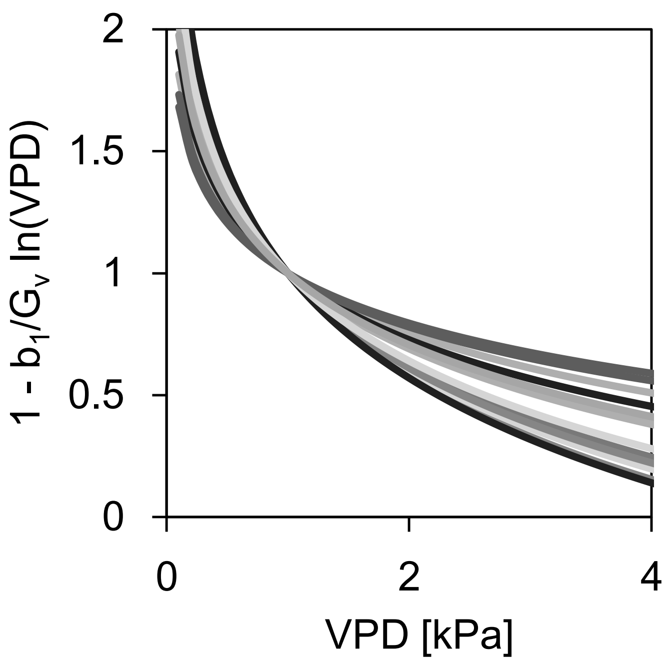
- ✓ Mean E_{cr}/E_{pot} was not different from forest (cf. Komatsu: *Hydrol. Processes* 2005)
- ✓ Large dispersion (variety of transpiration characteristics)

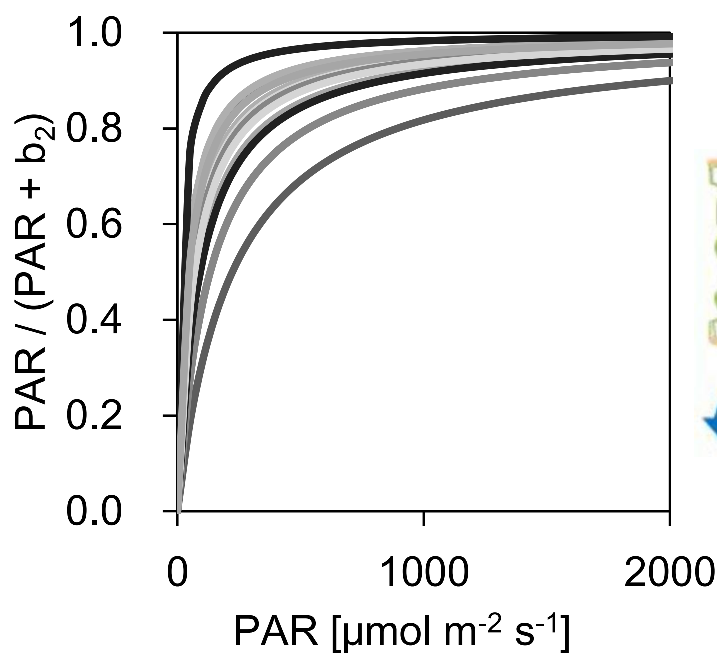
Species Variation of Sensitivity to Light & Humidity

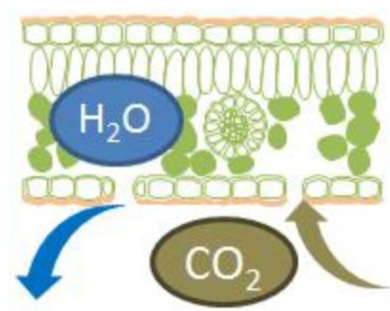
✓ Parameterize physiological response of vapor conductance (G_v) using Jarvis (1976) type empirical model

$$G_v = \left(G_{vref} - b_1 * \ln(VPD)\right)\frac{PAR}{PAR + b_2}$$

G_{vref}, b_1, b_2: Fitting Para.
PAR: Photosynthetic Active Radiation (Horizontal Plane)







✓ Horizontal PAR sensitivity differed 5-fold among trees

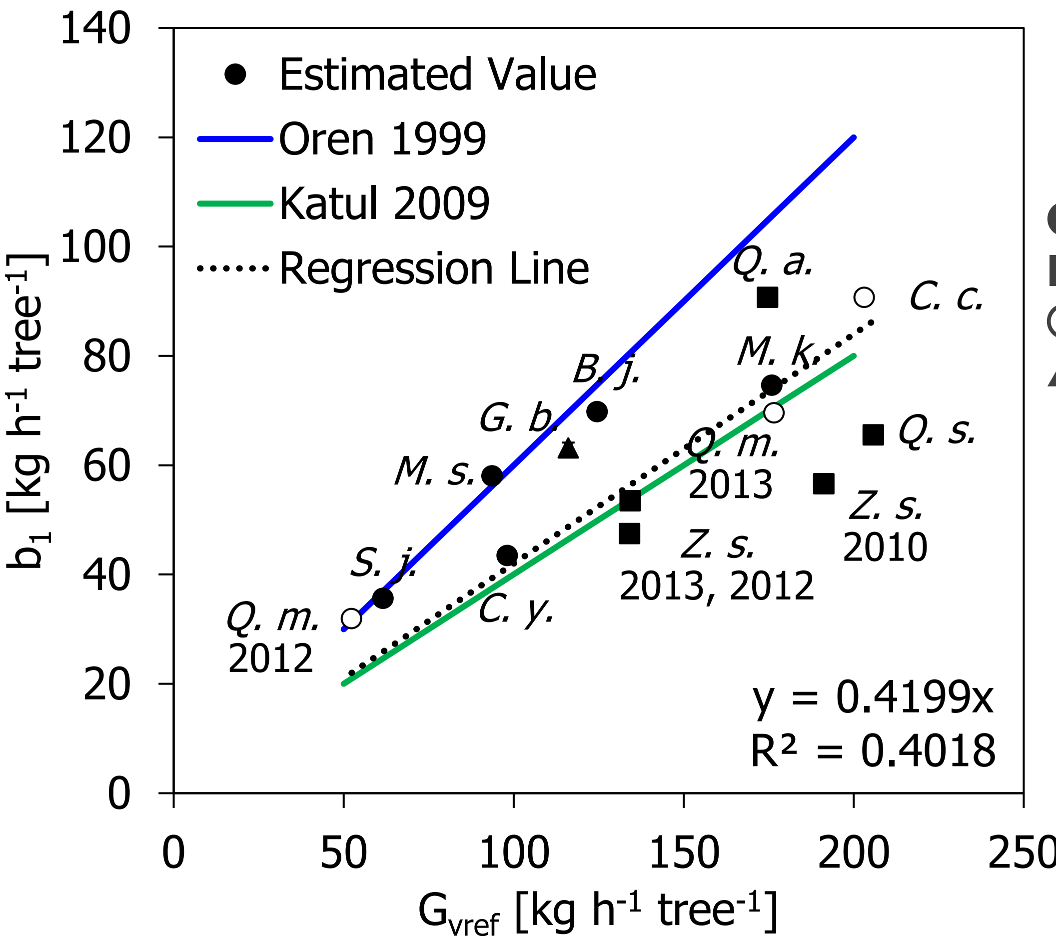
Both tree morphology and leaf level physiology affect

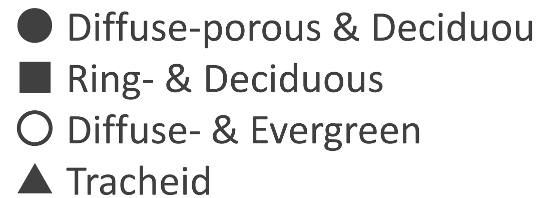
✓ VPD sensitivity differed ±20% in normal condition (1~3kPa)

Water Use Characteristics: G_{vref} & VPD Sensitivity

S. japonica

Q. m. 2012





Z. s. 2010

Q. serrata

- ✓ G_{vref} and b_1 correlated, the regression line was close to theoretical value of stomatal optimization (cf. Katul et al.: *Annals Bot.* 2009)
- ✓ *Z. serrata* 2010 was most insensitive to VPD (i.e. drought stress) ...pruning (increase of leaf/root area ratio) can affect

Comparison of Parameterization Schemes of G_v

✓ Evaluate relative importance of fitting parameters in G_v model to reconcile model simplicity and species variation

$$G_v = \left(G_{vref} - b_1 * \ln(VPD)\right) \frac{PAR}{PAR + b_2}$$

Transpiration Capacity

= we can estimate from daily value

Model (1)

Using each tree's estimated value for all parameters (G_{vref}, b_1, b_2)

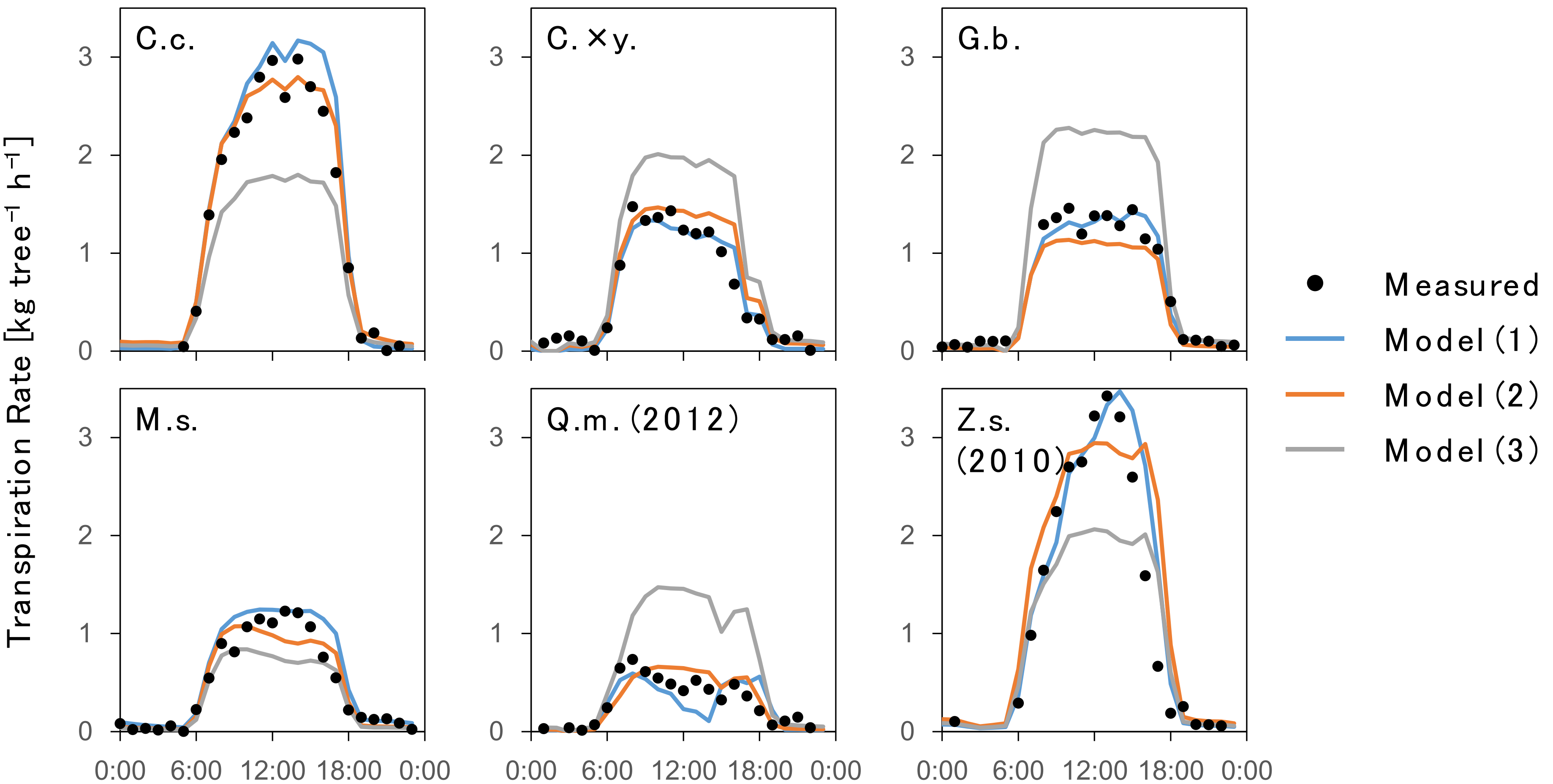
Model (2)

Using each tree's G_{vref} and species average value for $G_{vref}/b_1, b_2$

Model (3)

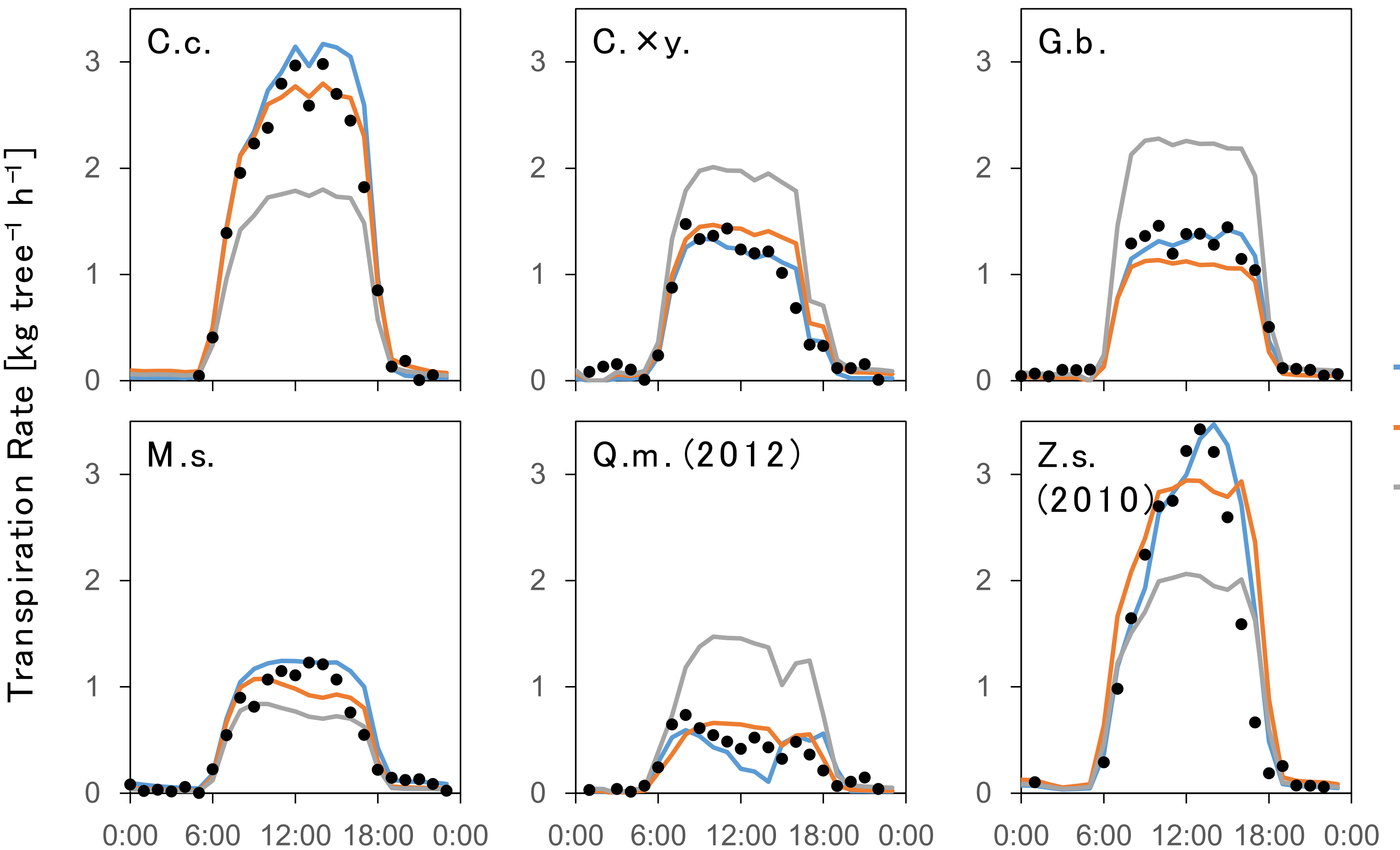
Using species average value for all parameters (G_{vref}, b_1, b_2)

Comparison of Parameterization Schemes of G_v



- ✓ Model (2) is close to Model (1), the error was below 0.4kg/h
- ✓ Most of daytime, G_v is nearly saturated to PAR; species difference of PAR sensitivity is not significant to max & daily transpiration

Comparison of Parameterization Schemes of G_v



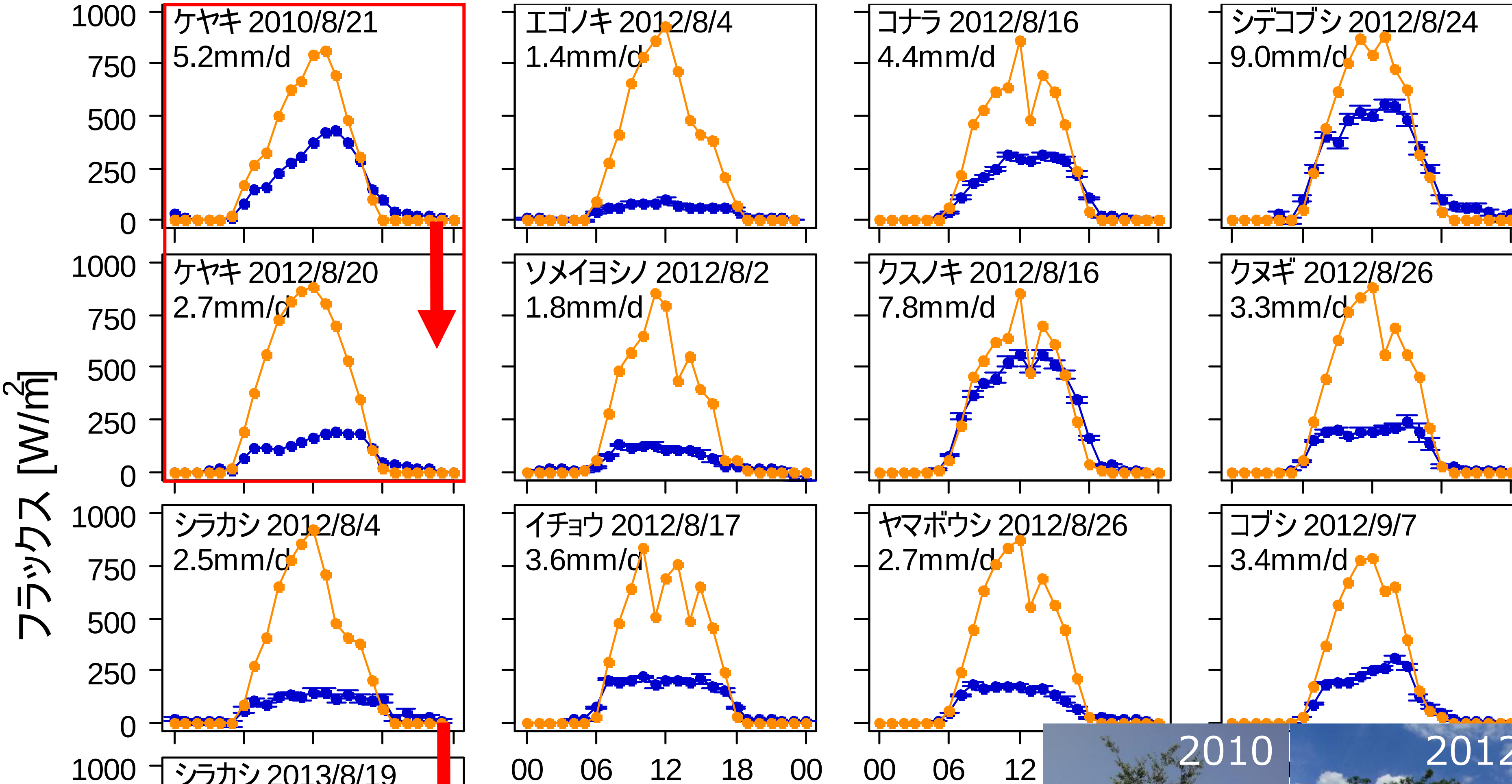
✓ Reasonable prediction will realized by combining mean value of parameter b_2 & b_1/G_{vref} in this study and individual tree's sap flow measurement (G_{vref})

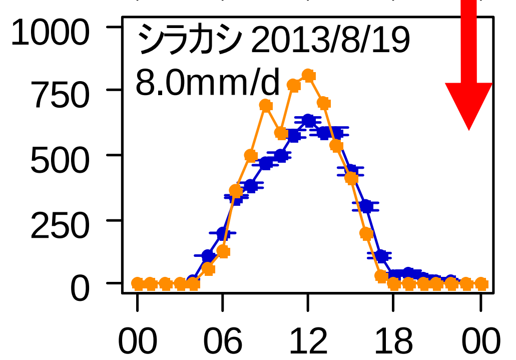
Conclusion

We measured 11 container-grown isolated tree (soil volume: 0.5m^3) in summer, sunny irrigation day and found

- ✓ Maximum hourly transpiration rate was over 3 kg/h (2kW) of *Z.s. 2010* & *Q.s.*
- ✓ Species/individual variation in daily transpiration amount was 10~30 kg, equivalent to 0.62±0.36 (Mean±S.D.) times of water evaporation from the same size of crown projection area
- ✓ Tree's variation in G_v response to VPD were relatively constant (20% in 1~3kPa) and close to previous theoretical relationship
- ✓ Sensitivities to PAR were significantly different between trees but its effect to hourly transpiration rate was restrictive
- ✓ Overall, the reference (maximum) value of G_v for each tree is the most important parameter when predicting whole-tree transpiration rate in hourly basis

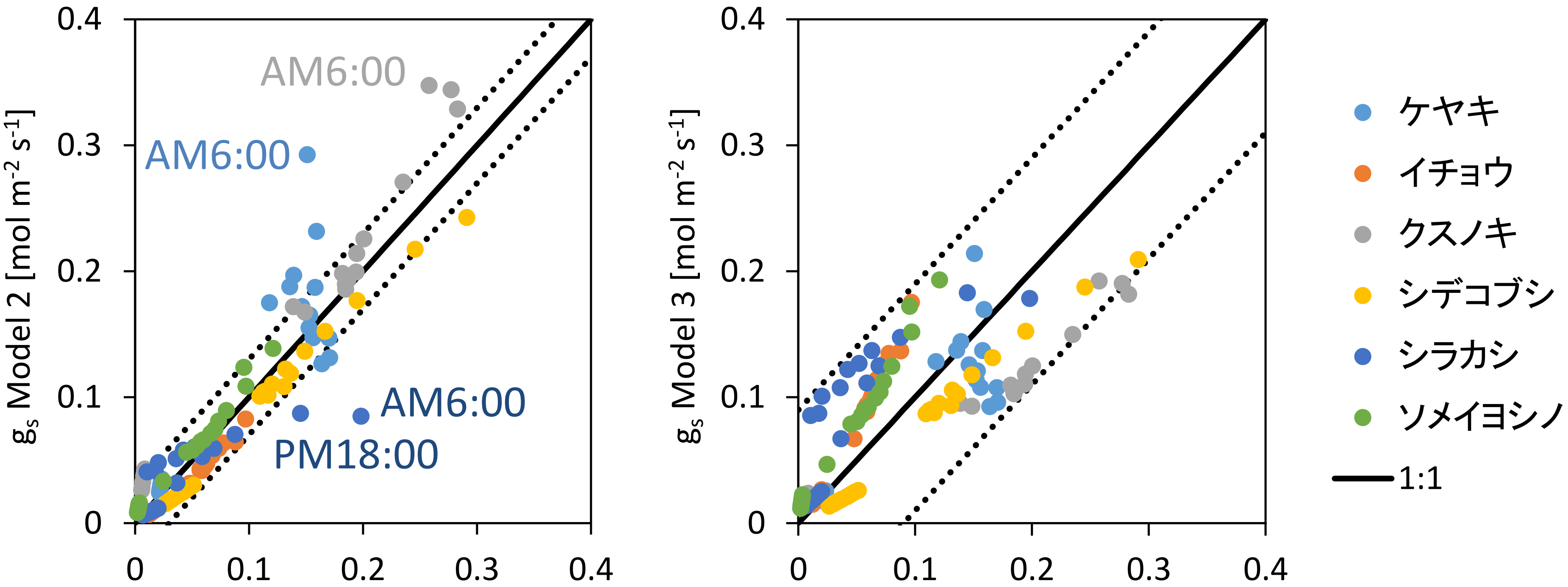
投影面積基準の潜熱フラックスと日射量の日変化





ケヤキ葉面積 15.2 → 28.9 m^2

通水(土壌容積)制限の影響？



Model 1～3 (APAR使用時)の g_s予測値の比較

実線はModel 1との1:1対応を，左図点線は ± 0.03 [mol m^{-2} s^{-1}] を，
右図点線は±0.09 [mol m^{-2} s^{-1}]の範囲を表す．

Table.2 Measurement period & morpho-physiological characteristics of sample trees

樹種	略記	重量計測期間（分析対象期間）	樹冠投影面積（8点推定）[m^2]	樹高 [m]	基部直径 [cm]	生枝下直径 [cm]	葉齢 [月]	道管種	耐陰性[24]＊＊	耐乾性[24]＊＊	街路樹数[20]
ケヤキ	*Z. s.*	(2010/08/1-31)＊	5.5（葉面積15.4m^2）	6.4	–	10	落葉樹	環孔材	2.1	3.4	3位
		(2012/08/1-31)＊	9.2（葉面積28.9m^2）	6.4	–	11					
シラカシ	*Q. m.*	2012/07/29-08/09	3.3	5.5	12	10	常緑樹(36)	散孔材	2.3	4	13位
		2013/08/18-21	–	–	12	10					
エゴノキ	*S. j.*	2012/07/29-08/09	6.6	4.4	11	9	落葉樹	散孔材	2.5	2.5	66位
ソメイヨシノ	*C. × y.*	2012/08/01-08	7.8	5.5	14	10	落葉樹	散孔材	–	–	2位
イチョウ	*G. b.*	2012/08/10-22	4.5	5.4	13	10	落葉樹	仮道管	1.3	4	1位
コナラ	*Q. s.*	2012/08/10-22	7.3	5.8	14	9	落葉樹	環孔材	3	3	79位
クスノキ	*C. c.*	2012/08/12-23	3.6	4.7	13	9	常緑樹(12)	散孔材	3.5	2.8	6位
ヤマボウシ	*B. j.*	2012/08/24-09/05	6.9	4.5	12	9	落葉樹	散孔材	–	–	–
シデコブシ	*M. s.*	2012/08/24-09/05	1.5	3.0	6	5	落葉樹	散孔材	3	1.8	–
クヌギ	*Q. a.*	2012/08/24-09/05	7.5	6.7	11	8	落葉樹	環孔材	2.3	4	98位
コブシ	*M. k.*	2012/09/05-09/26	6.1	4.1	13	8	落葉樹	散孔材	3	2.9	19位

＊2010年8月～2013年まで連続計測　　＊＊温帯806樹種中の5段階相対評価

Table.3　Measurement equipment

計測項目	機器	記録間隔
試験体重量	ロードセル(ミネベア, U3S1-500K-NS)各3台	1 or 5 [sec]
樹冠投影面積 葉面積(ケヤキのみ)	地上型レーザースキャナー(RIEGLE, VZ-400)	全樹種2012年 2010, 2012年
排水量(ケヤキのみ)	転倒升式雨量計(Campbell, TE525-L25)	10 [min]
気温	強制通風筒(Young, YG-43520) 白金抵抗温度計(4線式Pt100Ω)	1 [min]
相対湿度	静電容量式高分子湿度センサー	1 [min]
水平面全天日射量	サーモパイル式日射計(英弘精機, MS-402)	1 [min]
風向・風速	三次元超音波風向風速計(Young, YG-81000)	1 [sec]
樹冠放射温度	赤外線放射カメラ(NEC Avio, ThermoGEAR)	1 [hour]

Table.4 Descriptive statistics of sample weight (half hourly basis)

平均風速	標準偏差			|歪度|			尖度		
[m/s]	~.5	.5~2.	2.~	~.5	.5~2.	2.~	~.5	.5~2.	2.~
シラカシ	0.22	0.37	0.72	0.06	0.20	2.11	2.01	4.00	48.7
エゴノキ	0.17	0.82	0.62	0.05	0.54	1.43	2.14	4.97	7.40
ソメイヨシノ	0.07	0.28	0.47	0.21	1.05	1.12	3.81	9.24	9.80
イチョウ	0.67	0.78	1.78	0.25	0.44	0.51	4.20	5.34	7.24
コナラ	0.65	1.28	3.45	0.14	0.36	0.22	2.60	4.93	4.84
クスノキ	0.62	0.88	1.56	0.41	0.59	0.47	4.08	5.82	6.72
ヤマボウシ	0.42	0.44	0.41	0.18	0.73	1.10	3.24	7.46	8.84
シデコブシ	0.21	0.51	0.27	0.07	0.16	0.33	2.10	3.10	5.22
クヌギ	0.43	0.48	1.32	0.62	0.67	2.00	5.00	6.27	31.2
コブシ	0.14	0.35	0.87	0.37	1.04	1.24	4.64	7.27	7.84

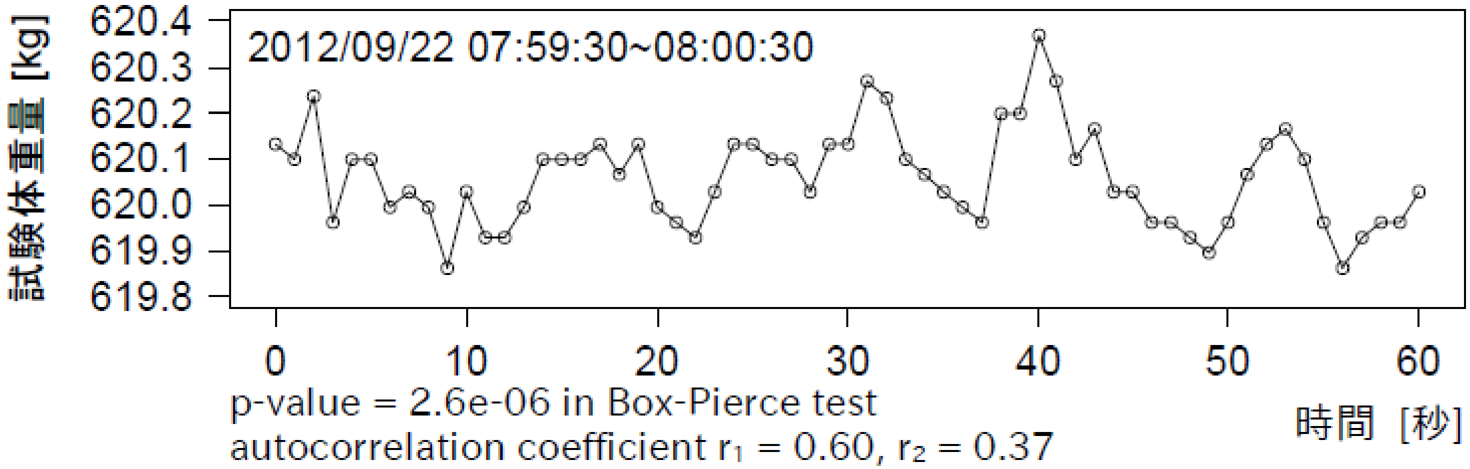


Fig.5 Weight change of *M.k.*, example of autocorrelation

$$N_{eff} = \frac{N}{T_0} \quad (1)$$

$$T_0 = \sum_{L=-N}^{N} \left(1 - \frac{|L|}{N}\right) r_L = 1 + 2\sum_{L=1}^{N} \left(1 - \frac{L}{N}\right) r_L \quad (2)$$

ここで，N_{eff}：有効標本数，N：標本数，T_0：実効的に独立な標本間の時間，L：ラグ次数，r_L： L次ラグの自己相関係数である．

$$x(t) = r_1 x(t-1) + \varepsilon(t) \quad (3)$$

$$T_0 = 1 + 2\sum_{L=1}^{N} \left(1 - \frac{L}{N}\right) r_1^L \approx \frac{1 + r_1}{1 - r_1} \quad (4)$$

ここで，$x(t)$：任意の時系列データ， r_1：1次ラグの自己相関係数，$\varepsilon(t)$：時刻tの誤差項である．

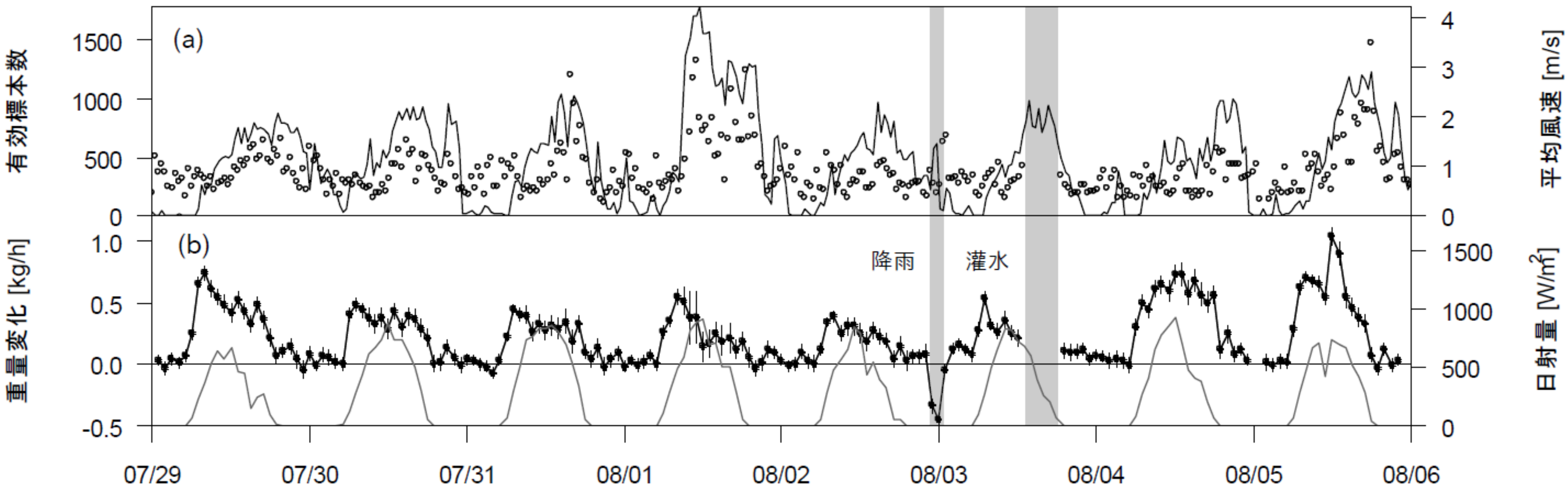


Fig.6 (a) Half hourly effective sample size of *Q.m.* (circles) & wind velocity (line)

(b) hourly weight change (black line) & short wave radiation R_s (gray line) in 2012 (bars: ± 2 S.E.)

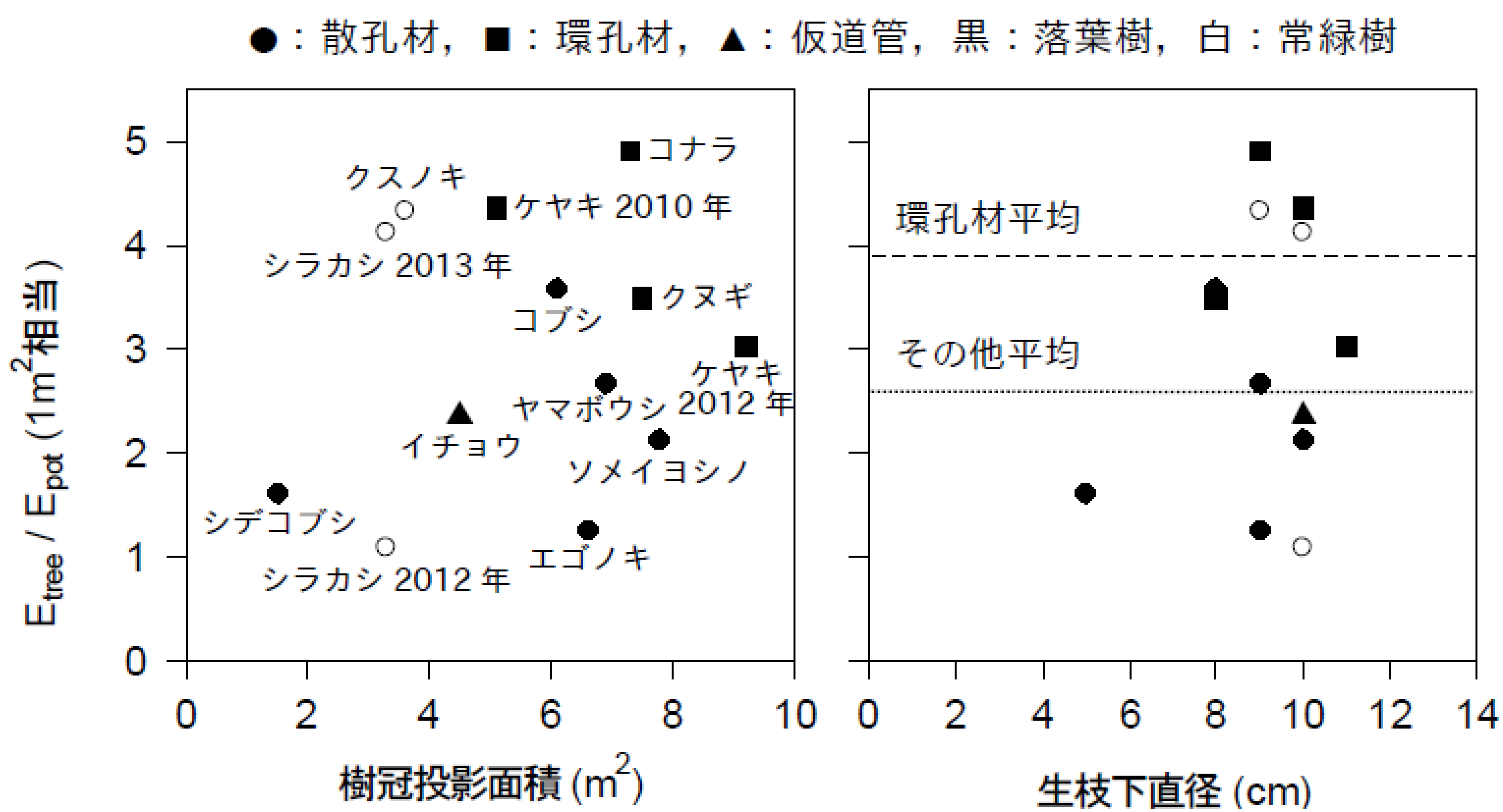


Fig.10 Relationships between E_{tree}/E_{pot} & morpho-physiological characteristics of sample trees

	測定年	フィッティングデータ測定日	Gsref	a	m	R^2
ケヤキ	2010	Aug 21, 22, 23	191.3	133	0.30	0.87
	2012	Aug 20, 21	134.1	40	0.35	0.62
シラカシ	2012	Jul 29, Aug 4, 8	52.3	57	0.61	0.64
	2013	Aug 19, 20	176.7	102	0.39	0.89
エゴノキ	2012	Jul 29, Aug 4, 8	61.6	39	0.58	0.62
ソメイヨシノ	2012	Aug 1, 2, 5	98.1	133	0.44	0.67
イチョウ	2012	Aug 21	116.1	17	0.54	0.83
コナラ	2012	Aug 13, 16, 17, 20	205.8	61	0.32	0.8
クスノキ	2012	Aug 13, 16, 17, 20	203.1	86	0.45	0.87
ヤマボウシ	2012	Aug 26, 27, 28, 29	124.5	63	0.56	0.67
シデコブシ	2012	Aug 25, 26	93.7	93	0.62	0.61
クヌギ	2012	Aug 25, 26, 27, 28, 29	174.7	70	0.52	0.82
コブシ	2012	Sep 7, 8, 9	175.9	47	0.42	0.71