LIFE URBANGREEN (LIFE17 CCA/ITA/000079)

UNIVERSITÀ DEGLI STUDI DI MILANO

R3GIS managing spaces

ProGea 4D

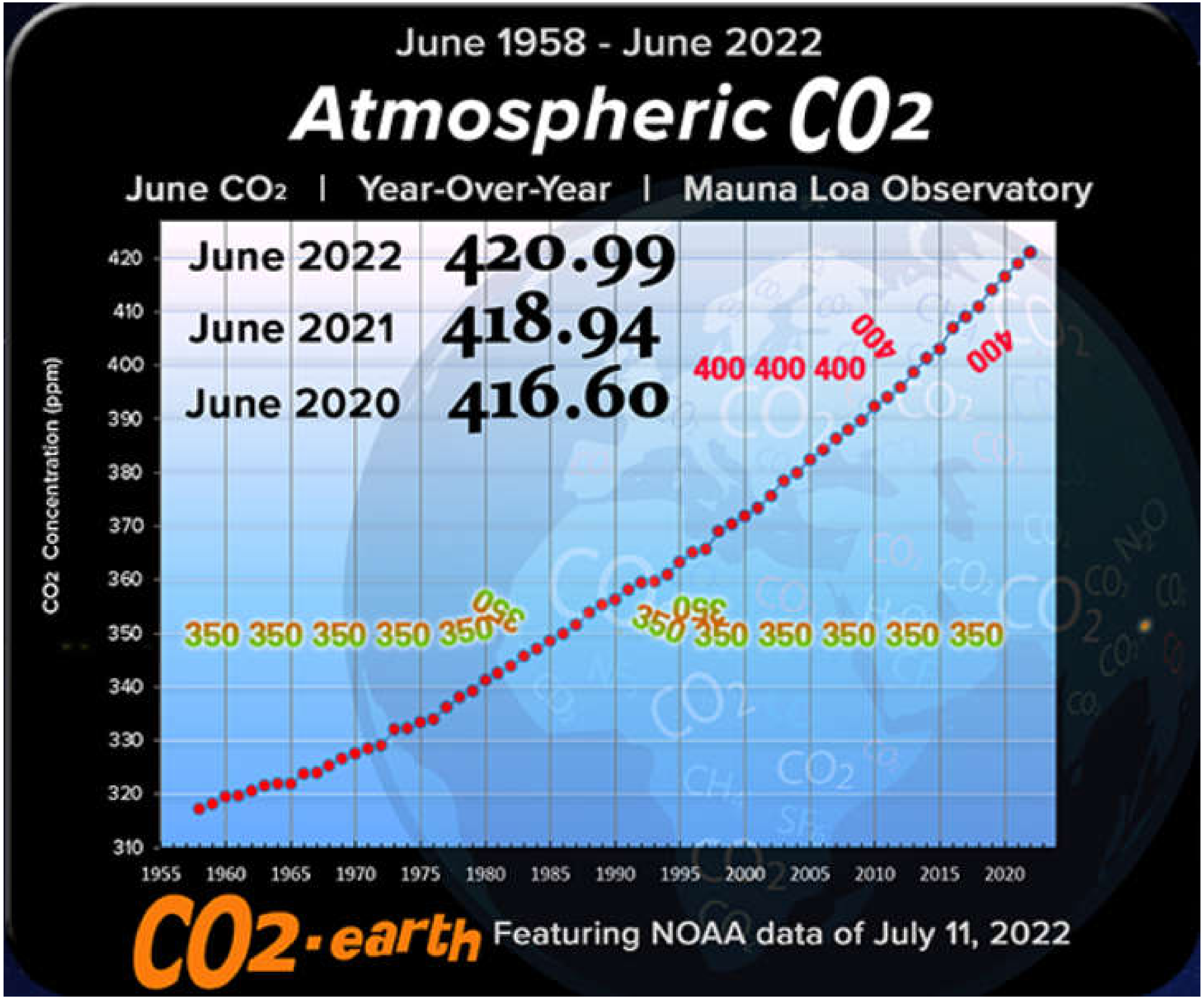
Anthea

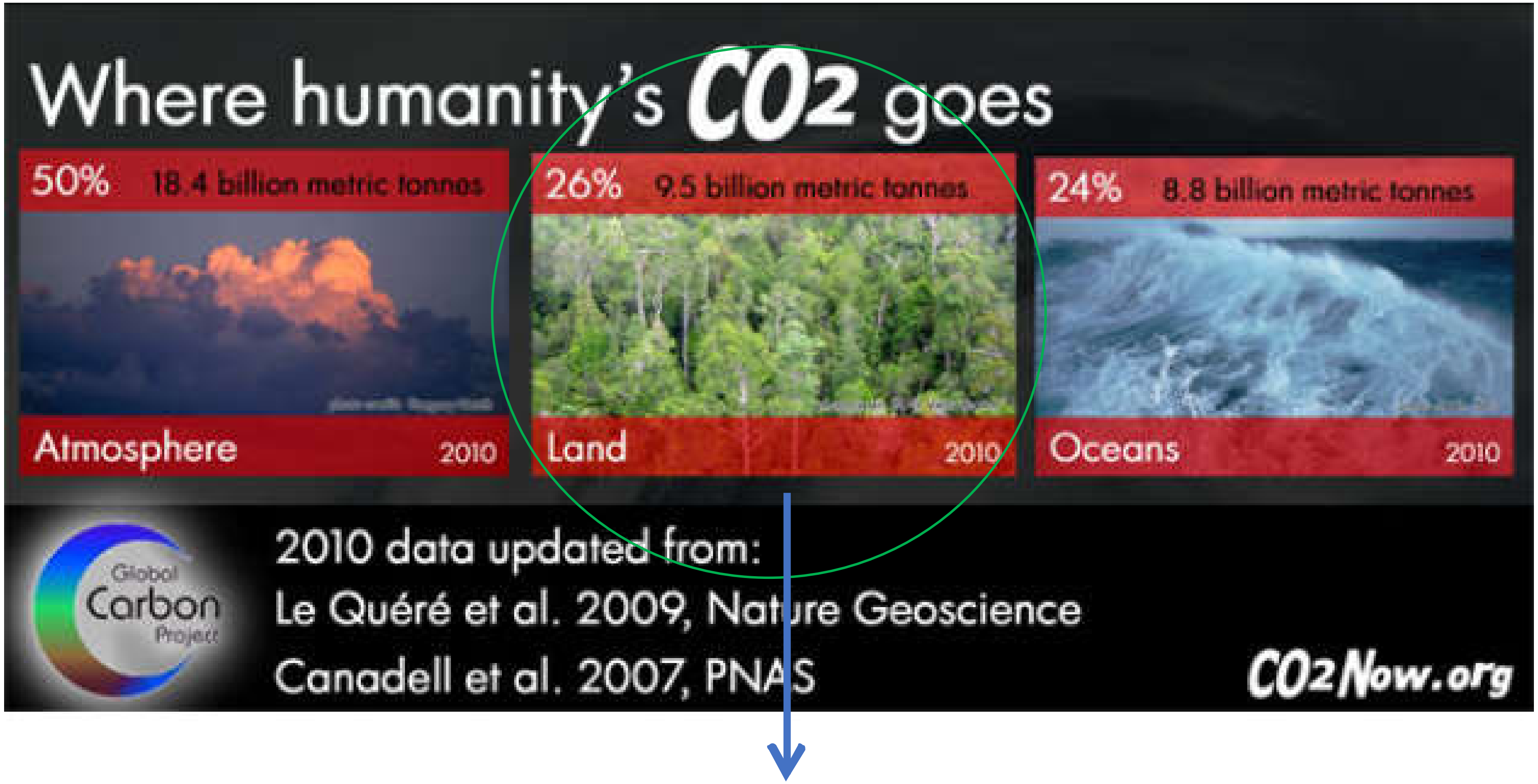
Zarząd Zieleni Miejskiej w Krakowie

LIFE URBANGREEN

The role of urban forests in a changing climate. II. CO_2 assimilation and storage

Alessio Fini – Disaa, Università di Milano

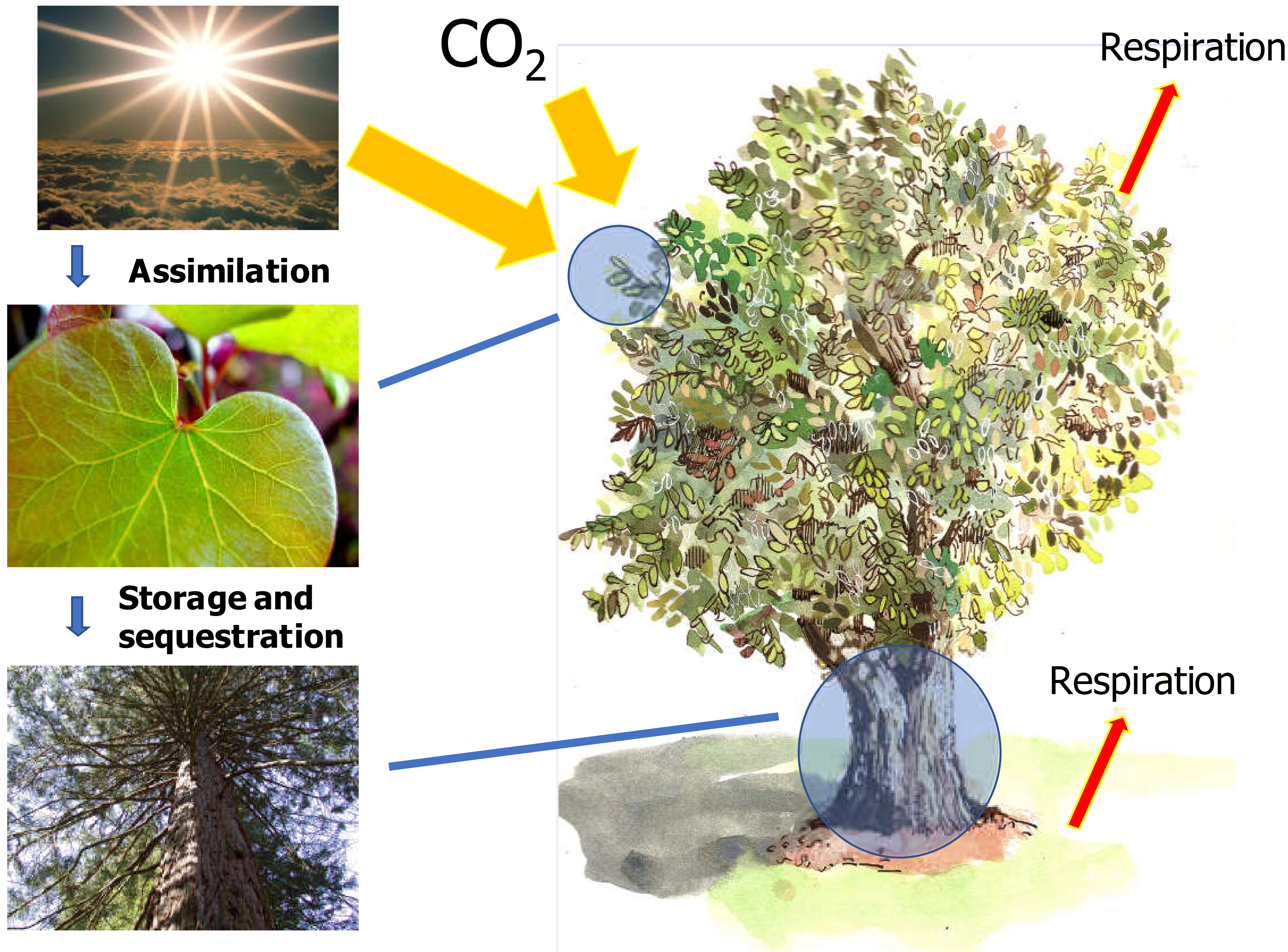

June 1958 - June 2022
Atmospheric CO2
June CO2 | Year-Over-Year | Mauna Loa Observatory
June 2022 420.99
June 2021 418.94
June 2020 416.60
CO2 Concentration (ppm)
CO2-earth Featuring NOAA data of July 11, 2022



Trees, shrubs and soil are effective contributors against global change.

How to quantify?

Which are the processes involved?


CO2
Respiration
Assimilation
Storage and sequestration
Respiration

Estimating CO_2 storage

Direct methods

- Plant harvest and weighing

1. Total harvest
2. Sample harvest

Indirect methods

- Volume measurement

1. Manual
2. Lidar

- Allometric relationships

Light detection and ranging (LiDAR)

TLS

CO_2 storage

CO2storage = 44/12 * 0,5 * Dwplant

Or

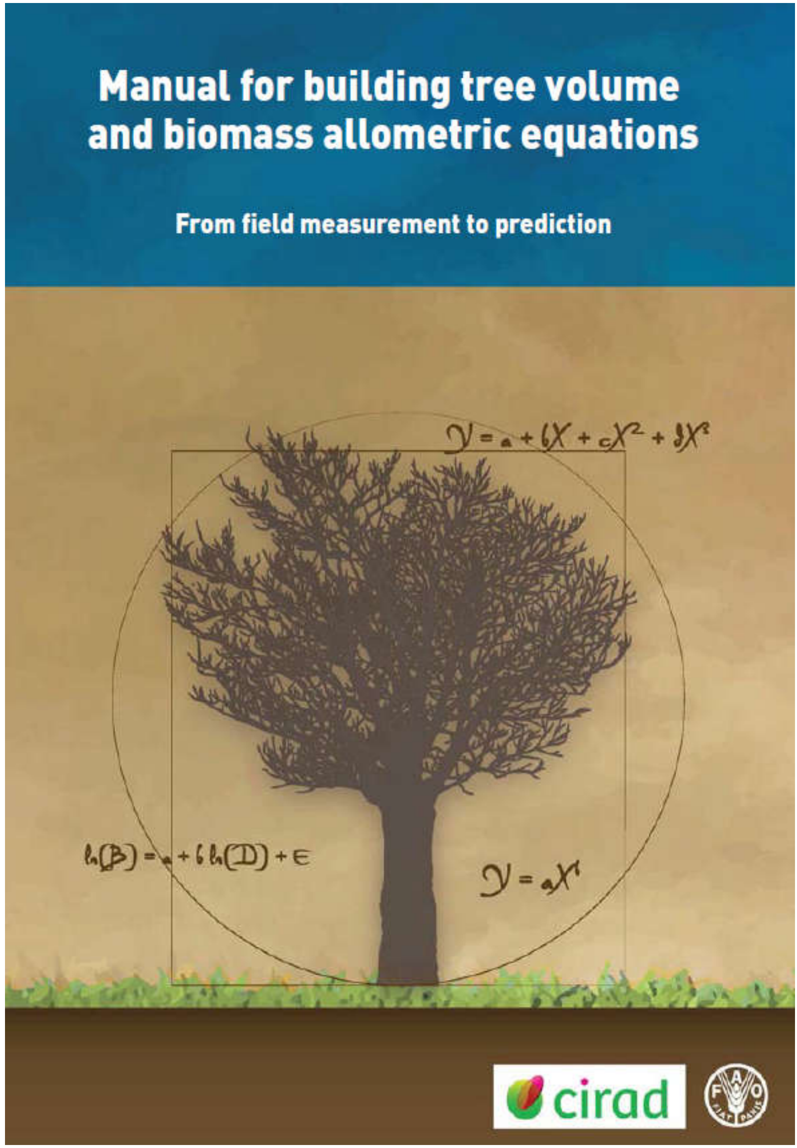
CO2storage = 44/12 * 0,5 * DryDensity * Vwoody * r

If no information about roots is available, DWplant can be calculated as:

DWplant = DWabg * r

Where r ranges from 1,28 (high fertility sites) to 1,81 (dry sites)

CO2sequestration = $\text{CO2storage}_{t(y+1)} - \text{CO2storage}_{ty}$



Biomass vs. volume

CO2 storage of 25 *Sorbus torminalis* was measured 20 years after planting using 2 methods:

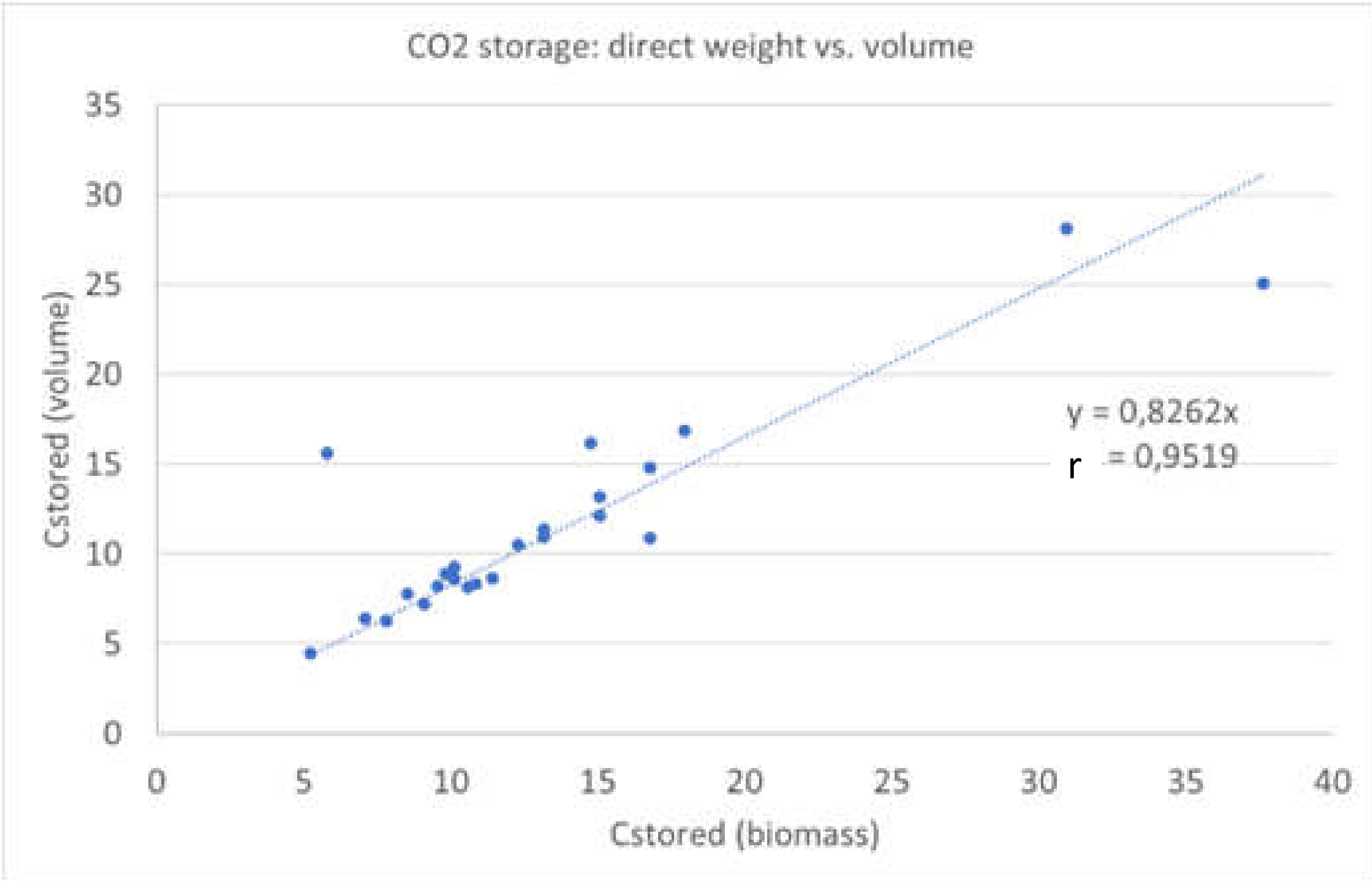
1- calculation from trunk volume, after directly measuring dry density

2- Felling the trees and direct weighing, after directly measuring wood moisture

Foglia, 2022, Bsc thesis

Biomass vs. volume

- The two methods correlated great!
- Volume underestimated Cstorage by 17% (branches were not considered)



Allometric relationships

- Describe the change in a plant trait (e.g. volume) in response to the change in another easily-measurable plant trait (e.g. DBH).

- Usually follow the equation

$Y = b * X^a$ (power function)

Often used in the log form:

$\ln Y = \ln b + a * \ln X$

The exponent indicates allocation ratio formula of the resources and growth between the organs x and y.

For instance, a = 2/3 means that height increases by 0.66% if the stem diameter increases by 1%.

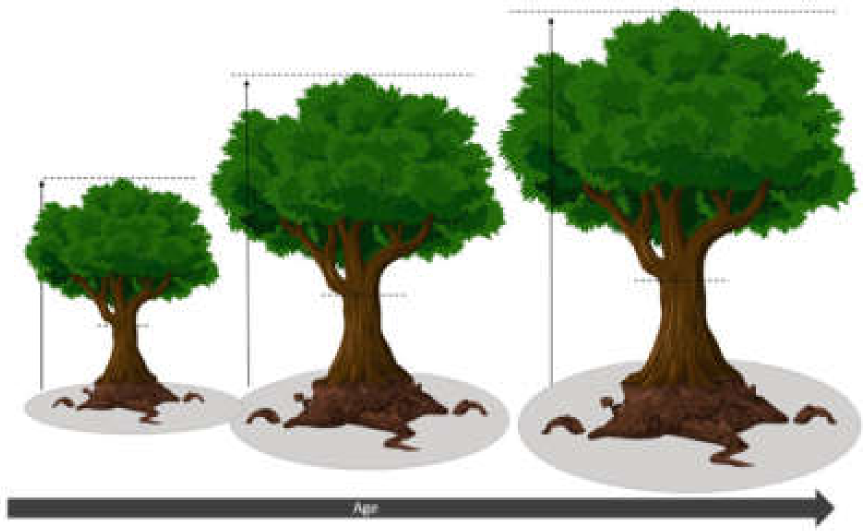


Fig. 2 Growth expected over age

Rotzer et al., 2020

Table 1 Overview of primary allometric relationships for the ideal allometric plant and stand

Allometry	Exponent	Dependent variable	Independent variable
$h \propto d^{2/3}$	$\alpha_{h,d} = 2/3$	Tree height, h	Stem diameter, d
$v \propto d^{8/3}$	$\alpha_{v,d} = 8/3$	Stem volume, v	Stem diameter, d
$cr \propto d^{2/3}$	$\alpha_{cr,d} = 2/3$	Crown radius, cr	Stem diameter, d
$cpa \propto d^{4/3}$	$\alpha_{cpa,d} = 4/3$	Crown projection area, cpa	Stem diameter, d
$cv \propto v^{3/4}$	$\alpha_{cv,v} = 3/4$	Crown volume, cv	Stem volume, v
$la \propto d^{2}$	$\alpha_{la,d} = 2$	Leaf area, la	Stem diameter, d
$la \propto m^{3/4}$	$\alpha_{la,m} = 3/4$	Leaf area, la	Stem mass, m
$ms \propto mr$	$\alpha_{ms,mr} = 1$	Shoot mass, ms	Root mass, mr
$v_q \propto N^{-3/4}$	$\alpha_{v_q,N} = -3/4$	Volume mean stem, vq	Tree number, N
$N \propto d_q^{-2}$	$\alpha_{N,d_q} = -2$	Tree number, N	Mean stem diameter, dq

The relationship $h \propto d^{2/3}$ between tree height and stem diameter means that a diameter increase by 1% is linked with a height increase by 2/3 = 0.67%. An increase of tree mass by 1% is linked with an increase of leaf area by 3/4 = 0.75% (for explanation of the tree variables, see Fig. 7)

Growth curves in the literature

SILVA FENNICA
Monographs 4 · 2005

Dimitris Zianis, Petteri Muukkonen, Raisa Mäkipää and Maurizio Mencuccini

Biomass and Stem Volume Equations for Tree Species in Europe

EQUATIONS FOR PREDICTING DIAMETER, HEIGHT, CROWN WIDTH, AND LEAF AREA OF SAN JOAQUIN VALLEY STREET TREES

by Paula J. Peper[1], E. Gregory McPherson[1], and Sylvia M. Mori[2]

Urban forest biomass estimates: is it important to use allometric relationships developed specifically for urban trees?

M. R. McHale · I. C. Burke · M. A. Lefsky · P. J. Peper · E. G. McPherson

Biomass equations for sixty-five North American tree species

Michael T. Ter-Mikaelian [a,*], Michael D. Korzukhin [b]

Urban Tree Database and Allometric Equations

E. Gregory McPherson, Natalie S. van Doorn, and Paula J. Peper

Hardwoods of North America

Harry A. Alden

Eur J Forest Res (2011) 130:911–934
DOI 10.1007/s10342-011-0481-9

ORIGINAL PAPER

Aboveground tree volume and phytomass prediction equations for forest species in Italy

Giovanni Tabacchi · Lucio Di Cosmo · Patrizia Gasparini

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES
» Forest ecology
» Plant ecology
» Climate-change ecology
» Light responses

Allometry and growth of eight tree taxa in United Kingdom woodlands

Matthew R. Evans[1], Aristides Moustakas[1], Gregory Carey[1], Yadvinder Malhi[2], Nathalie Butt[3], Sue Benham[4], Denise Pallett[5] & Stefanie Schäfer[5]

Article

Developing Allometric Equations for Estimating Shrub Biomass in a Boreal Fen

Annie He [1,*], Gregory J. McDermid [1], Mir Mustafizur Rahman [1], Maria Strack [2], Saraswati Saraswati [2] and Bin Xu [3]

Allometry

- Most research done on <u>forest trees</u>, caution is needed to transfer such findings to urban sites
- <u>Empiric relationships</u>: site and species specific

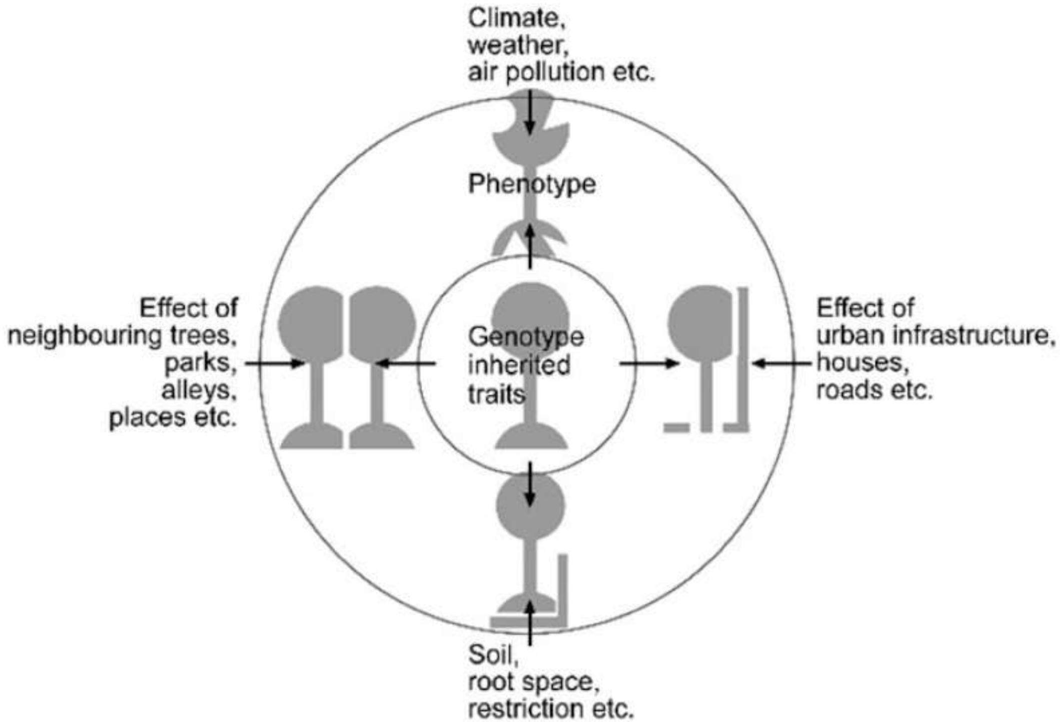


Fig. 4 Genotype and phenotype. Tree form and shape as a result of inner and outer determinants. Urban tree shape can be significantly determined by air pollution, infrastructures or root space restriction

Rotzer et al., 2020

LIFE URBANGREEN (www.lifeurbangreen.eu)

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LIFE URBANGREEN (2018–2022)

2 cities: Rimini (IT) and Krakow (PL)

10 model woody species

Aims:
1- Use eco-physiological traits for ES estimates
2- use tree eco-physiology to set management strategies
3- evaluate the [illegible]t of sound manag[illegible] on ES

Work in progress

Stratification

Experimental areas were stratified in:

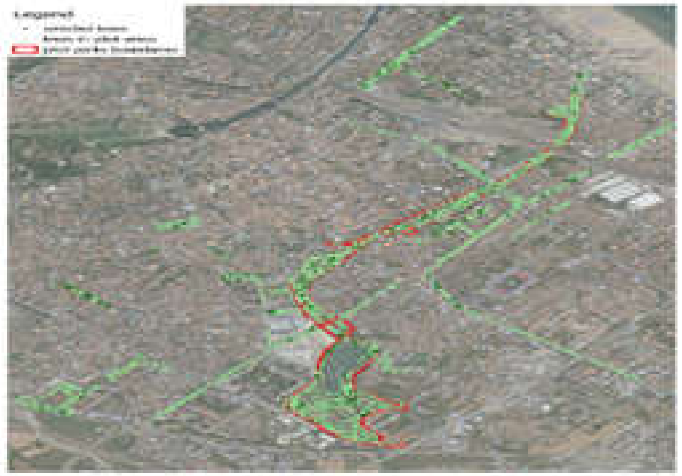
Paved areas: street trees, trees in parking lots, tree planted in well-defined planting pits or with visible conflicts with the built environment

Unpaved areas: tree in parks and gardens, growing in unpaved soil with negligible conflicts with the built environment

Trees in the experimental areas

Krakow, PL

Rimini, IT



- Ten model species per city were selected
- The selected genera accounted for 65% and 57% of total tree population in Rimini and Krakow, respectively
- 4 years of measurement

Species	n.	DBH min. (cm)	DBH max. (cm)
Rimini			
Acer negundo L.	80	7.50	67.62
Aesculus hippocastanum L.	105	5.00	76.43
Ligustrum lucidum Aiton	76	8.00	30.90
Platanus x acerifolia (Aiton) Willd.	78	5.30	77.55
Populus nigra L. 'Italica'	78	7.50	92.36
Prunus laurocerasus L.	12	4.00	37.88
Quercus ilex L.	110	11.50	109.18
Quercus robur L. 'Pyramidalis'	89	8.00	51.43
Tilia x europaea L.	109	6.20	58.93
Krakow			
Acer platanoides L.	135	5.00	84.39
Aesculus hippocastanum L.	125	4.50	109.71
Cornus alba L.	29	2.23	8.46
Fraxinus excelsior L.	128	4.50	84.87
Populus nigra L. 'Italica'	96	7.00	96.80
Quercus robur L.	126	5.00	129.14
Sorbus aucuparia L.	103	4.00	50.64
Tilia cordata Mill.	146	5.00	74.73
Ulmus laevis Pall.	87	4.00	118.15

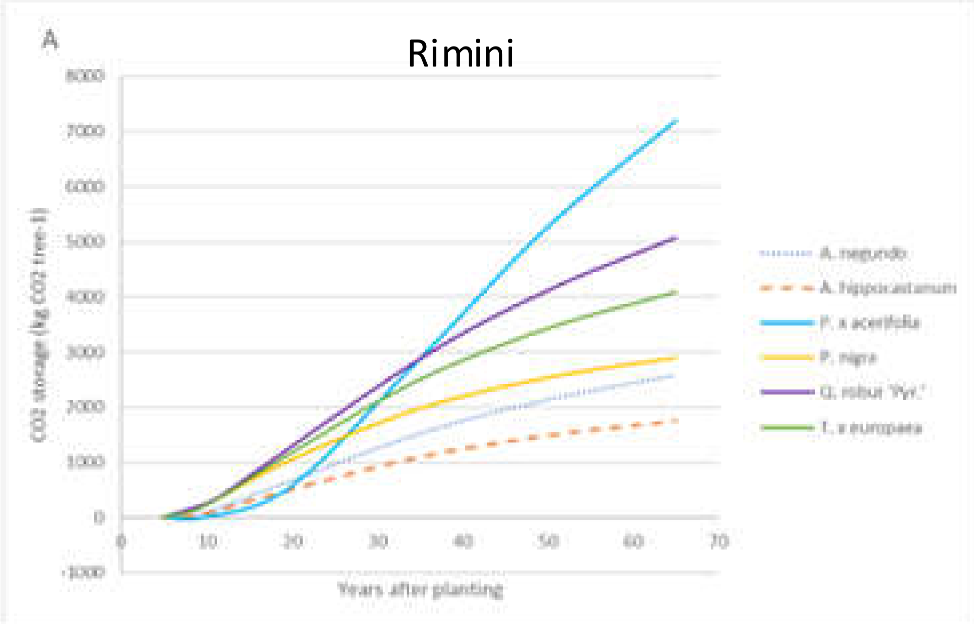
CO_2 storage and sequestration

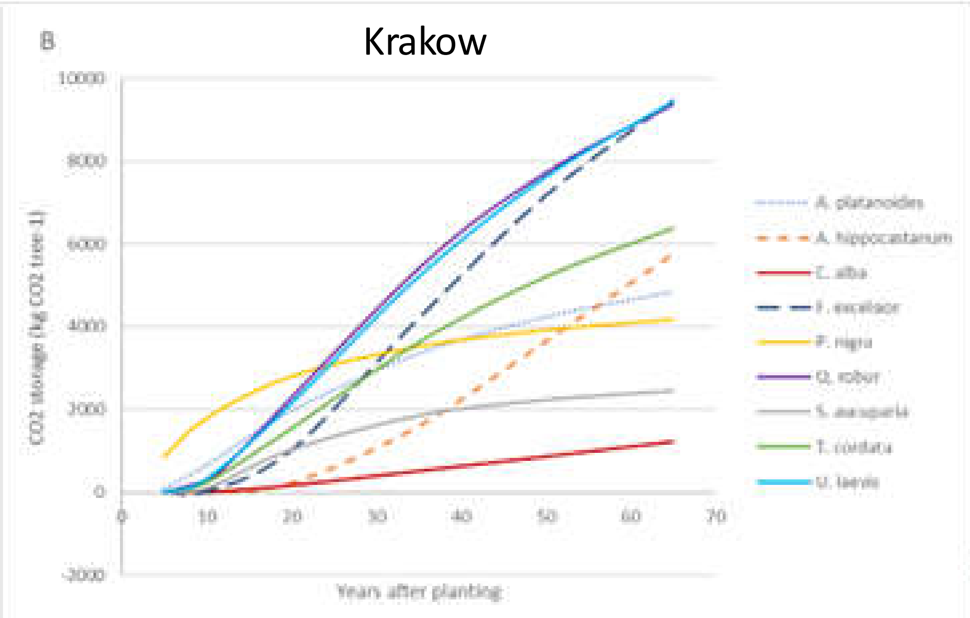
A terrestrial laser scanner RIEGL VZ 400i was used by project partner Progea 4D to collect point clouds of 120 trees, during the leaf-off period.

Point clouds were converted into volumes of trunk and main branches using specific algorithms

troduction

CO_2 storage in Rimini and Krakow





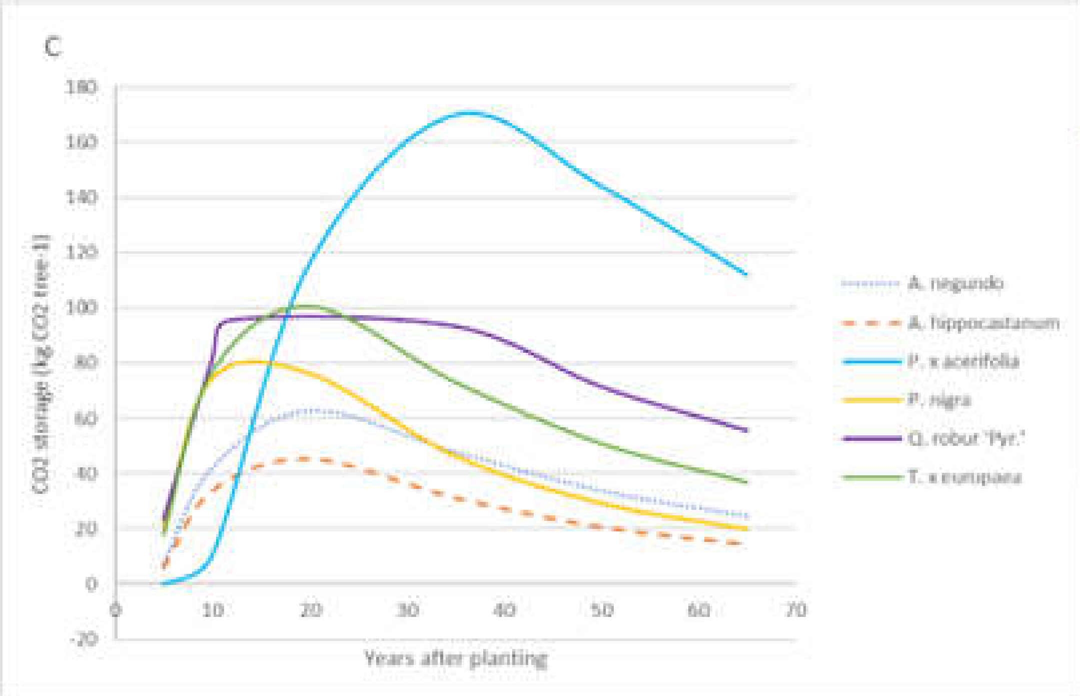
In Rimini, the CO_2 stored by a tree over a 65 years life-cycle ranged from 1750 kg CO_2 (*A. hippocastanum*) to 7203 kg CO_2 (*P. x acerifolia*)

Q. robur ‘Pyramidalis’, *T. x europaea*, and *P. nigra* stored more CO_2 than P. *x acerifolia* within 30 years from planting

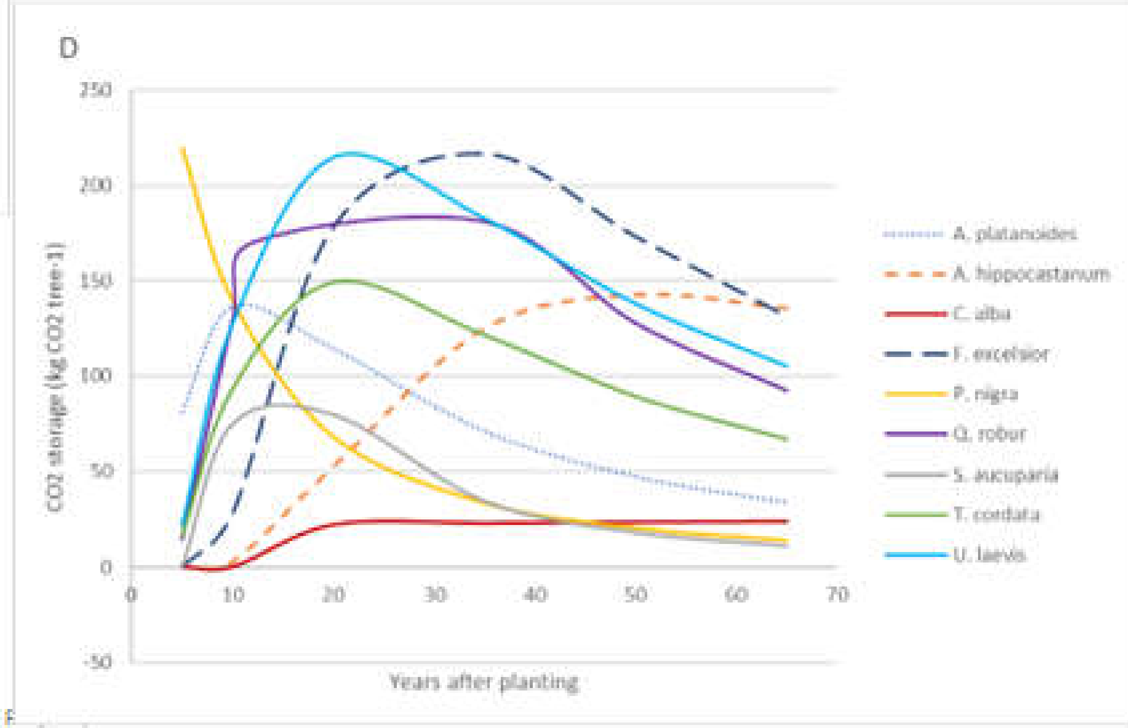
In Krakow, the CO_2 stored by a tree over a 65 years life-cycle ranged from 1230 kg CO_2 (*Cornus*) to about 9350 kg CO_2 (*F. excelsior, Q. robur, U. laevis*)

P. nigra stored more CO_2 than other species within 20 years from planting

CO_2 sequestration in Rimini and Krakow



Annual CO_2 sequestration in the two cities ranged from 20 to about 220 kg CO_2 per year



CO_2 sequestration depends on species and plant age

The peak of CO_2 sequestration may be related to tree longevity (e.g. short-lived species like poplar peak early; long-lived species like oak, London plane and ash showed delayed or long-lasting peak)

Back to processes

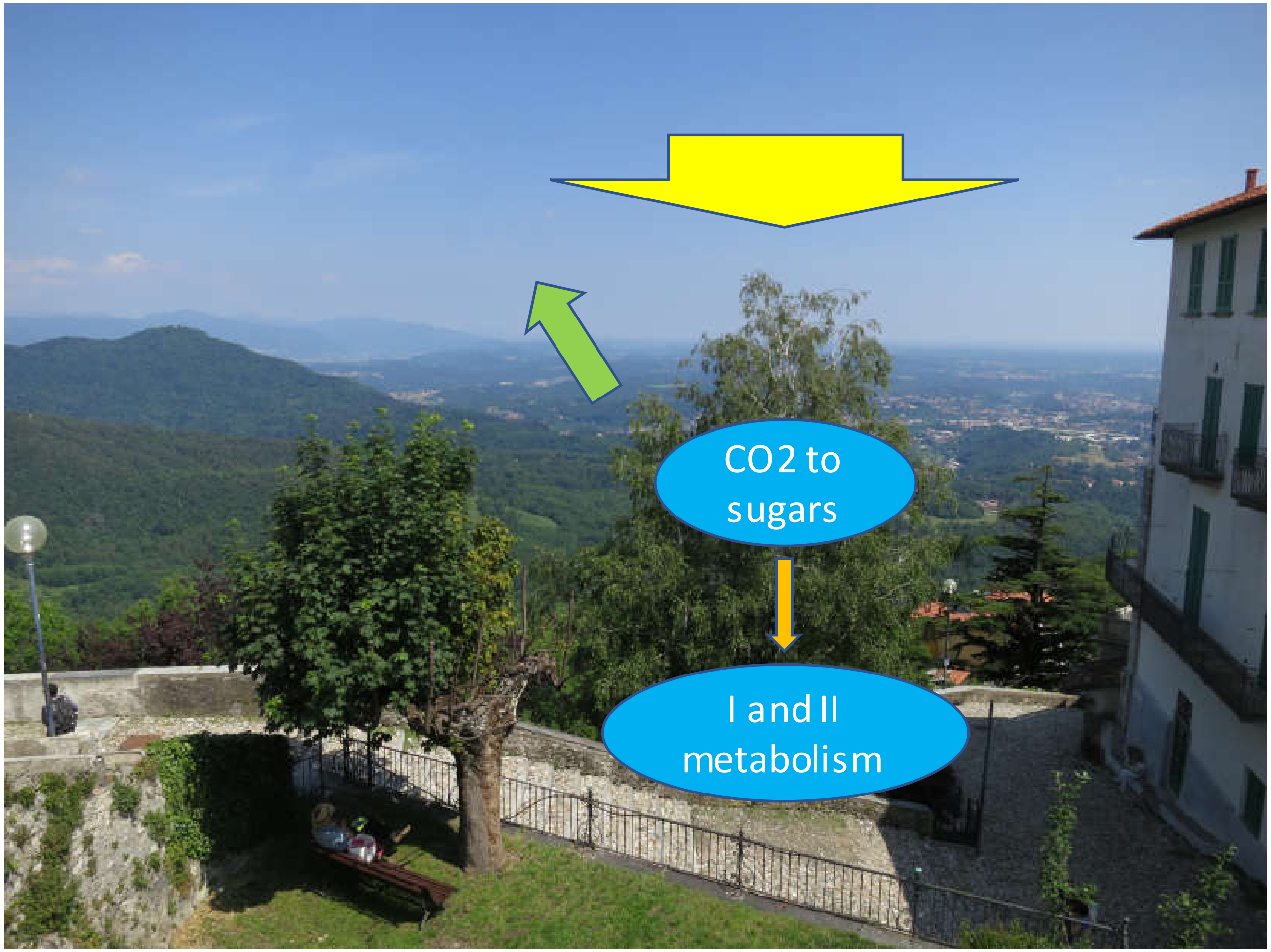
Dry matter production **(P)** is directly related to the amount of PAR intercepted by the canopy (Monteith, 1977).

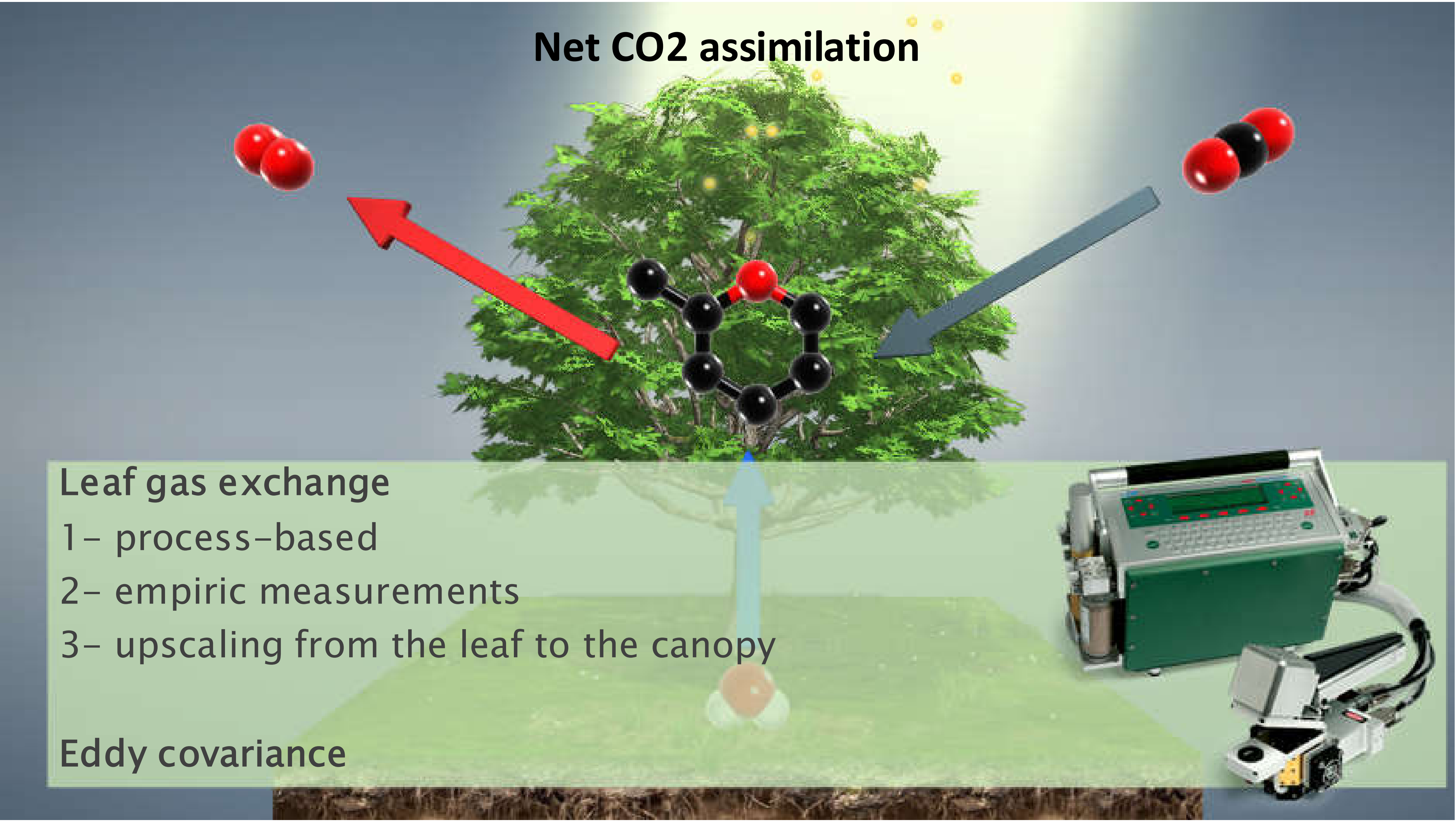
P = e f S

S = PAR reaching the canopy

f = fraction of irradiance intercepted by the canopy (fractional interception)

e = photosynthetic characteristics

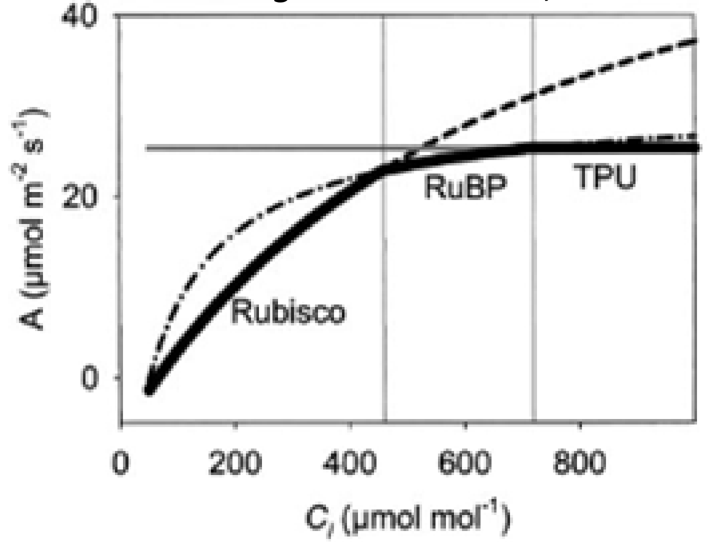




Net CO2 assimilation
Leaf gas exchange
1- process-based
2- empiric measurements
3- upscaling from the leaf to the canopy
Eddy covariance

Leaf gas exchange – process based

Long and Bernacchi, 2003



An = min {Av, Aj, Atpu) - Rday

An, the actual rate of net photosynthesis, is the minimum between the electron-transport rate limited photosynthesis (**Aj**), the Rubisco-limited photosynthesis (**Av**), and the triose-phosphate ulitization limitation (**Atpu**). The latter seldom occurs.
Rday is leaf respiration during the day
(*Farquhar et al., 1980; Long and Bernacchi, 2003; Sharkey, 2007*)

Av

$$A = V_{cmax}\left[\frac{C_i - \Gamma^*}{C_i + K_C(1 + O/K_O)}\right] - R_d$$

Aj

$$A = J\frac{C_c - \Gamma^*}{4C_c + 8\Gamma^*} - R_d$$

Atpu

$$A = 3TPU - R_d$$

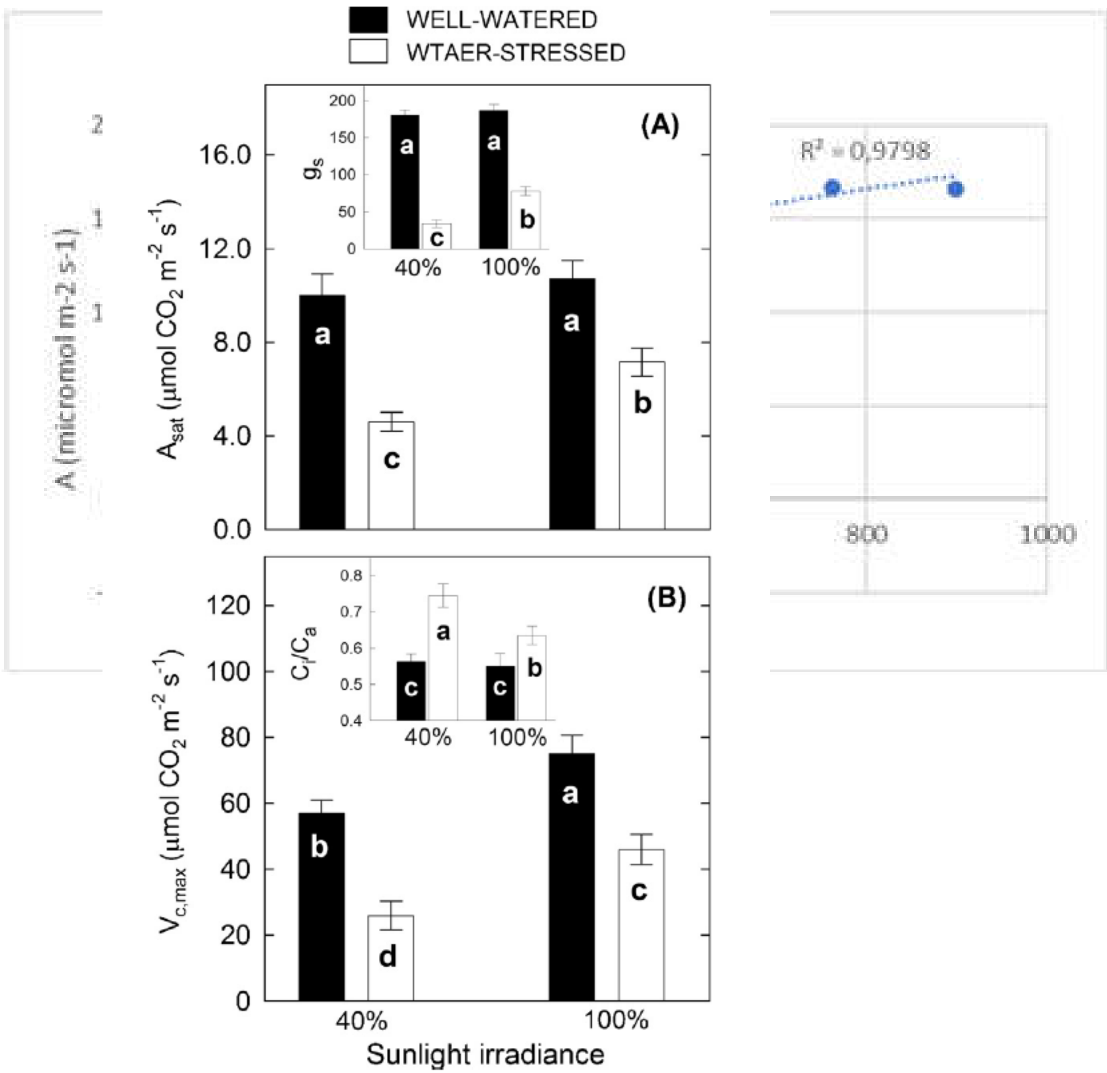
Where: **Vcmax** is the apparent maximum rate of carboxylation by Rubisco estimated by A/Ci curves; **J** is the apparent contribution of electron transport to RuBP regeneration, **TPU** is the rate of triose phosphate utilization (TPU = (Amax + Rd)/3; **Pi** (Pa) is the partial CO_2 pressure in the substomatal chamber, Γ***** (Pa) is Rubisco CO_2 compensation point in the absence of photorespiration, and **K'** is the effective Michaelis-Menten constant

Leaf gas exchange – process based

- Allow real time estimation of net CO2 assimilation based on environmental parameters (PAR, Temperature)

- It is time-consuming to draw A/Ci curves: is your data representative of the species?

- Vcmax(Ci) and Jmax(Ci) are far from being constants and can changed to a greater extent than photosynthetic rate during stress. Is your data representative of the species?

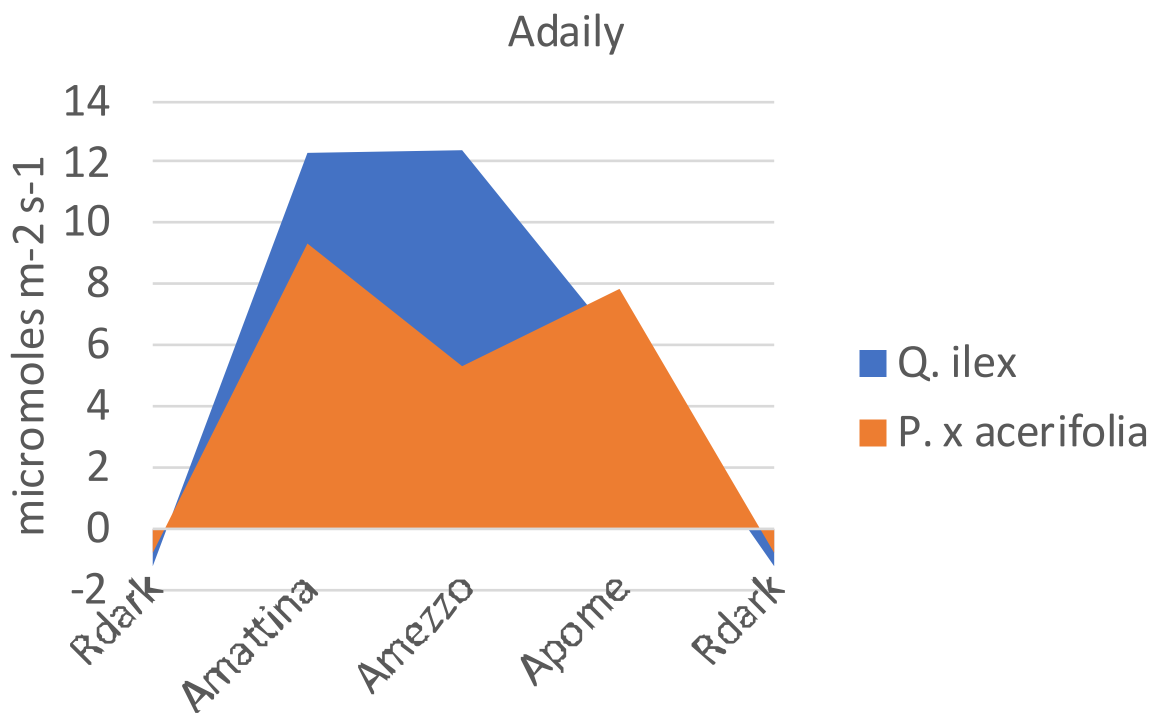


Leaf gas exchange – empirical

CO2 assimilation can be empirically measured. To be representative:

1- measure a large number of leaves

2- conduct daily measurements and consider dark respiration

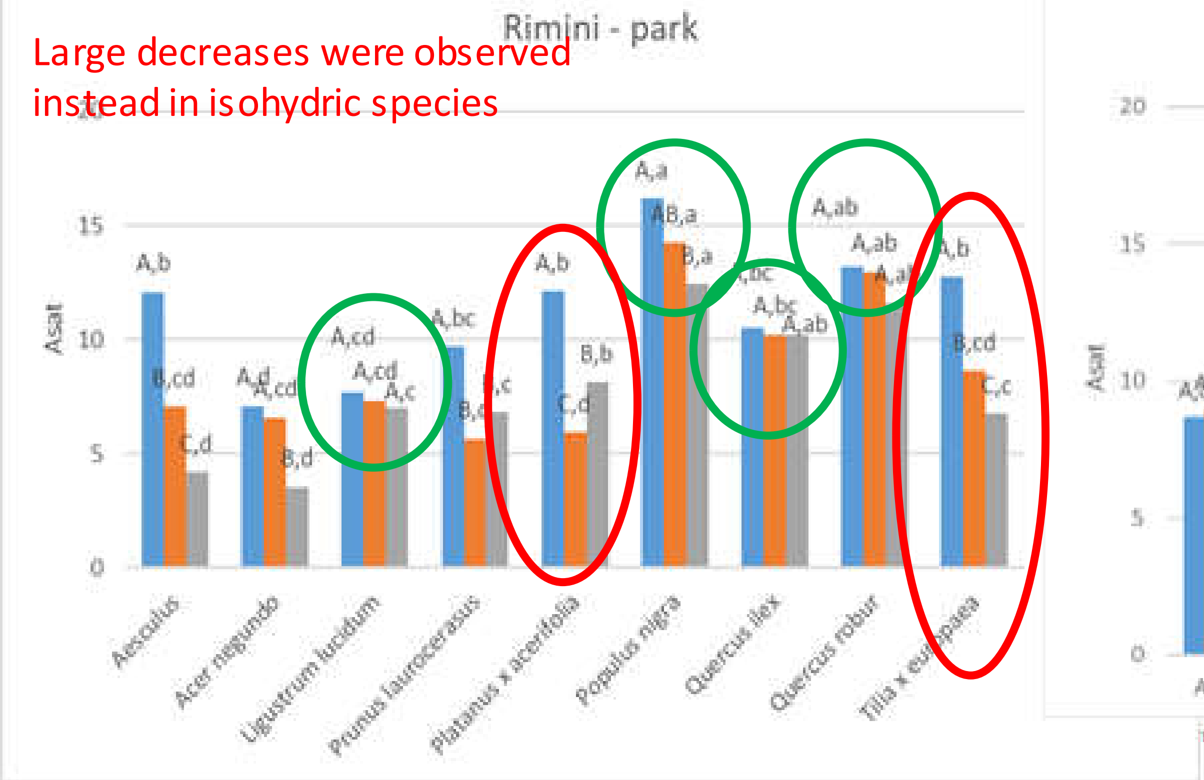


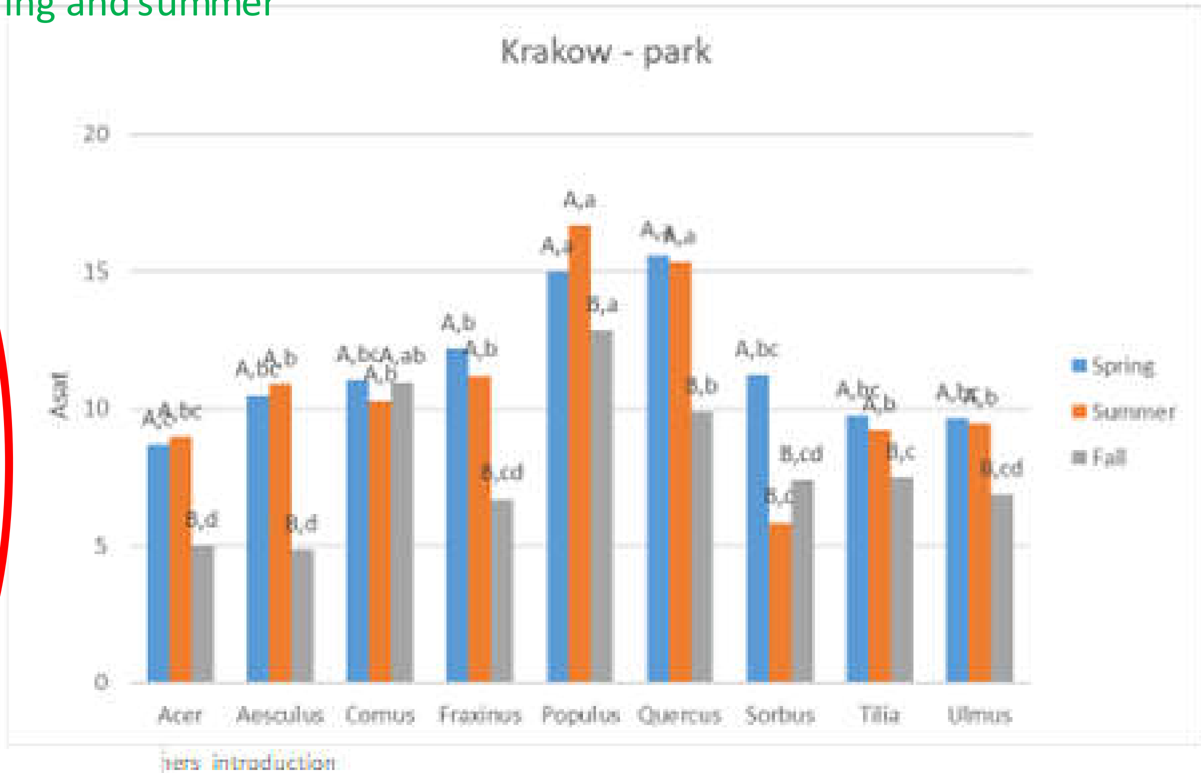
Net photosynthetic rate – LIFE URBANGREEN

Populus and *Q. robur* displayed higher net photosynthesis per unit leaf area than other species in both cities.
Acer species displayed low photosynthesis in both cities

Anisohydric species yielded a similar photosynthesis in spring and summer

Large decreases were observed instead in isohydric species





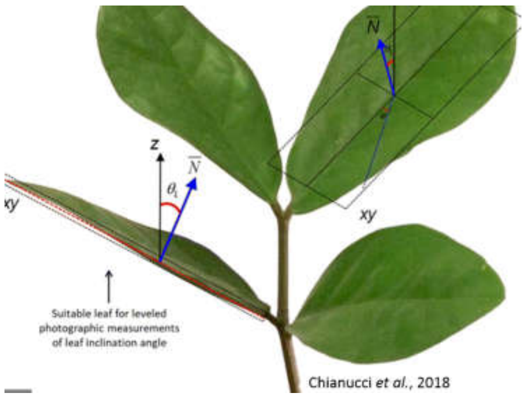
Plant, Woody, and Leaf Area Index

The apparent effective Plant area index (i.e. half of total leaf + woody area per unit horizontal soil area) was measured using the ceptometer Accupar on 6 (Rimini) or 7 (Krakow) replicate plants per species and strata.

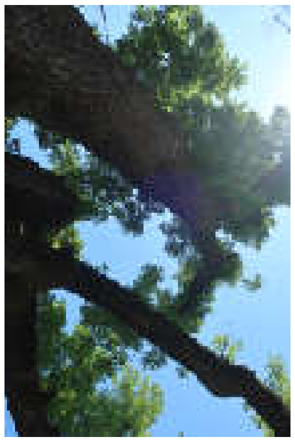
Measurements were conducted in May, June, and July between 11.30 and 14.30

Measured PAIe'

Leaf angle distribution



Clumping



Woody area/Plant area

True LAI

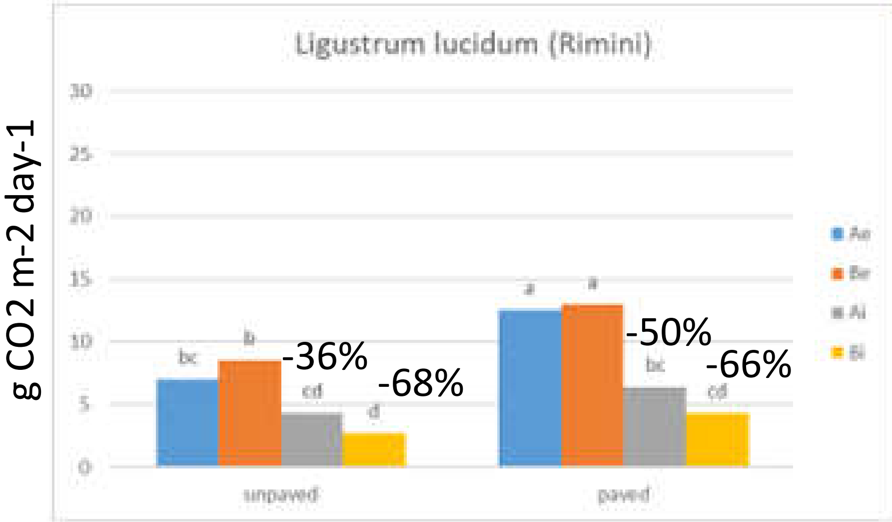
For details, see Yan et al., 2019, Agricultural and Forest Meteorology 265: 390–411

Including shaded leaves – 2 leaves models

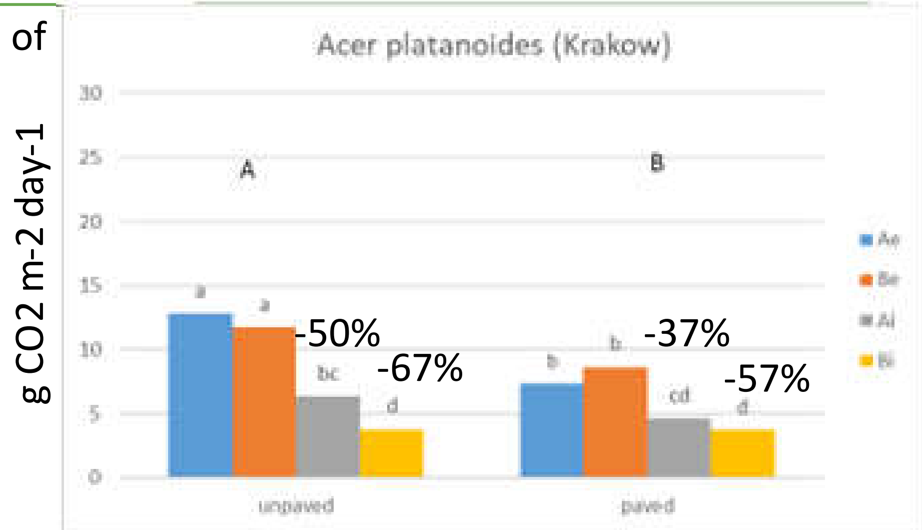
- Current research in tree modelling for CO2 assimilation suggest that, if ES quantification, rather than health assessment, is the goal of the research, measurements should also be conducted on shaded leaves, to take into account shade acclimation mechanisms within a canopy.
- Measurement of shaded leaves should be at growing irradiance
- Irradiance at which perform the measurement can be calculated as:

PAR * (1-f) = PAR * τ

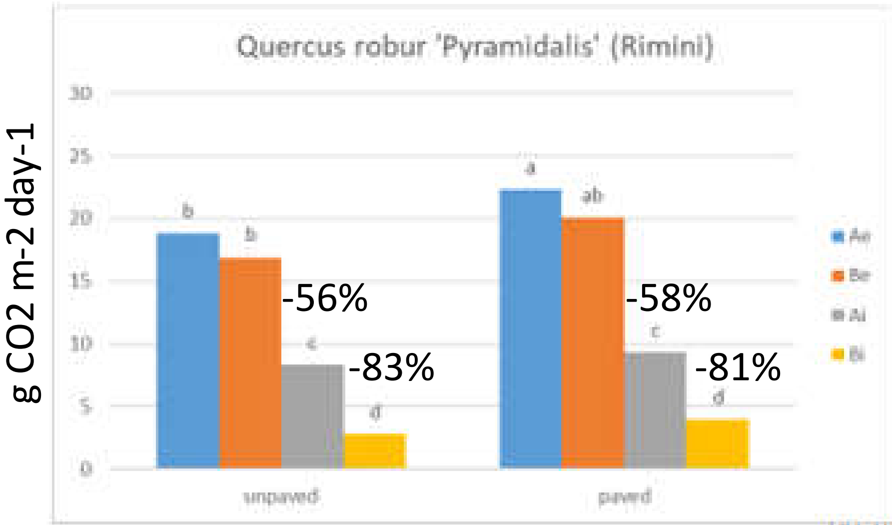
Daily CO_2 assimilation per unit leaf area: examples



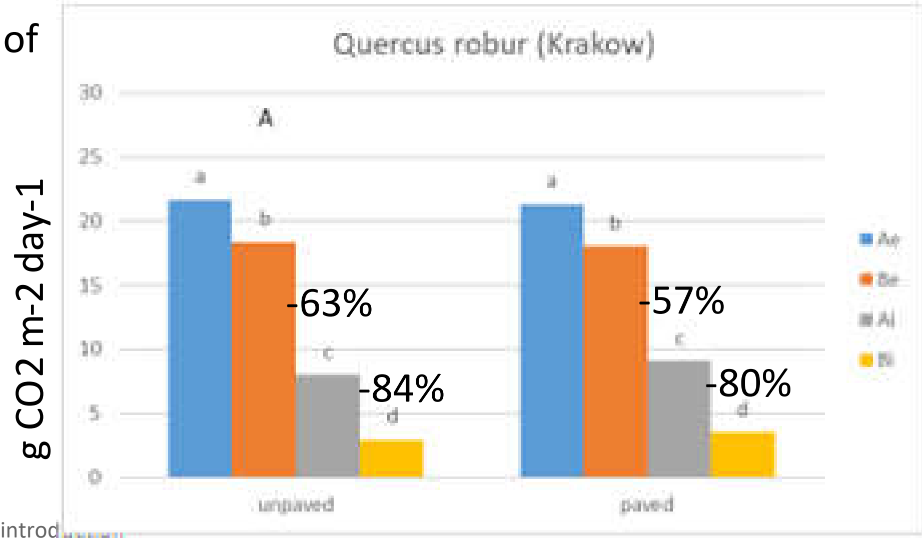
High contribution of shaded leaves



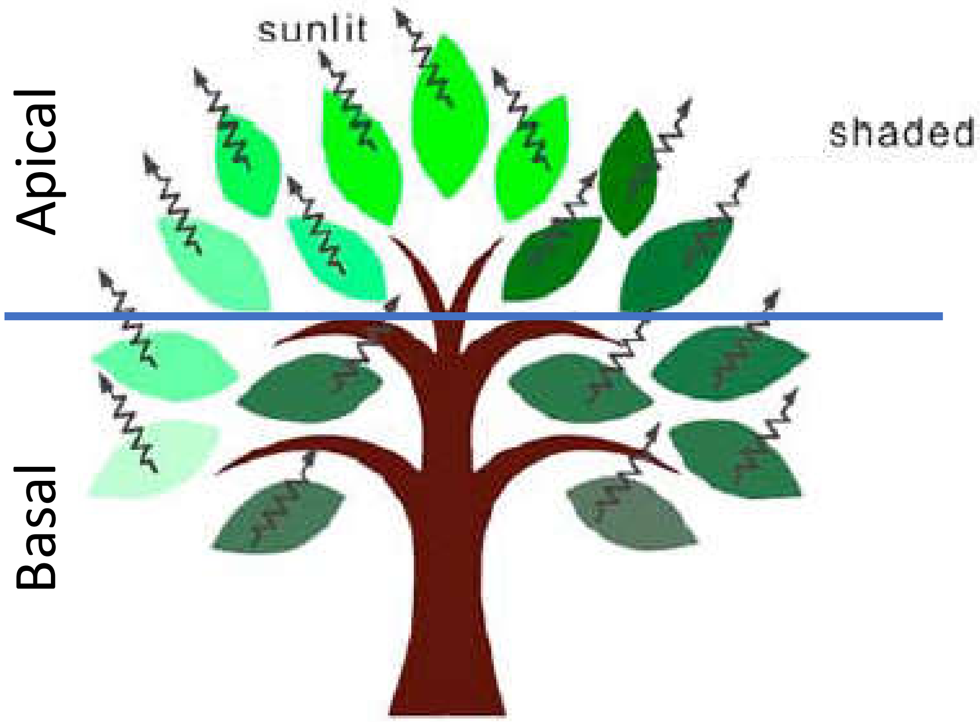
Canopy layers:
Ae = apical, full sun
Ai = apical, shaded
Be = basal, full sun
Bi = basal, shaded



Low contribution of shaded leaves



Multilayer models



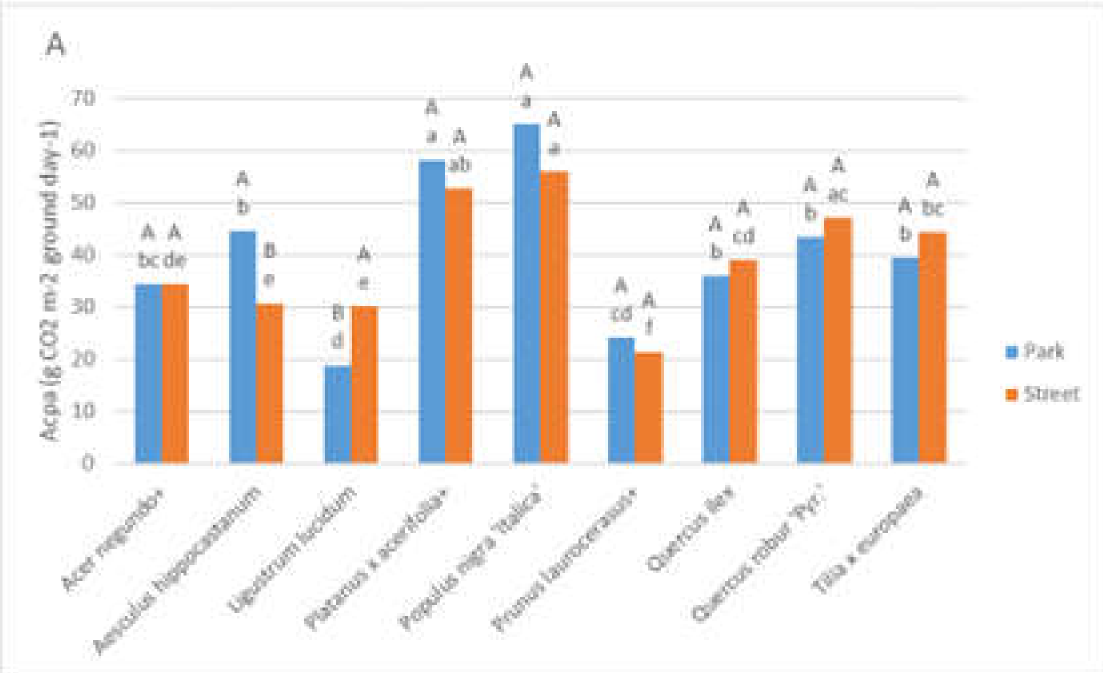
- The canopy is divided in layers: we used two layers (apical and basal)
- Each layer is divided into full sun and shaded leaves
- **$AcpaML = Adaily_{sun} * LAI_{sun} + Adaily_{shade} * LAI_{shade}$**
- Equations to calculate sun and shaded leaf area:
- **$LAI_{sun} = = 2\cos\theta * (1 - e^{-0.5*\Omega *LAI/\cos\theta})$** and
- **$LAI_{shade} = LAI - LAI_{sun}$**

where θ is solar zenith angle (rad)

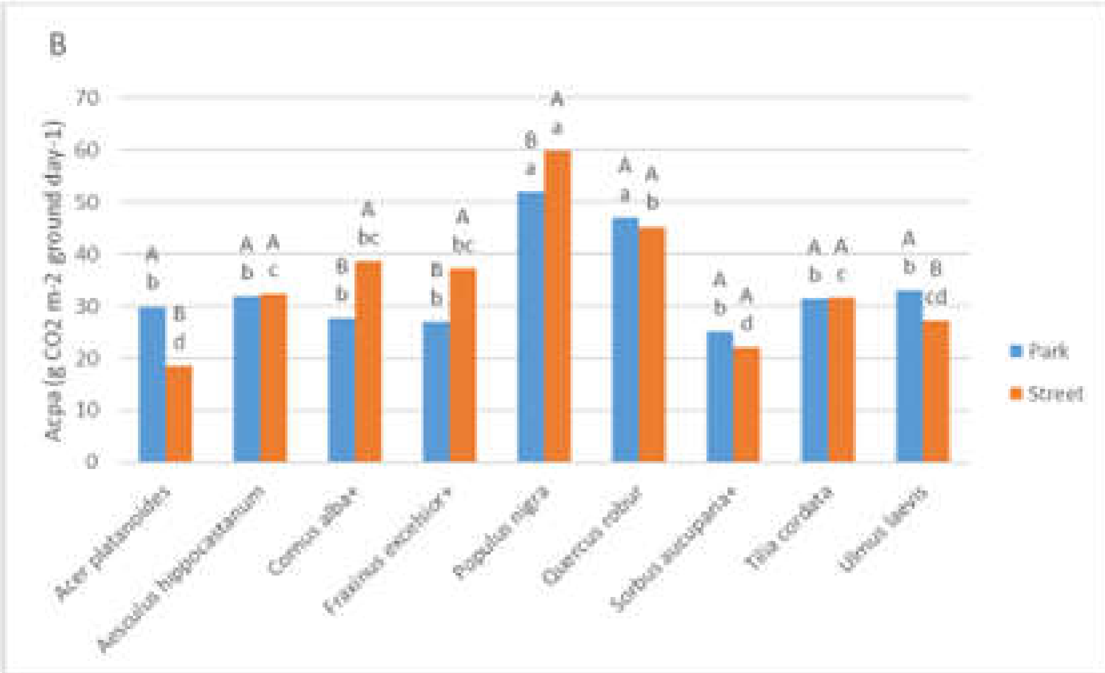
The model feeds with net CO2 assimilation of full sun and shaded leaves, and LAI

CO2 assimilation upscaled to unit crown-projection-area

Rimini



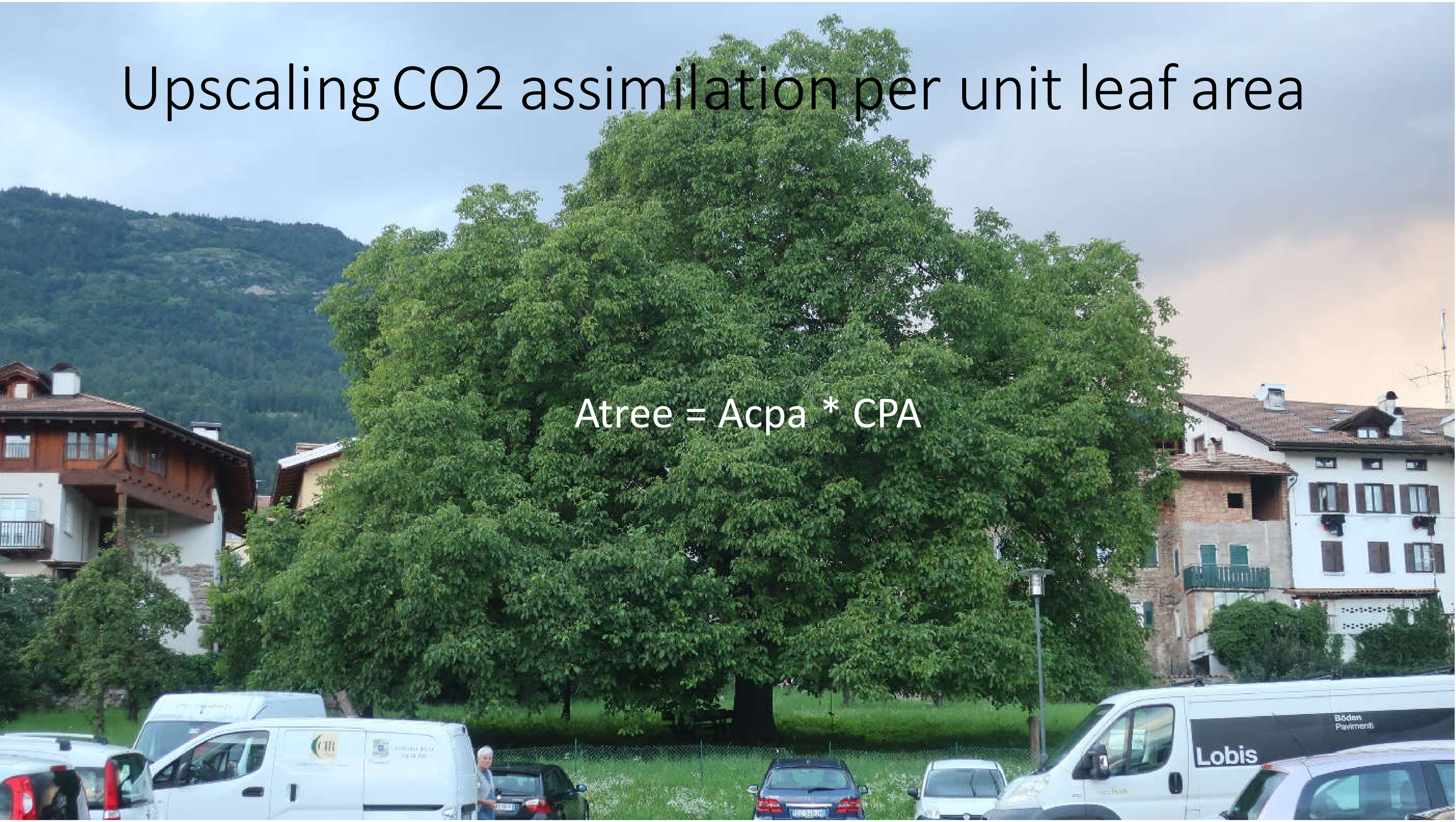
Krakow



Assuming a 30% canopy cover:

Populus nigra: about 22,7 t CO_2 ha-1 year-1
Acer platanoides: about 9,1 t CO_2 ha-1 day-1

Upscaling CO2 assimilation per unit leaf area



Atree = Acpa * CPA

Crown projection area

Tree age was retrieved with the assistance of Anthea and ZZM (municipal tree care companies)

About 800 combined measurements of **stem DBH, crown radius** and **crown projection area** (CPA) were done per city (Pretsch et al., 2015)

For multi-stemmed trees, diameter was measured at 30 cm height following the I-Tree protocol.

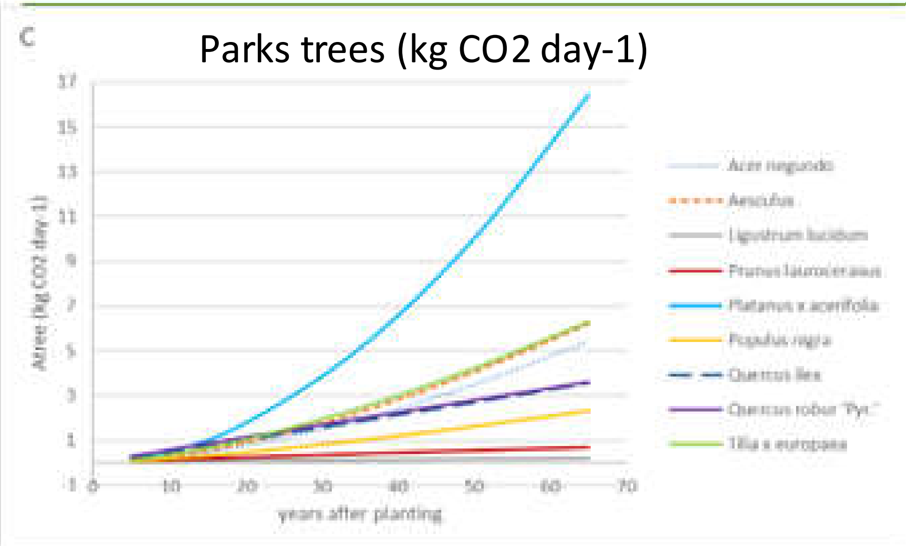
Data were used to generate allometric curves that correlate tree age with DBH and DBH with CPA

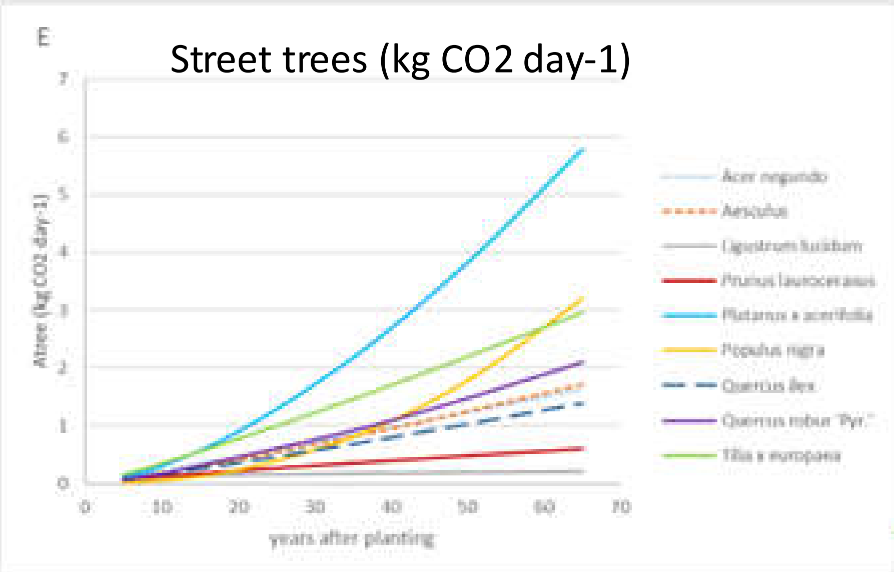
DBH (cm) = b*age (years)^a

CPA (m2) = π * R_{canopy}^2 = π * (b*DBH (cm)^a)^2

Species	b	a	R2	Function
Acer negundo	1,11393344815083	0,92401978988030	0,883	DBH = b * age^a
Aesculus hippocastanum	0,95897047949680	0,99963633912339	0,947	DBH = b * age^a
Quercus robur	2,10141368488829	0,75820986641471	0,736	DBH = b * age^a
Prunus laurocerasus	2,25460849836377	0,61414876018813	0,468	DBH = b * age^a
Quercus ilex	2,90733535606017	0,66277907159766	0,781	DBH = b * age^a
Ligustrum lucidum	3,56302969814312	0,45074695375881	0,416	DBH = b * age^a
Populus nigra	1,28491363078834	1,00839853426417	0,897	DBH = b * age^a
Platanus x acerifolia	0,65017485710193	1,14619326101069	0,858	DBH = b * age^a
Tilia x europaea	1,50390917211331	0,90314882990627	0,887	DBH = b * age^a
Pinus pinea	N.A.	N.A.	N.A.	N.A.

Daily CO_2 assimilation per tree, across the life-cycle (Rimini)

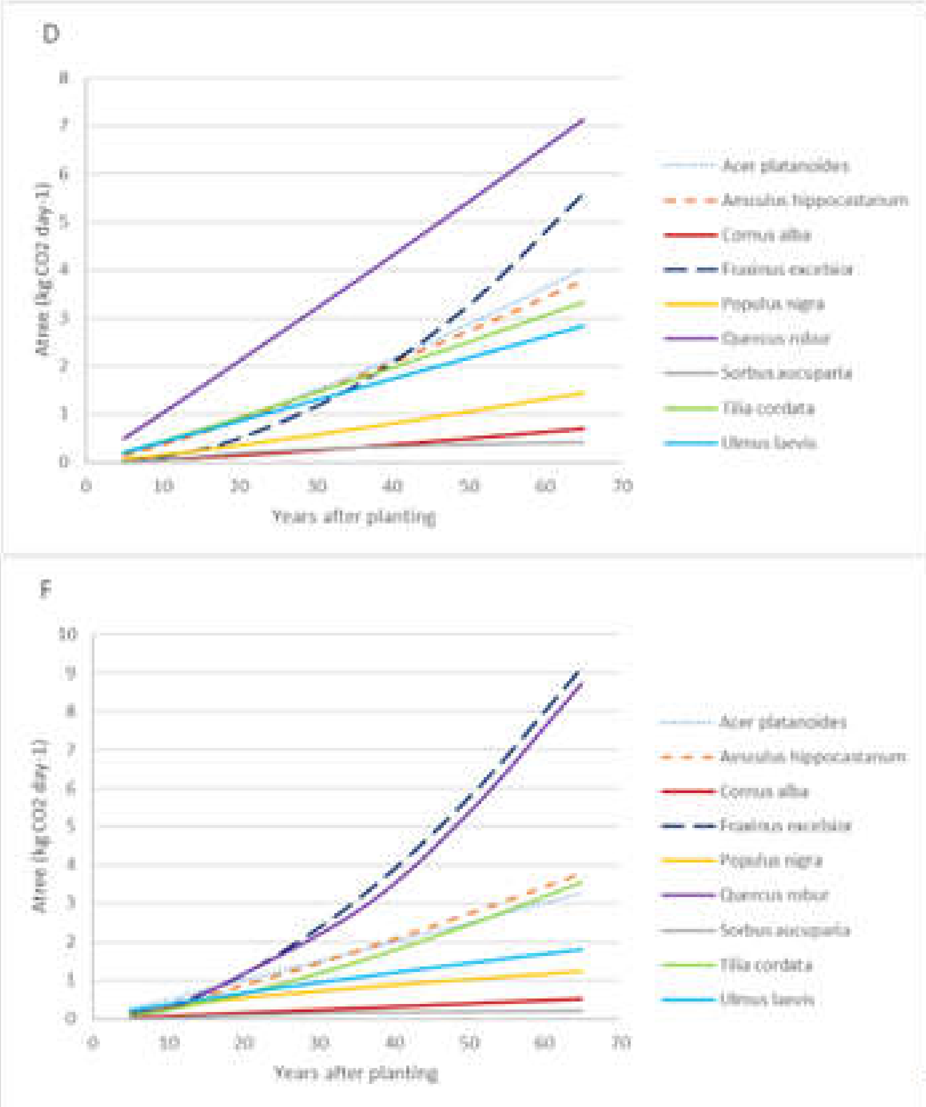


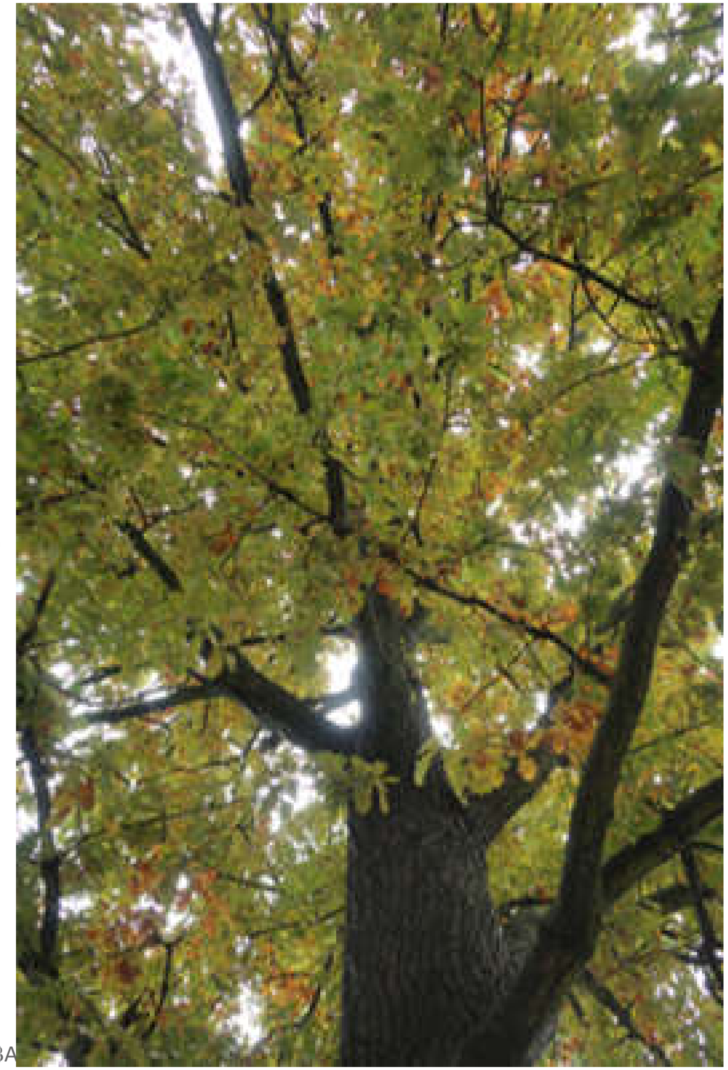


Park trees:
Q. Robur 'Pyramidalis' had higher Atree (about 0.594 kg CO_2 day^{-1}) for 12 years after planting.
Then, *P. x acerifolia* outcompeted other species (16.4 kg CO_2 day^{-1})

Street trees:
Tilia x europaea had higher Atree (about 0.368 kg CO_2 day^{-1}) for about 15 years after planting.
Then, *P. x acerifolia* displayed higher Atree (5.80 kg CO_2 day^{-1})

Daily CO_2 assimilation per tree, across the life-cycle (Krakow)



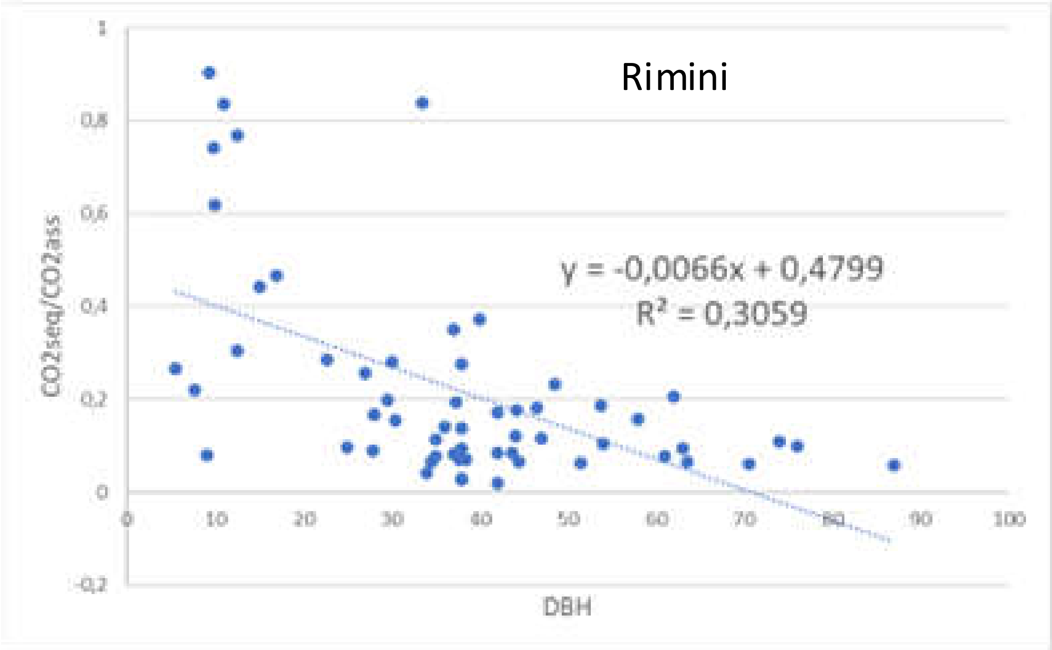


Q. robur and *F. excelsior* provided higher A_{tree} in both parks and streets (up to 8 kg CO_2 day^{-1} 65 years after planting)

In parks, to get the best from ash, life-span should be enhanced

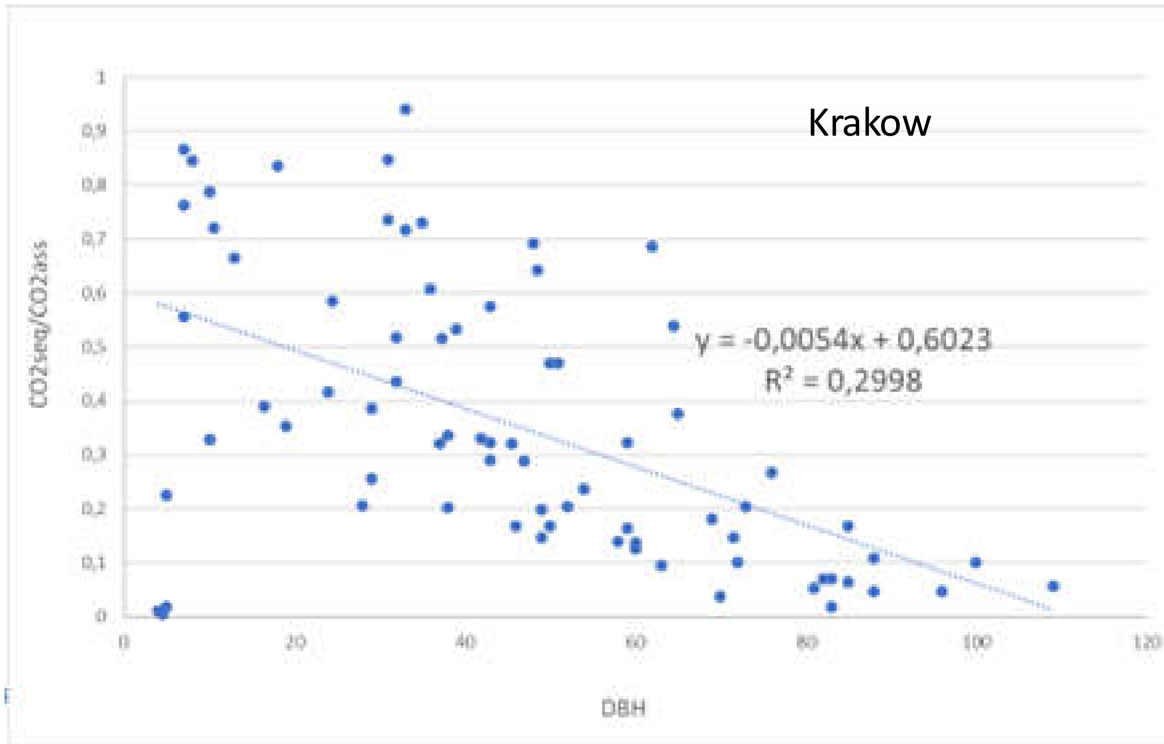
A. Platanoides is suitable for short-term street tree plantings because it is the species which had higher A_{tree} in the early post-establishment period (about 0.150 kg CO_2 day^{-1} for a Norway maple 10 years after planting)

Conclusion: Is it worth measuring net CO2 assimilation?



The ratio between CO_2 sequestration and CO_2 assimilation negatively scaled with DBH

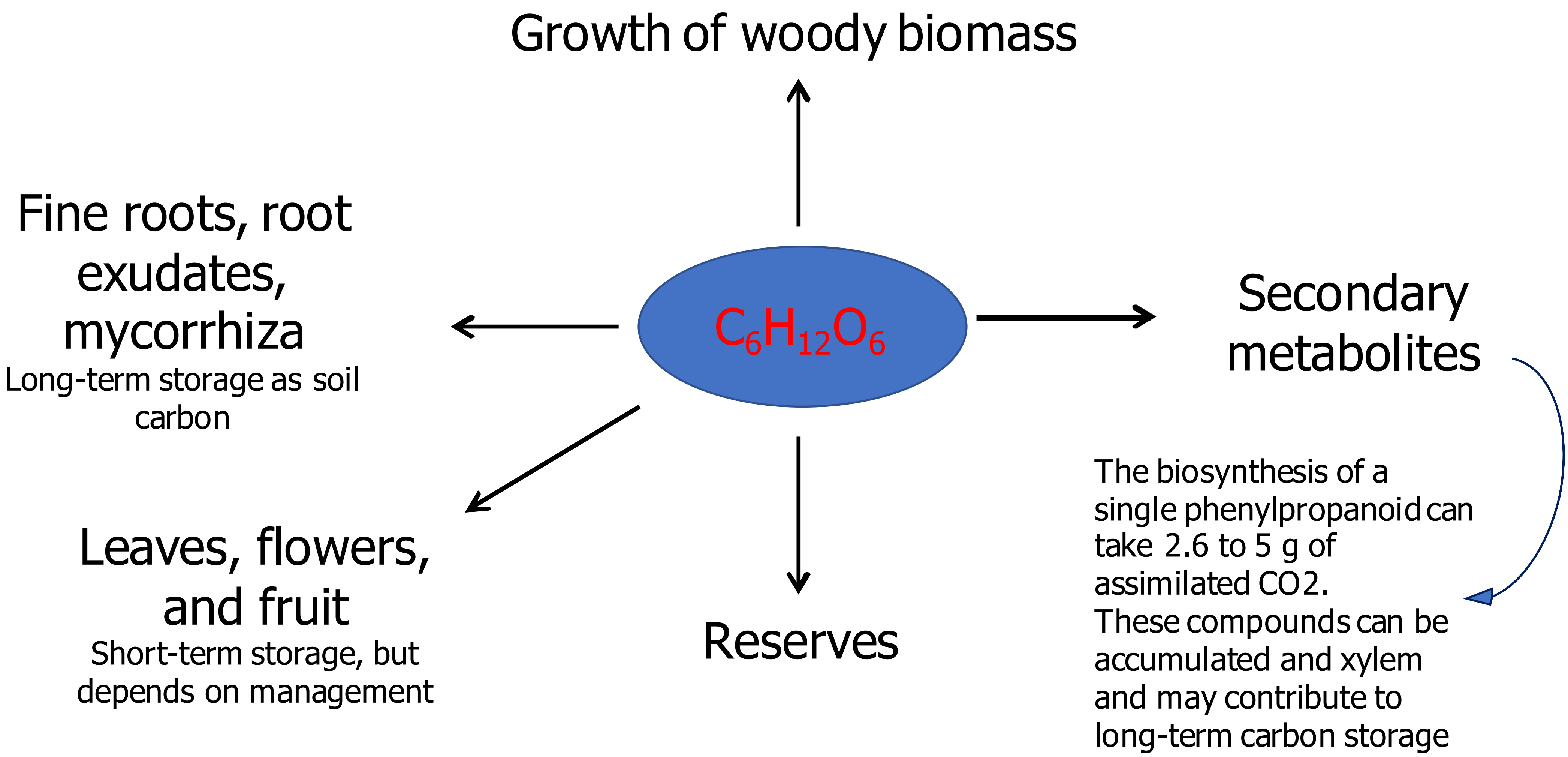
The amount of assimilated CO_2 allocated to woody growth is affected by plant age



Newly established trees allocated 48% (Rimini) to 60% (Krakow) of photosynthates to growth

Late mature trees, instead can allocate less than 10%

Fate of assimilated CO_2



Herms e Mattson, 1992, The Dilemma of plants: to grow or to defend. Quat. Rev. Biol., 67(3): 283-335

Thanks for your attention

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