UNIVERSITÀ DEGLI STUDI FIRENZE

Ecophysiology of urban trees

Filippo Bussotti

Dept. Agri-Food Production and Environmental Science, University of Firenze.
filippo.bussotti@unifi.it

Dipartimento di Scienze Agrarie Alimentari e Agro-Ambientali
Università di Pisa

1st International Workshop
"PLANT PHYSIOLOGY IN THE URBAN ENVIRONMENT"
June 23, 2014
Aula Magna, DiSAAA-a, Via del Borghetto, 80 – 56124 Pisa, Italy

TreeCity
An International Project for a Better Quality of Life in Our Cities
Sponsored by MIUR PRIN

Stress factors in urban areas include:

-Drought induced by waterproofed soils and insufficient watering.
- Salinity.
-Low soil fertility (poor artificial soils; compaction and lack of mycorrhization).
-Elevated carbon dioxide concentration and high temperatures (heat island).
-Air pollution and relative atmospheric processes (exhaust gases, particulate matter, nitrogen oxides, VOCs, ozone).

In a climate change perspective these stress factors are expected to become harsher.

DROUGHT

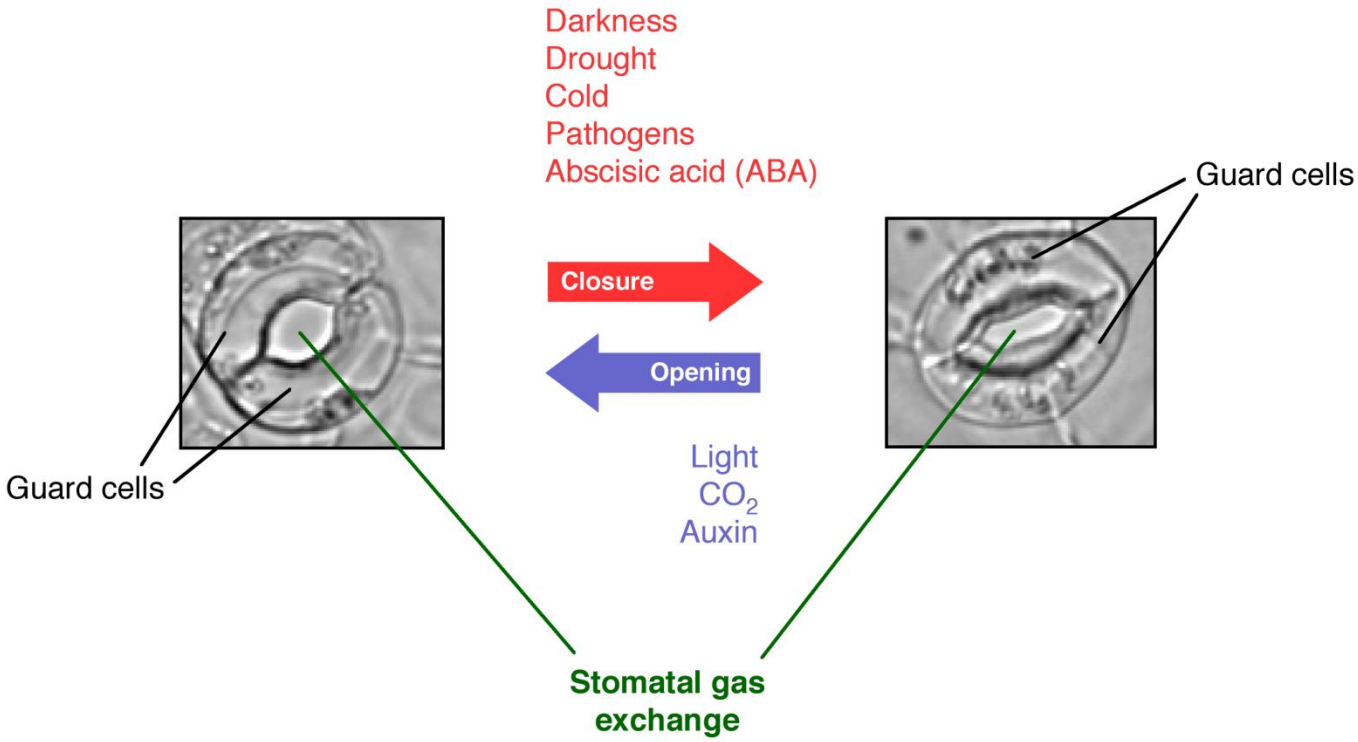
Fresh water availability will be one of the greatest challenge in the urban areas of the Mediterranean region, that are subjected to increasing inurbation and climate change.

Increasing drought, and increasing water consumption for civic uses, reduces water availability for urban trees.
Water spending tree species, that are commonly cultivated in cities (for ex. *Tilia*, *Platanus* ….), are threatened.

Drought reduces photosynthesis by:

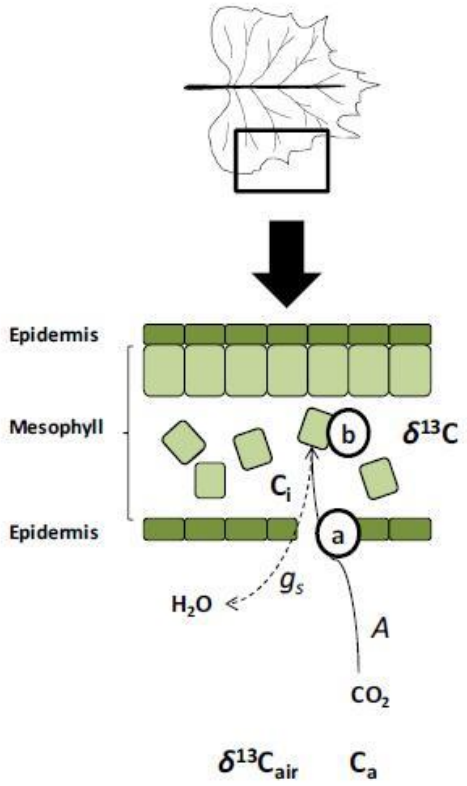
1. Mesophyll limitation (Rubisco inactivation);
2. Stomatal limitation (stomatal closure).

Both effects provoke carbon starvation and reduced growth.



Drought induces activation of PEP also in C3 plants:

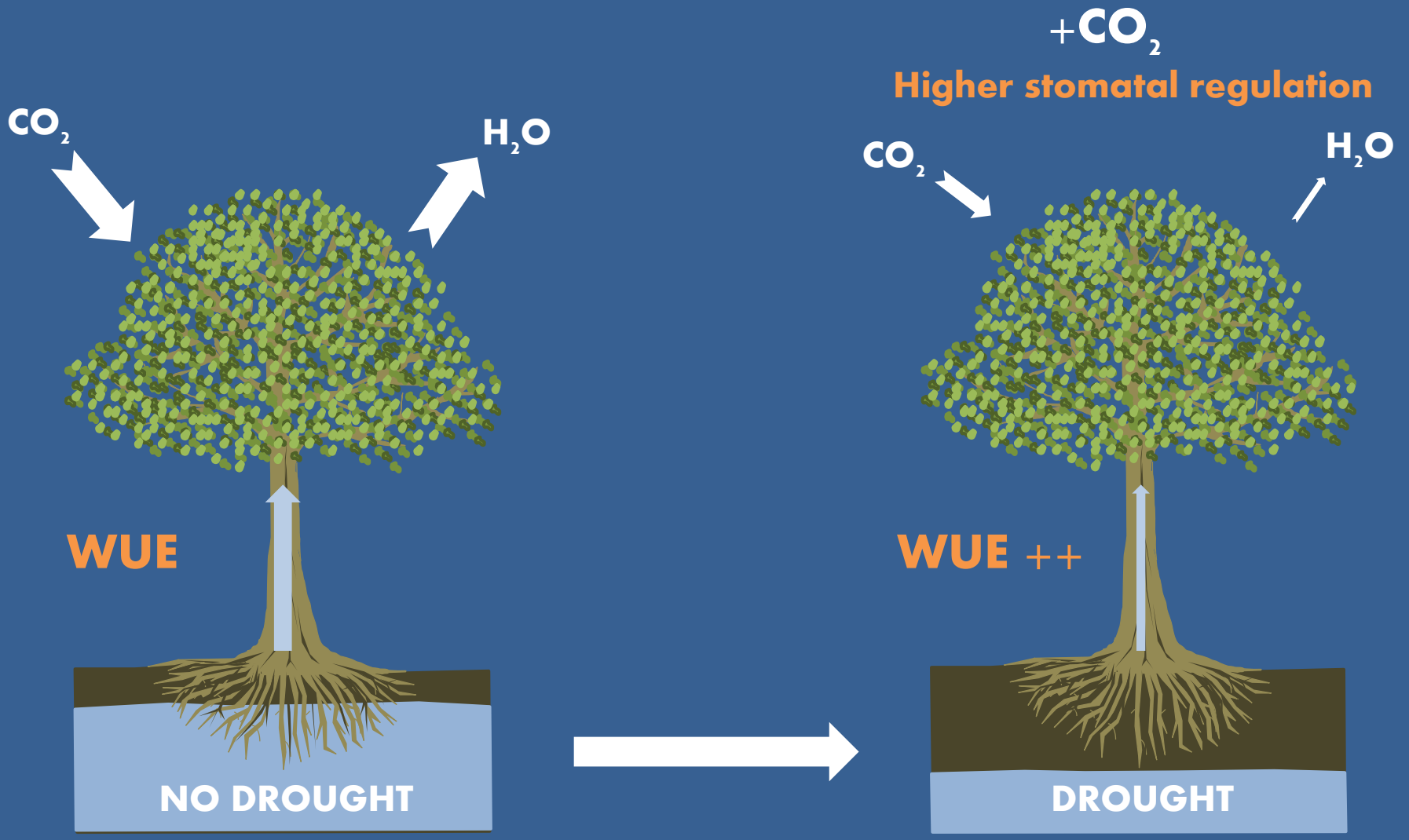
- PEP has more affinity to Carbon than Rubisco;
- PEP allows a more complete use of C than Rubisco, so increasing the Water Use Efficiency (WUE) in drought stressed plants;
- PEP increases the utilization of ^{13}C (higher $\delta\,^{13}C$ in water stressed plants).



Photosynthesis discriminates carbon isotopes using ^{12}C easier than ^{13}C .
In water stress conditions the use of ^{13}C is increased

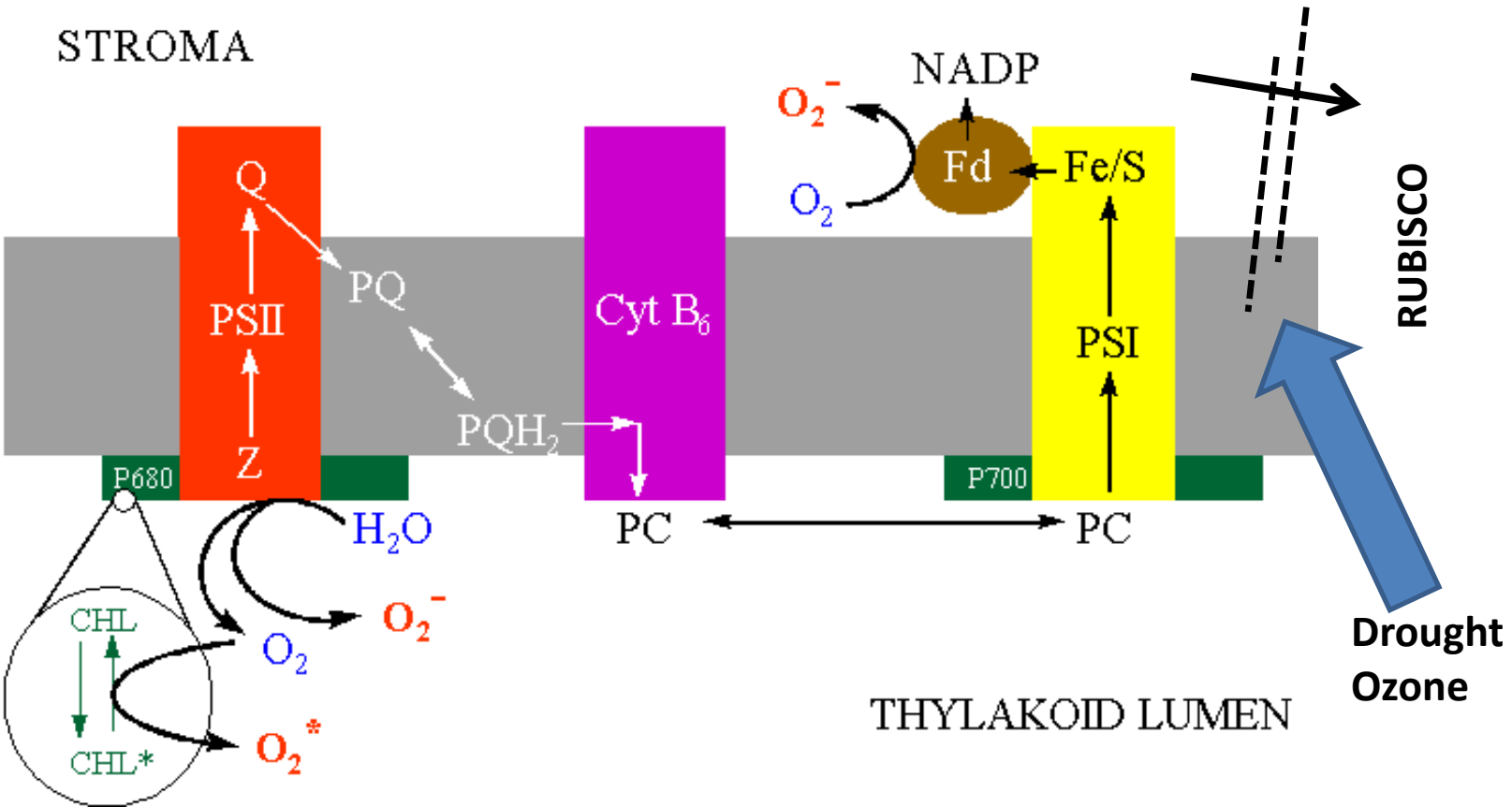
Carbon isotope discrimination is considered as a proxy for the intrinsic, time integrated, water-use efficiency.

Response of tree-level to drought



Another consequence of drought stress is the increase of oxidative pressure, especially under high light conditions (foliar bleaching).

Strong oxydative pressure occurs when high light feeds electron transport chain, but the CO_2 assimilation is blocked.



Urban trees for the future to cope with drought

A solution for future urban forestry is to use similar taxa, from more xeric environments but belonging to the same ecological series.

This option assures the ecological exchange and continuity with the surrounding rural areas, following the natural vegetational dynamics

From mesophilous plain forests ……
(*Quercus robur*, *Carpinus betulus*, *Fraxinus oxycarpa* etc.)

To xero-thermic forests ……
(*Quercus pubescens*, *Quercus cerris*, *Quercus ilex* etc.)

Excess of watering in urban trees:

- Increases mortality for anoxia in young trees;
- Induces root rot parasites;
- Nourishes the stomatal uptake of pollutants;
- Alters foliar physiology and reduces the defences against abiotic stress.

Drought /water stress are also consequence of the physical conditions of urban soils

URBAN SOILS CHARACTERISTICS:

- Often waterproofed;
- Often exogenous and artificial;
- Lack Physical structure;
- Lack of organic matter;
- Lack of nutrients and nutrient cycle;
- Lack of microbiological fertility.

Salinity

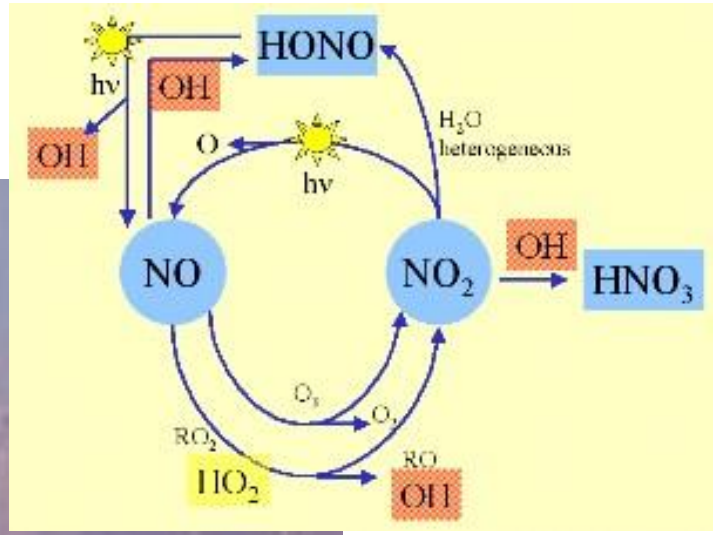
- Salinity is a problem due to the use of de-icing salt in Nordic cities.
- In Mediterranean regions, salinity may be due to pumping groundwater for civic uses.

- The use of saline water for watering is an option taken into consideration, but poses problems.

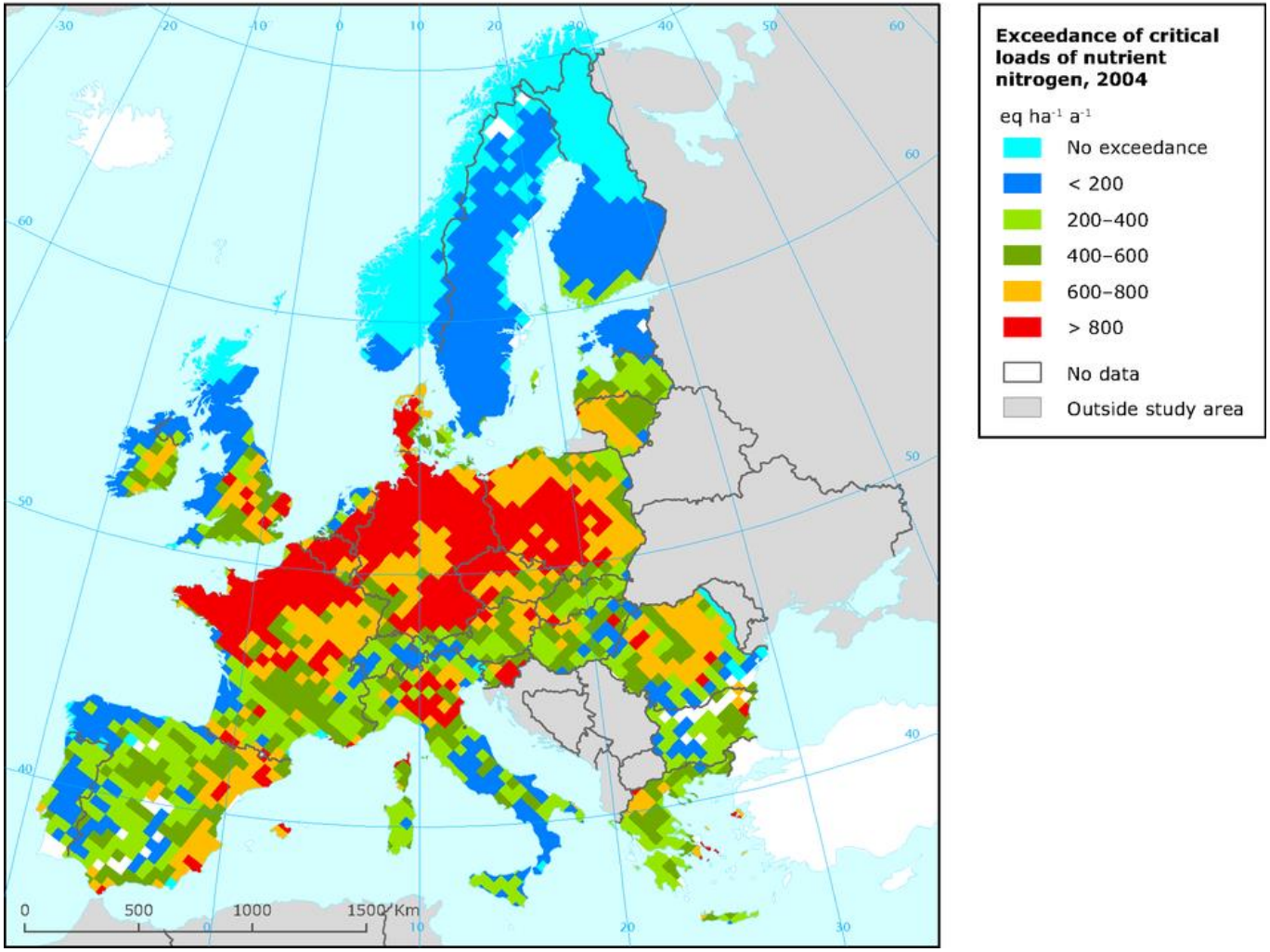
Exhaust gases from traffic can affect directly tree health

Traffic pollution produces nitrogen oxides and photochemical smog.

This effect is extended outside the urban areas.



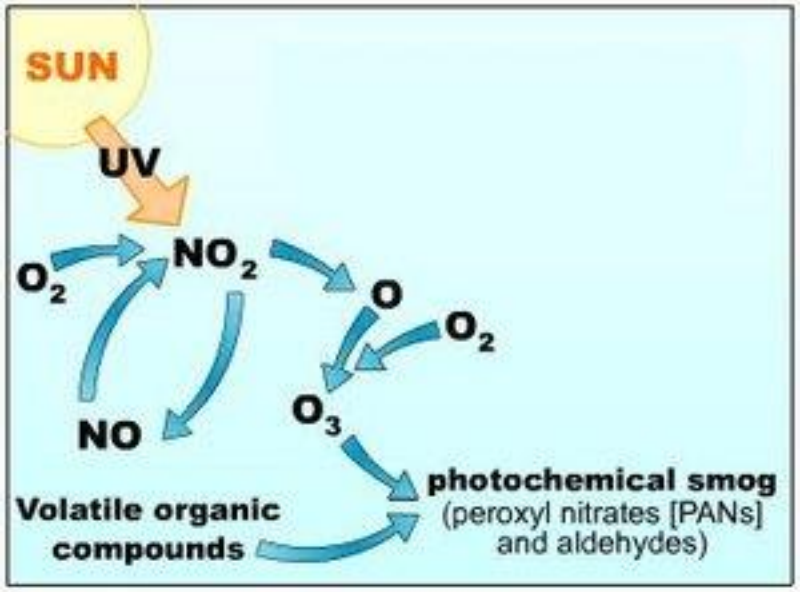
Nitrogen a widespread pollutant in European forests



Excess of nitrogen inputs in the atmosphere increases the production of proteins and plasmatic compounds.

Nitrogen enhances the growth but reduces mechanical defences.

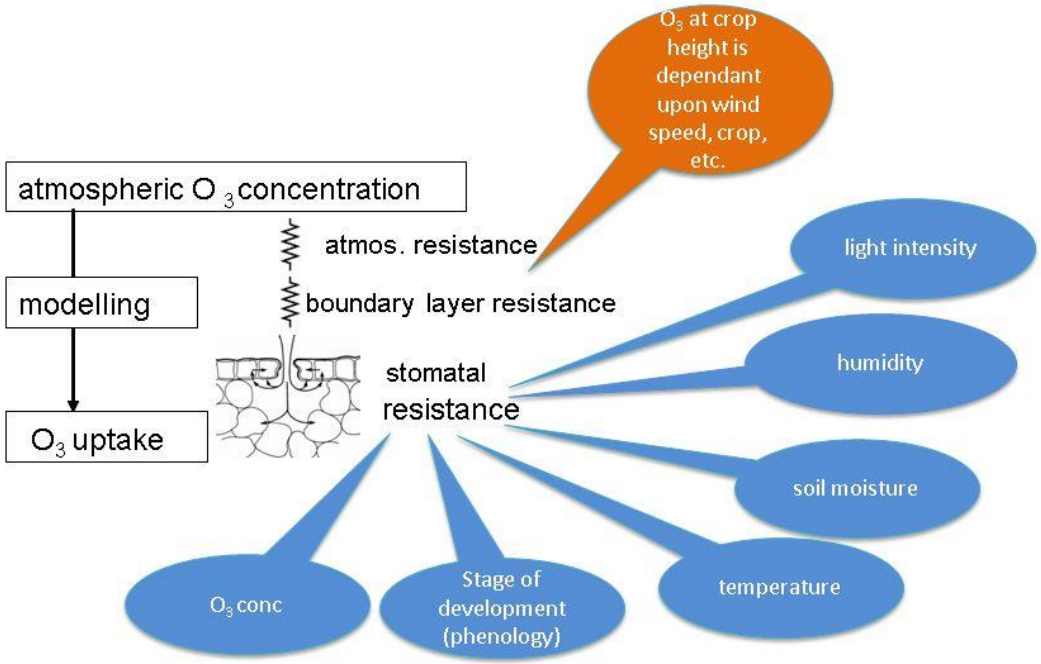
Trees subjected to nitrogen deposition are more vulnerable to parasites and climatic stress.

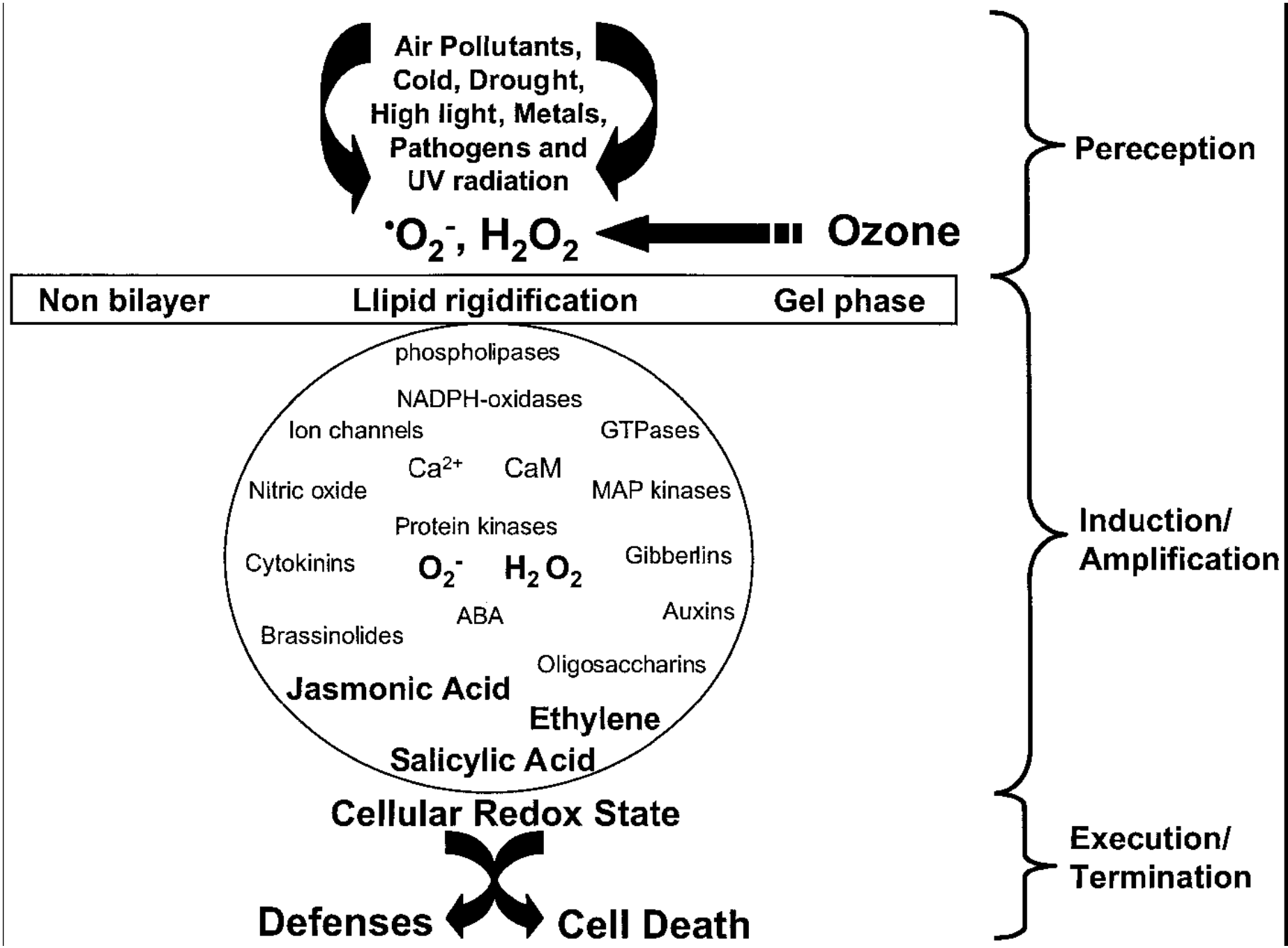


FORMATION OF PHOTOCHEMICAL SMOG

FROM OXIDE NITROGEN TO OZONE

Trees absorb ozone when stomata are open (i.e., without water stress)




Air Pollutants,
Cold, Drought,
High light, Metals,
Pathogens and
UV radiation
$^{\bullet}O_2^-$, H_2O_2
Ozone
Pereception
Non bilayer
Llipid rigidification
Gel phase
phospholipases
NADPH-oxidases
Ion channels
GTPases
Ca^{2+}
CaM
Nitric oxide
MAP kinases
Protein kinases
Cytokinins
O_2^-
H_2O_2
Gibberlins
ABA
Auxins
Brassinolides
Oligosaccharins
Jasmonic Acid
Ethylene
Salicylic Acid
Induction/
Amplification
Cellular Redox State
Defenses
Cell Death
Execution/
Termination

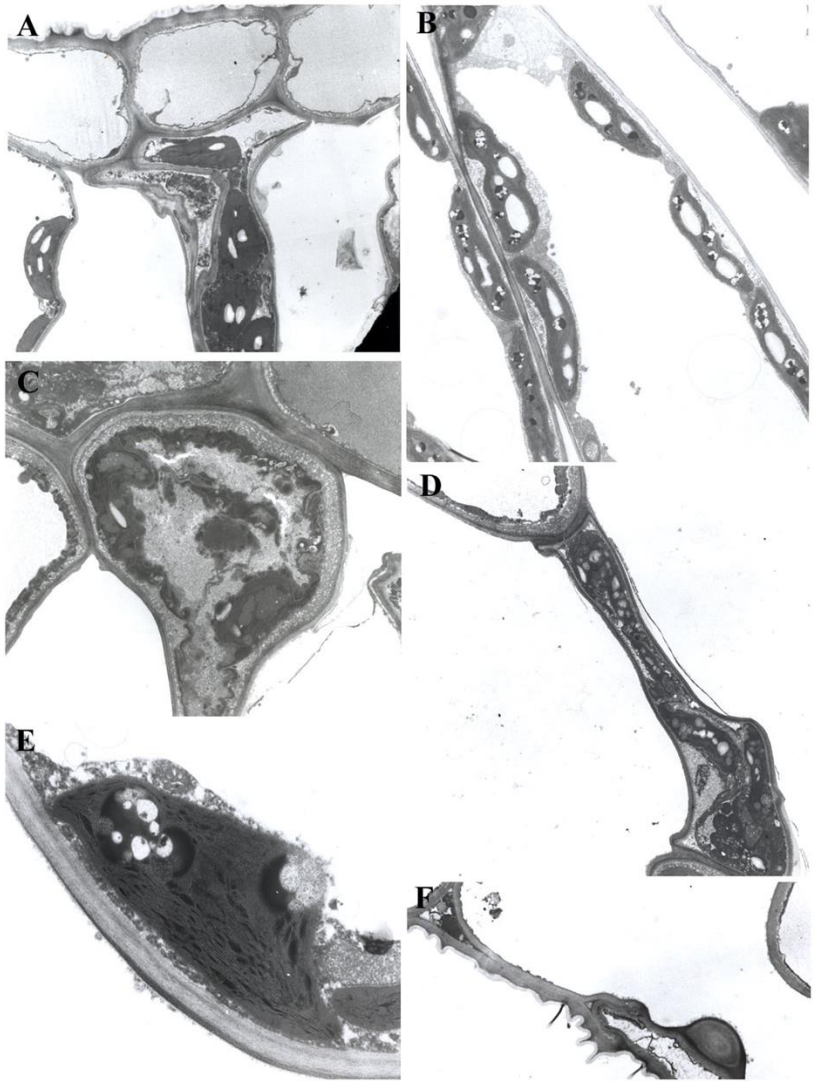

Acer pseudoplatanus

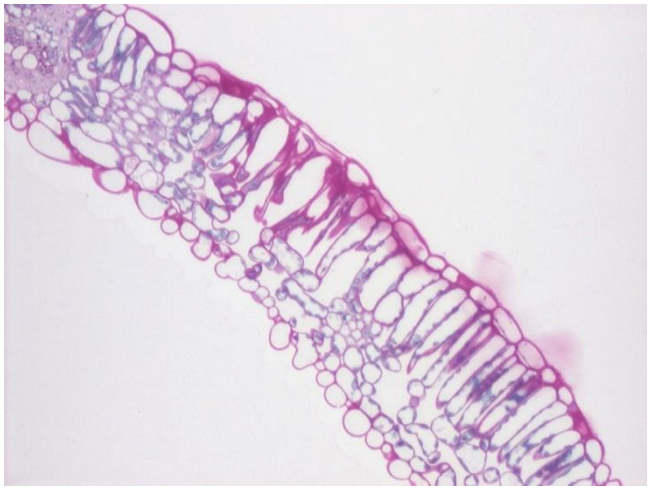

Fraxinus excelsior

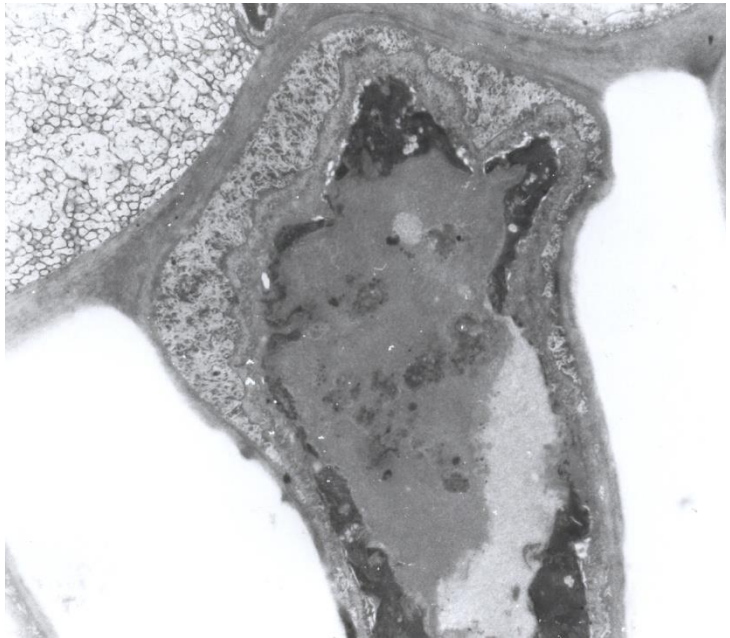

Ailanthus altissima


Sambucus nigra

Symptoms consist in necrosis produced by the collapse of the upper mesophyll cells.





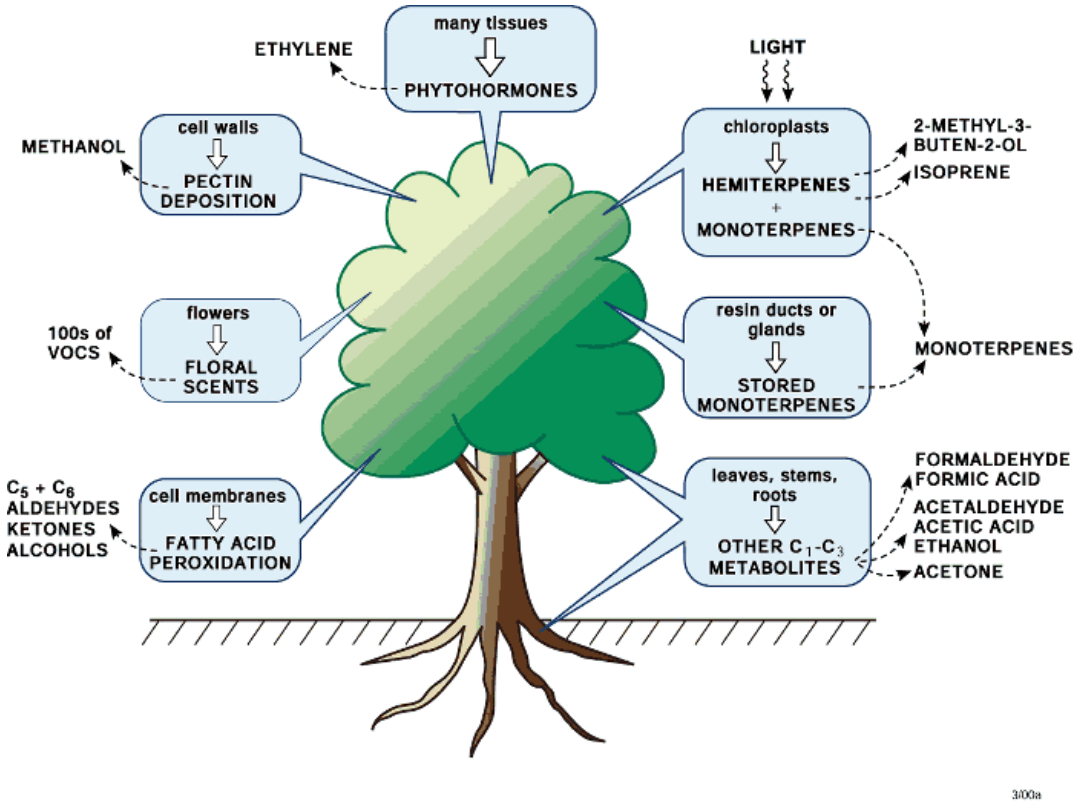


Ozone reduces photosynthesis by:

1. Mesophyll limitation (Rubisco inactivation);
2. Stomatal limitation (stomatal closure).

Tree growth and carbon sequestration are reduced by ozone.

VOCs EMISSION BY TREES



Trees produce large amount of different volatile compounds, that play several roles and functions.

Under high sunlight conditions VOCs react with nitrogen oxides so enhancing the production of ozone.
In cloudy conditions, VOCs induces the formation of condensation nuclei (CCN).

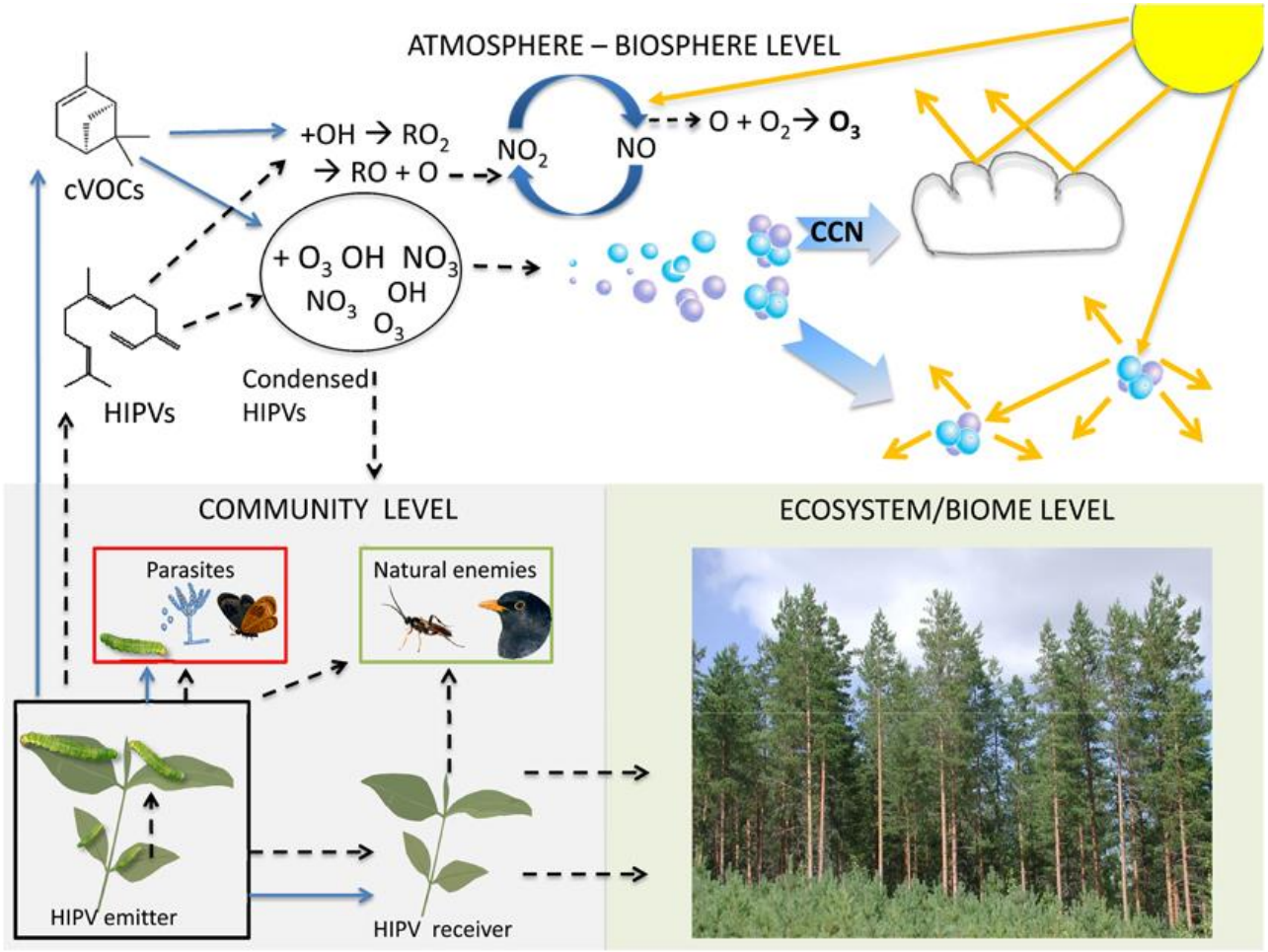


Table 1
Main tree species of Italian vegetation listed from the most to the less abundant in terms of coverage in natural ecosystems (excluding plantations; from Lenz et al., 2001) with their emission trait (adapted from Steinbrecher et al., in press). Emission rates for the different species are listed as:

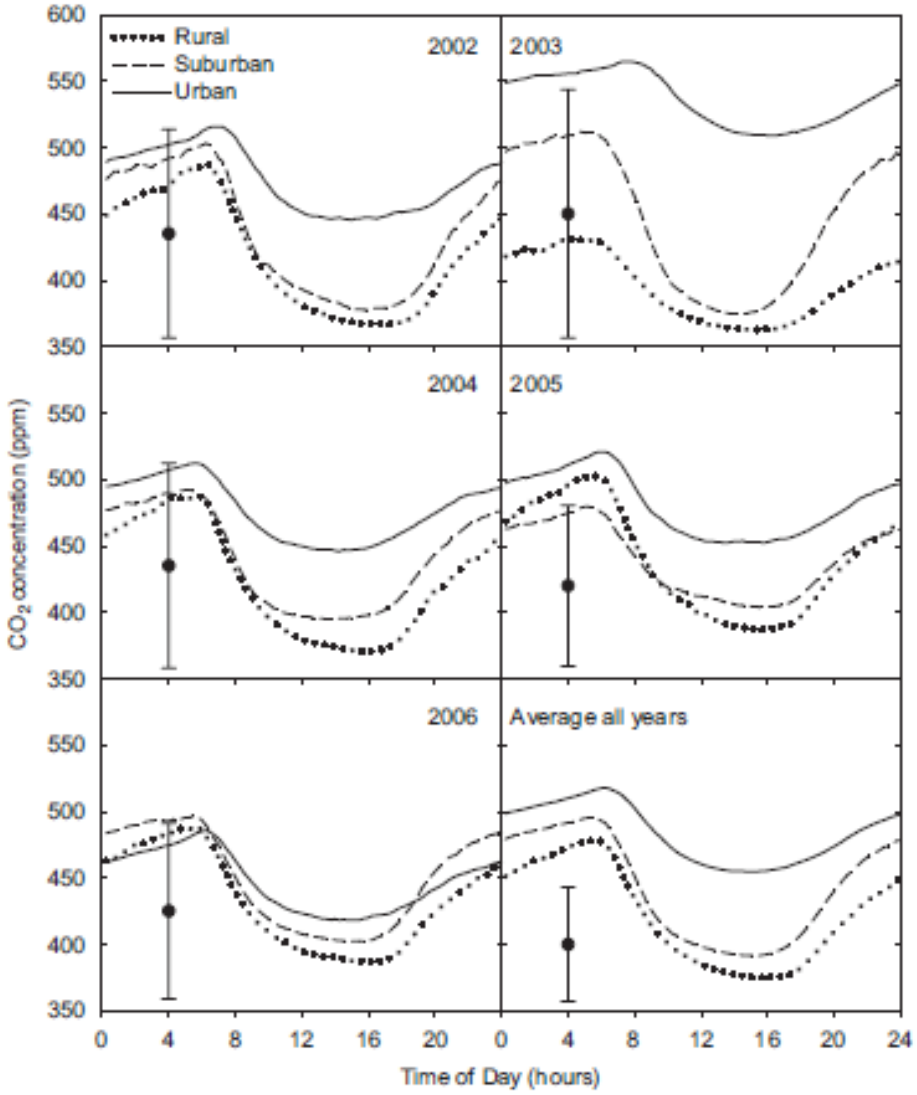
Species	Isoprene emission	Monoterpene emission	Approximate abundance in Italy (%)
Fagus sylvatica		High	18
Quercus pubescens	High	Low	13
Quercus cerris		Low	11
Castanea sativa		Medium	8
Picea abies	Low	Low	6
Larix decidua		Medium	5
Ostrya carpinifolia			4
Pinus nigra		Medium	3
Quercus ilex		High	3
Pinus sylvestris		Medium	3
Quercus petraea	High	Low	2
Abies alba	Low	Low	1
Alnus cordata		Low	1
Acer platanoides		Low	1
Robinia pseudoacacia[a]	Medium		<1
Fraxinus sp.			<1
Pinus pinea[a]		Medium	<1
Quercus robur	High	Low	<1
Pinus halepensis		Low	<1
Pinus pinaster		Low	<1
Cupressus sempervirens		Low	<1
Quercus suber	Low	Medium	<1
Betula pendula		Low	<1
Salix sp.[a]	High	Low	<1
Populus sp.[a]	High		<1
Carpinus betulus		Low	<1
Tilia cordata			<1
Eucalyptus sp.[a]	High	Medium	<1
Mediterranean macchia[b]		Low	N/A

Calfapietra et al., 2009

Atmospheric nteractions in the urban environment:

- NOx pollution reduces the formation of ozone in urban areas;
- Drought, high solar radiation and temperatures (expected from CC processes) enhance the production of VOCs from urban trees;
- VOCs elicit the production of ozone under high NOx pollution.

CARBON DIOXIDE (CO_2)



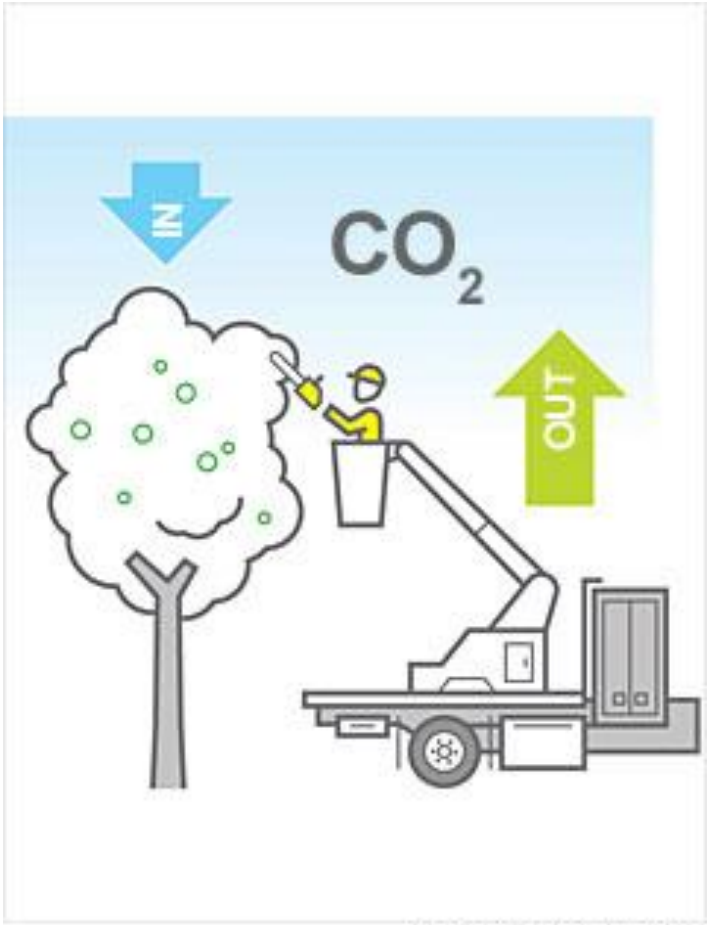
Urban concentrations of CO_2 are higher than in the surrounding rural areas

Da: George et al., 2006

Effects of CO_2 on trees

-Reduced density and size of stomata ;
-More efficient utilization of the light in carbon reduction processes, and lowered production of Reactive Oxygen Substances (ROS);
-Reduction of oxidative stress impacts;
-Enhanced growth.

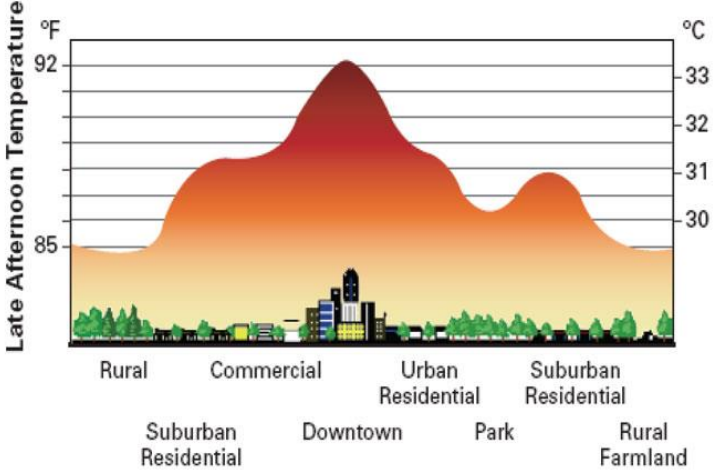
Urban trees are considered to be carbon sink (CC mitigation), but this function is affected by maintenance operations

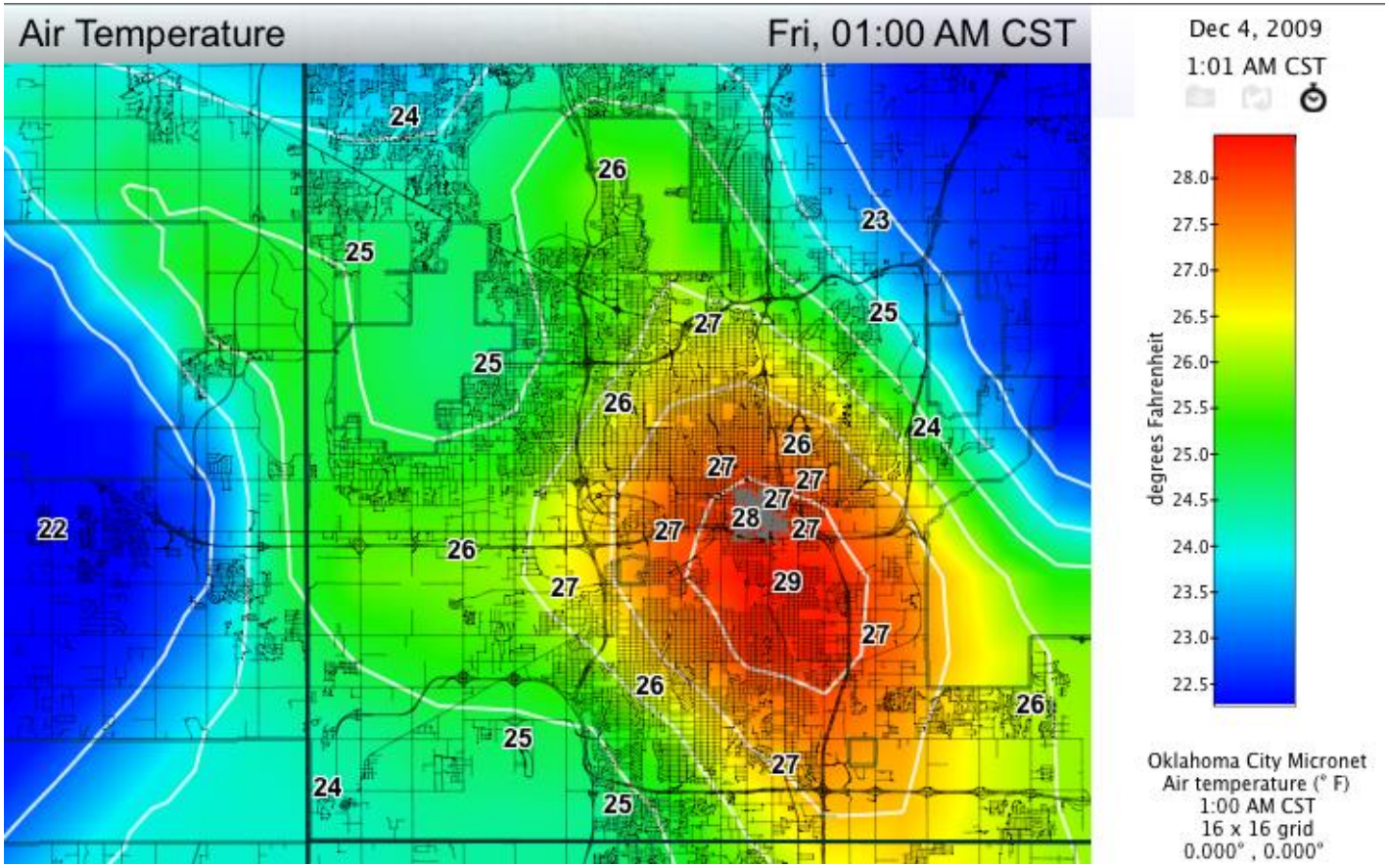


Carbon store relies on living biomass, soil, deadwood and biological cycles.

Managing urban forests as natural systems increases their effectiveness in climate change mitigation.

TEMPERATURE



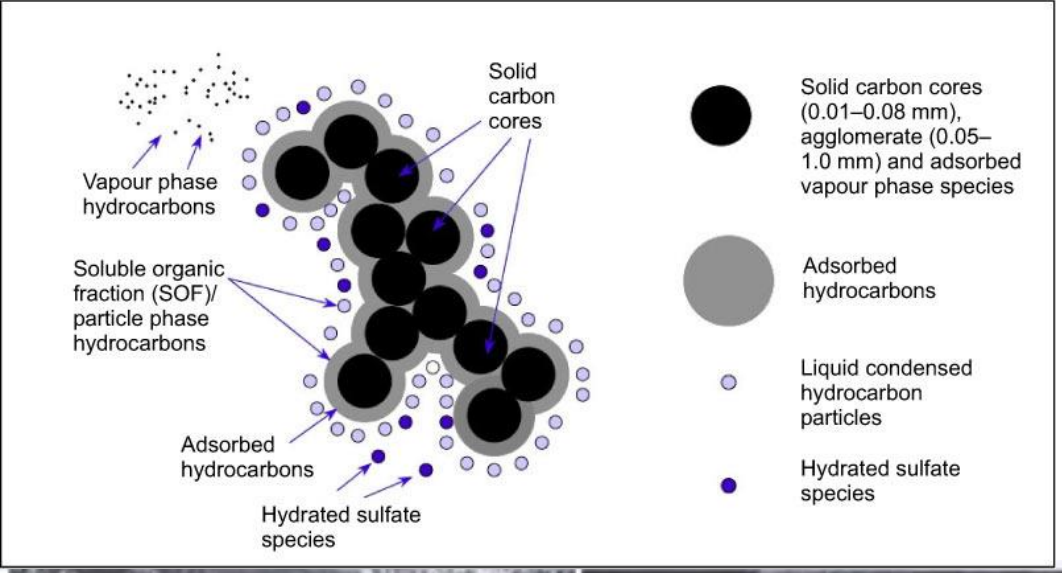


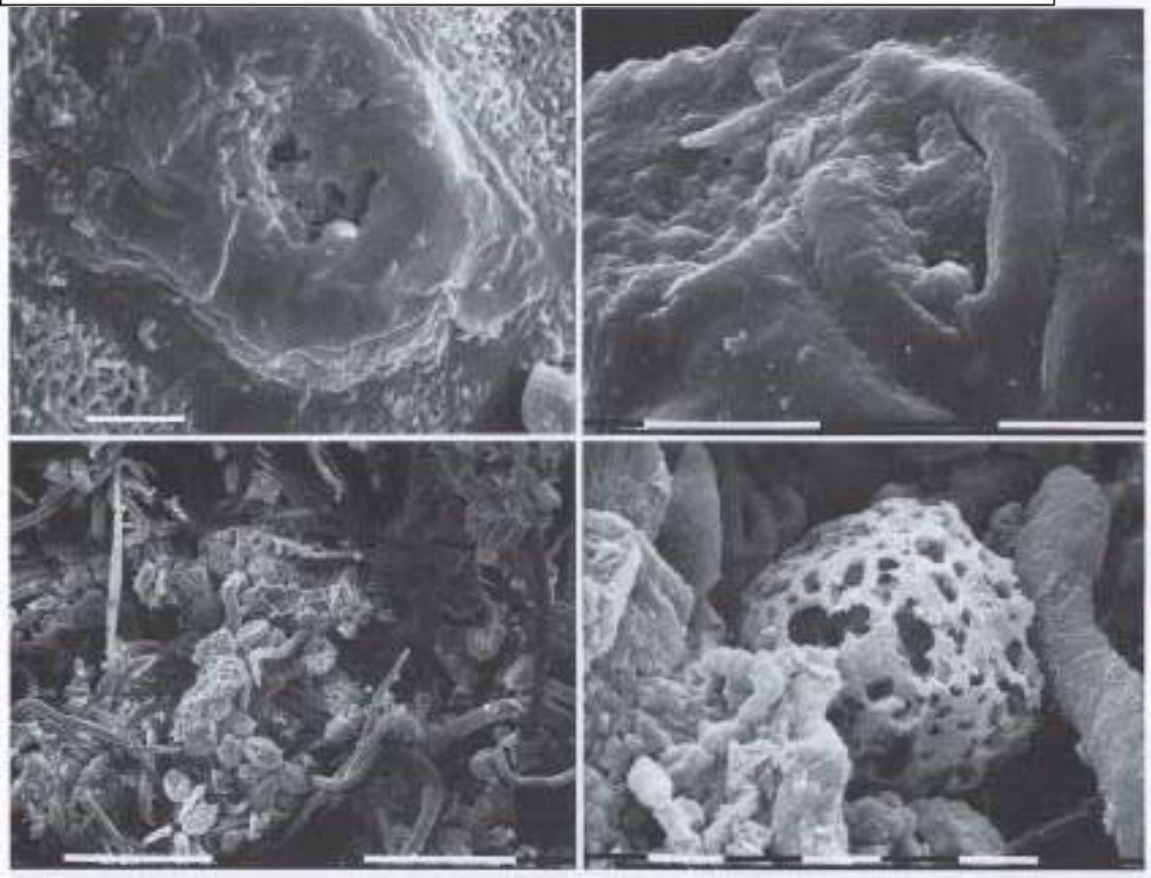
Higher temperatures, alongside with higher CO_2 concentration and water availability can enhance the photosynthetic function and the growth, but ….

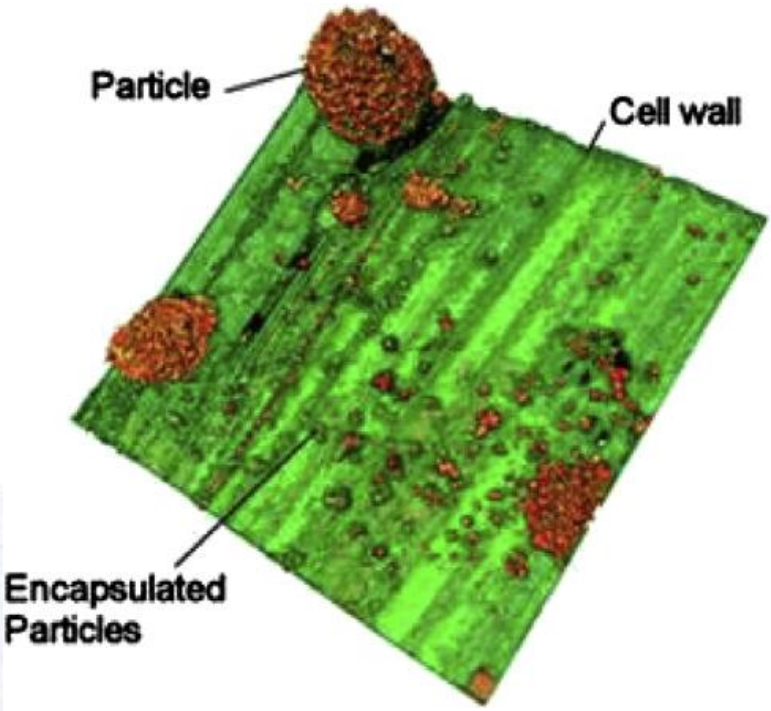
In the Mediterranean region the needs of temperature are already satured, and increasing temperatures don't stimulate photosynthesis and growth but respiration.

Increasing nighttime temperatures enhance dark respiration processes with loss of productivity and emission of CO_2.

Particulate matter (PM)







There are several mechanisms with which PM is trapped by leaf surfaces.

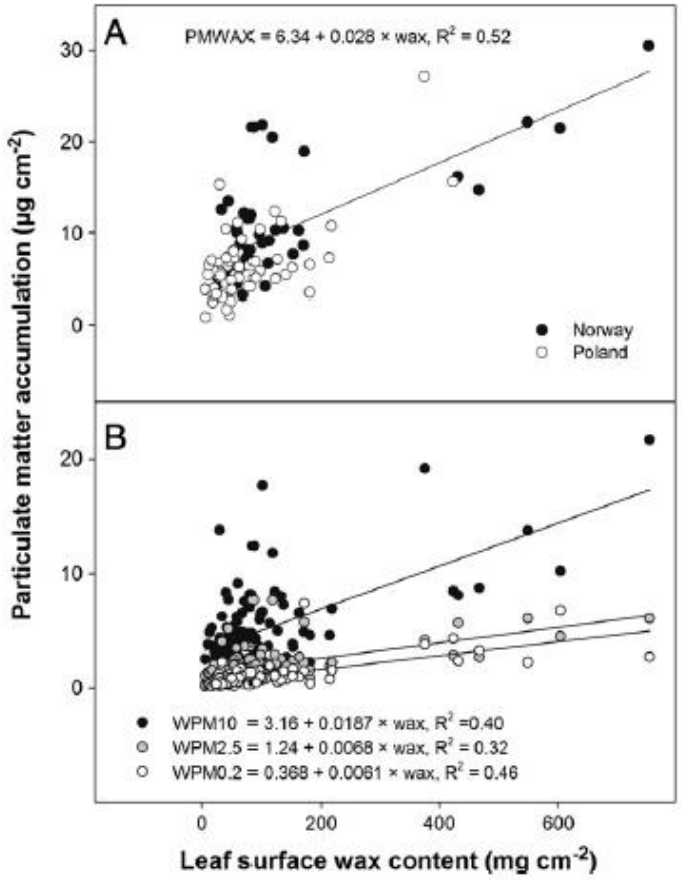
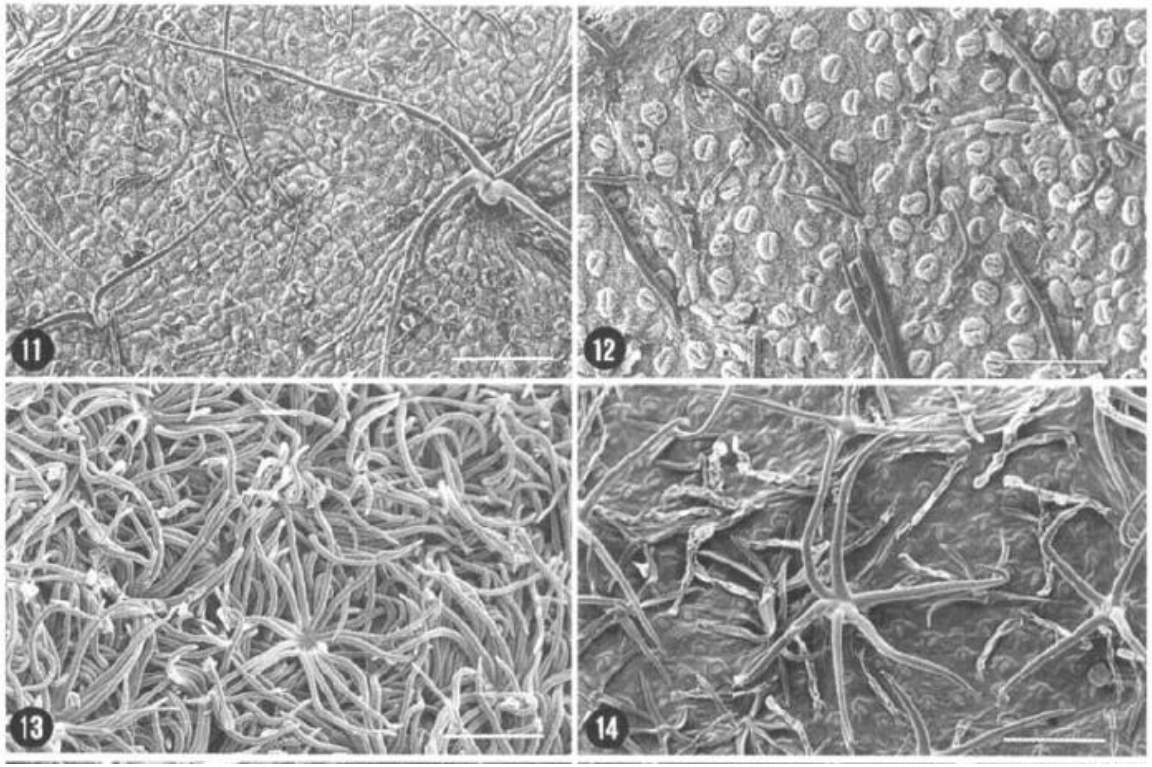


Fig. 4. Relationship between leaf surface wax content and accumulation of particulate matter in the wax layer. A) Accumulation of total PM in samples collected in Norway and Poland. B) Accumulation of different PM fractions in relation to wax content. The linear regression of wax content on PM accumulation is also shown. Significances of linear regression models are all <0.001.



The ability to trap PM depend from the amount of waxes

The features of leaf surface may be determinant to trap PM

How PM affects tree physiology?

- PM alter the stomatal functioning and transpiration become uncontrolled (trees are more sensitive to drought stress);
- According to its chemical nature, PM can act as dessiccant, or even as souce of nutrients;
- PM deposited on leaf surface act as screen against sun radiation.

Analyzing physiological conditions of urban trees

In urban environment tree crown are accessible by forklift.

1 - Indicators at *foliar level* → Functional leaf traits → Which functional significance?

Morphological traits

Morphological trait	Acronym	Unit
Direct measurements		
Leaf Area	LA	cm^2
Fresh weight	FW	mg
Satured weight	SW	mg
Dry weight	DW	mg
Leaf Thickness	LT	µm
Palizade Mesophyll Thickness	Pal	µm
Spongy Mesophyll Thickness	Spo	µm
Lenght of the lamina	LL	mm
Width of the lamina	LW	mm
Max width left part of the lamina	WL	mm
Max width right part of the lamina	WR	mm
Lenght of petiole	LP	mm
Stomatal Density	SD	stomata mm^{-2}
Fresh weight	FW	mg
Satured weight	SW	mg
Dry weight	DW	mg
Ratios		
Water Content $WC=\left[(FW-DW)/DW\right]100$	WC	%
Relative Water Content $RWC=\left[(FW-DW)/(SW-DW)\right]100$	RWC	%
Leaf Mass per Area $LMA=DW/LA$	LMA	mg cm^{-2}
Specific Leaf Area $SLA=LA/DW$	SLA	cm^2 mg^{-1}
Palizade/Spongy tissues ratio Pal/Spo	Pal/Spo	
Dry Matter Concentration $DCM=DW/(LA\times LT)$	DMC	mg cm^{-3}
Fluctuant Asymmetry $FA=2\times\lvert WL-WR\rvert/(WL+WR))$	FA	

Leaf chemical traits

Chemical trait	Acronym	Unit
Carbon and macroelements		
Carbon	C	%
Nitrogen	N	mg g^{-1}, %
Sulphur	S	mg g^{-1}
Calcium	Ca	mg g^{-1}
Magnesium	Mg	mg g^{-1}
Phosphorus	P	mg g^{-1}
Potassium	K	mg g^{-1}
Iron	Fe	mg g^{-1}
Ratios		
Nitrogen content per leaf area	N_{LA}	
Nitrogen/carbon ratio	N/C	
Nitrogen/potassium ratio	N/K	
Nitrogen/phosphorus ratio	N/P	
Nitrogen/calcium ratio	N/Ca	
Nitrogen/magnesium ratio	N/Mg	
Potassium/calcium ratio	K/Ca	
Magnesium/calcium ratio	Mg/Ca	
Microelements and heavy metals		
Zinc	Zn	mg Kg^{-1}
Copper	Cu	mg Kg^{-1}
Aluminum	Al	mg Kg^{-1}
Boron	B	mg Kg^{-1}
Lead	Pb	mg Kg^{-1}
Cadmium	Cd	mg Kg^{-1}
Mercury	Hg	mg Kg^{-1}
Arsenic	As	mg Kg^{-1}
Sodium	Na	mg Kg^{-1}
Chlorine	Cl	mg Kg^{-1}
Stable isotopes		
$^{13}C/^{12}C$	$\delta^{13}C$	‰
$^{18}O/^{16}O$	$\delta^{18}O$	‰
$^{15}N/^{14}N$	$\delta^{15}N$	‰

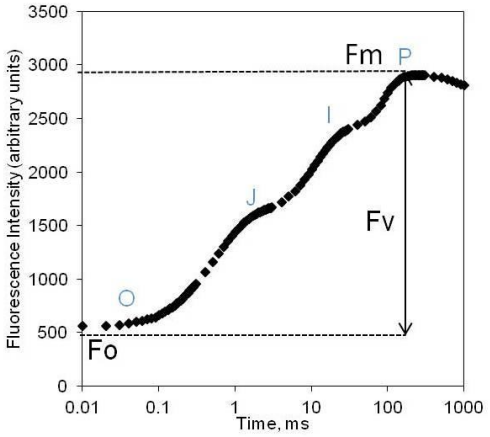
Leaf physiological traits

- Chlorophyll fluorescence

Red light excitation impulse

PocketPEA fluorimeter

- Chlorophyll content index



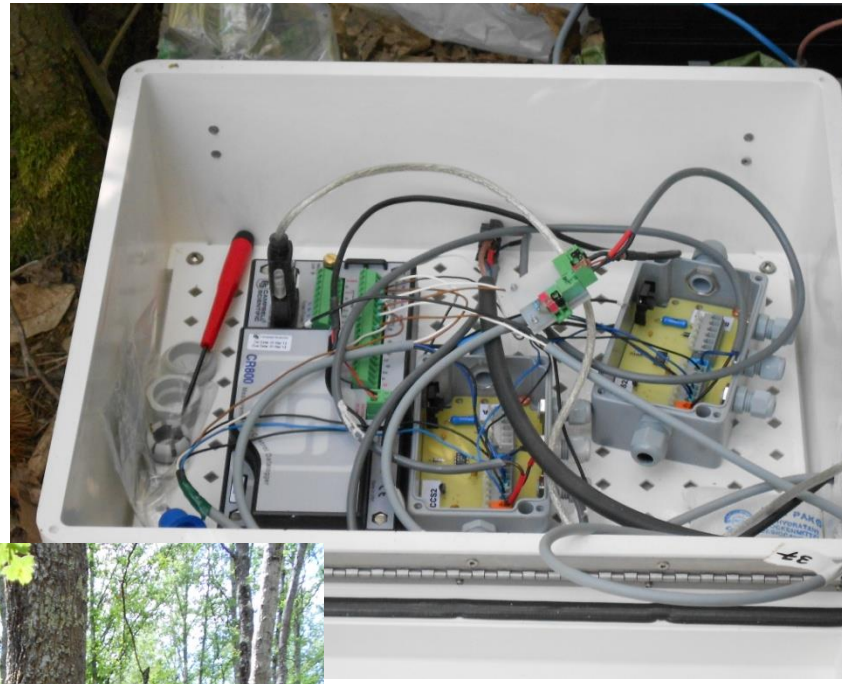
- Epidermal polyphenols

on fresh leaves with optical portable devices (not destructive measurements)

Chlorophyll fluorescence measurements needs of dark adaptation of the samples.

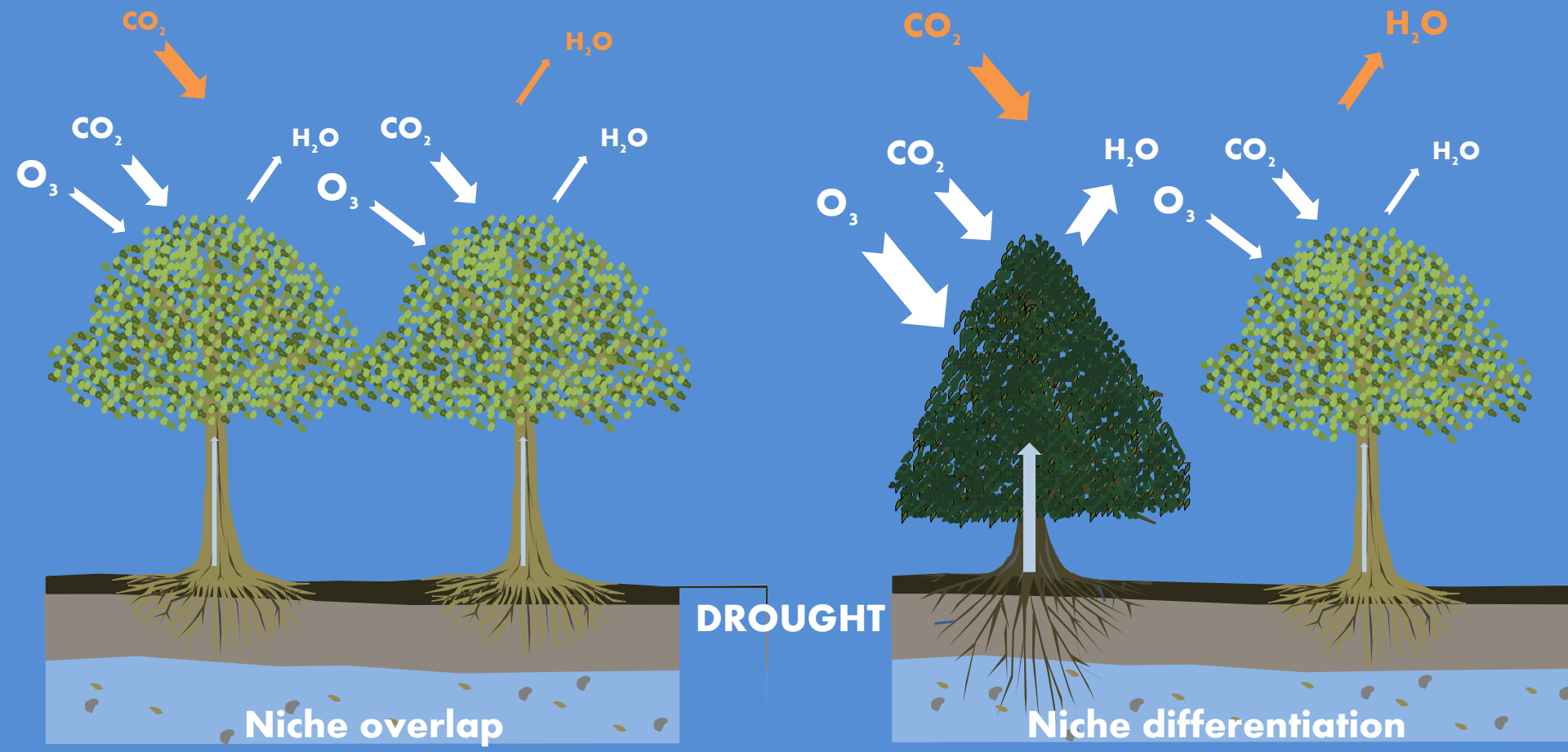
Water status can be measured by Scholander chamber on detached leaves.

Water consumption can be assessed directly by sap flow measurement.



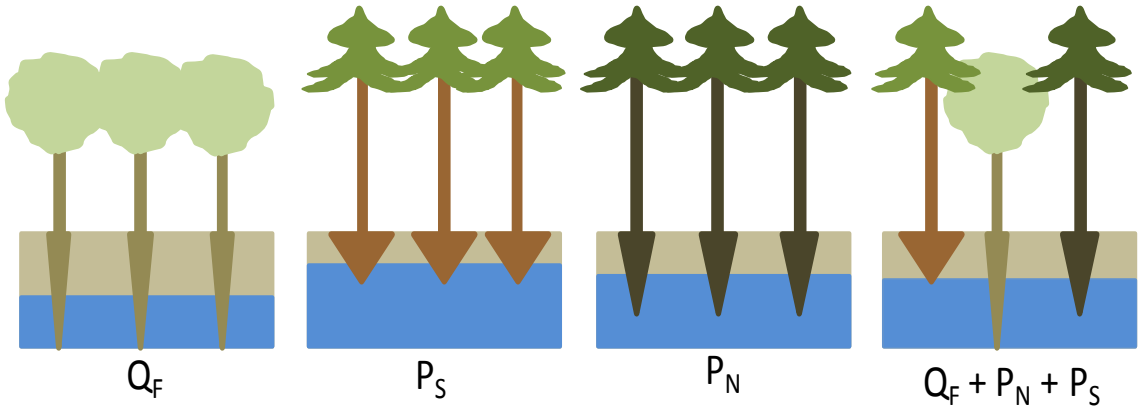
PHYSIOLOGICAL AND FUNCTIONAL INTERACTION, AND ECOSYSTEM SERVICES

Influence of tree diversity on the response of ecosystem-level gas exchange in drought condition



WUE_{ECO} +++

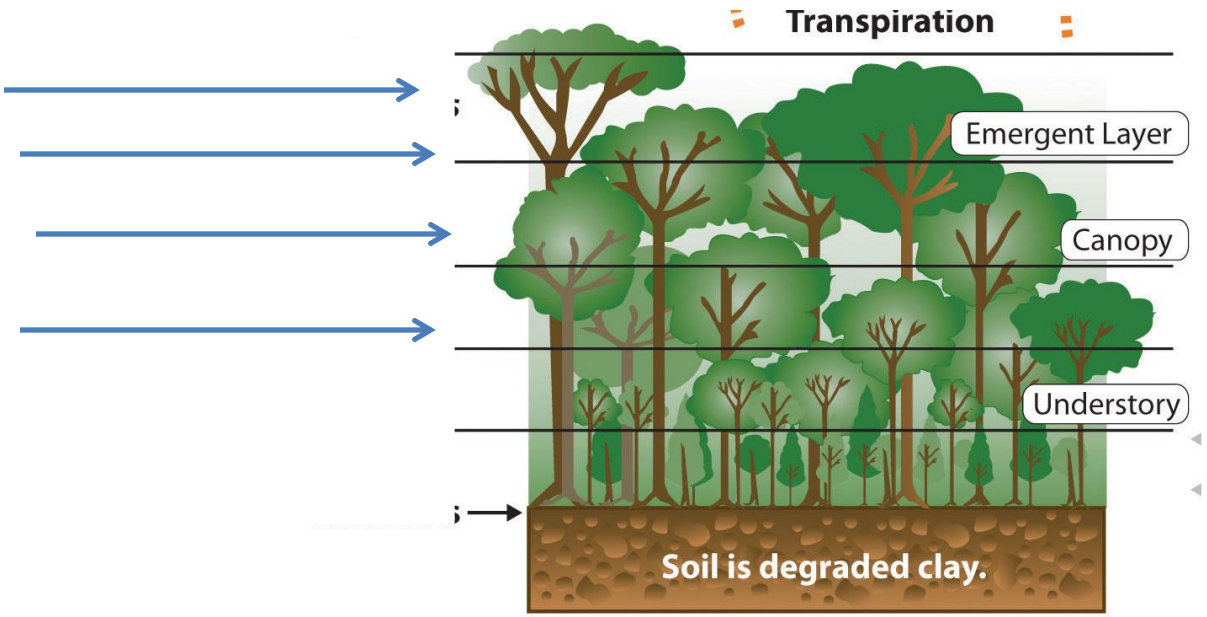
WUE_{ECO} +



Stabilizing WUE and stomatal functioning at stand level is crucial for the provision of Ecosystem Services as:

- Carbon sequestration in dry periods;
- Air cooling and climate regulation;
- Air cleaning and pollutants uptake.

A multilayered forest structure, with high Leaf Area Index and wood surfaces having different characteristics, has a greater capacity to inactivate ozone (non stomatal deposition) and trap particulate matter. Trees must have different shade tolerance.



Functional traits involved in the “air cleaning” ecosystem service.

Root depth
Stomatal behaviour
Stomatal conductance
Photosynthetic rates
Photosynthetic efficiency
Shade tolerance
Phenology

Leaf Area Index
Crown width
Branching
Leaf size
Leaf hairness
Epicuticular waxes
Bark roughness

Conclusions/1

- Environmental pressures in urban forests have local origin, but the effects can be extended to peri-urban and remote environments.
- There are no a specific stress factor for urban trees, but climate change effects can be anticipated in urban areas.
- Climate change is expected to exacerbated stress conditions and enhance the photochemical reactions between NOx – VOCs – O3.

Conclusions/2

- Trade-off effects can be described for ecosystem services exerted by urban trees: trees clean the atmosphere by absorbing ozone and other pollutants, but this ability is reduced by the ozone itself.
- An adequate combination of physiological and morphological characteristics (functional traits) enhance the capacity to deliver ecosystem services.

Thanks for attention!

TreeCity

An International Project for a Better Quality of Life in Our Cities

Sponsored by MIUR PRIN