Urban trees - Effective solutions to reduce increasing ozone levels in cities

P. Sicard (ARGANS, France)
E. Agathokleous (Institute of Ecology, School of Applied Meteorology, China)
V. Araminiene (Lithuanian Research Centre for Agriculture and Forestry, Lithuania)
E. Carrari, Y. Hoshika, E. Paoletti (IRET-CNR, Italy)
A. De Marco (ENEA, Italy)

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Context

- 2050: 70% of the world population will live in cities.

- ± 200 classes of air pollutants.

- Outdoor air pollution = 8 million deaths worldwide per year (WHO, 2019).

- O_3 & PM = most threatening air pollutants in cities for human health.

Context

Ozone pollution is increasing in cities

- 319 urban & 306 rural stations, 35 countries.
- 1995-2014: **+ 0.16 ppb year^{-1}** on av. at 89% of urban stations.
- Lower O_3 titration by NO.
- Exceed target values for human health & vegetation protection.

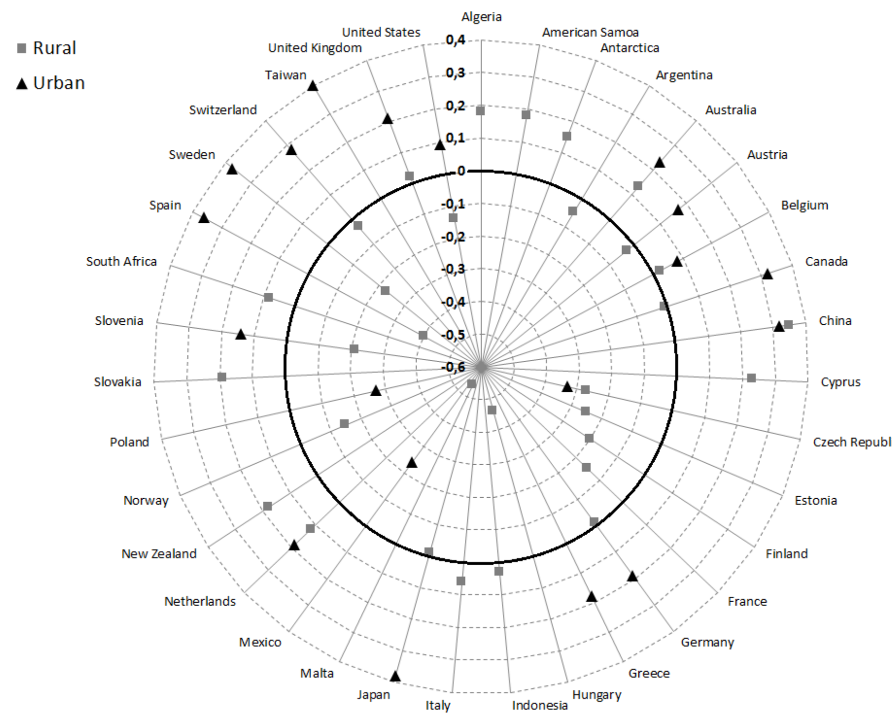


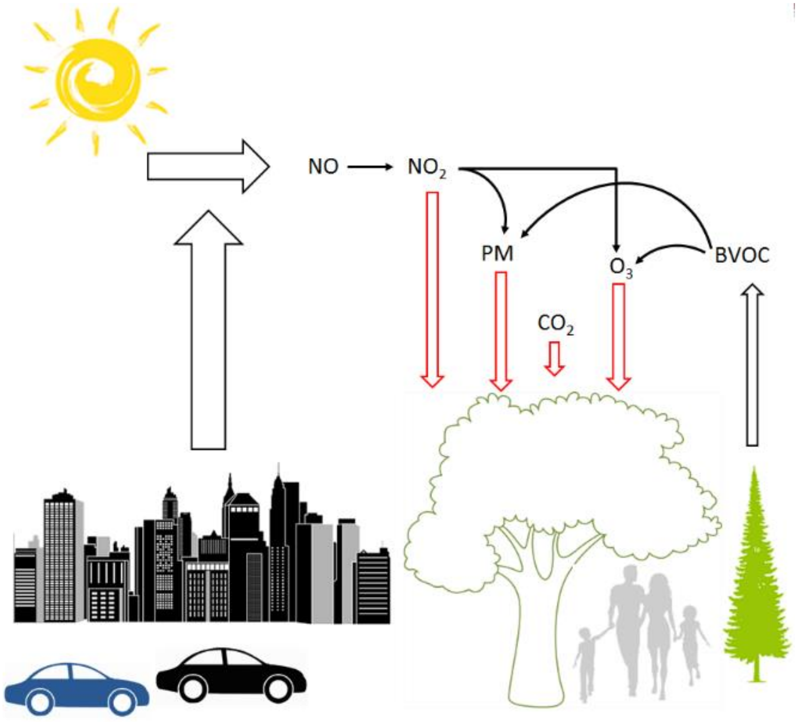
Fig. 1: Country-averaged trend (ppb per year) over the time period 1995-2014.

Background

The urban vegetation can:

- **Reduce air pollution**: deposition of PM & gases on plant surfaces & **absorbs gaseous air pollutants** through stomata & regulates transport of pollutants.
- *Sequester carbon,*
- *Regulate air temperature,*
- *Mitigate storm-water runoff,*
- *Reduce noise,*
- *Provide recreational & aesthetic benefits,*

etc…



Urban trees can improve air quality by removing O_3: provide a list of suitable trees species for municipalities.

Objectives

Extensive literature review: 150 peer-reviewed articles & technical reports over the time period 1990-2017.

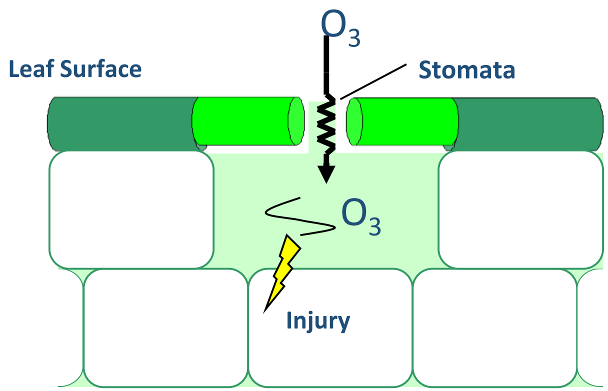
To:

- **Quantify O_3 removal** by urban vegetation: trees/shrubs & green roofs.
- Rank **95 plant species** based on the ability to maximize air quality & minimize disservices.

- Provide **novel insights** on the management of urban green spaces.

Quantification of O_3 removal capacity

- Passive samplers inside/outside canopy & **dry deposition models.**



- **UFORE** Urban FORest Effects & **i-Tree** model: **downward O_3 flux** (stomatal & non-stomatal).

$$F = V_d \cdot [O_3]$$ (F in g m^{-2} s^{-1})

where $[O_3]$ is the hourly O_3 concentration (g m^{-3}) & V_d the dry deposition velocity (m s^{-1}) i.e. inverse of the sum of the aerodynamic resistance, quasi-laminar boundary layer resistance & canopy resistance (s m^{-1})

- *F* is adjusted according to **local parameters** e.g. leaf-on & leaf-off dates.

- A module quantifies O_3 formation based on BVOCs emission.

- To consider concentration differences among cities - O_3 removal rates were **standardized** to the mean O_3 concentration in the city (g m^{-2} per ppb).

Ozone removal by green roofs

- Roofs can represent **20-30%** of the surface built-up areas: opportunity to be implemented on a large scale.

Tab. 1 - Standardized removal rate (g m^{-2} per ppb) & annual total O_3 removal (tons) for several cities using dry deposition models.

Green roofs area (ha)	Location	Year	Ozone conc. (ppb)	O_3 removal rate (g m^{-2} year^{-1})	Standardized O_3 removal rate (g m^{-2} per ppb)	Annual O_3 removal (tons year^{-1})	Reference
109	Toronto, CA	2002	22.6	2.9	0.13	3.14	Currie and Bass, 2008
201.6	Washington, US	2002	28.3	3.0	0.11	6.00	Deutsch et al., 2005
19.8	Chicago, US	08.2006 - 07.2007	19.0	4.4	0.23	0.88	Yang et al., 2008
28.9	Melbourne, AU	2013	15.9	1.2	0.07	0.36	Jayasooriya et al., 2017

- For instance, Toronto: 109 ha of green roofs removed **3.1 tons of O_3**.

- The annual standardized O_3 removal rates: **0.07 to 0.23 g m^{-2}** per ppb of O_3.

Ozone removal by urban forests

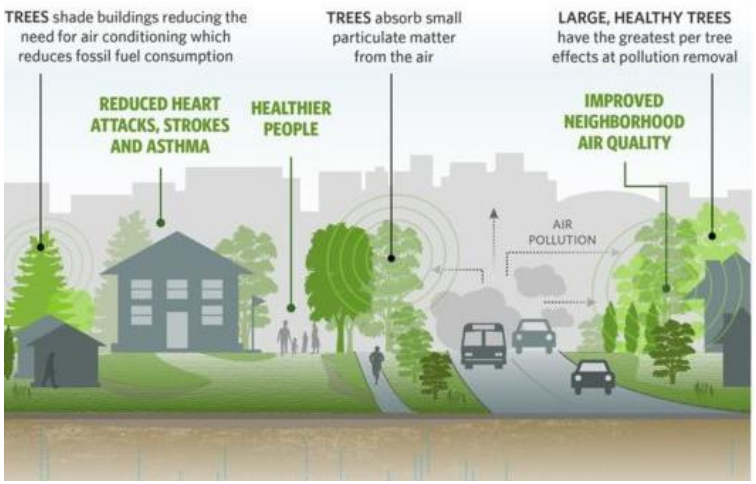
Tab. 2: Average annual O_3 removal rate, **standardized removal rate** to the mean O_3 concentration and annual total O_3 removal as well as the average **percent O_3 improvement in hourly concentrations** for several cities using dry deposition models.

Public trees, i.e. trees managed by the municipalities, removed e.g. **135-1179t of O_3** in 15 most populated cities in Canada in 2010.

Standardized removal rate (g m^{-2} per ppb)	Annual removal (tons)	O_3 reduction (%)	Reference
0.11	191		McPherson et al., 1994
	Total: 305,100 (8-5210)	< 1.00	Nowak et al., 2006
0.21	*514*	0.70	
0.18	*158*		
0.18	*101*	0.60	
0.24	*1160*	0.60	
0.10	*213*	0.30	
0.21	*5210*		
0.38	*1260*		
0.22	*104*		
0.21	*491*	0.40	
0.16	*289*		
0.13	*406*	0.80	
0.30	*549*	0.30	
0.23	*80*		
0.21	*252*	0.10	
0.16	*192*	0.60	
0.21	514		Nowak and Crane, 2000
0.19	180		
0.21	506	0.45	
	Total: 2296 (9-672)	0.61	Nowak and Dwyer, 2007
0.18	*672*		
0.19	*223*		
0.20	*108*		
0.21	*9*		
0.14	*13*		
0.19	*43*		
0.10	*26*		
0.19	*536*		
0.18	*185*		
0.20	*47*		
0.18	*161*		
0.16	*55*		

Ozone removal by urban forests

- The O_3 removal capacity of trees & shrubs: **3.4 g m^{-2} $year^{-1}$** on av.
- At city scale, the O_3 removal depends on local conditions (e.g. O_3 conc., meteo, phenology, forest cover).
- The mean annual **improvement is < 2% of O_3 levels.**



- The effects on O_3 removal are linked to **meteorological-dependent plant features** e.g. stomatal conductance, LAI, length of growing season…
- The optimal O_3 removal = **daytime & April-September** (± 80% of annual O_3 removal) during the **in-leaf season** due to greater LAI & higher O_3 concentrations.

Ozone removal by tree species

Tab. 3 – Average O_3 removal rate, **standardized removal rate** for several tree species using dry deposition model (stomatal + non stomatal O_3 deposition, S + NS), sap flow measurements or stomatal conductance measurements (stomatal O_3 uptake, S).

Top rated tree species to reduce O_3 pollution are**:**

Magnolia liliflora: 0.218 x 10^{-2} g m^{-2} per ppb of O_3
Aesculus chinensis: 0.182
Ginkgo biloba: 0.141
Liquidambar sp.: 0.138
Fraxinus excelsior: 0.114

Picea abies, Quercus ilex and *Robinia pseudocacia* : **low rated species**

						Standardized removal rate (g m^{-2} per ppb) x 10^{-2}	Deposition
						0.054	S + NS
						0.100	S + NS
						0.093	S + NS
						0.037	S + NS
						0.027	S
						0.141	S
						0.088	S + NS
						0.147	S + NS
						0.100	S
						0.090	S + NS
						0.083	S + NS
						0.057	S + NS
						0.182	S
						0.058	S + NS
Acacia auriculaeformis	SH	Guangzhou, CN	2013	0.007	21.2	0.033	S
Betula sp.	M	Florence, IT	06.2017-10.2017	0.028	41.2	0.068	S + NS
Castanea sp.	M	Florence, IT	2003	0.016	33.5	0.048	S
Cedrus deodara	CT	Beijing, CN	05.2009-09.2009	0.022	22.0	0.100	S
Cedrus deodara	M	Florence, IT	06.2017-10.2017	0.025	41.2	0.061	S + NS
Chamaecyparis lawsoniana	M	Florence, IT	06.2017-10.2017	0.021	41.2	0.051	S + NS
Eucalyptus citriodora	SH	Guangzhou, CN	2013	0.008	21.2	0.038	S
Eucalyptus viminalis	M	Florence, IT	06.2017-10.2017	0.017	41.2	0.041	S + NS
Fagus sylvatica	M	Madrid, ES	04.2003-09.2003	0.038	40.7	0.093	S + NS
F. sylvatica	M	Florence, IT	06.2017-10.2017	0.040	41.2	0.097	S + NS
F. sylvatica	M	Florence, IT	2003	0.016	33.5	0.048	S
Fraxinus excelsior	M	Florence, IT	06.2017-10.2017	0.047	41.2	0.114	S + NS
Fraxinus ornus	M	Florence, IT	06.2017-10.2017	0.040	41.2	0.097	S + NS
Ginkgo biloba	CT	Beijing, CN	05.2009-09.2009	0.031	22.0	0.141	S

Ranking plant species

Species-specific Air Quality Index - Major disservices (pollen & BVOCs emission) & benefits (effectiveness in removing O_3, NO_2 (precursor) and PM_{10} & tolerance to O_3, P&D & drought)

+++ most efficient, + less efficient

Shrubs	O_3	NO_2	PM_{10}	BVOC	OFP	Pollen allergenicity	O_3 sensitivity	Drought tolerance	P&D tolerance	S-AQI
Euonymus sp.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+	++	++	+	7.0
Lonicera sp.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+	++	++	++	4.7
Viburnum sp.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	+	+++	+++	+++	4.9
Conifers										
Abies alba	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.5
Larix decidua	+++	+++	+++	+	+	[illegible]	[illegible]	[illegible]	[illegible]	8.6
Metasequoia glyp.	+++	++	++	++	++	[illegible]	[illegible]	[illegible]	[illegible]	6.5
Leaved-trees										
Acer campestre	+++	++	+	+	+	++	+	+++	++	6.7
Alnus sp.	++	++	+	+	+	+++	+/+++	++	+++	5.2
Betula sp.	++	++	+	+	++	+++	+/++	++	+++	4.7
Carpinus sp.	+++	++	+++	+	+	+++	+	+++	+++	8.4
Crataegus sp.	+++	+++	+++	+	+	+	++	++	++	9.1
Eucalyptus sp.	+	+	++	+++	+++	+	++	+++	+	3.0
Fagus sylvatica	+++	+++	++	+	+	+	++	++	+	8.0
Ficus sp.	+	++	+++	++	+++	0	+++	+++	+++	4.9
Liquidambar sp.	+	+++	+	+++	+++	+	+++	++	+++	3.8
Platanus sp.	++	+++	++	+++	+	++	++/[illegible]	[illegible]	[illegible]	6.2
Tilia cordata	+++	++	++	+	+	++	[illegible]	[illegible]	[illegible]	7.1

A value 1=low, 2=medium, 3=high was attributed to **Primary criteria**

Secondary criteria
A value of 1 to 3 to each criterion and then we calculate a mean score

S-AQI: **1-10 scale**

S-AQI scoring

We recommend city planners to select species with **S-AQI > 8** i.e. with high O_3 removal capacity, low OFP, O_3-tolerant, resistant to pests & diseases, tolerant to drought and non-allergenic.

e.g. ***Acer sp., Carpinus sp., Larix decidua, Prunus sp.***

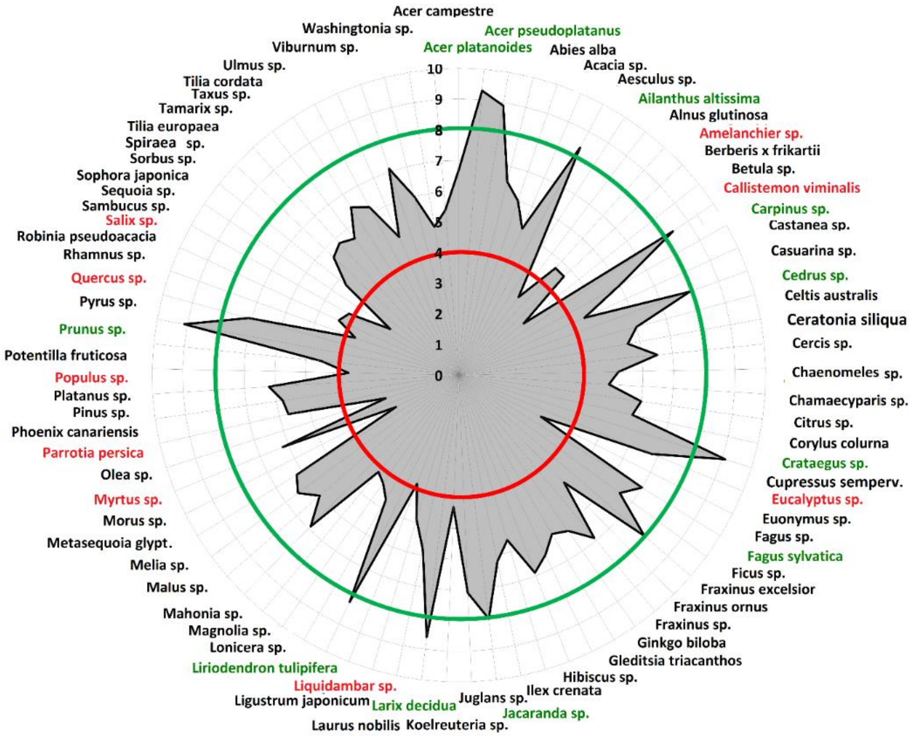


Fig. 2: Species-specific Air Quality Index S-AQI: 1-4: not recommended (below the red line); 8-10: recommended plant species for city planting program (over the green line).

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Conclusions & perspectives

- Trees show **higher O_3 removal capacity** (3.4 g m^{-2} $year^{-1}$ on av.) than green roofs (2.9 g m^{-2} $year^{-1}$) with lower installation & maintenance costs (± 10 times).

- The av. annual percent **air quality improvement** due to urban trees/shrubs is **< 2%.**

- Green roofs can be used to **supplement the use** of urban trees to improve air quality in a densely populated city.

- Urban vegetation (cost-effective & nature-based approach) aids in **meeting clean air standards.**

- Need to incorporate local-scale urban forest structure & an **improved parameterization of LAI** (seasonal variability) & **phenology** in the models of urban forest impacts on air quality.

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Acknowledges

THANKS

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Guest Editors:

Prof. Dr. Evgenios Agathokleous
Institute of Ecology, School of Applied Meteorology, Nanjing University of Information Science & Technology, Nanjing 210044, China

globalscience@frontier.hokudai.ac.jp

Dr. Elisa Carrari
Consiglio Nazionale delle Ricerche, Institute for Sustainable Plant Protection, Firenze, Italy

elisa.carrari@ipsp.cnr.it

Dr. Pierre Sicard
ARGANS, Sophia Antipolis, France

pierre.sicard@acri-he.fr

Deadline for manuscript submissions:
closed (15 July 2019)

Message from the Guest Editors

Dear Colleagues,

This Special Issue comprises papers presented at the International Conference on Ozone and Plant Ecosystems (2nd Ozone and Plants Conference), held from May 21 to May 25, 2018, in Florence, Italy. Excellent contributions from those who did not have the opportunity to attend the conference will also be considered.

This conference allowed all experts in the interactions between ozone and plant ecosystems to meet and discuss the state-of-the-art and strategies for continuous improvements. The three man subjects of the conference were:

1. Monitoring, modelling and assessing the risk of ozone damage to plant ecosystems
2. How plant ecosystems respond to ozone exposure
3. How plant ecosystems affect ozone concentration in the atmosphere

The Guest Editors invite papers that promote and advance the exciting and rapidly-changing field of Ozone and Plant Ecosystems. Papers which exclusively deal with any aspects of tropospheric ozone (physics-chemistry) are also welcome.

Dr. Evgenios Agathokleous
Dr. Elisa Carrari
Dr. Pierre Sicard
Guest Editors

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