Climate benefits of urban vegetation

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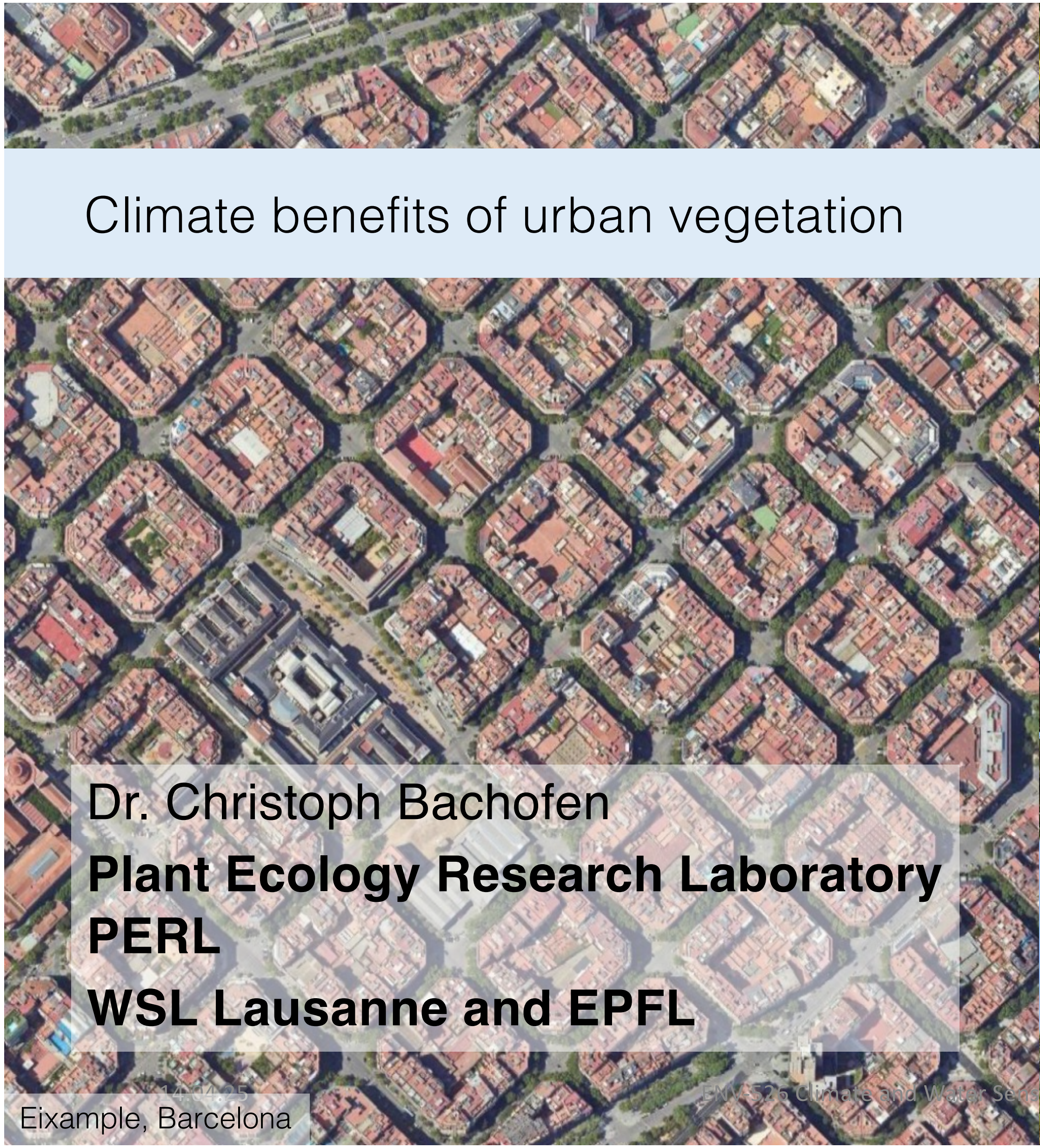
WSL Lausanne and EPFL

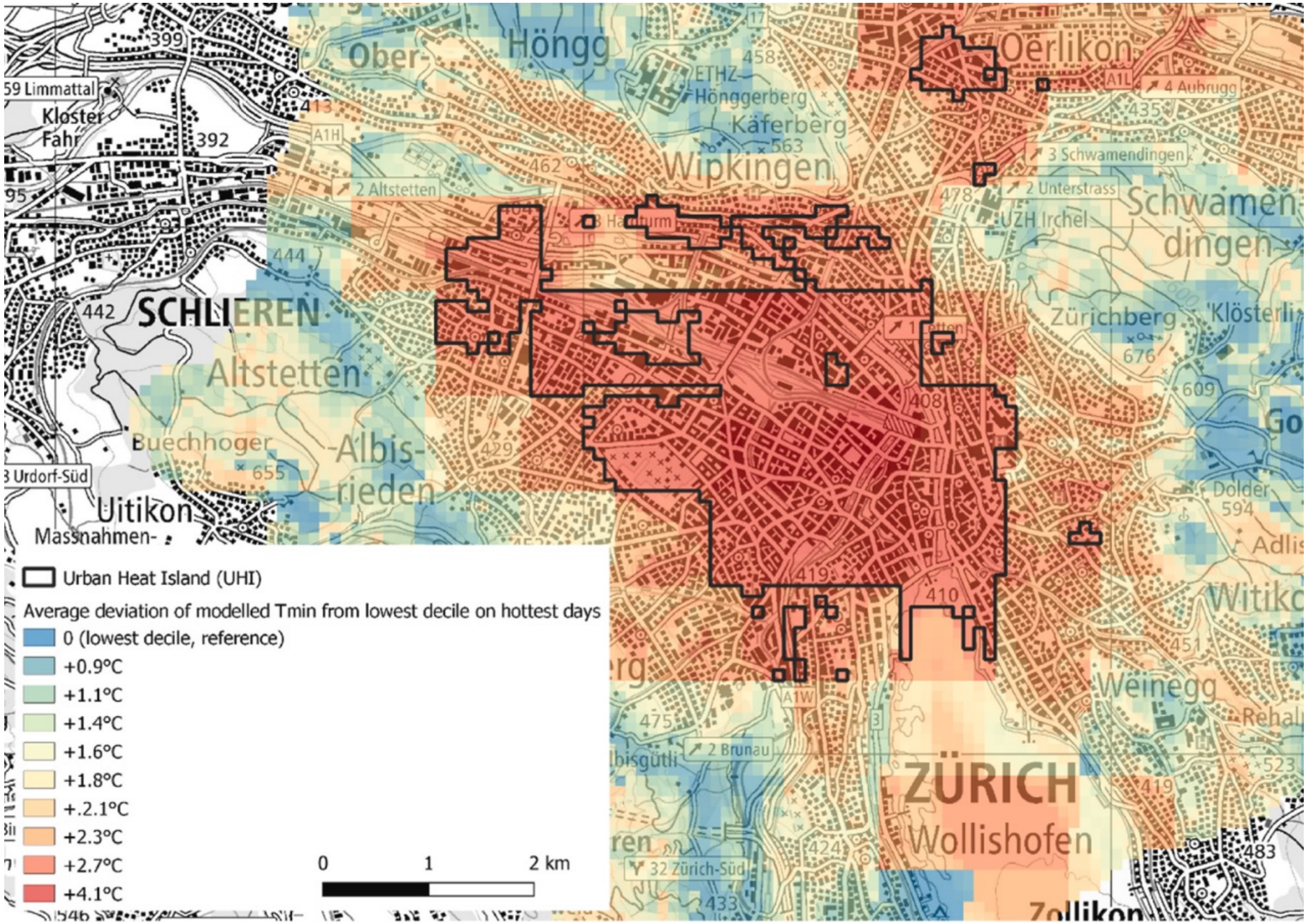

Eixample, Barcelona


Lancy, Geneva

"Cities have evolved naturally in many different cultures and are now the predominant habitat of our species"

Gross, Current Biology 2016

The urban heat island



"In 2018, only 15 stations out of 576 were located in inner cities"

Wicki *et al.* 2024
Flückiger *et al.* 2022

Urban heat island mitigation

"Plan canopé"

Ville de Lausanne
Service des parcs
et domaines

Ecoquartier "Plaines-du-loup"

Pellet et al. - Arborisation urbaine lausannoise et changements climatiques.

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Tableau 2. Liste des essences évaluées par classe d'adéquation climatique.

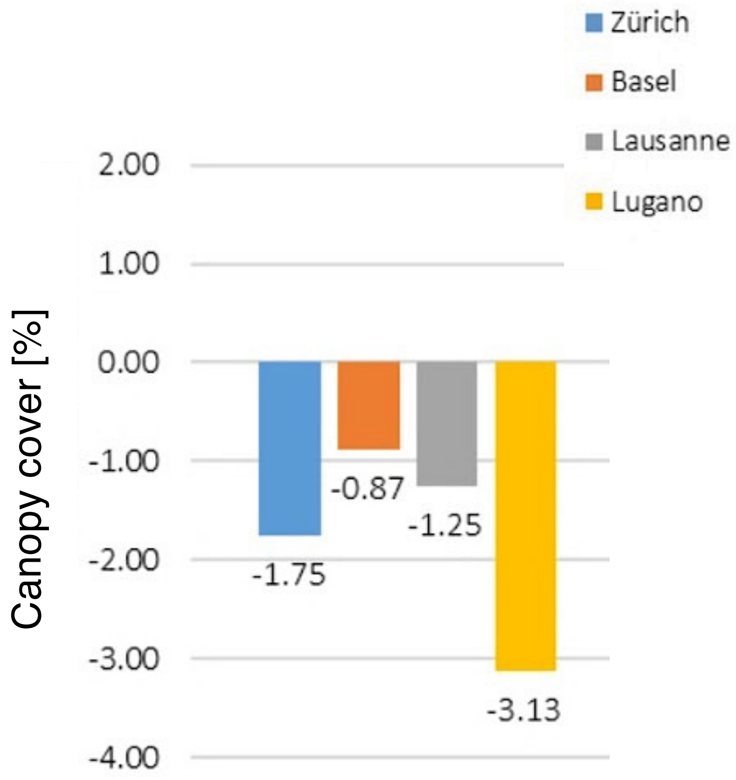
Famille	Essence	Quantile de l'axe 1	Quantile de l'axe 2	Trajectoire climatique	Classe d'adéquation climatique	Potentiel biodiversité	Écart à la distribution naturelle	Écart phylo-génétique	Risques
Altingiacée	*Liquidambar styraciflua*	55 %	50 %	1.34	1	Faible	Élevé	Élevé	
Bétulacée	*Betula nigra*	35 %	35 %	1.92	1		Élevé	Moyen	
Cupressacée	*Taxodium distichum*	70 %	50 %	2.24	1		Élevé	Élevé	
Fabacée	*Albizia julibrissin*	55 %	45 %	2.22	1		Élevé	Élevé	
Fabacée	*Cladrastis kentukea*	25 %	45 %	1.92	1		Élevé	Élevé	
Fabacée	*Gleditsia triacanthos*	45 %	25 %	1.95	1	Faible	Élevé	Élevé	Potentiellement envahissant
Fabacée	*Gymnocladus dioica*	25 %	65 %	1.44	1		Élevé	Élevé	Potentiellement envahissant, fortement drageonnant
Fabacée	*Styphnolobium japonicum*	75 %	60 %	1.82	1	Faible	Élevé	Élevé	
Magnoliacée	*Liriodendron tulipifera*	35 %	30 %	1.69	1	Faible	Élevé	Élevé	
Magnoliacée	*Magnolia grandiflora*	80 %	20 %	1.41	1	Faible	Élevé	Élevé	
Moracée	*Morus alba*	30 %	65 %	2.11	1		Élevé	Élevé	
Moracée	*Morus nigra*	25 %	80 %	0.58	1		Élevé	Élevé	
Rosacée	*Prunus yedoensis*	55 %	75 %	1.48	1	Élevé	Élevé	Moyen	
Rosacée	*Pyrus calleryana*	40 %	35 %	2.10	1	Très élevé	Élevé	Moyen	Hôte du feu bactérien
Sapindacée	*Acer buergerianum*	60 %	55 %	2.25	1		Élevé	Moyen	
Ulmacée	*Celtis occidentalis*	80 %	55 %	0.99	1		Élevé	Élevé	
Ulmacée	*Zelkova serrata*	55 %	45 %	1.74	1	Faible	Élevé	Élevé	
Cupressacée	*Sequoia sempervirens*	55 %	95 %	0.14	2		Élevé	Moyen	
Fabacée	*Cercis siliquastrum*	55 %	10 %	1.29	2	Faible	Moyen	Élevé	
Fagacée	*Quercus castaneifolia*	50 %	15 %	1.43	2	Élevé	Faible	Faible	
Fagacée	*Quercus frainetto*	50 %	10 %	1.09	2	Élevé	Faible	Faible	Processionnaire du chêne
Fagacée	*Quercus ilex*	55 %	90 %	0.50	2	Élevé	Faible	Faible	
Platanacée	*Platanus orientalis*	50 %	5 %	1.16	2		Moyen	Moyen	Sensible à l'Oïdium du platane
Salicacée	*Populus nigra*	55 %	5 %	0.27	2	Élevé	Faible	Faible	

Pellet et al. 2021

Plan vs. reality

Change in canopy coverage in swiss cities 2008 to 2018

Abbildung 21: Dokumentation einer Baumfällung in Lausanne, Standort: 46°32'27.53"N 6°37'54.80"E (Quelle: Google Earth).



Schubnell et al. 2020 ZHAW

Plan vs. reality

Plan vs. reality

Change in canopy coverage in the US: 36 million trees lost per year

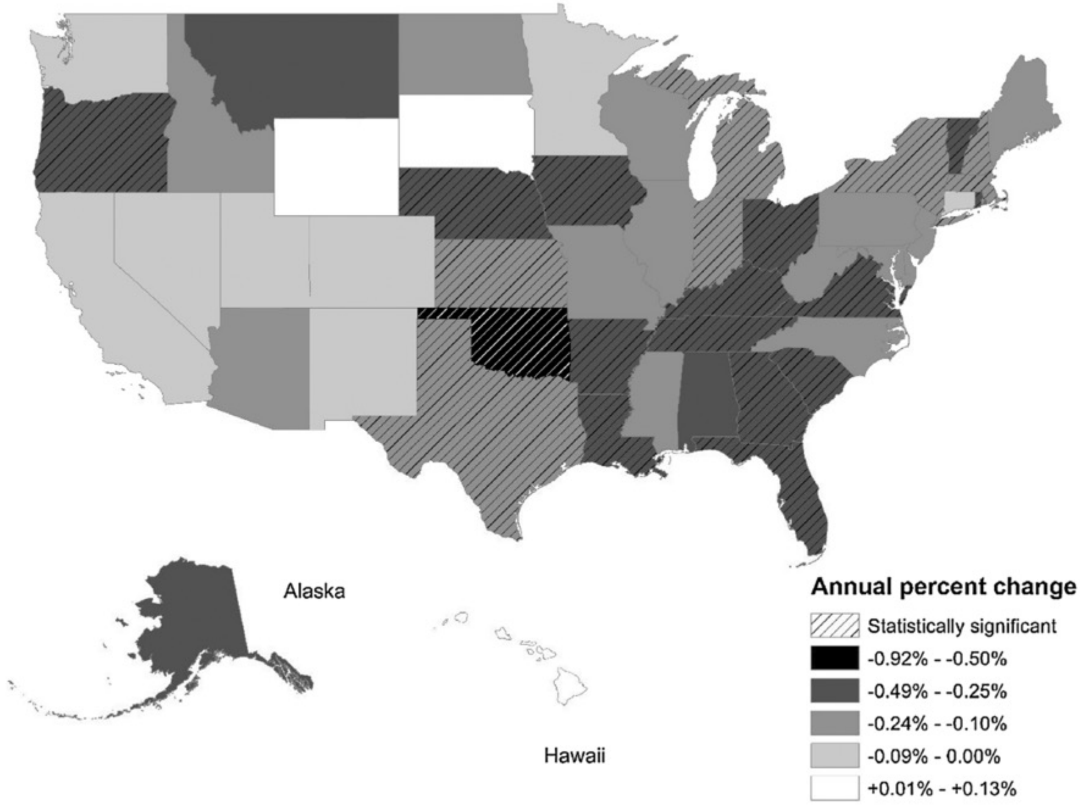


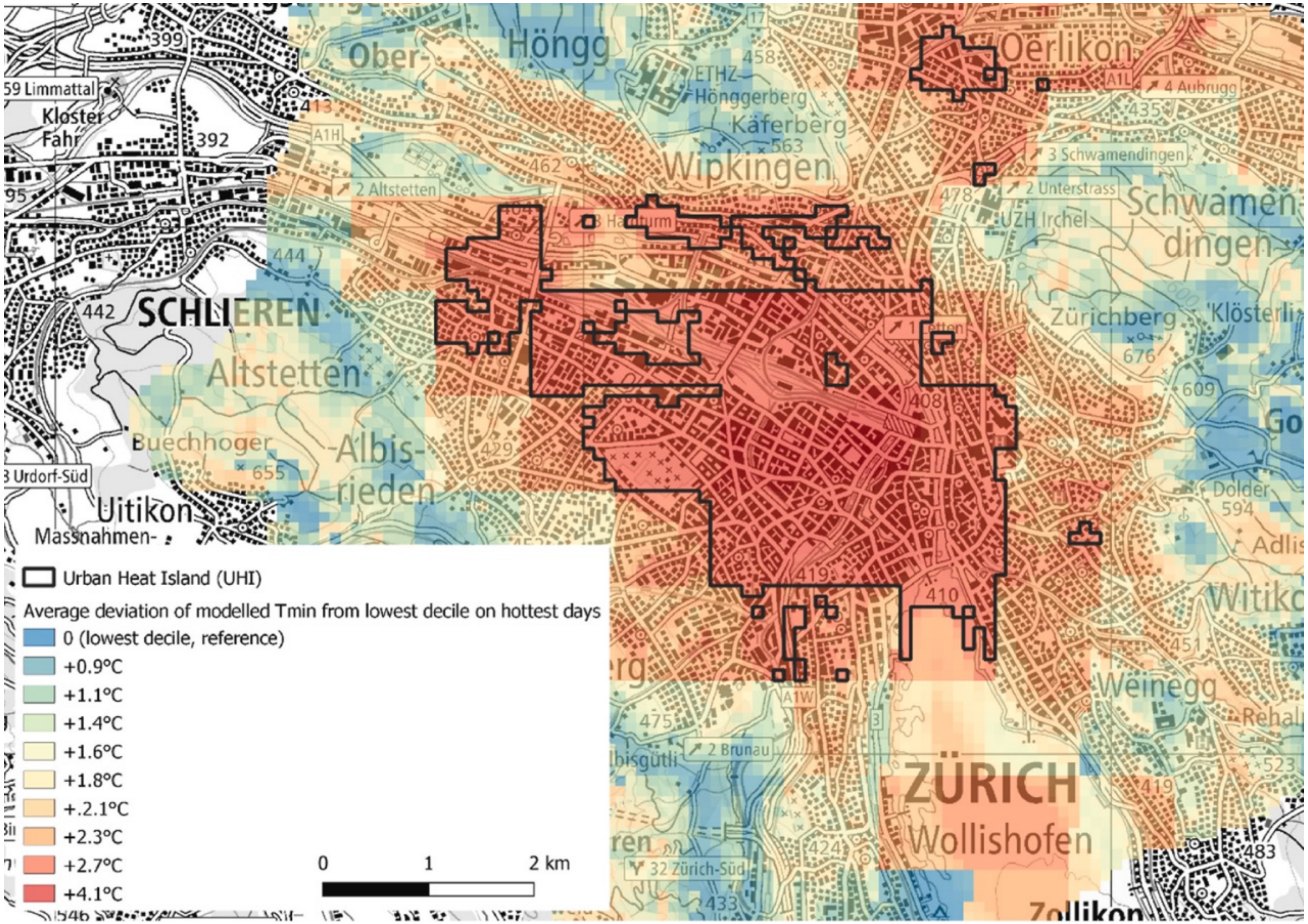
Fig. 3. Tree cover change in urban areas by state.

Nowak et al. 2018

Outline: Urban vegetation and microclimate

- Different kinds of urban heat
- Vegetation cooling mechanisms:
  - Transpiration and latent heat
  - Shading
  - Albedo and more
- Examples of vegetation cooling
- Biodiversity and invasion
- Carbon sequestration
- More stuff (if time)

What is urban heat?



"In 2018, only 15 stations out of 576 were located in inner cities"

Wicki *et al.* 2024
Flückiger *et al.* 2022

Where are the cities built?

Cities are built in warm (> 0 °C) and moist (> 300 mm) places with a few exceptions (e.g. Kairo and Khartoum < 300 mm rain)

Pully meteo swiss station
(MAT 11.3 °C, MAP 1132 mm)

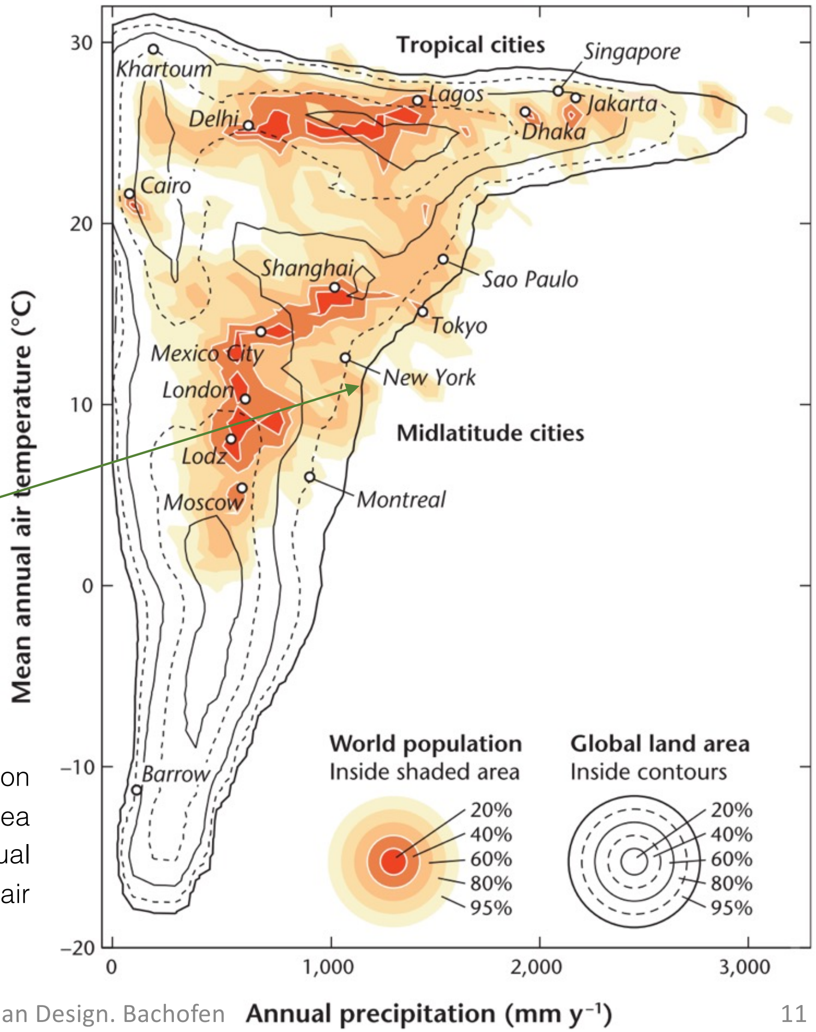
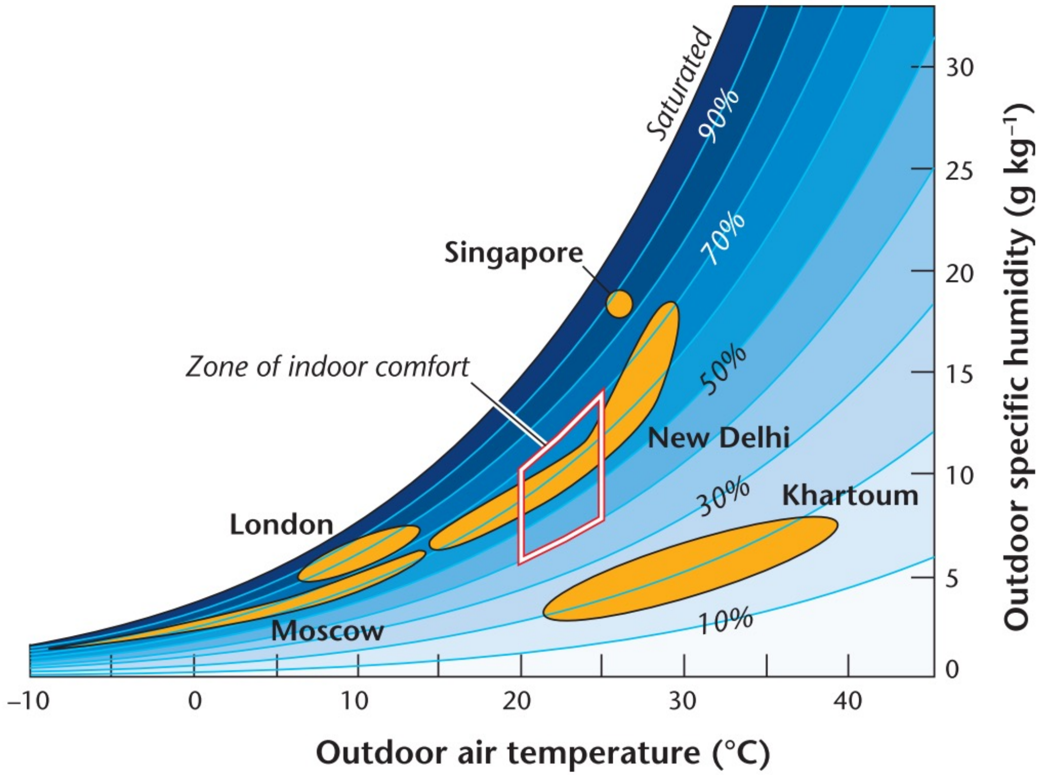


Figure 12.4 Map of global population distribution (shaded) and distribution of global land area (contours) in the parameter space of annual precipitation in mm yr^{-1} and annual mean air temperature in °C. (Oke et al. 2017)

Background climate matters



Distinct climate types give rise to different heating and cooling and (de)humidification needs.

- Singapore is wet and humid throughout the year
- London and Moscow are cool
- Khartoum (Sudan) is warm and dry
- New Delhi is warm at one time of the year and cool at another.

Figure 15.4 The climates of selected cities expressed in terms of the monthly air temperature and humidity. The area in the centre of the diagram represents a zone of indoor comfort that might be a desirable objective. (Oke et al. 2017)

Local climate and topography matters: Tahoua, Niger

- MAP: 250–750 mm, (60–80% between July and August can cause flooding)
- Dry season hot wind (Harmattan) blows from the Sahara and brings sand and dust, air temperatures to ~40 °C

→ Urban design should provide shade and protection from wind and dust.

→ Urban development should avoid steep slopes (> 8%) to limit erosion during rainfall event.

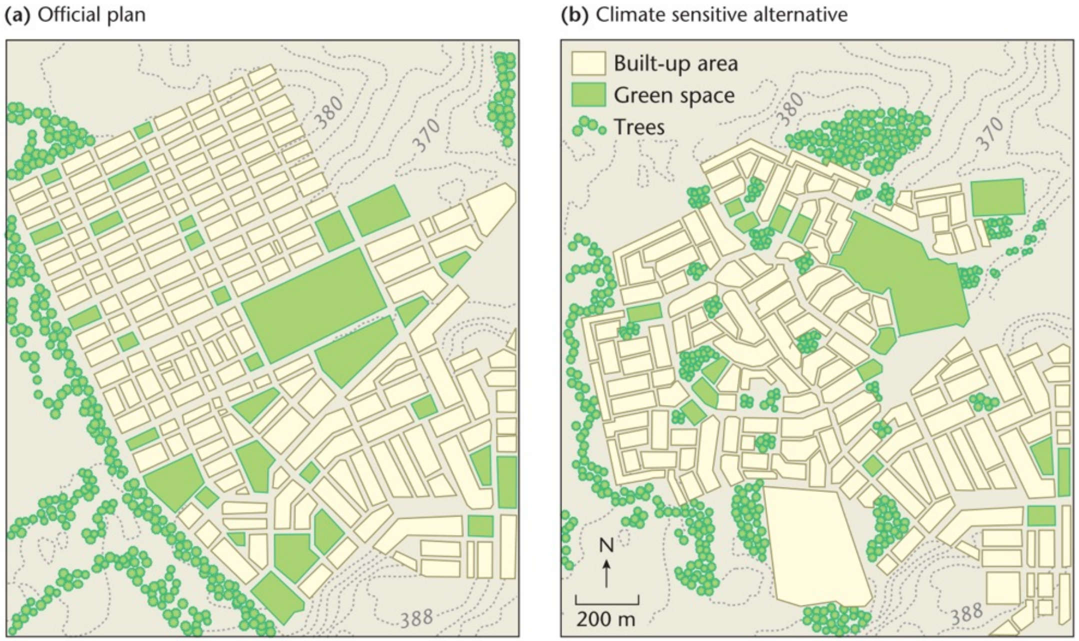


Figure 15.5 Alternative layout plans for the Koufan extension zone in Tahoua, Republic of Niger. The official plan (a) is based on a generic grid design (b) an alternative plan based on local climate and topography. (Oke et al. 2017)

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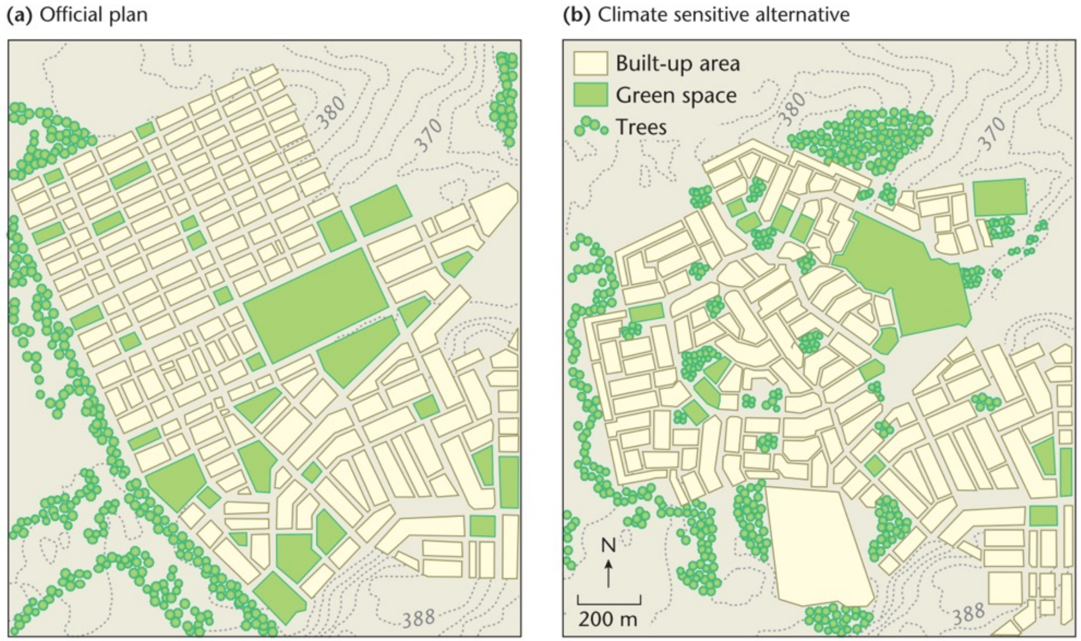
a) Edge is treated the same as its interior (little shelter), the roads are long and wide and aligned along wind direction. Limited use of green space to provide comfortable microclimates.

b) Avoiding steep slopes (follow contours), narrower streets (to provide shade) and reduced channelling of strong winds. Narrow gaps at the edge of the settlement maximize shelter. Trees to provide shelter and shade.



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Environmental factors:
wind, erosion, slopes, edges, precipitation seasonality

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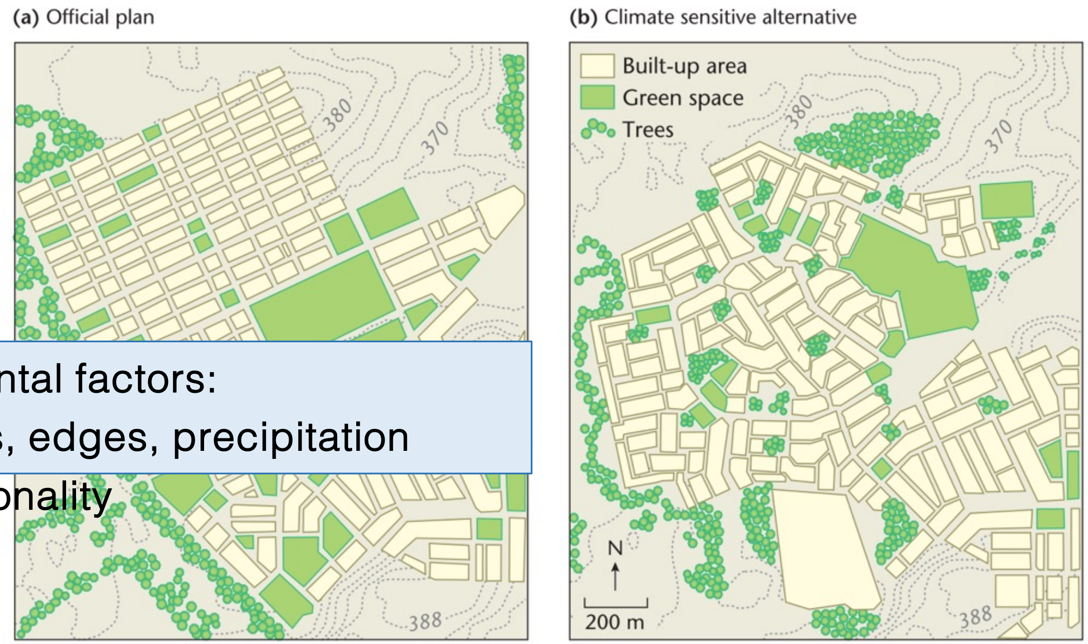

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Local climate and topography matters: Fermont, Canada

- Low winter temperatures with strong winds
- Relatively short periods of daylight around in winter
- Near a very large water body, most of the precipitation as snowfall that accumulates

→ Shelter is essential and time spent outdoors should be minimized – buildings should be close to one another.
→ Solar access for as long as possible
→ Avoid snow accumulation

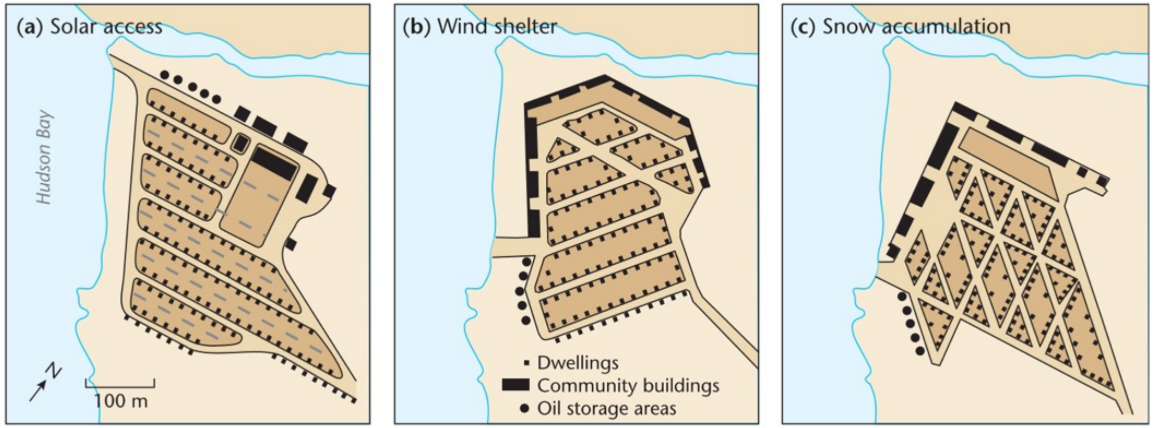

Figure 15.6 Three town plans for a high-latitude settlements developed to meet different climate objectives with regard to (a) solar access, (b) wind shelter and (c) snow accumulation. A final plan should be a synthesis of the three alternatives through negotiation and resolution of conflict. (Oke et al. 2017)

Many of these design principles are evident in Fermont, Canada (52.5 °N), a small mining town constructed in the early 1970s. (Oke 2017)

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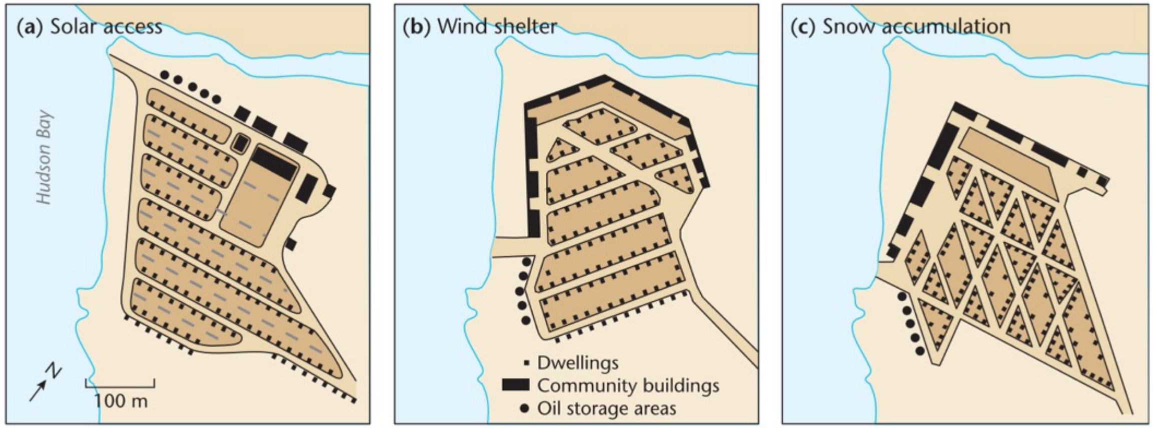
Different design solutions to (a) maximize solar access, (b) provide wind shelter, and (c) control snow accumulation

a) Solar solution: on streets oriented east-west and sufficiently wide to guarantee periods of direct sunlight
b) Shelter solution: a long building (for communal activities) that acts as a windbreak to the north of the settlement
c) Snow accumulation solution: street pattern aligned along the path of airflow



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→ Solar access for as long as possible
→ Avoid snow accumulation

Environmental factors:
wind, sunlight, precipitation (snow), low temperatures

Different design solutions to (a) maximize solar access, (b) provide wind shelter, and (c) control snow accumulation

a) Solar solution: on streets oriented east-west and sufficiently wide to guarantee periods of direct sunlight
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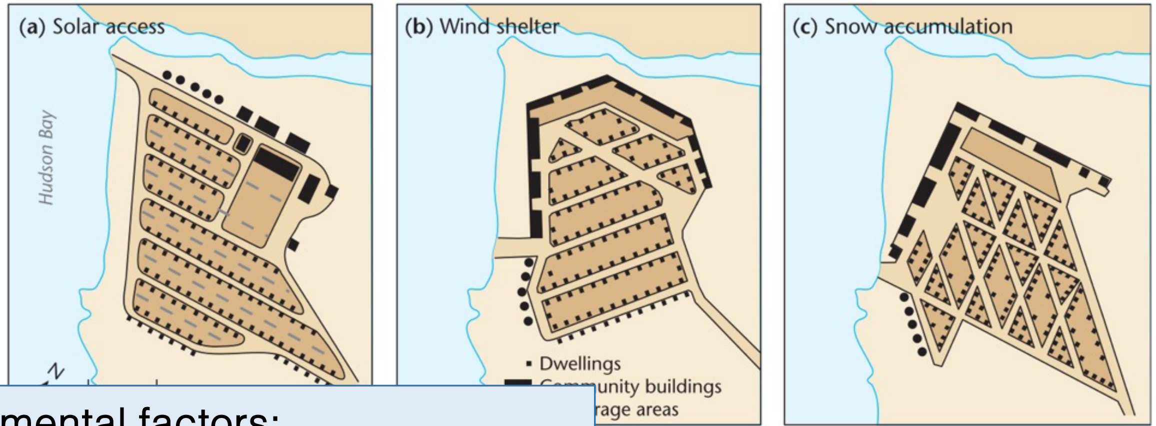

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Local climate and topography matters

Urban heat island effect can be harmful or beneficial

- In many cities in Europe urban warming is an advantage (in winter), except the dry and hot locations
- In summer, urban warming is still not desired

→ planning with cooler summers, but still warm winters (have your cake and eat it, too)

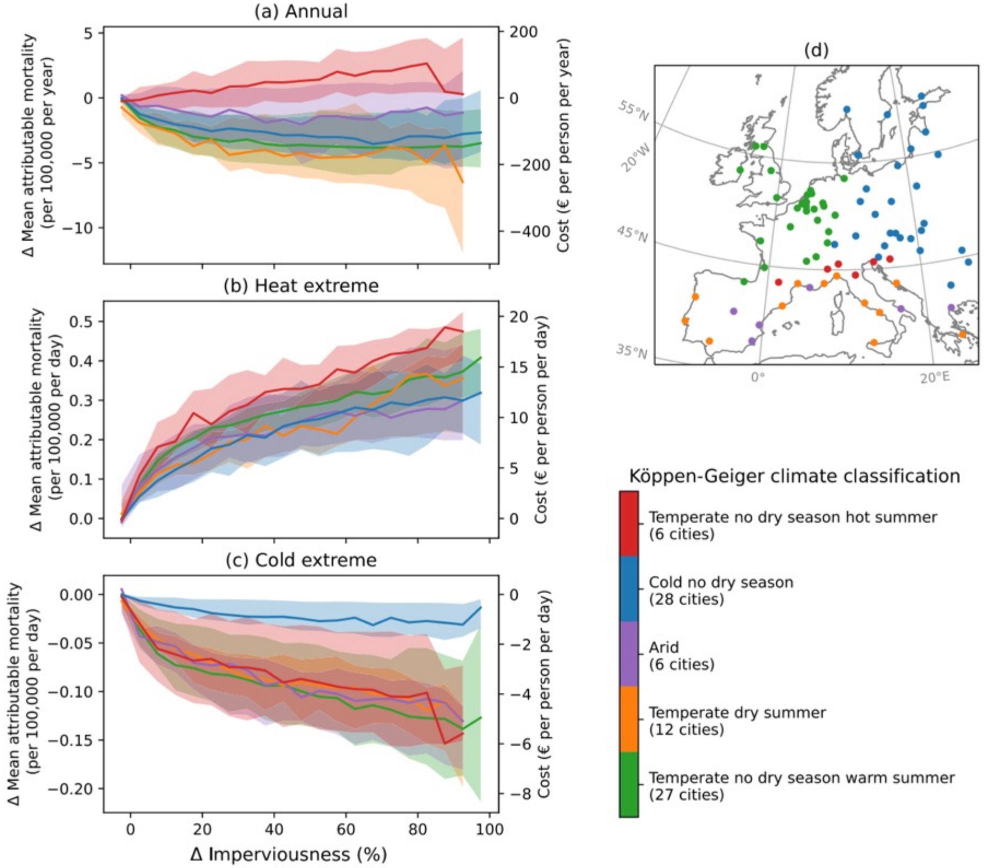


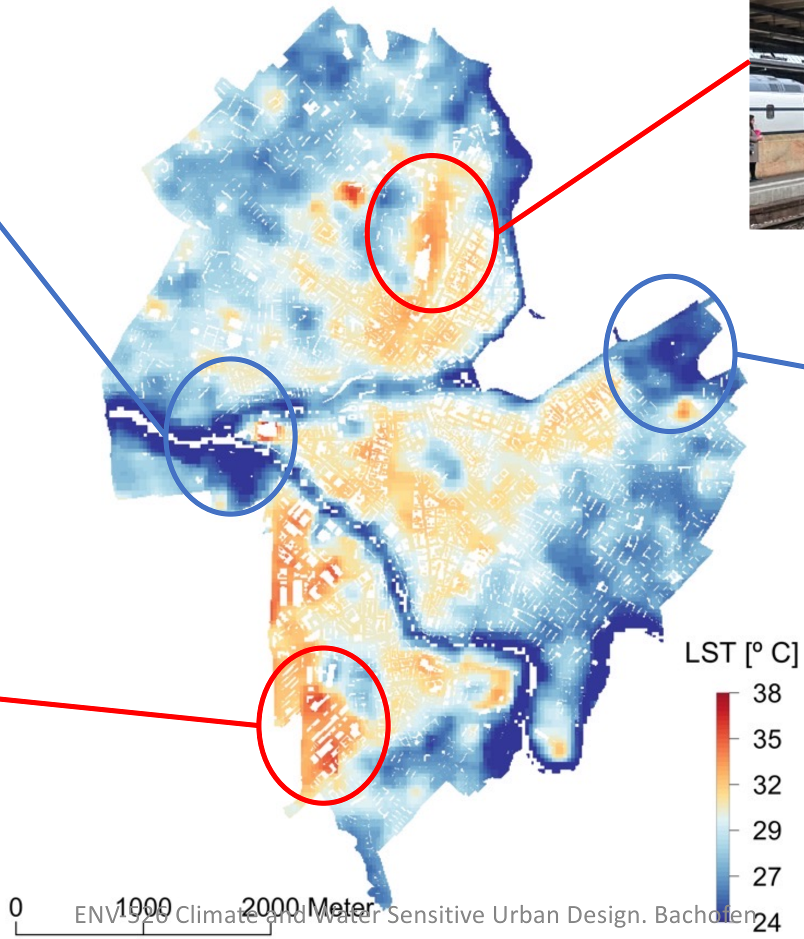
Fig. 2 | Difference in attributable mortality, and associated economic impact, compared to the rural mean, as a function of the difference in land imperviousness from the rural mean. (Huang et al. 2023)

Land surface temperature (LST) and heat stress

Pointe de la Jonction

La praille

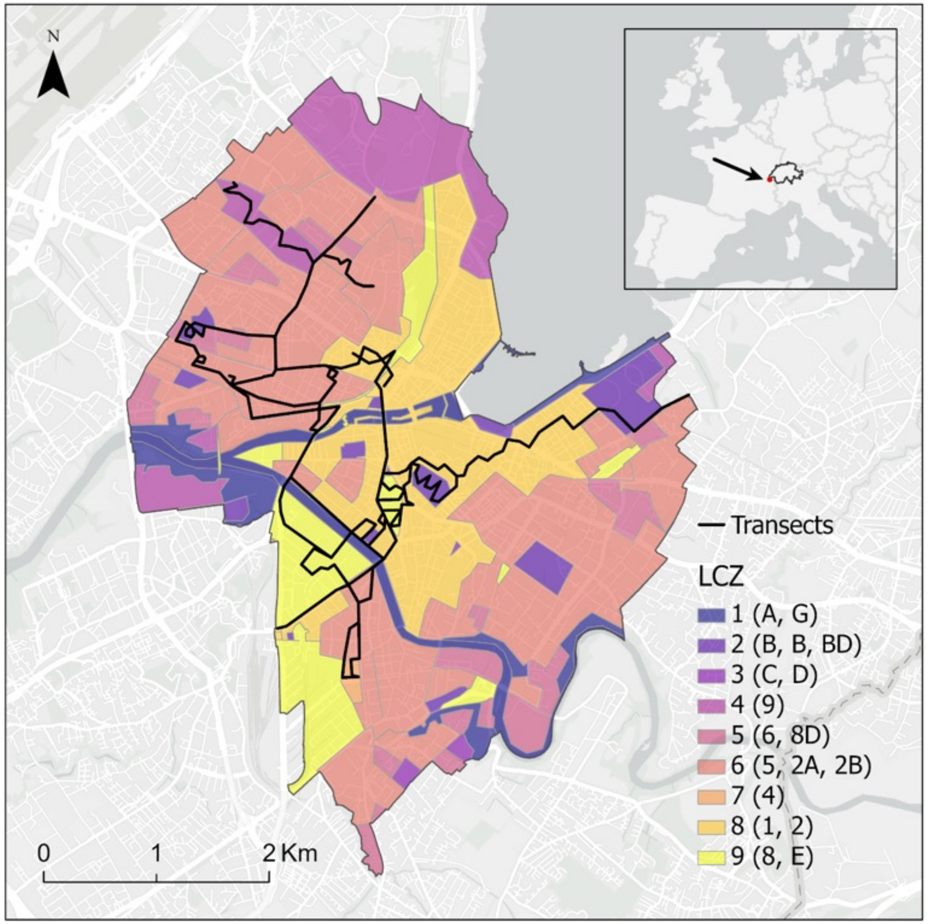
Mean summer LST, Landsat 8, resampled from 100 m to 30 m



Genève gare

Parc La Grange

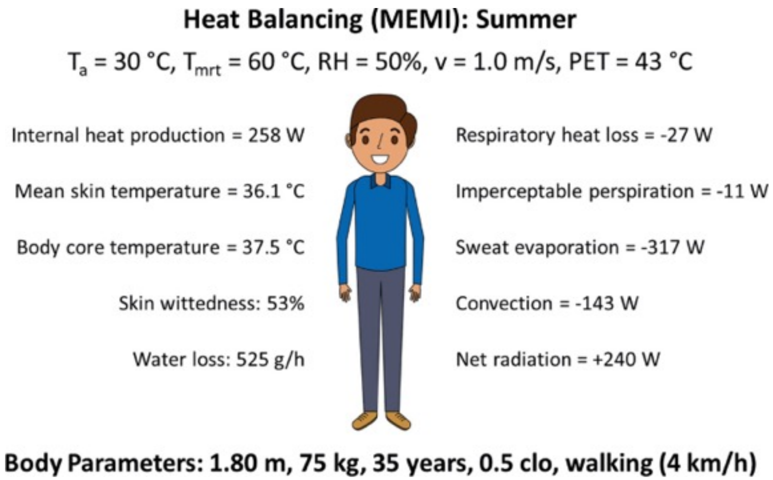
Microclimamètre for PET transects



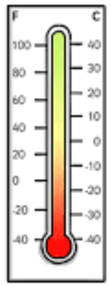
Heat stress: physiological equivalent temperature (PET)

Wind speed

Relative humidity



Solar radiation

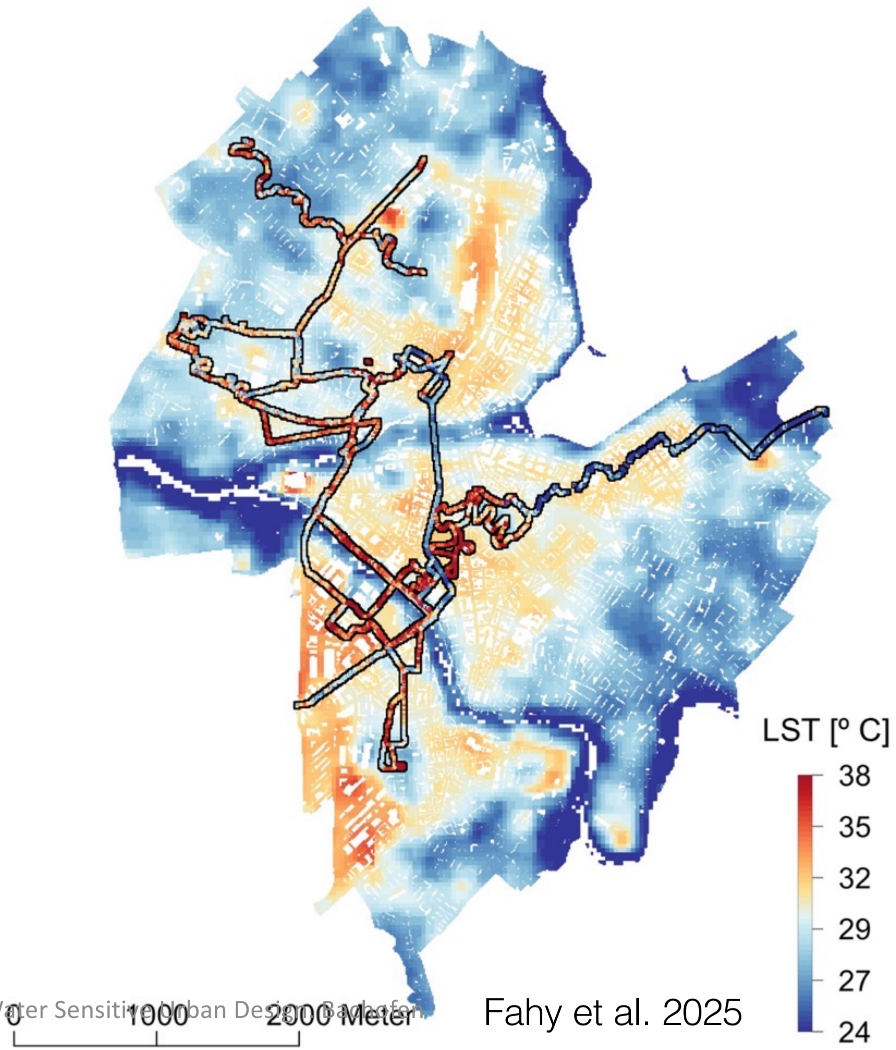


Air temperature

Höppe et al. 1999

Bad correspondence of LST and PET

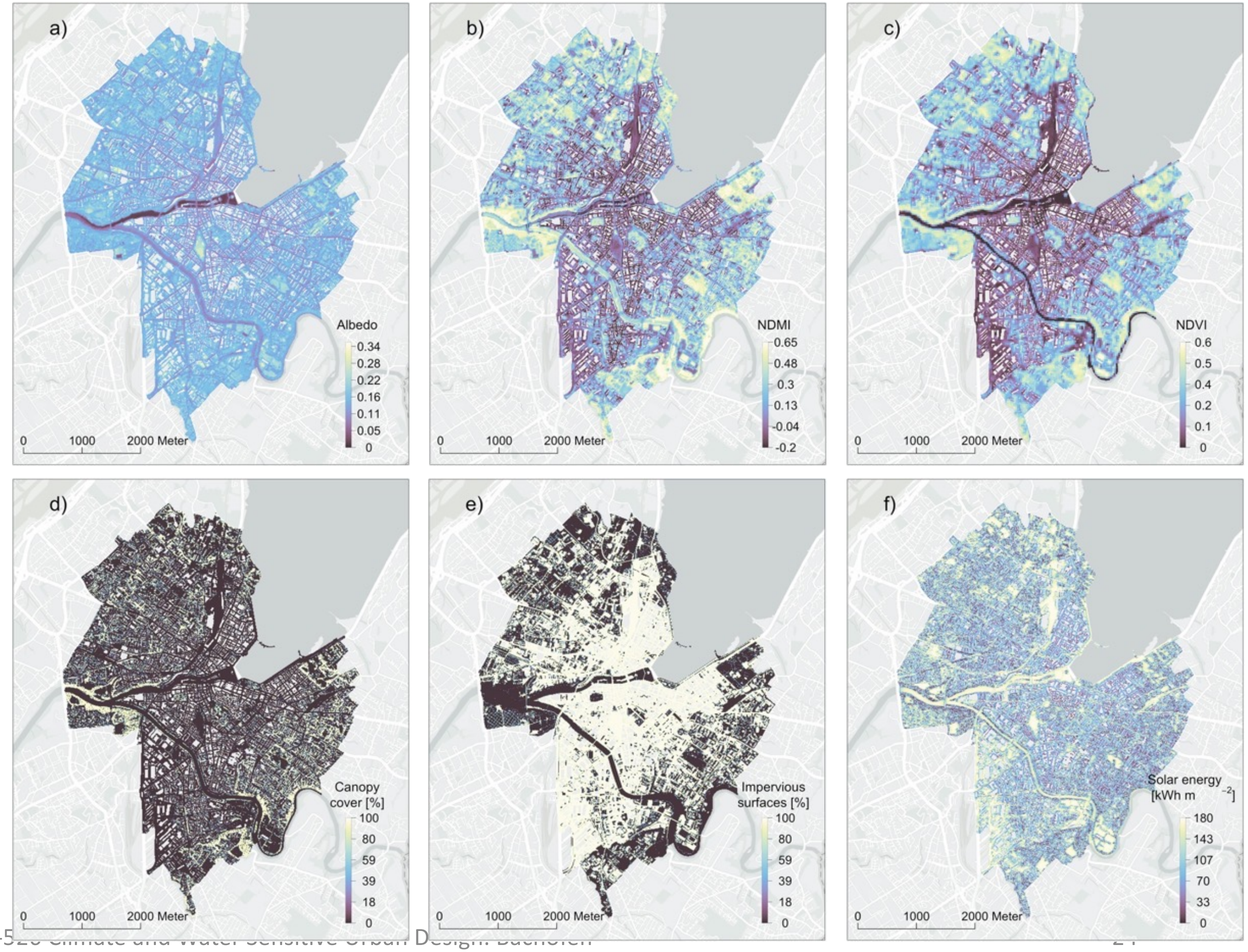
- Transects of heat stress measurements across Geneva
- "Perceived heat stress": physiological equivalent temperature (PET)
- Land surface temperatures do not represent PET measured by the microclimamètre well enough



Fahy et al. 2025

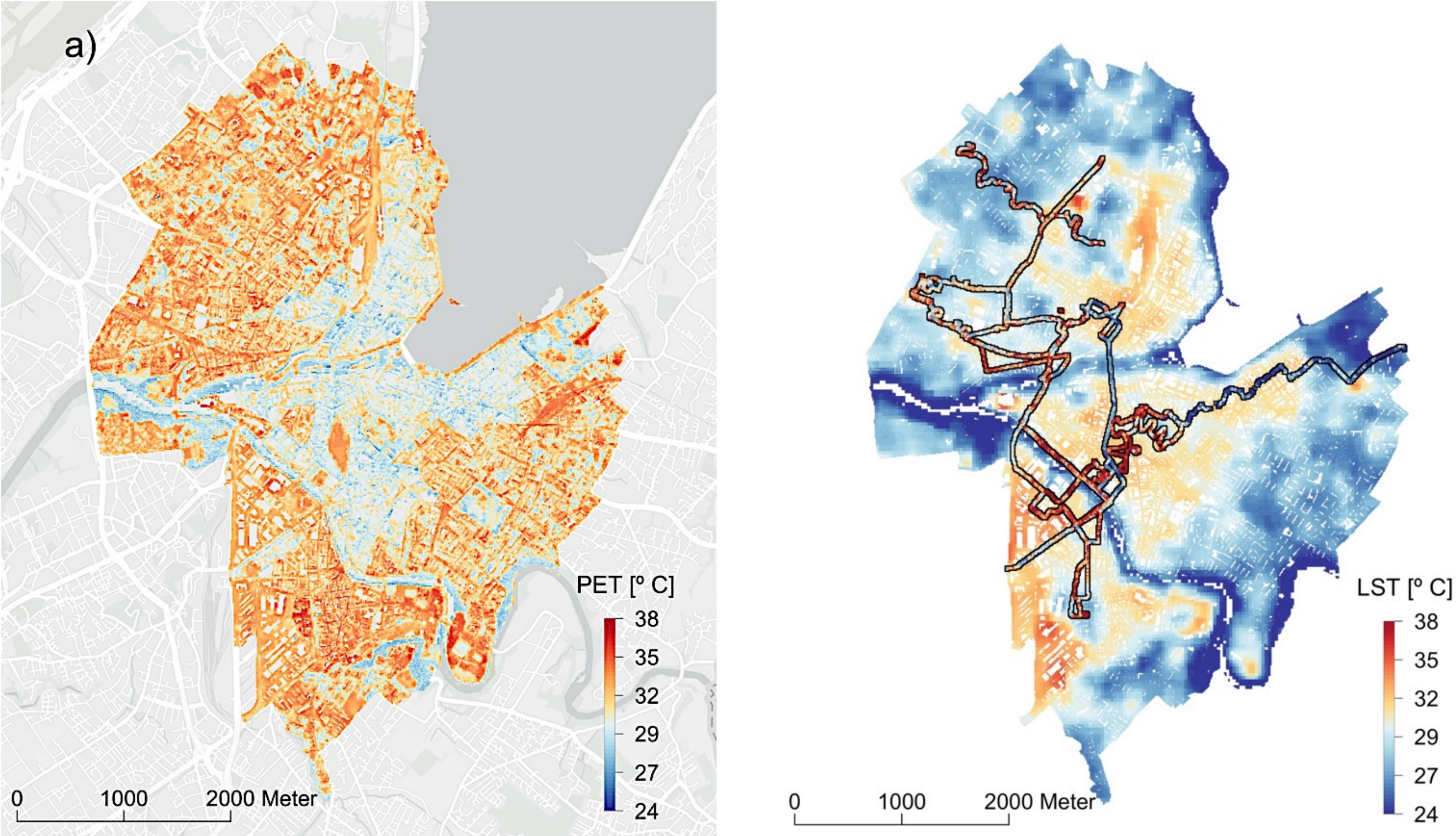
Remote sensing predictors of PET

- Albedo: Sentinel 2; 20 m
- NDMI: Sentinel 2; 20 m
- NDVI: Sentinel 2; 20 m
- Canopy cover: LiDAR; 10 m
- Percentage impervious surface: Public GIS repository Geneva; 10 m
- Solar irradiance July (sum): Public GIS repository Geneva; 0.5 m
- Local climate zones: Manually designated after Oke (2012); 0.02–67 ha



Fahy et al. 2025

Estimations de PET à Genève



Fahy et al. 2025

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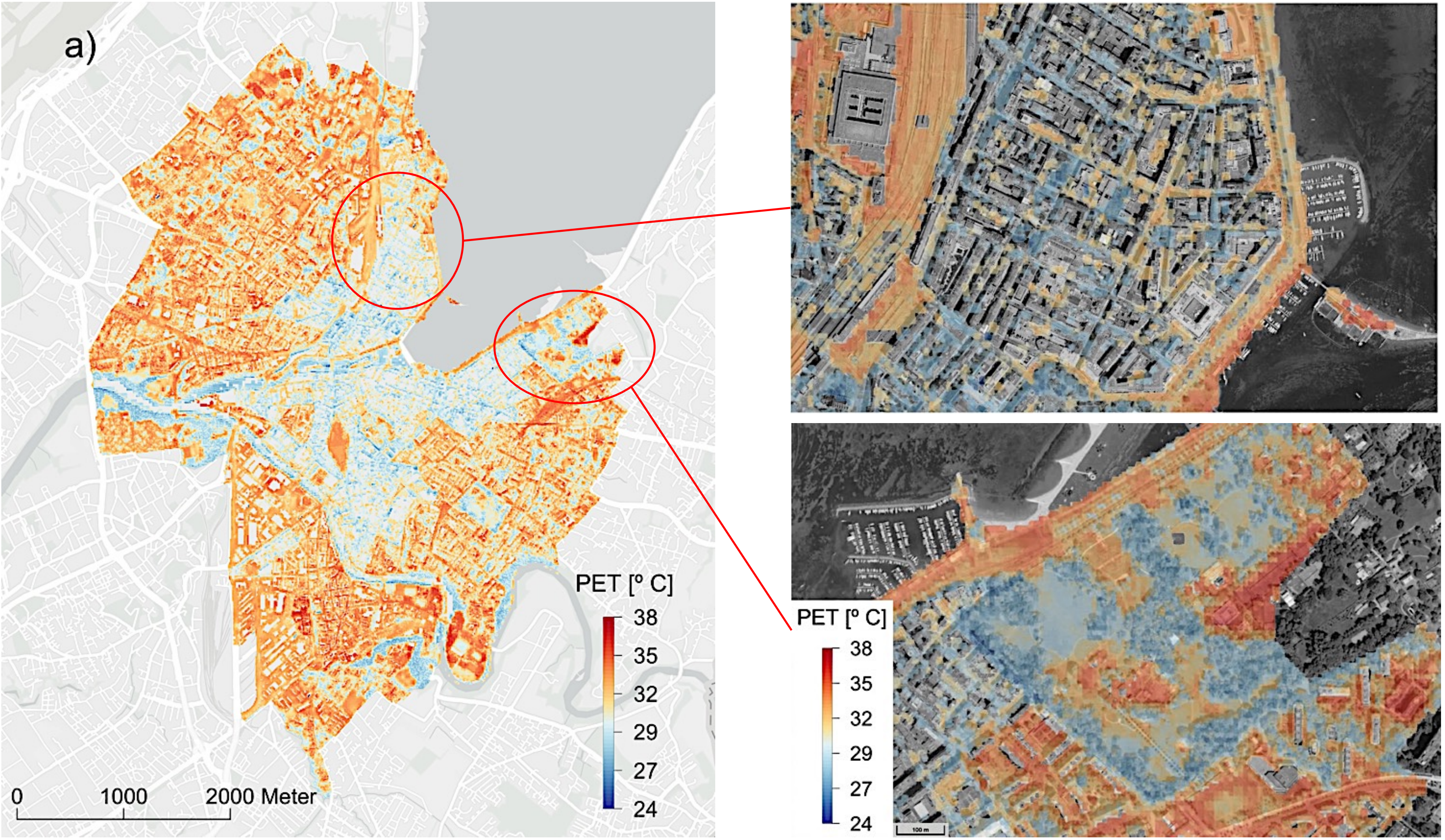


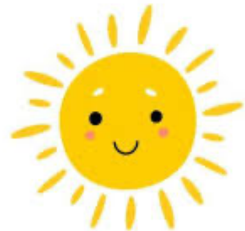
Paquis

Parc La Grange

Fahy et al. 2025

Compare predictions

Genève vieille ville



Heat Balancing (MEMI): Summer

T_a = 30 °C, T_{mrt} = 60 °C, RH = 50%, v = 1.0 m/s, PET = 43 °C

Internal heat production = 258 W

Mean skin temperature = 36.1 °C

Body core temperature = 37.5 °C

Skin wittedness: 53%

Water loss: 525 g/h

Respiratory heat loss = -27 W

Imperceptable perspiration = -11 W

Sweat evaporation = -317 W

Convection = -143 W

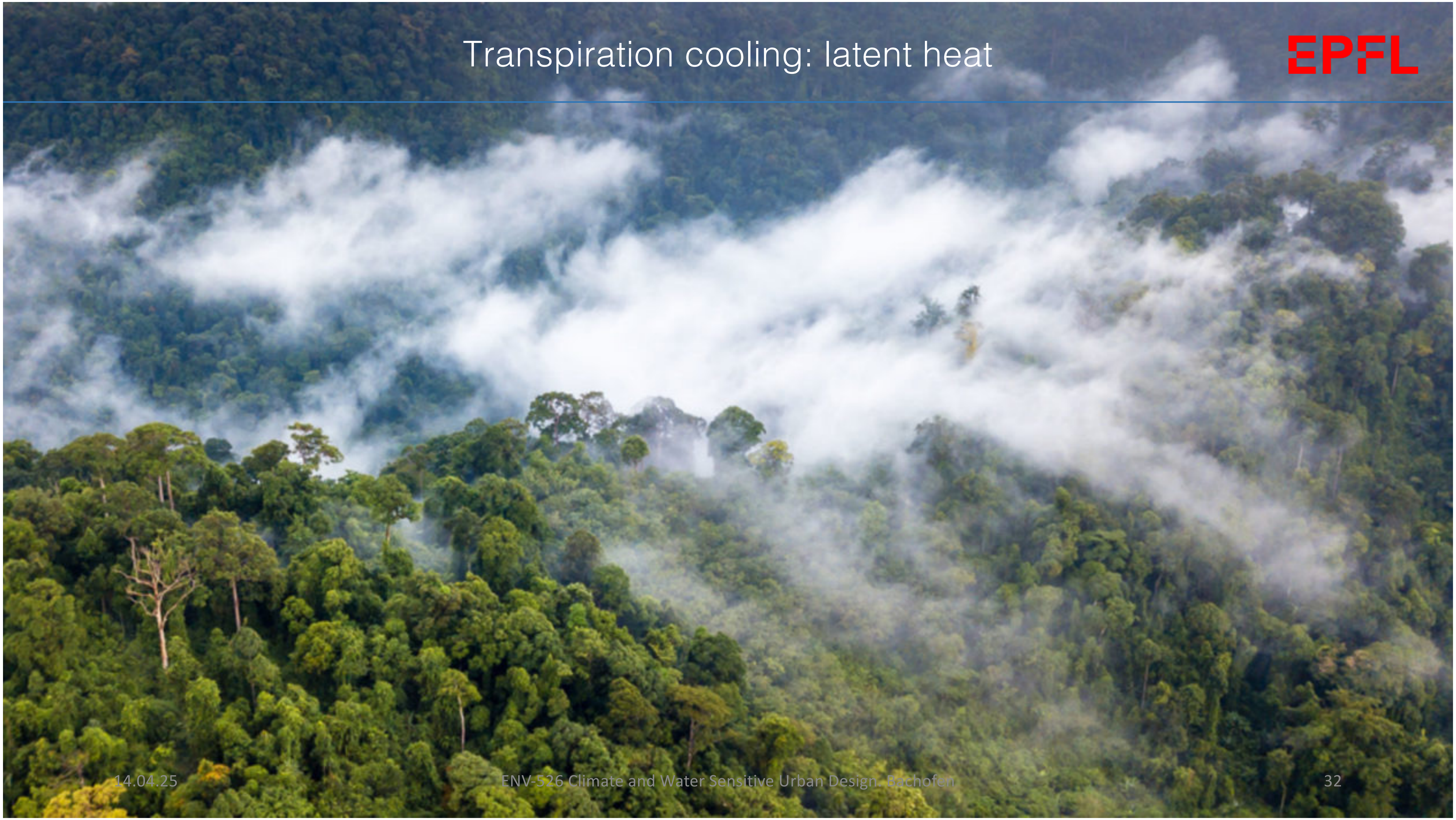
Net radiation = +240 W

Body Parameters: 1.80 m, 75 kg, 35 years, 0.5 clo, walking (4 km/h)

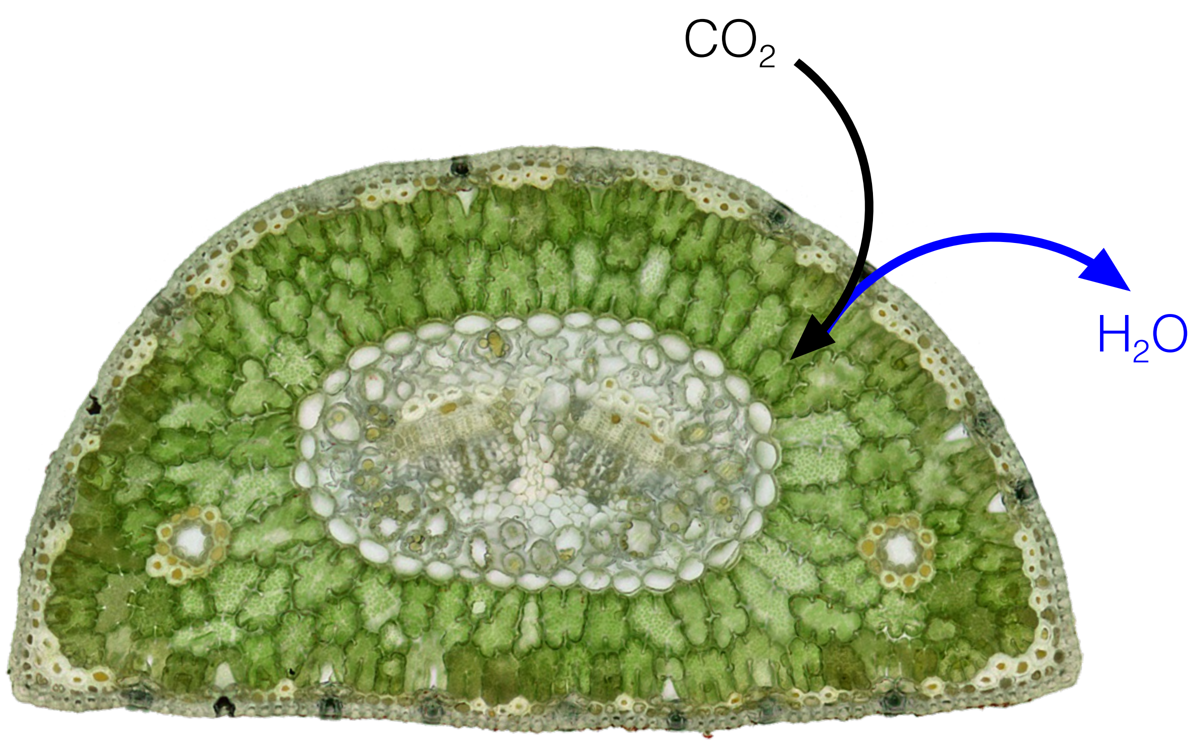
Many ways to measure urban heat

- Often **land surface temperature (LST)** is used to map urban heat, because it's easy (satellite data)
- LST is **not very informative** for human perceived heat
- Air temperature, solar radiation (shading), wind speed, air humidity play an important role!
- There are **many ways to estimate perceived heat** stress and cooling
- Urban planning needs to include all these aspects!

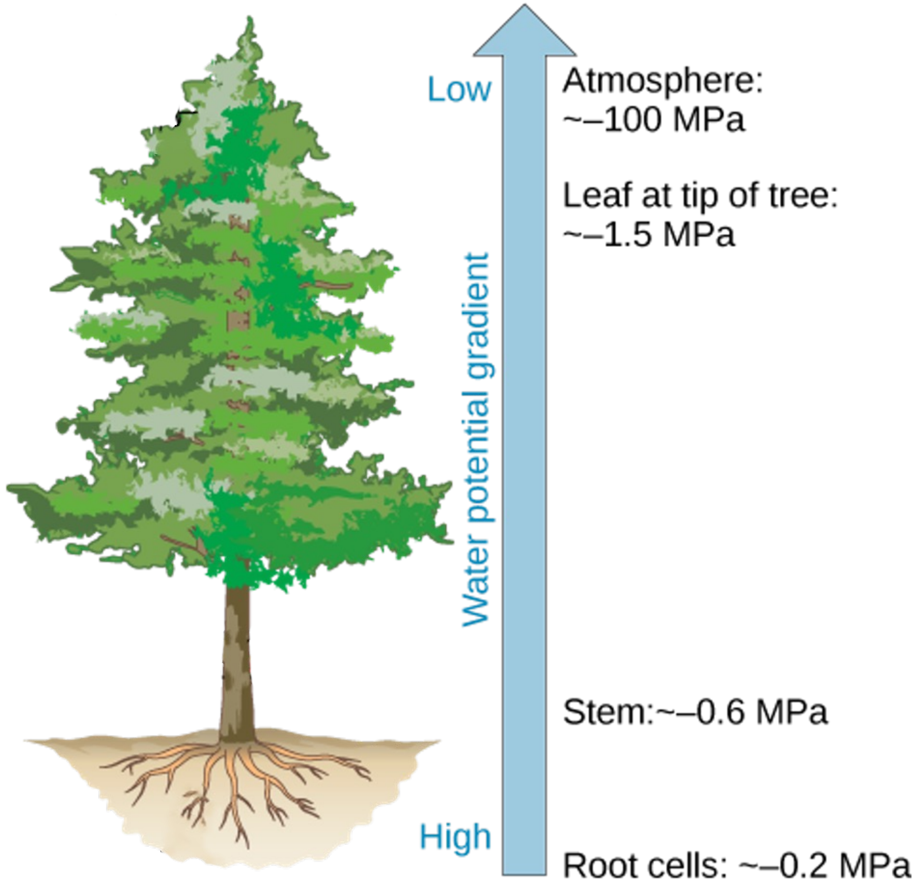
Transpiration cooling: latent heat



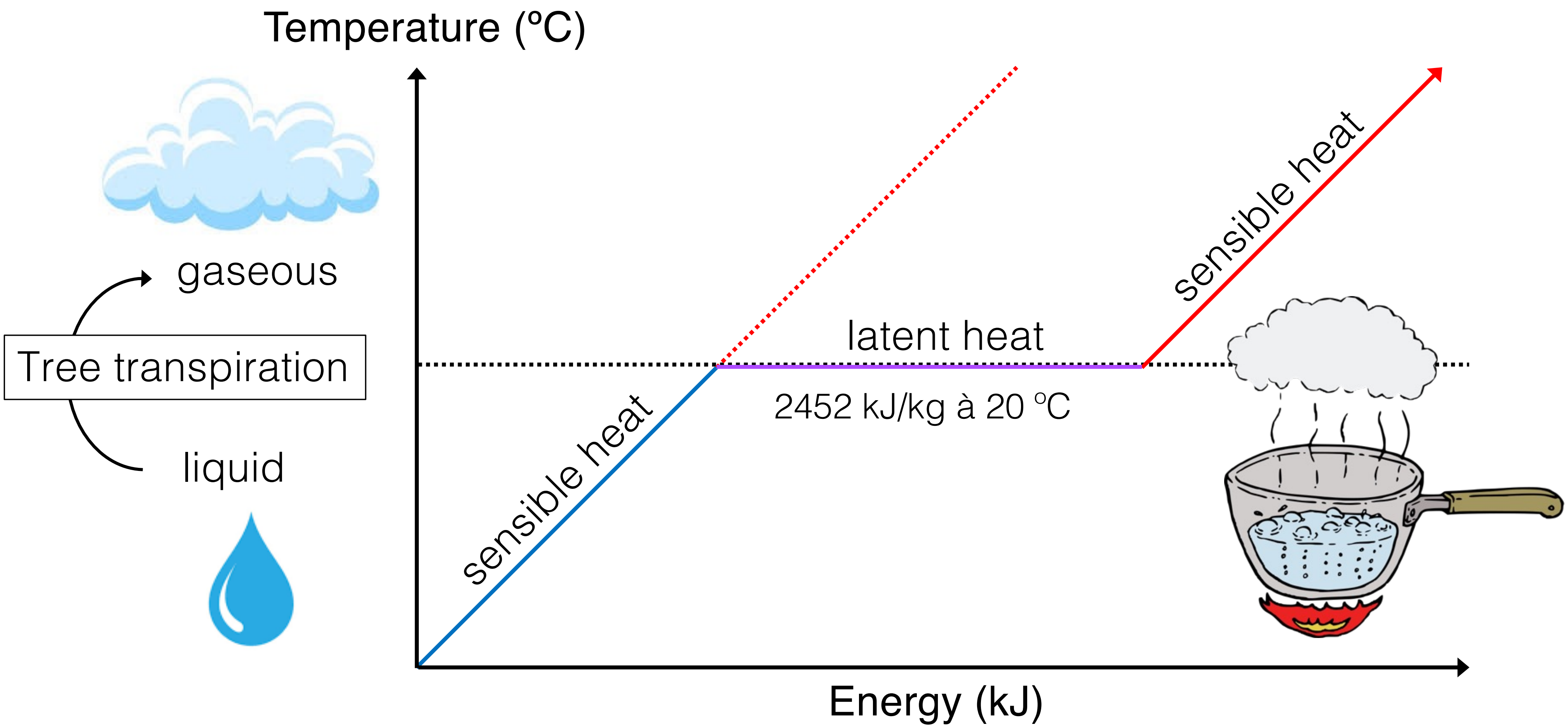
Soil – plant – atmosphere continuum



Cross-section of *Pinus nigra* needle



Transpiration and latent heat cooling



Transpiration and latent heat cooling

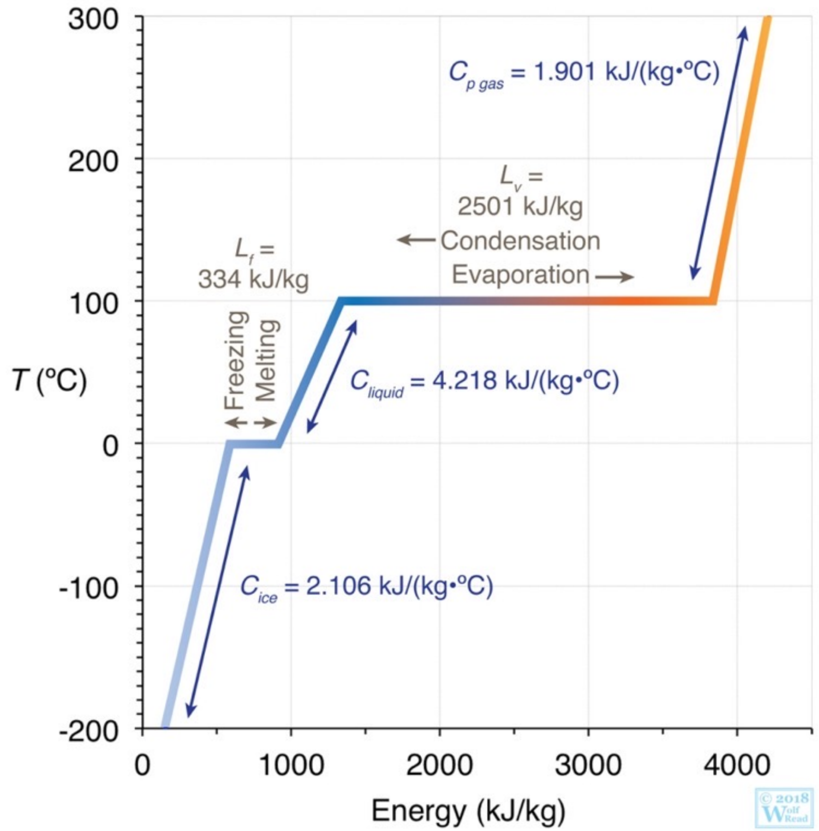
Evapotranspiration uses solar energy to convert liquid water into water vapour, replacing **sensible heat** with **latent heat**, lowering the **Bowen ratio** and temperature of surrounding landscapes.

"Heat loss" from state change of liquid water to water vapour:

- Enthalpy of saturated liquid water: 84 kJ/kg at 20 °C
- Enthalpy of saturated water vapour: 2537 kJ/kg °C
- Latent heat of vapourisation: 2452 kJ/kg at 20 °C

→ To calculate heat loss by transpiration multiply the enthalpy difference by the amount of water loss (in kg)

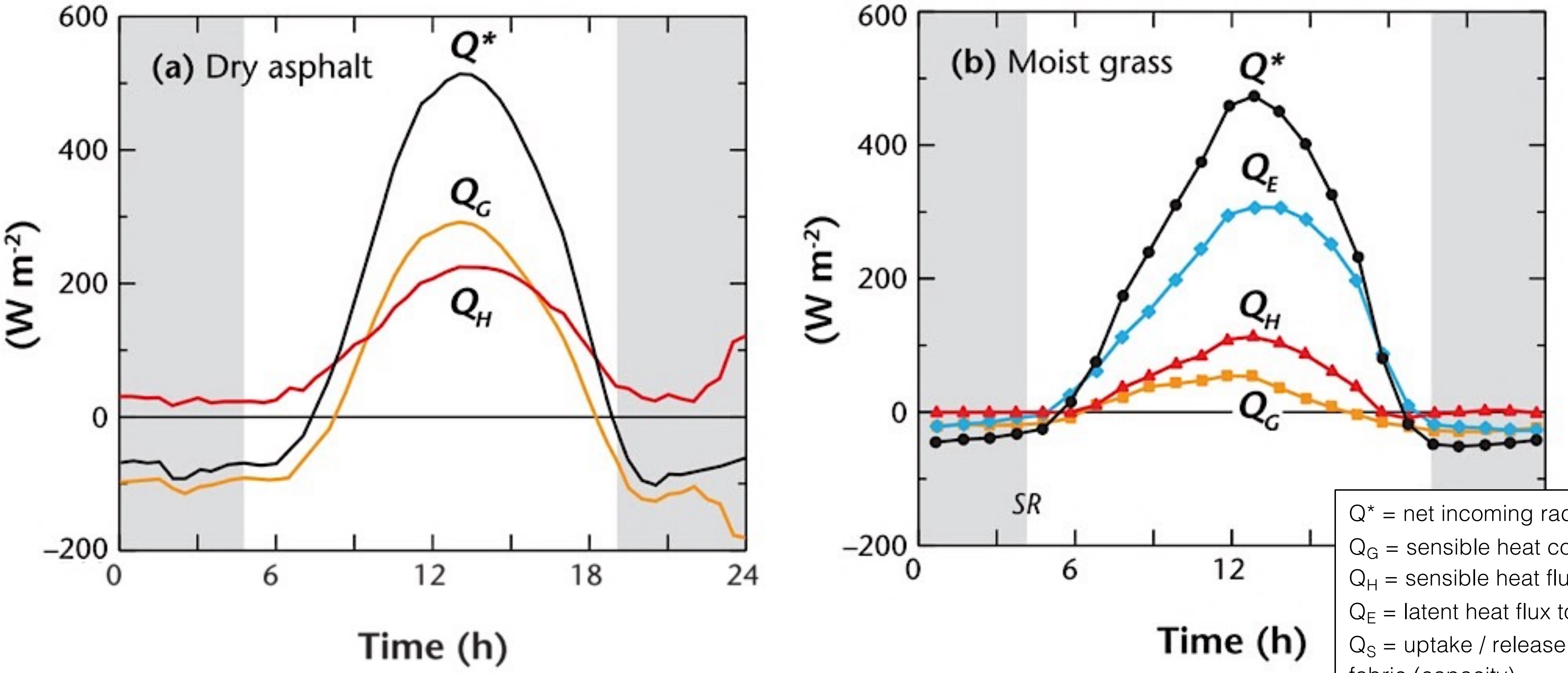
The reduction in sensible heat also lowers **plant canopy surface temperature** and decrease **longwave emission** to surroundings.



Energy required (kJ/kg) for water to go through three phase states: frozen, liquid and gas. Figure adapted from Stull (2017).

Sensible vs. latent heat

Example SEBs of unobstructed urban facets: (a) dry asphalt road near Vienna, Austria. (b) slightly moist grassed site in an urban park in Vancouver, Canada. (Oke et al. 2017)

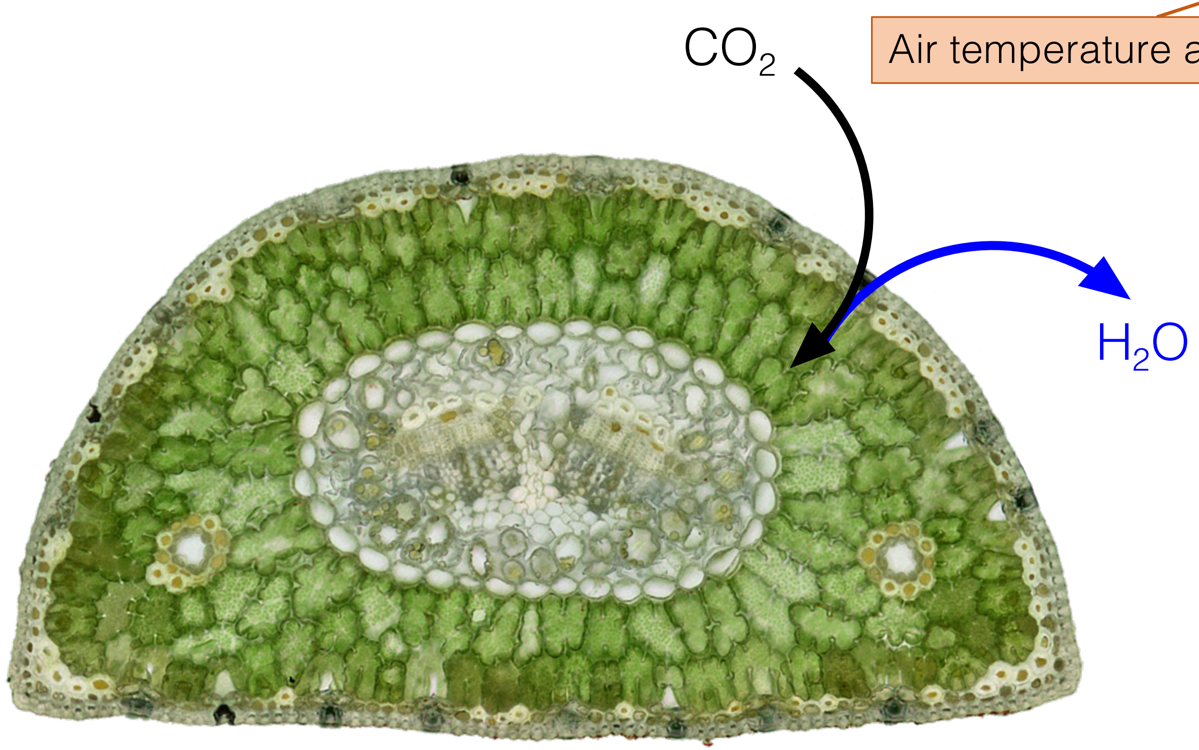


Q^* = net incoming radiation
Q_G = sensible heat conducted to the soil
Q_H = sensible heat flux to the air
Q_E = latent heat flux to the air
Q_S = uptake / release of heat from urban fabric (capacity)
SR and SS = sunrise and sunset

Soil – plant – atmosphere continuum

Vapour pressure deficit (VPD)
Stomatal conductance (g_S)

Air temperature and humidity



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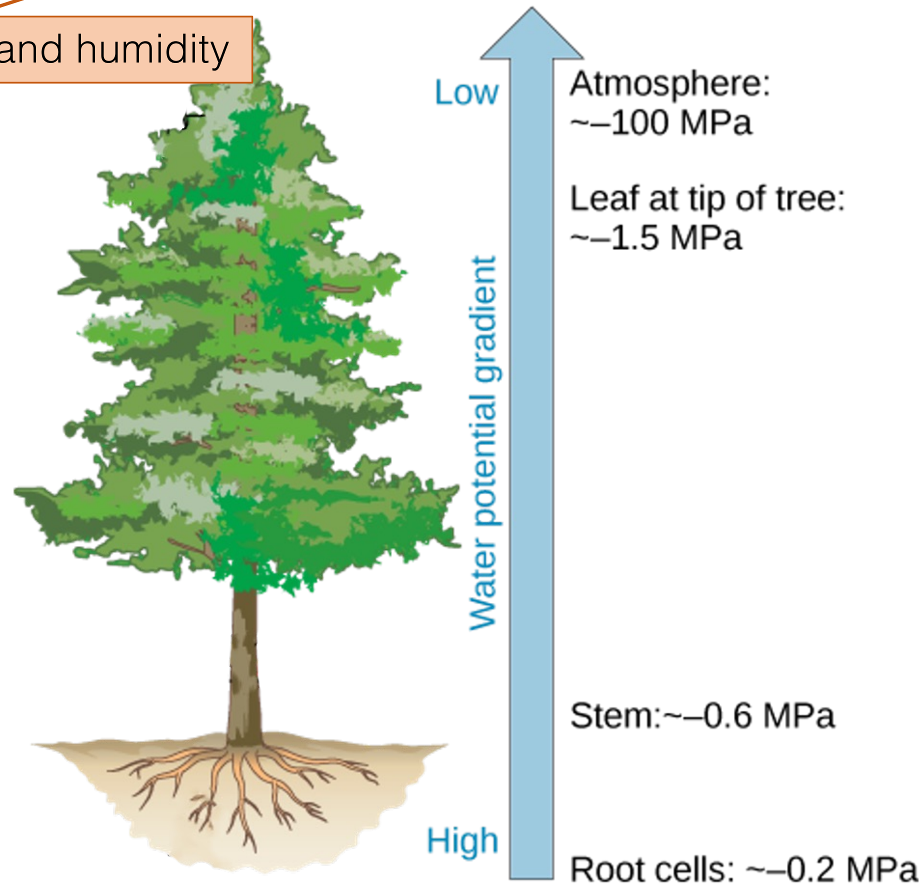
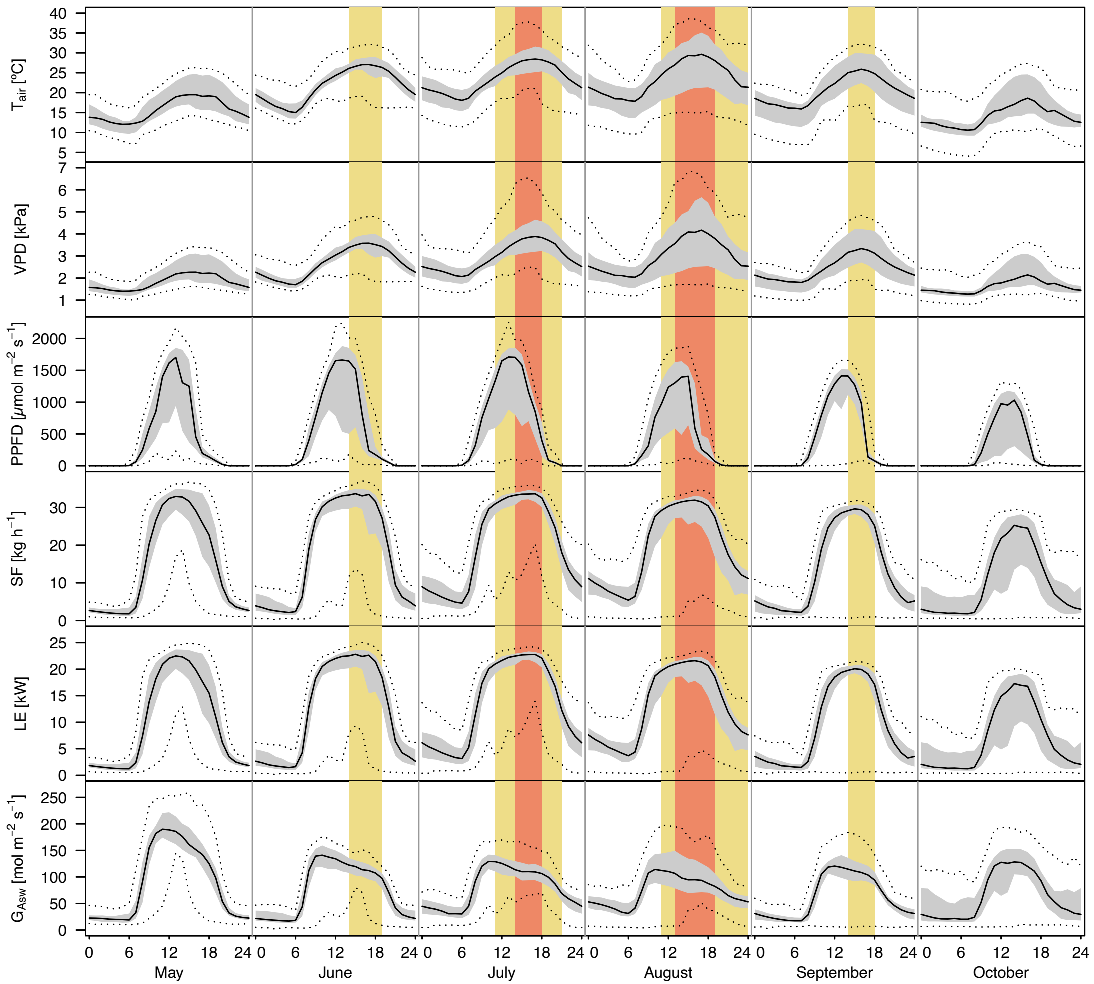


Soil water content
Soil water potential

Water flow through the vegetation



Air temperature (°C)

Vapour pressure deficit (kPa)

Light availability (µmol photons m^{-2} s^{-1})

Sap flow in tree stem (kg water h^{-1})

Latent heat flux (kJ s^{-1})

Canopy conductance for water vapour (mol m^{-2} s^{-1})

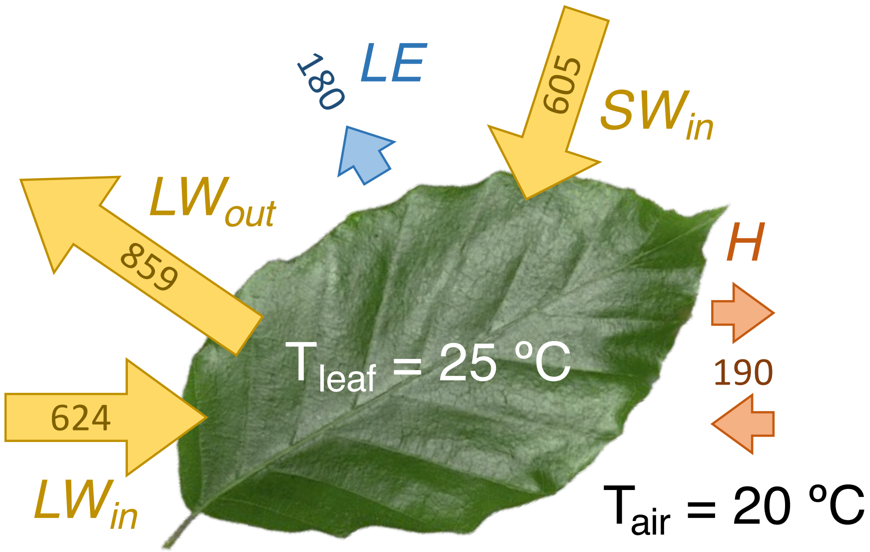
Bachofen et al. 2025

Transpiration cools leaves

SW_{in} : incoming shortwave radiation
LW_{out} : outgoing longwave radiation

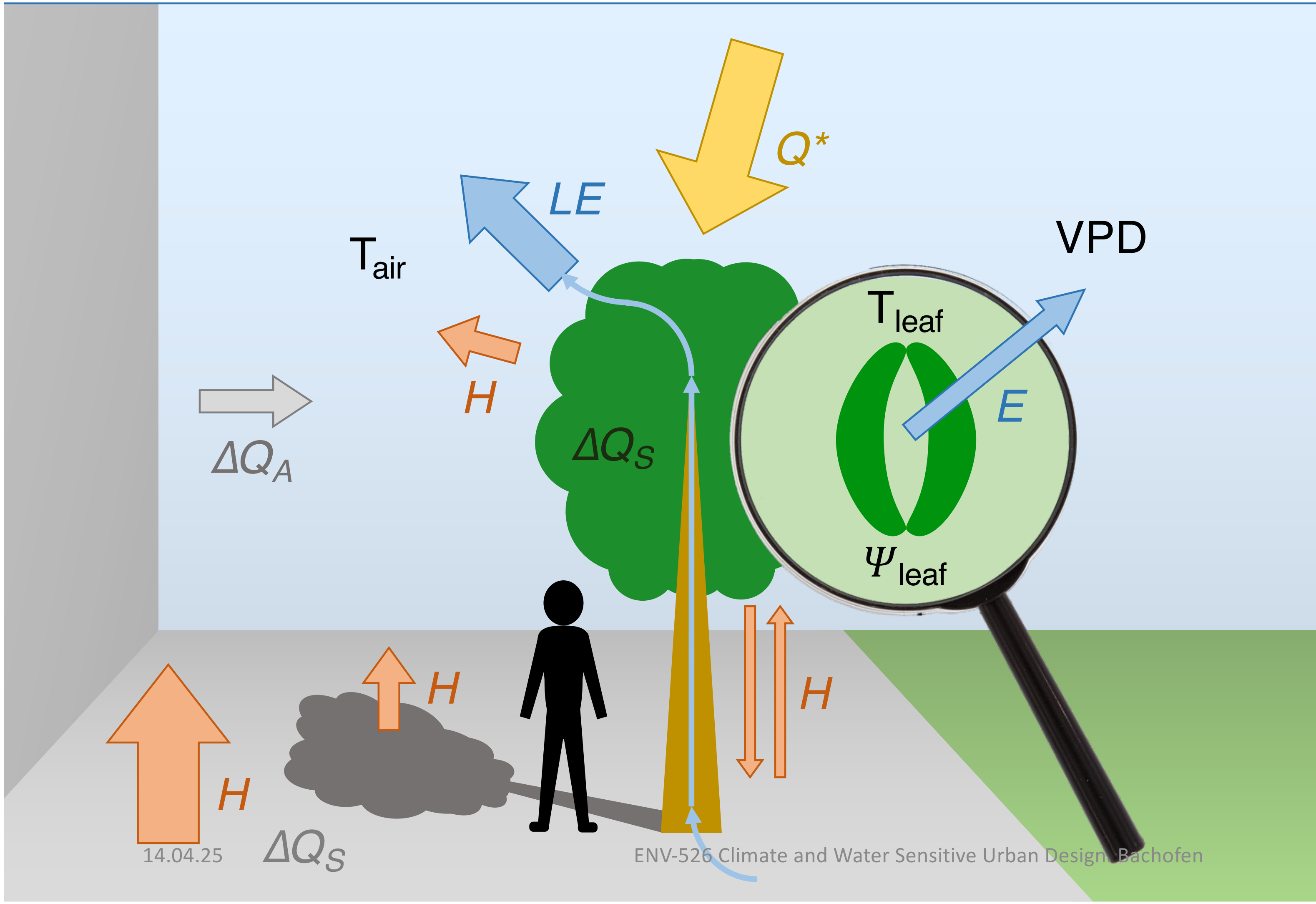
H : sensible heat flow

LE : latent heat flow



after Still et al. 2019

Transpiration cools the environment



Q^* : global incoming radiation

H : sensible heat flow

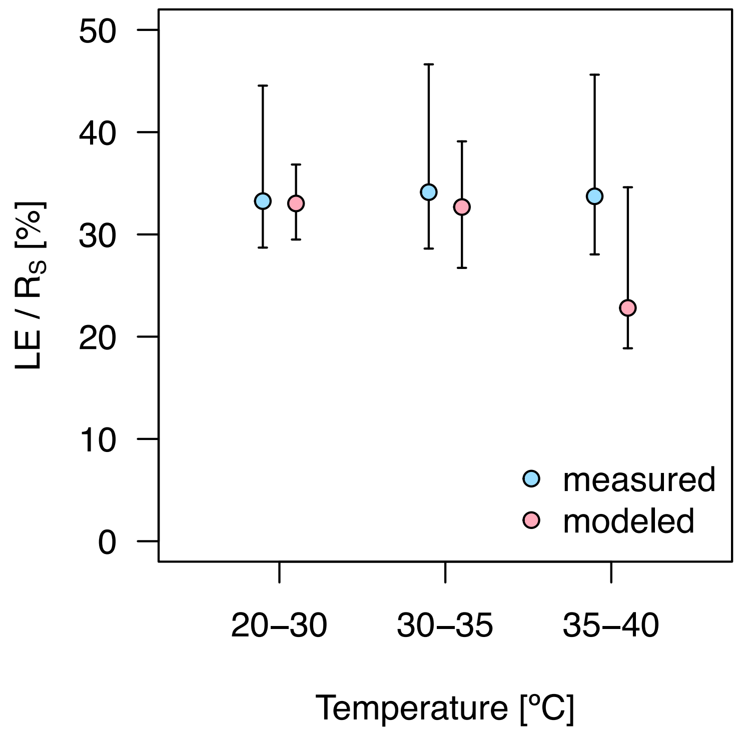
LE : latent heat flow
E : transpiration

ΔQ_A : imported heat
ΔQ_S : stored heat

T_{air} : air temperature
T_{leaf} : leaf temperature
Ψ_{leaf} : leaf water pressure
VPD : air vapour pressure

Transpiration cools the environment

- Approximately a third of the incoming solar energy was mitigated by latent heat cooling in Lancy (Geneva) in summer 2023
- Platanus trees were able to cool even during the most severe heatwaves (air temperatures reaching 40 °C)
- State-of-the-art model predictions underestimated tree cooling



Bachofen et al. 2025

Tree species differ in cooling potential

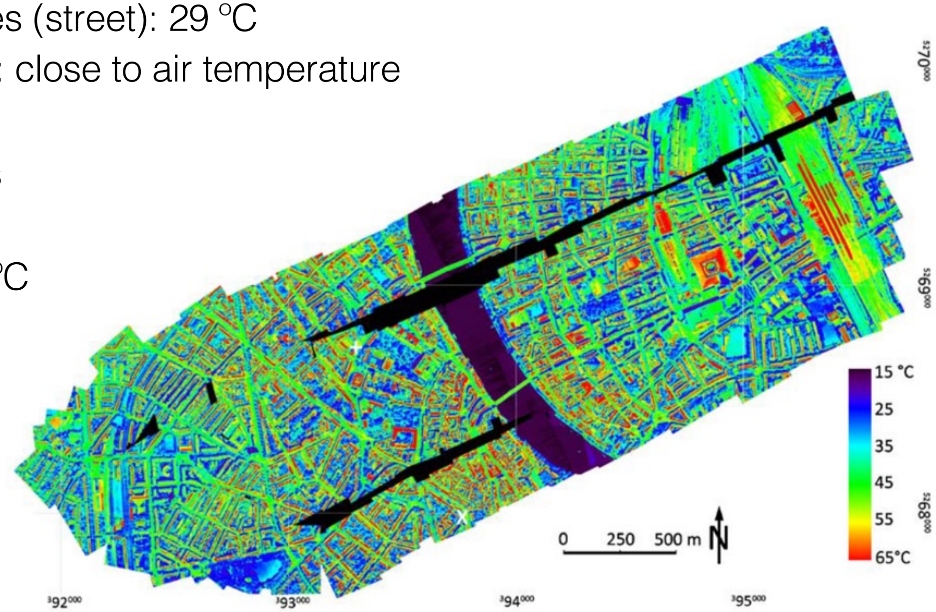
Parts of the city of Basel were scanned from a helicopter using a high-resolution thermal camera. Generally, small-leaved trees remained cooler than large-leaved trees

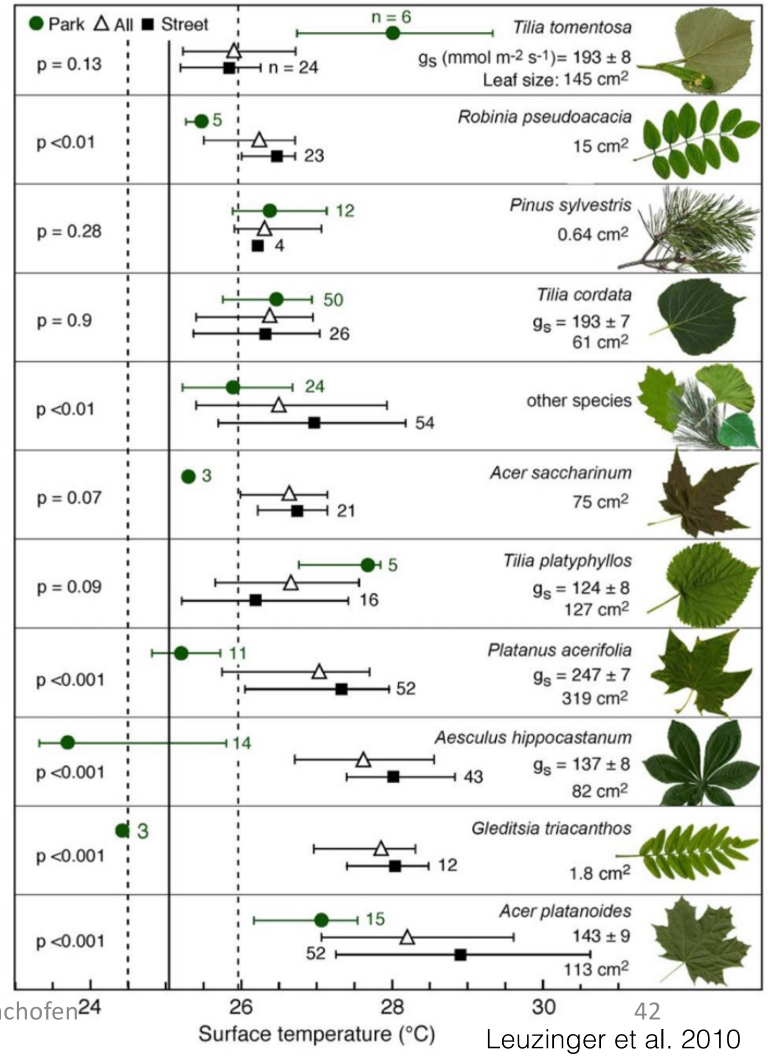
Crown temperatures

- Aesculus hippocastanum (park): 24 °C
- Acer platanoides (street): 29 °C
- Pinus sylvestris: close to air temperature

Peak temperatures

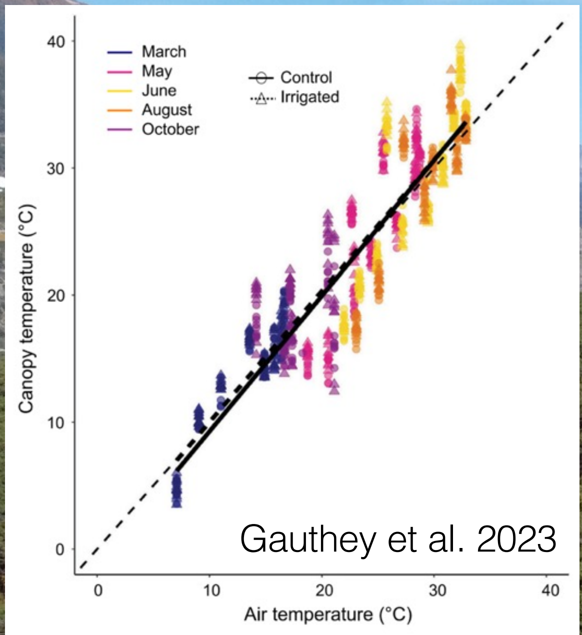
- Water: 18 °C
- Vegetation: 26 °C
- Streets: 37 °C
- Roofs: 45 °C

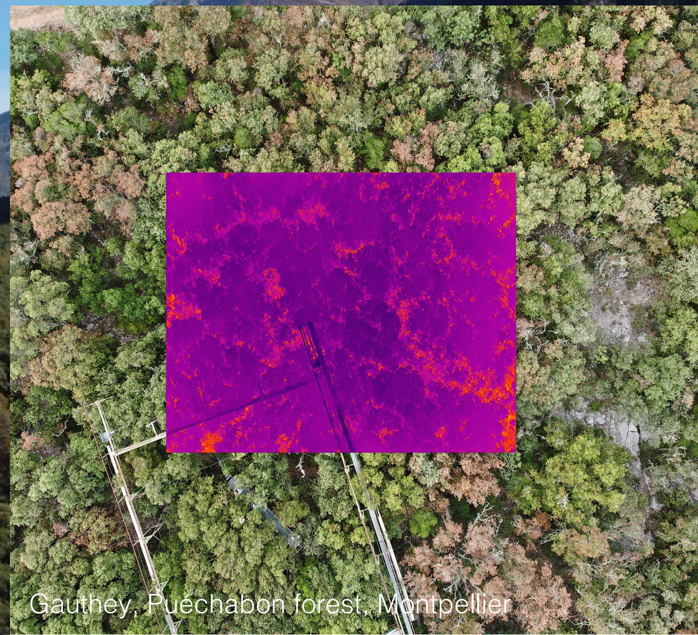




Leuzinger et al. 2010

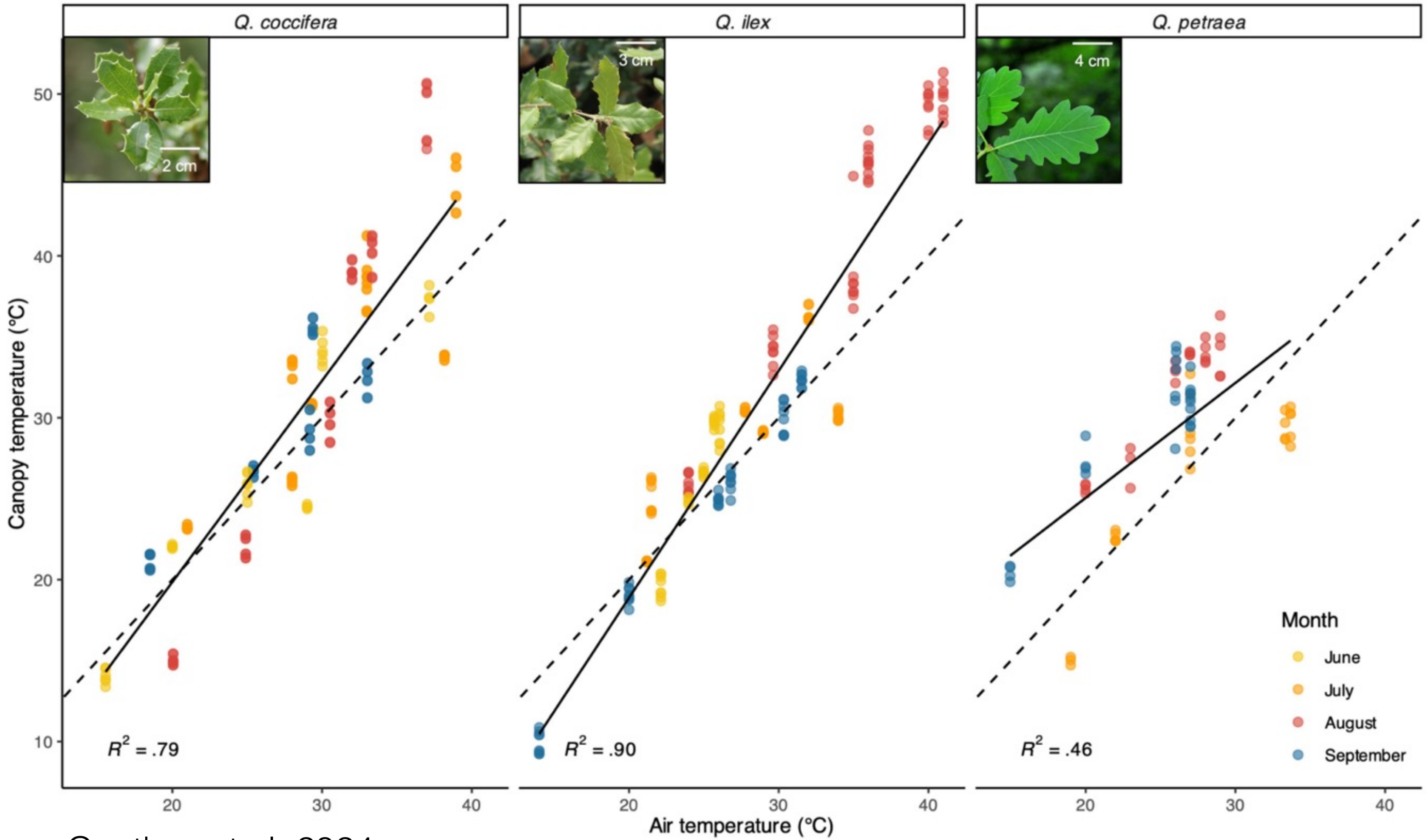
Canopy cooling by transpiration





Canopy cooling by transpiration

→ Species differ in their canopy cooling potential!



Gauthey et al. 2024

Transpiration cooling

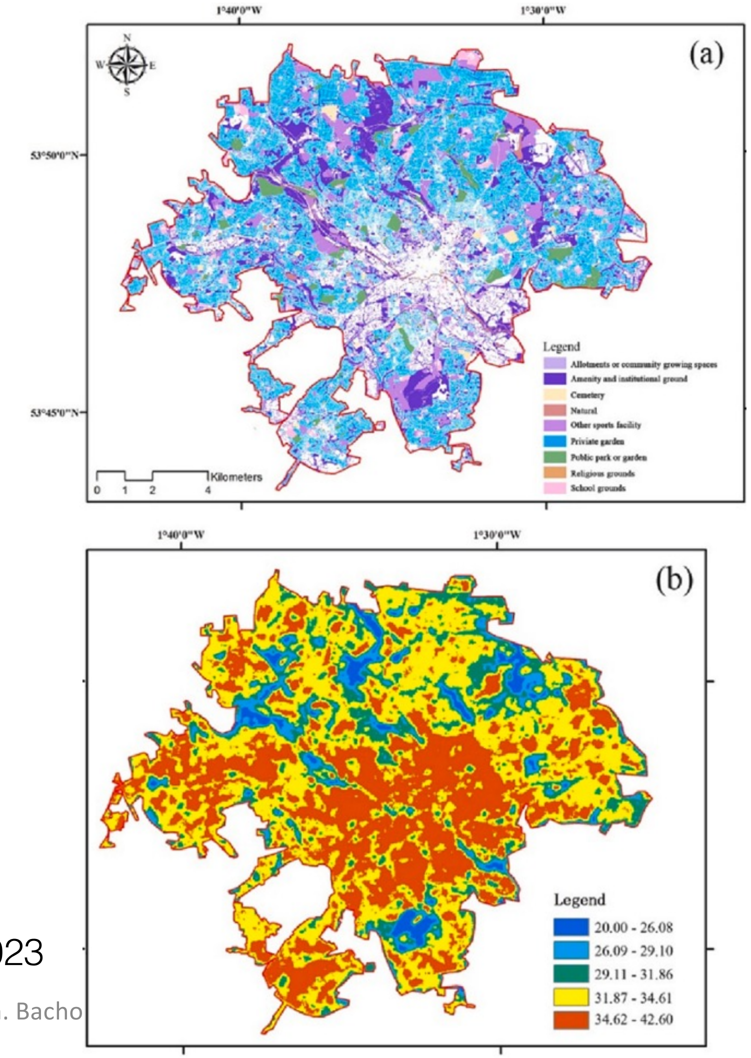
- Vegetation transports water from the soil to the atmosphere through the **soil – plant – atmosphere continuum**
- **Transpiration** at the leaf stomata cools the leaves and the environment
- The environment (**soil water, VPD**), and the vegetation responses to the environment (**stomatal conductance**) co-determine the amount of water flow and cooling effect
- **Species differ** in their cooling potential

Shade

Thermal image on the EPFL campus July 2024

Canopy cover and land surface temperature

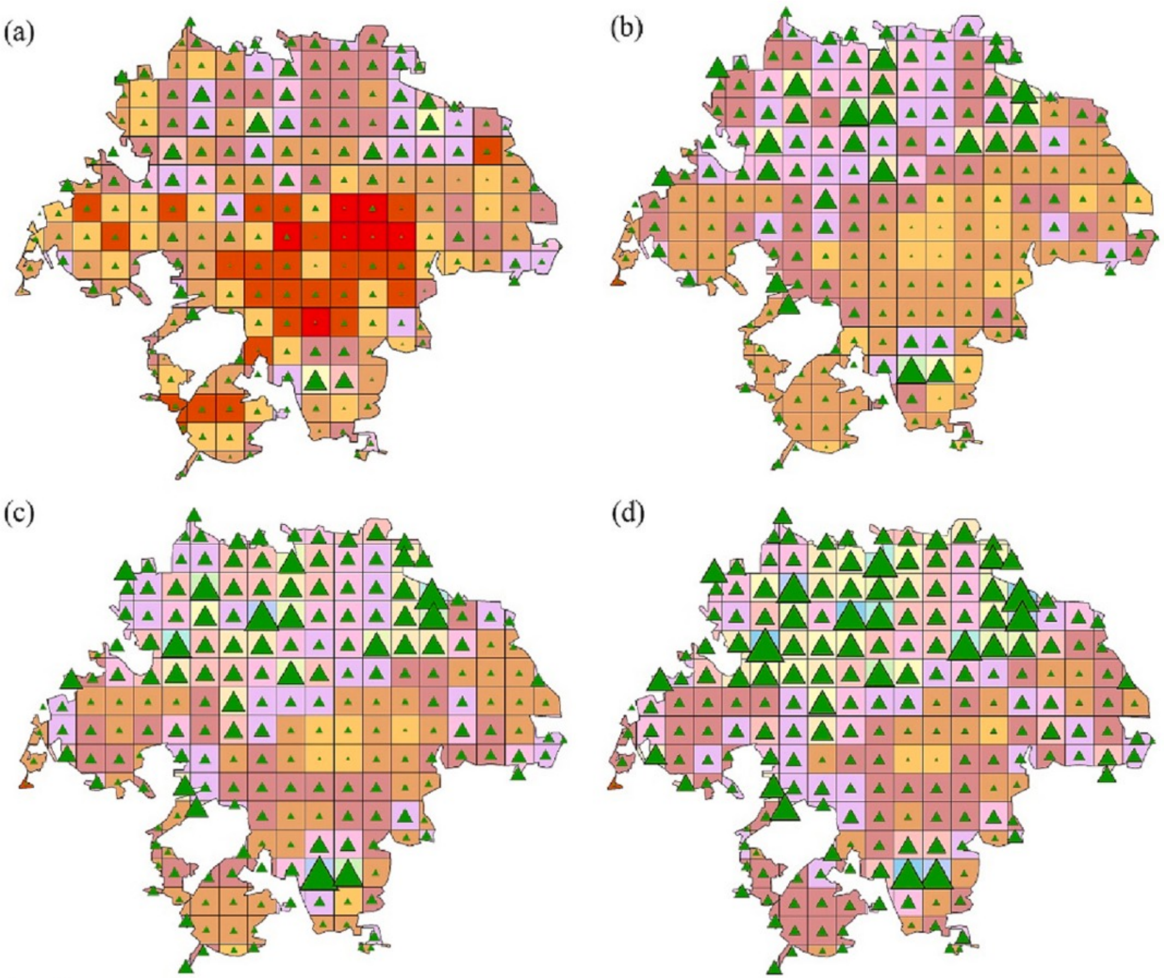
- Land surface temperature (LST) of areas covered by canopy was lower than that of the remaining greenspace
- LST decreased by 1.4 °C for every 10% increase in canopy coverage
- Differences to other vegetated areas: 2.03 °C for sports facilities, 0.26 °C for natural greenspaces



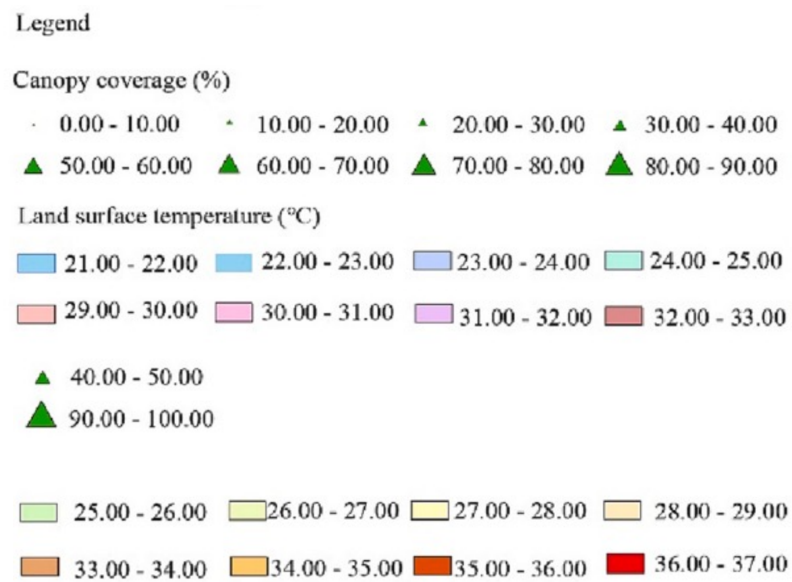
Leeds, UK

Wang et al. 2023

Canopy cover and land surface temperature



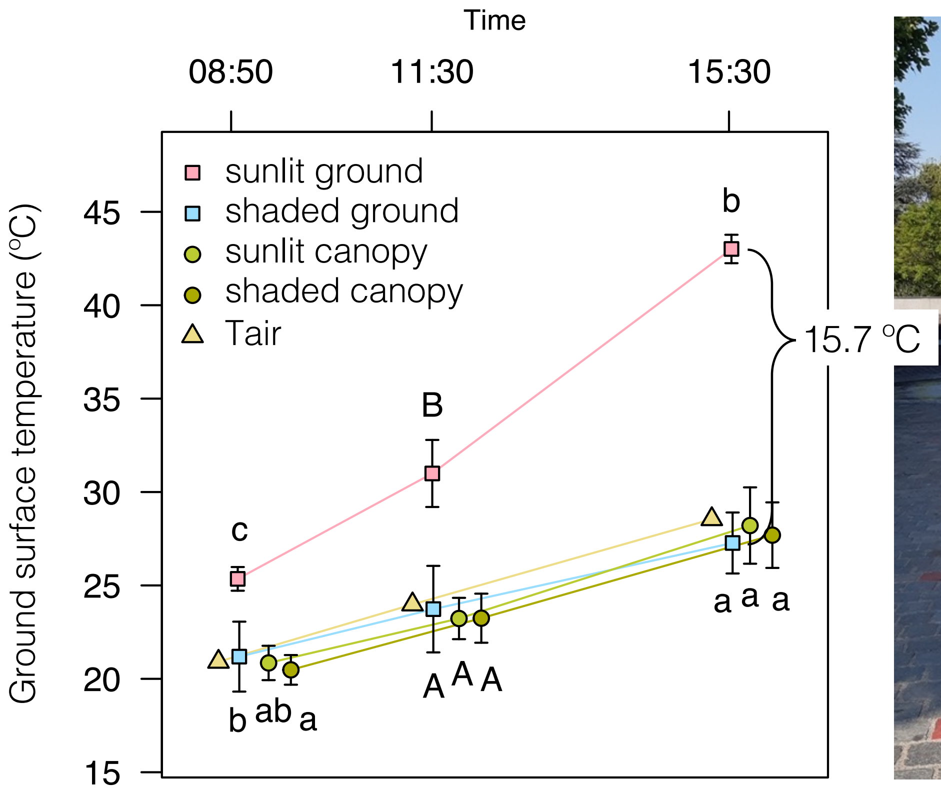
- A doubling of canopy coverage across the city could reduce the mean LST by around 2.5 °C during the warmest summer months



Wang et al. 2023

Shade and tree species

- Linden reduced the ground temperature more than Robinia
- Tree standing on grass: 3 °C lower LST per unit LAI (leaf area)
- Tree standing on asphalt: 6 °C lower LST per unit LAI (leaf area)

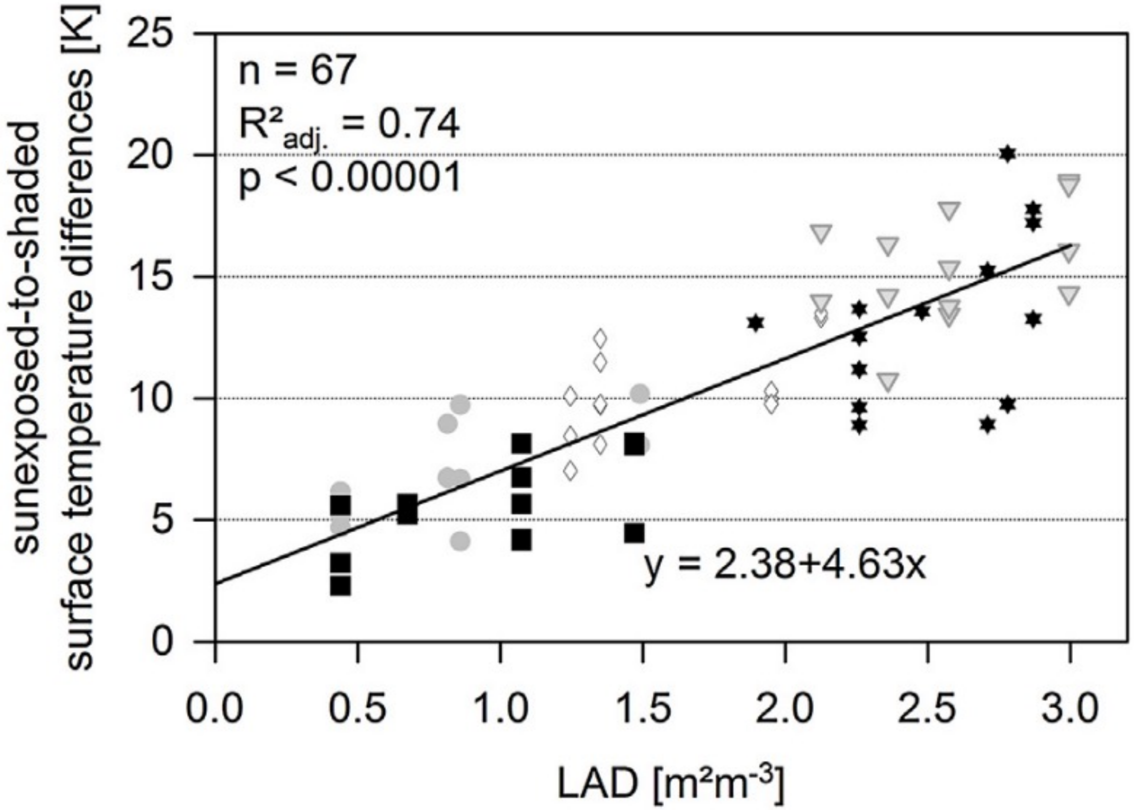


Munich, Rahman et al. 2019

Genève 2023

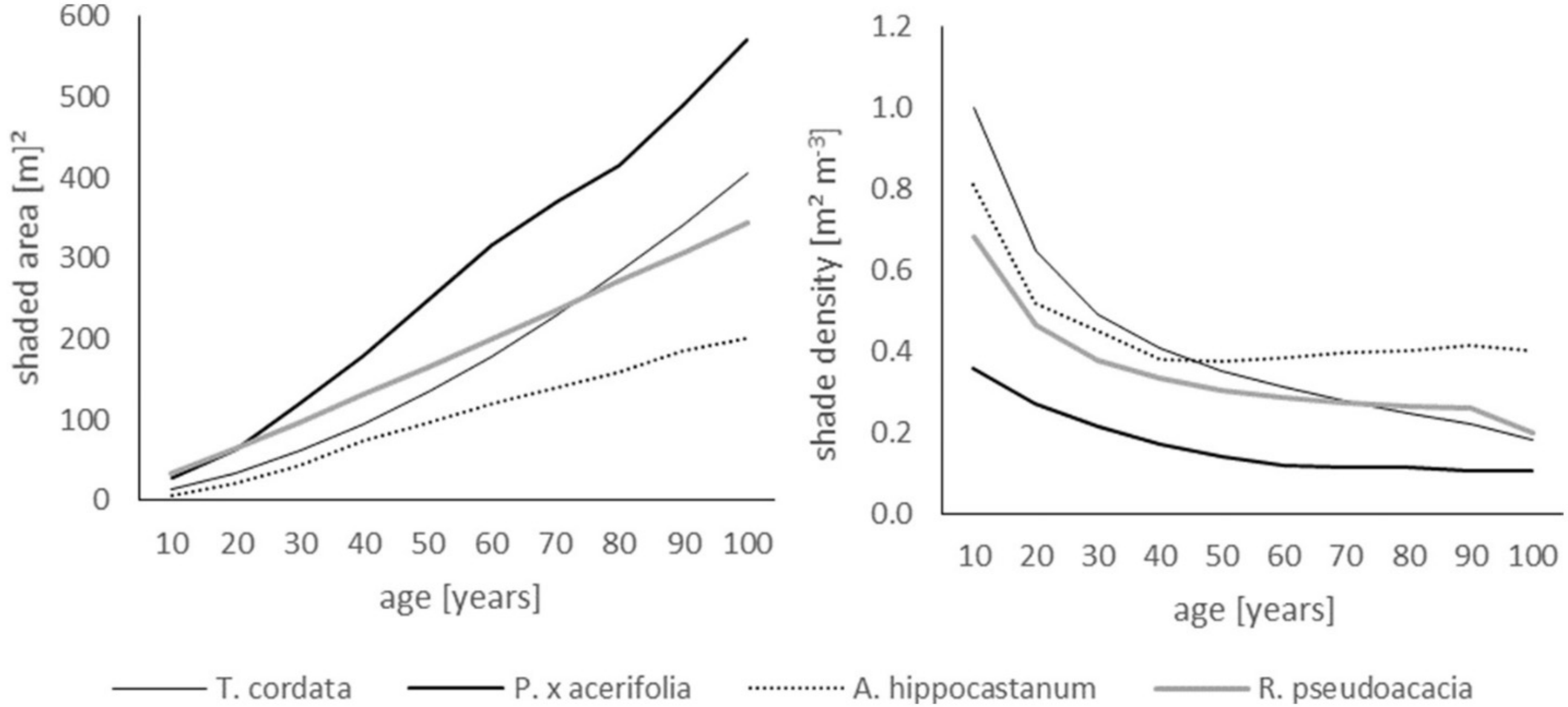
Shade cooling and canopy density

- Leaf area density (LAD) = leaf area per unit crown volume [m^2 m^{-3}]
- Shade cooling is directly related to LAD
- 4.63 K surface cooling per unit of LAD



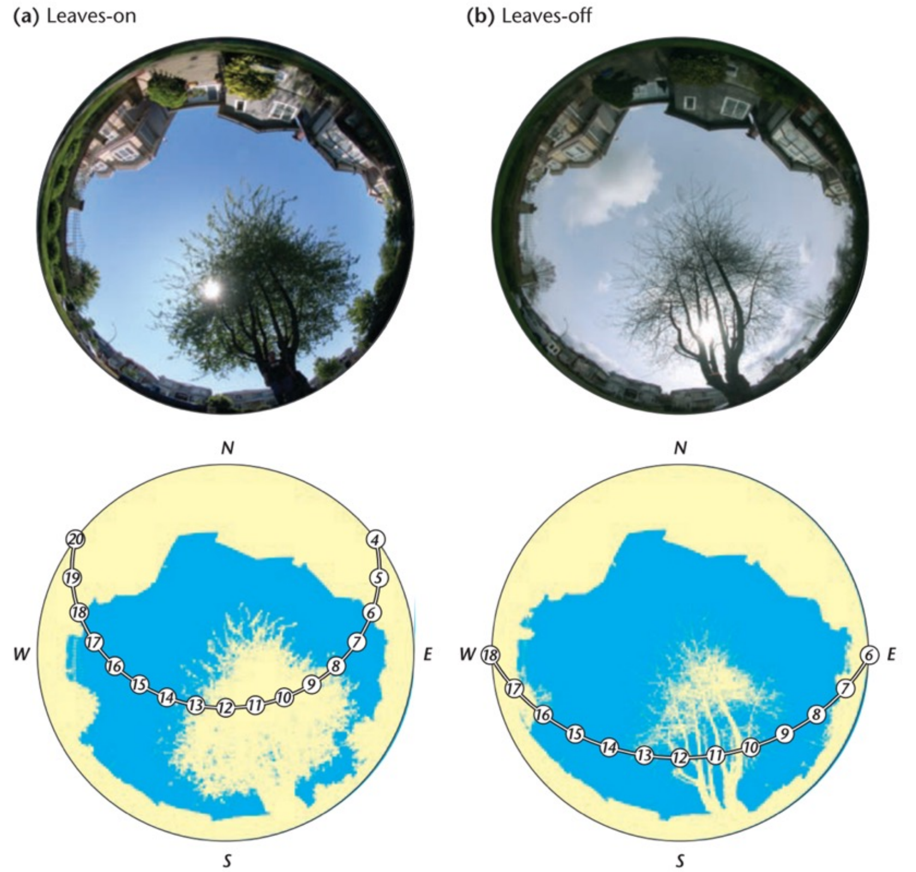
Gillner et al. 2015

Shade and tree size



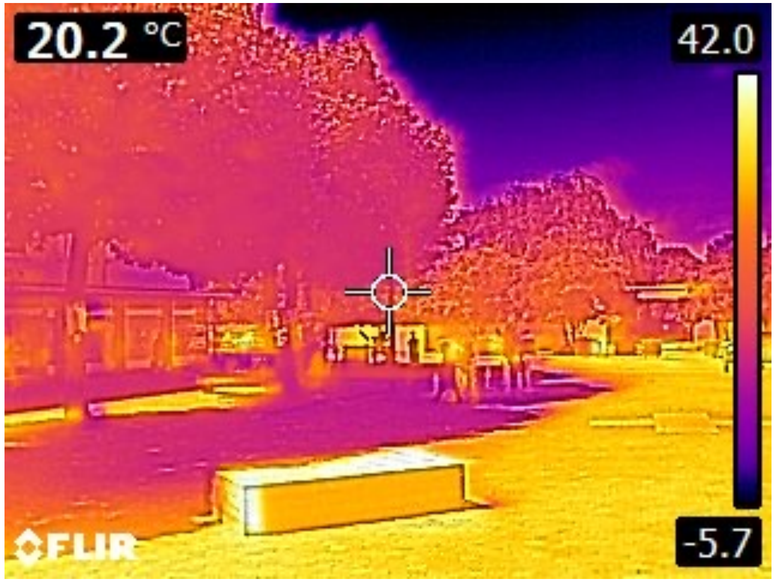
Rötzer et al. 2019

Shade: seasonality



Oke et al. 2017

While deciduous intercept 70–90% of solar radiation in summer, they intercept only 20–50% in winter. Coniferous species intercept 70–90% year round.



Thermal image of Lancy, near Geneva, August 2023

Shade and air temperature

- Urban tree canopy reduces daytime air temperatures (–0.026 °C per % cover)
- Tree canopy effects are reduced from –0.026 °C during the day to –0.016 °C at night
- Main driver of tree cooling: Tree canopy shades other surfaces, reducing solar radiation and stored heat
- Tree canopy increases surface albedos compared to asphalt

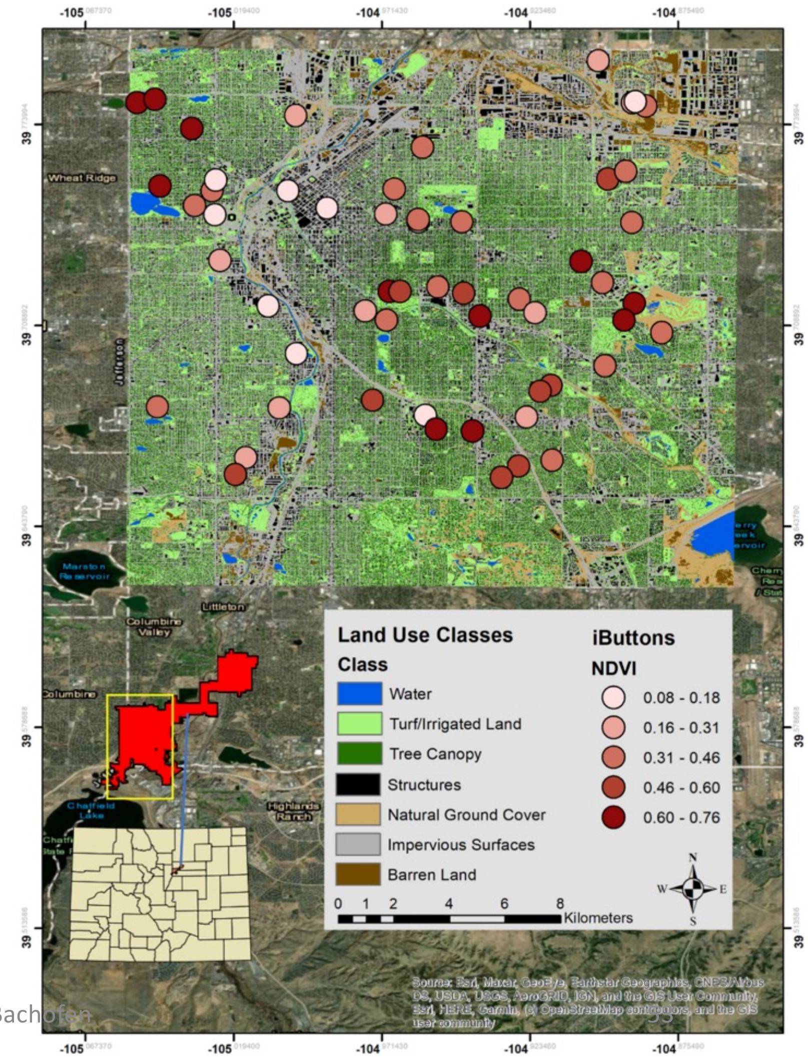


Fig. 1. Denver Regional Council ofGovernments land use-landcover imagery, overlaid with the iButton microclimate sensor locations (location size is visually enlarged and does not represent the exact 60 m buffer size), stratified against urban greenness (Normalized Difference Vegetation Index, NDVI).

Denver, US

Ibsen et al. 2022

The (un-)importance of transpiration versus shading of urban trees

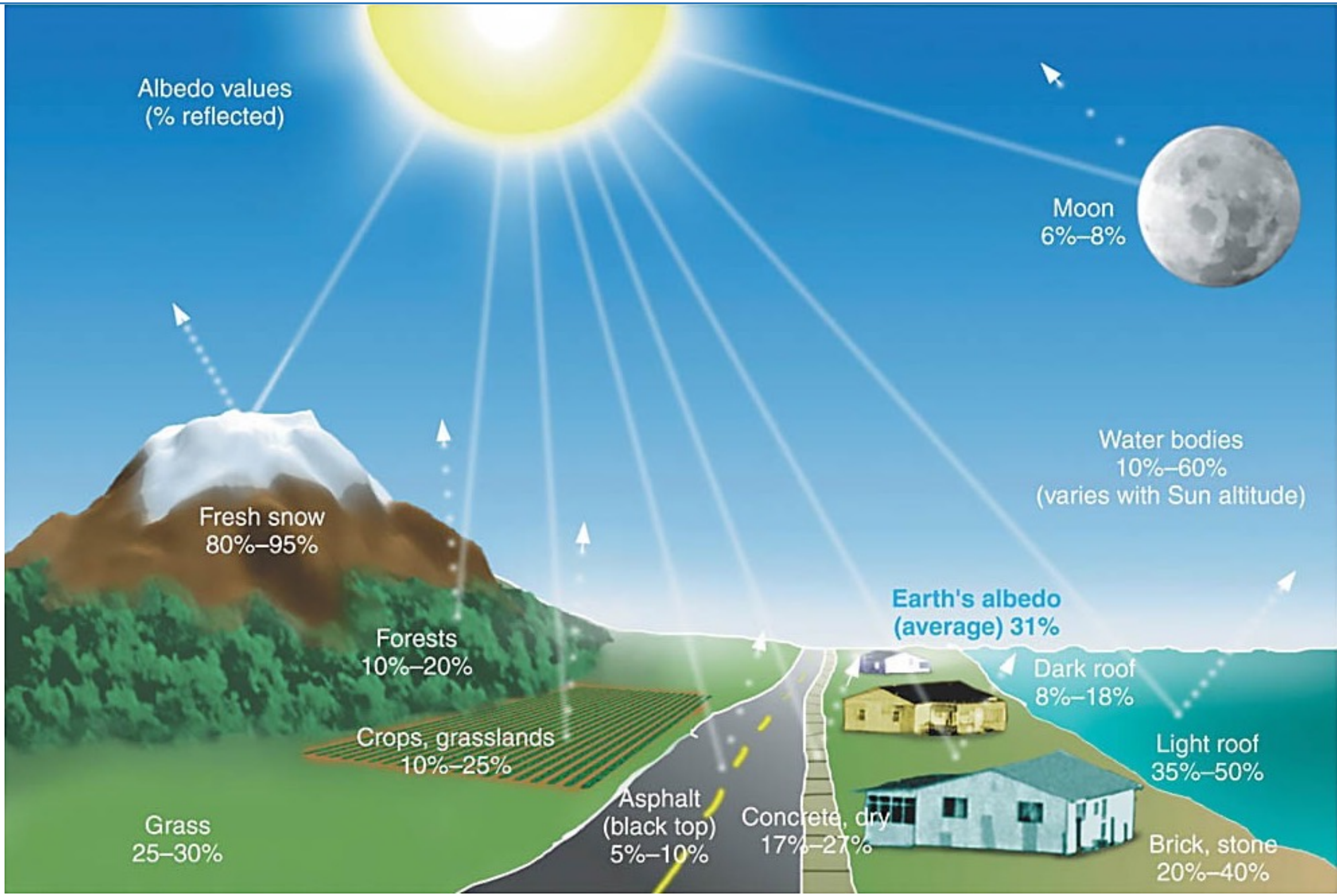
"Lowry (1988) made a simple calculation of the transpiration cooling provided by a rather dense array of six trees, each with a leaf area of 25 m^2, placed along 10 m of a street canyon with a 10 m x 10 m cross section.

Assuming an average **leaf transpiration rate** of about 70 W m^{-2} at midday and a **canyon ventilation rate** of 100 volume changes per hour, the resulting **cooling rate is 0.3 K h^{-1}**. For comparison, using the urban canyon observations of Nunez & Oke (1977) to characterize the sensible heat fluxes into a bare canyon (walls 25 W m^{-2}, floor 300 W m^{-2}) and the other conditions as before, gives a **warming rate of about 1.0 K h^{-1}**.

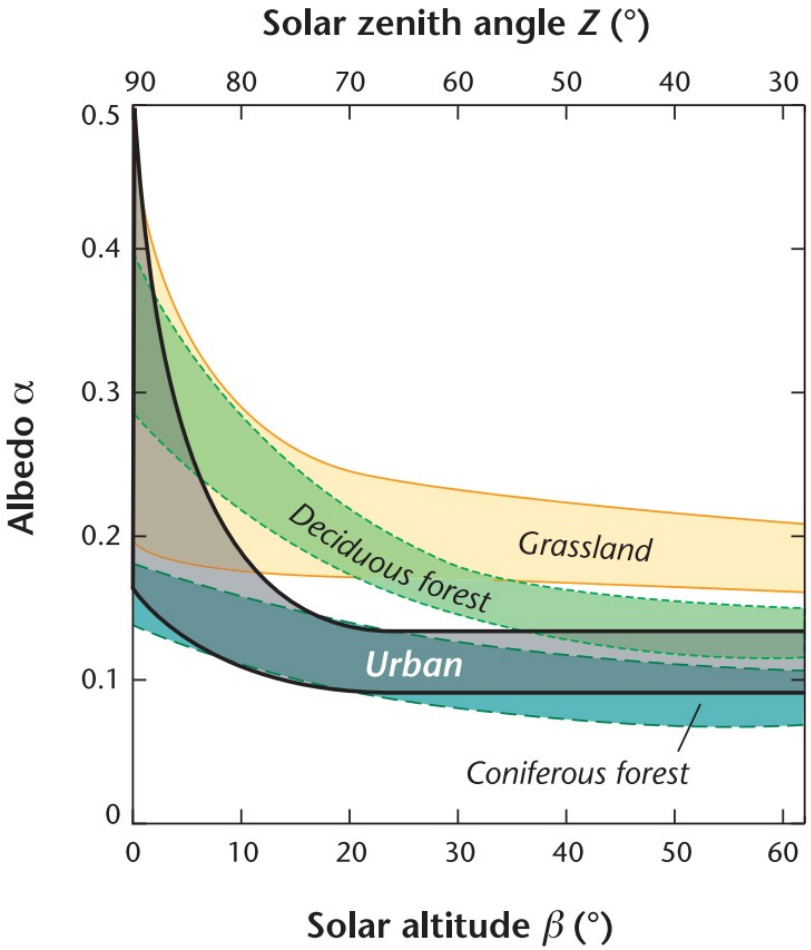
The case in the real world is complicated by such features as the shading of the trees, oasis advection and the probability that much of the transpiration occurs from the top of the trees and doesn't mix throughout the volume, but the calculation helps to put the cooling effects in realistic perspective. **A few saplings are certainly not effective; the case of large mature trees deserves detailed scrutiny**. These conclusions should not be construed to deny the cooling effects of trees due to their shade nor to minimize the role of the cool foliage and shaded areas as radiant heat sinks for surrounding hot surfaces. Also, the collective impact of trees on heat fluxes at the mesoscale can be great."

Oke et al. 2018

Albedo


Albedo values
(% reflected)
Moon
6%–8%
Water bodies
10%–60%
(varies with Sun altitude)
Fresh snow
80%–95%
Earth's albedo
(average) 31%
Forests
10%–20%
Dark roof
8%–18%
Crops, grasslands
10%–25%
Light roof
35%–50%
Asphalt
(black top)
5%–10%
Concrete, dry
17%–27%
Grass
25–30%
Brick, stone
20%–40%

Albedo

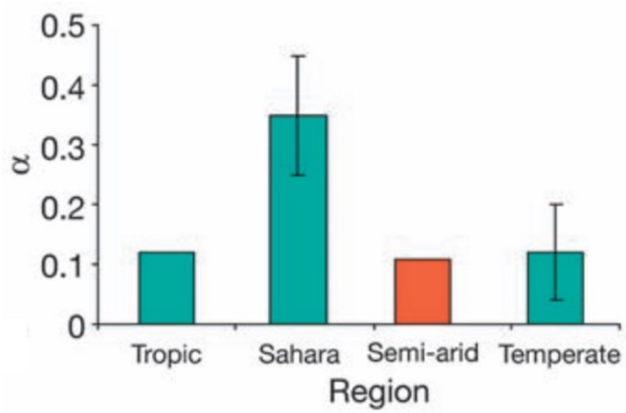


- In snow-free conditions urban and suburban albedo values are slightly (< 0.10) lower than in the surrounding countryside
- Cities surrounded by tropical or coniferous forest may have similar albedo

Figure 5.16 Relation between surface albedo α and solar altitude angle β (bottom axis) or zenith angle Z (top axis) for snow-free conditions.

Albedo and aforestation / desertification

- Forests are relatively dark and absorb incoming solar radiation (low albedo) that is converted into heat, causing local warming
- The atmosphere above deserts is overall cooler than above forests
- Desertification has thus likely contributed local cooling and partly offset the global warming from the carbon release



Albedo of different eco-systems. The semi-arid eco-system is represented by Yatir forest.

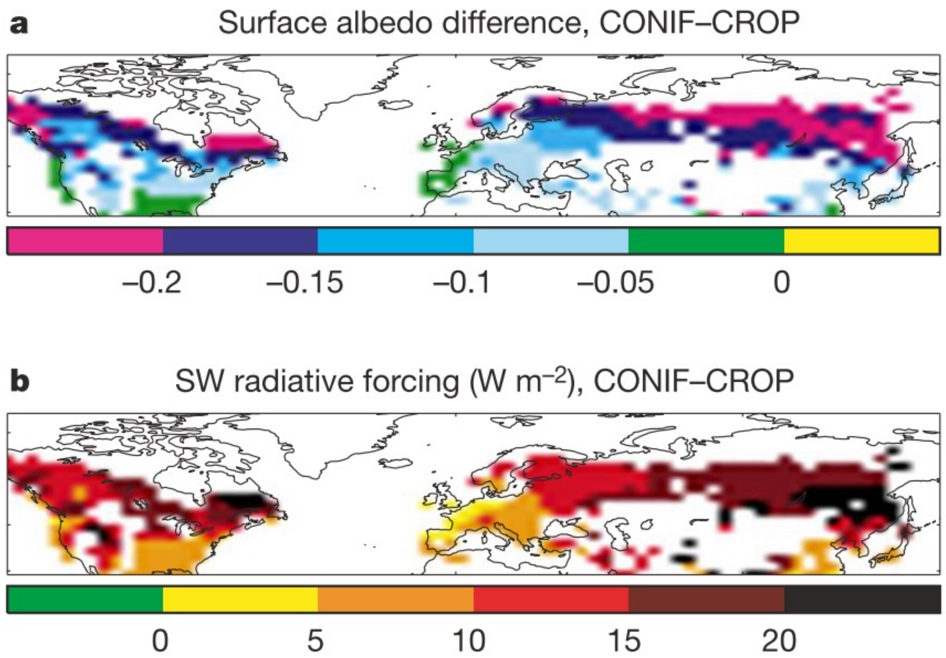


Figure 1: Effects of aforestation on the solar radiation budget
a) Simulated difference in annual-mean surface albedo
b) Simulated local shortwave (SW) radiative forcing at the tropopause due to surface albedo change

Betts 2000, Nature
Rottenberg 2010, Nature
Schimel 2010, Science

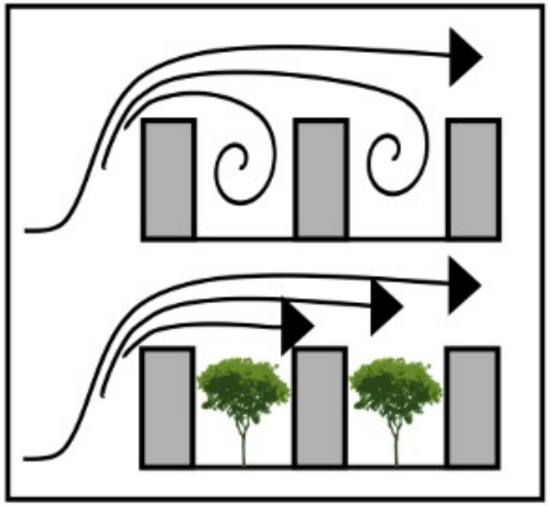
Surface roughness

Surface roughness regulates exchanges between the street level air and that above roof level.

- Mid-rise neighbourhoods (LCZ 2 and 5): mature trees are often about the same height as buildings and 'cushion' their effects on wind.
- In streets: a tree canopy disturbs circulations that might otherwise form.

→ If the canopy the space between buildings ventilation of street air is greatly restricted.
→ This degrades air quality at street level because ventilation of traffic emissions is disrupted.

Evergreen vs. deciduous trees:
The aerodynamic properties of an evergreen canopy remain similar through the year whereas a deciduous canopy provides significant slowing and shelter only in summer.

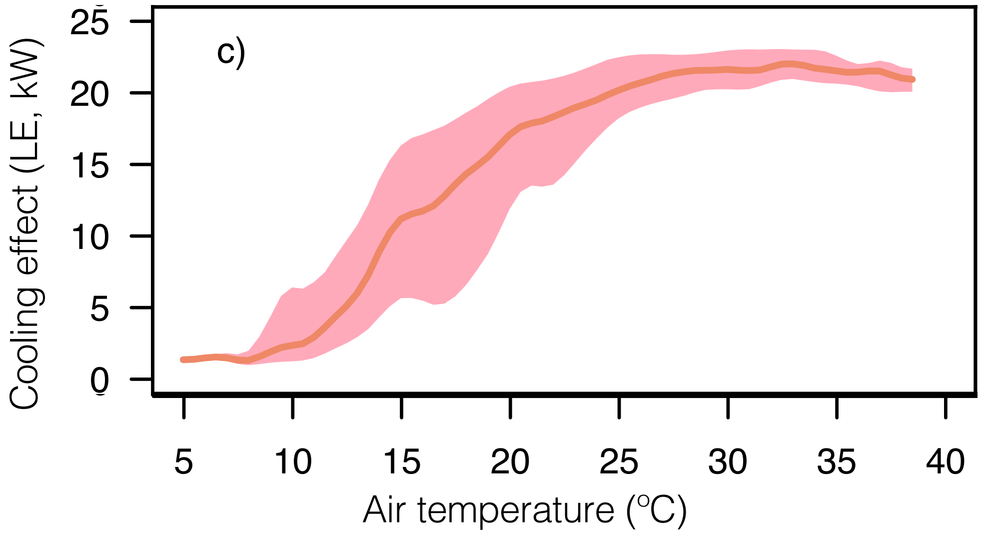


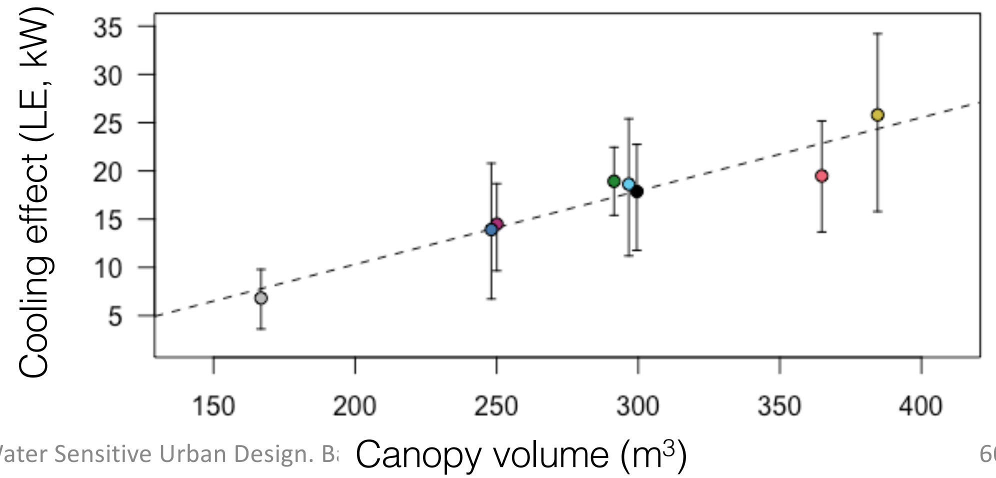
Meili et al. 2021

Figure 15.22 The seasonal character of deciduous trees can transform streets and their climates. (Oke et al. 2017)

Examples of vegetation cooling

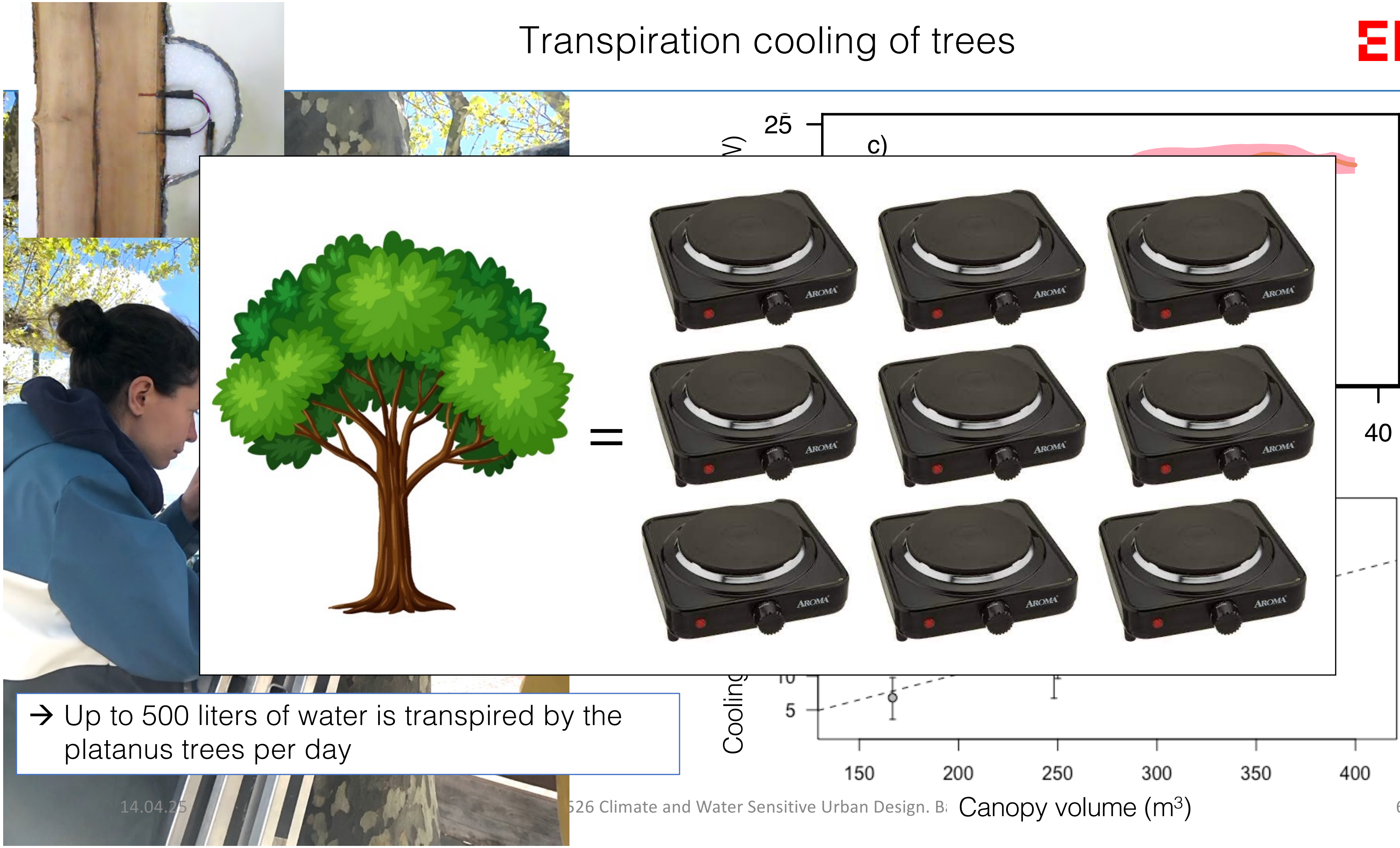
Transpiration cooling of trees





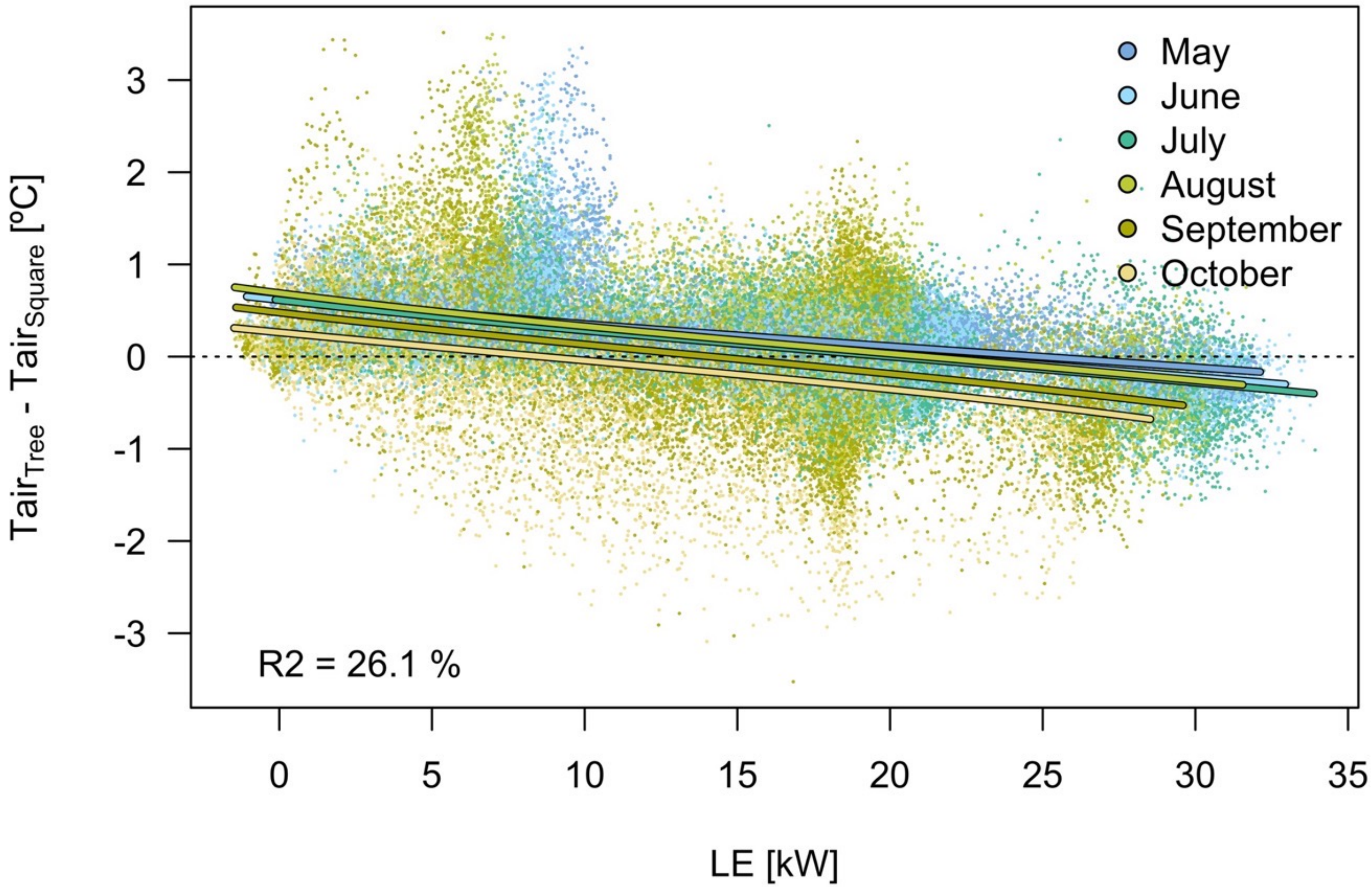
→ Up to 500 liters of water is transpired by the platanus trees per day

Transpiration cooling of trees



→ Up to 500 liters of water is transpired by the platanus trees per day

Relationship between transpiration and air temperature



Example studies: urban tree shade and transpiration

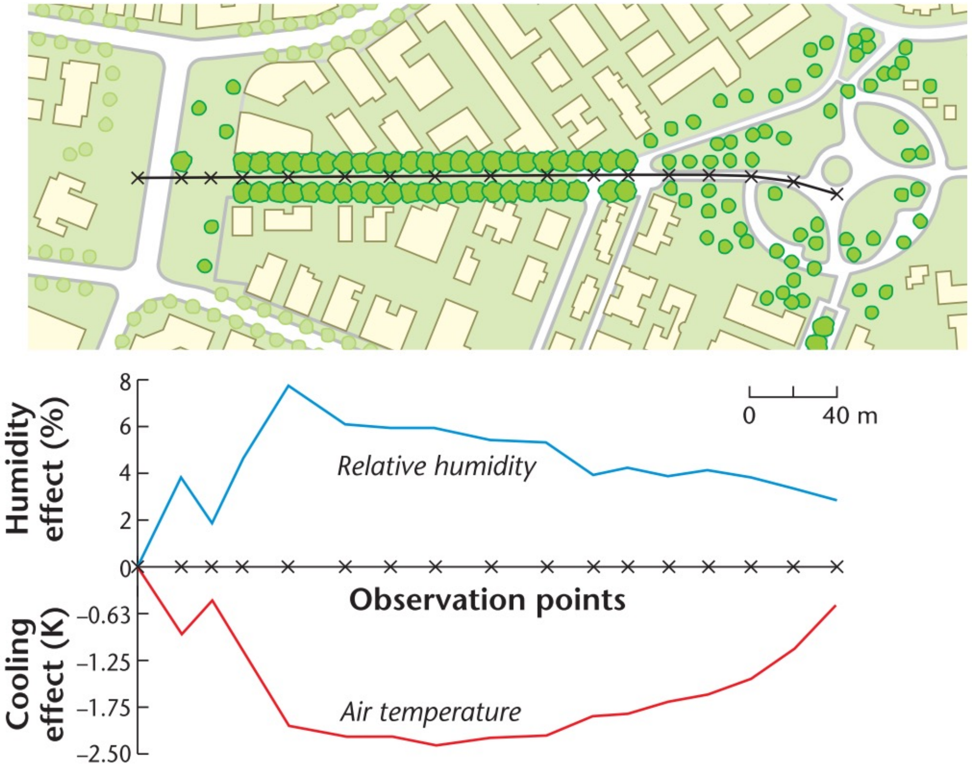


Figure 15.24 The humidity and cooling effects along Hayeled Avenue in Tel Aviv, Israel. The lower graph shows deviations from a reference point and the symbols correspond to measurements made at different points along the avenue. (Oke et al. 2017, Shashua-Bar & Hoffmann 2000)

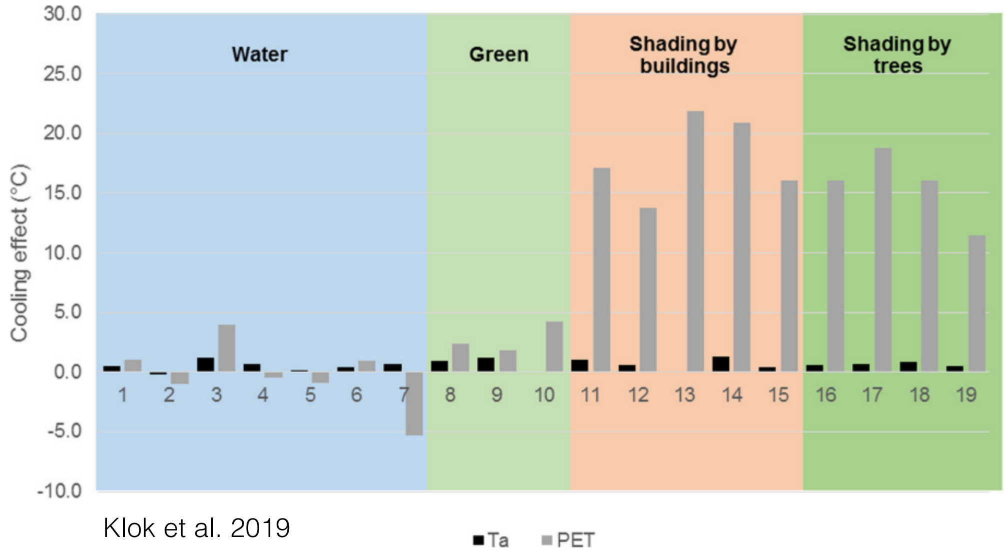
Air temperature and relative humidity measured close to the surface along a tree-lined avenue under calm conditions in a hot and dry climate (Tel Aviv)

- Cooling impact of the trees on Ta and RH is closely related to the area of shade
- Cooling effect of the trees is confined to the immediate surroundings due to weak advection
- Physiological impact on pedestrians is even greater, because trees reduce radiation directly through shade, and indirectly by lowering the mean radiant temperature of the surroundings

→ In another climate or during different weather, the thermal impact of the same tree-lined avenue **may be reduced**, for example in **cloudy conditions** the impacts of shade and solar interception by the canopy are less or in **humid conditions** evaporation is suppressed and in **windy conditions** effects are diluted.

Measuring heat island mitigation by vegetation

- **Empirical studies linking tree physiology to cooling potential are surprisingly rare!**
- Focus on spatial patterns of the UHI phenomenon



Klok et al. 2019

	ltstraat
D	Frederiksplein
E	Leidseplein
F	Mahlerplein
G	Museumstraat
H	Oosterdok – roof*
I	Oosterdokskade
J	Rembrandtplein
K	Spui
L	Stationsplein
M	Thorbeckeplein
N	Museumplein
O	Vondelpark
P	Frederiksplein fountain
Q	IJ promenade
R	Magere Brug
S	Museumplein pond
T	Reguliersgracht
U	Weesperzijde

Fig. 1 Map of the measurement sites. The colour indicates the type of location: grey are impervious urban spaces, green are parks with grass, shrubs and trees, and blue are locations near urban water. The locations are numbered in alphabetical order. *Data measured at Oosterdok are not used in this paper

Different cooling effects in the city: shade, evapotranspiration, albedo

- Measurement in two semi-enclosed courtyards in the Negev highlands over a 45-day period during summer (daytime temperatures > 30 °C).
- Different strategies to test the impact on near-surface air temperature: combinations of trees, grass and shading mesh.

→ The most effective scheme (up to 2 K cooler) uses trees that provide both shade and evaporative cooling.

→ Using grass alone was largely ineffective and the use of mesh shading produced a counterintuitive warming effect.

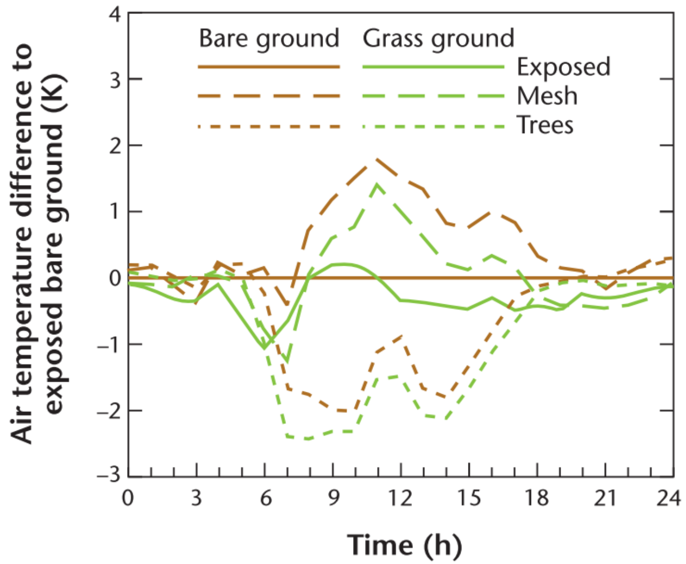


Figure 15.9 Hourly differences in air temperature (K) between courtyards treated with mesh and grass (a) or trees and grass (b), relative to the base case (Shashua-Bar et al. 2009)

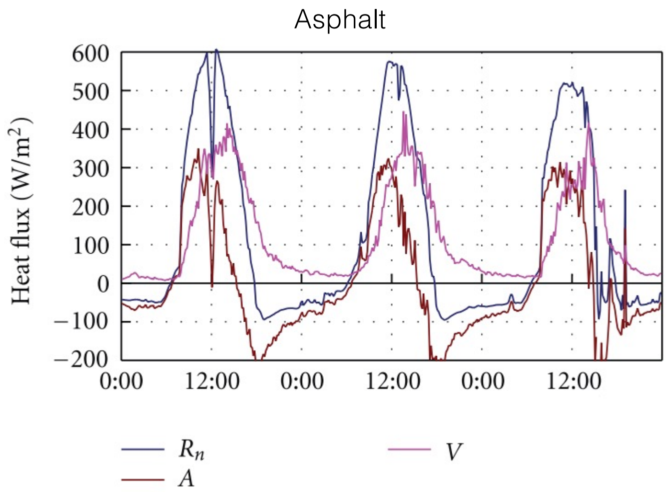
Permeable vs. impermeable surfaces

- Plots with different car park treatments in Kobe (Japan)
- Energy balance measured over a two month summer period.

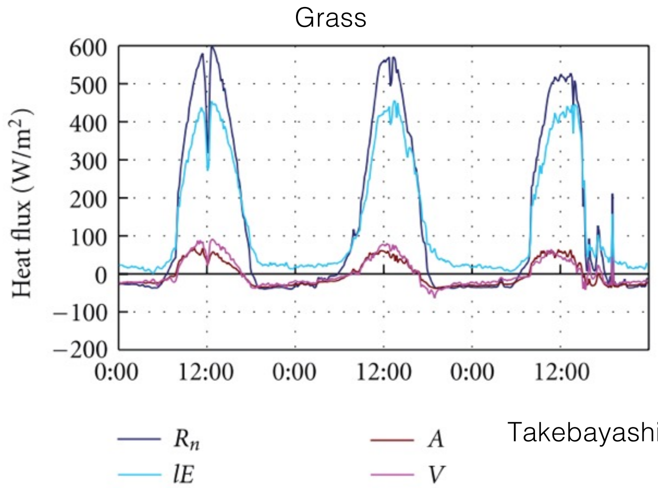
→ Reduction in sensible heat flux is 270 (day) and 40 (night) W/m^2 on bare soil and 350 (day) and 60 (night) W/m^2 on grass compared to asphalt

→ Permeable paving was cooler than traditional asphalt cover and the level of cooling (up to 20 K difference at mid-day) was related to the green area fraction.

→ Extending this cover to an urban neighbourhood with 6% car park cover has a marginal impact on the near-surface UHI.

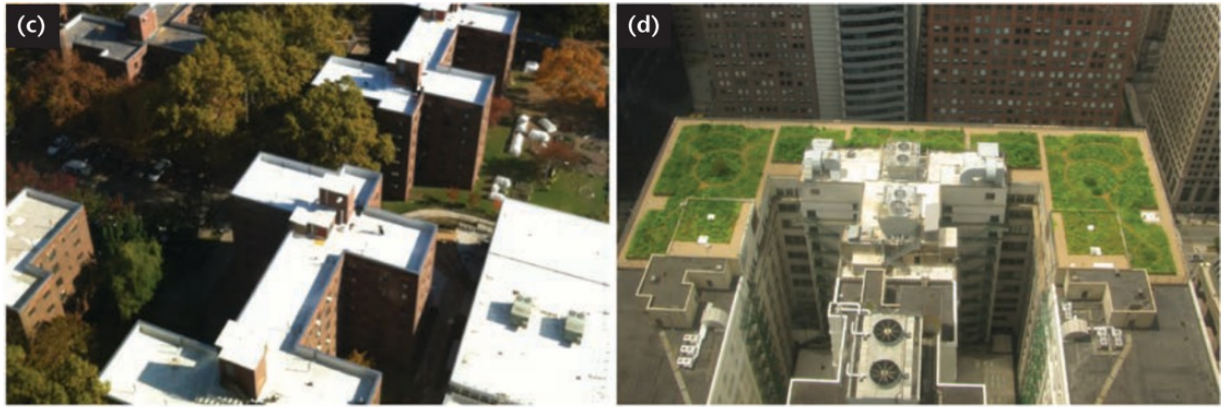


R_n = net radiation (W/m^2)
A = conduction heat flux (W/m^2)
V = sensible heat flux (W/m^2)
lE = latent heat flux (W/m^2)



Takebayashi & Moriyama 2012

Cool roofs: white?

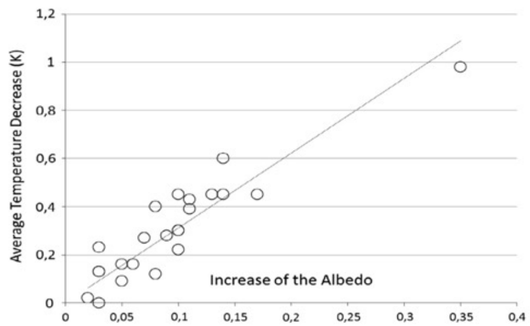


Rooftops in New York, United States, which are typically black but have been painted white to deal with high summertime temperatures

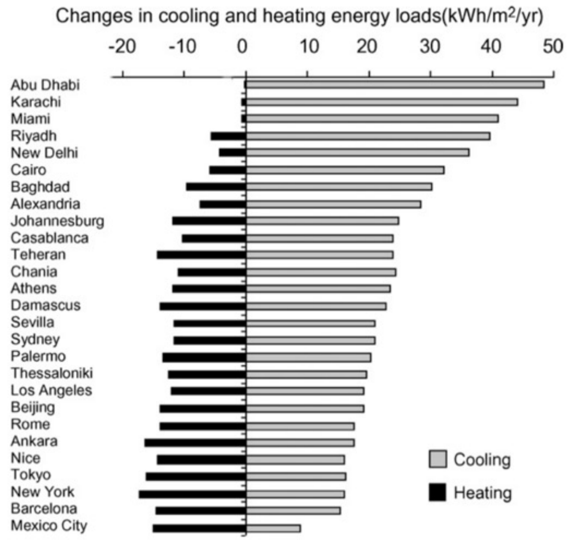
- Roofs are the lightest and least insulated surface and a major source of unwanted building heat gain and loss.
- Where building density is high the roof area is large, which offers a high management potential

Tiles were coated with highly reflective acrylic at visible (0.8) and long-wave (0.9) wavelengths

- Up to 20 K cooler in daytime compared to a dark tile
- Reduces cooling loads by 18–93%

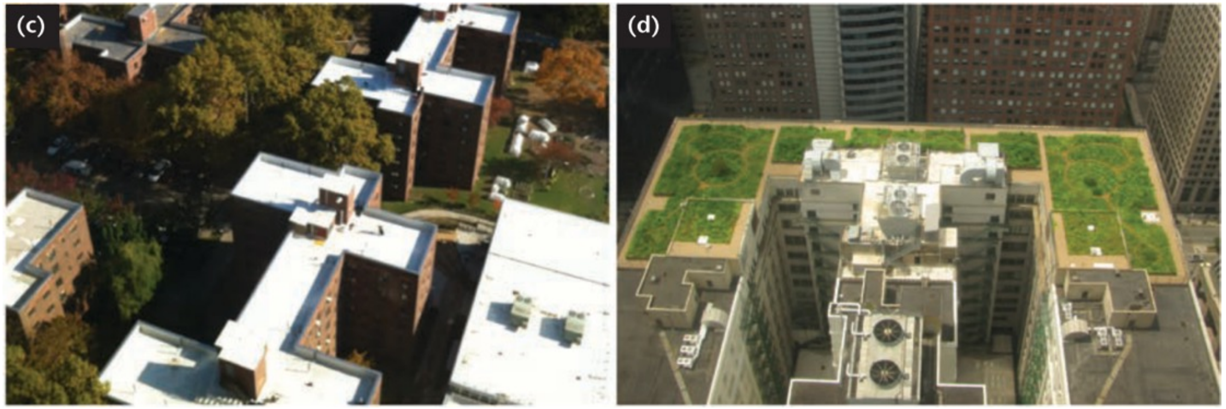


Possible albedo change and the corresponding decrease of the average ambient temperature in urban areas. (Santamouris 2014)



Climate effect on cooling and heating load changes for a change in roof solar reflectance of 0.65. (Synnefa et al. 2007)

Or green?



Rooftops in New York, United States, which are typically black but have been painted white to deal with high summertime temperatures

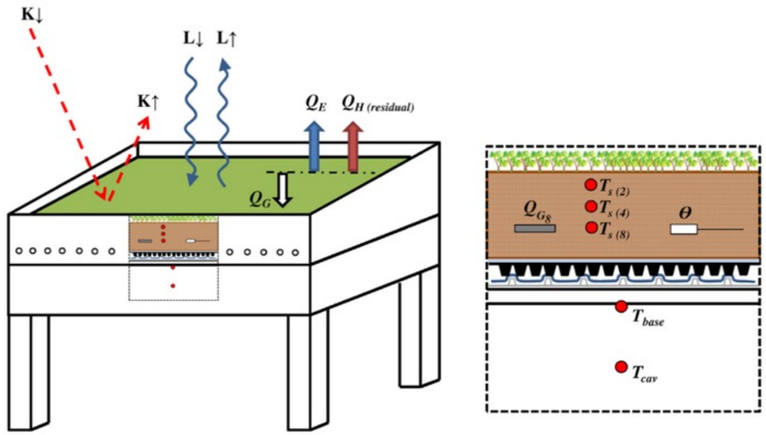
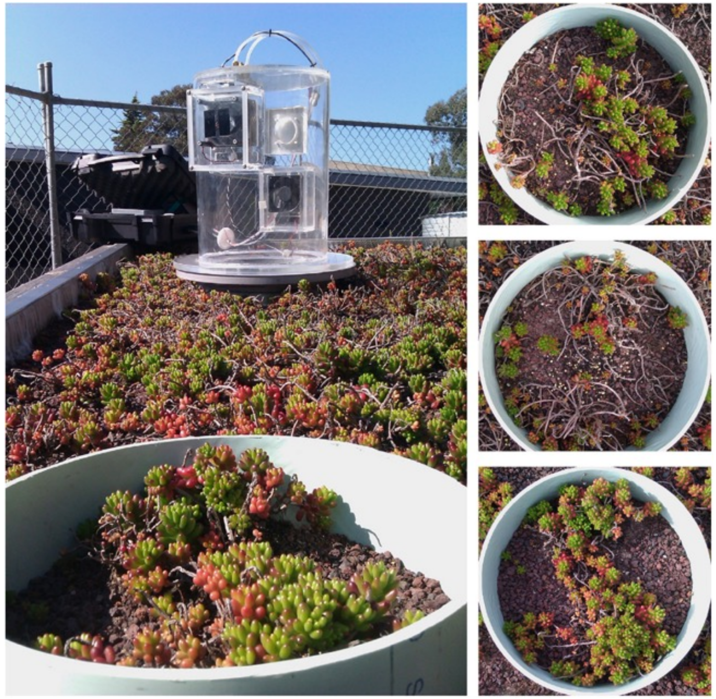


Fig. 1. Construction of the vegetated roof (VEG) and experimental approach.

- Green roof cooling function due to shade and/or insulation
- Little evidence for important evaporative cooling except during irrigation periods, when evapotranspiration is high (> 400 W/m^2)
- Performance depends on the nature of the vegetative cover and the climate to which it is exposed
- Insulation impedes night-time heat loss (which may be desirable)

- **Extensive green roofs**: lightweight structure, thin soil layer, short flowering plants (e.g. sedums) adapted to harsh environments and drought
- **Intensive green roofs**: deep rooted vegetation (e.g. trees), need more substrate

Or green?



Q^* = net radiation (W/m²)
Q_G = ground heat flux (W/m²)
Q_H = sensible heat flux (W/m²)
Q_E = latent heat flux (W/m²)

Sedum rubrotincum

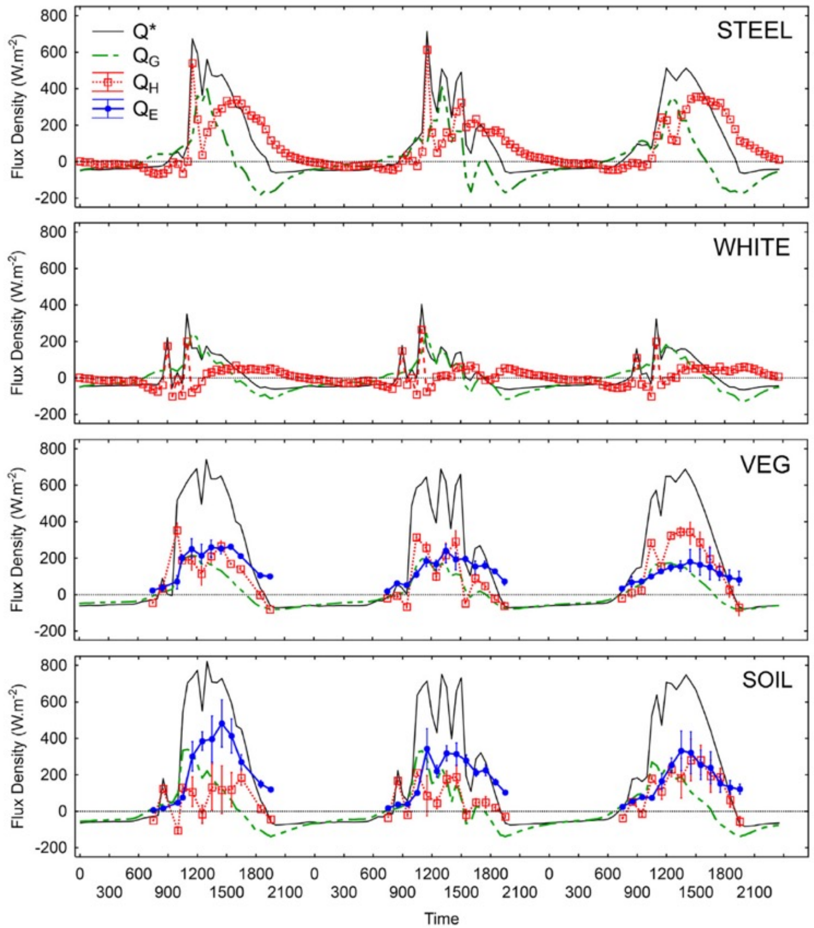


Fig. 9. Surface energy balance of each experimental roof over 1–3 Feb 2012 following irrigation (Coutts et al. 2013)

Many green roofs are constructed using a combination of **shallow soils** and **drought tolerant plant species** that can survive harsh rooftop environments and low water availability. Such environments may **compromise plant transpiration** due to stomatal closure and limit green roof cooling potential via Q_E.

Cool walls: green or white?

Cool walls and green walls have much the same effect for the building climate as roof treatments but their outdoor impact is different, as they affect the street climate directly.

Cool walls:

- Reflect solar radiation but this energy will fall on other surfaces and can increase the heat load of those outdoor.

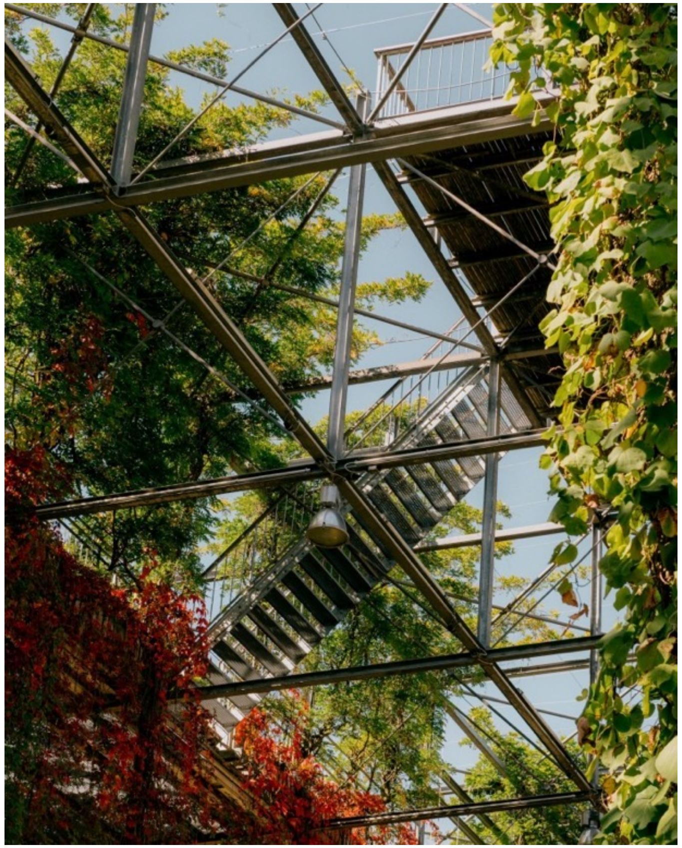
Green walls:

- No equivalent soil substrate to which the plants are anchored
- Moderate the underlying surface temperature for the building
- Lower the outdoor surface temperature to which pedestrians are exposed
- May help improve air quality by trapping air pollutants

→ The focus of green wall studies is of air pollutant trapping

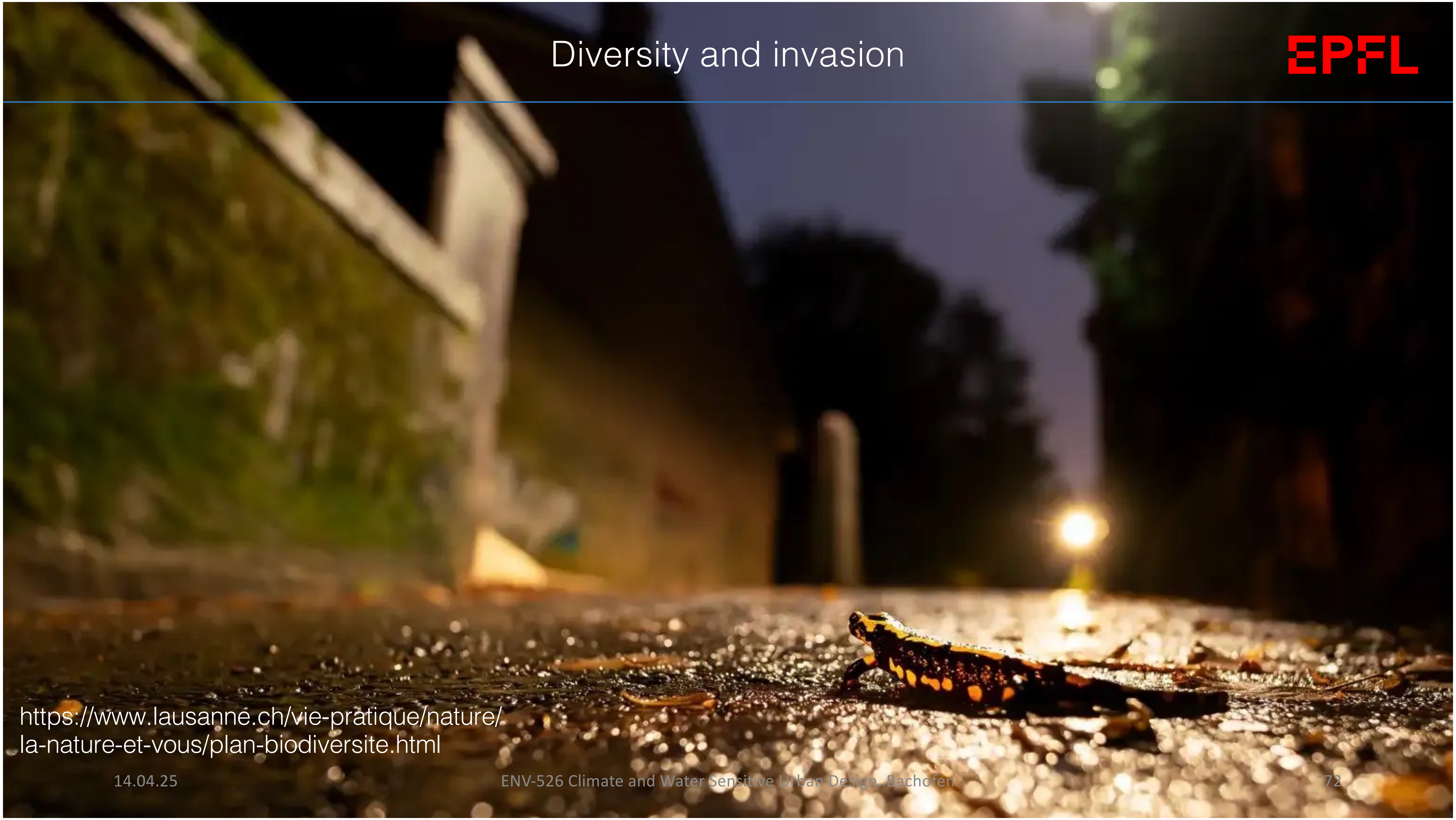
Fig. 1. On the left a direct green façade (GF) and on the right an living wall system (LWS) placed in a city. Below these pictures, the rooting system of the GF and the support structure (here a panel made of rockwool) of the LWS. (Ysebaert et al. 2021)

Cool green walls: MFO park Zürich



1.200 Climbing plants, 100 different genus, species, varieties

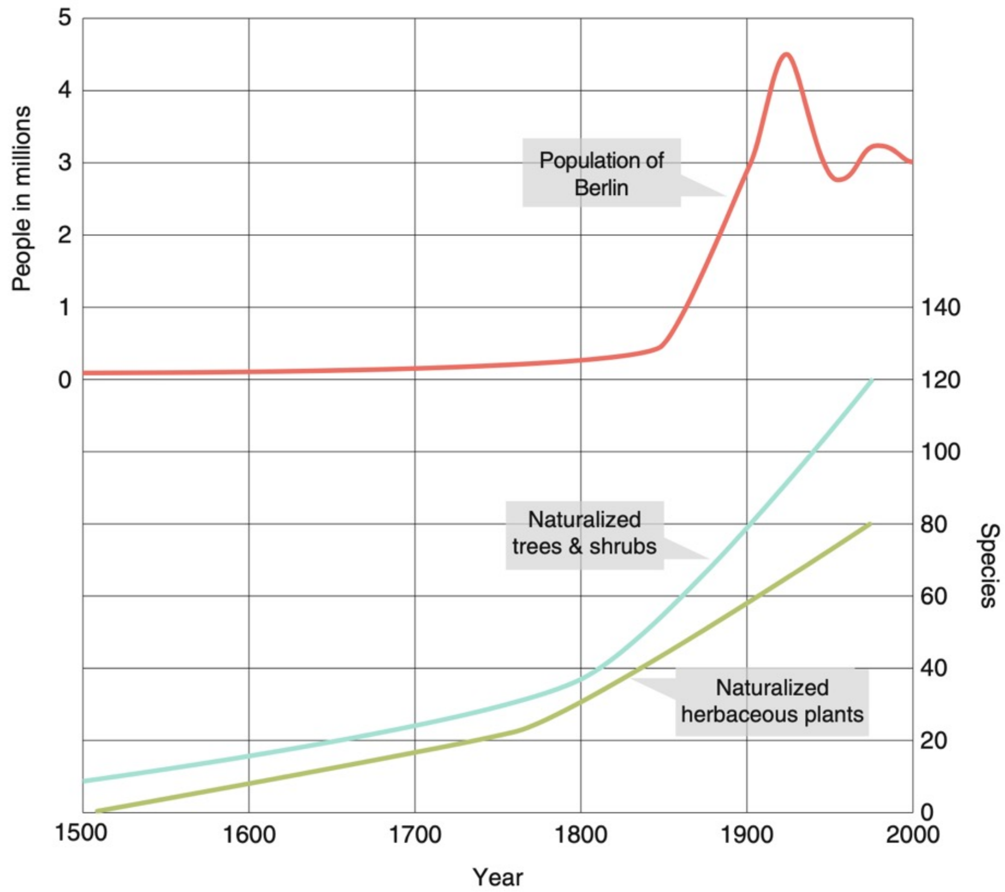
Diversity and invasion



https://www.lausanne.ch/vie-pratique/nature/la-nature-et-vous/plan-biodiversite.html

Diversity and invasion

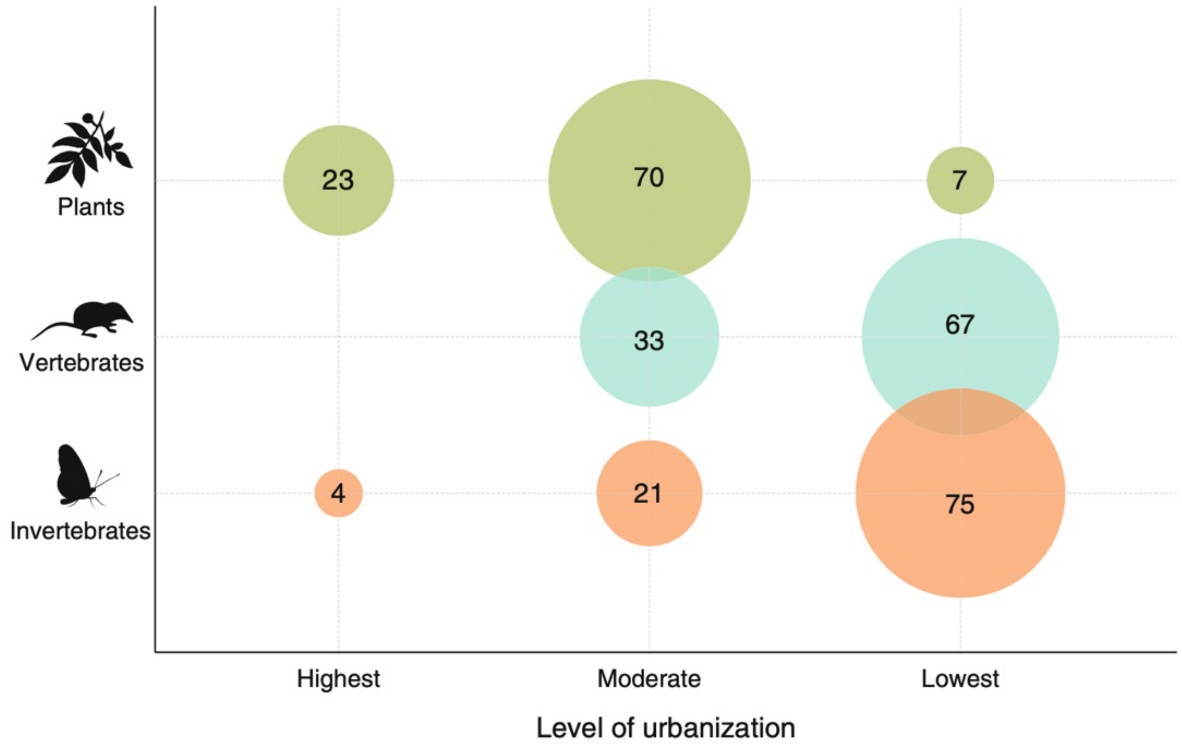
- Humans have a long history of transporting plant species and affecting local biodiversity.
- Since the Neolithic period, 12,000 species have been introduced into Central Europe for ornamental and cultural purposes and approximately 10 % (1,100) of those plants have become naturalized.



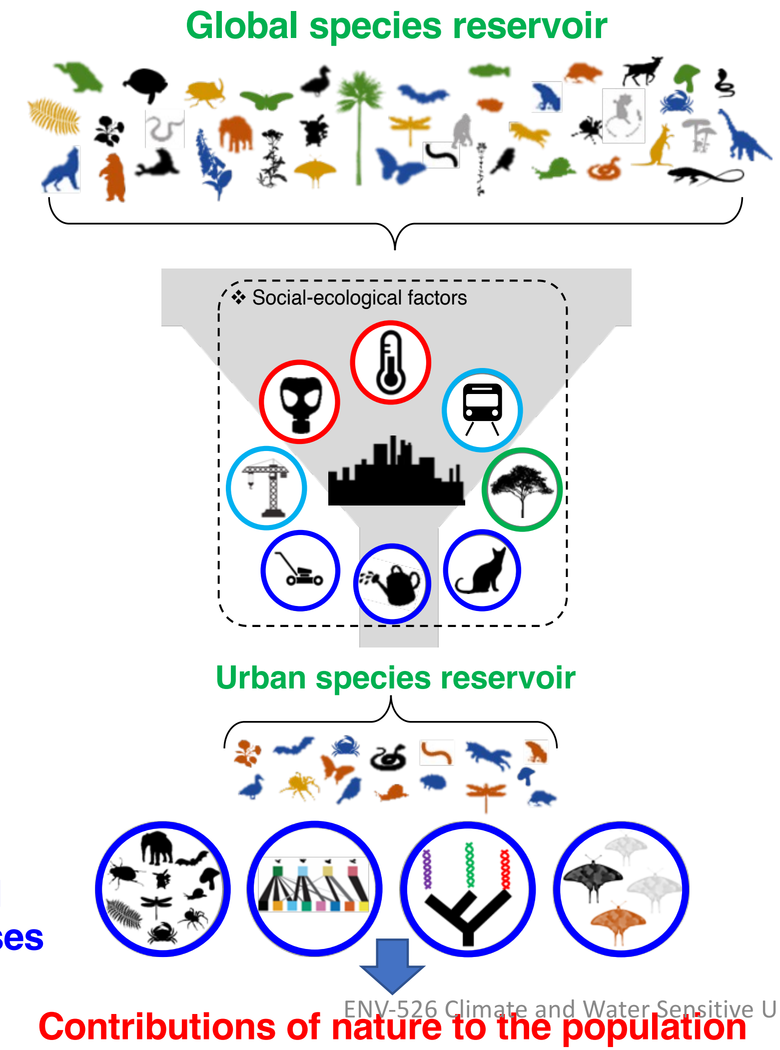
Lohmeyer and Sukopp 1992

Diversity and invasion

- Native species richness declines and non-native species increased as sites become more urbanized.
- Because of the addition of non-native species, overall species richness and diversity is highest in moderate (suburban) levels of urbanization



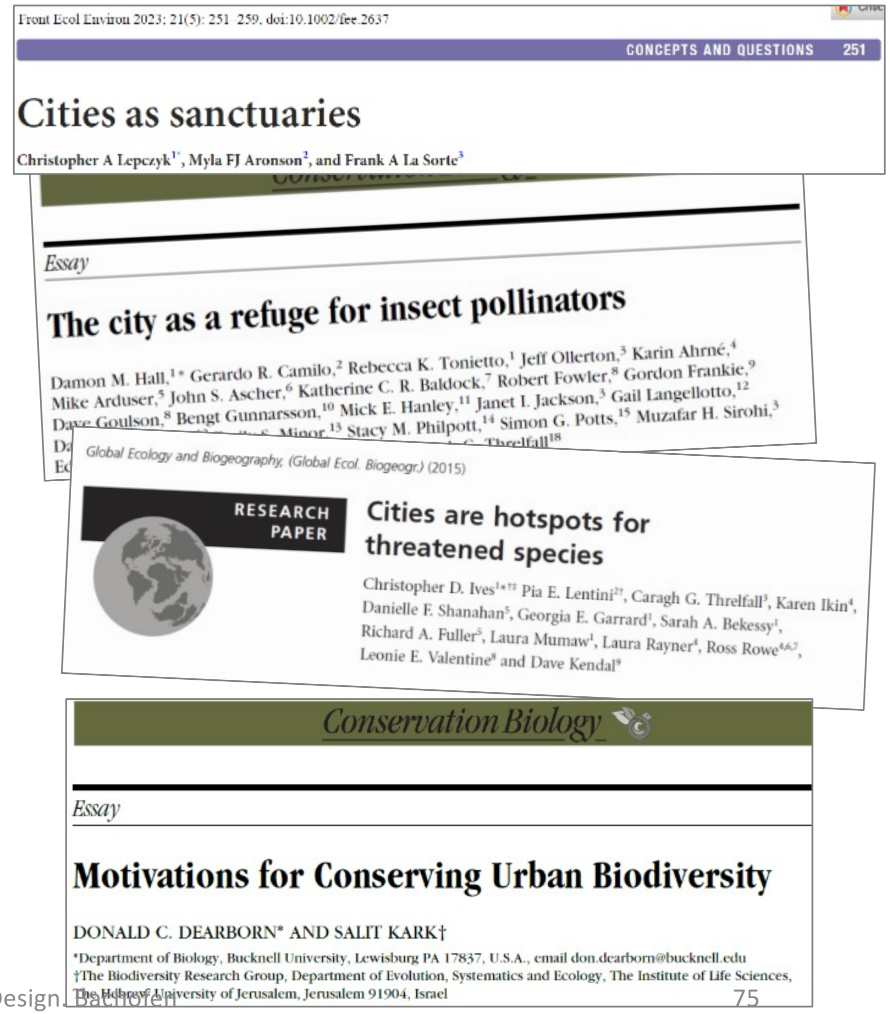
Cities: socio-ecological ecosystems



Abiotic, biotic and human filters

Homogenisation

New communities
Rapid ecological and evolutionary processes


Front Ecol Environ 2023; 21(5): 251–259, doi:10.1002/fee.2637

CONCEPTS AND QUESTIONS 251

Cities as sanctuaries

Christopher A Lepczyk[1*], Myla FJ Aronson[2], and Frank A La Sorte[3]

Essay

The city as a refuge for insect pollinators

Damon M. Hall,[1*] Gerardo R. Camilo,[2] Rebecca K. Tonietto,[1] Jeff Ollerton,[3] Karin Ahrné,[4] Mike Arduser,[5] John S. Ascher,[6] Katherine C. R. Baldock,[7] Robert Fowler,[8] Gordon Frankie,[9] Dave Goulson,[8] Bengt Gunnarsson,[10] Mick E. Hanley,[11] Janet I. Jackson,[3] Gail Langellotto,[12] ... Minor,[13] Stacy M. Philpott,[14] Simon G. Potts,[15] Muzafar H. Sirohi,[3] ... Threlfall[18]

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2015)

RESEARCH PAPER

Cities are hotspots for threatened species

Christopher D. Ives[1*], Pia E. Lentini[2], Caragh G. Threlfall[3], Karen Ikin[4], Danielle F. Shanahan[5], Georgia E. Garrard[1], Sarah A. Bekessy[1], Richard A. Fuller[5], Laura Mumaw[1], Laura Rayner[4], Ross Rowe[4,6,7], Leonie E. Valentine[8] and Dave Kendal[9]

Conservation Biology

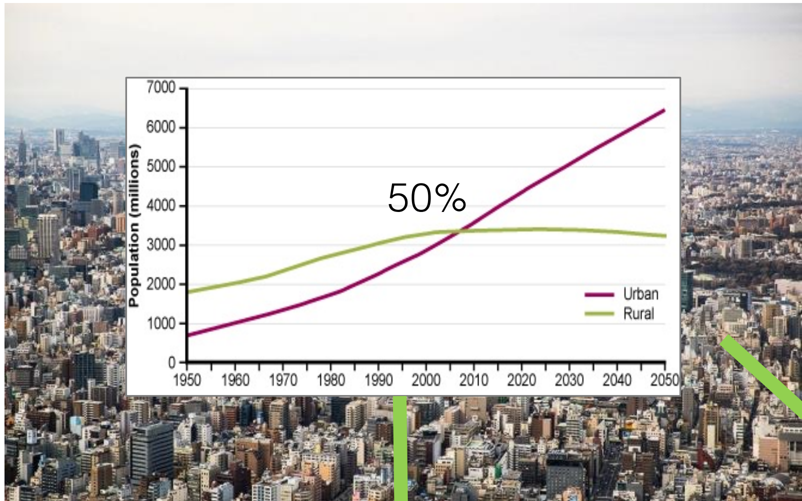
Essay

Motivations for Conserving Urban Biodiversity

DONALD C. DEARBORN* AND SALIT KARK†

*Department of Biology, Bucknell University, Lewisburg PA 17837, U.S.A., email don.dearborn@bucknell.edu
†The Biodiversity Research Group, Department of Evolution, Systematics and Ecology, The Institute of Life Sciences, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

The great challenge of cities



Accomodation, work
Social justice
Mobility
Security
Health
Leisure

Well-structured green spaces
Extensive management
Reduction of pollution
Reduction of traffic
Natural gardens
'Rewilding'

Nature-based solutions
Interdisciplinary approaches
Multifunctionality
Sustainability

Quality of life

Biodiversity

Trade-offs

Land sparing - Land sharing
(denser or greener)

How to promote biodiversity in cities?

Local scale

Habitat category	Summary effect size	N	p
Area	0.63	22	< 0.001 ***
Habitat richness	0.44	5	0.001 **
Age	−0.05	7	0.700
Edge effects	−0.24	10	0.173
Managed	0.25	12	0.006 **
Disturbance	−0.02	7	0.903
Pesticide	−0.13	4	0.147
Herb density	0.53	3	< 0.001 ***
Herb cover	0.39	11	0.002 **
Herb structure	0.14	11	0.016 *
Shrub structure	0.37	6	0.001 **
Shrub cover	0.17	6	0.017 *
Tree structure	0.37	11	< 0.001 ***
Tree cover	0.26	17	< 0.001 ***
Tree density	0.19	4	0.104
Vegetation structure	0.39	10	< 0.001 ***
Vegetation richness	−0.08	4	0.631
Microclimate	0.18	4	0.470
Bare soil cover	−0.33	4	0.192
Water cover	0.32	9	< 0.001 ***
Water body structure	−0.03	4	0.813

Size

Quality

−0.6 −0.4 −0.2 0 0.2 0.4 0.6

Landscape scale

Habitat category	Summary effect size	N	p
Corridor	0.63	5	< 0.001 ***
Connectivity	0.02	10	0.854
Distance to water body	0.21	7	0.143
Green area %	0.28	21	< 0.001 ***
Agricultural area %	0.10	4	0.414
Sealed surfaces %	−0.11	17	0.307

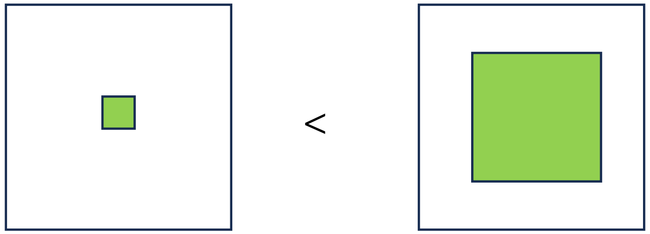
Connectivity

−0.6 −0.4 −0.2 0 0.2 0.4 0.6

75 cities worldwide

Beninde et al. 2015

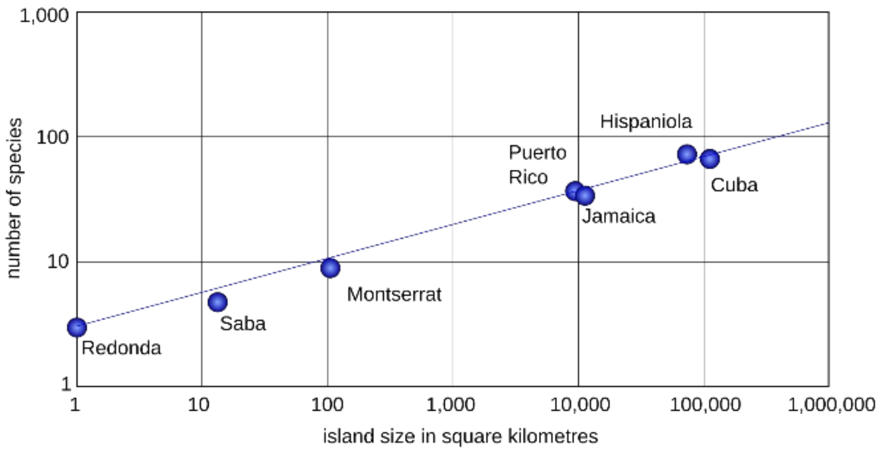
Size of green spaces



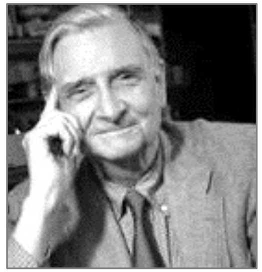
$$S = c^*A^z$$

S = number of species, A = surface, c = constant, z = constant that depends on species and distance to next island

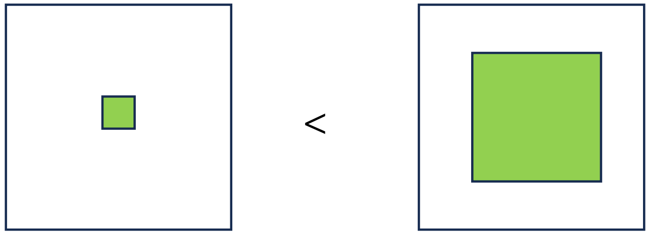
The number of species doubles if the surface increases by six



MacArthur & Wilson 1967. Island Biogeography Theory



Size of green spaces



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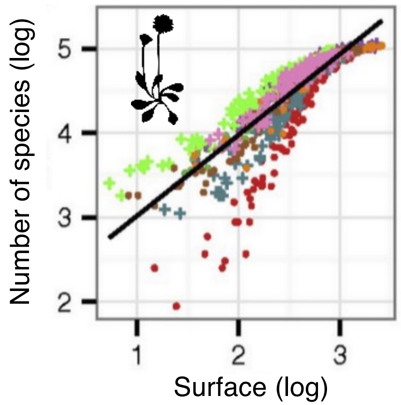
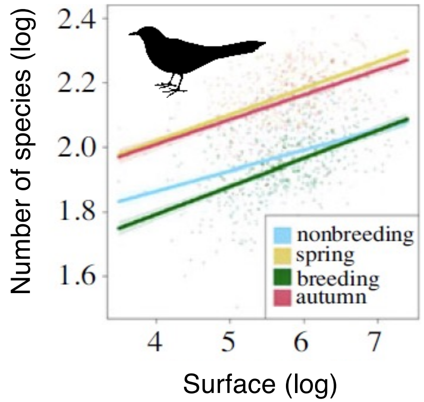


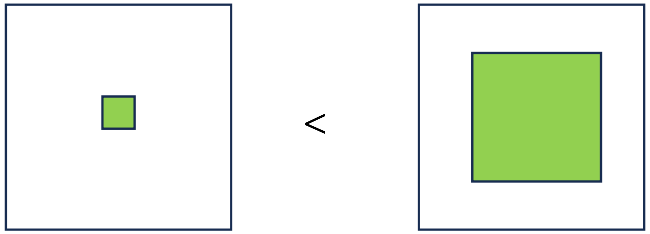


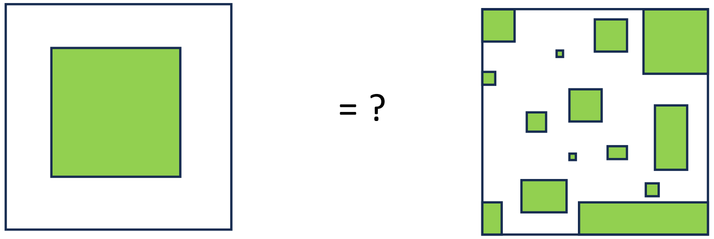
La Sorte et al. 2024

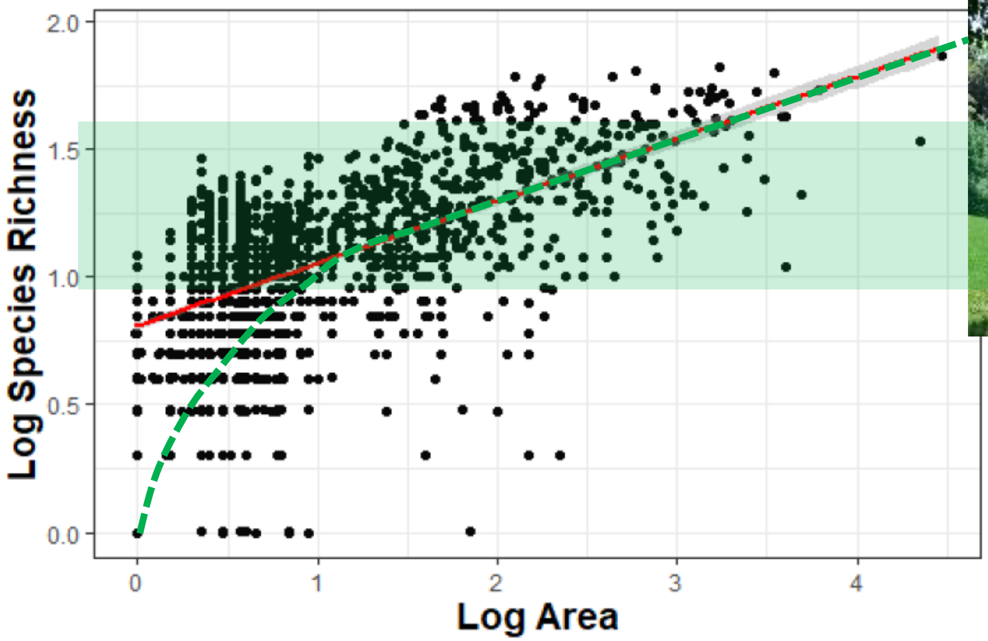
Flower bed

Urban park

SLOSS: Single large or several small?

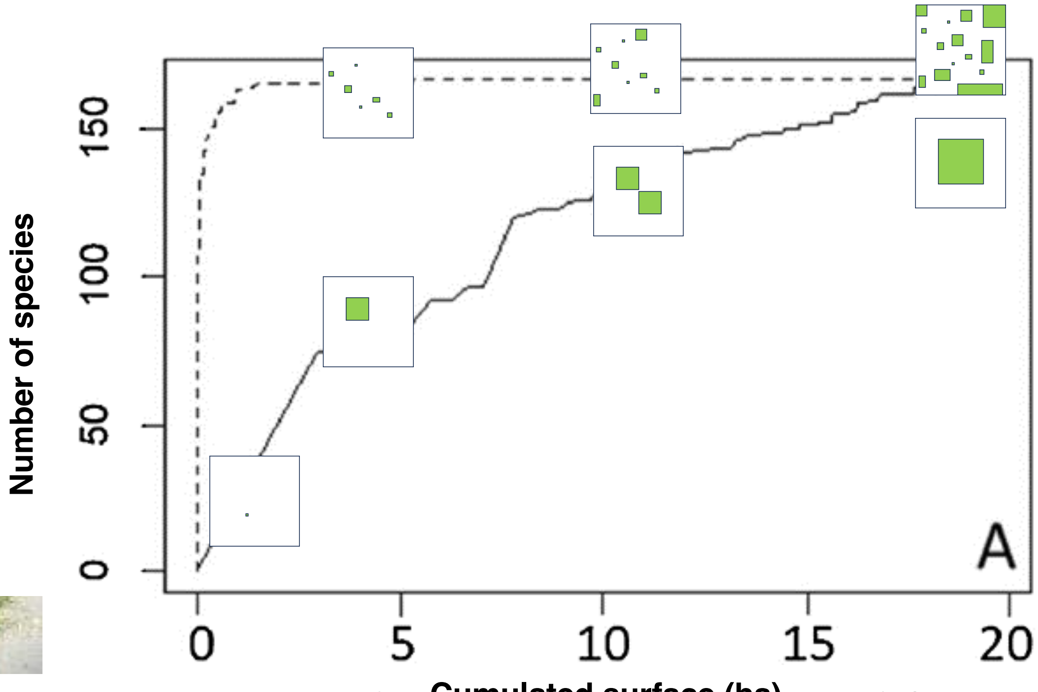






Vega & Küffer 2021

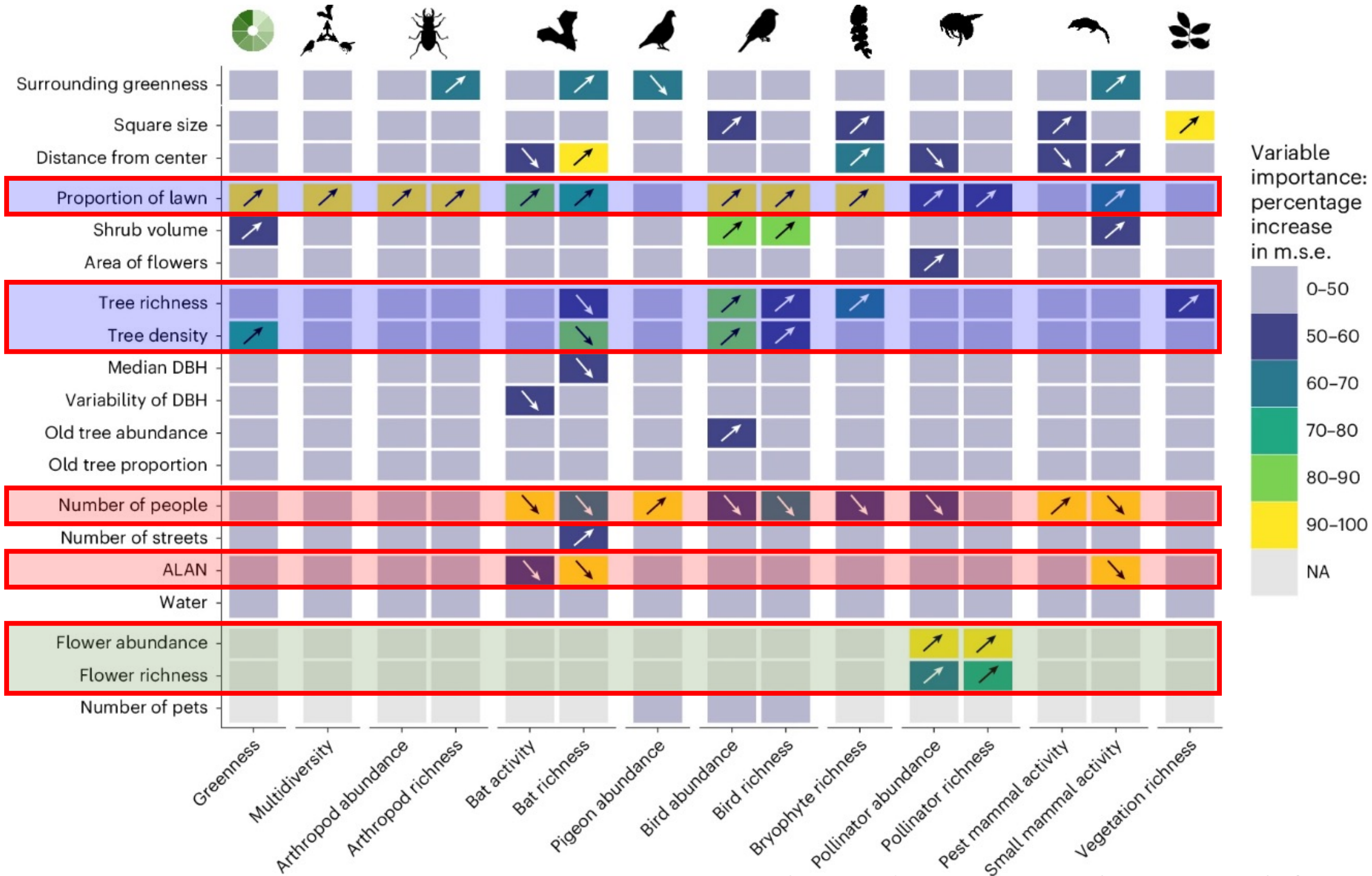
SLOSS: Single large or several small?



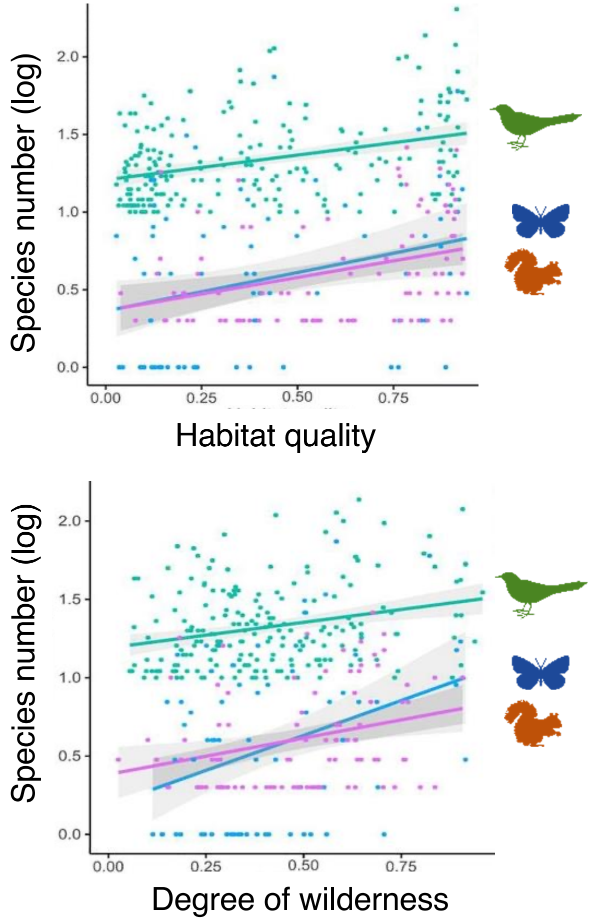
Vega & Küffer 2021

Quality of green spaces

Factors influencing the different taxonomic groups in 354 places in Munich



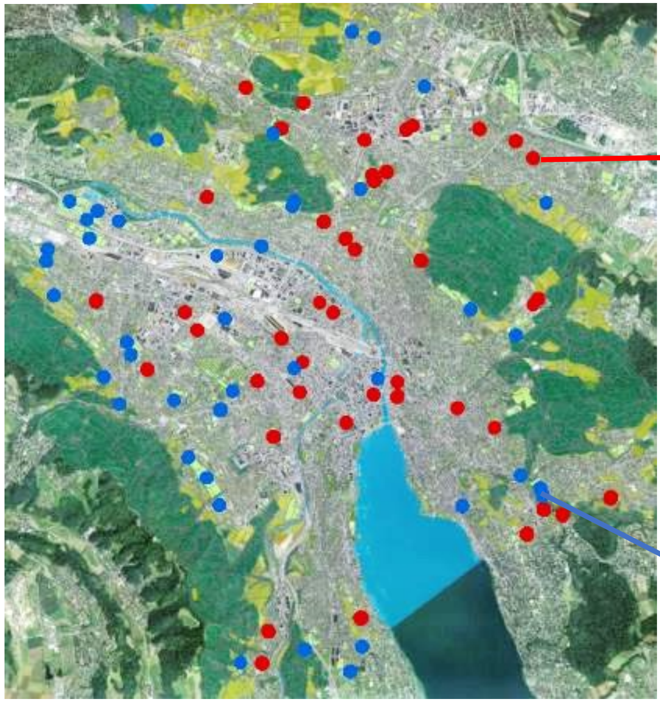
Fairbairn et al. 2024



Aznarez et al. 2022

Quality of green spaces

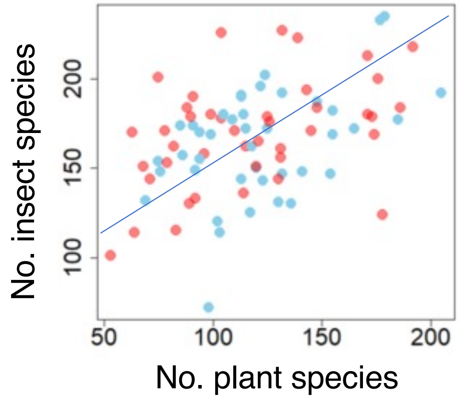
Zürich

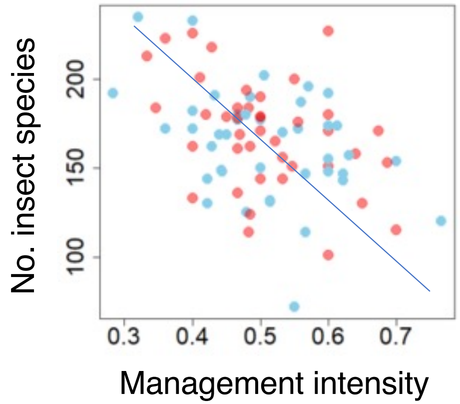


private gardens

family gardens

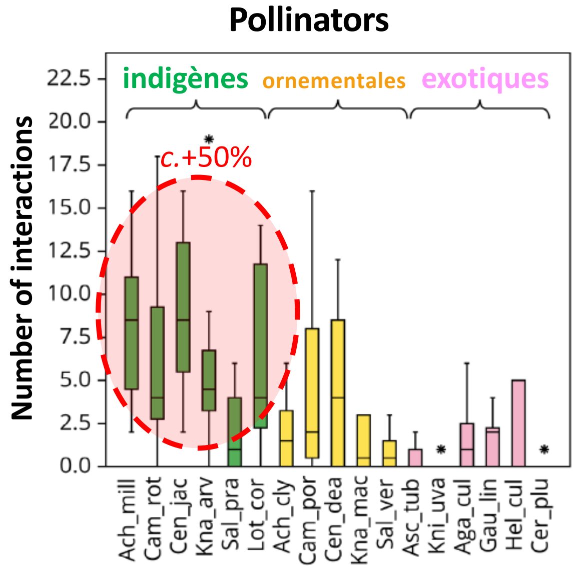
Frey 2019 PhD-thesis
Casanelles-Abella et al. in prep.

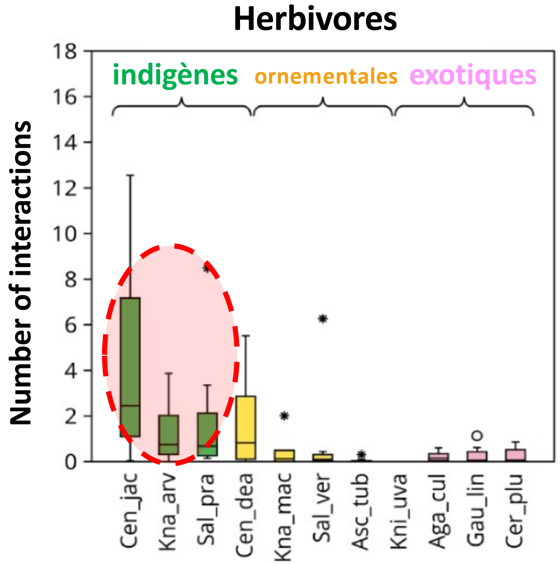


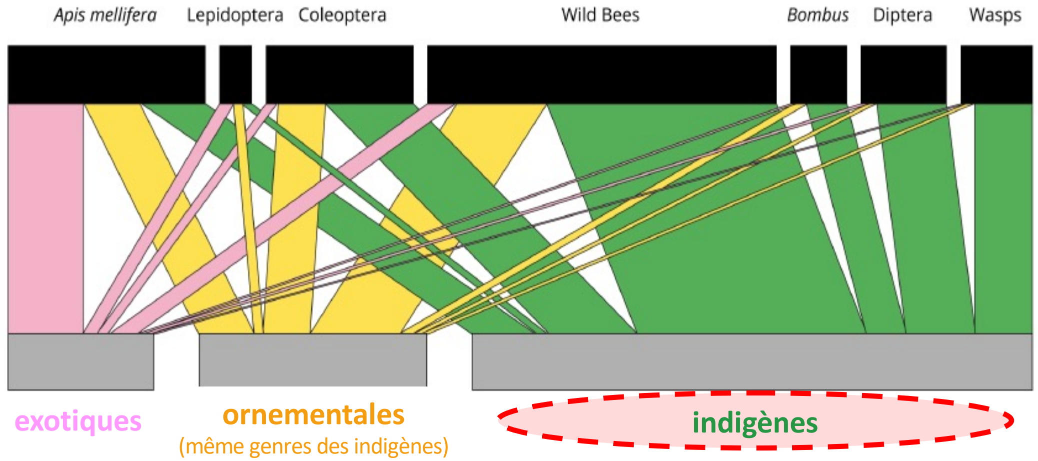


Quality of green spaces

Frey 2019 PhD-thesis
Casanelles-Abella et al. in prep.







Lerch et al. 2024

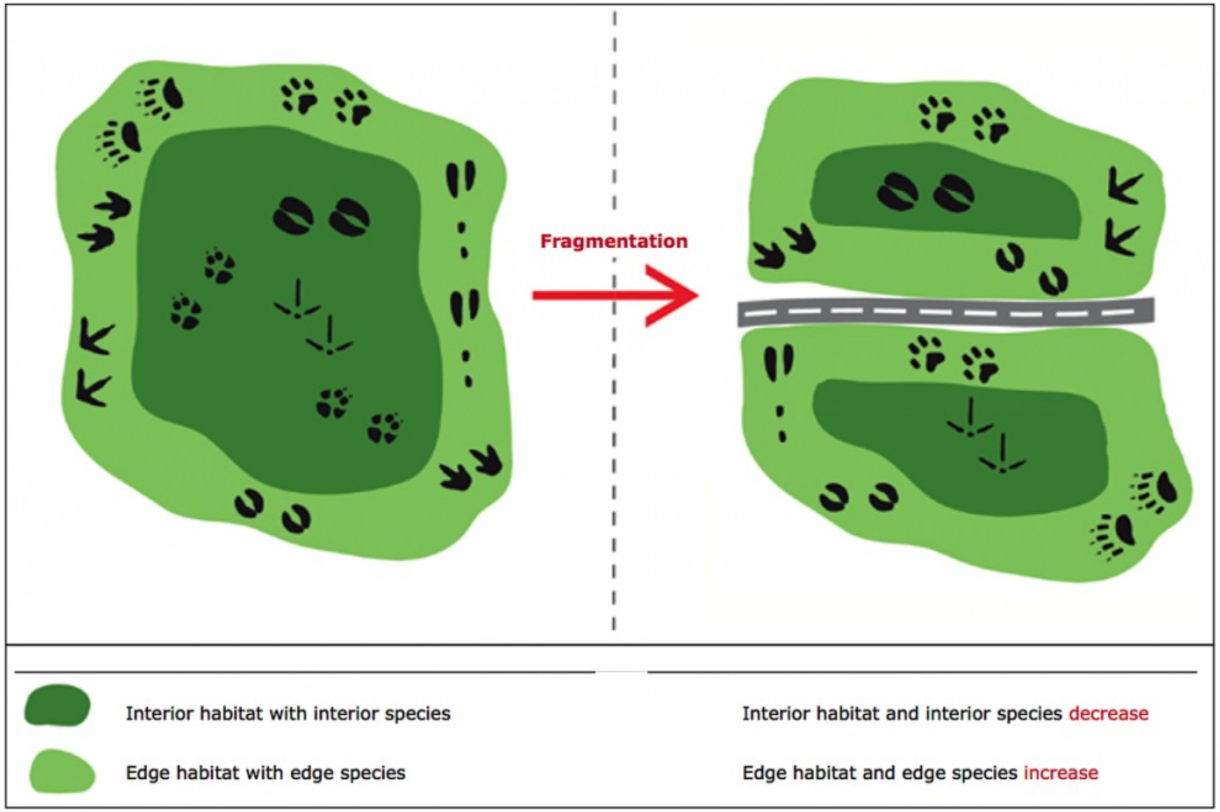
Connectivity of green spaces

Habitat fragmentation occurs when large, contiguous areas of habitat are reduced in area and divided into two or more smaller units.

The fragmented units are isolated from one another and embedded in a modified or degraded landscape.

As urbanization intensifies fragmentation occurs at a finer scale through the division of habitat by roads, utility rights-of-way, railroads, and other barriers which impede movement of wildlife.

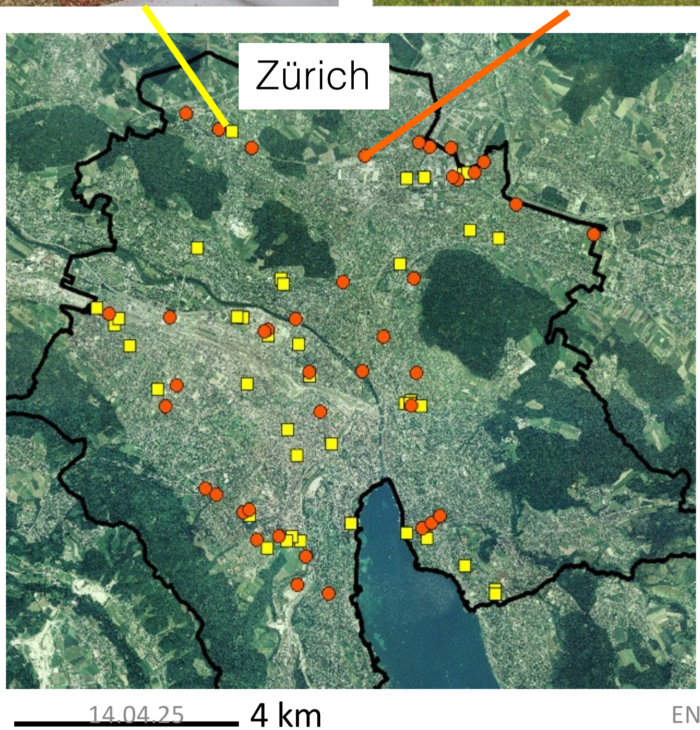
Illustration of the loss of core habitat (or interior habitat) caused by road construction cutting through a patch of habitat



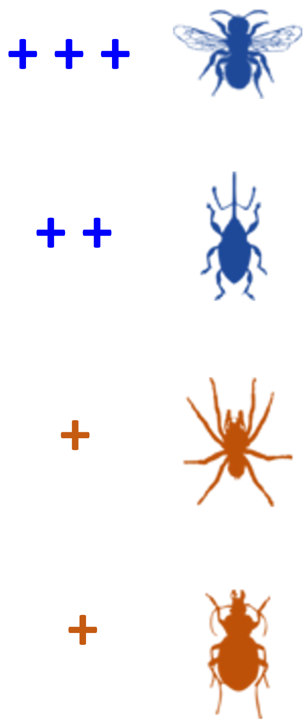
Connectivity of green spaces

Green roofs (N = 40)

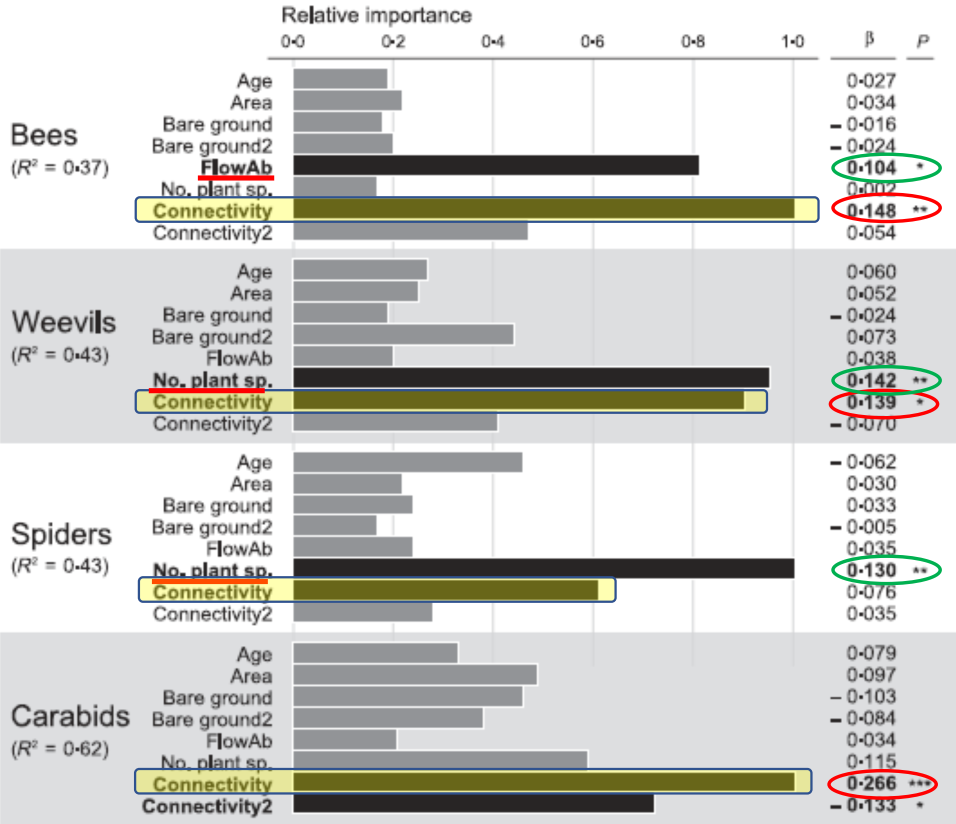
Ruderal ground (N = 40)



Dispersion capacity



Green roofs – Ruderal ground



Braaker et al. 2017

Non-native plant in cities


watson
Schweiz International Wirtschaft Sport Leben Spass Digital Wissen Blogs Quiz Videos Promotionen

Wilder Kirschlorbeer, wo er nicht sein sollte: Im Wesemlinwäldli am Stadtrand von Luzern. *bild: keystone*

INTERVIEW

«Schon seit vielen Jahren sage ich: Verbietet das!»

Der Bundesrat verbietet ab 1. September den Verkauf von Kirschlorbeer und weiteren Pflanzen. watson hat bei Gärtnereien nachgefragt, wie sie dazu stehen.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Vaud Modifié le 29 novembre 2023 à 17:23

Arbustes envahissants, les laurelles seront interdites à la vente dans le canton de Vaud

Bientôt la fin des haies de lauriers-cerises / On en parle / 11 min. / le 15 juin 2023

La laurelle, ou laurier-cerise, très utilisée dans les haies pour délimiter les propriétés, ne pourra plus être vendue dans le canton de Vaud, car trop envahissante et nuisible à la biodiversité locale. Cette interdiction est la conséquence de l'entrée en vigueur au 1er janvier 2023 d'une nouvelle loi vaudoise exigeant la mise à jour régulière de la liste des plantes exotiques envahissantes.

C'est bientôt la fin des haies de laurelles ou lauriers-cerises, ces murs de feuilles ... toute l'année. Le canton de Vaud et l'Office féd...

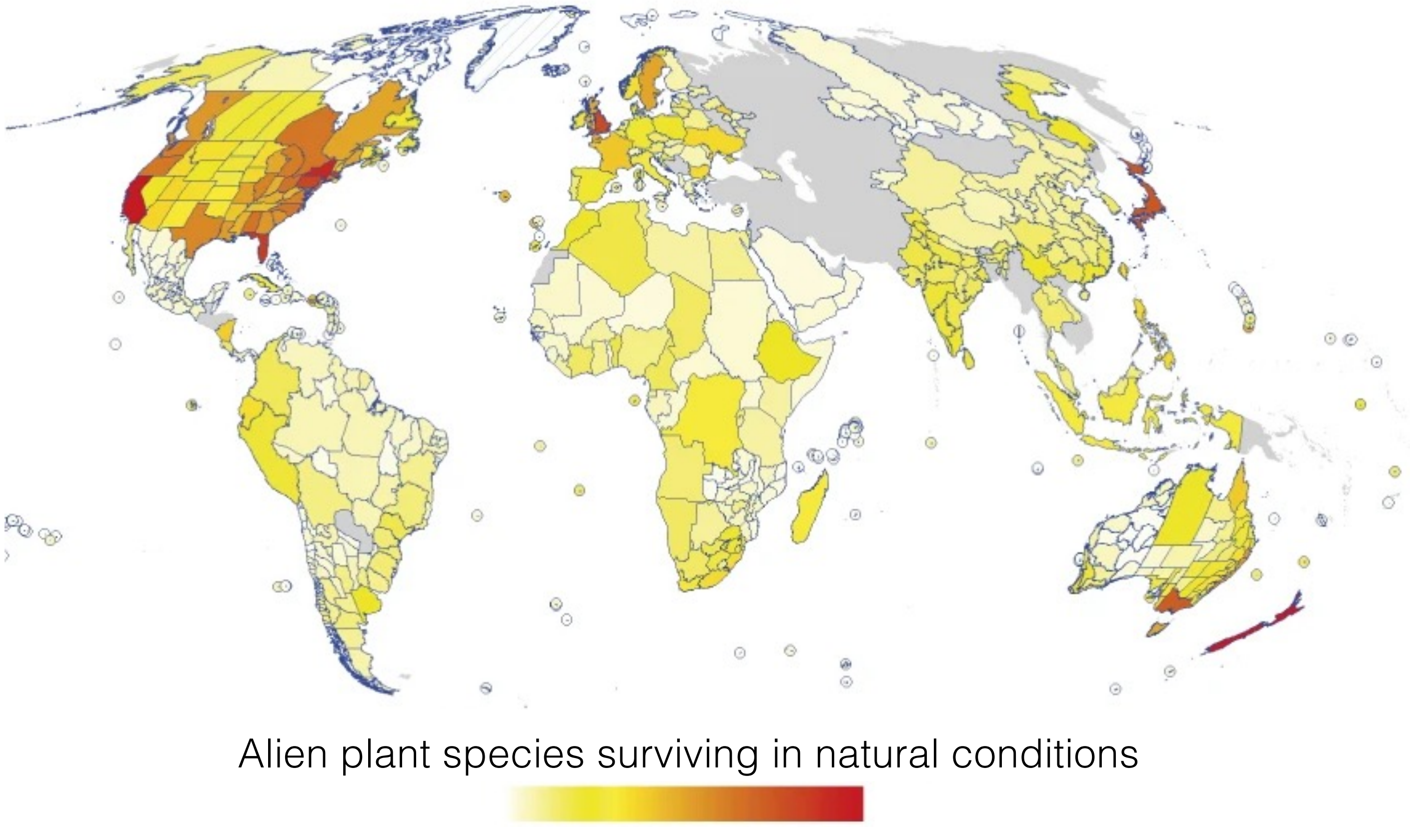
Non-native plant in cities

Heavily invasive *Ailanthus altissima* (Faux vernis du Japon) in Lausanne

Genre	Espèce	Cultivar	Circonference
Ailanthus	altissima		101
Ailanthus	altissima		117
Ailanthus	altissima		61
Ailanthus	altissima		75

Species invasion

The spread of invasive alien species continues to increase because of both deliberate translocations and accidental introductions related to growing trade and travel, with significant harmful consequences to native species and many ecosystem services.



Alien plant species surviving in natural conditions

0 1,753

Von Kleunen et al., 2010

Example of species invasion: Chinese windmill palm

- Since the early 1970s, *Trachycarpus fortunei* is spreading from urban settlements into the deciduous chestnut forests of the low-lands of the southern Alps
- Goal: understand the competitive advantage of Trachycarpus fortunei to native evergreen and deciduous trees

in the cities of Ticino

in the forests of Ticino

Global carbon pools

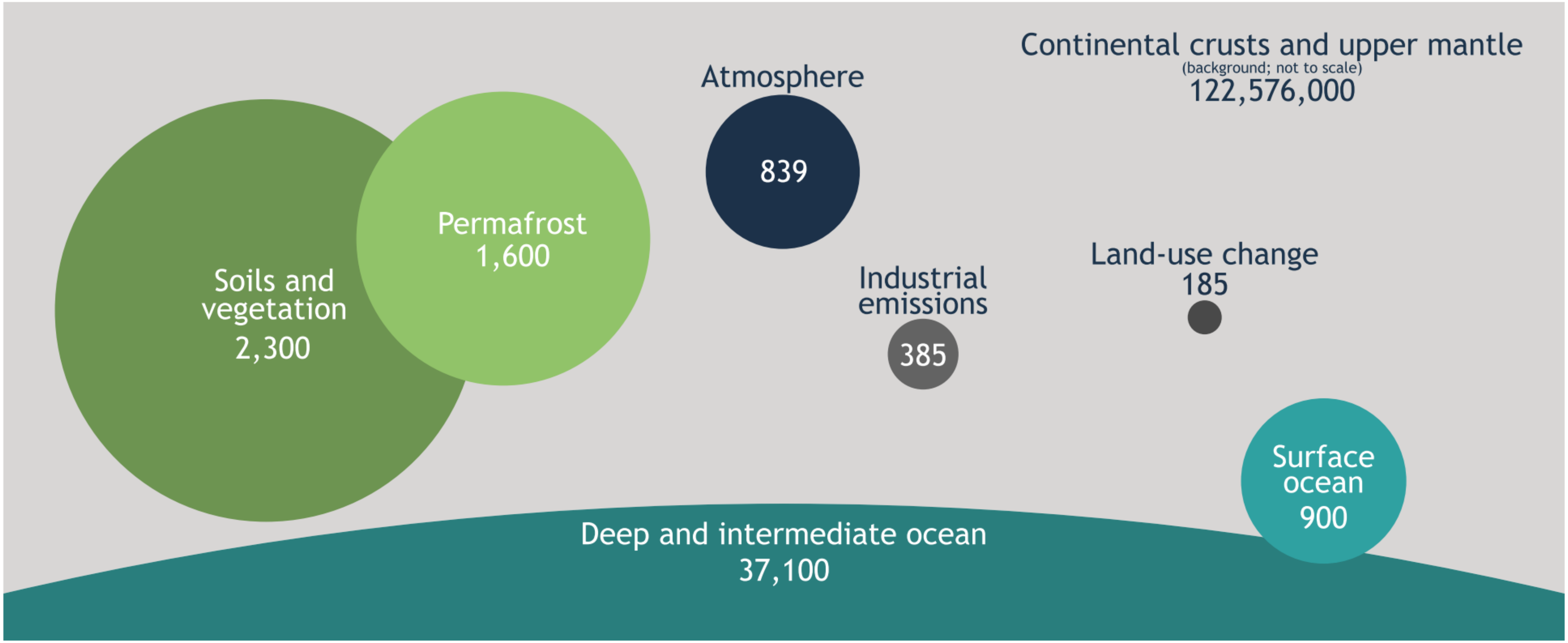


Figure 1. Global carbon stocks (carbon stored in pools), shown in gigatons.

Janowiak et al. 2017

Global CO_2 cycle

- CO_2 moves from the atmosphere to land through photosynthesis.
- CO_2 moves from land back to the atmosphere through plant and soil respiration, litter decomposition, and fires.
- Fluxes are typic[...]
  stocks
- Small shifts in global fluxes have a profound effect on the global carbon cycle (e.g. climate change)

Land ecosystems are absorbing ca. 25–30% of the annual anthropogenic CO_2 emissions

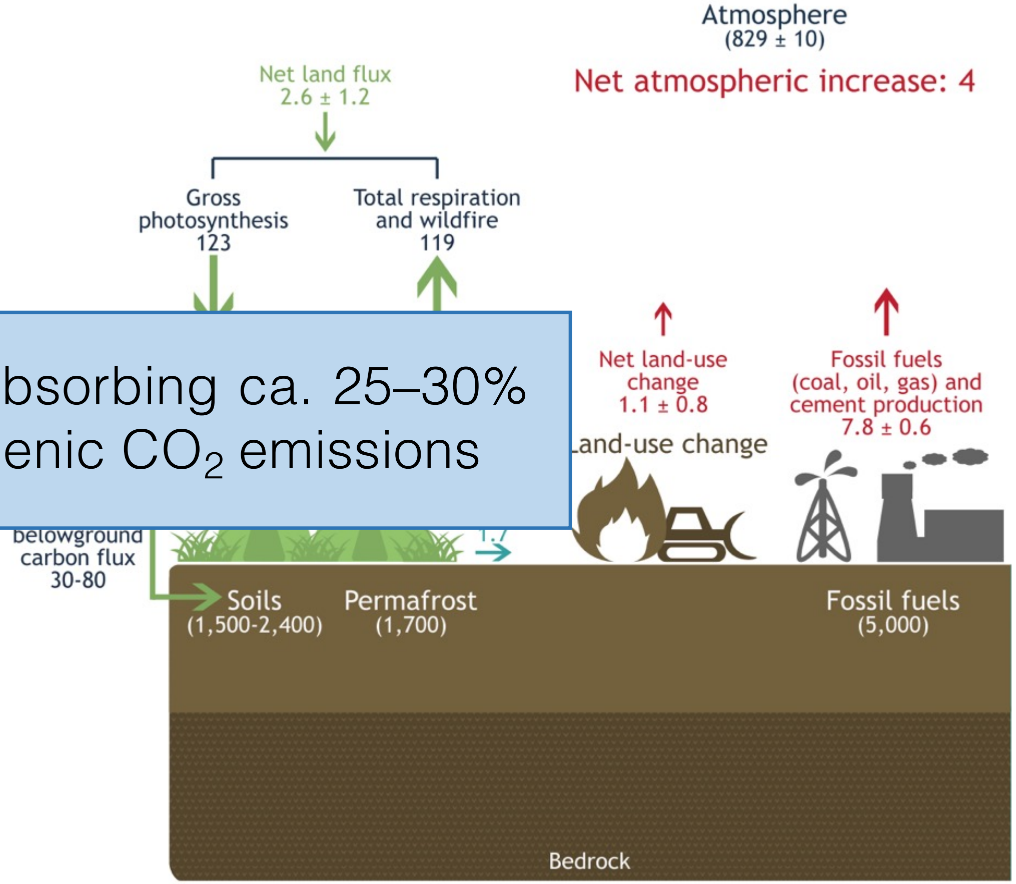


Figure 4. Global carbon cycle. Carbon (Gt C) stocks are denoted in parentheses and shown [...] year) are associated with arrows and shown in gigatons per year.

Janowiak et al. 2017

Importance of forests for the global CO_2 cycle

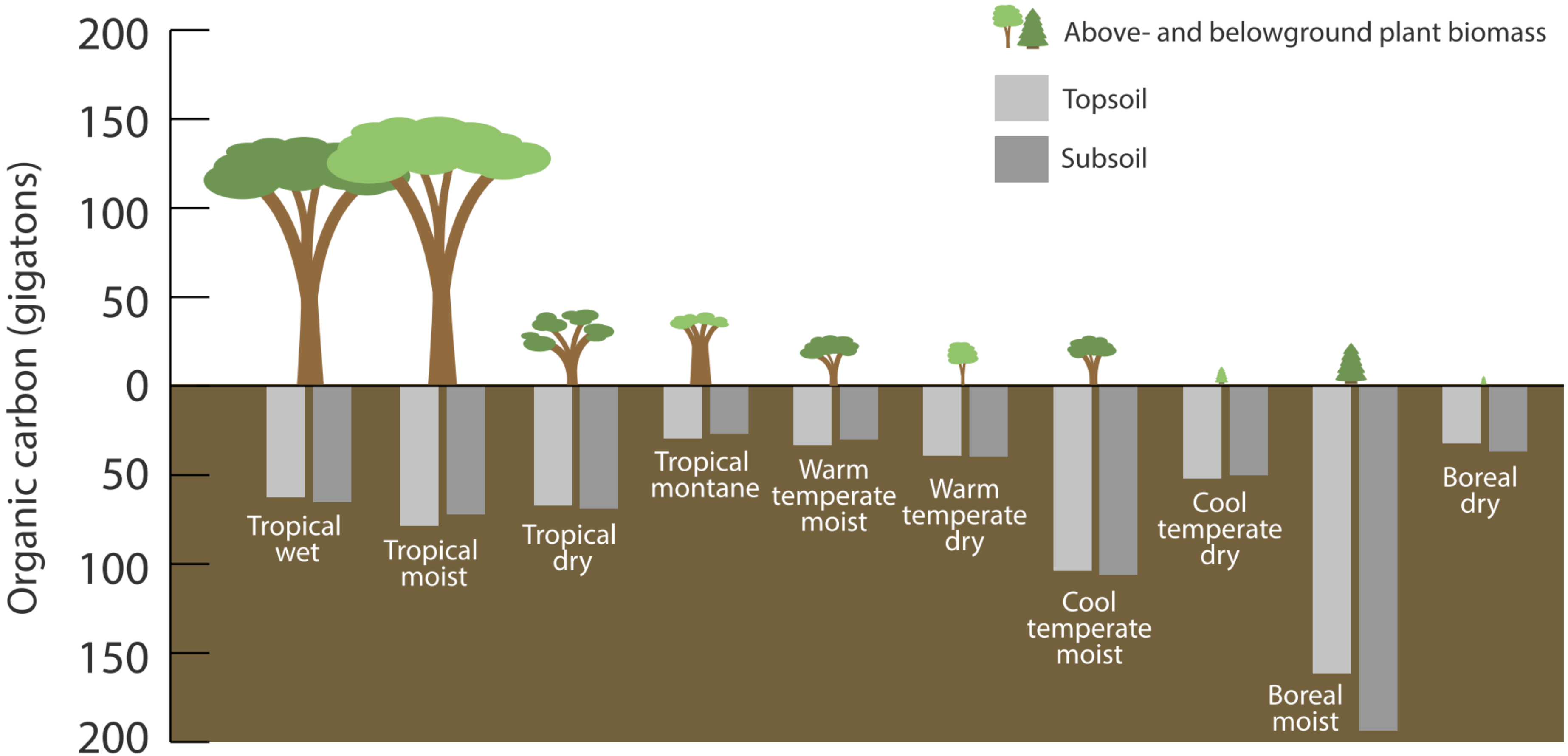


Figure 2. Carbon stored in ecosystems, shown in gigatons. Data from Scharlemann et al. (2014).

Janowiak et al. 2017

What is carbon sequestration?

EPFL

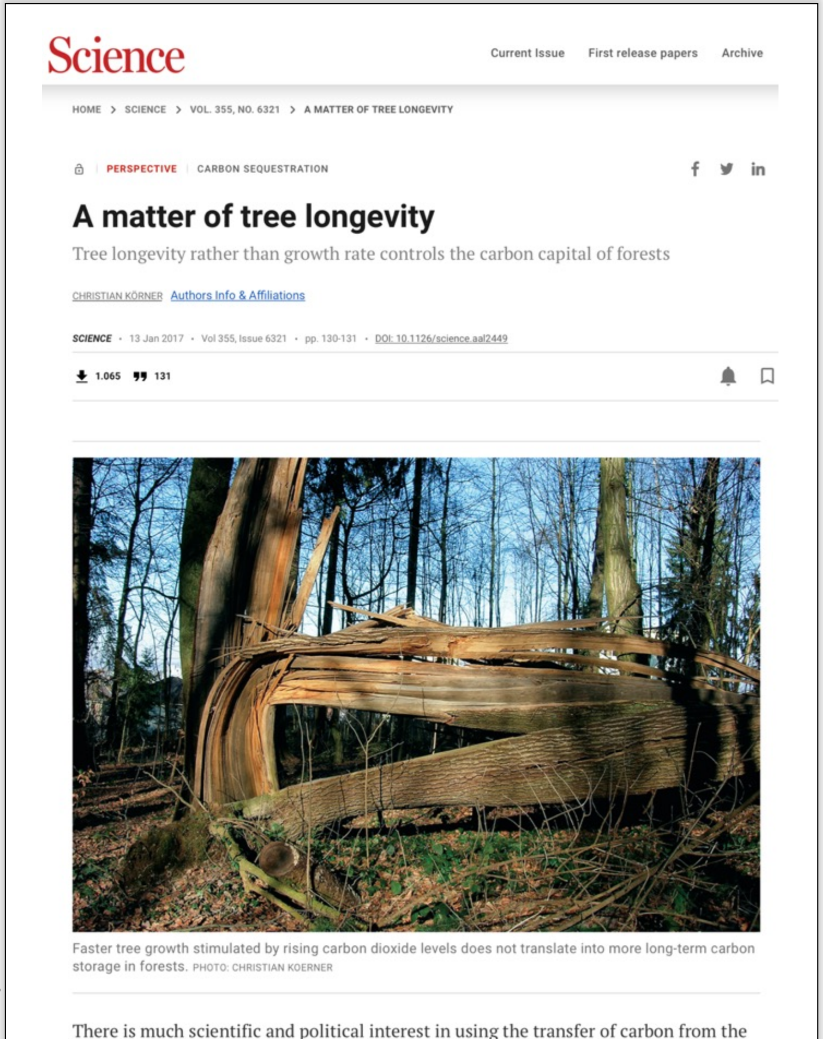
- "Nature based climate solution" (NBCS)
- **Transfer** of carbon (CO_2) from the atmosphere to the biosphere to help mitigate the greenhouse effect.
- **Storing** carbon that has been collected and removed as CO_2 from the atmosphere.

→ Faster CO_2 uptake by plants through faster growth is widely held to increase carbon sequestration.

→ But: Any gain in CO_2 storage from faster tree growth will be transitory!

> "Short-term storage, followed by carbon release within a couple of months or years, would burden the next human generation and has no sustained effect." (Körner 2017)

→ The best practice to retain the benefit of such stores is to protect carbon-rich old-growth forests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HOME > SCIENCE > VOL. 355, NO. 6321 > A MATTER OF TREE LONGEVITY

PERSPECTIVE | CARBON SEQUESTRATION

A matter of tree longevity

Tree longevity rather than growth rate controls the carbon capital of forests

CHRISTIAN KÖRNER Authors Info & Affiliations

SCIENCE • 13 Jan 2017 • Vol 355, Issue 6321 • pp. 130-131 • DOI: 10.1126/science.aal2449

1,065 131

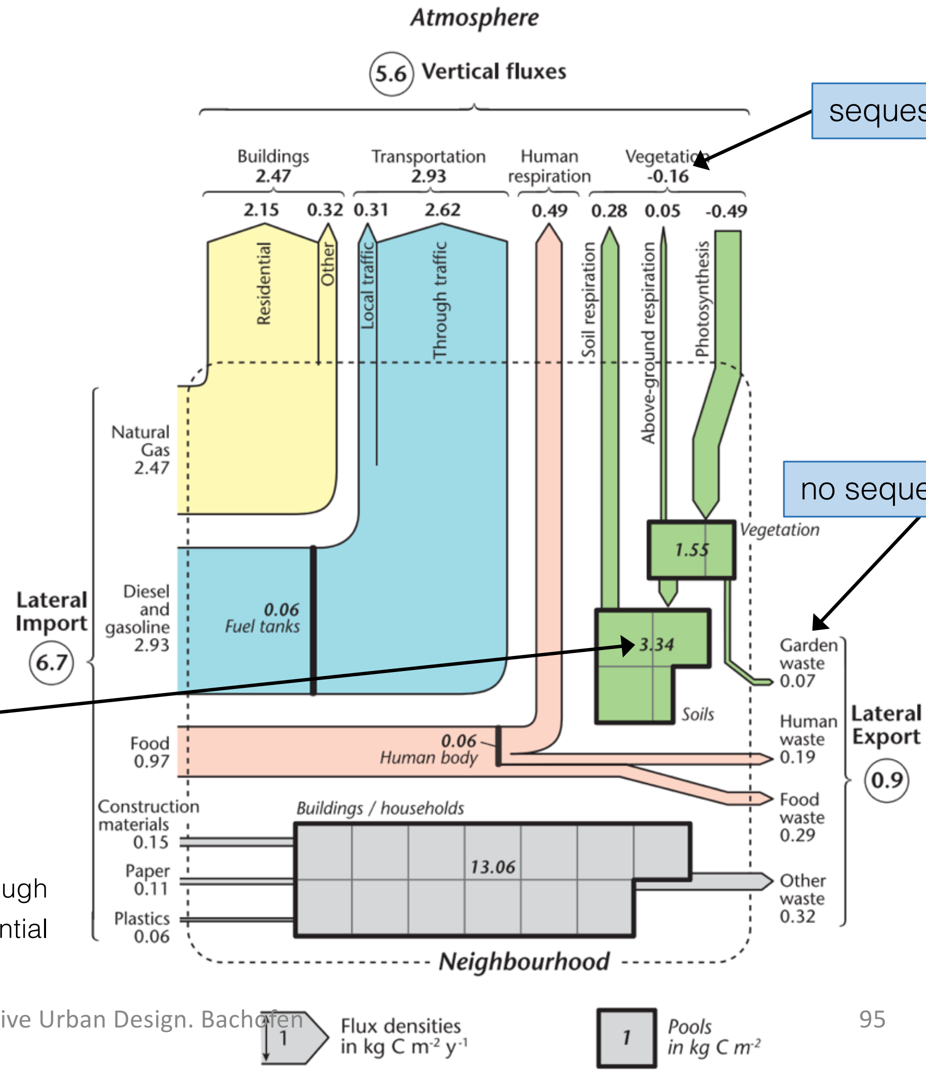
Faster tree growth stimulated by rising carbon dioxide levels does not translate into more long-term carbon storage in forests. PHOTO: CHRISTIAN KOERNER

There is much scientific and political interest in using the transfer of carbon from the

Körner 2017

Is carbon sequestration in cities relevant?

- "Urban trees in the US store about 700 million t C and sequester 22.8 million t C y^{-1}, which equates to about 5.5 months and 5 days of national emissions" (Nowak & Crane 2002)
- Forests sequester 0.2–0.6 kg C m^{-2} y^{-1} (Curtis et al. 2018)
- Urban soils are estimated to store three times more carbon than urban trees (1.9 billion tonnes; Nowak 2013)



sequestration?

no sequestration

"sequestration" only if it stays in the soil.
here 0.09 kg C m^{-2} y^{-1}

Figure 13.4 Fluxes and pools of carbon cycled through a typical urban ecosystem representing a residential neighbourhood in Vancouver, Canada.

Is carbon sequestration in cities relevant?

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I don't believe this!
Estimations are based on sink and source fluxes (not pools) with one single study for street tree mortality estimates

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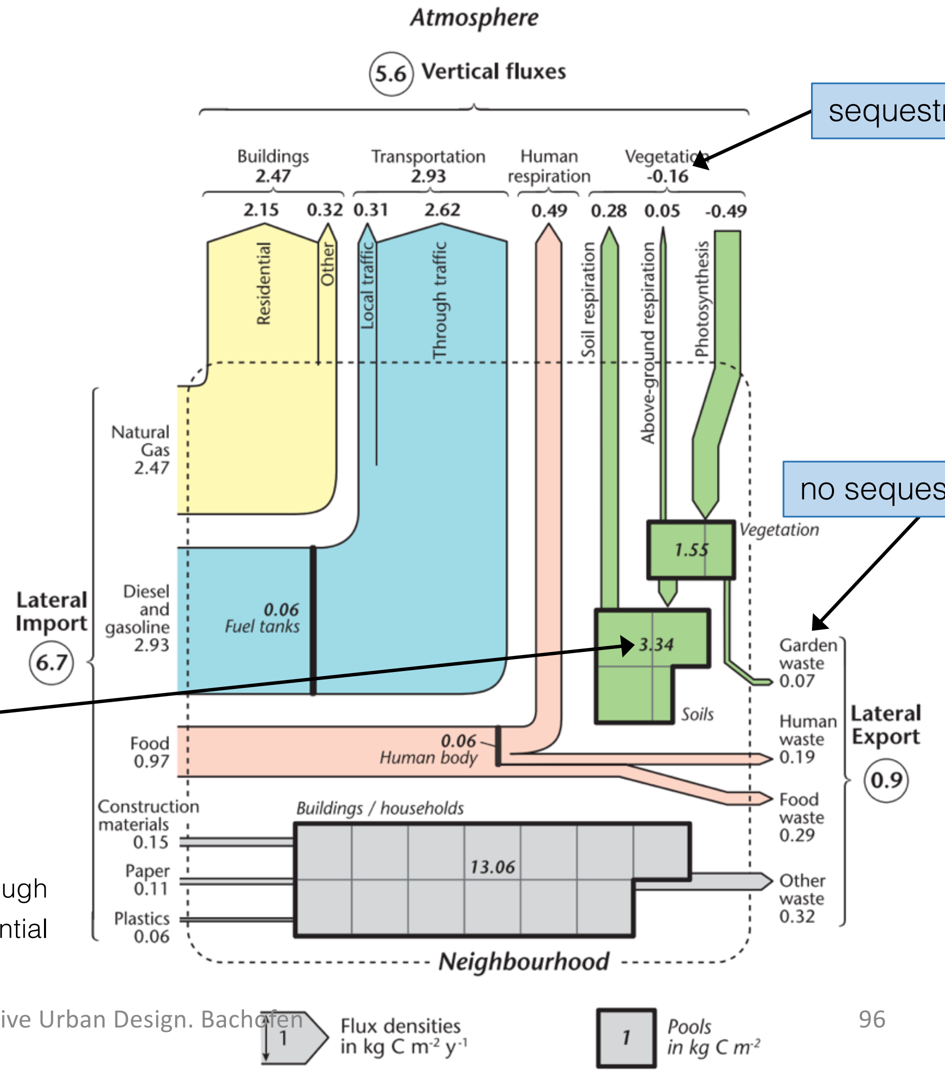

Figure 13.4 Fluxes and pools of carbon cycled through a typical urban ecosystem representing a residential neighbourhood in Vancouver, Canada.

Is carbon sequestration in cities relevant?

EPFL

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I don't believe this!
Estimations are based on sink and source fluxes (not pools) with one single study for street tree mortality estimates

compare these numbers!

"sequestration" only if it stays in the soil.
here 0.09 kg C m^{-2} y^{-1}

sequestration?

no sequestration

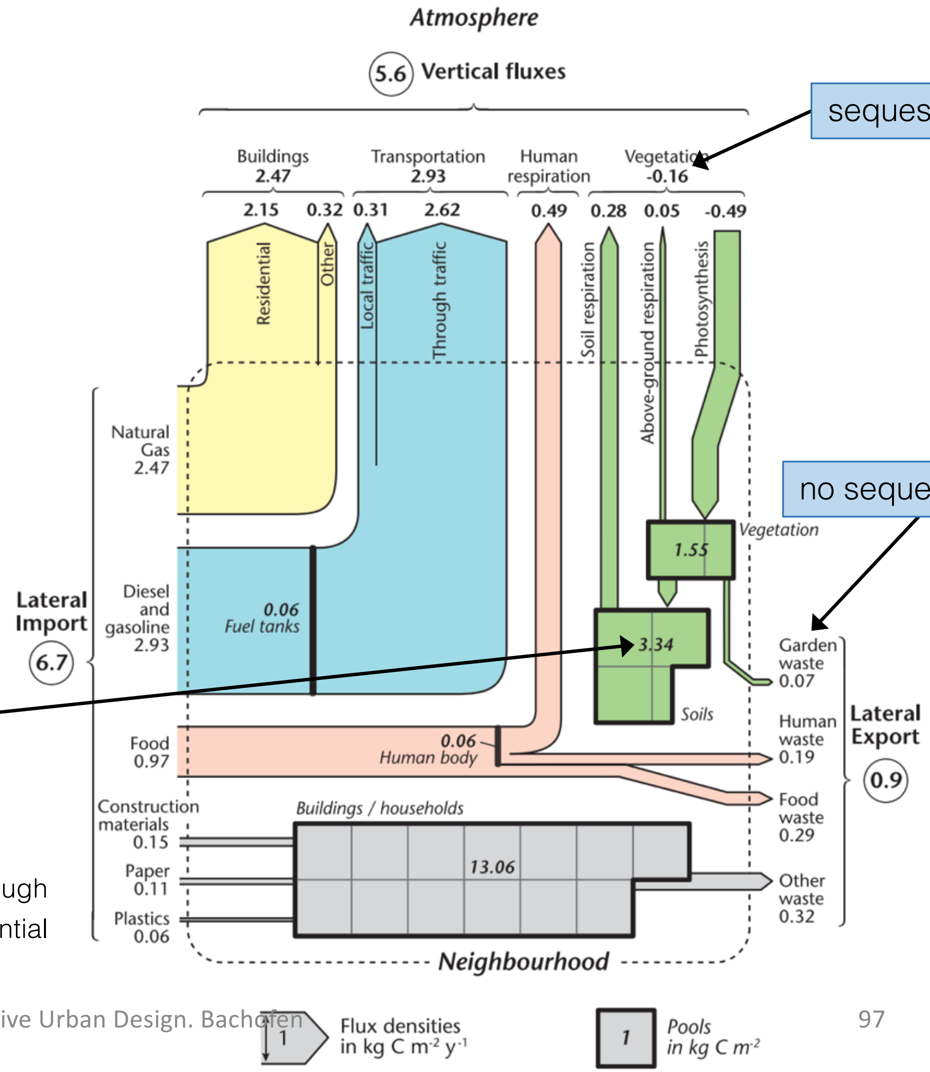


Figure 13.4 Fluxes and pools of carbon cycled through a typical urban ecosystem representing a residential neighbourhood in Vancouver, Canada.

Nature based climate solutions

- Lead to enhancements to carbon uptake and/or reductions of non-CO_2 GHGs that are **additional** to what would have occurred in a baseline or counterfactual scenario, and that integrate over **all ecosystem sources and sinks**.
- Lead to **net cooling** such that the biophysical effects on water and energy cycling do not overwhelm the gains in carbon uptake or emissions reductions.
- Achieve **durable carbon storage** by accounting for social and environmental risks to the permanence of ecosystem carbon storage and avoided GHG emissions.
- Account for **leakage** so that gains in one area are not canceled out by shifting activities to another area.

(Novick et al. 2022)

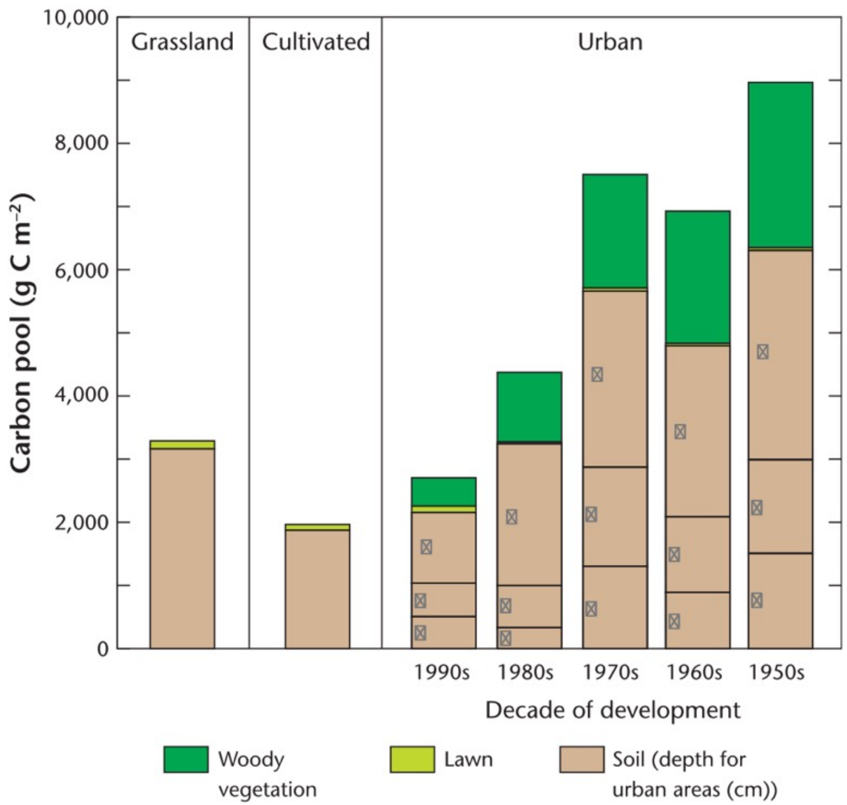
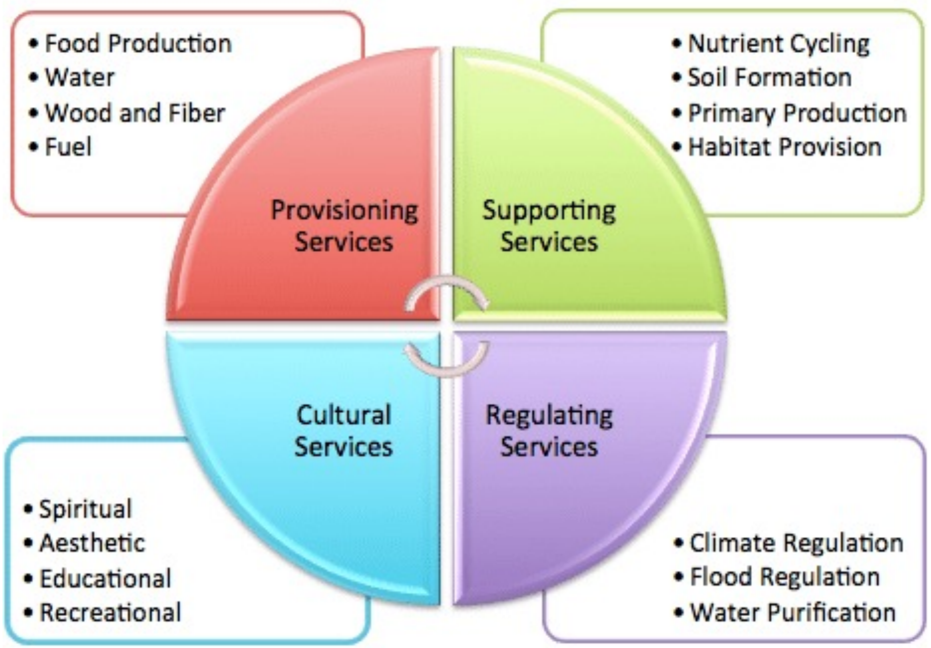


Figure 13.11 Carbon pools in soils and vegetation in the Denver-Boulder metropolitan area, United States

Ecosystem services

Benefits to humans provided by an ecosystem



Source: Millenium Ecosystem Assessment, 2005.


food production


slope stability


fire prevention


biodiversity


pollination

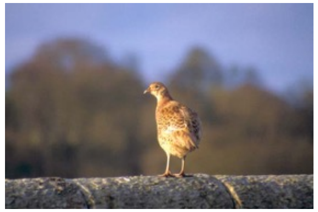

shelter for life stock


fodder production


carbon sequestration


water storage


tourist attraction


game reserve


fibre production


recreation


stabilising micro-climate


inspiration

Ecosystem services

Functions and components	*Ecosystem service*	*Examples*	*Examples of indicators/proxies*	*References*
Energy conversion into edible plants through photosynthesis	Food supply	Vegetables produced by urban allotments and peri-urban areas	Production of food (tons yr^{-1})	Altieri et al. (1999)
Percolation and regulation of runoff and river discharge	Water flow regulation and runoff mitigation	Soil and vegetation percolate water during heavy and/or prolonged precipitation events	Soil infiltration capacity; % sealed relative to permeable surface (ha)	Villarreal and Bengtsson (2005)
Photosynthesis, shading, and evapotranspiration	Urban temperature regulation	Trees and other urban vegetation provide shade, create humidity and block wind	Leaf Area Index; Temperature decrease by tree cover × m^2 of plot trees cover (°C)	Bolund and Hunhammar (1999)
Absorption of sound waves by vegetation and water	Noise reduction	Absorption of sound waves by vegetation barriers, specially thick vegetation	Leaf area (m^2) and distance to roads (m); noise reduction dB(A)/ vegetation unit (m)	Aylor (1972); Ishii (1994); Kragh (1981)
Filtering and fixation of gases and particulate matter	Air purification	Removal and fixation of pollutants by urban vegetation in leaves, stems and roots	O_3, SO_2, NO_2, CO, and PM_{10} µm removal (tons yr^{-1}) multiplied by tree cover (m^2)	Chaparro and Terradas (2009)
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Ecosystem services

Functions and components	*Ecosystem service*	*Examples*	*Examples of indicators/proxies*	*References*
Energy conversion into edible plants through photosynthesis	Food supply	Vegetables produced by urban allotments and peri-urban areas	Production of food (tons yr^{-1})	Altieri et al. (1999)
Percolation and regulation of runoff and river discharge	Water flow regulation and runoff mitigation	Soil and vegetation percolate water during heavy and/or prolonged precipitation events	Soil infiltration capacity; % sealed relative to permeable surface (ha)	Villarreal and Bengtsson (2005)
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Air quality and VOC's

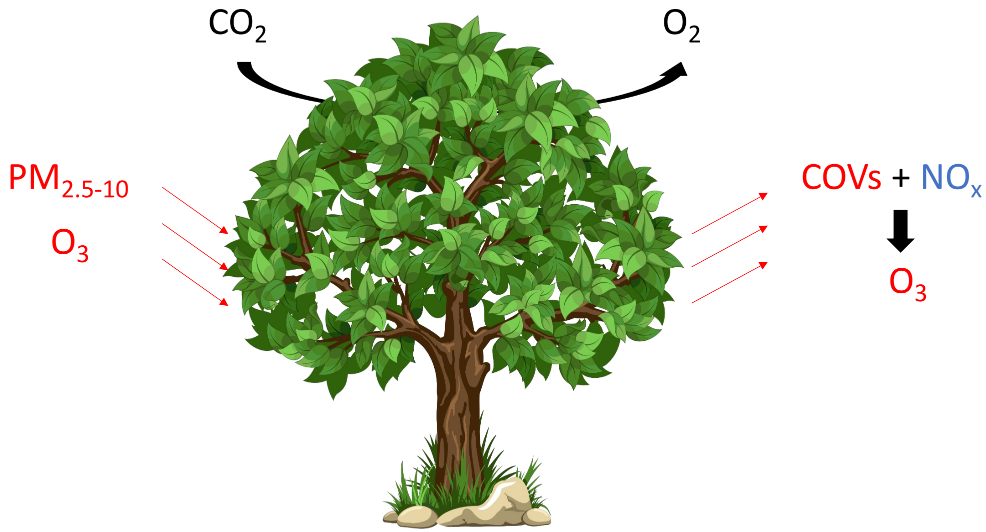
Air pollutants are removed by dry deposition and wet deposition.

- Particulate matter (PM_{10}, $PM_{2.5}$)
- Ozone (O_3)
- Nitrogen oxides (NO_X)
- Sulfur oxides (S_XO_Y)

- Adherence on the leaves
- Re-suspension to the air
- Washed off during rainfall
- Exchange of gases through open stomata

→ Transfer of common air pollutants to the plant interior (e.g. ozone, nitrogen oxides and sulfur dioxide)

→ Health of plants can be damaged. E.g. excessive PM sedimentation can restrict stomatal gas exchange (water and CO_2)



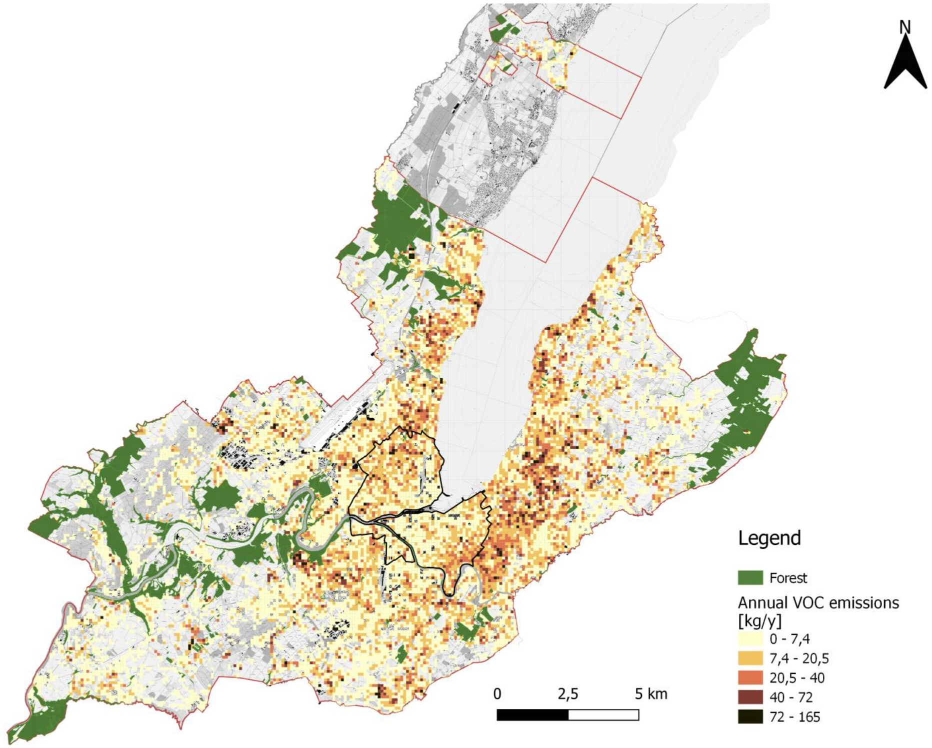
Ozone damage on *Populus nigra* leaf (Novak et al. 2003)

VOC emissions

Volatile organic compounds (VOCs) released by plants **protect** them from harm. But it is an important precursor of **photochemical smog** and secondary organic aerosols.

- Animal, insect, herbivore feeding, and anthropogenic disturbance affect the release of VOCs from plants.
- There are many types of VOCs, and the release mechanisms are complex and many factors influence it.
- Urban tree species selection should consider VOC emission

Genre	Pourcentage population	VOC émis [g/année]	PM_{10} déposées [g/année]	BVOC score	PM_{10} score	Score total
Chêne	10.8 %	2'347	398	3	2	5
Érable	10.4 %	76	243	0	3	3
Pin	7.5 %	246	480	1	2	3
Bouleau	6.7 %	91	180	0	4	4
Charme	5.7 %	104	326	0	3	3
Épicéa	5.6 %	543	589	1	1	2
Tilleul	5.5 %	166	396	0	2	2
Prunus	4.7 %	2	59	0	4	4
Frêne	3.9 %	33	354	0	3	3
Peuplier	3.7 %	3'813	462	4	2	6



Kofel et al. 2023

Liu et al. 2023

Edible green infrastructure (EGI)

Domestic garden, Italy | Rooftop kitchen garden, Italy | Allotment garden, Finland | Date palm streetscape, United Arab Emirates

Urban agriculture lot, Germany | Orange trees in street, Greece | Riparian urban-agricultural zone, Japan | Vegetables in Park, Russia

Russo et al., 2017

Edible green infrastructure (EGI)

Domestic garden, Italy | Rooftop kitchen garden, Italy | Allotment garden, Finland | Date palm streetscape, United Arab Emirates

- Contribute socially, economically, and environmentally to urban sustainability and food security
- It teaches people from all socioeconomic levels the benefits of locally grown food

→ potential health risks caused by human exposure to heavy metals and organic chemical contaminants often present in urban surroundings (see dioxin-contaminated soils in Lausanne!)

Urban agriculture lot, Germany | Orange trees in street, Greece | Riparian urban-agricultural zone, Japan | Vegetables in Park, Russia

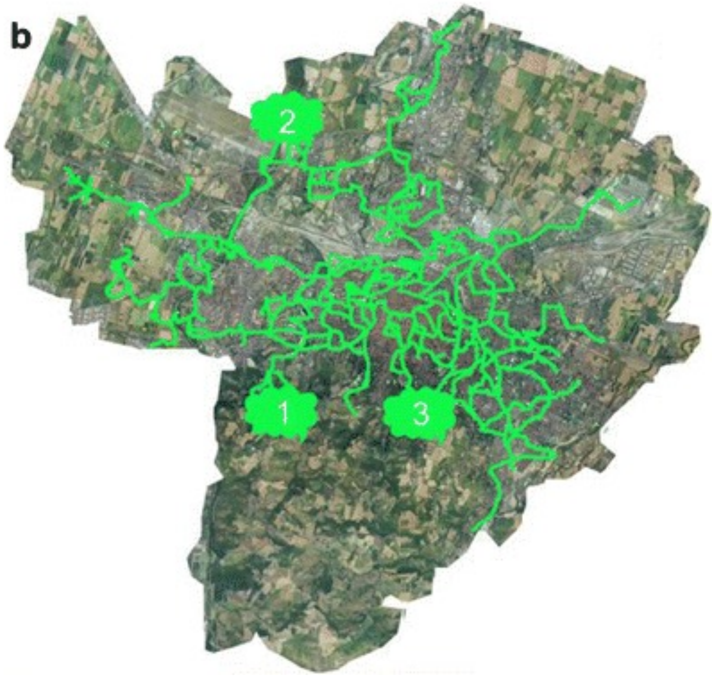
Russo et al., 2017

Rooftop gardens

Rooftop gardens could provide more than 12,000 t year^{-1} vegetables to Bologna, satisfying 77 % of the inhabitants' requirements.

Table 3 Potential RTG vegetable production in Bologna. Available flat surfaces (number and hectares), potential productivity and extent of city requirements satisfied if those surfaces were converted into RTGs

Element	Value
Flat rooftops	3,500
Flat area	82 ha
Potential rooftop yield	41.7 g m^{-2} d^{-1}
Potential vegetable daily production	34,233 kg d^{-1}
Potential vegetable yearly production	12,505 t year^{-1}
Urban vegetable requirements	16,169 t year^{-1}
Contribution to city needs	77 %
Green corridors	94 km
Green corridor density	0.67 km km^{-2}
Potential carbon storage	624 t CO^2



It is necessary to create a network of green spaces so that pollinators can find their foraging spaces

Ecosystem disservices in urban areas

Ecosystem functions	*Disservice*	*Examples*	Indicators	References
Photosynthesis	Air quality problems	City tree and bush species emit volatile organic compounds (VCOs)	Emission of VOCs (tons yr^{-1})/vegetation unit	Chaparro and Terradas (2009); Geron et al. (1994)
Tree growth through biomass fixation	View blockage	Blockage of views by trees standing close to buildings	Tall trees close to buildings	Lyytimäki et al. (2008)
Movement of floral gametes	Allergies	wind-pollinated plants causing allergic reactions	Allergenicity (e.g. OPALS ranking)	D'Amato (2000)
Aging of vegetation	Accidents	Break up of branches falling in roads and trees	Number of aged trees	Lyytimäki et al., 2008
Dense vegetation development	Fear and stress	Dark green areas perceived as unsafe in night-time	Area of non-illuminated parks	Bixler and Floyd (1997)
Biomass fixation in roots; decomposition	Damages on infrastructure	Breaking up of pavements by roots; microbial activity	Affected pavement (m^2) wood (m^3)	Lyytimäki and Sipilä (2009)
Habitat provision for animal species	Habitat competition with humans	Animals/insects perceived as scary, unpleasant, disgusting	Abundance of insects, rats, etc.	Bixler and Floyd (1997)

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Ecosystem disservices in urban areas

December 2013 ice storm

Ecosystem disservices in urban areas

Goal: Examine residents' experiences, attitudes, and actions related to an ice storm, which created a set of urban forest disservices

Residents from the Greater Toronto Area were surveyed six month after the December 2013 ice storm

<u>Damages from tree falling:</u>

Monetary costs - 26% hired someone to remove debris/17% removed standing trees

Damages to other vegetation – 40%

Damages to built structures – 20%

Loss of electricity - 80% (for more than 4 days – 40%)

<u>Changed plans:</u>

Tree removal – damages to structure

Not planting

Planting other species– smaller trees or evergreen

Massive pruning

Conway & Yip, 2016

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